# Head-Mounted Display Based Teleoperation of a Humanoid Robot Surrogate for Users with Life-Limiting Illnesses

*Tackling Social Isolation Through Feelings of Presence*


By

BETHANY ANN MACKEY

Department of Aerospace Engineering
UNIVERSITY OF BRISTOL
&
Department of Engineering Design and Mathematics
UNIVERSITY OF THE WEST OF ENGLAND


A PhD dissertation submitted to the University of Bristol and the University of the West of England in accordance with the requirements of the degree of DOCTOR IN PHILOSOPHY in the Faculty of Engineering.

14TH APRIL 2025

# Abstract

Individuals with life-limiting illnesses are at an increased risk of social isolation, and this became particularly evident during the COVID-19 pandemic. Social robots are often used to provide companionship, but are rarely used to facilitate social interaction between users and their loved ones.

This work aimed to design and develop a teleoperation system which combined a head-mounted display based virtual reality system with a humanoid robot surrogate. The goal for this research was to allow users to navigate in a remote location and interact with others within that environment. Furthermore, the developed system, by choosing hardware proven to facilitate this, aimed to produce feelings of place and social presence in order to tackle social isolation and improve quality of life.

The development of this system followed a user-centered design protocol, and allowed for the identification of user requirements prior to development. The system was then evaluated using user studies, a case study, and focus groups to ensure the collection of in-depth qualitative data, as well as quantitative findings. This work has provided a proof of concept for a head-mounted display based teleoperation system for a humanoid robot surrogate, with a focus on users with life-limiting illnesses. Additionally, the case study involved deployment of the teleoperation system in a potential end user's home, which is a novel contribution to the field.

The developed system has shown to be well received by the intended users and their primary interactants - their loved ones - and has shown a trend towards being able to produce feelings of place and social presence. Furthermore, a list of suggested user requirements has been formulated to assist future researchers in designing similar systems.

## Dedication and acknowledgements

Firstly, a huge thank you to my supervisors, Dr Paul Bremner and Professor Manuel Giuliani for your never ending patience, kindness, and support. Your insight, expertise, and guidance has been invaluable and I'm grateful to have been able to work with you.

A wholehearted thank you to my participants, alongside Prospect Hospice and Marie Curie West Midlands. You were so adaptable and willing to help, even while the world went through a pandemic. I am especially grateful to the participants who took part in my case study and focus groups. Thank you for giving up your incredibly precious time to help me. I will keep working towards helping people as you hoped for when you agreed to take part.

To my wonderful friends, thank you for making me smile through the stress, and giving me words of encouragement when I've felt close to throwing in the towel. To my fellow FARSCOPERS, especially Richard and Joe, thank you for letting me complain and rant about things no one else could possibly understand. Thank you for endless chats, hugs, and cups of tea when the writing became too much. We did it friends! Kaya, thank you for being an unwavering rock of support, for being the kind of friend that I could count on no matter what without judgement. Thank you for giving me the easy kind of friendship where I know I could turn up at your house in pyjamas without warning and be greeted with a cuppa, a friendly face, and some food. You are the best kind of person.

To my parents, Alan and Jackie, thank you for giving me the foundation to keep working on my education and for always being proud of me. I'm so grateful for everything you have done for me and I couldn't have finished it without you. To my Nanny, thank you for being my biggest cheerleader, I miss you always.

To my incredible partner, Myles, your sacrifices to help me through this have meant the world to me. I have never met someone so selfless. Thank you for letting me uproot our lives to take on this mammoth project and never complaining. Thank you for giving me all the time and support I've needed to get here. You are the best Dad and partner and I am so grateful for you.

Finally, I dedicate this PhD thesis to my beautiful Son, Kayden. Little Spud, thank you for lifting my spirit when I've felt so tired. Your smile brings me so much joy. You inspire me. Always chase your dreams and work hard. You can achieve anything.

# Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED:  DATE: 11th July 2024

# Table of Contents

Page

# List of Tables

# List of Figures

**Figure** **Page**

# Chapter 1

# Introduction

Once reserved for science fiction, robot surrogates are the focus of much academic research in recent years. Generally remotely controlled, these robots are often applied to hazardous environments such as nuclear decommissioning [1] and industrial manufacturing [2]. However, they are rarely used in applications involving social interaction. This PhD project focuses on the application of these technologies in a social setting, more specifically to benefit users who have life-limiting illnesses by facilitating social interaction in order to reduce social isolation and improve quality of life. The remainder of this chapter briefly introduces the technologies used, currently available assistive technologies, the motivation behind the PhD research, the aims of the project, the research questions the work aims to answer, and the objectives identified to achieve this.

## 1.1 Background and Context: Project Motivation, Existing Assistive Technologies, and Technologies Utilised

This section discusses the motivation behind the PhD research, which is primarily to improve quality of life for those with life-limiting illnesses. The goal is to achieve this by providing technological support to palliative (end of life) healthcare services, allowing for remote navigation, and facilitating social interactions with loved ones. It also explores currently available assistive technologies, and briefly introduces technologies utilised in the technical development of system.

### 1.1.1 Project Motivation: Quality of Life for Individuals Living with Life-Limiting Illnesses

This section discusses the motivation behind the project, which is to improve quality of life for those living with life-limiting illnesses. Literature investigating the issues faced by these individuals is explored below, as well as some barriers to receiving the support needed. These topics are also covered in more detail in Chapter 2.

Individuals with life-limiting illnesses and especially those in palliative care are likely to be at risk of mental health issues, with some experiencing helplessness, depression, demoralisation syndrome, and suicidal thoughts [3]. Palliative care is a vital service that supports those living with terminal illness and helps them overcome or avoid these mental health issues. The World Health Organisation estimates that 40 million people worldwide need palliative care each year, and this is expected to grow with the ageing population; however, only 14% actually receive it [4]. Early access to palliative care reduces pressure on other health services, but a lack of available training for health professionals limits improvements [4]. It is important to use emerging technologies to assist services where possible, both for healthcare professionals and patients in need of care, especially in the economic climate where hospice funding is in crisis [5]. This provides a core motivation to the work presented here in providing technological support to palliative healthcare services.

Individuals with life-limiting illnesses often face social isolation [6] and reduced quality of life [7], which became especially evident during the COVID-19 pandemic [8]. Research tackling social isolation by using robotics usually involves a companion robot [9]. Companion robots can assist in alleviating social isolation [10], and robotic pets in particular can decrease need for medication, have a "significant positive clinical response" in behavioural changes, and provide emotional benefit [11]. However, these can end up removing human interaction for these individuals [12]. Human connection is highly valuable, as stated by Marie Curie, a charity supporting patients and their families to ensure the best quality of life possible [13]. As part of their end of life care, the charity suggest that individuals living with life-limiting illnesses may want to see old friends, visit significant places, talk to loved ones, and take part in favourite activities [14]; however, physical symptoms may limit some opportunities. This research aims to utilise telepresence technology by giving patients the ability to navigate remotely and have meaningful social interactions as recommended by Marie Curie [14].

There is a lack of research into possible methods of helping people with life-limiting illnesses become more connected to their loved ones, rather than just providing them with further companionship. Current telecommunications systems lack the same interactions found in face-to-face communication required for social presence [15]. There is a need for a means of communication, that will allow for increased social presence and higher quality interaction for these users. The following doctoral research aims to explore the use of head-mounted display based teleoperation for a humanoid robot surrogate, in order to improve quality of life and reduce social isolation for those with life-limiting illnesses. It is hypothesised that by providing high feelings of place and social presence, the system can produce high quality social interaction between the users and their loved ones. Additionally, the system aims to allow those at the end of life to be able to visit meaningful places and take part in social events.

### 1.1.2 Existing Assistive Technologies for Individuals with Life-Limiting Illnesses

In order to understand if and how an immersive telepresence system could improve quality of life for those living with life-limiting illnesses, it is important to discuss the assistive technologies currently available to them. Assistive Technology refers to "any device that allows a person with a disability to perform the tasks that non-disabled people are able to do without it" [16]. These devices aim to promote independence for the end users [17], improve their quality of life [18], and improve social inclusion [19]. This section explores the available technologies and their limitations, but further literature is also discussed in Chapter 2.

Assistive technology is often designed with convenience, novelty, and luxury in mind for those without disabilities; however, these can be empowering and allow for increased independence for those with them [20]. In a guide for "Best Smart Assistive Devices for People With Disabilities", Todd Stabelfeldt, CEO of C4 Database Management, who is quadriplegic, is quoted as saying that "convenience for you is independence for me" [20]. The guide lists devices for everyday tasks, such as smart switches, voice control, smart screens. However, this list lacks devices which aim to assist in communication. There are many devices, known as Augmentative and Alternative Communication Devices, which assist non-verbal individuals with communication, such as text-to-speech and speech-to-text software, and eye-tracking devices [21]. Bradley and Poppen [22] investigated the effect of communicating via the internet for isolated individuals. Elderly citizens, disabled individuals and caregivers commented on a sense of "camaraderie and friendship", with results showing that contact with others had still increased significantly at a one-year follow-up [22]. While these devices are useful for their own use cases, there are still limitations. Internet based communication limits mobility and close interaction, as discussed further in Chapter 2, and many individuals with life-limiting illnesses are not non-verbal. Therefore, the system developed as part of the PhD research aims to address these limitations through more mobile communication for verbal individuals.

As highlighted in the above "Project Motivation" section, communication is only one aspect of an individual's life affected by life-limiting illnesses, and the ability to travel to meaningful places is also vital. Dowds et al [23] highlighted the importance of "imaginative or other metaphorical methods of travel" for individuals who become isolated from their wider community. One option to address this is the use of virtual reality, which this PhD research utilises and address further in the section below. An additional approach is the use of traditional telepresence robots, such as the Double 3 [24] (Figure 1.1). However, Schouten et al [25] found that these robots resulted in robomorphism, where users attributed robotic characteristics to their interaction partners, despite higher levels of social presence. Therefore, the system developed as part of this project aims to facilitate social interaction while avoiding this effect by utilising social robots.

Figure 1.1: Double 3 Telepresence Robot [24]

Despite some assistive technologies already being available for individuals living with life-limiting illnesses, there are issues with user friendliness affecting adoption of some of these devices [26]. Magnusson et al [26] stated that to support independence and autonomy, technological solutions must be based on an individual's perceived needs. Additionally, it was suggested that individualised design should be emphasised, functionality should be adaptable, and healthcare professionals should be regularly educated in the use of assistive technologies [26]. While this research is from 2004, findings have remained consistent, and Howard et al [**?** ] found similar results when exploring assistive technology. They found that personalised care for developing strategies, and making information more accessible could tackle psychological and societal barriers to assistive technology [**?** ]. They also highlighted the complex barriers faced by individuals with chronic conditions, including limitations of the devices themselves, and suggested more user involvement that utilises the users' "lived knowledge and experiences" [**?** ]. These findings highlight the need for user-centred design methodologies, as is utilised in the design and development of the system proposed in this PhD research. The system itself utilises and modifies existing technologies, which are described in the section below.

### 1.1.3 Technologies Utilised in System Development

Having explored the options currently available to those with life-limiting illnesses, technologies that were possible to be used in a newly implemented system had to also be discovered. The system developed as part of the PhD research utilised pre-existing pieces of hardware, which were integrated and modified to create the system designed and developed as part of this PhD research. These technologies were chosen due to their current uses and existing literature. They are introduced below, and discussed in more detail in Chapters 2 and 3, including how these are often evaluated in Chapter 4.

Surrogates can take several forms, but often as a 2D or 3D avatar in a virtual space. Alternatively they are sometimes a robot which has physicality and can offer a sense of embodiment [27]; where the user experiences the technology as part of the self [28]. This experience as being part of the self can be especially evident when implemented using virtual reality (VR) [29]; where VR refers to the use of a head-mounted display (HMD) system to become immersed in a virtual environment [30]. Robot surrogates are most often used for providing telepresence, which was first coined by Marvin Minsky in 1980 [31] and commonly defined as the feeling of "being there" in a physically separate location [32]. Presence can be separated into place and social presence. Place presence refers to "being in one place or environment, even when one is physically situated in another" [33]. Social presence refers to accessing the psychological, emotional, and intentional states of another person [34]. These are discussed in more detail in Chapter 3 and are used as measures in studies conducted as part of the PhD research.

Media portrayal can have an impact on the general public's perception of robots [35]. Although often portrayed in media as sentient tools of villains or technologically advanced objects to be feared (Figure 1.2), robots in general, and social robots in particular, are actually usually designed to interact and integrate with humans [36]. Despite this, telepresence rarely involves social robots, which are designed for the purpose of this integration, and even less so humanoid social robots. This project aims to bridge this gap between telepresence and social robots in order to allow users with life-limiting illnesses to interact with others more naturally from a remote environment.

Figure 1.2: Robot Surrogates Portrayed in Surrogates Film [37]

## 1.2 Aims, Research Questions, and Objectives

The aim of this PhD project is to design, implement and evaluate an immersive control system for a humanoid robot surrogate. The target users for the system are patients with life-limiting illnesses who may not have full mobility, but have the use of their upper body. The overarching goal is to improve the user's quality of life, by allowing them to navigate remotely and take part in meaningful social interactions, when their symptoms may make it otherwise difficult.

The telepresence system designed as part of the PhD project comprises a head-mounted display (HMD) of a virtual reality (VR) system combined with a humanoid robot surrogate. The system, which is described in detail in Chapter 3, uses a camera to stream a remote environment to a user wearing the HMD, who is located in a separate location. The HMD controls the head of the robot surrogate, allowing the user to independently navigate the environment, in addition to also using a controller for movement. Using microphones and speakers, the user is able to communicate with others in the environment - referred to throughout this thesis as ***interactants*** as described by Tsui and Yanco in their extensive research [38].

### 1.2.1 Research Questions

This section lists the three overarching research questions for the PhD project, along with justification for the formulation of those questions.

1. Can a virtual reality head-mounted display be used to create a teleoperation system that allows the user to feel present in a remote location? (RQ1)

   As discussed above, place, or spatial presence refers to the feeling of being physically present in a remote location [39]. This type of presence is frequently used as a measure for telepresence systems [40], especially those using virtual reality [41] (discussed further in Chapter 3). Therefore, it is important that the system being designed gives a high level of perceived place presence to improve interaction quality.

2. Can the teleoperation system create effective, natural, social interaction between the user and others interacting with them? (RQ2)

   Staying connected to others is a necessity for maintaining quality of life for individuals living with life-limiting illnesses [42]. Unfortunately, due to ever-changing symptoms this may be disrupted [43] (discussed further in Chapters 2 and 4). How successful the system is at improving connectedness and social interaction, as measured by the sense of social presence [44], is a key question for this research, which focuses on the experience and perspective of the user.

3. What design features are necessary to create a usable teleoperation system that achieves the aims of the project? (RQ3)

   It is vital that the designed and implemented system is technically usable, as poorly designed telepresence systems result in low levels of presence [38]. This also applies to social robots, including the ones used in this project, where poorly designed robots are subject to the Uncanny Valley - the curvilinear relationship between a robot's degree of human likeness and the observers' responses to the robot [45] (Figure 1.3). They also can evoke negative attitudes, perceptions, and distrust from those interacting with them [46]. Literature into what makes a well designed system is covered in detail in Chapters 2 and 3, as well as literature into well accepted social robots and the Uncanny Valley.

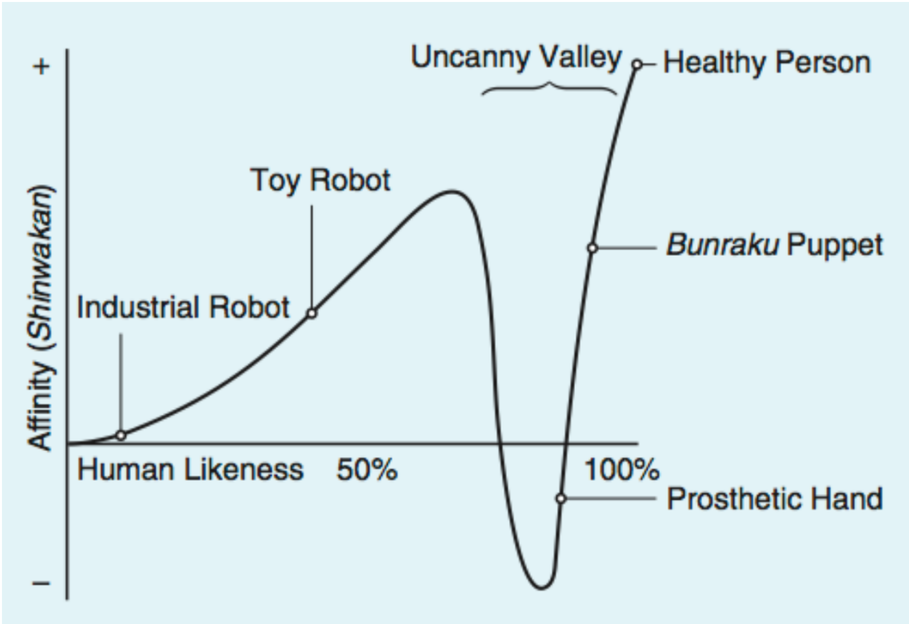



Figure 1.3: The Uncanny Valley [47]

### 1.2.2 Objectives

As aforementioned, the main goal of the project is to allow users with life-limiting illnesses to interact with loved ones, with the aim that this will improve quality of life and tackle social isolation. In addition, the research is primarily concerned with the experiences and perspective of the end user. With this in mind, the objectives for the project are listed below, alongside the overarching research questions each aims to answer, and the Chapters in which they are addressed.

1. Identify user requirements to aid design of a successful head-mounted display based teleoperation system for a humanoid robot surrogate (RQ2, RQ3)

   This objective is addressed in Chapter 2, which details the design, undertaking, and analysis of three focus groups to formulate these user requirements.

2. Identify and implement design features needed to meet the specified requirements, within the scope of the PhD research. (RQ1, RQ2, RQ3).

   This is covered in Chapter 3 which details a system overview of the robot telepresence system developed for this thesis. In addition it also discusses the design and implementation of developing the system based on the identified user requirements and related work. The process of developing the system involved combining and modifying existing hardware and creating software to integrate elements of the system.

3. Conduct user studies to evaluate the usability of the system and the effect it has on presence in a remote location and social interaction with others (RQ1, RQ2, RQ3)

   Chapter 3 also details the process and findings of user studies conducted to assess the usability of the system, as well as comparing the system to existing telecommunications software, and assessing the effect on presence in a remote location and social interaction with others.

4. Deploy the system with an end-user to assess the ability to successfully create feelings of presence in a remote location, the ability to facilitate social interaction with their primary interactant, and the usability of the system (RQ1, RQ2, RQ3).

   This objective is addressed in Chapter 4. This chapter thoroughly discusses a case study conducted with an end user with a life-limiting illness, where the system was deployed in the home they shared with their partner. An abundance of qualitative data was collected and analysed. This chapter also details a follow up focus group conducted with care professionals to discuss system efficacy in use and refine the design requirements.

## 1.3 Summary

This chapter introduced the aim of the PhD research, which was to design, implement and evaluate an immersive control system for a humanoid robot surrogate using existing hardware. This was with an overall goal of improving the user's quality of life, by allowing them to navigate remotely and take part in meaningful social interactions, when their symptoms may make it otherwise difficult. This chapter also discussed the motivation behind the system and introduced the technology used in its development. Existing assistive technology for individuals with life-limiting illnesses was also explored. Finally, the research questions that the PhD project aims to answer, and the objectives identified to achieve this, alongside where they are addressed in the thesis were discussed.

The following chapter, **Chapter 2**, describes the three focus groups conducted to formulate user requirements for the system. **Chapter 3** covers the technical development and evaluation of the usability of the system, as well as comparing existing telecommunications software, and assessing the effect of the system on place presence in a remote location and social interaction with others. **Chapter 4** discusses a case study covering the deployment of the system with an end-user in their home. The final chapter in the thesis, **Chapter 5**, summarises, discusses, and concludes the overall project. This chapter also examines any key contributions of new knowledge to human-robot interaction and the implications for the field as a whole.

CHAPTER 2

# IDENTIFYING USER REQUIREMENTS AND ESSENTIAL FEATURES

As covered in the Introduction in Chapter 1, the aim of this project is to design, implement and evaluate a teleoperation system combined with a humanoid robot for users with life-limiting illnesses. Where the main goal is to tackle social isolation and improve quality of life. As such, it is vital to identify user requirements and essential features for this system, while taking into consideration any potential additional needs of individuals with life-limiting illnesses. Therefore, three focus groups were conducted with experts in the field consisting of patients, healthcare professionals, and caregivers. The findings from these groups, combined with existing literature, informed development of the system in order to allow for successful navigation and interaction in a remote environment using a humanoid robot surrogate, which is discussed in Chapter 3. This chapter covers the design and running of the focus groups, starting with related work, and followed by aims, objectives, and research questions as described below, as well as the resulting identified requirements.

## 2.1 Introduction

This section covers the relevant literature for this Chapter and the aims, objectives, and research questions related to it. The literature justifies and informs the choices made with regards to design decisions for the focus groups, including methodologies and participants. In addition, the aims and objectives, and research questions are specific to this Chapter, but relate to the aims, objectives, and research questions for the PhD research as a whole, which are addressed in Chapter 1.

### 2.1.1 Background and Context: Life-Limiting Illnesses and Existing Technologies

The effect that life-limiting illnesses have on the individuals living with them provides significant motivation for the research conducted as part of the PhD research. Therefore, research into life-limiting illnesses, the needs of those living with them, and palliative care are discussed in this section. In addition, current uses of telepresence and social robots within this field are also discussed.

As highlighted in Chapter 1, it is important that those living with a life-limiting illness do not become socially isolated and housebound, as the co-existence of these can increase risk of mortality [48]. Additionally, Bradley et al [7] discussed the importance of social support on quality of life, and the high value placed by patients on day care and group therapies provided by palliative care to help provide this support. However, as discussed in Chapter 1, the majority of people requiring palliative care do not receive it. Therefore, additional ways of accessing social support are needed, providing further justification for systems such as the one developed.

Furthermore, an individual's symptoms can change extremely quickly [49] and their needs and preferences can change rapidly in their last months, weeks and days [50]. Marie Curie states that good communication is essential to making sure patients' needs are understood [50]. Since the COVID-19 pandemic, the use of telemedicine has increased dramatically [51, 52, 53, 54]. However, while telemedicine is a useful tool for those who cannot get to appointments [55], it does not provide the same level of personal connection as face-to-face appointments [56]. This further supports the need for a means of communication, not just for social interactions with friends and family, but also with healthcare professionals.

Given the proven benefit of palliative care services for social support and communication, it is important to also rely on the people providing those vital services. Marie Curie, alongside many other charities and healthcare professionals, provide a range of support services [57], some of which focus specifically on social interaction, such as their companion service [58]. Given the experience that patients, caregivers, and healthcare professionals have with both life-limiting illnesses and supporting those living with them, it is of great importance to consult them when designing the system. Therefore, this PhD research follows a user-centred design. The focus groups are made up of these experts to assist in identifying user requirements and essential features; this is to increase the usefulness of the system for the intended end users.

Focus groups are one of the most widely accepted techniques for gauging perceptions towards robotics within human-robot interaction (HRI) and are useful for facilitating group discussions [59]. As robots are used heavily within the system, it is important to measure the perceptions of the experts. It has been found that by using mutual shaping as part of the focus groups, robot acceptance can be increased [60], and it has been shown that users with life-limiting illnesses had generally positive attitudes towards virtual reality [61]. With this in mind, this research will utilise these techniques in order to include target users in the design process as much as possible.

Existing technology within the field has proved beneficial for those with life-limiting illnesses. For example, artificial intelligence (AI) is being used with relatively good success for administration tasks, such as treatment mapping [62]. Another example are the use of companion robots. However, the observed misalignment of opinion between end users and developers on desirable design features of companion robots demonstrates the need for user-centred design during development [63]. Additionally, telepresence is frequently combined with virtual reality (VR) and current research has shown it to be a powerful tool in pain and symptom management [64], psychological wellbeing [65], and distraction techniques in both adult [66] and paediatric medicine [67]. It has also been shown to be effective for navigation in Google Earth VR for patients whose symptoms do not allow them to travel [64]. There are many opportunities for the use of robotics in palliative care that have yet to be explored [68] and could prove pivotal in improving quality of life for those with life-limiting illnesses. While some of these technologies are utilised in the system developed as part of this PhD research, the current uses do not allow for navigating the real world in real-time or satisfy the need for improved social interaction, which is what this project aims to tackle.

### 2.1.2 Aims, Objectives, and Research Questions

As stated above, the aim of this chapter was to formulate a series of user requirements and essential features for the system as identified by experts in this field. In order to do this, focus groups were conducted with the intended end users: individuals with life-limiting illnesses, their families and caregivers, and healthcare professionals. The research questions that the focus groups aimed to answer, as well as the relevant thesis level research questions in brackets, are as follows:

1. What do family members/friends deem to be the most important aspects when interacting with the users? (RQ2)

2. What do healthcare professionals deem to be the most important aspects when interacting with the users? (RQ2)

3. How can such a system be designed to maximise its utility for end user groups? (RQ2 and RQ3)

4. What essential features must the system possess to achieve navigation and interaction capabilities for the intended end users? (RQ3)

In order to answer the research questions, the following objectives were identified:

1. Identify any potential additional needs of the end users
2. Identify the appropriateness of the proposed robot (NAO Robot - Figure 2.1 [69])
3. Identify any essential features required for a successful system
4. Identify possible uses of the system that would benefit intended end users

Figure 2.1: NAO Robot - United Robotics Group [69]

## 2.2 Methodology

This section of the chapter describes the process of conducting the focus groups, including the participants and how they were recruited, the materials and measures used, and the procedure.

### 2.2.1 Ethical Considerations

The study was approved by the University of the West of England (UWE) Ethics Committee (Reference No. FET.19.12.022). All ethical conduct and data handling guidelines were adhered to.

### 2.2.2 Participants

The participants who took part in the focus groups were recruited from Prospect Hospice (Healthcare Professionals: N = 4 and Patient/Caregiver: N = 2) and Marie Curie West Midlands (Healthcare Professionals: N = 6) using an opportunity sample. The split between healthcare professionals and patient/caregiver was due to participant availability and for the purpose of this study all participants are considered as one group of experts. A recruitment poster (Appendix A.1) was circulated by the hospices and potential participants contacted the researcher directly.

Due to the varying availability of the participants, a total of three focus groups were run with a total of 12 participants, where 9 identified as female and 3 as male. Two groups were made up of healthcare professionals. There were a range of ages between 25 and 74. The majority had "a little" experience with virtual reality and for robotics most had "none at all". One participant was a patient with Motor Neurone Disease (MND) and one was a bereaved family member/carer. The remaining participants (N = 10) were made up of healthcare professionals from Prospect Hospice and Marie Curie West Midlands. Of the healthcare professionals there was a range of years experience working in palliative care as demonstrated in Table 2.1.

| Number of Years Worked in Palliative Care | Count |
|---|---|
| Just started - 0 months | 1 |
| 8 months | 1 |
| 7 years | 1 |
| 8 years | 1 |
| 10 years | 2 |
| 15 years | 1 |
| 20 years | 2 |
| 21 years | 1 |

Table 2.1: Experience Working in Palliative Care (Years)

### 2.2.3 Materials and Measures

The participants were provided with an information sheet and privacy notice once joining the Microsoft Teams meeting. Qualtrics was then used to provide participants with a consent form, demographics questionnaire, two semi-structured interviews, and debrief information. Semi-structured interviews and focus groups provide rich qualitative data, while still providing some structure to keep the conversation relevant towards the information required by the researcher [70]. All materials can be found in the appendices (A.2, A.3, A.4, A.5, A.6, A.7, A.8 respectively).

The participants were shown three videos during the groups in order to demonstrate the teleoperation system and provide context to the semi-structured interviews. These are described below, and available at the following links:

1. https://www.youtube.com/watch?v=SASHEJJpw68 (robot with out-of-the-box autonomous behaviours)
2. https://youtu.be/o26NBNfrgwM (system being used)
3. https://youtu.be/a1Hmr9n6x08 (system being used from the view of the camera attached to the robot)

### 2.2.4 The system

The version of the system demonstrated to participants was as described in Chapter 3 Section 3.3.5. The initial development of the system was largely informed by literature and user studies with healthy adults. Unfortunately due to COVID-19 restrictions the focus groups had been delayed and therefore these were conducted with the later iteration of the system.

### 2.2.5 Procedure

The focus groups were conducted online using Microsoft Teams due to ongoing COVID-19 restrictions. Once the participants had read the information sheet and privacy notice they were provided with a password to access the Qualtrics forms, where they could provide consent and demographics information such as age, gender, and levels of experience with palliative care (for the healthcare professionals), virtual reality, and robotics. The pre-demonstration discussion then took place with the following questions being posed via a semi-structured interview:

1. What do you think of when you hear the word "robot"?
2. Does this change for "social robot"?
3. Do you think technology can be beneficial for people with a terminal illness?

This discussion aimed to assess current perceptions of robots in general, social robots, and the benefits of technology for users with life-limiting illnesses. At this point, participants had not be given any context or seen any images or videos of the system.

The participants were then shown three videos as described below:

1. Robot with out-of-the-box autonomous behaviours (Figure 2.2). These are built-in behaviours on the NAO robot that imitates "breathing" by swaying slightly side to side. The robot also looks around the environment and, having recognised when someone is in front of it, its eyes flash and it follows the person's face.
2. The system being used (Figure 2.3). A person is sitting in front of a desk, puts on the head-mounted display, and picks up the controller. The NAO robot is on the desk next to the user. The user then uses the controller to move the robot forwards and rotate it, while moving their head to also move the robot's.
3. The system being used from the view of the camera attached to the robot (Figure 2.4). This video is as the video above, but from the alternate perspective.

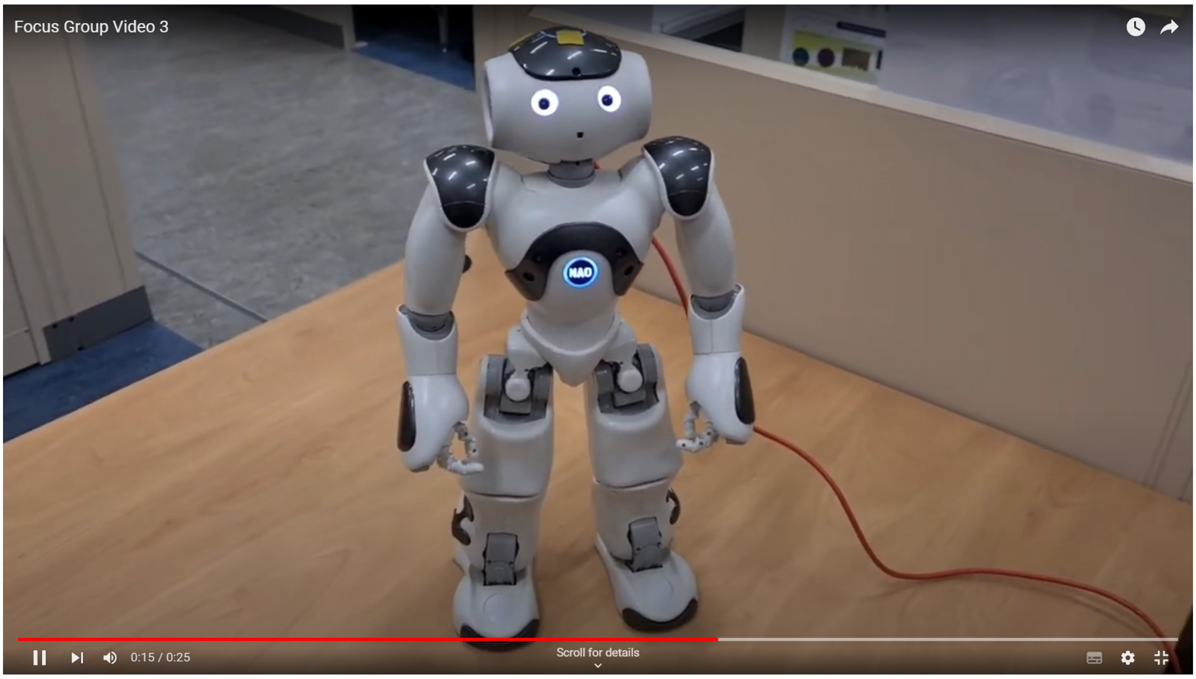



Figure 2.2: Screenshot from the Video Portraying the Robot with Out-Of-The-Box Autonomous Behaviours.


Figure 2.3: Screenshot from the Video Portraying the System Being Used.

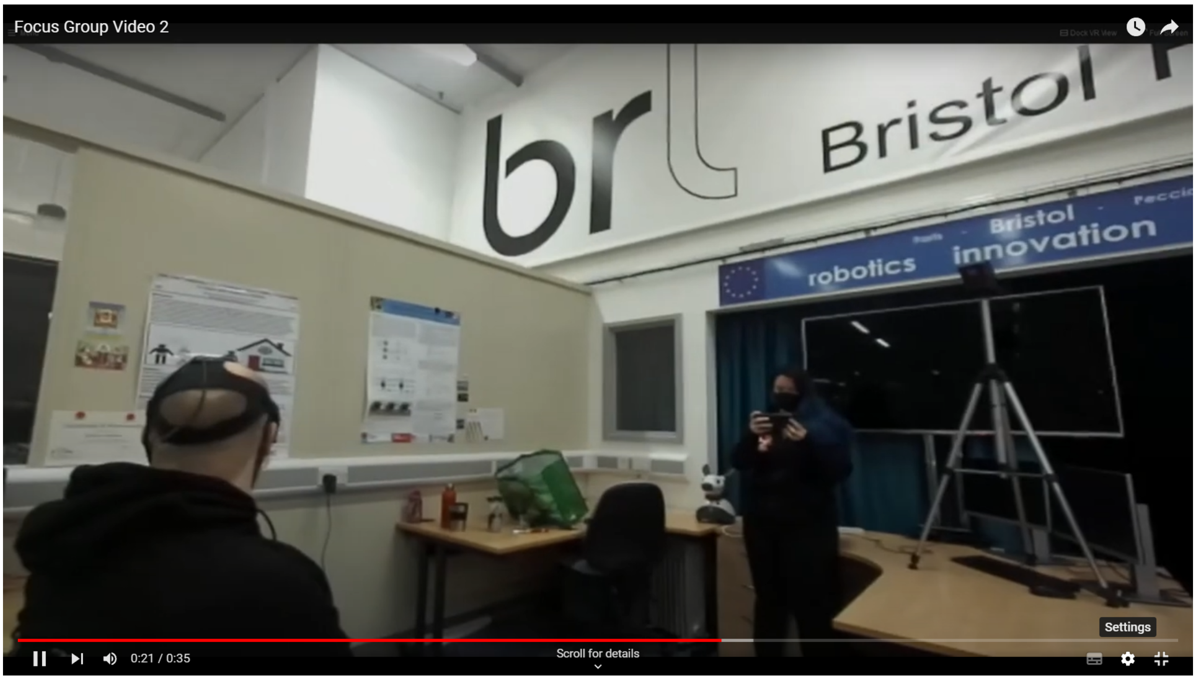



Figure 2.4: Screenshot from the Video Portraying the System Being Used from the View of the Camera Attached to the Robot.

Following the participants watching the videos, the post-demonstration discussion took place. The questions were as follows:

1. What features of the current system do you like and dislike?

2. Are there any other features that you think are essential and need to be added?

3. Do you think the robot is an appropriate choice to be a surrogate? Please explain your answer.

4. Do you think you could feel as though you were in another environment using the system? Please explain your answer.

5. Do you think you could have a natural interaction with another person while one of you is communicating using the system? Please explain your answer.

6. Any other comments?

Having seen the videos, this discussion aimed to assess thoughts surrounding the features of the system, any features they felt were essential, the appropriateness of the chosen robots, and the possibility of place and social presence when using the system or interacting with the user. During the third question in this session, participants were shown images of Pepper and Socibot to add context to comments made by other participants. The option to add any additional comments was also offered here. Finally, the participants were debriefed and given a final chance to withdraw their responses from the study.

## 2.3 Results

Thematic analysis was conducted on all qualitative data collected during the focus groups. The themes were formulated by looking for patterns in the data, these were then used to code the data and are listed below. The summarised findings for each theme are also listed in this section. The findings consider the groups as one group of experts due to very few relative differences in opinions between groups. Additionally, it should noted that the participants of the focus groups were unable to test the system in-person due to COVID-19 restrictions and therefore were only able to comment based on videos and descriptions.

### 2.3.1 Themes Identified During Thematic Analysis

Following an inductive approach allowed themes to become evident from the data without having any preconceptions about what to look for [71]. The identified codes were:

1. Media Portrayal
2. Real-World Uses
3. Current Assistive Uses
4. Current Studies
5. Cultural Differences
6. Generational Differences
7. Current Studies
8. Robot Surrogate
9. Liked Features
10. Disliked Features
11. Suggested Features

When considering these codes in the context of the study three overall themes were determined, as shown in Table 2.2. The findings from the focus groups in relation to these themes are discussed in the following section.

| Theme | Included Codes |
|---|---|
| Perception of Robots | Media Portrayal<br>Real-World Uses<br>Current Assistive Uses<br>Current Studies |
| Differences | Cultural<br>Generational |
| Essential Features | Robot Surrogate<br>Liked Features<br>Disliked Features<br>Suggested Features |

Table 2.2: Themes Identified During Thematic Analysis and Included Codes

### 2.3.2 Findings

This section discusses the quantified data from the focus groups. It also covers the qualitative findings in relation to the themes that were identified during the thematic analysis.

#### Quantitative Findings

The below tables highlight the quantified data collected during the focus group. These are broken down further into two tables for clearer comparison. Table 2.3 shows the total number of times each code was mentioned by each group over the course of each discussion, including number of responses in total. Finally, Table 2.4 shows the total number of occasions that each code is mentioned per question, plus the number of responses. The table showing the breakdown of how many times each code was mentioned by each focus group for each question and also the number of responses by each group can been seen in Appendix A.9.

| Theme | Perception of Robots | | | | Differences | | Essential Features | | | | Total Responses |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Group/Code | Media Portrayal | Real-World Uses | Current Assistive Uses | Current Studies | Cultural | Generational | Robot Surrogate | Liked Features | Disliked Features | Suggested Features | |
| Patient and Relative | 1 | 8 | 6 | 0 | 0 | 0 | 5 | 7 | 6 | 5 | 38 |
| Marie Curie West Midlands | 9 | 5 | 1 | 3 | 3 | 3 | 10 | 9 | 8 | 4 | 55 |
| Prospect Hospice | 2 | 2 | 2 | 1 | 0 | 2 | 6 | 20 | 10 | 5 | 50 |
| **Total Responses** | 12 | 15 | 9 | 4 | 3 | 5 | 21 | 36 | 24 | 14 | 143 |

Table 2.3: Breakdown of Total Number of Times each Theme is Mentioned per Group and Total Number of Responses

| Discussion/Question | Perception of Robots | | | | Differences | | Essential Features | | | | Total Responses |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Media Portrayal | Real-World Uses | Current Assistive Uses | Current Studies | Cultural | Generational | Robot Surrogate | Liked Features | Disliked Features | Suggested Features | |
| Discussion 1: Q1 | 7 | 12 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 25 |
| Discussion 1: Q2 | 4 | 1 | 0 | 2 | 1 | 0 | 11 | 0 | 0 | 0 | 19 |
| Discussion 1: Q3 | 0 | 2 | 5 | 0 | 1 | 3 | 0 | 9 | 5 | 0 | 25 |
| **Total Discussion 1** | 11 | 15 | 7 | 4 | 2 | 3 | 13 | 9 | 5 | 0 | 69 |
| Discussion 2: Q1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8 | 6 | 0 | 15 |
| Discussion 2: Q2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 3 | 6 | 12 |
| Discussion 2: Q3 | 0 | 0 | 1 | 0 | 0 | 0 | 8 | 0 | 1 | 0 | 10 |
| Discussion 2: Q4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 7 | 2 | 16 |
| Discussion 2: Q5 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 9 | 1 | 2 | 14 |
| Discussion 2: Q6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4 | 7 |
| **Total Discussion 2** | 1 | 0 | 2 | 0 | 1 | 2 | 8 | 27 | 19 | 14 | 74 |
| **Total Responses** | 12 | 15 | 9 | 4 | 3 | 5 | 21 | 36 | 24 | 14 | 143 |

Table 2.4: Breakdown of Total Number of Times each Theme is Mentioned per Question and Total Number of Responses

The section below discusses this quantitative representation of the findings, alongside other qualitative findings, in relation to each overarching theme.

#### Perception of Robots

Some of the main findings concerned perception of robots, and social robots in particular. Initially, most participants did not associate anything social or humanoid with robotics, but rather immediately thought of practical, existing real-world uses, such as military, industrial, and domestic. However, one participant mentioned a "non-human" appearance, while another specifically mentioned a "humanoid" appearance. There were also some participants who commented on current assistive uses such as feeding aids and prostheses for Paralympians. Meanwhile, the majority of participants generally struggled with the concept of social robots and most were unfamiliar with the term. The response was fairly mixed, where some participants felt that hearing “social robot” either made robots sound “friendlier” or did not change their opinion. However, a number of participants agreed that robotics and social were "a direct contradiction".

Another main point of discussion was regarding media portrayal of robots, and in particular science fiction media and the disparity between this and robots in reality. Furthermore, the participants commented on two studies conducted with robots. One was hitchBOT which “hitch-hiked” across Canada in 2013 and visited Germany and the Netherlands, but was vandalised in 2015 when it was in the United States [72]. The other was a documentary about robots used in hospitals; the participant did not remember the study, but remembered a patient stating “take that Dalek away” when presented with the robot.

Overall there was a fairly equal discussion surrounding perception and the effects that media portrayal and real-world uses have (8% and 10% of total responses respectively). However, current research portrayal discussed amongst the experts only made up 3% of total responses, highlighting the limited knowledge of research within the general public. Overall, participants liked the innovation, especially as they stated that when they were children this system would have been considered science fiction.

**Cultural and Generational Differences**

The experts also discussed the effect of generational and cultural differences on perceptions of robots. Most participants commented that younger generations would be more open to such technologies and would manage more effectively when they reached the approximate age when they could benefit from such a system, rather than the current population. It was compared to when online banking and Amazon Alexa were first introduced and how they have "mostly been adjusted to now". Additionally, comments were made regarding both sides of the interaction about "getting used" to the system with time, and how younger grandchildren would "not be phased" by interacting with the robot. Participants felt similarly with regards to culture, and felt that cultures more widely familiar with robots, such as "some Eastern cultures", would also be more accepting. However, literature is inconsistent with regards to cultural and generational effects on perceptions of robots; this is discussed further in the Discussion section.

**Essential Features**

Prior to watching videos of the teleoperation system working, all participants agreed that technology in general could benefit individuals living with a life-limiting illness, however this was conditional. Participants commented on existing assistive technology, such as environmental control systems, sensors, and bio-markers to send data to healthcare professionals automatically. They felt technology could "support people", assist with tasks, "such as making tea", and "help to tackle isolation" via "communication with the outside world". In addition, one participant commented that they felt that technology should "not be used to provide interaction" specifically. However, groups felt that most technological solutions could be expensive and that patients would struggle to access it.

Having seen the system working, the experts commented on a higher number of features that they liked rather than ones they disliked (25% and 17% of total responses respectively). The majority of comments focused on the head-mounted display (HMD) based teleoperation system specifically. There were concerns around how "bulky" the headset was, but other participants said that they felt the headset was "OK", was the "same size as ones currently at [their] hospice", and that family members could assist with putting it on. Additionally, they were generally satisfied with the clarity of the camera stream, but multiple participants commented on the “wonky” and “jerky” view as a result of the robot’s "unsteady gait", and had concerns surrounding motion sickness. Another concern was how future-proof the system as a whole would be for users. The patient who took part in the focus group shared that their diagnosis was Motor Neurone Disease (MND), and that they were "losing mobility in [their] hands and fingers", resulting in not being able to use the controller. The experts generally felt positively about feeling present in a remote environment and the ability to verbally interact, but they also stated that watching the video was insufficient to fully assess without being able to test the system in-person. They also stated that the presence felt could depend on previous experience of telepresence. The participants commented on the ability to look around and it feeling "like a 3D environment" rather than "just looking at a screen" as with telecommunication software. However, they commented on the need for training and the chance to get used to moving around the space. In addition, participants felt that the system would be of most use in familiar environments rather than new ones; some examples included: a child’s house, or their own house when they are waiting for carers to assist them in getting out of bed, as was the case with the patient in the group. Finally, the groups discussed the impact of the technology; they felt that for the system to be successful in its aims the "technology would need to advance further".

Similarly to place presence, participants responded positively to the concept of natural interaction and communication using the system, but that this was dependent on the performance of the technology itself, especially sound quality and delays. They felt this applied for both the users of the system and people interacting with them through the robot, especially when those were children. Participants felt that it would be similar to "seeing a patient when they were in bed", but stated it may "take more effort" for those interacting to get used to communicating via the robot. To tackle this, it was suggested that having a static picture on the robot to show who the user is would be better. They also discussed that people would need time to get used to the system and used Ring doorbells and Zoom as examples where this had occurred. In response, they added that virtual reality would be beneficial as Zoom generally "only shows the top half of an individual's body".

In addition to the HMD, experts had many opinions with regards to the robot surrogate, where this made up 15% of all total opinions. Generally, participants agreed on most comments, and having seen both the NAO robot and images of the Pepper robot during question 3 of the post-demonstration discussion (Figure 3.8 [73]), all participants unanimously stated they preferred the appearance of the NAO robot. They preferred NAO's smaller size and stated that it looked more “friendly” and less “artificial” than Pepper. One group of healthcare professionals stated that patients "with Dementia in particular" would be "more comfortable with NAO". However, other participants, despite preferring the NAO, mentioned that the overall appropriateness of the robot would depend on accessibility, environment, and individual circumstances, citing the case of a patient in the United States who used head movement to control a mobility chair. Finally, they discussed the “Uncanny Valley” - the relationship between the extent to which a humanoid entity resembles an actual human being and the emotional response such an entity evokes [45]. They discussed that mimicking a person could be “creepy” and questioned whether it would be "socially unacceptable to mimic a person that closely". One participant suggested projecting the users face onto a robot, at which point (question 3 of the post-demonstration discussion) the participants were shown Socibot (Figure 2.6 [74]), which the participants unanimously agreed was "not an idea that should be considered". Additionally, experts generally liked the look of the robot and commented that it looked “friendly” and that the colour was “unobtrusive”. Participants also liked the robot's autonomous gestures and commented on the "suggestion of being alive". However, one participant did specifically comment that they “slightly disliked” the robot, but "could not pinpoint" why they felt that way.

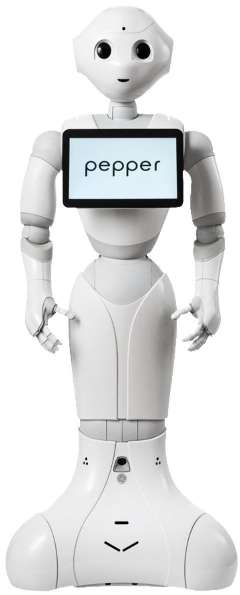



Figure 2.5: Pepper Robot - United Robotics Group [73]

Figure 2.6: Socibot Kiosk and Socibot Mini - Engineered Arts [74]

Finally, the experts provided some suggestions for essential features which made up 10% of total responses. Only one participant could not think of any additional features, though felt that "nothing [needed] to be taken away" from the current iteration of the system. Some participants had concerns around the wired nature of the system and questioned whether the technology would become "lighter and wireless" in the future, as well as whether the system would be able to control multiple robots at once. The nature of life-limiting illnesses means that symptoms, both physically and regarding personality, are constantly changing. Therefore, it was suggested by multiple participants that voice commands would be "more appropriate" in the case of changing mobility. Additionally, there was much discussion around the inclusion of gestures, whether they should be tempo or context based if implemented, and whether there should be an option to toggle them on and off. It was suggested that gestures, personality, and body language could be recorded when the patient was well enough in order to continue to accurately portray them later on. There were a very small number of additional comments made, mostly regarding the technology itself. These included comments regarding reliance on a stable connection if communicating with family abroad, which they stated would be "an excellent use case". They also questioned what would happen if the robot were to fall over. Participants also generally agreed that the system should remain simple to avoid it becoming “cumbersome and expensive”, such as maintaining an "accessible, uncomplicated headset" and keeping possible task performance simple.

## 2.4 Discussion

This section lists user design requirements formulated from the findings from the focus groups. It also discusses these requirements in relation to the research questions identified for this chapter specifically, as well as the themes identified during the thematic analysis of the qualitative data. The research questions primarily focused on the essential design features for social interaction (RQ2 and RQ3 at thesis level). This section also covers the implications of the findings, and how they lead onto future work.

### 2.4.1 Discussion of Findings: Formulating User Requirements

This section discusses user requirements formulated from the findings resulting from the focus groups.

**Consideration to Perception and Acceptance of Robots**
The findings from the focus groups highlight the importance of perception of robots for acceptance of the system. It was found that a number of factors affect this for experts in the field of life-limiting illnesses, such as: media portrayal, real-world uses, current assistive uses, current research studies, and cultural and generational differences.

While real-world uses generally involve industrial or domestic robots, media portrayal is often rooted in science fiction. Media exposure of robots is generally linked to a positive attitude towards them, but trust is generally only affected by "fact-based" media channels [35]. This supports findings as participants talked extensively about science fiction media, and were generally positive, but did not consider trust as a factor. These findings highlight the importance of adhering to literature with regards to the selected robot surrogate, as generally the perception of the general public relies heavily on media. The related literature is discussed further in Chapter 3.

It was also suggested that acceptance would be widely effected by the technology itself. Older adults willingness to accept technology is strongly related to level of education; while perceived ease of use and usefulness, attitude and experience with technology, and perceived hedonism is moderately related [75]. Furthermore, there is a shift in the acceptance of robots as the ageing population changes over time [76]. This indicates that robots will be more widely accepted as an integral part of healthcare going forward, which was also suggested by all experts in the study. However, another study examining perceptions of robots found no significant difference of negative attitudes towards them between younger, middle-aged, and older adults [77]. This challenges suggestions that older adults are not as receptive to robots, which corresponds with experts in the groups who commented on the current acceptance of technology and virtual reality already present in their respective hospices.

Participants felt similarly with regards to culture, and felt that cultures more widely familiar with robots would also be more accepting. However, it was found that despite some cultures having stronger more positive attitudes towards robots, there was no significant difference between some Eastern and Western cultures in their attitude towards robots [78], as was suggested in the focus groups. In addition, it was found that acceptance is higher for non-verbal behaviours that more closely mimic those of the users culture [79]. Aside from this, participants felt there was potential for such a system to take off, but that it was reliant on such technology becoming culturally accepted. This is especially relevant for the treatment of patients in a country as diverse as the United Kingdom, where the experts are based.

**Usability of the Teleoperation System**

One finding was regarding the usability of the system. Participants generally agreed that the system should remain uncomplicated to avoid unnecessary expense and technology. In addition, participants talked about needing to get used to technology, especially for older generations, which is supported by the literature discussed above. However, they also discussed current assistive uses of technology, including having virtual reality headsets already available within their hospices. They highlighted the benefits of these and positive anecdotes provided by their patients and residents, which supports the proposed use case for this PhD research.

**Head-Mounted Display Based Teleoperation System** With regards to the head-mounted display (HMD), participants had concerns about the the weight and accessibility of the technology, due to the changing nature of the patients' symptoms, as discussed above in the Background and Context section. Some participants also had concerns surrounding the wired nature of the system and questioned whether the technology would become lighter and wireless in the future. Furthermore, there were comments about reliance on a stable connection if communicating with family abroad, which they stated would be an excellent use case. Overall, the findings showed that the experts felt that the success of the system would be largely dependent on technical advancements and improvements in this area. Therefore, it is vital to consider the impact that participant symptoms will have on the success of the system, and to continue to iterate as newer technologies become available.

**Robot Surrogate**
The participants generally approved of the choice of robot surrogate as described in the Results section, however there were some additional suggestions made. For example, it was suggested that gestures, personality, and body language could be recorded when the patient was well enough in order to continue to accurately portray them later on.

Furthermore, participants discussed using a projected face of the user onto a robot, but after being shown Socibot (Figure 2.6) decided that it would be too susceptible of producing effects akin to the "Uncanny Valley" [45]. However, some studies show that research into the dimension of human likeness and the "Uncanny Valley" produce inconsistencies [80]. As a result, it was suggested that a static picture of the user could be beneficial, which corresponds to research conducted by Tsui [38], which states that telepresence robots which do not have a live or static image of the user may be suspicious to interactants and bystanders. This could be implemented if the Pepper robot were to be used, but not with the NAO robot; the differences between these two robots are explored further in Chapter 3.

**Out of Scope Suggested Features**
While the experts made several suggestions, some were not within the scope of this PhD research. One such suggestion was the use of voice commands and pre-recorded gestures to combat changing mobility due to the nature of life-limiting illnesses symptoms frequently evolving. Additionally, participants also felt that the need for controllers would be restrictive for patients with limited upper mobility. However, this project focuses throughout on patients with full mobility in their hands and arms, and therefore, this concern is out of scope for the PhD project; however, this is briefly discussed in the Future Work section of Chapter 5.

An additional request made by the experts was to be able to perform simple actions using the robot, such as make a cup of tea. However, this is not the aim of the PhD project and therefore has not been explored further at this stage. This misunderstanding of the overall aim of the research highlights the need to manage user expectations when designing the teleoperation system following a user-centred design protocol.

Finally, participants questioned possible solutions if the robot were to fall over. This was explored by Daly [81] who found that the portrayal of "happy" and "sad" emotions had an effect on the willingness of bystanders to intervene and assist robots. They also investigated the ethics of including such emotions in development with the specific goal of manipulating human interactants into assisting; their findings suggested that whilst people did not feel that using emotion was entirely unethical, they did perceive them as less ethical than an entirely emotionally neutral robot [81]. These findings suggest that future development could focus on autonomous behaviour portraying emotion to promote assistance should the user find themselves with the robot stuck or compromised; this is discussed further in Chapter 5 as this development is out the scope of the doctoral research conducted.

### 2.4.2 Implications for Development

The focus groups aimed to identify user requirements and essential features for the head-mounted display based teleoperation system for a humanoid robot surrogate. Given that the intended users are individuals living with life-limiting illnesses, it was important to consult experts in the relevant field. The groups took part in two discussions, the first of which aimed to discuss existing perceptions of robots in general, social robots, and the benefits of technology within the field. The second focused on their opinions of the HMD based teleoperation system and robot surrogate having seen videos of it being demonstrated. The findings from these have been used to inform user requirements for further development of the system following a user-centred design protocol. The implication of these for both development and the wider field of human-robot interaction is the ability to use these requirements going forward for developed of a teleoperation system for humanoid robot surrogates for users with life-limiting illnesses; a novel application for this technology.

### 2.4.3 Summary of User Requirements

This is a summarised list of user requirements for further development of a head-mounted display (HMD) based teleoperation system for humanoid robot surrogates for users with life-limiting illnesses. They are categorised following the most prevalent themes that emerged from the findings of the focus groups. These themes are consistent throughout the remaining thesis, though are reevaluated and strengthened throughout the PhD research.

**Development Approaches**

*Continue to iterate the system as technology advances*
Findings suggested that many of the limitations of the system were due to the limitations of the technology itself. This could be somewhat alleviated by upgrading the utilised hardware as it improves.

*The system should remain simple, uncomplicated, and as accessible as possible*
All participants, as supported by literature, acknowledged that users would be able to adapt to the system, but suggested that the system remain simple and uncomplicated to avoid unnecessary expense and confusion.

**Head-Mounted Display Based Teleoperation System**

*Utilise available technology to ensure the HMD is as streamlined and lightweight as possible*
Experts highlighted that symptoms may make it challenging to wear the HMD for long periods of time, due to discomfort and fatigue. Similarly to the above, utilising the most appropriate currently available technology to reduce the bulk and weight of the HMD may alleviate some of these challenges.

*Utilise a wireless streaming protocol*
Participants expressed concern regarding the wired nature of the system. It would be optimal to implement wireless streaming capabilities to improve the mobility of the system.

*Ensure the most stable network connection for optimal interaction*
To alleviate any concerns around connection while users are communicating with the interactants, it is vital to utilise the most reliable network connection available.

**Robot Surrogate**

*Include a static image of the user if possible*
Literature highlights the importance of including a representation of the user, if possible, for the benefit of the interactants.

*Use humanoid robots, but not one with projected faces due to "Uncanny Valley" effect*
Experts, as supported by literature, suggested the use of humanoid robots for the system. However, it was agreed that currently available robots with projected faces produce "uncanny valley" effects.

**User-Centred Design**
*Consider perception and acceptance of robots and technology*
Literature highlights general findings surrounding perceptions and acceptance of robots. However, participants stated that, from their experiences, this varies among individuals. Therefore including the users in design is vital.

*Consider cultural and generational differences when designing the system*
Similarly to the above, experts highlighted an awareness of cultural and generational differences between individuals. However, literature shows some inconsistencies. Therefore, it is important to consult intended end-users during development.

*Manage user expectations with regards to system capabilities and performance*
Individuals without expert knowledge in robotics tend to have higher expectations with regards to potential system capabilities, partially due to media portrayal of robots. These expectations must be managed during development and deployment to avoid disappointment.

### Publication

The work contained in this chapter has not yet been submitted for publication, but is currently being written up for submission to the Frontiers in Robotics and AI Journal.

## 2.5 Conclusion

This chapter covered focus groups conducted with experts in life-limiting illnesses. The aim of the groups was to identify user requirements which could inform development of the head-mounted display (HMD) based teleoperation system for a humanoid robot surrogate, alongside relevant literature. Three main themes were identified as areas of consideration for development by participants: Perception of Robots, Cultural and Generational Differences, and Essential Features. The key findings for this chapter, and relevant research questions (RQs) at thesis level are as follows:

- Individuals' perceptions of robots and levels of trust, when controlling and interacting with them, can be largely affected by media portrayal. Therefore, literature into guidelines for social robots and telepresence systems must be adhered to when selecting an appropriate robot surrogate. (RQ2 and RQ3)

- Cultural and generational differences have an impact on the acceptance of the system. However, some assumptions made by participants were inconsistent with those suggested by literature, such as attitudes of the older population and Eastern cultures. Literature must be adhered to, and attitudes of the potential users further explored during development. (RQ2 and RQ3)
- Participants discussed assistive technologies already present in their everyday lives and available in their places of work. They suggested that while some time may be needed to get used to the technology, they believed it would be possible and intended end users would be willing to based on their experience. This supports the suggested use case for the system. (RQ3)
- Participants showed some concern regarding the hardware used in the system due to its bulk and weight due to the end users' changing symptoms. Therefore, research into the best available technology within the budget set for this PhD research should be conducted prior to further development. (RQ3)
- Additional features such as minor task completion, and behaviour to assist the robot when it fails, is beyond the scope of this doctoral research and it is important to manage user expectations when further evaluating the developed system. (RQ3)
- A list of user design requirements was formulated to inform further development for this system, and future systems catering to individuals living with life-limiting illnesses (RQ3)

The findings of this chapter were that experts felt generally positively with regards to the head-mounted display based telepresence system, though concerns were expressed around the technology used. The themes identified throughout the focus group provide much needed user requirements formulated with the help of experts in the field. These requirements, alongside relevant literature, assist in the development of the system. The following chapter documents initial development of the system, plus additional development conducted as a result of the findings from the focus groups, and evaluation studies which are also discussed.

CHAPTER 3

# Technical Development and User Evaluation

The previous chapter discusses in detail the process of identifying the necessary user requirements formulated by exploring related literature and conducting focus groups with experts in the field. These formulated design requirements, alongside additional related work, informed design decisions for the system that has been developed as part of the PhD research. This chapter covers the technical design and implementation of this head-mounted display based teleoperation system; as well as the design, implementation, findings, and implications of user studies conducted with healthy participants to evaluate the system. The studies evaluated the usability of the system and compared its capabilities with currently available telecommunications software.

## 3.1 Introduction

This section covers related work relevant to the technical development of the system designed and evaluated as part of the PhD research. It also covers the aims and objectives of this chapter. The literature partially justifies and informs the choices made with regards to design decisions for the developed system, including hardware choices which are discussed further in the development section of this chapter. In addition, the aims and objectives are specific to this chapter, but relate to the aims, objectives, and research questions for the PhD research as a whole, which are addressed in Chapter 1.

### 3.1.1 Background and Context: Design Features for Telepresence Systems and Social Robots

One of the aims of the PhD project is to allow for effective social interaction between the user and others in the remote environment. Guidelines for successful social interaction when using mobile telepresence were created by Tsui and Yanco [38], where the end goal should be effective interpersonal communication between the user and interactants. Three vital interactions were identified: the human-robot interaction between the user and the robot's interface, the human-robot interaction between the robot's local human interactants (those who interact with the telepresence robot), and the human interaction between the user and interactants, which is also covered in Chapter 2. Tsui and Yanco [38] also suggested that if the human-robot interaction is successful then the human interaction is maximised. This PhD research aims to allow users to achieve all of these types of interaction successfully by following design features highlighted by research discussed below.

Furthermore, Tsui and Yanco [38] found that presence and engagement could be reduced if the interactants are unwilling to communicate via the robot; therefore, it is important to consider how others view the chosen robot surrogate, especially when investigating the use of teleoperation in social interaction. They stated that technology "should disappear" for the user and interactants if a system has been designed well, and that the focus should be on communication and interpersonal relationships [38]. Unlike more physical task-oriented telepresence robots, social robots with the specific goal of human-robot interaction have to be able to successfully act as a believable human proxy, or they will not be accepted by the human interactants. Therefore they recommended the use of humanoid robots for social roles [38]. However, Leite [82] warned that selecting a humanoid would create higher expectations of social capabilities than a zoomorphic robot. Additionally, Adalgeirsson [83] conducted a study measuring the effects of expressivity and found that socially expressive robots were more engaging and likeable than a static ones, as well as contributing to more psychological involvement and better cooperation. Pepper is marketed as an "emotional robot" and is capable of acting as a believable human proxy and also has high levels of expressivity [84]. For users to be able to interact with loved ones, it is vital that interactants are comfortable interacting with the robot surrogate, therefore meeting the requirements set by prior research is a necessity, as is managing users expectations as is highlighted in the findings from Chapter 2 and literature [82].

Interactant behaviour towards the robot surrogate is also important for successful interaction. Takayama [85] noted that it was vital that the robot surrogate is not touched; they reported that the user felt that the interaction was as invasive as if they had been standing there in-person, which suggests high levels of presence for the user. With this in mind, inspiration was taken from research investigating the impact of certain features and behaviours on willingness to interact with a robot for a short time [86]. They hypothesised that being able to turn towards the person that the robot was interacting with to indicate attention, was one of the minimal requirements of successful social human-robot interaction. They found that this was important for giving a slight increase in performance. This finding was important for this PhD research as it suggested that connecting the HMD movement with the robot's head movement was critical for interaction. Additionally, they also found that having a robot with the ability to convey expression with a humanoid face produced similar results, and that the two factors together produced the most compelling results. However, findings from the focus group from Chapter 2 suggested that the robot surrogate should not have the user's face on the robot to avoid issues with feelings of discomfort due to the "Uncanny Valley" [45]. Furthermore, the findings from Chapter 2 found that Pepper and NAO were acceptable surrogates as experts felt that they looked "friendly".

Having compiled their list of guidelines, Tsui [38] highlighted the importance of perceived presence for the interactant as well, and claimed that the quality of the interaction with the embodied teleoperated robot will depend on how present the interactants feel the user is. They questioned whether the use of virtual or augmented reality could improve social presence in addition to place presence and whether the need for more processing power would be worth the extra amount of sensory information provided by a more immersive system [87]; this research aims to bridge the gap between virtual reality controlled telepresence, social presence, and social robots.

### 3.1.2 Aims and Objectives

The aims of this chapter were to design and implement the head-mounted display (HMD) based teleoperation system for a humanoid robot surrogate, while taking into consideration the user requirements formulated from the focus groups described in Chapter 2 and related literature as summarised above. Additionally, two user studies were conducted with healthy participants to evaluate the usability of the system and the effect on place and social presence when compared to telecommunication software Skype. The design, findings, and implications of these studies are discussed at the end of this chapter.

With the above aims in mind the following objectives were identified:

1. Identify the appropriate hardware for operating the robot
2. Identify the appropriate robot to act as a surrogate
3. Identify software requirements to integrate the system together
4. Conduct user studies to evaluate the system's usability and capabilities

The section below covers the technical development of the system designed to satisfy these aims and objectives.

## 3.2 Technical Development

This section of the chapter describes the system overview, which has remained consistent throughout the PhD research, and the process of developing the system, along with the hardware and software involved. The user studies conducted to evaluate the system and their findings are described in the section of this chapter following the initial development, along with any system modifications completed as a direct result. A section describing the Final System Specification and Setup, as well as the development stage leading to this, is included at the beginning of Chapter 4.

### 3.2.1 System Overview

The system that has been developed allows for communication between two users via the use of a robot surrogate and head-mounted display (HMD) based teleoperation system. The system is compromised of the HMD based input system using virtual reality (VR) and a humanoid robot surrogate. A Ricoh Theta V 360 camera (Figure 3.1), and later Zed Stereo Camera (Figure 3.2), was streamed into a HTC Vive virtual reality (VR) (Figure 3.3) head-mounted display (HMD) using C# and the Unity Game Engine. The two parts of the system communicate using Python 2.7 and Unity Game Engine (C#) across a networked socket.

Figure 3.1: Ricoh Theta V 360 Camera


Figure 3.2: ZED Stereo Camera

Figure 3.3: HTC Vive Virtual Reality System

Figure 3.4 shows the connections between the different hardware used in the system and the physical locations of that hardware. The direct connections show which hardware is wired to the PC. The indirect connections show that the head-mounted display (HMD) controls the head movement of the robot via the PC; it also shows that the camera is streamed to the HMD via the PC. The software used in these connections is discussed below.

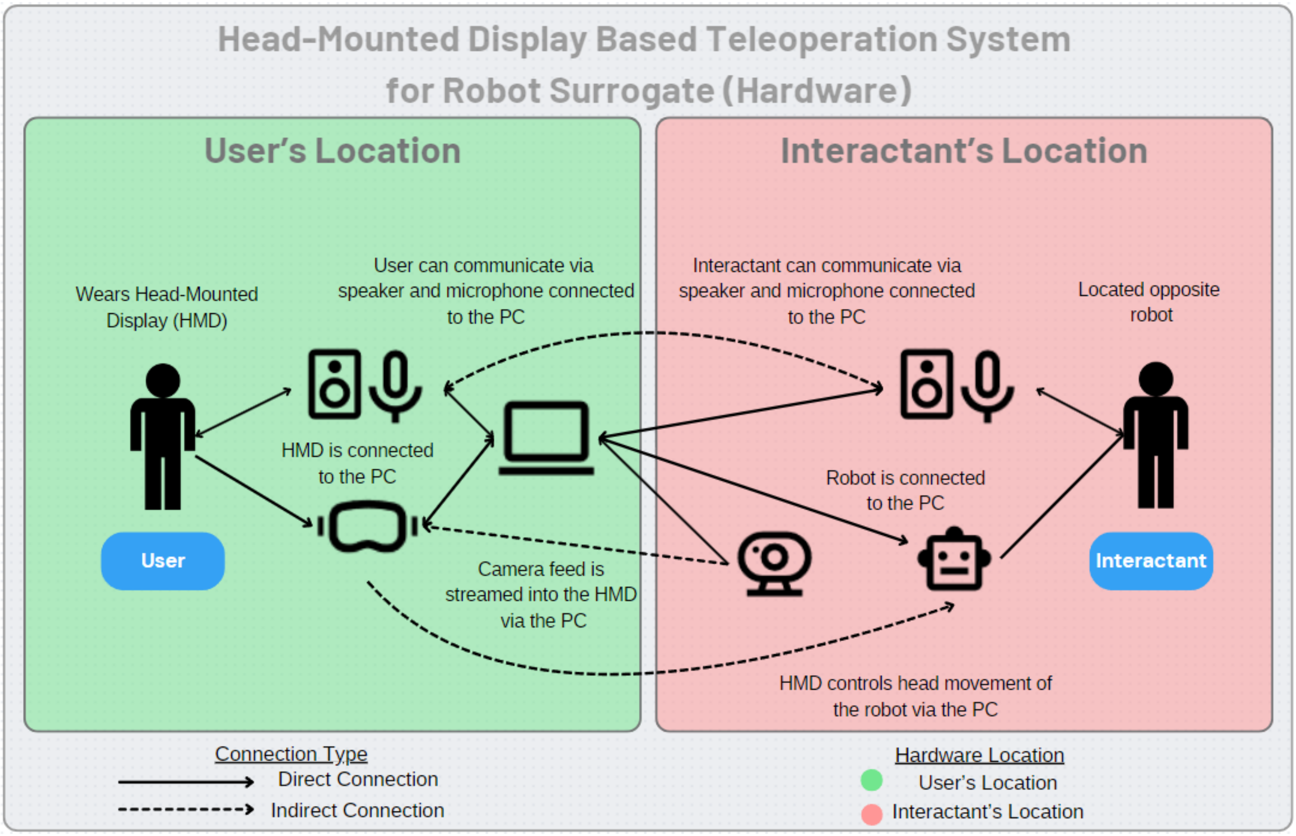



Figure 3.4: Diagram of Connections Between Hardware Used in the System

Figure 3.5 shows the integration of the system. The part of the system that is made up of the HMD based teleoperation system utilises Unity and C#. The camera is accessed and streamed to the HMD via Unity; additionally, Unity accesses and manipulates the positional and rotational data of the HMD. This data is passed from the socket server to the receiver via a network connection. On the side of the robot surrogate, Python code is used to receive and further manipulate the positional and rotational data, before using that data to move the robot's head. The result of this is that the robot's head moves at the same time and location as the user moves the HMD while wearing it.

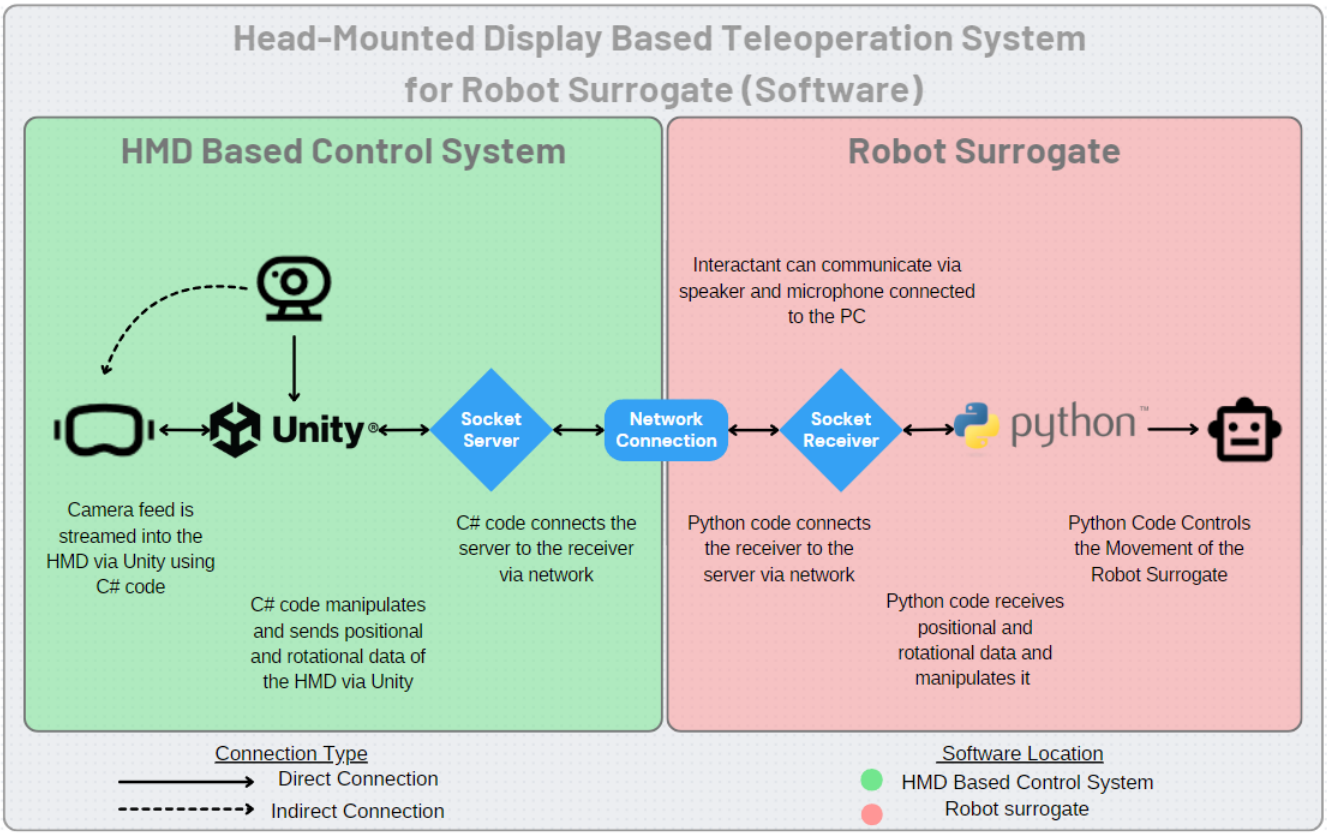



Figure 3.5: Diagram of Connections Between Software Used in the System

**Software Functionality**

The below diagram provides a visual representation of the software functionality, and further describes the technical contribution of this PhD research (Figure 3.6). The functionality of each module is also described below.

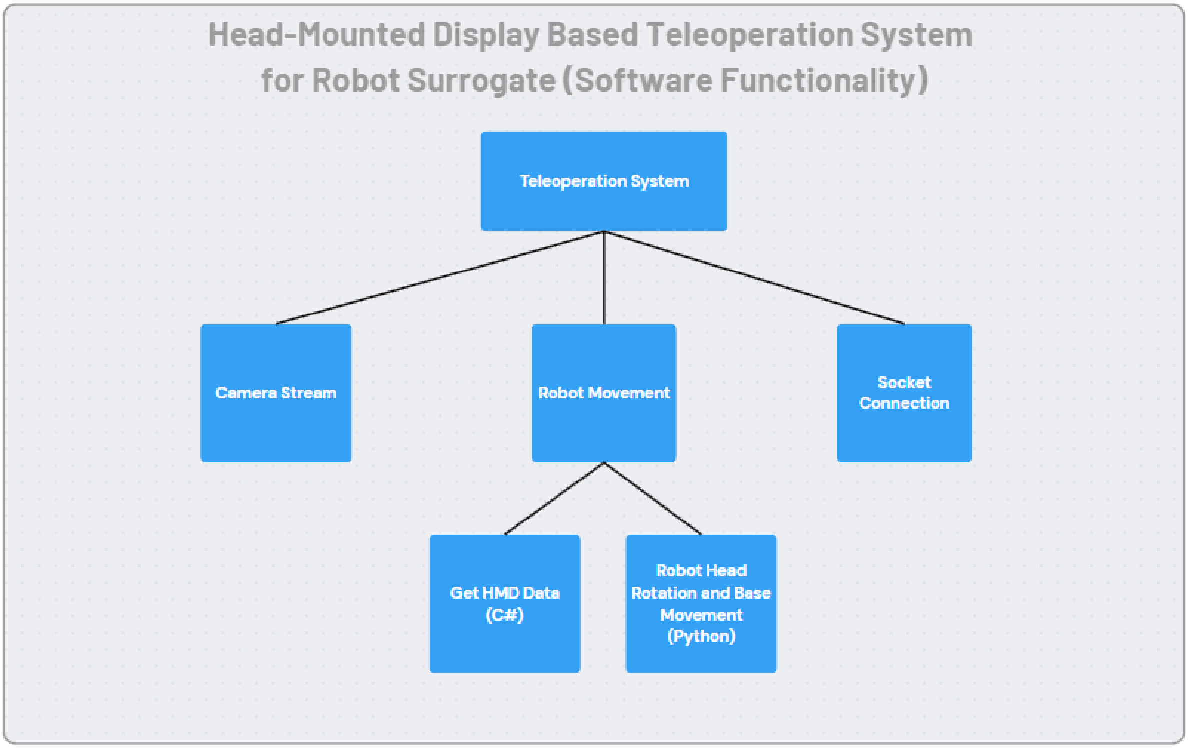



Figure 3.6: Diagram Showing Visual Representation of Software Functionality

***Camera Stream:***

This module locates any cameras connected to the PC and lists them in the console. It adds an "Index" box to the Unity Inspector and allows easy assignment of the appropriate index of the Ricoh Theta V and later the Zed Stereo camera. It then streams the feed of the selected camera into the head-mounted display (HMD) of the Vive.

***Robot Movement:***

*Get HMD Data (C#):*

This used the SteamVR plugin and later the Zed Stereo Plugin. It takes the current positional and rotational data of the HMD in Quaternions, converts them to Euler angles, and then into a String type value.

*Robot Head Rotation and Base Movement (Python):*
This controls the robot's head movement allowing for simultaneous movement with the HMD. The HMD's orientation Euler angles are fed to Pepper's head joints (pitch and yaw only) via the socket connection. The values are received as a String type value before being reverted to Euler Angles. This was first tested in simulation using SoftBank Robotics' program Choregraphe, which allows for connection to a virtual robot, and then connected to the physical robot using the IP address and Port of the local machine.

In a later iteration of the system, it also receives binary values from the Vive controller to determine whether to move the robot's base. These values are converted into velocity along the x-axis, in meters per second, and velocity around Z-axis, in radians per second. This determines whether the robot should translate forwards/backwards, strafe left/right, and/or rotate clockwise/anti-clockwise.

***Socket Connection:***
When integrating the Python and C# scripts, the software proved to be impossible to run side by side, as both could not access the HMD at the same time. In order to run both pieces of code, it was decided that sockets should be used, which involved connecting the software over a network connection rather than locally. This meant that only the C# code being read by Unity would access the Vive and the Python code would receive the angles provided by the Vive via the socket server, enabling the robot's head to move almost in real-time with the user's.

The components and development for both the HMD based teleoperation system and the robot surrogate are described further below.

### 3.2.2 Initial Design and Development

This section covers the initial design and development of the system described in the overview above, which the user requirements from Chapter 2 suggested should be as uncomplicated and accessible as possible. The process of development is described including design decisions made by the researcher. Furthermore, the system is broken up below into four more detailed sections: Head-Mounted Display (HMD) Based Teleoperation System, Robot Surrogate, Communication and Interaction, and Network.

**Head-Mounted Display Based Teleoperation System**
Typically research involving virtual reality is conducted using the HTC Vive and the Oculus Rift; due to previous experience using the Vive, this seemed the most sensible choice. Looking into the systems further, there was an abundance of documentation and tutorials on the Vive,the Unity

game engine, and the Steam VR API which were used to program both systems; this further supported the decision to use that system. User requirements in Chapter 2 showed the importance of utilising available technology to ensure the HMD was as streamlined and lightweight as possible. The HTC Vive VR system was the most popular system amongst developers at the time of development and therefore this was chosen [88]. Given the decision to use the Vive, it was important to select a camera that could be used with it.

Unfortunately, the robot's built-in cameras are 2D only and, despite a resolution of up to 2560x1080 at 5 frames per second, do not produce an high enough quality image to stream into the HMD. Therefore, external cameras were used instead. Due to resource availability and good reviews, the first camera tested with the system was the Garmin 360 Virb (Figure 3.7), which allowed for 4k streaming. However, after many attempts it was not possible for the PC to recognise the camera as anything other than a storage device and could only stream to an app, and therefore it was not feasible to be used with the VR system.


Figure 3.7: Garmin 360 Virb Camera

Only the high definition setting was available as the 4k setting caused too much latency for the system to be usable.

In order to access the camera using Unity, it was important that it could be recognised as a webcam by the computer. Another factor to consider was cost, as a budget of approximately £300 was allowed for this component of the system. Additionally, the camera had to be standalone and not part of a rig in order to be feasibly attached to the robot. Finally, the camera had to have the ability to live stream, and not just record and store footage. Several tutorials for streaming into a head-mounted display (HMD) were found which used the Ricoh Theta V 360 degree camera (Figure 3.1), which also allows for 4k streaming. With these factors in mind, the Ricoh Theta V was deemed the most appropriate choice of camera due meeting these requirements, fitting within the available budget, and scoring highly in reviews both for the camera model specifically (Theta V) and the brand in general (Ricoh) [89, 90, 91, 92].

The Ricoh Theta V is capable of 2K and 4K resolution and the details of this and the available frame rates for still images, videos, and USB live streaming are detailed in the table below (Table 3.1) as taken from the manufacturers website [93]. However, when streamed into the HMD a 720p resolution is more realistic.

| | |
|---|---|
| File Size (still images) | 5376 × 2688 |
| File size / Frame rate / Bit rate (Videos) | 2K, H.264: 1920 × 960 / 29.97 fps / 16 Mbps |
| File size / Frame rate / Bit rate (Videos) | 2K, H.265: 1920 × 960 / 29.97 fps / 8 Mbps |
| File size / Frame rate / Bit rate (Videos) | 4K, H.264: 3840 × 1920 / 29.97 fps / 56 Mbps |
| File size / Frame rate / Bit rate (Videos) | 4K, H.265: 3840 × 1920 / 29.97 fps / 32 Mbps |
| File size / Frame rate (live streaming (USB) | 2K, H.264: 1920 × 960 / 29.97 fps / 42 Mbps |
| File size / Frame rate (live streaming (USB) | 4K, H.264: 3840 × 1920 / 29.97 fps / 120 Mbps |

Table 3.1: The Technical Specification for the Ricoh Theta V 360 Camera [93]

The choice of game engine was primarily down to industry standard technology and available documentation. The Unity or Unreal game engines were the obvious options for VR development, with 67% of nominees in the AR/VR category of The Game Awards between 2018 and 2022 made using either Unity or Unreal and both engines averaging the same number of titles nominated each year [94]. However, Unreal focuses on high end 3D assets and graphics, which are not required for this project, while Unity uses a simpler programming language [94], making Unity a more sensible choice for this particular use case.

The camera feed was accessed using Unity and streamed onto a static sphere, the wearer of the HMD is positioned in the centre of the sphere in the VR environment. The camera was attached to the head of a humanoid robot in a location separate to the user, and therefore the user appeared to be in the centre of the image. The user would be sitting at a computer wearing the HMD and communicating via a speaker and microphone connected to the PC, in the form of noise cancelling headphones. Images of the setup at the user's location can be found in Figure 3.10. The position and rotation information was taken from the HMD and controls the head of the robot - and therefore moves the camera - allowing the user to look around the remote environment. This is discussed further below.

**Robot Surrogate**

The Final step in selecting the appropriate hardware was to choose the robot to integrate with the system. The robot chosen was a Pepper humanoid robot (Figure 3.8 [73]) and the camera was attached to the head of the robot to give the user the illusion of embodiment. The Pepper robot was chosen due to its humanoid features, which was identified as a user requirement in Chapter 2, and its tendency to be known as the more "trustworthy" and “emotional robot” [95, 96]. However, the importance of consulting literature regarding perceptions of robots, as well as cultural and generational differences, was also highlighted in the user requirements and Pepper was proved to meet the relevant guidelines laid out by Tsui [38] as described in the Background and Context section above. In addition, it also proved to have the relevant capabilities to be used in further development, by being able to meet the guidelines laid out by Leite (2013) [82]. The Pepper robot supports both C++ and Python programming languages, however, Python was chosen for its simplicity as any behaviours performed by the robot did not require complexity, as advised by experts in Chapter 2.

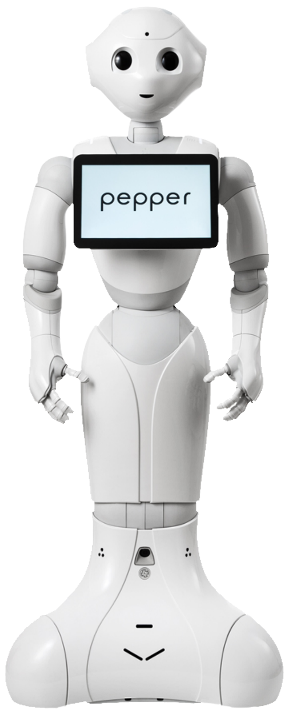



Figure 3.8: Pepper Robot - United Robotics Group [73]

As described in the system overview section, the positional and rotational data of the HMD is accessed using Unity, which relies on the C# programming language. The data is then manipulated and sent to the corresponding Python code via a networked socket. Finally, after some further manipulation, the data is used to move the robot's head; matching the positional and rotational data of the HMD that the user is wearing. Images of the setup at the interactant's location can be found in Figure 3.11 in the section discussing the user studies conducted to evaluate the system below.

**Communication and Interaction**

Using microphones and speakers connected to the PC, communication between the user and an interactant in the remote environment utilises a telecommunication system. During this stage of development, both users were required to wear noise cancelling headphones to avoid any background noise from their locations.

**Network**

The system requires the PC and robot to be connected to the same network, this includes over wifi, however, the connection is more robust when using wired ethernet connection, which was highlighted as a user requirement in Chapter 2. During development the system used a connection with the following data:

- Download Speed: 74.5 Mbps
- Upload Speed: 48.7 Mbps
- Data Delay: 10.3ms

In addition, for this proof of concept the system relies on a wired USB connection between the camera and PC, but in future a wireless streaming protocol would allow for remote connection provided that it avoids creating frame rate issues, which is a user requirements that was also identified in Chapter 2.

## 3.3 Evaluation and System Modifications

Two user studies were designed and conducted in order to evaluate the performance of the system. The first of these compared the effect of the system on place and social presence to readily available telecommunications software. The second evaluated the usability of the system. Both of these studies are discussed below along with related background literature, and any system modifications made as a direct result of them.

### 3.3.1 Background and Context: Place and Social Presence

As stated in Chapter 1, presence is the primary measure for telepresence systems, and one of the aspects systems such as these aim to achieve. As previously described, presence can be further broken down into two main types - place or spatial presence, and social presence. These are discussed below, alongside literature on virtual reality and telepresence.

Wei et al [97] stated that communication is an interactive process where verbal and non-verbal messages are mutually exchanged and interpreted. They also specified that good communication helps to build trust, improve relationships, solve problems, and handle conflicts [97]. Technology has been used more frequently to facilitate communication, especially since the COVID-19 pandemic, which hindered our ability to communicate in person [98]. However, not all types of telecommunication technology, such as videoconferencing software, provide an immersive environment similar to that of face-to-face interaction [97]. Consequently, these technologies do not always provide the user with feelings of "bodily closeness, emotional closeness, and the experiences of physical presence" that this PhD research aims to provide [97]. However, telepresence systems have been shown to successfully provide these feelings [99].

Telepresence refers to a person feeling virtually present in a remote location [100], often known as place or spatial presence. As originally stated in Chapter 1 Witmer and Singer [33] defined presence, as "the subjective experience of being in one place or environment, even when one is physically situated in another". Witmer and Singer [33] created a presence questionnaire as a metric to evaluate this, and this is the measure that has been adapted to be used in the studies described in this chapter.

Samani et al [101] stated that "the sense of presence is a multi-component and subjective concept that is achieved when a person has the impression of actually being present in a remote environment", making it hard to successfully achieve. Ching [102] suggested that this could be achieved with "low latency, high frame rate and good calibration of the device". At the time of development, the HTC Vive had the highest resolution (1080x1200 per-eye) in 2 x OLED binocular screens and refresh rate (90 Hz), as well as 108° horizontal/97° vertical field of view, within the necessary budget [103]; therefore, this was the selected hardware for the project. Further justification for hardware choices are also discussed in the Technical Development section of this chapter.

While hardware choices can have an impact on place presence, it can also have a significant impact on social presence as well. Social presence was described by Biocca et al [104] as "being together with another"; both physically and emotionally. More specifically Biocca and Harms [34] further described it as having a "sense of being with another in a mediated environment", where it is possible to access the psychological, emotional, and intentional states of the other person. Social presence can be separated into first order co-presence, physically being together in the same space (Table 3.2), and second order psycho-behavioural interaction, perceived psychological engagement and mutual understanding [105]. Second order psycho-behavioural interaction can be further separated into perceived attentional engagement, perceived emotional contagion, and perceived comprehension as shown in Table 3.3. In order to measure this they created the Networked Minds Social Presence Inventory [105]. This measure was used in the study described below that compared the system developed as part of the PhD with telecommunication software; this was to ensure that the interactions between the local and remote participants were not only positive, but also equal in experience.

| Perception of self | Perception of the other |
|---|---|
| I often felt as if (my partner) and I were in the same (room) together. | I think (my partner) often felt as if we were in the same room together. |
| I was often aware of (my partner) in the (room). | (My partner) was often aware of me in the (room). |
| I hardly noticed (my partner) in the (room) | (My partner) didn't notice me in the (room). |
| I often felt as if we were in different places rather than together in same (room) | I think (my partner) often felt as if we were in different places rather than together in the same (room). |

Table 3.2: First Order Social Presence: Co-Presence

*Perceived psychological engagement*

| Perception of self | Perception of the other |
|---|---|
| **Perceived attentional engagement** | |
| I paid close attention to (my partner). | (My partner) paid close attention to me |
| I was easily distracted from (my partner) when other things were going on. | (My partner) was easily distracted from me when other things were going on. |
| I tended to ignore (my partner). | (My partner) tended to ignore me. |
| **Perceived emotional contagion** | |
| I was sometimes influenced by (my partner's) moods. | (My partner) was sometimes influenced by my moods. |
| When I was happy, (my partner) tended to be happy. | When (my partner) was happy, I tended to be happy. |
| When I was feeling sad (my partner) also seemed to be down. | When (my partner) was feeling sad, (my partner) I tended to be sad. |
| When I was feeling nervous, (my partner) also seemed to be nervous. | When (my partner) was nervous, (my partner) I tended to be nervous. |
| **Perceived comprehension** | |
| I was able to communicate my intentions clearly to (my partner.) | (My partner) was able to communicate their intentions clearly to me. |
| My thoughts were clear to (my partner). | (My partner's) thoughts were clear to me. |
| I was able to understand what (my partner) meant. | (My partner) was able to understand what I meant. |

*Perceived behavioral interdependence*

| Perception of self | Perception of my partner |
|---|---|
| My actions were often dependent on (my partner's) actions. | (My partner's) actions were often dependent on my actions. |
| My behavior was often in direct response to (my partner's) behavior. | The behavior of (my partner) was often in direct response to my behavior. |
| What I did often affected what (my partner) did. | What (my partner) did often affected what I did. |

Table 3.3: Second Order Social Presence: Psycho-Behavioural Interaction

### 3.3.2 Pilot Study: The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software

This section briefly details a pilot study conducted to refine the design of the teleoperation system for a humanoid robot surrogate and design an experimental protocol for healthy adults to compare the system with telecommunication software.

#### Aims

The designed study aimed to identify any changes required for the technical development of the teleoperation system. Additionally, it aimed to design an experimental protocol to measure place presence, social presence, and usability for the developed teleoperation system when compared to telecommunications software Skype.

**Methodology**

The procedure for this pilot was to run iterations of the user study described in the corresponding User Study section below. The pilot took part over four session and a total of eight healthy participants took part in the pilot studies using the system. Qualitative feedback was provided by the participants, the experimental setup adapted through several iterations based on this feedback, and the final experimental setup was decided on and approved by expert participants who were familiar with the hardware.

**Findings**

The pilot study successfully resulted in an experimental protocol capable of comparing the teleoperation system and telecommunication software Skype. However, the studies highlighted several changes that had to be made before the study could be run in full. It was important to improve the resolution of the image streamed into the headset as this was said to make the system "uncomfortable" and "unusable". Participants also stated that it “ruined feelings of presence” and that it felt “disorientating”. Furthermore, there was also a comment regarding the stitching of the 360 degree image distorting their view of the environment. It was also identified that the use of headphones ruined the immersive nature of the study, and felt like "being on the phone" where participants found themselves "ignoring Pepper entirely". The participants suggested that the sound needed to come from Pepper’s “mouth”; this is to be expected as Tsui and Yanco [38] claimed that the quality of an interaction between a human and an embodied robot is dependent on the feelings of presence and that it was vital for “the user’s voice to come from the robot’s perceived mouth”. Further to this, they showed that it was vital to have at least a static image of the user’s face in order to placate any feelings of suspicion; this may explain why users found it relatively easy to forget that Pepper was being controlled by the user [38]. These findings support the user requirements identified by focus groups in Chapter 2 and need to be addressed further prior to running the full user study. These system modifications are described below.

### 3.3.3 System Modifications: Improve Technical Performance and Robustness

Prior to the full user study being conducted, and given the requirement from Chapter 2 to continue iterating the system as technology advances, it was important to address any issues highlighted in the pilot study if possible. In order to improve the issues with perceived resolution of the 360 Ricoh Theta V camera, which appeared "blurry" to participants during the pilot study, the camera was replaced with a StereoLabs ZED stereo camera (Figure 3.2), which provides depth data unlike the Ricoh Theta V. The image from the ZED Camera appeared as a screen within the headset; however, the increased perceived resolution performance was deemed to be of more benefit and importance than having a 360 degree image with issues surrounding image stitching and resolution; despite both cameras being listed as providing 720p resolution performance in Unity. This camera was also deemed to be a standard for research and development according to HTC Vive support at the time of development [106]. Finally, using plugins designed for Unity to access the feed for the camera reduced issues with firewalls blocking the connection and causing disconnection issues.

The following shows the delay in milliseconds for the video feed at each level of resolution. This has been calculated by subtracting the current time displayed on the video feed from the current printed system time, and then taking the average of multiple calculations.

- HD720 at 60 fps: approx. 135.41250266 Milliseconds
- HD1080 at 30 fps: approx. 135.56728700 Milliseconds
- HD2K at 15 fps: approx. 209.44504874 Milliseconds

Additionally, a Jabra Speak (Figure 3.9) was used as a microphone and speaker to enable for clearer sound and removing the need for any headphones. It was attached to the front of the Pepper robot to give the impression of the sound coming from the robot rather than a laptop or headphones. Both of these adjustments address issues highlighted in findings from the pilot study. This setup is shown in Figures 3.10 and 3.11.


Figure 3.9: Jabra Speak

### 3.3.4 User Study: The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software

Having discussed the importance of presence for teleoperated systems in the related work section above, this study aimed to compare the effect of the system on place and social presence to readily available, widely accepted, and utilised, telecommunications software. The study, including its methodology and findings, is discussed in this section.

**Research Questions and Hypotheses**

As highlighted in the related work for this chapter, place and social presence are of vital importance in evaluating a teleoperated system and are an industry standard in this regard. Meanwhile, regular telecommunications systems, specifically videoconferencing software, are able to produce feelings of presence and provide a much needed means of close communication between those at the end of life and their loved ones [107]. In addition, they can provide superior audio quality when compared to a regular telephone, even over network [108]. However, Wei et al [97] found that perceived social presence was higher for virtual reality than in telecommunication software and social media apps. Additionally, they stated that people felt physically and emotionally closer in VR and showed the same connection with partners as in face-to-face communication [97]. Therefore, it is important to compare these two means of communication in order to develop the system with the highest chance of tackling social isolation by providing users with life-limiting illnesses with a means of interaction.

Therefore, this study aims to address the following research questions to address the overarching research questions listed in Chapter 1. The overall research questions at thesis level can be found in the brackets at the end of each:

1. Can a head-mounted display based teleoperation system facilitate higher feelings of place presence than telecommunication software? (RQ1)
2. Can a head-mounted display based teleoperation system facilitate higher feelings of effective, natural, social presence between the user and others interacting with them than telecommunication software? (RQ2)
3. Can a head-mounted display based teleoperation system be more usable than telecommunication software? (RQ3)

With these questions and literature covered in the related work section in mind, the following hypotheses have been identified for the study:

1. The HMD condition will produce higher feelings of place presence than the telecommunication condition.

2. The HMD condition will produce higher feelings of social presence than the telecommunication condition.

3. The telecommunication condition will produce a higher system usability score than the HMD condition.

The **null hypothesis** is that there will be no difference between the scores produced by the two conditions.

**Methodology**

This section describes in detail the methodology of the refined study conducted following the pilot and system modifications.

***Ethical Considerations***

The study was approved by the University of the West of England (UWE) Ethics Committee (Reference No. FET.18.11.016). All ethical conduct and data handling guidelines were adhered to.

***Participants***

An opportunity sample of participants were recruited via a Doodle poll distributed around social media and an internal email at the University. A total of 13 pairs of healthy participants (19 male and 7 female) took part in the study, where 73% of participants were aged 25-34 and the remainder were over 18 in other age brackets. The participants had varying degrees of experience in virtual reality, robotics, and telecommunication software, and were awarded a £10 Amazon voucher for their participation.

***Experimental Setup***

The system allowed the user (known throughout the study as the ***local participant***) to see into the next room where the other participant was sitting opposite the robot (known throughout the study as the ***remote participant***). In turn, the remote participant could follow the local participant's gaze as the Pepper robot mimicked the user's head movement as described in the section above. The chosen telecommunication software was Microsoft Skype due to it's popularity at the time of development [109]. It was run on two computers allowing for audio communication between the participants, in addition to video communication during the telecommunication condition. The study consisted of two conditions as described below:

*Head-Mounted Display (HMD) Condition:*
The remote participant sat at a table opposite a Pepper robot. The local participant sat at a table in another room wearing the HMD. Pepper's head moved in the same direction as the headset to represent where the user is looking. A camera mounted on the robot provided the video stream to the HMD.

*Telecommunication Condition:*
The remote participant sat at a table opposite a laptop running Skype. The local participant sat at a table in a separate room opposite a laptop hosting the Skype call.

The study used a within-subject design and the remote participant remained consistent throughout both conditions. The ordering of the conditions was pseudorandomised between each set of pairs of participants.

***Task***
While in separate rooms, the participants communicated through the two different systems to complete a collaborative task. The task for this study was adapted from a ranking task used by Bremner et al [110] in a similar teleoperation study, and was chosen for its collaborative nature. The remote participant was asked to read the provided instructions (B.1.1) to the local participant and then together they were required to rank 5 words in order of importance to a survival scenario, where the scenario changed between conditions: a desert island [111] (B.1.2) and a crash landing on the moon [112] (B.1.3). They were not required to write down the order, but to place the words in their decided order on the table in front of the remote participant.

***Measures***
A number of quantitative measures were used in this study. Firstly, place presence was measured using Witmer and Singer's Presence Questionnaire [33] (B.1.4). Social presence was measured using the Networked Minds Social Presence Inventory [34] (B.1.5), which measures how technology may effect social presence, but does not aim to explain social presence as a concept. The questionnaire separated social presence into two main theories: First order social presence (co-presence) and second order social presence (psycho-behavioural interaction). In turn, second order social presence can be further divided into perceived psychological engagement (attentional engagement, emotional contagion, and comprehension) and perceived behavioural interdependence (Table 3.3). Additionally, system usability was measured for each system [113] (B.1.6). Only the local participant completed the presence and system usability questionnaires, whereas, both participants completed the Networked Minds questionnaire; the questionnaires were completed at the end of each condition.

***Procedure***

Each trial consisted of a local participant and a remote participant. The local participant was required to use the virtual reality head-mounted display (HMD) to control the head movements of a Pepper robot (the HMD condition - Figure 3.10) and also take part in a Skype call with the remote participant (the telecommunication condition). The remote participant was asked to sit at a table across from the Pepper robot in a separate room (Figure 3.11) and later take part in the Skype call.

Figure 3.10: HMD Condition - Local Participant Setup

The participants were asked to read an information sheet (B.1.7), and complete a demographics questionnaire (B.1.8) and consent form (B.1.9). Following this, they were invited to inspect the Pepper robot. During each condition the participants were asked to perform the collaborative ranking task, which allowed for involved discussion and social interaction, as well as group decision making. The order in which the conditions were executed was pseudorandomised between participant trials and the participants were assigned to conditions randomly. Following each condition, the local participant was asked to complete a number of questionnaires to measure place presence, social presence, and system usability, while the remote participant filled out the

Figure 3.11: HMD - Remote Participant Setup

questionnaire to measure social presence. They were asked to do this without discussing their answers. Following the completion of both conditions, the participants were given the opportunity to provide verbal feedback and ask any questions; they were fully debriefed prior to leaving the study (B.1.10).

**Results**

A number of two-tailed Paired-Samples T-tests were conducted using SPSS statistical software to analyse the questionnaire responses, having verified the data for normality using Shapiro-Wilk tests. Overall, the results showed no significant difference for place or social presence felt by those using the HMD system, or those interacting with them, when compared to Skype; therefore the null hypothesis could not be rejected. However, as hypothesised, the telecommunication condition scored significantly higher for system usability ($t = -2.846$, $df = 25$, $p < 0.05$).

While the results did not hold statistical significance, verbal feedback from the participants following the study trials suggested feelings of place and social presence, which was used as a measure for social interaction in this study. Participants commented on feeling as though they were "in the room", that conversations were "more natural", and that they felt like they were "chatting in the same room". In support of this, there was a trend in the data that showed slightly higher place and social presence for the HMD condition than the place and social presence for the telecommunication condition.

***Presence Analysis***

The process of analysis for place and social presence is described in this section. When analysing the presence questionnaire data, it was concluded that, despite there being higher mean scores overall for the HMD condition (Figure 3.12), there was no significant difference in the place presence felt between the HMD ($M = 4.731$, $SD = 0.697$) and telecommunication ($M = 4.433$, $SD = 0.425$) conditions ($t = 1.324$, $df = 12$, $p > 0.05$).

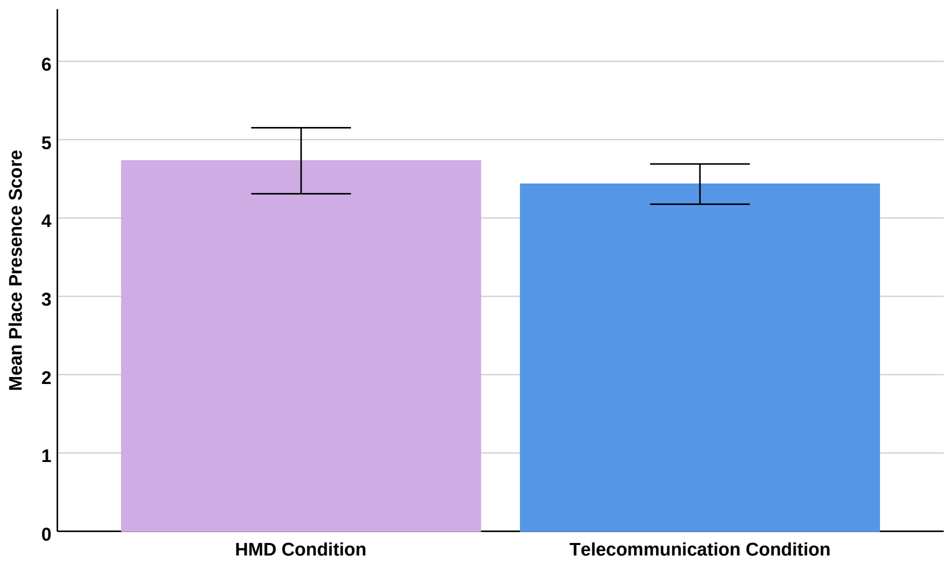



Figure 3.12: Mean Place Presence Scores for HMD and Telecommunication Conditions

Next, the different categories making up social presence were individually analysed, as well as the total mean scores for first order social presence and second order social presence, and the total mean scores for social presence as a whole.

When analysing second order social presence, no significant differences were found between the HMD and telecommunication conditions for the local (N = 13) or remote (N = 13) participants. This suggests that there is no significant differences between the constructs from the Networked Minds Social Presence Inventory for local and remote participants. The means and standard deviations (SD) are shown in Table 3.4 and t values displayed in Table 3.5, where second order social presence is separated into Perceived Psychological Engagement (PPE) and Perceived Behavioural Interdependence (PBI) as explained in the related work section of this chapter and shown in Table 3.3.

| | | Mean (Remote) | SD (Remote) | Mean (Local) | SD (Local) |
|---|---|---|---|---|---|
| Pair 1: PPE | Attentional Engagement: VR | 5.551 | 0.570 | 5.923 | 0.792 |
| | Attentional Engagement: Skype | 5.628 | 0.863 | 5.346 | 0.994 |
| Pair 2: PPE | Emotional Contagion: VR | 4.278 | 0.987 | 3.826 | 1.140 |
| | Emotional Contagion: Skype | 4.019 | 0.808 | 3.836 | 1.120 |
| Pair 3: PPE | Comprehension: VR | 6.256 | 0.801 | 5.923 | 1.302 |
| | Comprehension: Skype | 6.320 | 0.936 | 6.025 | 0.754 |
| Pair 4: PPE | Total PPE: VR | 5.253 | 0.567 | 5.084 | 0.734 |
| | Total PPE: Skype | 5.192 | 0.520 | 4.946 | 0.647 |
| Pair 5: PBI | Total PBI: VR | 5.346 | 0.951 | 5.551 | 0.668 |
| | Total PBI: Skype | 5.243 | 0.762 | 5.410 | 0.780 |

Table 3.4: Mean Scores and Standard Deviations for Second Order Social Presence

| | | t values (Remote) | t values (Local) |
|---|---|---|---|
| Pair 1: PPE | Attentional Engagement | -0.410 | 1.772 |
| Pair 2: PPE | Emotional Contagion | 1.173 | -0.028 |
| Pair 3: PPE | Comprehension | -0.328 | -0.228 |
| Pair 4: PPE | Total PPE | 0.615 | 0.473 |
| Pair 5: PBI | Total PBI | 0.373 | 0.683 |

Table 3.5: t values for Second Order Social Presence

Similar findings were found when second order social presence was analysed as a whole for participants in the HMD (M = 5.234, SD = 0.540) and telecommunication conditions (M = 5.129, SD = 0.511) ($t = 0.850$, $df = 25$, $p > 0.05$). However, it was found that when looking at first order social presence (co-presence) the scores tended towards being higher for the HMD condition (M = 4.654, SD = 0.969) than the telecommunication condition (M = 4.010, SD = 1.015) ($t = 2.010$, $df = 25$, $p > 0.05$, $p = 0.055$), as seen in Figure 3.13. This effect was found mostly for the local participant, who scored telecommunication lower than HMD for social presence; however, the remaining means were similar between local and remote participants across conditions.

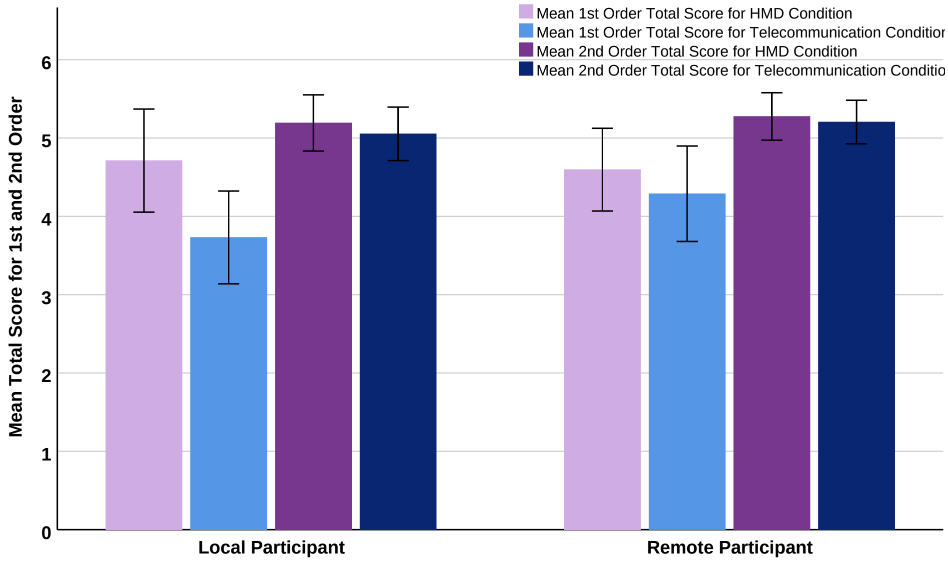



Figure 3.13: Mean First and Second Order Social Presence Scores for Local and Remote Participants in the HMD and Telecommunication Conditions

Similarly, when looking at the scores for social presence as a sum of its parts, the scores tended towards being higher for the HMD condition (M = 5.097, SD = 0.518) than the telecommunication condition (M = 4.865, SD = 0.505) (t = 1.717, df = 25, p > 0.05, p = 0.098), as seen in Figure 3.14.

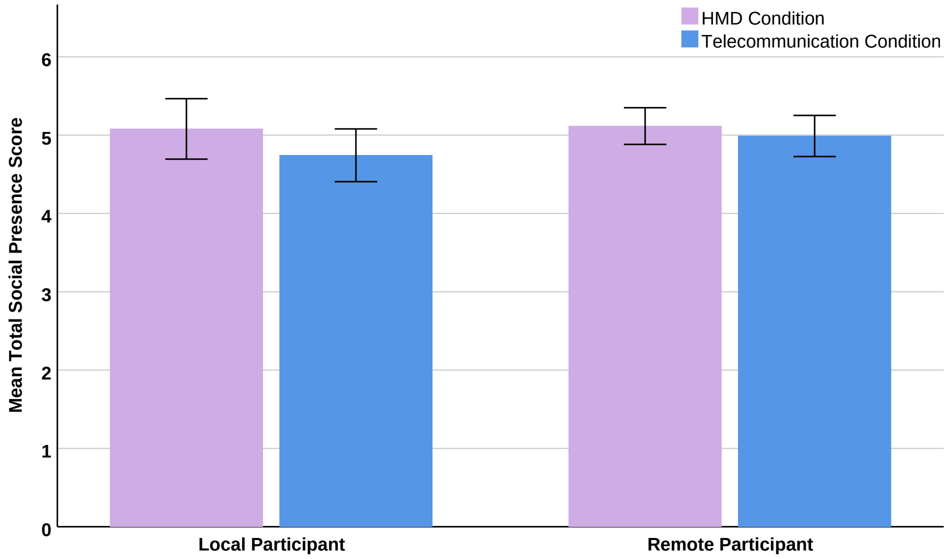



Figure 3.14: Mean Social Presence Scores for for Local and Remote Participants in the HMD and Telecommunication Conditions

***Usability Analysis***

As hypothesised, system usability was judged significantly higher for the telecommunication condition (M = 1.738, SD = 2.802) than the HMD condition (M = 1.441, SD = 2.513) ($t = -2.846$, $df = 25$, $p < 0.05$), as seen in Figure 3.15.

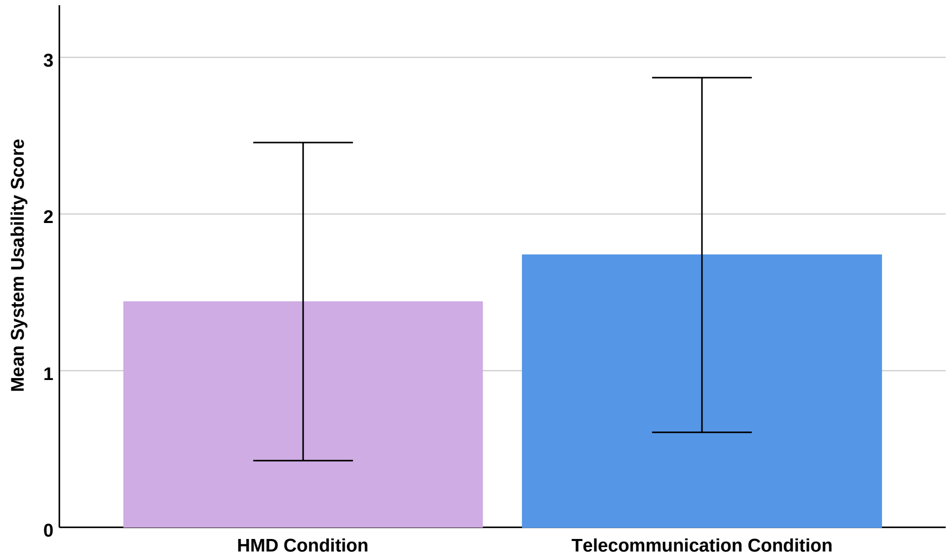



Figure 3.15: Mean System Usability Scores for HMD and Telecommunication Conditions

**Discussion**

This section covers a summary of findings with relation to the identified research questions. Additionally it briefly covers limitations of the study, and how the findings lead into future work.

***Place and Social Presence (RQ1 and RQ2)***

The findings show that there was a general trend towards higher feelings of both place and social presence for the HMD condition. Additionally, this was evident in all aspects of social presence for both the local and remote participants. However, there was a non-significant effect for both. This general trend suggests that the PhD research is still worth pursuing as it is possible that the subtle effect shown could have been statistically significant had the study been conducted with a larger sample. Furthermore, social interaction can be highly impacted by proxemics [114], and therefore, further investigation into possible navigation capabilities is needed to fully evaluate potential feelings of place and social presence.

***Usability (RQ3)***
As hypothesised, Skype was found to be significantly easier to use than the teleoperation system. One consideration is the familiarity of Skype, which has been consistently improved since its release in 2003 [115]. Despite virtual reality being coined in 1989 by Jaron Lanier [40] and being studied more frequently in the early 1990s [116], virtual reality (VR) only became a more widely recognised commercially available phenomenon in the 2010s when companies introduced headset that leveraged powerful graphics and motion tracking technology [117]. Participants using the HMD based system had limited physical movement, suffered minor latency in the movement of the robot's head and camera, and commented on slight levels of discomfort caused by the head mounted display. Therefore, further work looked into the usability of the currently available technology to see the effect it's capabilities may have had.

***Implications***
Considering there was a non-significant trend towards higher feelings of place and social presence for the HMD condition, it is reasonable to continue to pursue the research area, especially when paired with the generally positive comments and user requirements discussed in Chapter 2. As the telecommunication condition was found to be significantly easier to use as hypothesised, it is worth considering the usability of the head-mounted display teleoperation system overall in future work, and this was the following study that was conducted. Given the inconclusive nature of the comments surrounding the most appropriate robot surrogate, both Pepper and NAO teleoperation will implemented and evaluated in future work. Additionally, as discussed above, proxemics is important for social interaction and therefore navigation capabilities will also be implemented and evaluated. This development is discussed in the section below following details on the publication of this work.

**Publication**
This study was accepted for publication as a Late-Breaking Report in the Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20) (Appendix D.1). The citation for this publication is:

Bethany Ann Mackey, Paul A. Bremner, and Manuel Giuliani. 2020. The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20). Association for Computing Machinery, New York, NY, USA, 349–351. DOI:https://doi.org/10.1145/3371382.3378268

Additionally, a paper discussing the PhD research project as a whole was also accepted at this time as a Pioneers Workshop submission in the Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20) (Appendix D.2). The citation for this publication is:

Bethany Ann Mackey, Paul A. Bremner, and Manuel Giuliani. 2020. Immersive Control of a Robot Surrogate for Users in Palliative Care. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20). Association for Computing Machinery, New York, NY, USA, 585–587. DOI:https://doi.org/10.1145/3371382.3377445

### 3.3.5 System Modification: Implement Movement and Additional Robot

Two of the most impactful changes were the ability to use the head-mounted display (HMD) teleoperation system with either the NAO or Pepper robots and the ability to navigate remotely by physically moving the robot. Moreover, this is the iteration of the system that was demonstrated to the participants in the focus groups described in Chapter 2. The justification behind these additions, the differences and similarities between the two robots, and the process of implementing movement are discussed in this section.

***Pepper and NAO Humanoid Robots***

During this stage of development, the system was extended to include the control of a NAO robot as well as the Pepper robot (Figure 3.16). Pepper had been chosen as the robot surrogate in the initial development stage due to its design as a popular social robotics platform [118]. The manufacturer states that Pepper is capable of fostering "empathetic connections by understanding and responding to human emotions", which they claim "leads to meaningful and fulfilling interactions" [73], as is one of the overall aims of this PhD research. However, standing at 121cm tall with its arms by its side [119], Pepper became an impractical choice during the COVID-19 Pandemic, as is described below.

Due to the NAOqi API shared by both robots the system was able to interchangeably control both NAO and Pepper robots with some minor calibration. They also share many of the same capabilities as both are marketed as social humanoid robots [73, 69]. The primary differences between the two types of robots included the differences in height, with NAO measuring 57.4cm [120], therefore making the NAO robot a more feasible option for the home working that was required by the United Kingdom Government [121]. An additional difference was the presence of individual leg actuators on NAO, resulting in a more humanoid walking motion, in comparison to Pepper's wheeled base which allowed for smoother locomotion.

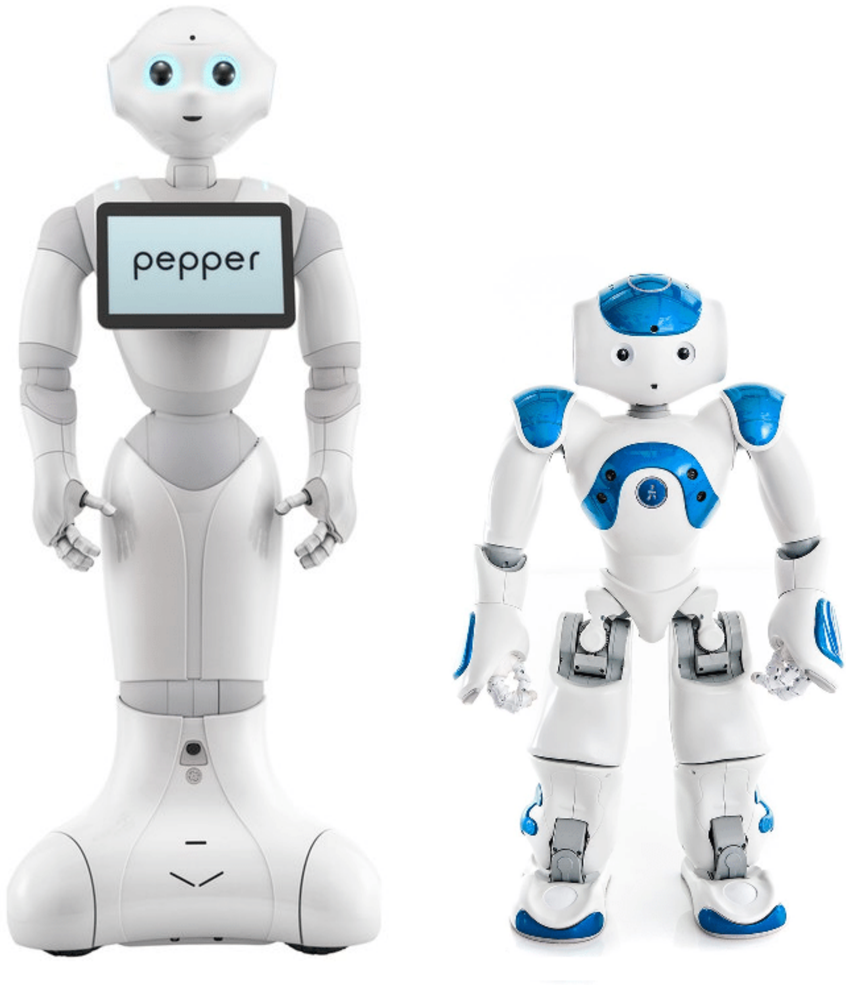



Figure 3.16: Pepper and NAO Robots - United Robotics Group [73, 69]

These similarities and differences allowed the NAO to be used for movement implementation during COVID-19 lockdowns to avoid halting development of the system and delaying the PhD research project. This implementation of movement is discussed below, along with any additional hardware modifications.

***Implement Movement***

Movement is highly important for presence and can compensate for loses in spatial resolution, and this has been the case since as far back as 1995 [122]. Therefore, it was a vital feature to be able to move the robot around the location in addition head. In order to implement movement, controllers for the HTC Vive were introduced (Figure 3.17), where the large circular directional pad controlled forward/backwards translation and rotation.


Figure 3.17: Vive Controller

In order to receive inputs from the user via the Vive controllers Unity was used, allowing actions to be assigned to specific buttons when pressed. These actions are then defined and the information passed to the robot via the networked socket. For this project the actions were assigned a binary value for translation and rotation where the robot was either moving forwards, moving backwards, rotating to the left, rotating to the right, or remaining stationary. This is in addition to the existing head movement taken from the positional and rotational data of the head-mounted display.

Finally, in order to hold the camera more securely to the robots' heads when moving, a helmet was designed and 3D printed for each as shown in Figures 3.18 and 3.19.

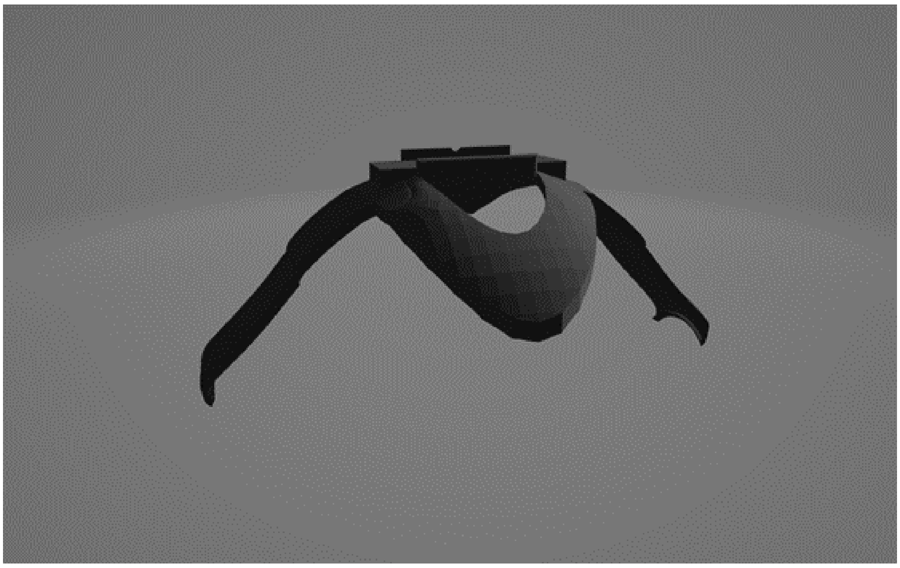


Figure 3.18: 3D Model of Pepper's Camera Helmet

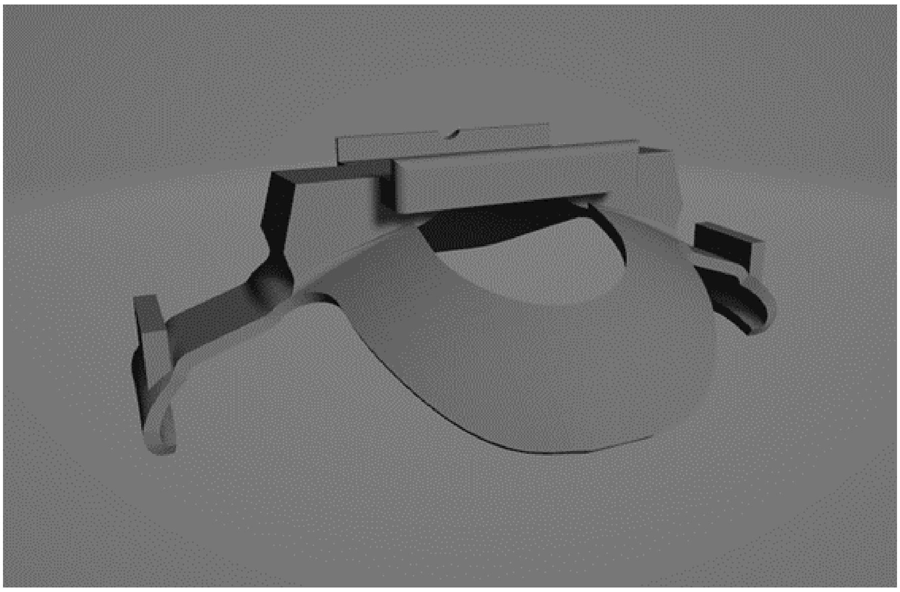


Figure 3.19: 3D Model of NAO's Camera Helmet

***Movement Latency***

The following shows the latency in milliseconds between the user moving their head or pressing a button and the robot performing the action. This was calculated by displaying the difference between when the action is received and immediately after the robot has completed the action.

- User Input to Movement: approx. 20-25 Milliseconds

### 3.3.6 User Study: Usability of an Immersive Control System for a Humanoid Robot Surrogate

As discussed in Chapter 2, user requirements were formulated using literature and focus groups conducted with experts in the field of life-limiting illnesses. However, it was also important to evaluate technical usability. Therefore, a study was conducted to evaluate this and is discussed in this section. In addition, participants in the groups had expressed uncertainty between Pepper and NAO robots with regards to which would be more appropriate. Therefore, having been able to implement control for both robots, and being able to return to work in a limited capacity, the system was evaluated with both robots during the study discussed in this section.

**Research Questions and Hypotheses**

Usability studies are commonly used to evaluate technical systems that have been developed using a user-centred design, by testing it with a group of representative users [123]. Given that the participants of the focus groups were only able to assess the system virtually, it was also important to evaluate the technical usability of it. In addition, as explained above and in Chapter 2, there was uncertainty on the most appropriate robot. There were also concerns surrounding the resolution of the camera, in both the focus groups and the telecommunication comparison study, despite having changed the camera to the Zed stereo camera. Therefore, with these points in mind, this study aims to address the following research questions to address the overarching research questions listed in Chapter 1, and more specifically focuses on necessary design features to create a usable system (RQ3):

1. How usable is the system in its current form? Which robot produces the best task performance?
2. Which robot is preferred by the participants?
3. What is the maximum resolution that can be used without resulting in an unusable delay in responsiveness by the system?

In addition to the research questions for this study, hypotheses were identified using the highlighted related work described above for each task performed in the study. These hypotheses are described in detail in the methodology section below.

1. ***Task 1:*** Participants would be able to identify the correct picture within a similar time frame equally with each robot.
2. ***Task 2:*** Participants would be able to navigate more quickly and accurately with the Pepper robot.

3. ***Task 3:*** Participants would prefer to interact using the Pepper robot over the NAO when controlling it and when it was being controlled by the researcher.

4. ***Task 4:*** Participants would prefer the resolution/delay trade off of 720p.

**Methodology**
This section covers the ethical considerations, experimental setup, participants, procedure, tasks, and measures of this study in detail.

***Ethical Considerations***
The study was approved by the University of the West of England (UWE) Ethics Committee (Reference No. FET.20.11.019). All ethical conduct and data handling quidelines were adhered to. Additionally, as well as following the university's official COVID-19 guidance, the following measures were taken to mitigate any COVID-19 related risks:

- The headset and controllers were sterilised between each participant.
- A separate foam piece for the headset was used for each participant.
- Social distancing between the participant and researcher was adhered to as strictly as possible.
- Participants were from the university and aware of the risk regarding COVID-19. They had also taken "return to work" safety courses provided by the university.
- Disposable gloves were offered to each participant at the beginning of the study.
- Face coverings were worn by the researcher and participants at all times. New masks were offered at the beginning of each trial.

***Experimental Setup***
For this study a NAO and Pepper robot were placed either side of a wall, with Pepper in a standing position on the floor and NAO in a standing position on a desk (Figure 3.20).

Two identical sets of seven photos were printed with numbers 1-7 and attached to either side of the wall, and a red cross taped to the floor in front of the robots. The numbers and locations of the pictures differed for each robot (Figures 3.21 and 3.22).

The control system for the robot, as described in the technical development sections, was located in an adjacent room to the robots.

Figure 3.20: Setup with NAO and Pepper Robots for Usability Study.

***Participants***

A total of 20 (N = 20) students and staff from within the university were recruited via internal emails and Doodle polls. Participants received a £10 amazon voucher for participation in the study.

***Procedure***

Before beginning the study the participants were asked to read an information sheet and privacy notice, and to fill in a consent form and demographics questionnaire (Appendices B.2.1, B.2.2, B.2.3, and B.2.4). Following this they were then invited to inspect both NAO and Pepper.

The participants were asked to put on the head-mounted display (HMD) and complete four tasks, which are described below alongside the measures used to collect data during the study. The tasks were completed once with each robot, following a within-subject design. Robot condition order was randomised to minimise practice effects. Throughout the study, participants were asked to use the concurrent think aloud process where they describe their actions, thoughts, and feelings out loud while undertaking an activity. This method allows for insight into "the way

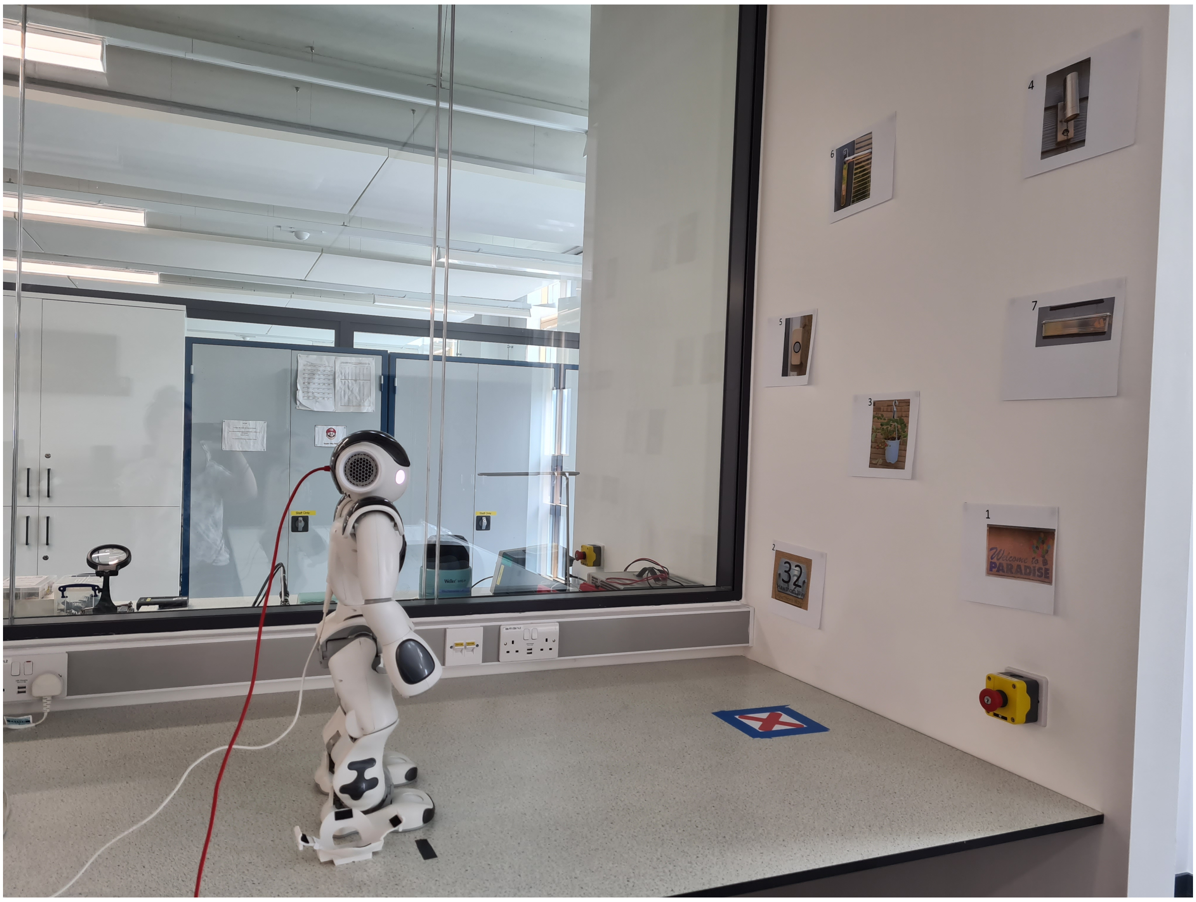


Figure 3.21: NAO Robot with Setup for Tasks.

users understand, mentally process, and respond to a material or a product" without the flaws of introspection and retrospection found in other approaches [124].

Following the tasks, participants were asked to complete a System Usability Scale (Appendix B.2.5) to assess how usable they found the system to be. A semi-structured interview was also conducted. This contained three open-ended questions, where participants could answer as much or little as they wished, as well as making any additional comments (Appendix B.2.6). The questions were as follows:

1. What features of the system do you like and dislike?

2. Which robot do you prefer to use overall out of NAO and Pepper? Please explain why.

3. At which resolution did the delay in responsiveness become too unusable?

Figure 3.22: Pepper Robot with Setup for Tasks.

**Tasks and Measures**

The following are the tasks completed by the participants to evaluate the usability of the system:

***Task 1: Identification***

Each robot was placed in front of 7 identical pictures, but placed in different locations (Appendix B.2.7). The participant was asked to locate the picture of the "doorbell" and say the word "found" as soon as they located it. The time taken to find the picture and whether or not it was the correct picture was noted (Appendix B.2.8).

***Task 2: Navigation***
The participant was given the controller and asked to navigate to the middle of a cross marked on the floor with Pepper or table with NAO. They were asked to stop the middle front of the robot into the centre of the cross and say the word "finished" when they felt they were in place. The time taken to complete the task and the distance the robot was from the desired navigation point was noted (Appendix B.2.9).

***Task 3: Interaction***
Using a set of 5 pre-defined questions, the participant was interviewed while standing opposite the robot. In turn, the participant asked the researcher a separate set of questions when the researcher was controlling the robot using the headset. The researcher gave pre-determined answers. The question sets were randomised out of a selection of 4 (Appendix B.2.10).

***Task 4: Resolution/Delay Comparison***
The participant was asked to view 4 different resolutions while using the NAO robot, which resulted in 4 different frames per second (fps) values. They were asked to rate the resolution and delay for each pair out of 10, where 10 was perfect vision/real-time movement and 1 was completely unusable vision/movement delay (Appendix B.2.11).

**Results - Quantitative**
This section details the quantitative findings of the study which were statistically analysed using SPSS statistical software. This involved data collected from tasks 1, 2, and 4.

***Task 1:***
A two-tailed Paired-Samples T-test was conducted. Due to technical issues with the Pepper robot during the study, one participant's data could not be used for this task (N = 19). As hypothesised there was no significant difference found for time taken to locate the "doorbell" image with Pepper (m = 3.8063 secs, SD = 1.5054) or NAO (m = 5.4705 secs, SD = 4.4296). All participants correctly identified the right image.

***Task 2:***
Two-tailed Paired-Samples T-test was conducted. Due to technical issues with the Pepper robot, one participant's data could not be used for this task (N = 19). There was no significant difference found for time taken with Pepper (m = 29.7458, SD = 24.5077) and NAO (m = 41.0837, SD = 26.9701) to complete the navigation task to the participants' satisfaction.

In addition, there was also no significant difference found for the distance to the target with Pepper (m = 16.3421 cm, SD = 15.7269) and NAO (m = 16.6842 cm, SD = 12.5158). Therefore, there was no significant different difference found between the two robots for the navigation task.

***Task 4:***
A one-way repeated measures MANOVA was conducted on the data for task 4 (N = 20). A significant difference was found between the resolution (independent variable) and both resolution score and delay score awarded by the participants for each resolution. Mauchly's test of sphericity was significant in both cases, resulting in a Tukey's range test being conducted.

*Resolution Score:* A significant difference was found between VGA (m = 3.050, SD = 1.7614) and all other resolutions (720p, 1080p, and 2k) where their mean scores out of 10 were 5.350 (SD = 1.8144), 6.050 (SD = 1.8489), and 6.000 (SD = 2.2711) respectively (Figure 3.24). However, there was no significant difference between any of the remaining resolutions.Therefore, the gain in resolution is worth upgrading to 720p from VGA, but not any higher.

*Delay Score:* There was no significant difference between VGA and 720p, but there was a significant difference between the scores for VGA/720p (m = 5.675/4.725, SD = 1.7791/1.4279) and 1080p/2k (m = 3.275/2.800, SD = 1.4279/1.6092) (Figure 3.23). Therefore the delay is manageable for VGA and 720p resolutions, but not for 1080p or 2k, as hypothesised.

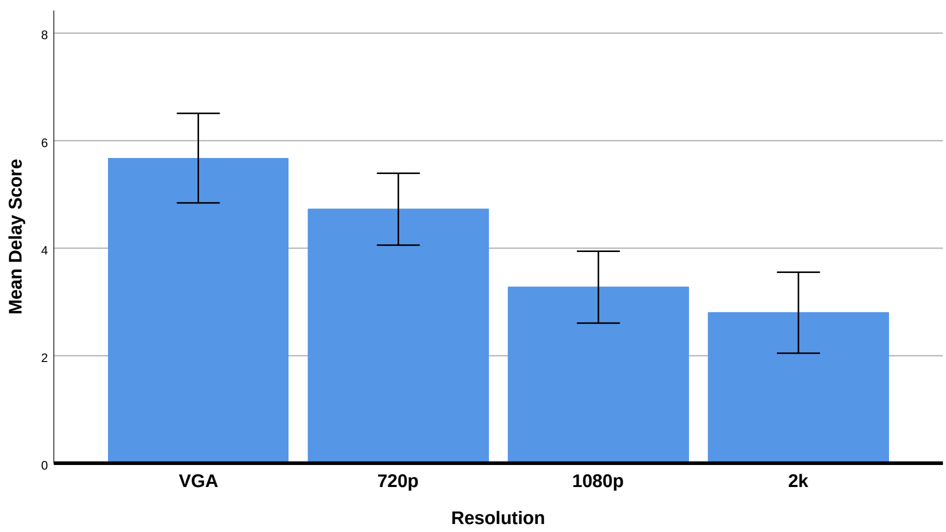



Figure 3.23: Marginal means for Delay Scores for each Resolution

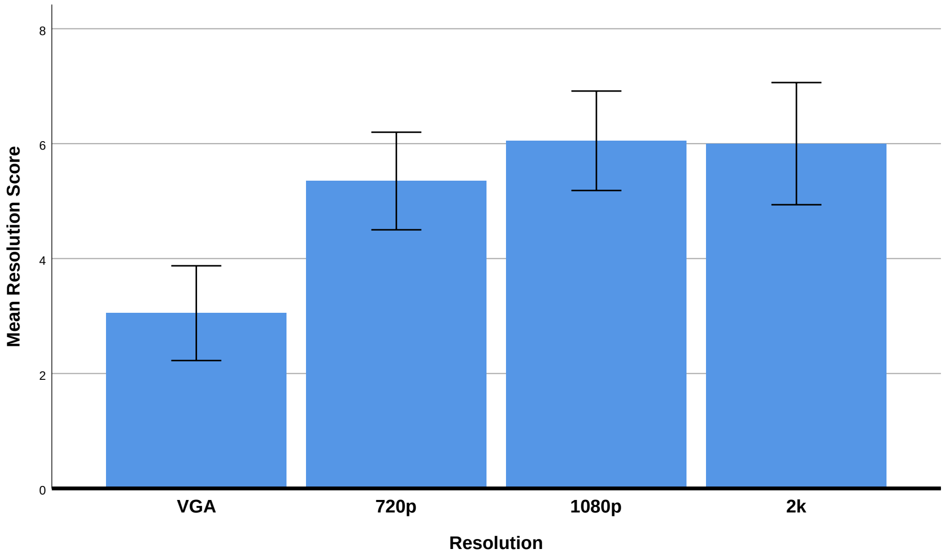



Figure 3.24: Marginal Means for Resolution Scores for each Resolution

**Results - Qualitative**

Thematic analysis was conducted for all qualitative data gathered throughout the study. This included overall experience and from task 3 (interaction) using written data gathered from the semi-structured interview questions and anecdotal comments made during the concurrent think aloud process. Below the quantified data is shown in Table 3.6. The identified themes are also discussed.

***Quantified Data***

Table 3.6 shows the breakdown of how many times each code was mentioned by each participant, if at all; it also includes the total number of responses.

| Theme | Liked Features | | | Disliked Features | | | Preferred Robot | | Number of Responses |
|---|---|---|---|---|---|---|---|---|---|
| Participant/Code | HMD | Robot | Interaction | HMD | Robot | Interaction | Pepper | NAO | |
| P1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 3 |
| P2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| P3 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 5 |
| P4 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 4 |
| P5 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 3 |
| P6 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 1 | 5 |
| P7 | 2 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 6 |
| P8 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 5 |
| P9 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 4 |
| P10 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 6 |
| P11 | 0 | 2 | 0 | 1 | 0 | 0 | 2 | 2 | 7 |
| P12 | 0 | 2 | 2 | 0 | 0 | 0 | 1 | 0 | 5 |
| P13 | 0 | 3 | 0 | 1 | 0 | 0 | 2 | 1 | 7 |
| P14 | 1 | 1 | 1 | 0 | 0 | 1 | 2 | 1 | 7 |
| P15 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4 |
| P16 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 7 |
| P17 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 4 |
| P18 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 5 |
| P19 | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 6 |
| P20 | 1 | 1 | 0 | 2 | 0 | 0 | 1 | 0 | 5 |
| **Total for Codes** | 17 | 15 | 8 | 16 | 4 | 2 | 20 | 18 | 100 |
| **Total for Themes** | 40 | | | 22 | | | 38 | | |

Table 3.6: Breakdown of Total Number of Times each Code is Mentioned per Participant and Total Number of Responses

***Themes Identified During Thematic Analysis***

Following an inductive approach allowed themes to become evident from the data without having any preconceptions about what to look for [71]. The initial codes identified were:

- Liked Features: Head-Mounted Display (HMD) Based Teleoperation System
- Liked Features: Robot Surrogate
- Liked Features: Interaction
- Disliked Features: Head-Mounted Display (HMD) Based Teleoperation System
- Disliked Features: Robot Surrogate
- Disliked Features: Interaction
- Preferred Robot: Pepper
- Preferred Robot: NAO

When considering these codes in the context of the study three overall themes were determined, as shown in Table 3.7.

| Theme | Included Codes |
|---|---|
| Liked Features | Head-Mounted Display (HMD) Based Teleoperation System<br>Robot Surrogate<br>Interaction |
| Disliked Features | Head-Mounted Display (HMD) Based Teleoperation System<br>Robot Surrogate<br>Interaction |
| Preferred Robot | Pepper Robot<br>NAO Robot |

Table 3.7: Themes Identified During Thematic Analysis and Included Codes

The section below discusses this quantitative representation of the findings, alongside other qualitative findings, in relation to each overarching theme.

***Liked Features:***

Overall, participants were positive about their experiences with the robots and the general concept of the system, with 40% of total responses referring to features that they liked, compared to 22% of disliked features. They spoke extensively about being able to look, move, and explore around the remote environment and feeling "much more immersed" than when using a screen or phone. Generally participants enjoyed using the system and said the experience was "fun". With regards to the system itself, participants commented specifically on Pepper's base movement and NAO's head movement, which they called "natural", "intuitive", "cool", and "useful". They liked "seeing the world from a different perspective" and praised the field of depth of the camera as well as the clarity of the 2K resolution for close up writing; however this was only the case when they were still. They also commented on being able to control the movement of the robot and "look around on [their] own" without relying on another person to assist them. Participants generally were equally happy with the HMD and the robot surrogate (17% and 15% of total comments respectively). However, they expressed liked features of the robot much more frequently than disliked features (15% and 4% of total responses respectively), for both controlling and interacting with the robot. These findings support the use case of the robot surrogate. Furthermore, participants discussed being able to interact with others via the system and "gain the context of the other person's environment". Participants talked about a "sense of embodiment" when being able to move the head and body. They compared the experience to talking on the phone, but said they felt they could speak to people at a greater distance and felt it was a "more interactive experience" when using the system. Participants were also impressed with the interactivity experienced when the researcher was controlling the robot. They mentioned being able to interact with a humanoid figure and make "eye contact". As well as this they enjoyed the appearance of the robots, their interactivity, and responsiveness - especially the eyes and hands, which supports literature around expressive, humanoid robots being used as likeable human proxies [38][83][84].

***Disliked Features:***
The main aspect that participants disliked the most was the hardware itself. Multiple participants commented on camera resolution, delay, and "jerky" movement. The majority of disliked comments were with regards to the head-mounted display (HMD) based teleoperation system (73% of comments on disliked features and 16% of total responses). Participants mostly commented on the "bulky, heavy headset", and velcro strap; these especially affected participants wearing glasses. They suggested that a "more up to date", lighter, headset may assist with these issues. Some participants also mentioned feeling "slightly queasy", as can be common with virtual reality, and some audio issues. However, when discussing any disliked features of the robots, some participants had mixed feelings. One commented that they "preferred looking around" and did not like the "feeling of moving". A couple of participants commented on not being able to "see their own feet" or tell their orientation, followed by a suggestion to use augmented reality to show this. Other participants commented on "clunky movements" and head movement limits, despite this being the case with human bodies also. Additionally, some had a preference over which robot they liked interacting with or controlling; this is discussed further below.

***Preferred Robot:***
Overall participants showed no difference between which robot they preferred, with Pepper and NAO being equally specified (20% and 18% of total responses respectively). However, analysis did show that generally participants preferred the Pepper robot for ***navigating*** around the environment, and the NAO robot for ***looking*** around the environment. When interacting with the robot, analysis showed that preference was also equal here, with some individuals contradicting each other. For example, some participants preferred the "cuteness" and portable height (on the desk) of NAO and felt "spoken down to like a child" as Pepper, others preferred the height of Pepper and felt restricted as NAO. How much these findings mattered to participants, and whether it changed their overall preference, varied by individual, highlighting the need to consider the individual differences of users.

**Discussion**
This section covers a summary of findings with relation to the identified research questions for the study. These research questions aimed to answer the overall research question for the PhD which focuses on design features and usability (RQ3). Additionally it briefly covers limitations of the study, implications of the findings, and how they lead into future work.

***Usability and Task Performance***
Findings show that the system is usable overall and that participants generally felt positively about it. In particular, thematic analysis suggested that participants enjoyed the interactivity and embodiment felt when using the system and interacting with the robot. Though this study focused on design features and usability (RQ3), this suggests that a sense of place and social presence is produced by the system (RQ1 and RQ2). Additionally, it was found that there was no statistically significant difference in task performance between the two robots. However, the majority of disliked features involved the hardware, where participants found the system to be bulky and that the headset could benefit from a technical upgrade. Therefore, future work could focus on utilising technological advancements, such as upgrading the camera and virtual reality head-mounted display, to improve the resolution/delay trade-off and range of view. Doing so would also address the issue of the bulky, heavy headset as newer headsets are becoming more lightweight with every iteration. This future work is discussed further in Chapter 5 as upgrading the hardware used in the system was out of scope for the PhD project.

***Preferred Robot Surrogate***
Generally, the participants felt positively about the two robots as a potential robot surrogate and about their humanoid features, as was supported by literature [38, 83, 84]. There were a range of both liked and disliked features for both robots. Ultimately, thematic analysis of the qualitative data collected highlighted the importance of tailoring the system to each individual's needs based on what they require of the system, which supports the findings from Chapter 2. For example, whether they would mainly want the system for navigation (Pepper was preferred) or for looking around the environment only (NAO was preferred).

***Resolution and Delay***
Overall the results have shown that statistically and anecdotally the ideal resolution at which to use the system is currently 720p. Participants were generally most happy with this resolution due to latency at higher resolutions, though they preferred 2k resolution for close-up viewing when stationary. In addition, they suggested that the ability to switch between resolutions for different ranges of view (far-away vs close-up) would be beneficial.

***Study Limitations***
While the study itself provided a great deal of insight into the usability of the system, there were limitations. Due to COVID-19 restrictions, only participants from the university who had already undergone training were allowed to take part - resulting in a relatively small sample size (N = 20). This was reduced further (N = 19) for tasks one and two due to technical issues with Pepper where the head and base did not move when instructed to by the participant. Additionally, the majority of the participants were from the UK and had experience with the technology based on

responses from the demographics questionnaire, meaning the results cannot be generalised to the wider population.

***Implications***

What these findings suggest is that social telepresence systems such as these have to be tailored to the user's individual needs, and no one system can address all requirements of every possible user. This provides helpful insights for future development of this system and others like it, as well as informing future studies and highlighting the importance of conducting both wider user studies and more in-depth case studies where the system has been tailored for that specific user; such a case study has been conducted and is discussed in Chapter 4. However, this does bring into question how commercially available and widely used systems like these could become. Furthermore, these findings support the user requirements already formulated as a result of the focus groups discussed in Chapter 2.

**Publication**

This usability study conducted to evaluate the system was accepted for publication and presentation at the 2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN) (Appendix D.3). The citation is:

B. Mackey, P. Bremner and M. Giuliani, "Usability of an Immersive Control System for a Humanoid Robot Surrogate," *2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, Napoli, Italy, 2022, pp. 678-685, doi: 10.1109/RO-MAN53752.2022.9900587

## 3.4 Conclusion

This chapter discussed the design and implementation of the head-mounted display (HMD) based teleoperation system for a humanoid robot surrogate that was based on literature and user requirements identified in Chapter 2. It also covered two user studies conducted in order to evaluate the system. The first study evaluated the effect that the system had on place and social presence when compared to telecommunication software. The second study assessed the usability of the system and compared the performance and preferences between two robots - Pepper and NAO. The key findings for this chapter, and relevant research questions (RQs) at a thesis level are as follows:

- The system is capable of producing a general trend towards higher place and social presence when compared to telecommunication software. (RQ1 and RQ2)
- The system is capable of producing feelings of place and social presence when used by healthy adults. (RQ1 and RQ2)

- The system is statistically significantly harder to use than telecommunication software. (RQ3)
- The hardware used in the control system is limited by the technology that was available at the time of development and was deemed to be bulky, heavy, and jerky. The system would benefit from utilising newer technology that is now available, which has higher resolution, higher frame rates, and is more lightweight. However, in its current form the system should be used at 720p resolution. (RQ3)
- The teleoperation system works with both Pepper and NAO and there is no statistically significant difference in the task performance of either robot. However, Pepper is preferred by participants for physical navigation, whereas NAO is preferred for looking around a remote environment. (RQ3)
- Participants generally like both using the system and interacting with users. However, there is no decisive answer between which robot should be used, as this is determined by users' individual differences and requirements for the system. (RQ3)
- User requirements formulated as a result of the focus groups described in Chapter 2 are supported by findings from the usability study discussed in this chapter. However, considering individual difference when designing a teleoperation system for users with life-limiting illnesses is to be added to the list of user requirements. (RQ3)

The findings of this chapter highlight the importance of individual differences found between each user. The next stage of development involved making system modifications with the aim of tailoring the system to an individual user. A case study was then conducted with the individual and their partner, where the system was deployed in their home and in-depth analysis performed. This case study is the focus of the following chapter.

# Chapter 4

## Deployment with an End User

Chapter 3 described the technical development of the head-mounted display (HMD) based teleoperation system for a humanoid robot surrogate. It also discussed key findings from user studies conducted to evaluate the effect on place and social presence when compared to telecommunication software and system usability. This chapter uses those findings to inform further system development. Furthermore, Chapter 2 discussed the need for expert opinion when developing a system with particular end users in mind. In order to thoroughly evaluate the success of the system, a case study was conducted over a period of weeks in the home of an individual living with a life-limiting illness and their partner. The case study is discussed in detail in this Chapter. Additionally, as part of the case study, a follow-up focus group was conducted with some of the healthcare professionals who took part in the focus groups described in Chapter 2. The purpose of this was to assess whether the findings from the deployment with the end user and their partner could also be generalised to other patients. This focus group is also discussed in detail in this chapter.

### 4.1 Introduction

This section covers literature related to different research methods in in-situ human-robot interaction research. It also covers the aims, objectives, and research questions for this Chapter specifically but which relate to the overall aims and research questions for the research at PhD level, which are addressed in Chapter 1.

### 4.1.1 Background and Context: Research Methodologies in Human-Robot Interation (HRI)

Case studies are a tried and tested research method in the field of human-robot interaction due to their ability to allow researchers to gain a "deeper understanding of complex phenomena in real-life contexts" [125]. In addition, they are useful tools for situations where collecting from additional cases is difficult [125]. Due to the need of this study to consult experts, such as an intended end user, it involved conducting studies with individuals living with life-limiting illnesses, who are classed as vulnerable participants. Due to the COVID-19 pandemic restrictions having only recently eased, it was not feasible to involve multiple participants. Therefore a case study was used to collect in-depth data in the participants' home where they had appropriate safety measures in place. This in-depth data allowed for evaluation of the teleoperation system, while still staying within user-centred design methods. Winkle [60] defined user-centred design as the act of understanding and incorporating user perspective and needs into robot design. Given the use of experts in the focus groups described in Chapter 2, this PhD research has followed a user-centred design approach and will continue to do so in this case study, which is designed to evaluate the developed teleoperation system.

Given that the development of the teleoperation system followed a user-centred design, it was important to follow guidelines towards how best to conduct qualitative research with an end user to evaluate the system further. Research conducted by Veling and McGinn [59] reviewed multiple studies to assess the qualitative research methods used in human-robot interaction (HRI). They separated qualitative research into two dimensions: "study-type" and "qualitative method". Study-type can be separated into three categories: insights-driven, design, and hypothesis-driven. Insights-driven studies aim to develop new understandings of perceptions about robots generally. Design studies focus around the design of a robot, or within a defined design process such as user-centred design. Hypothesis-driven are experimental studies that are usually tested through the collection and analysis of quantitative data. Additionally, Veling and McGinn [59] stated that they had also characterised studies that were part of an overarching participatory or user-centred process as design research studies. This chapter focuses on a user-centred design study in collaboration with an intended end user and their partner in order to evaluate the teleoperation system developed as part of the PhD research.

The second dimension described by Veling and McGinn [59], "qualitative methods", was identified as six methodologies: qualitative observation, semi-structured interviews, focus groups, generative activities, reflective and narrative accounts, and textual/content analysis. These different methods are described in Table 4.1 below. Of the studies reviewed, many design research studies combined interviews and observations to gain a deeper understanding behind the interactions. While a combination of observation and interview was most common, a number of studies also combined these with other methods, such as with focus groups. These methods have multiple advantages, for example, observation allows researchers to study "the context, as well as the tacit or embodied knowledge, that is a part of interacting with robots". Additionally, semi-structured interviews are often used to gauge people's opinions on specific robot systems. Finally, focus groups in collaborative design studies were used to gain insight into possible integration of robotics into relevant contexts. Therefore, the case study described in this chapter uses semi-structured interviews, qualitative observation, and focus groups.

The research methodology carefully considered the findings from this literature in order to elicit the more valuable qualitative evaluation from this case study. Furthermore, an online follow-up focus group with some of the healthcare professionals from the focus groups described in Chapter 2 was run after the case study. This was conducted with experts who had helped to formulate the user requirements and already knew the context of the teleoperation system, in order to evaluate whether the findings from the case study could be generalised to other patients with life-limiting illnesses. The aims, and research questions surrounding this evaluation are covered in the following section.

| Method | Description |
|---|---|
| Qualitative observation | Observations of people in everyday contexts and uncontrolled environments. Data is primarily gathered in the form of field notes. Less commonly, qualitative observations may be video recorded |
| Semi-structured interview | Semi-structured interviews follow a pre-defined interview protocol but allow for flexibility to respond to the natural flow of the interaction. Data is usually captured in notes, as well as being audio recorded |
| Focus group/group interviews | A focus group is a group interview or discussion with a small group of participants (usually 6–10) on a specific topic. Focus groups are guided by a moderator or facilitator. Data is usually captured in notes, as well as being audio or video recorded |
| Generative activities | Qualitative data is gathered during a generative activity, such as brainstorming, ideation or prototyping. These activities often take place in a workshop setting |
| Reflective and narrative accounts | Qualitative data is produced by participants writing reflective or creative descriptions related to the study |
| Textual/content analysis | The use of written text or documents as a source of qualitative data. This category also includes free participant responses in questionnaires |

Table 4.1: List of Qualitative Methods with Descriptions [59]

### 4.1.2 Aims and Research Questions

The aim of this chapter was to thoroughly evaluate the head-mounted display (HMD) based teleoperation system for a humanoid robot surrogate. The method of evaluation was a case study where the system was deployed in the home of an intended end user and their partner. The research questions identified for this study, and their corresponding research questions at a PhD thesis level are shown below:

1. Can the end user feel present in a remote environment? (RQ1)

2. Does the teleoperation system allow for social interaction between the end user and interactant? (RQ2)

3. Does the teleoperation system allow for one-to-one and group interactions? If so, which is preferred by the user and interactant? (RQ2)
4. Can the teleoperation system improve social isolation (RQ2)
5. Does the system meet the requirements set by the participants (RQ2 and RQ3)
6. How usable is the teleoperation system? What adjustments could be made to increase usability? (RQ3)

## 4.2 System Modifications: Tailor to Individual Requirements

The findings from the focus groups from Chapter 2 and the usability study conducted in Chapter 3 highlighted the need to take the individual differences of each end user into account when developing the system. The appropriateness of the chosen robot surrogate (NAO or Pepper) is highly dependent on the preferences of the user and what they would like to use the system for. Therefore, for the case study, the participants - specifically the end user - were consulted while preparing for the study, following a user-centred design approach [60]. These requirements are listed below with their justifications:

- One of the end user's primary motivations for using the system is to feel present with their partner in a remote location of their home (RQ1).

  The end user requires carers to visit to put them to bed at night due to their life-limiting illness. Due to the degenerative nature of their illness (Motor Neurone Disease) the participant will continue to get tired more frequently as their illness progresses. However, due to needing a consistent schedule for the carer, this results in them being put to bed at 8pm, which is sometimes earlier than they would prefer. Therefore, when they are feeling awake, they would like to use the system to be present in the living room with their partner to watch television. Being able to satisfy this requirement will allow the participant to feel present in the remote location, which works towards answering RQ1 at a PhD level.

- Another important motivation for the end user is to be able to interact naturally with their partner (RQ2).

  As above, due to the earlier bedtime, the participants would like to be able to socialise with each other if they want to, as they would be able to during the day. Linked with the above requirement, they would like to watch television together and chat about their days. These are normal conversations for them, and they would like to be able to continue to interact like this via the system. Taking this requirement into consideration works towards RQ2 at PhD level.

- The participants are concerned about the amount of space physically available in their home (RQ3).

  The participants home is a two bedroom semi-detached house with a garage conversion, which has been converted to the participant's bedroom due to an inability to use the stairs. Their life-limiting illness requires the participant to have a lot of equipment in their home, including a hospital bed, a motorised wheelchair, and various lifts. Therefore, they are concerned about the amount of technology associated with the system. Being able to address this concern to make the system more usable for them will address RQ3 at PhD level.

- The end user's partner was extremely fearful of technology (RQ3).

  The end user was very fond of different technologies and used to be a software engineer. However, their partner was fearful of the amount of technology, especially alongside the end user's medical equipment. Therefore, they requested that no cameras or recording equipment be used. This consideration feeds into usability and RQ3 at PhD level.

In order to address these requirements, in collaboration with the participants, the following decisions were made:

- Due to the concern surrounding space, and the focus on being able to interact rather than navigate, movement capabilities were disabled.
- The NAO robot was used as the robot surrogate to save space in the participants home. This also fulfilled requirements from Chapter 3, which showed that NAO was the preferred robot for looking around a remote environment.
- No audio or video recordings were taken at the participants request. Notes were taken during observation instead.

The final technical specifications and experimental setup is described in the section below.

## 4.3 Final Technical Specifications, Experimental Setup, and Methodology

This section describes the final specification of the system following changes made when liaising with the participants. It also covers the experimental setup of the system at their home during the case study. Finally it covers participant demographics and study methodology.

### 4.3.1 Ethical Considerations

The study was approved by the University of the West of England (UWE) Ethics Committee (Reference no. FET-2122-20). All ethical conduct, data handling quidelines, and COVID-19 guidelines were adhered to.

### 4.3.2 System Components

- Camera: Stereolabs Zed 2
- Resolution: 720p at 60 frames per second
- Game Engine: Unity Engine (Version: 2019.3.13)
- Head-mounted Display: HTC Vive
- Plugins: SteamVR, Zed
- Robot Surrogate: NAO (NAOqi version 2.8.4.2)
- Python Version: 2.7.15.

### 4.3.3 Experimental Setup

The setup was broken into two locations: the Head-mounted display (HMD) based teleoperation system, and the robot surrogate. A diagram showing the setup of the system in the participants' home can be seen in Figure 4.1.

**Head-mounted display (HMD) based Teleoperation system**

In the end user's bedroom the HMD of a HTC Vive Virtual Reality System was connected to a PC using the Unity game engine. An ethernet cable and Stereolabs Zed 2 camera were connected to the PC and fed through a small hole in the wall into their living room.

**Robot Surrogate**

In the participants' living room a NAO robot was connected to the ethernet cable and the Zed 2 camera attached to the head of the robot using the 3D printed mount shown in Chapter 3 (Figure 3.19).

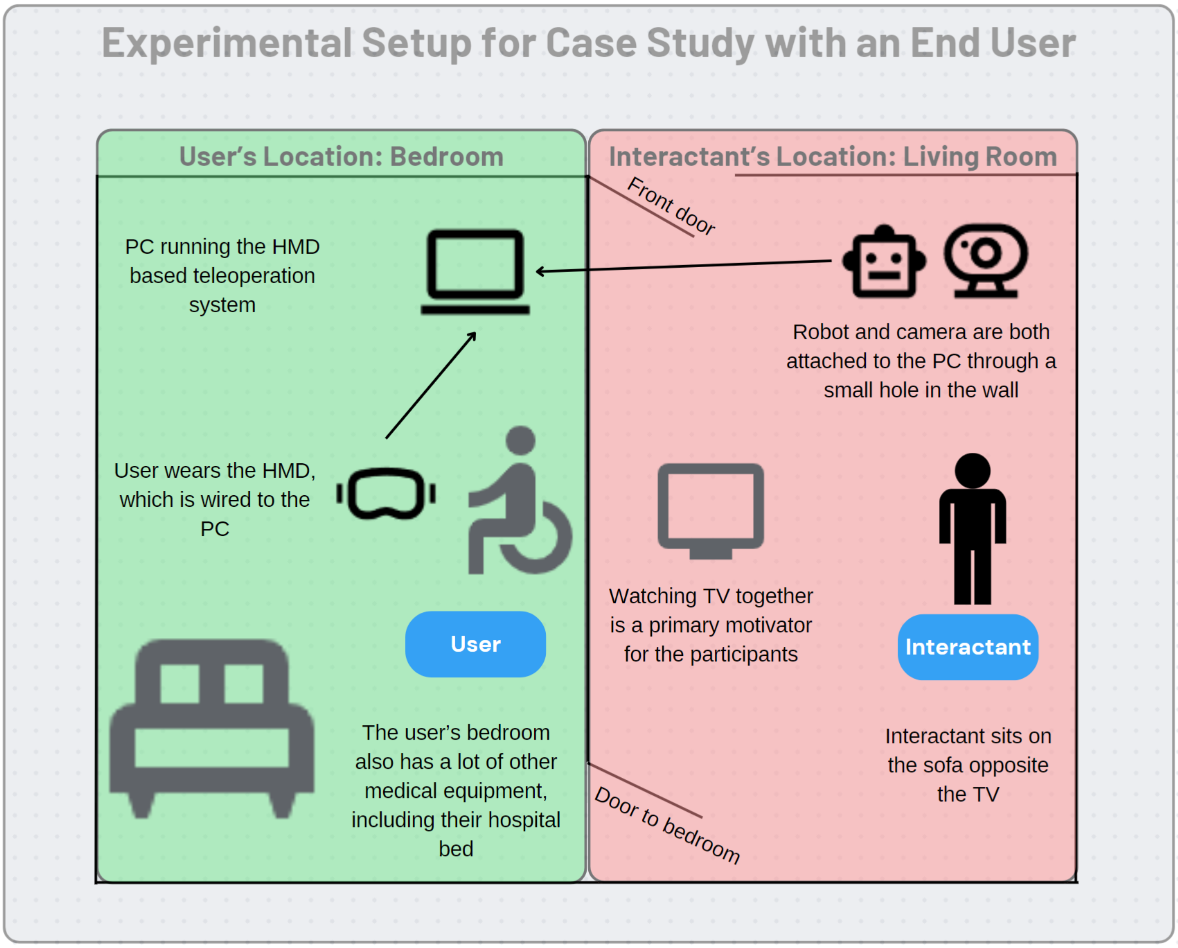



Figure 4.1: Diagram Showing the Setup of the Teleoperation System in the Participants' Home

### 4.3.4 Latency

The HMD based teleoperation system and robot surrogate were on the same network and used an ethernet connection. The following latency was found for the network:

- Download Speed: 74.5 Mbps
- Upload Speed: 48.7 Mbps
- Data Delay: 10.3ms

### 4.3.5 Participants

Two participants (N = 2) took part in the case study, 1 male and 1 female, both between the ages of 65 and 74. The male participant was a patient living with Motor Neurone Disease (MND) and had been the patient to take part in the focus groups discussed in Chapter 2. The female participant was his partner, lived with him, and was also his primary caregiver. The patient was approached by Prospect Hospice following the focus groups, on behalf of the researcher, asking if he would be interested in taking part in any follow-up studies. The male had "a little" virtual reality experience, while the female participant had "none at all". Neither participant had any experience with robotics. The focus group participants were the same as the one conducted with Prospect Hospice as described in Chapter 2.

### 4.3.6 Measures

Throughout this case study qualitative data was collected due to ability to collect "holistic, multi-factorial and emergent data in a way that is nonetheless formal, rigorous and systematic" [59]. The case study used multiple methodologies, which are justified above in the Background and Context section. There were three sessions involving semi-structured interviews and observations, one open-ended interview by phone, and one follow-up focus group with the staff from Prospect Hospice. The procedure for these are described below.

### 4.3.7 Procedure

The original study design had been for the researcher to visit once per day for an hour for a week. However, following the first session, the participants requested a change. Therefore, the case study was made up of three sessions, and one focus group, which are described in more detail below:

**Session One - 11th April 2022**
The researcher and a colleague travelled to the home of the participants to set up the system as described above. Prior to starting, the participants were asked to read an information sheet and privacy notice (Appendices C.1.1 and C.1.2), asked to fill in a demographics questionnaire (Appendix C.1.3), offered the chance to ask any questions, and asked to sign a consent form (Appendix C.1.4). The participants then took part in an initial semi-structured interview (Appendix C.1.5) that explored their thoughts and feelings regarding the study and the system itself, which had been described to them during the setup. The initial questions were as follows:

1. What are your current feelings regarding the study?
2. What are your current feelings regarding the system itself?
3. Are you looking forward to anything in particular about the study or using the system?
4. Are you not looking forward to anything in particular about the study or using the system?
5. Do you think the system could be useful now or in the future?
6. Any other thoughts or comments?

Following this, the participants had a conversation with the end user controlling the robot via the HMD in their bedroom and the end user's partner sat across from the robot in their living room. A second semi-structured interview (Appendix C.1.6) then took place in order to complete a comparison with how the participants were feeling prior to using the system with the following questions:

1. How are you feeling about the session now?
2. How would you describe your mood following the session?
3. Were there features that you were pleased/disappointed with?
4. Any other thoughts or comments?

All of the participants' responses are discussed in the Results section below. The system was left at the participants house following the interview, with the intention for the researcher to return the following day. However, the participants asked to have a phone call two days later instead, as is discussed below.

**Session Two- 13th April 2022**

During the requested phone call, the participants discussed their thoughts on the system, and the study in general, along with any concerns; these are discussed in detail in the results section. In addition, they asked for a change to the study protocol due to the tiredness experienced by the end user. Between the participants and the researcher it was decided that instead of several one hour sessions through the week, the system would stay at the participants home and there would be one significantly longer session later on instead.

**Session Three - 21st April 2022**

During this session, a semi-structured interview (Appendix C.1.7) focusing on system usability was conducted by the researcher while the end user was wearing the HMD. The questions were:

1. Is the headset comfortable?
2. How long do you think you could wear it for comfortably?
3. What, if anything, would improve the comfort of the system?
4. Do you find the system intuitive to use?
5. What would make the system easier to use?
6. How do you find interacting one on one using the system?

7. What, if any, technological changes or adjustments would you make to the system to improve usability?
8. Do you feel that the system is usable in its current development phase?
9. How are you feeling physically and emotionally following this section?
10. Any other thoughts or comments?

Following this, a 5 minute group interaction took place between the end user (wearing the HMD), the end user's partner, and a colleague of the researcher. The researcher observed this conversation and took field notes of any relevant interactions. Finally, a semi-structured interview took place between the participants and researcher in-person. The questions were:

1. How have you found having the system/equipment in your home?
2. Have your feelings or comfort with it changed seeing it every day?
3. What adjustments, if any, could be made to increase your comfort and the convenience of having the equipment at home?
4. What are your current feelings regarding the overall study, how do you feel it went?
5. What are your current feelings regarding the system itself specifically?
6. Did the system live up to or exceed your expectations in anyway?
7. Was there anything that disappointed you about the system or study?
8. Are there any features you particularly like or dislike?
9. What, if any, changes/adjustments would you make to improve the system as a whole?
10. Do you think the system could be useful now or in the future?
11. Would you use the system by choice if it were available?
12. Did you feel there was a difference between one-to-one interaction and group interaction while using the system? Is one "better" than the other?
13. Do you feel that being able to see loved ones in another location is beneficial?
14. Do you think such a system could improve social isolation?
15. Do you think such a system could have an impact on quality of life?
16. Do you feel, in your opinion, that it is worth continuing to develop the system further, and if so, what should be the next development focus?

17. Any other thoughts or comments?

All responses are discussed in the Results section below.

**Follow-up Focus Group - 4th May 2022**

Following the final session a follow-up focus group was conducted online via Microsoft Teams with the same experts from the focus group with Prospect Hospice. The healthcare professionals who took part in this were familiar with the participants from the case study. The information sheet, privacy notice, consent form, and interview questions can be seen in Appendices C.2.1, C.2.2, C.2.3, and C.2.4 respectively. The aim of the focus group was to see if some of the statements made during the study were, in their opinion, generalisable to other intended end users with life-limiting illnesses. The chosen questions reflect the general findings from initial analysis conducted on the interviews with the end-user and their partner, and include overarching themes that presented themselves throughout the case study. The questions were as follows where p1 refers to the end user, and p2 refers to their partner:

1. P2 generally strongly disliked technology, would that be the same for the majority of patients?
2. P1 has deteriorated since arranging the original focus group and sleeps more often, does that affect the usefulness of the system?
3. There is a disjoint between robots to perform tasks and robots to talk through. Please discuss.
4. The participants questioned the need for the robot. What are your thoughts on having no Head-mounted display but with a robot? Does the robot make the system?
5. What about a non-humanoid robot? Does it need to use limbs to be worth it?
6. The participants discussed not being able to see the end user and a lack of visual social cues, the example given was being able to tell a lie from body language. Please discuss.
7. Is there anything that patients frequently say they miss or wish they could do?
8. Could the system work to improve this if they cant do it in person?
9. P1 mentioned children would be better for the system, do you agree? Should the system be targeted towards parents with life-limiting illnesses?
10. P1 regretted asking for movement capabilities to be removed. Please discuss.
11. The system could be tailored to individuals or more general for use in hospice. Please discuss.

12. Some technology has advanced since starting development of the system, does this override any need for it?

13. The participants were overwhelmed by the amount of equipment, could this be tackled by managing expectations?

14. Any other thoughts or comments?

All responses are discussed in the results section below.

## 4.4 Results

This section discusses the thematic analysis conducted on the qualitative data collected during the case study and subsequent focus group. This data was collected via a series of semi-structured interviews and thematic analysis was chosen due to being best-practice for this data collection method [59]. Below the coding used during thematic analysis, and subsequently identified themes, is discussed. Following this the quantified representations of the findings, and the qualitative findings in relation to the themes are reported.

### 4.4.1 Themes Identified During Thematic Analysis

Following an inductive approach allowed themes to become evident from the data without having any preconceptions about what to look for [71]. The initial codes in the order they were identified from the data were:

- Fear/Negativity (Fear)
- Hope/Positivity (Hope)
- Uncertainty (Uncertainty)
- Technical Concerns (Tech Concerns)
- Existing Technology (Existing Tech)
- Future Usage (Future)
- Generational Differences (Generation)
- Place Presence - Positive and Negative (Place Pos. & Place Neg.)
- Social Presence - Positive and Negative (Social Pos. & Social Neg.)
- Usage (Use)
- Individual Differences (ID)

The brackets identify how each code is represented in the tables below in the Findings section (Tables 4.4, 4.5, and 4.6).

When considering these codes in the context of the study three overall themes were determined, as shown in Table 4.2. The findings from the case study and focus group in relation to these themes are discussed in the following section.

| Theme | Included Codes |
|---|---|
| Individual Differences and Emotions | Usage<br>Individual Differences<br>Fear/Negativity<br>Hope/Positivity<br>Uncertainty<br>Generational Differences |
| Technical Considerations | Technical Concerns<br>Existing Technology<br>Future Usage |
| Presence and Social Interactions | Place Presence (Positive and Negative)<br>Social Presence (Positive and Negative) |

Table 4.2: Themes Identified During Thematic Analysis and Included Codes

### 4.4.2 Findings

This section discusses the quantified data from the case study and focus group. It also covers the qualitative findings in relation to the themes that were identified during the thematic analysis. It is also important to note that, while participant p1 was vocal throughout the study, p2 did not speak as much (14% of all responses of 6 participants and 18% of case study responses). However, they frequently expressed agreement with p1 and at no point did they disagree with each other. The focus group participants had some differences of opinion, and these are discussed in the qualitative findings below.

**Quantitative Findings**

The tables in this section highlight the quantified representations of the qualitative data collected during the case study. Additionally, the participants were assigned identification numbers and the breakdown of these are shown in Table 4.3.

| Session | Participant ID | Role |
|---|---|---|
| Case Study | p1<br>p2 | End User<br>Primary Interactant |
| Focus Group | p3<br>p4<br>p5<br>p6 | Healthcare Professionals |

Table 4.3: Session, Participant Identification Numbers, and Role for Case Study and Focus Group

The below tables highlight the quantified data collected during the case study. These are broken down further into three tables for clearer comparison. Table 4.4 shows the total number of times each code was mentioned by participants one and two over the course of the entire study, including number of responses in total. Meanwhile, Table 4.5 shows the total number of times each code was mentioned by participants three, four, five, and six during the focus group, including number of responses in total. Finally, Table 4.6 shows the total number of occasions that each code is mentioned by session, plus the number of responses. A table showing the breakdown of how many times each code was mentioned by each participant in each session and also the number of responses by each participant in each session can be found in Appendix C.1.8.

| Theme | Individual Differences and Emotions | | | | | | Technical Considerations | | | Presence and Social Interactions | | | | Number of Responses |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Participant/Code** | Use | ID | Fear | Hope | Uncertainty | Generation | Tech Concerns | Existing Tech | Future | Place Pos. | Place Neg. | Social Pos. | Social Neg. | |
| P1 | 3 | 3 | 9 | 25 | 18 | 9 | 23 | 10 | 7 | 7 | 1 | 13 | 4 | 132 |
| P2 | 1 | 0 | 9 | 6 | 5 | 0 | 1 | 0 | 1 | 1 | 0 | 3 | 1 | 28 |
| **TOTALS** | 4 | 3 | 18 | 31 | 23 | 9 | 24 | 10 | 8 | 8 | 1 | 16 | 5 | 160 |

Table 4.4: Total Number of Times each Code is Mentioned by each Participant Over the Case Study and Number of Responses

| Theme | Individual Differences and Emotions | | | | | | Technical Considerations | | | Presence and Social Interactions | | | | Number of Responses |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Participant/Code** | Use | ID | Fear | Hope | Uncertainty | Generation | Tech Concerns | Existing Tech | Future | Place Pos. | Place Neg. | Social Pos. | Social Neg. | |
| P3 | 0 | 7 | 1 | 2 | 1 | 4 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 20 |
| P4 | 0 | 4 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| P5 | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 10 |
| P6 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 4 |
| **TOTALS** | 0 | 13 | 2 | 5 | 1 | 8 | 3 | 3 | 0 | 2 | 0 | 3 | 1 | 41 |

Table 4.5: Total Number of Times each Code is Mentioned by each Participant During the Focus Group and Number of Responses

| Theme | Individual Differences and Emotions | | | | | | Technical Considerations | | | Presence and Social Interactions | | | | Number of Responses |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time/Code | Use | ID | Fear | Hope | Uncertainty | Generation | Tech Concerns | Existing Tech | Future | Place Pos. | Place Neg. | Social Pos. | Social Neg. | |
| Session One (Initial) | 0 | 0 | 5 | 3 | 5 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 17 |
| Session One (After) | 0 | 0 | 2 | 5 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 1 | 12 |
| Session Two | 0 | 0 | 4 | 1 | 2 | 0 | 3 | 3 | 0 | 1 | 0 | 0 | 0 | 14 |
| Session Three (Usability) | 0 | 0 | 3 | 15 | 3 | 3 | 6 | 1 | 3 | 2 | 0 | 6 | 2 | 44 |
| Session Three (ex. Usability) | 4 | 3 | 4 | 7 | 13 | 6 | 11 | 6 | 3 | 4 | 1 | 9 | 2 | 73 |
| Session Three Total | 4 | 3 | 7 | 22 | 16 | 9 | 17 | 7 | 6 | 6 | 1 | 15 | 4 | 117 |
| Follow-up Focus Group | 0 | 13 | 2 | 5 | 1 | 8 | 3 | 3 | 0 | 2 | 0 | 3 | 1 | 41 |
| TOTALS | 4 | 16 | 20 | 36 | 24 | 17 | 27 | 13 | 8 | 10 | 1 | 19 | 6 | 201 |

Table 4.6: Total Number of Times each Code is Mentioned per Session and Number of Responses

The section below discusses this quantitative representation of the findings, alongside other qualitative findings, in relation to each overarching theme.

**Individual Differences and Emotions**

During the case study and subsequent focus group the most prominent theme to emerge was the consideration of individual difference and the emotions people felt. This theme was most commonly mentioned by all participants from the case study and focus group, with 58% of all responses relating to this theme. The codes that made up this theme all related to how an individual would feel and their specific wants and needs. The findings relating to the different elements of this theme are discussed below.

Participant p2 had expressed feelings of fear and negativity towards technology as a whole from the initial interview in session one saying that they were "worried to death about [the study]", and with 45% of their responses being coded as Fear/Negativity. This response was not unexpected as the participant had expressed concern over technology during the requirement setting stage. During their first use of the teleoperation system, participant p2 walked away from the robot, picked up a small table and went into the room where participant p1 was wearing the HMD. When asked why they did that by participant p1 they stated that they were "just putting the table away". Participant p1 encouraged participant p2 to return to the robot, but they stated that they "just wanted to talk to [p1]", that they "didn't like it" and did not "want to talk to a machine". The session ended earlier than planned as participant p2 did not want to continue. However, over the course of the case study their percentage of fear responses dropped to 40% for the interview immediately after the session. They stated they were "always on edge anyway" and mentioned losing their dog recently. Participant p1 mentioned that participant p2 had become more anxious with their illness "deteriorating so fast". At this point participant p2 repeated that they "don't like talking to a machine, don't like machines anyway", referencing recent equipment that had been installed to help manage participant p1's illness, and that it "causes a lot of grief". Surprisingly, the fear response dropped further to 21% of responses in session three where the response had notably changed from "worried to death" to "not worried, just inconvenienced".

Although not as strongly, p1 also showed some fear responses, however their focus was on "wasting [the researcher's] time". They commented in the initial interview that they were a "little apprehensive it could be a waste of time". This continued in session two when it was mentioned a few times that they were "really concerned about [the researcher] travelling so far" and again in session three where they repeated that they "didn't want [the researcher] to spend an hour setting up and only use it for a couple of minutes". When the focus group participants were asked about patients' general fear surrounding technology they suggested that perhaps a humanoid robot could be more fear inducing for people who are already frightened of technology. They also said that they know that participant p1 was extremely concerned generally about inconveniencing people, and went to bed early to "not be an inconvenience"; this highlights how important individual personalities are when taking the findings of studies such as this into consideration.

Individual differences was a prominent code throughout the case study and focus group being mentioned 16 times in total. It was also the primary topic in the focus group, making up 32% of their total responses. It was also a topic on which all focus group participants agreed, with most participants mentioning that "choice is key" and that each patient's wants and needs are "very individual". They also felt that there was a possible distinction between whether patients had been "living with their illness for long time" or were "newly diagnosed". Overall, this topic proved the most unifying for the focus group participants. Ultimately, whether the system is to be of benefit to an individual user depends on their specific life-limiting illness and their needs, as the focus group participants stated that each "different impairment would have different needs" and that it depends on "how quickly the disease progresses", which supports comments made by participant p1 regarding their own illness. For the end user and their partner it did not suit their overall needs, with them stating in their final interview that "if we wanted to communicate we wouldn't use it", saying that it was "from our point of view, not really suitable" and that they did not "know if it's a benefit to us personally", despite giving generally positive responses regarding their experiences with the teleoperation system.

Feelings of hope and positivity were the most prominent comments for this theme and the case study and focus groups overall, making up 18% of all responses. They were also the most common comments from participant p1 (19% of all of their responses) who was hopeful and positive towards the teleoperation system from the initial focus group they took part in (Chapter 2). This continued in the initial interview of session one where they stated they were "hoping to generate some benefits" for others by taking part in the research. Following the first use of the system they were still feeling positive saying "worked well didn't it" straight after removing the HMD. Additionally, they began to justify what they deemed to be negative points such as the system requiring "lots of setup" by stating "but that's fair enough especially with any computer".

When questioned about the usability of the system participant p1 was extremely positive with 34% of all responses being hopeful and positive. They were satisfied with the comfort of the HMD, which they mentioned six times, and stated they were "quite happy wearing it" and could easily do so for "half an hour to an hour" at a time. They also complimented the visibility and audio capabilities of the system. Additionally, having requested a change of protocol during the phone call in session two, participant p1 expressed that "doing it this way has allowed for more output" and that it was "more productive for sure", placating some of the fears they had expressed surrounding the researcher having to travel. By the final interview of session three participants p1 and p2 were uncertain about some aspects of the teleoperation system, but still remained positive and hopeful that, with some changes, the system could contribute to improving social isolation and quality of life. These suggested changes are discussed further in the Technical Considerations section of the findings.

Despite the general positivity towards the system from all participants, there was also uncertainty expressed towards it (12% off all responses). Although uncertain during the initial interview about what the researcher and participants would acheive during the study, participants p1 and p2 showed the most uncertainty during the final interview of session three (14% of responses during that interview, where Hope/Positivity made up 19% of responses). It was mentioned on multiple occasions that "despite reading the information" in hindsight they "didn't fully understand what was going to happen" and felt "a bit disappointed" and "expected a bit more" after the first session as they expected the robot to be able to perform simple tasks for them, such as make drinks for participant p1. Due to this, they felt that the novelty of the robot would be more applicable to children.

The appropriateness of the teleoperation system for use with children was mentioned mostly in session three by participant p1. They felt that the only use case for the system in combination with the robot surrogate was "something like a nursing home" where children would interact with the robot and the novelty would "keep them enthralled". They felt that the robot would dissuade them from getting bored having simply said hello to their family member. They felt that "something like a terminal" would be more appropriate for their age group. However, the topic of Generational Differences caused disagreements within the focus group. For example, participant p3 discussed that they have a lot of patients in their thirties and late teens who benefit from relaxation virtual reality apps. They also agreed that a humanoid robot could be "fun for a younger person" and that it "could be age specific" as "lots of patients are older and not all are great with tech". Participant p4 questioned whether the teleoperation system would be better in a children's hospice to allow patients to interact with siblings. They also had experience where one of their colleagues used virtual reality and "had lots of interest from all ages". On the other hand, participants p5 and p6 told the other participants not to "make assumptions about who could benefit" as they had experience of "fifty and sixty year olds" improving with technology, and an "older lady" who had been using virtual reality in the hospice and was "really motivated". Overall, this topic proved the most divisive for the focus group participants.

**Technical Considerations**

While the above findings aided in understanding the individual differences and emotions behind comments on the teleoperation system, the findings discussed here provided practical opinions on the technical aspects of the system. This primarily consisted of any concerns that the participants had, comparisons to existing technology, and any future considerations. The findings relating to the different elements of this theme are discussed below.

Participant p1 expressed a number of technical concerns during the case study, particularly during the usability interview and final interview during session three where it made up 15% of responses for session three in total. It also made up 13% of all total responses making it the second most commented on topic overall and the most mentioned topic for this theme. There were two main concerns expressed by participants, where participant p1 was responsible for 85% of the comments relating to this topic. The first was the amount of equipment involved in setting up for the study, where a little under half of the comments related to this concern. It had been commented on multiple times throughout the case study and seemed to cause the participants some distress. It also attributed to the fear responses discussed in the section above as the amount of equipment was described as "off putting". The other major concern for participant p1 was the presence of wires attached to the system. This also made up just under half of the comments on this topic. Participant p1 felt that they were unsafe moving in their wheelchair in case they ran over the cables. They mentioned multiple times throughout the case study that the system had to be wireless moving forward to be truly usable.

The final main concern that was expressed was the presence of the robot. As discussed above in the Individual Differences and Emotions section, while the participants had no issue with the robot in general, they felt that it did not "bring anything to the table" as it could not perform tasks; this could have been due to a misunderstanding in what was involved . Additionally, they felt that the robot was "only of benefit if children were involved". While the focus group participants did not necessarily agree or disagree with these concerns they did understand participants p1 and p2's points of view. In their experience they stated that participant p1 was a "fairly typical patient" who lived in "a normal sized house". They further offered insight into patients' concerns as they often "have lots of big items already to aid independence" and therefore are "conscience of the amount of space things take up". Additionally, they felt that the general public also are "used to everything being small" and therefore, for prototypes, expectations should be managed in comparison to existing technology.

Though not mentioned a significant amount (6% of total responses), existing technology did feature in the usability interview of session three. Participant p1 stated that "Skype could give the same functionality as the system" and that it was a method they already used to communicate. This is relevant to this study as previous work described in Chapter 3 compared the teleoperation system to telecommunication software Skype and found that the teleoperation system had anecdotally higher feelings of place and social presence than Skype. However, they also stated that they felt a "terminal" would be beneficial for patients their age, which would be combined with the head-mounted display (HMD), and that the robot would be excellent for children as discussed above. Finally, they highlighted that since the development of the teleoperation system, technology has advanced and other solutions are available which may be cheaper and more accessible. However, participants also commented on potential future usage for the teleoperation system as it continues to be developed, for example, that the system would not require the use of tripod for the HMD. Additionally, they stated that "the robot wasn't for now" as there was a "quantum jump between what it is now and doing household tasks" which is what they personally wanted a robot for, but is not applicable for the overall aims of the PhD research.

**Presence and Social Interactions**

One of the primary aims of the PhD research is to be able to create feelings of presence for users with life-limiting illnesses. Therefore the findings surrounding this theme were particularly relevant to the overall research questions at thesis level. However, presence and interactions were not mentioned by either participant p1 or p2 during the initial interview in session one; this is the only theme identified where this was the case.

Having tried the teleoperation system in session one, the participants began to make comments relating to presence and interactions and this grew in frequency over the course of the case study. One of the first comments made was by participant p1 who commented how much they "liked being able to see [their partner]", this was mentioned multiple times throughout. Additionally, they felt that they wanted to move around in the space they could see and tried to look down for their wheelchair controls in order to do so. Both participants could see the benefits "for any family" being able to "look around the room" and "see loved ones", especially as participant p1 would normally have been in bed while using the system. The focus group participants also agreed with these comments and felt it could be beneficial to dementia patients to see "the place they grew up" and "something they knew really well". On the other hand, participant p1 felt that feelings of place presence were affected negatively by "being in the next room" rather than somewhere further away. They also highlighted that although it may have not been the best environment to test the system, it was "a real environment", which is vital to the findings gathered throughout this case study. However, no other negative comments regarding place presence were made by any participants throughout the study, making up only 0.5% of total responses (3% of responses for this theme) and was the least mentioned topic of the entire case study and focus group.

While place presence - both positive and negative comments - did not feature heavily in responses for this theme (31%), positive comments for feelings of social presence did (53% of all responses for this theme and 9% of all responses in total). Following using the system in session one, participant p1 spoke extensively about being able to use the system to watch TV with their partner. They commented that using their existing technology to do this resulted in unusable delay between the two programs and restricting the ability to interact with each other regarding them. Given that being able to do this was a requirement set at the beginning of the study, this is a positive outcome as discussed in the section below, and the participants mentioned that it would allow them to maintain the relationship they already had between them. Both participants p1 and p2 also felt that the teleoperation system could be beneficial in tackling social isolation, with participant p1 stating that "It's got to be hasn't it. It's a big problem for people who don't have family nearby". Additionally, during the group interaction, which both participants p1 and p2 preferred over the one-to-one interactions, it was observed that both participants were conversing consistently and laughing. Notably, despite participant p1 saying that they preferred the structure of a set of questions for one-to-one interactions over an open discussion, both participants felt that the group conversation described in the procedure section - also an open discussion - was more interactive than one-to-one. However, it was observed that participant p1 would sometimes get talked over during the group interaction, which had not been obsessed in either one-to-one interaction between the user and the primary interactant or researcher.

Despite this, negative comments regarding feelings of social presence only made up 17% of total comments for this theme and only 3% of total responses. The comment mostly focused on the inability of participant p2 to see participant p1 as they both felt it would be difficult to read non-verbal social cues that are usually provided by body language and that there was "no visual feedback for other people". To remedy this, both participants suggested the use of a static image (as a video feed would just see the user wearing the HMD), which is validated by literature [38] and discussed in the Discussion section below. However, the focus group participants generally felt that, although a static image would be "better", they also felt that people are "getting used to" reading verbal queues only due to the changes in communication during the COVID-19 pandemic when individuals with life-limiting illnesses were especially vulnerable.

Having summarised the findings for the case study and focus group in relation to the identified themes, the following section discusses the implications of these findings on the research questions this PhD research aims to answer.

## 4.5 Discussion

This section details the findings from the case study and focus group in relation to the research questions at a thesis level. Additionally, the research questions from this chapter specifically are discussed. The implications for the field of human-robot interaction and future work are also discussed.

### 4.5.1 Feelings of Place Presence (RQ1)

One of the main research questions for this study, as well as the PhD research as a whole, was whether feelings of place presence could be evoked when using the teleoperation system that had been developed as part of the PhD. It was also one of the end user's requirements for the system due to having carers visit early to put them to bed. To meet this requirement the NAO robot was used to be able to stay in the living room of their house as unobtrusively as possible, where the end user wanted to be present with their partner. Generally the study showed that feelings of place presence were experienced by the end user, and these feelings became more evident as the study progressed and they had more opportunities to try the system. In addition, there was only one negative comment relating to feelings of place presence. These findings suggest that the teleoperation system is capable of producing feelings of place presence in a remote location (RQ1 at thesis level).

### 4.5.2 Social Interactions (RQ2)

There were three research questions investigating solely social interactions using the system for this chapter. These concerned allowing social interactions between the end user and their partner, comparisons between group and one-to-one interactions, and whether the system could improve social isolation. Social interaction was also an extremely important element of the end user's requirements, as their primary motivation was to interact with their partner after going to bed. Generally, participants from both the case study and the focus group were positive with regards to feelings of social presence, which grew with each session, and expressed very few negative opinions about it. However, when compared to participant p1, participant p2 gave far fewer responses, making it hard to obtain a balanced view between the end user and system interactant. When considering participant p2, it became apparent from the initial interview that they were extremely concerned about technology in general, and a large percentage of their responses were fear related. However, these responses dropped over time, suggesting an ability to "get used to" the system. This was validated by the focus group who provided anecdotal feedback of their own patients of all ages getting used to technology available in the hospice. In addition to familiarity with regards to the technology, the findings also highlighted a need for non-verbal cues that play a factor in interaction. Participants p1 and p2 suggested that a static picture was necessary, which is consistent with guidelines suggested by Tsui and Yanco [38]. However, focus group participants disagreed and stated that communication had adapted during the COVID-19 pandemic [126]. Finally, having requested that movement capabilities were removed due to a lack of space in their home, participant p1 showed some regret and commented many times that social presence would have been improved if they could have navigated the robot around the space. Overall, in addition to the findings above, the findings from the thematic analysis have also shown that the system is capable of producing feelings of social presence in one-to-one and group interactions, though participants p1 and p2 preferred group interactions, and is generally capable of improving social isolation in the future (RQ2 at thesis level).

### 4.5.3 Usability (RQ3)

The research questions surrounding usability for this chapter investigated whether the requirements set by participants p1 and p2 had been met, whether the teleoperation system was usable, and what adjustments could be made to increase usability. One of the main requirements surrounded the space available in the participants' home alongside the equipment needed to assist with the symptoms of participant p1's life-limiting illness. While NAO was chosen to maximise space, the participants were still concerned about the amount of equipment involved in setting up the system, and this was discussed in detail. Overall, they made some suggestions for the system, such as implementing wireless capabilities to improve usability in the future. An additional requirement was to take into consideration participant p2's fear and general dislike of technology. Their wishes were respected throughout, observation notes were taken in lieu of recordings, and when participant p2 wanted to stop the initital use of the system this was done so promptly. As a result participant p2's fear responses dropped steadily throughout the study as discussed above. Also discussed above were the requirements involving place and social presence, which resulted in generally positive comments. Overall, the participants felt the system was usable in its current state and were generally positive about it, they also felt it held further potential when technical advancements had been made. Additionally, they did not feel the robot was applicable to their needs, but felt it would be useful with children. Focus group participants were in disagreement within the group, and while all saw the potential uses with children, not all felt that the robot should only be used with them.

### 4.5.4 Implications and Limitations

Ultimately, thematic analysis is subject to researcher interpretation to some extent, however certain conclusions can be drawn by quantifying the data and identifying key themes. The findings from this study give several suggestions for future work in the field. They also have implications on the user requirements formulated in Chapter 2, which are supported by studies discussed in Chapter 3.

Firstly, it is vital to take individual differences into account when formulating user requirements. This includes personality, concerns, preferences, and requirements of their specific life-limiting illness or illnesses; this further supports the addition in Chapter 3 of considering individual differences to the user requirements. However, it is also extremely important to manage user expectations, as this can cause disappointment or misunderstandings with regards to the system's capabilities. This is validated by literature into social robots for use in long-term interactions that showed that it is vital to select the correct levels of embodiment for the robot's purpose, expected capabilities, and intended environment [82]. It is also expressed in literature that it is better to aim for realistic successful interactions, than overplaying expectations of currently available hardware [127], which was also confirmed by the findings of this study. This supports user requirements already formulated in Chapter 2.

Not only are the user's individual differences vitally important during development, it is also important to consider the individual differences of the people they wish to interact with the most. For example, taking participant p2's general fear of technology into account from the system modifications stage allowed for that fear to be reduced over the course of the study. Hancock [128] highlighted the importance of trust when people interact with robots, and this proves to be the case here as participant p2 had to trust that participant p1 was controlling the robot due to not wanting to "talk to a machine". Additionally, it is important to gain a multi-generational perspective when developing systems such as these as different age groups may display differing opinions, and the findings of this study show this is not a definitive topic. Having this understanding also allows for insights into how family members may or may not share attitudes towards robots [129]. Furthermore, future design would consider literature on how to improve long-term acceptance for users and interactants, especially for non-technical individuals, such as participant p2. One example, is the phased adoption approach discussed by Graaf et al [130, 131] who contributed to research on the long-term evaluation of social robots.

Given that individual differences have such an impact in the success of the system, it is important to include the user - and relevant interactants if possible - as early in the design process as possible, following a user-centred design process [60]. This allows researchers and developers to formulate user requirements and take these into consideration when tailoring their systems. Going forward it is possible to follow participant suggestions gained during this study in order to improve the teleoperation system. For example, it will be important to strive for wireless capabilities, especially for wheelchair users. As also suggested by Tsui and Yanco [38], the findings suggest to also have at least a static image of the user available to any interactant. Should these recommendations be taken into consideration for future work then both feelings of place and social presence should improve, as well as tackling social isolation and improving quality of life for those with life-limiting illnesses and their loved ones.

### Publication

The work contained in this chapter has not yet been submitted for publication, but is currently being written up for submission to the Frontiers in Robotics and AI Journal.

## 4.6 Conclusion

This chapter covered a case study involving the deployment of the head-mounted display (HMD) based teleoperation system with an intended end user and their partner - their primary interactant. It also discussed the findings of a subsequent focus group conducted to investigate how generalisable the comments made by the participants of the case study could be to other patients from the perspective of healthcare professionals working in palliative care. The key findings for this chapter, and relevant research questions (RQs) at a thesis level that the findings help to answer are as follows:

- The teleoperation system is generally well received by potential end users and healthcare professionals for navigation and social interaction (RQ1 and RQ2)
- It is possible to evoke feelings of place and social presence when using the developed HMD teleoperation system. (RQ1 and RQ2)
- The developed teleoperation system allows for one-to-one social interaction and in a group. (RQ2)
- It is vitally important to take individual differences of the user, and relevant interactants if possible, into account when formulating user requirements for the system. (RQ3)
- Expectation management has an impact on the perceived usability of the system. (RQ3)
- Technical advancement must be utilised to achieve wireless capabilities for the system to be more successful. (RQ3)
- The user requirements formulated in Chapter 2 and added to in Chapter 3 are further supported by findings from this chapter.

The findings of this study allowed for in-depth evaluation of the developed teleoperation system when combined with a humanoid robot surrogate. This study further highlighted the importance of individual difference for users and their loved ones, alongside the findings from Chapter 2. However, they also highlighted the importance of managing expectations when formulating user requirements, and that the users should be involved in this process as soon as possible. The following chapter will summarise and conclude the findings of the PhD research, discuss general implications and contributions to the field of human-robot interaction, and explore possible future work.

# Chapter 5

# Conclusion

The overall aim of this PhD research was to design and implement a head-mounted display (HMD) based teleoperation system for a humanoid robot surrogate, with a focus on users with life-limiting illnesses. The motivation behind this work was to develop a system which would allow users to effectively navigate in a remote location and interact naturally with others when their symptoms may not allow them to do so in-person. By creating high feelings of place and social presence, the goal was to tackle social isolation and improve quality of life.

This chapter discusses the findings of this work in relation to the research questions identified in Chapter 1 along with any implications. Also covered are the limitations of the PhD work overall and how these can be addressed, alongside any future work. Next, key contributions and the novelty of this PhD research is explored. The content of the thesis chapters are summarised below.

**Chapter 1** introduced key concepts for the thesis and the motivation behind this work. It also covered the aims and objectives for the research and introduced the overarching research questions with justification for exploring them. Finally, it contained a general thesis overview describing the structure of the thesis.

**Chapter 2** covered online focus groups conducted with experts in the field of life-limiting illnesses. These focus groups were made up of several healthcare professionals in palliative care, a patient, and a separate patient's family member. These focus groups investigated general perspectives on robots, but also opinions on the developed teleoperation system, which was shown to them via videos. The findings from these groups allowed for the formulation of user requirements and essential features, which were used to inform further development of the system.

**Chapter 3** described the process of designing and developing the head-mounted display (HMD) based teleoperation system combined with a humanoid social robot. Furthermore, it covered two user studies conducted to evaluate the system. The first study investigated the feelings of place and social presence produced by the teleoperation system when compared to existing telecommunications software. The second study assessed the usability of the system with healthy adults. The findings from these two user studies further informed decisions on system design and development, as well as highlighting the need for system modifications tailoring the system for individual use prior to the case study discussed in the following chapter.

**Chapter 4** covered the deployment of the teleoperation system with a potential end user and their partner. The individual who took part had also taken part in the focus group described in Chapter 2. The case study took part in their home and evaluated the usability of the system, as well as the extent of any feelings of place and social presence. They also provided opinions on possible adjustments for the system in future work. A follow-up focus group with some of the healthcare professionals involved in the focus groups from Chapter 2 is also discussed in this chapter. The focus group discussed findings from the case study and provided insight into how generalisable they could be for other patients with varying life-limiting illnesses. Qualitative research methodologies were utilised to gain an in-depth understanding of the responses provided. These findings provided a valuable insight to the evaluation of the system from the perspective of an end user and their primary interactant.

Throughout the thesis the findings from each chapter have answered research questions specific to that chapter. However, they have also aimed to answer research questions at thesis level that the PhD research aimed to answer. These are discussed in the sections below.

## 5.1 Place Presence in a Remote Location (RQ1)

*Can a virtual reality head-mounted display be used to create a teleoperation system that allows the user to feel present in a remote location?*

Overall, findings from the research conducted during the PhD project suggest that it is possible to use a virtual reality head-mounted display (HMD) to create a teleoperation system that allows the user to feel present in a remote location. The user studies described in Chapter 3 were conducted as part of evaluating the teleoperation system. The findings show that the system capable of producing feelings of place presence when used by healthy adults, including a general trend towards higher place presence when compared to telecommunication software. Having the opportunity to deploy the teleoperation system with an end user and their partner allowed for insight into how they experienced it from a user and interactant's point of view. The thematic analysis further showed that it was possible to evoke feelings of place presence, as discussed in Chapter 4.

However, some aspects of the system were identified by participants across all studies that limited feelings of place presence. The majority of these focused on the need for advancements in the technology utilised as part of the teleoperation system and are discussed further in the Limitations and Future Work section below.

Generally the findings show that the teleoperation system is well received by healthy adults and experts – end users, their loved ones, and healthcare professionals. It is also capable of producing feelings of place presence. The implications of these findings are that the developed system is capable of allowing patients with life-limiting illnesses to navigate in a remote location. This is further evidenced by all participants successfully completing the identification and navigation tasks in the usability study discussed in Chapter 3. Furthermore, the system is capable of producing higher feelings of place presence than existing telecommunications software. The importance of this is the ability for patients to utilise the possibility of seeing "significant places" to them to aid in their acceptance of their life-limiting illness, and to be able to experience it as closely as possible to real-life [14].

## 5.2 Social Interaction Between the User and Others (RQ2)

*Can the teleoperation system create effective, natural, social interactions between the user and others interacting with them?*

Findings from this PhD research show that the teleoperation system is capable of facilitating social interaction, as measured by feelings of social presence, in group and one-to-one interactions. The focus groups discussed in Chapter 2 gained insight into the perspectives of experts and allowed user requirements to be formulated as a result. It was found that levels of trust can be affected by media portrayal of robots, and therefore guidelines from recent literature must be followed when choosing the most appropriate social robot to act as the surrogate. Additionally, experts suggested that cultural and generational differences can have an impact on the acceptance of technology. Surprisingly, the opinion of the experts, such as Eastern cultures being more accepting of robots in general,is not consistent with findings from relevant literature [78]. This further highlights the need to follow relevant literature and take potential users' perspectives into consideration during any future development; which can be achieved by following user-centred design methodologies.

As with place presence, findings from Chapters 3 and 4 showed an ability to produce feelings of social presence, and a general trend towards higher feelings of social presence when compared to existing telecommunications software. Furthermore, with regards to social interaction, even more so than with place presence, experts had positive opinions. However, the limitations identified by the participants also restricted some of the possible social presence. These are discussed in the Limitations and Future Work section.

The implications from the findings on social interaction relate to how best to achieve it. Similarly to place presence, it is important to take individual differences into account due to the differences identified in Chapters 2, 3 and 4. The findings highlight the necessity of user-centred design when developing a system for users with life-limiting illnesses, due to the different and changing symptoms of a wide variety of illnesses. Additionally, it is vital to consider the needs of the users' primary interactants, often loved ones, as that can highly impact the ability to interact using the teleoperation system. Finally, due to the fairly recent advancement in human-robot interaction as a field of research [132], literature can often be inconsistent and does not always align with expert opinion. Therefore, it is important to be thorough in researching the relevant fields as well as consulting experts during the design and development stages.

## 5.3 Essential Design Features for System Usability (RQ3)

*What design features are necessary to create a usable teleoperation system that achieves the aims of the project?*

Some of the most substantial findings from this thesis relate to designing essential features for the teleoperation system. General guidelines into designing teleoperation systems and social robots was followed. However, this PhD research has also been able to use the opinions and perspectives of healthy adults and experts in the field of life-limiting illnesses to further inform these guidelines with these specific users in mind. The findings from the focus groups described in Chapter 2 supported the suggested use case for the system due to patient acceptance within their hospices. Additionally, they highlighted the need for adhering to literature and taking into consideration potential users' needs as discussed in the sections above and further supported by the findings from the case study and focus group described in Chapter 4.

As above, participants highlighted some technical concerns, and desirable features that limited the usability and appropriateness of the system. These are discussed in the Limitations and Future Work section. While some of the technical concerns were addressed in further development, some restrictions remained, and the usability study in Chapter 3 showed that the optimal resolution for the system in its current iteration is 720p without resulting in unusable delay. Furthermore, findings from the user study comparing the teleoperation system to existing telecommunications software showed that the system is significantly harder to use, though findings from Chapters 2 and 4 suggest that people of all ages can adapt to newer technologies with relative ease. However, user expectation must be managed during development as this has an impact on the perceived usability of the system.

Finally, the findings showed that the teleoperation system is usable with both NAO and Pepper humanoid social robots and that there is no statistically significant difference in the task performance of either robot. Participant feedback suggested that Pepper is preferred by participants for physical navigation, whereas NAO is preferred for looking around a remote environment. Additionally, while participants generally approved of the system as a whole, there was no decisive answer as to which robot was preferred and this is subject to users' individual differences and requirements for the system.

The implications of these findings are that it is possible to create a usable head-mounted display based teleoperation system for a humanoid robot surrogate, and that this is a positively received system for users with life-limiting illnesses, as is the primary aim of the PhD research. These findings also further highlight the need to consider literature, individual differences, and user requirements throughout system development, and to follow a user-centred design protocol as early on in the process as possible.

## 5.4 Limitations and Future Work

While the research questions were partly answered, there were some limitations and suggestions identified regarding the system and research methodologies used to conduct the evaluations of it. These are discussed below along with recommended future work for any further development.

### 5.4.1 Research Methodologies

While participants did not highlight any concerns with the methodologies, there are limits to the generalisability of the research findings. For example, due to the restrictions surrounding the COVID-19 pandemic there were limited opportunities to involve intended end users, who were deemed clinically vulnerable, with the studies. Therefore the focus groups in Chapter 2 were skewed towards healthcare professionals working in palliative care. Additionally, the focus groups had to be conducted online via Microsoft Teams, limiting their experience with the system to watching videos and not demonstrating it in person. Similarly, the evaluation user studies from Chapter 3 were only able to be conducted with healthy adults from the university, limiting the generalisability to others. While the case study described in Chapter 4 was conducted to obtain in-depth analysis with an end user and their primary interactant in order to combat this limitation, in the future further studies would be conducted in-person in collaboration with the hospices to strengthen the findings.

### 5.4.2 Head-Mounted Display Based Teleoperation System

Technical limitations highlighted by participants restricted the full feelings of place and social presence that could be experienced. Despite making improvements to the system throughout the PhD research, as described in the system modification sections of the thesis, there needed to be further adjustments made that were not in the scope of the PhD due to time and budget. More specifically, participants commented throughout on the "bulky" nature of the headset, issues surrounding camera resolution, and lack of wireless capabilities. Some of these issues resulted in concerns around the comfort of end users, who experience ever changing symptoms and frequent periods of fatigue. Future work would tackle these issues by utilising more recent technical advancements allowing for higher resolutions and lighter headsets.

Furthermore, in order to address some of the identified limitations and improve the range of possible navigation it is recommended to implement wireless capabilities. Within the scope of the PhD a wired connection was relied on. However, in future system iterations a streaming protocol would be used to allow remote connection without creating frame rate issues. Removing the need for the large number of wires, though some would likely still be required, would work toward the "plug and play" functionality requested by the end user in Chapter 4. However, user-centred design and high levels of expectation management would still be implemented as early in the continued development process as possible.

Additionally, while the scope of the PhD required the end users to have the use of their upper body, future work will focus on integrating development kits from charity Special Effect, who specialise in accessibility in games [133]. These kits allow developers to integrate specially designed controllers into their systems to improve motor accessibility, which would be of great benefit to users who have lost some motor function due to their life-limiting illness.

### 5.4.3 Robot Surrogate

The experts and healthy adults participating in the studies were generally positive regarding the chosen robot surrogates for the teleoperation system - Pepper and NAO. However, there were some general considerations suggested throughout the studies. Task performance from studies in Chapter 3 showed that both robots were capable of being used successfully when combined with the teleoperation system. However, participants commented on the desire to have an image of the end user available to the interactants in order to increase social presence. This is supported by literature which states that teleoperation systems need at least a static image of the user to avoid feelings of suspicion by the interactants [38]. The importance of thoroughly consulting literature became evident in findings from all Chapters; this was due to the vast number of individual differences and needs that need to be considered for users with life-limiting illnesses. For example, literature also shows the importance of sound coming from the robot's "mouth", which is not the case with the speaker attached to the current robot surrogates; this would be explored in future work.

An additional aspect which was discussed in detail with participants was the appropriateness of having the system used with a robot at all; and the case study discussed in Chapter 4 found differing opinions between experts. The end user and their partner felt that the robot was mostly appropriate when combined with the system to be used with children, and that a terminal would be sufficient for their needs. However, the focus group participants from Chapters 2 and 4 generally felt that the robot was appropriate. Some participants felt that the success of the robot could be dependent on the age of users and interactants, but others felt that their experiences with older patients suggested a desire to adapt to new technologies as much as younger patients. This controversial topic highlights the need for further study into the appropriateness of the robot surrogate and whether other humanoid or anthropomorphic robots should be considered, which will be explored in future work.

## 5.5 Key Contributions to Human-Robot Interaction

This PhD research has discussed the design, development, and evaluation of a head-mounted display (HMD) based teleoperation system for a humanoid robot surrogate, with a focus on users with life-limiting illnesses. The main motivation for this research was to tackle social isolation and improve quality of life for the users. A user-centred design process was followed involving experts in palliative care. The novelty behind this research is the combination of HMD teleoperation for a humanoid robot surrogate, but also the application of such a system to the field of life-limiting illnesses. Several key contributions to the field of human-robot interaction (HRI) have resulted from this research and are listed below:

- Findings to suggest the ability to produce feelings of place presence and facilitate social interaction using the developed teleoperation system, including when compared to existing telecommunications software (Chapter 3)
- Proven usability of the developed teleoperation system through task performance (Chapter 3)
- A suggested want and need for such a teleoperation system with a humanoid robot surrogate for users with life-limiting illnesses (Chapters 2 and 4)

- Findings highlighting the need to consider individual differences and needs for users with varying life-limiting illnesses, supporting a need for user-centred design methodologies (Chapters 2 and 4)
- A teleoperation system which, when applied to users with life-limiting illnesses, can improve social isolation and quality of life (Chapter 4)
- Findings which suggest that design features are heavily linked to usability and feelings of presence, suggesting an improvement to the system will result in higher feelings of place and social presence for users with life-limiting illnesses (thesis level findings)
- User requirements for a head-mounted display based teleoperation system for a humanoid robot surrogate as formulated with experts in the field of life-limiting illnesses. (thesis level findings)

The formulated list of user requirements are one of the key contributions for the thesis research and have evolved over the course of the PhD research. The final list is presented below and is categorised in the most prevalent themes throughout the the PhD research.

**User Requirements for Designing a Head-Mounted Display Based Teleoperation System for a Robot Surrogate for Users with Life-Limiting Illnesses:**

**Development Approaches**

*Continue to iterate the system as technology advances*

Findings suggested that many limitations of the system were due to the limitations of the technology itself. This could be somewhat alleviated by upgrading the utilised hardware as it improves.

*The system should remain simple, uncomplicated, and as accessible as possible*

All participants, as supported by literature, acknowledged that users would be able to adapt to the system, but suggested that the system remain simple and uncomplicated to avoid unnecessary expense and confusion.

**Head-Mounted Display Based Teleoperation System**

*Utilise available technology to ensure the HMD is as streamlined and lightweight as possible*

Experts highlighted that symptoms may make it challenging to wear the HMD for long periods of time, due to discomfort and fatigue. Similarly to the above, utilising the most appropriate currently available technology to reduce the bulk and weight of the HMD may alleviate some of these challenges.

*Utilise a wireless streaming protocol*
Participants expressed concern regarding the wired nature of the system. It would be optimal to implement wireless streaming capabilities to improve the mobility of the system.

*Ensure the most stable network connection for optimal interaction*
To alleviate any concerns around connection while users are communicating with the interactants, it is vital to utilise the most reliable network connection available.

**Robot Surrogate**
*Include a static image of the user if possible*
Literature highlights the importance of including a representation of the user, if possible, for the benefit of the interactants.

*Use humanoid robots, but not one with projected faces due to "Uncanny Valley" effect*
Experts, as supported by literature, suggested the use of humanoid robots for the system. However, it was agreed that currently available robots with projected faces produce "uncanny valley" effects.

**User-Centred Design**
*Consider perception and acceptance of robots and technology*
Literature highlights general findings surrounding perceptions and acceptance of robots. However, participants stated that, from their experiences, this varies among individuals. Therefore including the users in design is vital.

*Consider cultural and generational differences when designing the system*
Similarly to the above, experts highlighted an awareness of cultural and generational differences between individuals. However, literature shows some inconsistencies. Therefore, it is important to consult intended end-users during development.

*Manage user expectations with regards to system capabilities and performance*
Individuals without expert knowledge in robotics tend to have higher expectations with regards to potential system capabilities, partially due to media portrayal of robots. These expectations must be managed during development and deployment to avoid disappointment.

*Consider individual differences, such as personality, beliefs, desires, and needs when designing the system*
Experts highlighted the wide variety of individual differences in those living with life-limiting illnesses. This can include beliefs, personality, desires, and symptoms, amongst others. These result in complex and individual needs for each user with regards to the developed system. Fol-

lowing user-centred design methodologies are vital, as is tailoring the system to each individual for their specific needs.

These novel contributions to the field of human-robot interaction have provided a proof of concept for a teleoperation system for a humanoid robot surrogate for users with life-limiting illnesses. The findings have suggested that the system is capable of providing feelings of place presence and facilitating social interaction by allowing users to navigate around a remote location and interact with people in that environment. In addition, a list of suggested user requirements has been formulated for researchers developing such a system in the future. This research has also highlighted improvements that can be made by utilising more recent technological advancements, and will explore this in future work.

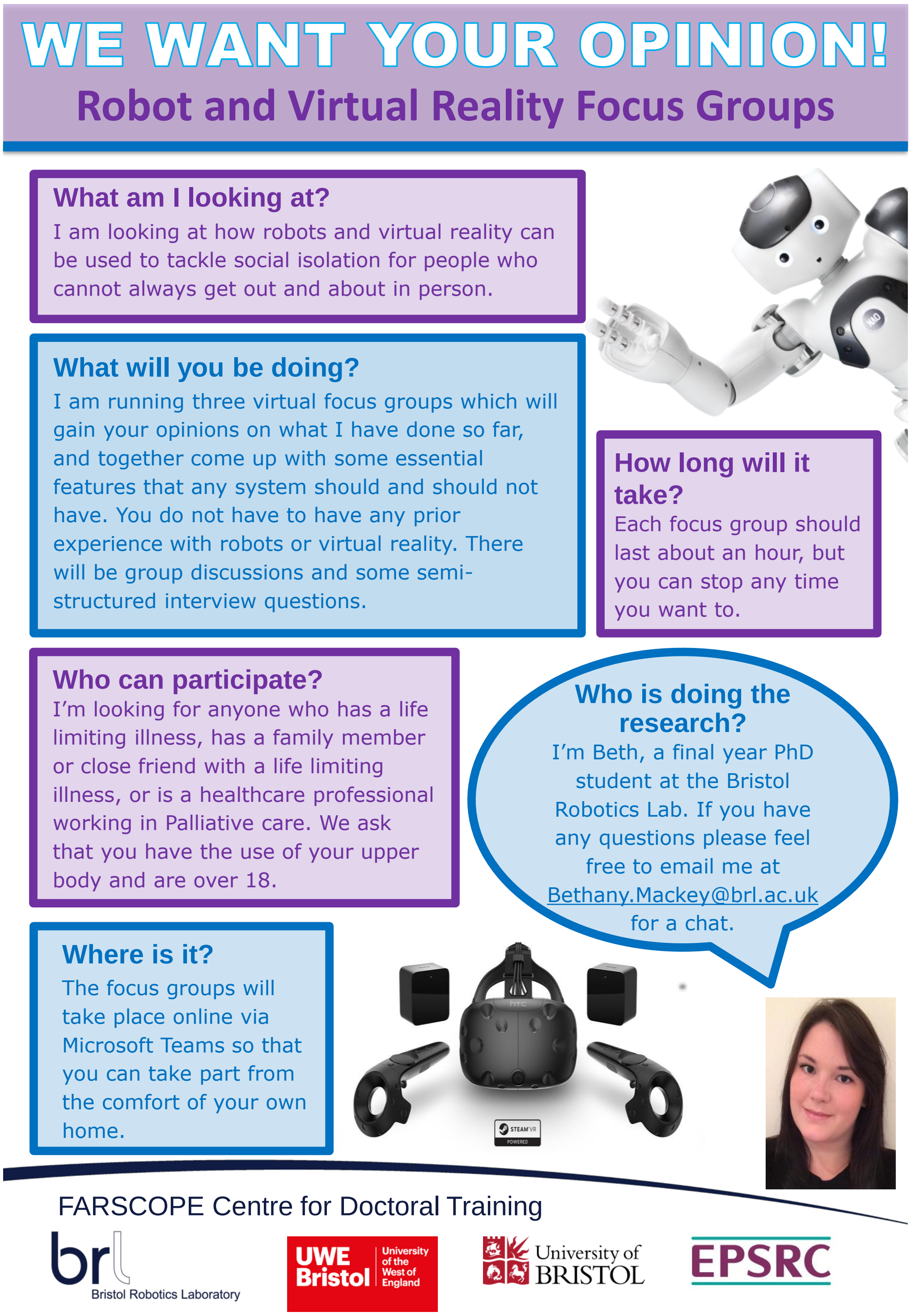
# Appendix A

## Chapter 2: Identifying User Requirements and Essential Features

This appendix relates to work described in Chapter 2. It contains copies of the documentation and materials used during the focus group conducted to formulate user requirements. It also contains a table with the full quantified data showing the breakdown of how many times each code was mentioned by each focus group for each question; it also includes the number of responses by each group. The documents are as follows:

- Focus Group Recruitment Poster
- Focus Group Information Sheet
- Focus Group Privacy Notice
- Focus Group Consent Form
- Focus Group Demographics Questionnaire
- Focus Group Semi-Structured Interview: Discussion One
- Focus Group Semi-Structured Interview: Discussion Two
- Focus Group Debrief Information Sheet
- Breakdown of Total Number of Times each Theme is Mentioned and Total Number of Responses

## A.1 Focus Group Recruitment Poster



## A.2 Focus Group Information Sheet

# Study Information Sheet

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements.

**STUDY SUMMARY:**

### What am I looking at?

This study looks at how robots and virtual reality can be used to tackle social isolation for people who cannot always get out and about in person.

### What will you be doing?

I am running three virtual focus groups which will gain your opinions on what has been done so far, and together come up with some essential features that any system should and should not have. You do not have to have any prior experience with robots or virtual reality. There will be group discussions and some semi-structured interview questions.

### Who can participate?

I'm looking for anyone who has a terminal diagnosis, has a family member or close friend with a terminal diagnosis, or is a healthcare professional working in Palliative care. We ask that you have the use of your upper body and are over 18.

### Where is it?

The focus groups will take place online via Microsoft Teams so that you can take part from the comfort of your own home. You can join as a guest so you do not have to create an account.

### How long will it take?

Each focus group should last about an hour, but you can stop any time you want to.

### What's next?

Please email me at bethany.mackey@brl.ac.uk if you would like any further information, or to arrange a time to join a focus group. Please find more detailed information about the study, what it involves, and myself below.

**FURTHER INFORMATION:**

You are invited to take part in research taking place virtually in collaboration with Marie Curie Liverpool. It is funded by the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following information carefully and if you have any queries or would like more information please contact Bethany Mackey, Faculty of Technology, Bristol Robotics Laboratory, University of the West of England, Bristol bethany.mackey@brl.ac.uk.

## Who is organising and funding the research?

The project lead is Bethany Mackey, final year PhD student on the FARSCOPE CDT program, part of the Embodied Cognition for Human-Robot Interactions (ECHOS) group, based at the Bristol Robotics Laboratory, University of the West of England. Paul Bremner and Manuel Giuliani are the supervisors for this PhD research. Please find their details at the end of this document.

## What is the aim of the research?

The research is looking at developing an immersive control system for a robot surrogate for users in palliative care. To assist us in identifying essential features and user requirements for the system, we will be running a series of focus groups with people who have been diagnosed with a terminal illness, their families and friends, and healthcare professionals working in palliative care. The results of our study will be analysed and may be used in conference papers and peer-reviewed academic papers.

## Do I have to take part?

You do not have to take part in this research. It is up to you to decide whether or not you want to be involved. If you do decide to take part, you will be given a copy of this information sheet to keep and will be asked to sign a consent form via an online platform called Qualtrics. You will be sent the appropriate Qualtrics link during the study. You are free to stop and withdraw from the study at any time without giving a reason. After you have left the Teams call it will be no longer possible to withdraw as all data collected is anonymous and cannot be identified as yours at a later date. Deciding not to take part or to withdraw from the study does not have any penalty.

## What will happen to me if I take part and what do I have to do?

The focus group will take approximately 60 minutes.

You will first be asked to read a privacy notice, sign a consent form, and provide some basic demographic information. You will be invited to investigate the Nao robot on camera for as long as you would like and complete a questionnaire regarding your opinion of it. Once you have given consent we will have a brief group discussion surrounding robotics in general. You will be invited to watch a video demonstrating the system being used. Finally, we will have another discussion about the system and your opinion of it. Recordings will be taken of the full study for later transcription and analysis, and I will be taking notes throughout the study. All of your data and responses will be fully anonymised.

All materials will be sent via a link to Qualtrics during the study. Data will be gathered using the following:

- ***Questionnaires***
  You will be asked to fill in a "Godspeed Questionnaire", which is designed to measure perception of a robot.
- ***Semi-structured focus group questions***
  The experimenter will ask you open questions to collect subjective feedback. Any other comments can be made here. You have the option to answer as much or as little as you wish.

## What are the benefits of taking part?

By taking part in this study you will be helping us to gain a better understanding of the usability, effectiveness, and appropriateness of the developed system, highlight any further issues that need to be addressed, and any features that are deemed essential for the system to be successful.

## What are the possible risks of taking part?

We do not foresee or anticipate any significant risk to you in taking part in this study. If you feel uncomfortable at any time you can stop the study without giving a reason. If you need any support during or after the study then the researchers will be able to put you in touch with suitable support agencies. The research team are experienced in conducting studies and are sensitive to the subject area. The focus group has been designed with these considerations in mind.

## What will happen to your information?

All the information we receive from you will be treated in the strictest confidence.
All the information that you give will be kept confidential and anonymised immediately after the completion of the study. Recordings will be transcribed and anonymised, after which they will be destroyed. Hard copy research material will be kept in a locked and secure setting to which only the researchers will have access in accordance with the University's and the Data Protection Act 2018 and General Data Protection Regulation (GDPR) requirements. Your anonymised data will be analysed together with other interview and file data, and we will ensure that there is no possibility of identification or re-identification from this point.

## Where will the results of the research study be published?

A Report will be written containing our research findings. This Report will be available on the University of the West of England's open-access Research Repository. The project funder is the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT, which requires all publications funded through them to be open access. Key findings will also be shared both within and outside the University of the West of England. Anonymous and non-identifying direct quotes may be used for publication and presentation purposes.

## Who has ethically approved this research?

The project has been reviewed and approved by University of the West of England University Research Ethics Committee. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England at: Researchethics@uwe.ac.uk

## What if something goes wrong?

If you have any questions about the ethical conduct of this research, have any complaints or concerns, or are uncertain about any aspect of your participation please contact the project supervisors or the University's research ethics committee.

**Project Supervisors:**
Dr Paul Bremner paul.bremner@brl.ac.uk
Professor Manuel Giuliani manuel.giuliani@brl.ac.uk

## What if I have more questions or do not understand something?

If you would like any further information about the research please contact in the first instance:

Bethany Mackey
Bristol Robotics Laboratory
University of the West of England, T Block, Frenchay Campus
Coldharbour Lane, Bristol, BS16 1QY.
bethany.mackey@brl.ac.uk

Thank you for agreeing to take part in this study.

You will be emailed a copy of this Participant Information Sheet and your signed Consent Form to keep.

## A.3 Focus Group Privacy Notice

UWE Bristol | University of the West of England

# Privacy Notice

**Study Title**: Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements.

### Purpose of the Privacy Notice

This privacy notice explains how the University of the West of England, Bristol (UWE) collects, manages and uses your personal data before, during and after you participate in this focus group. 'Personal data' means any information relating to an identified or identifiable natural person (the data subject). An 'identifiable natural person' is one who can be identified, directly or indirectly, including by reference to an identifier such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

This privacy notice adheres to the General Data Protection Regulation (GDPR) principle of transparency. This means it gives information about:

- How and why your data will be used for the research;
- What your rights are under GDPR; and
- How to contact UWE Bristol and the project lead in relation to questions, concerns or exercising your rights regarding the use of your personal data.

This Privacy Notice should be read in conjunction with the Participant Information Sheet and Consent Form provided to you before you agree to take part in the research.

### Why are we processing your personal data?

UWE Bristol undertakes research under its public function to provide research for the benefit of society. As a data controller we are committed to protecting the privacy and security of your personal data in accordance with the (EU) 2016/679 the General Data Protection Regulation (GDPR), the Data Protection Act 2018 (or any successor legislation) and any other legislation directly relating to privacy laws that apply (together "the Data Protection Legislation"). General information on Data Protection law is available from the Information Commissioner's Office (https://ico.org.uk/).

### How do we use your personal data?

We use your personal data for research with appropriate safeguards in place on the lawful bases of fulfilling tasks in the public interest, and for archiving purposes in the public interest, for scientific or historical research purposes.

We will always tell you about the information we wish to collect from you and how we will use it.

We will not use your personal data for automated decision making about you or for profiling purposes.

Our research is governed by robust policies and procedures and, where human participants are involved, is subject to ethical approval from either UWE Bristol's Faculty or University Research Ethics Committees. This research has been approved by UWE Bristol's Ethics Committee. The research team adhere to the **Ethical guidelines of the British Educational Research Association (and/or the principles of the Declaration of Helsinki, 2013) and the principles of the General Data Protection Regulation (GDPR).**

For more information about UWE Bristol's research ethics approval process please see our Research Ethics webpages at:
www1.uwe.ac.uk/research/researchethics

## What data do we collect?

The data we collect will vary from project to project. Researchers will only collect data that is essential for their project. The specific categories of personal data processed are described in the Participant Information Sheet provided to you with this Privacy Notice.

## Who do we share your data with?

We will only share your personal data in accordance with the attached Participant Information Sheet and your Consent.

## How do we keep your data secure?

We take a robust approach to protecting your information with secure electronic and physical storage areas for research data with controlled access. If you are participating in a particularly sensitive project UWE Bristol puts into place additional layers of security. UWE Bristol has Cyber Essentials information security certification.

Alongside these technical measures there are comprehensive and effective policies and processes in place to ensure that users and administrators of information are aware of their obligations and responsibilities for the data they have access to. By default, people are only granted access to the information they require to perform their duties. Mandatory data protection and information security training is provided to staff and expert advice available if needed.

## How long do we keep your data for?

Your personal data will only be retained for as long as is necessary to fulfil the cited purpose of the research. The length of time we keep your personal data will depend on several factors including the significance of the data, funder requirements, and the nature of the study. Specific details are provided in the attached Participant Information Sheet. Anonymised data that falls outside the scope of data protection legislation as it contains no identifying or identifiable information may be stored in UWE Bristol's research data archive or another carefully selected appropriate data archive.

## Your Rights and how to exercise them

Under the Data Protection legislation you have the following **qualified** rights:

(1) The right to access your personal data held by or on behalf of the University;
(2) The right to rectification if the information is inaccurate or incomplete;
(3) The right to restrict processing and/or erasure of your personal data;
(4) The right to data portability;
(5) The right to object to processing;
(6) The right to object to automated decision making and profiling;
(7) The right to complain to the Information Commissioner's Office (ICO).

**Please note, however, that some of these rights do not apply when the data is being used for research purposes if appropriate safeguards have been put in place**.

We will always respond to concerns or queries you may have. If you wish to exercise your rights or have any other general data protection queries, please contact UWE Bristol's Data Protection Officer (dataprotection@uwe.ac.uk).

If you have any complaints or queries relating to the research in which you are taking part please contact either the research project lead, whose details are in the attached Participant Information Sheet, UWE Bristol's Research Ethics Committees (research.ethics@uwe.ac.uk) or UWE Bristol's research governance manager (Ros.Rouse@uwe.ac.uk)

v.1: This Privacy Notice was issued in April 2019 and will be subject to regular review/update.

## A.4 Focus Group Consent Form

# Consent Form

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements.

This consent form will have been given to you with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet

If you are happy to take part in this study please sign and date the form. You will be given a copy to keep for your records.

**Please read the statements below and sign below to give consent:**

| |
|---|
| I have read and understood the information sheet |
| I have been given the opportunity to ask questions and have had my questions answered to my satisfaction. |
| I am aware that data collected, including audio recordings, will be anonymised, kept in accordance with General Data Protection Regulation (GDPR), and will be viewed and analysed by the research team as part of their studies. |
| I am aware that I have the right to withdraw consent and discontinue participation without penalty before or during the study, up until the point that I finally leave the focus group. I understand it will not be possible to withdraw after that point as my data is anonymised and will no longer be identifiable. |
| I have freely volunteered and am willing to participate in this study. |
| I am willing to have my questionnaire responses collected. |

Name (Printed)……………………………………………………………………….

Signature……………………………………………………. Date…………………….

V2 03/03/2020

## A.5 Focus Group Demographics Questionnaire

Participant ID:

# Demographics Questionnaire

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements.

The information that you provide below will be anonymised and handled in accordance with data protection regulations. The information will be associated with a participant ID and not with any personal data.

**Please circle the most appropriate response:**

**Age range:**

18 – 24 / 25 – 34 / 35 – 44 / 45 – 54 / 55 – 64 / 65 – 74 / 75+ / Prefer not to say

**Gender:**

Male / Female / Other / Prefer not to say

**Previous experience with virtual reality:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Previous experience with robotics:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Please only answer this question if you are a healthcare professional who currently is/previously has worked in palliative care.**

**Years working in Palliative Care (Please enter a number to the nearest 6 months):**

V1 03/03/2020

## A.6 Focus Group Semi-Structured Interview: Discussion One

Participant ID:

# Focus Group: Discussion 1

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements

1. **What do you think of when you hear the word "robot"?**

2. **Does this change for "social robot"?**

3. **Do you think technology can be beneficial for people with a terminal illness?**

V1 03/03/2020

## A.7 Focus Group Semi-Structured Interview: Discussion Two

Participant ID:

# Focus Group: Discussion 2

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements

1. **What features of the current system do you like and dislike?**

2. **Are there any other features that you think are essential and need to be added?**

3. **Do you think the robot is an appropriate choice to be a surrogate? Please explain your answer.**

V1 03/03/2020

Participant ID:

4. **Do you think you could feel as though you were in another environment using this system? Please explain your answer.**

5. **Do you think you could interact with another person through the robot? Please explain your answer.**

V1 03/03/2020

## A.8 Focus Group Debrief Information Sheet

# Study Debrief Sheet

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements.

Thank you for taking the time to participate in my research project. This debrief sheet provides some more information about the study for you to consider before giving final consent for us to use your data. Please feel free to ask any questions.

### What were the aims of this study?

Further to the information sheet given at the beginning of this experiment, this project is concerned with designing an immersive control system for a robot surrogate, and this study in particular with formulating a list of user requirements for the system to be successful. The aim is to develop a system that allows people to navigate in a different location to where they currently are and feel immersed in that environment. It is also hoped that the system will allow people to interact naturally with friends and family via the system if they cannot otherwise be with them. As a result, we are hoping that the system can tackle social isolation, particularly for people in palliative care. Future work will include developing the system to meet the requirements identified by these focus groups.

### Final Consent

Now that you have completed the focus group and have been made aware of its full purpose and data collected, we would like to ask for final consent to use your data in our analysis of the study results. As previously stated, you are free to withdraw at any point before you leave the focus group call, so are free to withdraw at this point. Please also feel free to ask any questions you may have about the study or data collected.

V2 03/03/2020

## A.9 Breakdown of Total Number of Times each Theme is Mentioned and Total Number of Responses

| Discussion/Question | Theme | Perception of Robots | | | | Differences | | Essential Features | | | | Total Responses |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Group/Code | Media Portrayal | Real-World Uses | Current Assistive Uses | Current Studies | Cultural | Generational | Robot Surrogate | Liked Features | Disliked Features | Suggested Features | |
| Discussion 1: Q1 | Patient and Relative | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| Discussion 1: Q1 | Marie Curie West Midlands | 5 | 3 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 11 |
| Discussion 1: Q1 | Prospect Hospice | 2 | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 7 |
| **Total: Discussion 1: Q1** | | 7 | 12 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 25 |
| Discussion 1: Q2 | Patient and Relative | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 6 |
| Discussion 1: Q2 | Marie Curie West Midlands | 3 | 0 | 0 | 2 | 1 | 0 | 6 | 0 | 0 | 0 | 12 |
| Discussion 1: Q2 | Prospect Hospice | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| **Total: Discussion 1: Q2** | | 4 | 1 | 0 | 2 | 1 | 0 | 11 | 0 | 0 | 0 | 19 |
| Discussion 1: Q3 | Patient and Relative | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 6 |
| Discussion 1: Q3 | Marie Curie West Midlands | 0 | 2 | 0 | 0 | 1 | 2 | 0 | 4 | 4 | 0 | 13 |
| Discussion 1: Q3 | Prospect Hospice | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 6 |
| **Total: Discussion 1: Q3** | | 0 | 2 | 5 | 0 | 1 | 3 | 0 | 9 | 5 | 0 | 25 |
| **Total Discussion 1** | | 11 | 15 | 7 | 4 | 2 | 3 | 13 | 9 | 5 | 0 | 69 |
| Discussion 2: Q1 | Patient and Relative | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 5 |
| Discussion 2: Q1 | Marie Curie West Midlands | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 1 | 0 | 5 |
| Discussion 2: Q1 | Prospect Hospice | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 5 |
| **Total: Discussion 2: Q1** | | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8 | 6 | 0 | 15 |
| Discussion 2: Q2 | Patient and Relative | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| Discussion 2: Q2 | Marie Curie West Midlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 4 |
| Discussion 2: Q2 | Prospect Hospice | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 1 | 6 |
| **Total: Discussion 2: Q2** | | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 3 | 6 | 12 |
| Discussion 2: Q3 | Patient and Relative | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 3 |
| Discussion 2: Q3 | Marie Curie West Midlands | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| Discussion 2: Q3 | Prospect Hospice | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 |
| **Total: Discussion 2: Q3** | | 0 | 0 | 1 | 0 | 0 | 0 | 8 | 0 | 1 | 0 | 10 |
| Discussion 2: Q4 | Patient and Relative | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| Discussion 2: Q4 | Marie Curie West Midlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Discussion 2: Q4 | Prospect Hospice | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 2 | 13 |
| **Total: Discussion 2: Q4** | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 7 | 2 | 16 |
| Discussion 2: Q5 | Patient and Relative | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 4 |
| Discussion 2: Q5 | Marie Curie West Midlands | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 3 |
| Discussion 2: Q5 | Prospect Hospice | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 7 |
| **Total: Discussion 2: Q5** | | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 9 | 1 | 2 | 14 |
| Discussion 2: Q6 | Patient and Relative | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 |
| Discussion 2: Q6 | Marie Curie West Midlands | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 3 |
| Discussion 2: Q6 | Prospect Hospice | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| **Total: Discussion 2: Q6** | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4 | 7 |
| **Total Discussion 2** | | 1 | 0 | 2 | 0 | 1 | 2 | 8 | 27 | 19 | 14 | 74 |
| **Total Responses** | | 12 | 15 | 9 | 4 | 3 | 5 | 21 | 36 | 24 | 14 | 143 |

# Appendix B

## Chapter 3: Technical Development and User Evaluation

Supplementary documents for work detailed in Chapter 3 are listed below. This appendix is separated into two sections covering the two user studies conducted to evaluation the teleoperation system. The sections are as follows:

- User Study: The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software
- User Study: Usability of an Immersive Control System for a Humanoid Robot Surrogate

## B.1 User Study: The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software

This section of the appendix contains documentation used in the user study investigating the feelings of presence produced by the teleoperation system in comparison to existing telecommunications software. The documents listed are:

- Ranking Task: Instructions
- Ranking Task: Desert Island Words
- Ranking Task: Moon Landing Words
- Presence Questionnaire
- Networked Minds Social Presence Inventory
- System Usability Scale
- Participant Information Sheet
- Participant Demographics Questionnaire
- Participant Consent Form
- Participant Debrief Sheet

### B.1.1 Ranking Task Instructions

## Ranking Task Instructions 1

Please follow the below instructions:

1. You have found yourself on a desert island, you only have the 5 items in front you.
2. The remote participant needs to read the items out to the local participant.
3. Between you, please decide on the order of importance of the items for your survival.
4. The items cannot be tied in their order of ranking.
5. Please say out loud when you have finished.

# Ranking Task Instructions 2

Please follow the below instructions:

1. You have crash landed on the moon, you only have the 5 items in front you.
2. The remote participant needs to read the items out to the local participant.
3. Between you, please decide on the order of importance of the items for your survival.
4. The items cannot be tied in their order of ranking.
5. Please say out loud when you have finished.

### B.1.2 Words for Desert Island Scenario

# Mobile Phone

# Hammock

Family

Photo

# Signalling Mirror

# Machete

### B.1.3 Words for Moon Landing Scenario

Solar-powered FM Receiver-Transmitter

# First Aid Kit

# Two 100lb Tanks of Oxygen

# Food Concentrate

# 20 Gallons of Water

### B.1.4 Presence Questionnaire

Participant ID: Condition:

## Presence Questionnaire

Please place an 'X' in the appropriate box in accordance with your experience. If you are unsure about a question's wording, please assume your own interpretation. Please consider the entire scale before selecting your response.

1. How completely were all of your senses engaged?

|_______|_______|_______|_______|_______|_______|_______|

NOT ENGAGED — MODERATELY ENGAGED — COMPLETELY ENGAGED

2. How much did the visual aspects of the environment involve you?

|_______|_______|_______|_______|_______|_______|_______|

NOT INVOLVED — MODERATELY INVOLVED — COMPLETELY INVOLVED

3. How aware were you of your display devices?

|_______|_______|_______|_______|_______|_______|_______|

NOT AWARE — MODERATELY AWARE — COMPLETELY AWARE

4. How completely were you able to actively survey or search the environment using vision?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL — SOMEWHAT — COMPLETELY

5. How closely were you able to examine objects?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL — MODERATELY CLOSELY — VERY CLOSELY

Participant ID: Condition:

6. How involved were you in the experience?

|_______|_______|_______|_______|_______|_______|_______|

NOT INVOLVED — MODERATELY INVOLVED — COMPLETELY INVOLVED

7. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL — SOMEWHAT — COMPLETELY

8. How distracting was the control mechanism?

|_______|_______|_______|_______|_______|_______|_______|

NOT DISTRACTING — MODERATELY DISTRACTING — COMPLETELY DISTRACTING

9. How quickly did you adjust to the virtual environment experience?

|_______|_______|_______|_______|_______|_______|_______|

SLOWLY — MODERATELY QUICKLY — VERY QUICKLY

10. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL — SOMEWHAT — COMPLETELY

11. How much did the auditory aspects of the environment involve you?

|_______|_______|_______|_______|_______|_______|_______|

NOT INVOLVED — MODERATELY INVOLVED — COMPLETELY INVOLVED

Participant ID: Condition:

12. How aware were you of events occurring in the real world around you?

|_______|_______|_______|_______|_______|_______|_______|

NOT AWARE MODERATELY AWARE COMPLETELY AWARE

13. How inconsistent or disconnected was the information coming from your various senses?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL SOMEWHAT COMPLETELY

14. How well could you identify sounds?

|_______|_______|_______|_______|_______|_______|_______|

NOT WELL MODERATELY WELL VERY WELL

15. How well could you localize sounds?

|_______|_______|_______|_______|_______|_______|_______|

NOT WELL MODERATELY WELL VERY WELL

16. How much delay did you experience between your actions and expected outcomes?

|_______|_______|_______|_______|_______|_______|_______|

NO DELAYS MODERATE DELAYS LONG DELAYS

### B.1.5 Networked Minds Social Presence Inventory

Participant ID: Condition:

UWE Bristol University of the West of England

# Networked Minds Social Presence Inventory

Please circle your responses to the questions below. Please consider the entire scale before selecting your response.

| First Order Social Presence – Co-presence | Strongly Disagree | Disagree | Some-what Disagree | Neither Agree nor Disagree | Some-what Agree | Agree | Strongly Agree |
|---|---|---|---|---|---|---|---|
| I often felt as if my partner and I were in the same place together. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I think my partner often felt as if we were in the same place together. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I was often aware of my partner in the next room. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner was often aware of me in the next room. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I hardly noticed my partner in the next room. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner did not notice me in the next room. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I often felt as if we were in different places rather than together in the same place. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I think my partner often felt as if we were in different places rather than together in the same place. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| Second Order Social Presence: Psycho-behavioural Interaction | Strongly Disagree | Disagree | Some-what Disagree | Neither Agree nor Disagree | Some-what Agree | Agree | Strongly Agree |
|---|---|---|---|---|---|---|---|
| I paid close attention to my partner. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner paid close attention to me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I was easily distracted from my partner when other things were going on. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner was easily distracted from me when other things were going on. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I tended to ignore my partner. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner tended to ignore me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I was sometimes influenced by my partner's moods. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner was sometimes influenced by my moods. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| When I was happy, my partner tended to be happy. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| When my partner was happy I tended to be happy. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| When I was feeling sad, my partner also seemed to be sad. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| When my partner was feeling sad, I tended to be sad. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Participant ID: Condition:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| When I was feeling nervous, my partner also seemed to be nervous. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| When my partner was nervous, I tended to be nervous. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I was able to communicate my intentions clearly to my partner. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner was able to communicate their intentions clearly to me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My thoughts were clear to my partner. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partners thoughts were clear to me. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I was able to understand what my partner meant. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner was able to understand what I meant. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My actions were often dependent on my partner actions. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner’s actions were often dependent on my actions. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My behaviour was often in direct response to my partner’s behaviour. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| My partner’s behaviour was often in direct response to my behaviour. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| What I did often affected what my partner did. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| What my partner did often affected what I did. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

### B.1.6 System Usability Scale

Participant ID: Condition:

## System Usability Scale

| | Strongly disagree | | | | Strongly agree |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1. I think that I would like to use this system frequently | | | | | |
| 2. I found the system unnecessarily complex | | | | | |
| 3. I thought the system was easy to use | | | | | |
| 4. I think that I would need the support of a technical person to be able to use this system | | | | | |
| 5. I found the various functions in this system were well integrated | | | | | |
| 6. I thought there was too much inconsistency in this system | | | | | |
| 7. I would imagine that most people would learn to use this system very quickly | | | | | |
| 8. I found the system very cumbersome to use | | | | | |
| 9. I felt very confident using the system | | | | | |
| 10. I needed to learn a lot of things before I could get going with this system | | | | | |

### B.1.7 Participant Information Sheet

# Study Information Sheet

**Study Title:** The effect of virtual reality control of a robotic surrogate on presence and social presence in comparison with telecommunications software.
**Date:** September 2019
**Contact Address:** Bethany Mackey, Bristol Robotics Laboratory, University of the West of England, Coldharbour Lane, Bristol, BS16 1QY.
**Email:** bethany.mackey@brl.ac.uk

Thank you for taking the time to consider participating in my research project. This information sheet tells you more about the nature of the project and explains how the data you supply to me will be used and the protections of your privacy and confidentiality that are in place. Feel free to ask questions about any part of the study, and what you are being asked to do.

## Who is doing the work?

Bethany Mackey, second year PhD student on the FARSCOPE CDT program, part of the Embodied Cognition for Human-Robot Interactions group, based at the Bristol Robotics Laboratory, University of the West of England.

## What is the project and study for?

This study is part of PhD research aiming to design a control system for a robotic surrogate. The study is concerned with comparing two types of computer-mediated communication between two users. One of these is virtual reality control for the head of a robotic surrogate and the other is telecommunications software, Skype.

## What will happen if I agree to take part?

You will first be asked to sign a consent form, then provide some basic demographic information. You will then be invited to inspect a Pepper robot and assigned one of the following conditions:

**Condition 1** - will see you either sitting at a table controlling the head movement of a Pepper robot via a HTC Vive virtual reality system or sitting at a table as a remote participant.

**Condition 2** - will see you sitting at a table hosting a skype call or sitting at a table as a remote participant.

You will take part in both conditions, where the remote participant will remain consistent. During each condition you will be asked to discuss a set of words and decide on a ranking order based on each item's appropriateness for a survival scenario. During the study you will be asked to fill in a number of questionnaires. Before you leave the room you will be debriefed. Throughout the study audio recordings will be taken to be assessed later. You may stop the study or withdraw any time until after leaving the room.

## Your rights

Your participation in this research is entirely voluntary and you are free to withdraw from the study at any point during the study or directly after taking part. When wearing the virtual reality headset, you may experience some mild motion sickness. Please let me know if you suffer from any conditions or injuries that may be affected by this study, such as Vertigo or Meniere's disease, so that I can assign you to the appropriate condition.

You are free to stop the study at any time should you feel uncomfortable. After you have left the room it will be no longer possible to withdraw as all data collected is anonymous and cannot be identified as yours at a later date.

**Protecting your confidentiality**

Your data, including the audio recordings, will be stored, analysed and presented anonymously as per university data protection regulations (http://www1.uwe.ac.uk/its/itpolicies/dataprotection.aspx) and the EPSRC research data policy (https://www.epsrc.ac.uk/about/standards/researchdata/). Specifically, data will be stored on a University PC hard drive, which is password protected. Only the researcher and their collaborators shall have access to the raw data collected during experiments. Anonymised data collected during the study will be used in academic outputs (e.g. publications and conferences) from the project.

If you have any questions about the ethical conduct of this research or are uncertain about any aspect of your participation please contact the project supervisor Dr Paul Bremner or the University's research ethics team (contacts given below).

Project Supervisor: Dr Paul Bremner Address: Bristol Robotics Laboratory, University of the West of England, Coldharbour Lane, Bristol, BS16 1QY Telephone: 0117 32 86336 Email: paul.bremner@brl.ac.uk

Ethics Contact: Research Ethics Admin Team Address: Research Administration, Northavon House, Frenchay Campus Bristol, BS16 1QY Telephone: 0117 32 81170 Email: researchethics@uwe.ac.uk

### B.1.8 Participant Demographics Questionnaire

Participant ID:

# Demographics Questionnaire

**Project Title:** The effect of virtual reality control of a robotic surrogate on presence and social presence in comparison with telecommunications software.

The information that you provide below will be anonymised and handled in accordance with data protection regulations. The information will be associated with a participant ID and not with any personal data.

**Please circle the most appropriate response:**

**Age range:**

18 – 24 / 25 – 34 / 35 – 44 / 45 – 54 / 55 – 64 / 65 – 74 / 75+ / Prefer not to say

**Gender:**

Male / Female / Other / Prefer not to say

**Previous experience with telecommunications software:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Previous experience with virtual reality:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Previous experience with robotics:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

### B.1.9 Participant Consent Form

UWE Bristol | University of the West of England

# Consent Form

**Study Title:** The effect of virtual reality control of a robotic surrogate on presence and social presence in comparison with telecommunications software.

**Please put your initials in the appropriate boxes:**

| | |
|---|---|
| I have read and understood the information sheet | |
| I have been given the opportunity to ask questions and have had my questions answered to my satisfaction | |
| I am aware that data collected, including audio recordings, will be anonymised, kept in accordance with the data protection act, and will be viewed and analysed by the research team as part of their studies. | |
| I am aware that I have the right to withdraw consent and discontinue participation before or during the study, up until the point that I leave the room. I understand it will not be possible to withdraw after that point as my data is anonymous and will no longer be identifiable. | |
| I have freely volunteered and am willing to participate in this study. | |
| I am willing to have my questionnaire responses collected. | |

Your first name and surname (Please use Block Capitals):

Your signature:

Date signed:

### B.1.10 Participant Debrief Sheet

# Study Debrief Sheet

**Study Title:** The effect of virtual reality control of a robotic surrogate on presence and social presence in comparison with telecommunications software.
**Date:** September 2019
**Contact Address:** Bethany Mackey, Bristol Robotics Laboratory, University of the West of England, Coldharbour Lane, Bristol, BS16 1QY.
**Email:** bethany.mackey@brl.ac.uk

Thank you for taking the time to participate in my research project. This debrief sheet provides some more information about the study for you to consider before giving final consent for us to use your data. Feel free to ask any questions.

## What were the aims of this study?

Further to the information sheet given at the beginning of this experiment, this study is concerned with designing an immersive control system for a robot surrogate. The study evaluated the presence, and social presence, felt when using the VR system and the telecommunication system. Presence typically refers to feelings of "being in an environment, even when one is physically situated in another" [1]. On the other hand, social presence can be broken into co-presence, which refers to the feeling of being in close proximity to another person, and psycho-behavioural accessibility, which measures "perception of attention, emotional contagion, and mutual understanding" with another person [2]. The time taken for discussion was also recorded. The results will be analysed and compared between the two conditions. The audio data will be used to assess non-verbal social and behavioural cues typically found in human interaction. It is hypothesised that the VR system will show greater feelings of both place and social presence.

## Final Consent

Now that you have completed the study and have been made aware of its full purpose and data collected, we would like to ask for final consent to use your data in our analysis of the study results. As previously stated, you are free to withdraw at any point before you leave the experimental room, so are free to withdraw at this point. Please also feel free to ask any questions you may have about the study or data collected.

## References

[1] Witmer, B. G., & Singer, M. J. (1998). *Measuring Presence in Virtual Environments: A Presence Questionnaire*. *Presence* (Vol. 7). Retrieved from https://nil.cs.uno.edu/publications/papers/witmer1998measuring.pdf

[2] Biocca, F., & Harms, C. (n.d.). *Guide to the Networked Minds Social Presence Inventory (Version 1.2): Measures of co-presence, social presence, subjective symmetry, and intersubjective symmetry*. Retrieved from http://cogprints.org/6743/1/2002_guide_netminds_measure.pdf

## B.2 User Study: Usability of an Immersive Control System for a Humanoid Robot Surrogate

This section of the appendix contains documentation used in the user study evaluating the usability of the teleoperation system. The documents listed are:

- Participant Information Sheet
- Participant Privacy Notice
- Participant Consent Form
- Participant Demographics Questionnaire
- System Usability Scale
- Semi-structured Interview
- Images for Task 1 for NAO and Pepper Conditions Respectively
- Table for Recording Performance for Task 1
- Table for Recording Performance for Task 2
- Sets of Interview Questions with Researcher Answers for Task 3
- Table for Recording Responses for Task 4

### B.2.1 Participant Information Sheet

# Study Information Sheet

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

PLEASE READ THIS SHEET IN ITS ENTIRETY

You are invited to take part in research taking place at the University of the West of England, Bristol. It is funded by the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following information carefully and if you have any queries or would like more information please contact Bethany Mackey, Faculty of Technology, Bristol Robotics Laboratory, University of the West of England, Bristol bethany.mackey@brl.ac.uk.

## Who is organising and funding the research?

The project lead is Bethany Mackey, final year PhD student on the FARSCOPE CDT program, part of the Embodied Cognition for Human-Robot Interactions (ECHOS) group, based at the Bristol Robotics Laboratory, University of the West of England. Paul Bremner and Manuel Giuliani are the supervisors for this PhD research. Please find their details at the end of this document.

## What is the aim of the research?

The research is looking at the usability of a system that has been developed as an immersive control system for two humanoid robots, Nao and Pepper. To help us answer these questions we will be comparing performance in tasks using the system with each robot and analysing recordings of concurrent think aloud feedback. The results of our study will be analysed and may be used in conference papers and peer-reviewed academic papers.

## Why have I been invited to take part?

We are recruiting participants who are already working in the Bristol Robotics Laboratory and are aware of the current risk and safety procedures due to COVID-19 restrictions. The purpose will be to assess the usability of the system and compare the appropriateness of the two humanoid robots.

## Do I have to take part?

You do not have to take part in this research. It is up to you to decide whether or not you want to be involved. If you do decide to take part, you will be given a copy of this information sheet to keep and will be asked to sign a consent form. If you do decide to take part, you are free to stop and withdraw from the study at any time without giving a reason. After you have left the room it will be no longer possible to withdraw as all data collected is anonymous and cannot be identified as yours at a later date. Deciding not to take part or to withdraw from the study does not have any penalty.

## What will happen to me if I take part and what do I have to do?

If you agree to take part you will be asked to select a time to participate via a doodle poll. This will be conducted by Bethany Mackey in the Bristol Robotics Laboratory. The team are all experienced in the subject matter and are sensitive to issues it may raise. The usability study will take approximately 60 minutes.

You will first be asked to sign a consent form, read a privacy notice, and provide some basic demographic information. You will be invited to look at both robots, Nao and Pepper, for as long as you would like and complete a questionnaire regarding your opinion of them. You will then be asked to complete several simple navigation and description tasks using each robot. Finally, you will be asked to perform a final task with your preferred robot at different camera resolutions and asked to complete a short interview. Audio recordings will be taken of the full study for later analysis and I will be taking notes throughout the study. All of your data and responses will be fully anonymised

The study will be broken into 3 main questions: control system usability, resolution/delay trade off, robot comparison. Data will be gathered using the following:

- ***Questionnaires***
  You will be asked to fill in a "Godspeed Questionnaire", which is designed to measure perception of a robot, and a "System Usability Questionnaire", which is designed to measure how usable a system is.
- ***Concurrent Think Aloud***
  You will be asked to describe your activity and what you are thinking as you carry it out.
- ***Task Performance***
  Whether a task is completed, how well a task is completed, and the time in which it took to complete will be noted.
- ***Semi-structured interview***
  The experimenter will ask you three open questions to collect subjective feedback. Any other comments can be made here. You have the option to answer as much or as little as you wish.

## What are the benefits of taking part?

This study is part of a large project which aims to develop a system that allows those experiencing social isolation to navigate outside of their homes and interact with loved ones; by taking part in this study you will be helping us to gain a better understanding of the usability of the developed system and highlight any further technical issues that need to be addressed. You will also receive a £10 Amazon voucher.

## What are the possible risks of taking part?

We do not foresee or anticipate any significant risk to you in taking part in this study. When wearing the virtual reality headset, you may experience some mild motion sickness. Please let me know if you suffer from any conditions or injuries that may be affected by this study, such as Vertigo or Meniere's disease. If you feel uncomfortable at any time you can ask for the study to stop. If you need any support during or after the study then the researchers will be able to put you in touch with suitable support agencies. The research team are experienced in conducting studies and are sensitive to the subject area. The usability study has been designed with these considerations in mind.

In addition to the normal risk assessments, care has been taken to ensure the experiment is COVID-19 safe. You and the experimenter will be required to wear a mask and sanitise hands before the study, and safe distancing will be observed. You will also be offered disposable gloves and the researcher will wear a new pair of disposable gloves for each participant. All surfaces will be disinfected before and after the study. All participants will be drawn from staff and students already complying with BRL COVID-19 safety rules.

## What will happen to your information?

All the information we receive from you will be treated in the strictest confidence. All the information that you give will be kept confidential and anonymised immediately after the completion of the study. Audio recordings will be transcribed and anonymised, after which the audio recording will be destroyed. Hard copy research material will be kept in a locked and secure setting to which only the researchers will have access in accordance with the University's and the Data Protection Act 2018 and General Data Protection Regulation (GDPR) requirements. Your anonymised data will be analysed together with other interview and file data, and we will ensure that there is no possibility of identification or re-identification from this point.

## Where will the results of the research study be published?

A Report will be written containing our research findings. This Report will be available on the University of the West of England's open-access Research Repository. The project funder is the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT, which requires all publications funded through them to be open access. Key findings will also be shared both within and outside the University of the West of England. Anonymous and non-identifying direct quotes may be used for publication and presentation purposes.

## Who has ethically approved this research?

The project has been reviewed and approved by University of the West of England University Research Ethics Committee. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England at: Researchethics@uwe.ac.uk

## What if something goes wrong?

If you have any questions about the ethical conduct of this research, have any complaints or concerns, or are uncertain about any aspect of your participation please contact the project supervisors or the University's research ethics committee.

**Project Supervisors:**
Dr Paul Bremner paul.bremner@brl.ac.uk
Professor Manuel Giuliani manuel.giuliani@brl.ac.uk

## What if I have more questions or do not understand something?

If you would like any further information about the research please contact in the first instance:

Bethany Mackey
Bristol Robotics Laboratory
University of the West of England, T Block, Frenchay Campus
Coldharbour Lane, Bristol, BS16 1QY.
bethany.mackey@brl.ac.uk

Thank you for agreeing to take part in this study.

You will be given a copy of this Participant Information Sheet and your signed Consent Form to keep.

### B.2.2 Participant Privacy Notice

# Privacy Notice

**Study Title**: Usability of an Immersive Control System for a Humanoid Robot Surrogate

## Purpose of the Privacy Notice

This privacy notice explains how the University of the West of England, Bristol (UWE) collects, manages and uses your personal data before, during and after you participate in this focus group. 'Personal data' means any information relating to an identified or identifiable natural person (the data subject). An 'identifiable natural person' is one who can be identified, directly or indirectly, including by reference to an identifier such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

This privacy notice adheres to the General Data Protection Regulation (GDPR) principle of transparency. This means it gives information about:

- How and why your data will be used for the research;
- What your rights are under GDPR; and
- How to contact UWE Bristol and the project lead in relation to questions, concerns or exercising your rights regarding the use of your personal data.

This Privacy Notice should be read in conjunction with the Participant Information Sheet and Consent Form provided to you before you agree to take part in the research.

## Why are we processing your personal data?

UWE Bristol undertakes research under its public function to provide research for the benefit of society. As a data controller we are committed to protecting the privacy and security of your personal data in accordance with the (EU) 2016/679 the General Data Protection Regulation (GDPR), the Data Protection Act 2018 (or any successor legislation) and any other legislation directly relating to privacy laws that apply (together "the Data Protection Legislation"). General information on Data Protection law is available from the Information Commissioner's Office (https://ico.org.uk/).

## How do we use your personal data?

We use your personal data for research with appropriate safeguards in place on the lawful bases of fulfilling tasks in the public interest, and for archiving purposes in the public interest, for scientific or historical research purposes.

We will always tell you about the information we wish to collect from you and how we will use it.

We will not use your personal data for automated decision making about you or for profiling purposes.

Our research is governed by robust policies and procedures and, where human participants are involved, is subject to ethical approval from either UWE Bristol's Faculty or University Research Ethics Committees. This research has been approved by UWE Bristol's Ethics Committee. The research team adhere to the **Ethical guidelines of the British Educational Research Association (and/or the principles of the Declaration of Helsinki, 2013) and the principles of the General Data Protection Regulation (GDPR).**

For more information about UWE Bristol's research ethics approval process please see our Research Ethics webpages at:
www1.uwe.ac.uk/research/researchethics

## What data do we collect?

The data we collect will vary from project to project. Researchers will only collect data that is essential for their project. The specific categories of personal data processed are described in the Participant Information Sheet provided to you with this Privacy Notice.

## Who do we share your data with?

We will only share your personal data in accordance with the attached Participant Information Sheet and your Consent.

## How do we keep your data secure?

We take a robust approach to protecting your information with secure electronic and physical storage areas for research data with controlled access. If you are participating in a particularly sensitive project UWE Bristol puts into place additional layers of security. UWE Bristol has Cyber Essentials information security certification.

Alongside these technical measures there are comprehensive and effective policies and processes in place to ensure that users and administrators of information are aware of their obligations and responsibilities for the data they have access to. By default, people are only granted access to the information they require to perform their duties. Mandatory data protection and information security training is provided to staff and expert advice available if needed.

## How long do we keep your data for?

Your personal data will only be retained for as long as is necessary to fulfil the cited purpose of the research. The length of time we keep your personal data will depend on several factors including the significance of the data, funder requirements, and the nature of the study. Specific details are provided in the attached Participant Information Sheet. Anonymised data that falls outside the scope of data protection legislation as it contains no identifying or identifiable information may be stored in UWE Bristol's research data archive or another carefully selected appropriate data archive.

## Your Rights and how to exercise them

Under the Data Protection legislation you have the following **qualified** rights:

(1) The right to access your personal data held by or on behalf of the University;
(2) The right to rectification if the information is inaccurate or incomplete;
(3) The right to restrict processing and/or erasure of your personal data;
(4) The right to data portability;
(5) The right to object to processing;
(6) The right to object to automated decision making and profiling;
(7) The right to complain to the Information Commissioner's Office (ICO).

**Please note, however, that some of these rights do not apply when the data is being used for research purposes if appropriate safeguards have been put in place**.

We will always respond to concerns or queries you may have. If you wish to exercise your rights or have any other general data protection queries, please contact UWE Bristol's Data Protection Officer (dataprotection@uwe.ac.uk).

If you have any complaints or queries relating to the research in which you are taking part please contact either the research project lead, whose details are in the attached Participant Information Sheet, UWE Bristol's Research Ethics Committees (research.ethics@uwe.ac.uk) or UWE Bristol's research governance manager (Ros.Rouse@uwe.ac.uk)

v.1: This Privacy Notice was issued in April 2019 and will be subject to regular review/update.

### B.2.3 Participant Consent Form

# Consent Form

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

This consent form will have been given to you with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet

If you are happy to take part in this study please sign and date the form. You will be given a copy to keep for your records.

**Please read the statements below and sign below to give consent:**

| |
|---|
| I have read and understood the information sheet |
| I have been given the opportunity to ask questions and have had my questions answered to my satisfaction. |
| I am aware that data collected, including audio recordings, will be anonymised, kept in accordance with General Data Protection Regulation (GDPR), and will be viewed and analysed by the research team as part of their studies. |
| I am aware that I have the right to withdraw consent and discontinue participation without penalty before or during the study, up until the point that I leave the room. I understand it will not be possible to withdraw after that point as my data is anonymous and will no longer be identifiable. |
| I have freely volunteered and am willing to participate in this study. |
| I am willing to have my questionnaire responses collected. |

Name (Printed)…………………………………………………………………….

Signature…………………………………………………. Date…………………….

### B.2.4 Participant Demographics Questionnaire

Participant ID:

# Demographics Questionnaire

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

The information that you provide below will be anonymised and handled in accordance with data protection regulations. The information will be associated with a participant ID and not with any personal data.

**Please circle the most appropriate response:**

**Age range:**

18 – 24 / 25 – 34 / 35 – 44 / 45 – 54 / 55 – 64 / 65 – 74 / 75+ / Prefer not to say

**Gender:**

Male / Female / Other / Prefer not to say

**Previous experience with virtual reality:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Previous experience with robotics:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

### B.2.5 System Usability Scale

Participant ID: Robot:

UWE Bristol | University of the West of England

## System Usability Scale

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

| | disagree | | | | agree |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1. I think that I would like to use this system frequently | | | | | |
| 2. I found the system unnecessarily complex | | | | | |
| 3. I thought the system was easy to use | | | | | |
| 4. I think that I would need the support of a technical person to be able to use this system | | | | | |
| 5. I found the various functions in this system were well integrated | | | | | |
| 6. I thought there was too much inconsistency in this system | | | | | |
| 7. I would imagine that most people would learn to use this system very quickly | | | | | |
| 8. I found the system very cumbersome to use | | | | | |
| 9. I felt very confident using the system | | | | | |
| 10. I needed to learn a lot of things before I could get going with this system | | | | | |

### B.2.6 Semi-structured Interview

Participant ID:

UWE Bristol | University of the West of England

## Semi-Structured Interview

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

1. **What features of the system do you like and dislike?**

2. **Which robot do you prefer to use overall out of Nao and Pepper? Please explain why.**

3. **At which resolution did the delay in responsiveness become too unusable?**

### B.2.7 Images for Task 1 for NAO and Pepper Conditions Respectively

1


2


3

4

5

6

7

4


1


2

5

7

3

6

### B.2.8 Table for Recording Performance for Task 1

**Scenario 1**

| | Pepper | Nao | Pepper | Nao | Pepper | Nao | Pepper | Nao |
|---|---|---|---|---|---|---|---|---|
| Participant ID | Time Taken | | No. Identified | | Correct No. | | Match? | |
| 1 | | | | | 7 | 5 | | |
| 2 | | | | | 7 | 5 | | |
| 3 | | | | | 7 | 5 | | |
| 4 | | | | | 7 | 5 | | |
| 5 | | | | | 7 | 5 | | |
| 6 | | | | | 7 | 5 | | |
| 7 | | | | | 7 | 5 | | |
| 8 | | | | | 7 | 5 | | |
| 9 | | | | | 7 | 5 | | |
| 10 | | | | | 7 | 5 | | |
| 11 | | | | | 7 | 5 | | |
| 12 | | | | | 7 | 5 | | |
| 13 | | | | | 7 | 5 | | |
| 14 | | | | | 7 | 5 | | |
| 15 | | | | | 7 | 5 | | |
| 16 | | | | | 7 | 5 | | |
| 17 | | | | | 7 | 5 | | |
| 18 | | | | | 7 | 5 | | |
| 19 | | | | | 7 | 5 | | |
| 20 | | | | | 7 | 5 | | |

**Scenario 1**

| | Pepper | Nao | Pepper | Nao | Pepper | Nao | Pepper | Nao |
|---|---|---|---|---|---|---|---|---|
| Participant ID | Time Taken | | No. Identified | | Correct No. | | Match? | |
| 21 | | | | | 7 | 5 | | |
| 22 | | | | | 7 | 5 | | |
| 23 | | | | | 7 | 5 | | |
| 24 | | | | | 7 | 5 | | |
| 25 | | | | | 7 | 5 | | |
| 26 | | | | | 7 | 5 | | |
| 27 | | | | | 7 | 5 | | |
| 28 | | | | | 7 | 5 | | |
| 29 | | | | | 7 | 5 | | |
| 30 | | | | | 7 | 5 | | |
| 31 | | | | | 7 | 5 | | |
| 32 | | | | | 7 | 5 | | |
| 33 | | | | | 7 | 5 | | |
| 34 | | | | | 7 | 5 | | |
| 35 | | | | | 7 | 5 | | |
| 36 | | | | | 7 | 5 | | |
| 37 | | | | | 7 | 5 | | |
| 38 | | | | | 7 | 5 | | |
| 39 | | | | | 7 | 5 | | |
| 40 | | | | | 7 | 5 | | |

### B.2.9 Table for Recording Performance for Task 2

**Scenario 2**

| | Pepper | Nao | Pepper | Nao |
|---|---|---|---|---|
| **Participant ID** | **Time Taken** | | **Distance From Goal** | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| 11 | | | | |
| 12 | | | | |
| 13 | | | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| 18 | | | | |
| 19 | | | | |
| 20 | | | | |

**Scenario 2**

| | Pepper | Nao | Pepper | Nao |
|---|---|---|---|---|
| **Participant ID** | **Time Taken** | | **Distance From Goal** | |
| 21 | | | | |
| 22 | | | | |
| 23 | | | | |
| 24 | | | | |
| 25 | | | | |
| 26 | | | | |
| 27 | | | | |
| 28 | | | | |
| 29 | | | | |
| 30 | | | | |
| 31 | | | | |
| 32 | | | | |
| 33 | | | | |
| 34 | | | | |
| 35 | | | | |
| 36 | | | | |
| 37 | | | | |
| 38 | | | | |
| 39 | | | | |
| 40 | | | | |

### B.2.10 Sets of Interview Questions with Researcher Answers for Task 3

Participant ID:

# Question Set A and Answers

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

1. **What fictional place would you most like to go?**
   I would love to go to Atlantica from the Little Mermaid, providing I could breathe under water. Or Wonderland.

2. **What skill would you like to master?**
   I'm currently learning to sew and would love to master how to make clothes and soft toys. My proudest creation so far is a Halloween Bulbasaur plush.

3. **What's your favourite drink?**
   I love a virgin Mojito, but only when it's full of Sugar!

4. **What pets did you have while you were growing up?**
   I had two dogs, a guinea pig, two Hamsters, a rabbit, and a tortoise who I still have, she's called Speedy and is about 15 years old.

5. **What's the farthest you've ever been from home?**
   I volunteered in South Africa, so that is probably the farthest.

Participant ID:

# Question Set B and Answers

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

1. **If you didn't have to sleep, what would you do with the extra time?**
   Sort out more of my house and spend more time sewing.

2. **What hobby would you get into if time and money weren't an issue?**
   I would love to learn to ice skate and horse ride, I used to do them as a child.

3. **When was the last time you climbed a tree?**
   In my early teens. I was on an adventure course and I got up and got stuck. One of the instructors had to get me back down so I haven't tried it since.

4. **Are you usually early or late?**
   I'm almost always late, it's a terrible habit of mine.

5. **What takes up too much of your time?**
   Washing my hair. I have fairly long, brightly coloured hair, so it requires a special routine that takes forever.

Participant ID:

# Question Set C and Answers

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

1. **Where is the most interesting place you've been?**
   I did lots of excursions in the Caribbean and have also toured around Auschwitz. I have also volunteered in South Africa, which was pretty eye-opening.

2. **What's the best way to start the day?**
   Getting up without having an alarm set and have coffee and cereal with my household before leisurely getting dressed for the day.

3. **How often do you play sports?**
   Almost never, but I love Swimming and I'm hoping to learn how to play Squash.

4. **What would be the most amazing adventure to go on?**
   I would love to go to Japan for a few weeks, and then go on to New Zealand to visit the Lord of the Rings exhibitions.

5. **What do you wish you knew more about?**
   I wish I understood space and politics better.

Participant ID:

# Question Set D and Answers

**Study Title:** Usability of an Immersive Control System for a Humanoid Robot Surrogate

1. **What are some small things that make your day better?**
   Putting on one of my favourite comfy jumpers, having time to read my book before bed, and having a cup of tea with a friend.

2. **Who's your go to band or artist when you can't decide on something to listen to?**
   I usually will stick Babymetal on if I just want music on in the background while I'm doing things. It always makes me feel so happy and energetic.

3. **What would be your ideal way to spend the weekend?**
   Go out for sushi and cocktails on Friday evening, then on Saturday have a wander round the shops, and have a night in with friends or family watching a movie with some pizza. On Sunday I like to play D&D and sort my house out.

4. **What's your favourite genre of book or movie?**
   My favourite books and movies are fantasy, but I love Psychological thriller movies too.

5. **What's something you like to do the old-fashioned way?**

### B.2.11 Table for Recording Responses for Task 2

**Scenario 4**

| | Combination 1 | | Combination 2 | | Combination 3 | | Combination 4 | |
|---|---|---|---|---|---|---|---|---|
| Participant ID | Resolution Score | Lag Score | Resolution Score | Lag Score | Resolution Score | Lag Score | Resolution Score | Lag Score |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |
| 14 | | | | | | | | |
| 15 | | | | | | | | |
| 16 | | | | | | | | |
| 17 | | | | | | | | |
| 18 | | | | | | | | |
| 19 | | | | | | | | |
| 20 | | | | | | | | |

**Scenario 4**

| | Combination 1 | | Combination 2 | | Combination 3 | | Combination 4 | |
|---|---|---|---|---|---|---|---|---|
| Participant ID | Resolution Score | Lag Score | Resolution Score | Lag Score | Resolution Score | Lag Score | Resolution Score | Lag Score |
| 21 | | | | | | | | |
| 22 | | | | | | | | |
| 23 | | | | | | | | |
| 24 | | | | | | | | |
| 25 | | | | | | | | |
| 26 | | | | | | | | |
| 27 | | | | | | | | |
| 28 | | | | | | | | |
| 29 | | | | | | | | |
| 30 | | | | | | | | |
| 31 | | | | | | | | |
| 32 | | | | | | | | |
| 33 | | | | | | | | |
| 34 | | | | | | | | |
| 35 | | | | | | | | |
| 36 | | | | | | | | |
| 37 | | | | | | | | |
| 38 | | | | | | | | |
| 39 | | | | | | | | |
| 40 | | | | | | | | |

# Appendix C

## Chapter 4: Deployment with an End User

Documents used in the case study and follow-up focus group detailed in Chapter 4 are listed below. This appendix is separated into two sections listed below:

- Case Study with an End User and Primary Interactant
- Follow-up Focus Group with Healthcare Professionals

## C.1 Case Study with an End User and Primary Interactant

This section of the appendix contains documentation used in the case study conducted with a potential end user and their partner - their primary interactant. It also contains a table with the full quantified data showing the breakdown of how many times each code was mentioned and the number of responses. The documents contained are:

- Participant Information Sheet
- Participant Privacy Notice
- Participant Demographics Questionnaire
- Participant Consent Form
- Session One - Initial Interview
- Session One - After System Demonstration Interview
- Session Three - Final Interview
- Breakdown of Total Number of Times each Code is Mentioned and Total Number of Responses

### C.1.1 Participant Information Sheet

## Study Information Sheet

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care.

**STUDY SUMMARY:**

**What am I looking at?**
This study looks at how robots and virtual reality can be used to tackle social isolation for people who cannot always get out and about in person, especially those living with a life limiting illness.

**What will you be doing?**
I am running a case study where you will be able to use the system for an hour per day for seven days. You do not have to have any prior experience with robots or virtual reality. Before and after each session there will be a short interview, with a longer interview at the end of the study. The sessions will be video and audio recorded and these recordings will be shared and discussed with staff at Prospect Hospice in a follow up focus group.

As Covid-19 is ongoing, I will wear appropriate PPE whilst in your home as well as sanitising all equipment prior to setting up.

You are able to withdraw at any time without giving a reason and without penalty. You are able to have a chaperone present should you wish.

**Where is it?**
The study will take place at your home and will take all the relevant precautions to be COVID safe.

**How long will it take?**
Each session will should last about an hour, but you can stop any time you want to. There will also be some setup time where the researcher will need access to your home.

**What's next?**
Please email me at bethany.mackey@brl.ac.uk if you would like any further information. Please find more detailed information about the study, what it involves, and myself below.

**FURTHER INFORMATION:**

You are invited to take part in research taking place at your home, as previously discussed. It is funded by the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following

V1 08/12/2021

information carefully and if you have any queries or would like more information please contact Bethany Mackey, Faculty of Technology, Bristol Robotics Laboratory, University of the West of England, Bristol bethany.mackey@brl.ac.uk.

## Who is organising and funding the research?

The project lead is Bethany Mackey, final year PhD student on the FARSCOPE CDT program, part of the Embodied Cognition for Human-Robot Interactions (ECHOS) group, based at the Bristol Robotics Laboratory, University of the West of England. Paul Bremner and Manuel Giuliani are the supervisors for this PhD research. Please find their details at the end of this document.

## What is the aim of the research?

The research is looking at developing an immersive control system for a robot surrogate for users in palliative care. To assist us in assessing the success of this system in providing natural social interaction, and also its usability, we will be conducting a case-study where you will have the chance to use the system to interact with your partner. A follow up focus group will be conducted with staff at Prospect Hospice where the session recordings will be shown and discussed. The results of our study will be analysed and may be used in conference papers and peer-reviewed academic papers.

## Do I have to take part?

You do not have to take part in this research. It is up to you to decide whether or not you want to be involved. If you do decide to take part, you will be given a copy of this information sheet to keep and will be asked to digitally sign a consent form. You are free to stop and withdraw from the study at any time without giving a reason. A week after the final session it will no longer be possible to withdraw as analysed data may be used in publication and PhD study. Deciding not to take part or to withdraw from the study does not have any penalty.

## What will happen to me if I take part and what do I have to do?

Each session will last approximately an hour and will take part once per day over seven days at previously discussed times.

You will first be asked to read a privacy notice, sign a consent form, and provide some basic demographic information at the beginning of the study. You will be invited to investigate the system for as long as you would like. Once you have given consent we will have a brief discussion about how the system works and given a demonstration. The system will then be sanitised. You will then be invited to use the system to interact with each other, where the patient with the life-limiting illness will use the headset, and the robot will be placed with their partner. The partner will also be shown how to safely manoeuvre the robot if required, when supervised by the researcher. At the beginning and end of each session a short interview will be conducted. A long interview will be conducted at the very end of the study. Video and audio recordings will be taken of each session and will be shared and discussed later with palliative care staff at the hospice during a focus group. The researcher will be taking notes throughout the study and all of your data and responses will be fully anonymised.

## What are the benefits of taking part?

By taking part in this study you will be helping us to gain a better understanding of the usability, effectiveness, and appropriateness of the developed system, highlight any further issues that need to be addressed, and any features that are deemed essential for the system to be successful during any future development.

## What are the possible risks of taking part?

We do not foresee or anticipate any significant risk to you in taking part in this study. If you feel uncomfortable at any time you can stop the study without giving a reason. If you need any support during or after the study then the researchers will be able to put you in touch with suitable support agencies. The research team are experienced in conducting studies and are sensitive to the subject area. The sessions have been designed with these considerations in mind.

There is a small risk when interacting with the moving robot, however, you will have full control of the robot and the robot itself is designed for safe human-robot interaction. The robot also has a built in distance that it will not pass to avoid any collisions. In addition, the researcher will be on hand to ensure minimised risk associated with the system and its use. Secondly, virtual reality headsets are known to potentially cause minor motion sickness, therefore this is possible. To combat this, the you will be reminded that you are able to remove the headset at any point should you feel uncomfortable.

As Covid-19 is ongoing, the researcher will also wear appropriate PPE whilst in your home as well as sanitising all equipment prior to setting up.

You are able to withdraw at any time without giving a reason and without penalty. You are able to have a chaperone present should you wish.

## What will happen to your information?

All the information we receive from you will be treated in the strictest confidence.
All the information that you give will be kept confidential and anonymised immediately after the completion of the study. Hard copy research material will be kept in a locked and secure setting to which only the researchers will have access in accordance with the University's and the Data Protection Act 2018 and General Data Protection Regulation (GDPR) requirements. We will ensure that there is no possibility of identification or re-identification from this point.

## Where will the results of the research study be published?

A Report will be written containing our research findings. This Report will be available on the University of the West of England's open-access Research Repository. The project funder is the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT, which requires all publications funded through them to be open access. Key findings will also be shared both within and outside the University of the West of England. Anonymous and non-identifying direct quotes may be used for publication and presentation purposes.

## Who has ethically approved this research?

The project has been reviewed and approved by University of the West of England University Research Ethics Committee. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England at: Researchethics@uwe.ac.uk

## What if something goes wrong?

If you have any questions about the ethical conduct of this research, have any complaints or concerns, or are uncertain about any aspect of your participation please contact the project supervisors or the University's research ethics committee.

**Project Supervisors:**
Dr Paul Bremner paul.bremner@brl.ac.uk
Professor Manuel Giuliani manuel.giuliani@brl.ac.uk

## What if I have more questions or do not understand something?

If you would like any further information about the research please contact in the first instance:

Bethany Mackey
Bristol Robotics Laboratory
University of the West of England, T Block, Frenchay Campus
Coldharbour Lane, Bristol, BS16 1QY.
bethany.mackey@brl.ac.uk

Thank you for agreeing to take part in this study.

You will be emailed a copy of this Participant Information Sheet and your signed Consent Form to keep.

### C.1.2 Participant Privacy Notice

# Privacy Notice

**Study Title**: Immersive Control of a Robot Surrogate for Users in Palliative Care.

## Purpose of the Privacy Notice

This privacy notice explains how the University of the West of England, Bristol (UWE) collects, manages and uses your personal data before, during and after you participate in this focus group. 'Personal data' means any information relating to an identified or identifiable natural person (the data subject). An 'identifiable natural person' is one who can be identified, directly or indirectly, including by reference to an identifier such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

This privacy notice adheres to the General Data Protection Regulation (GDPR) principle of transparency. This means it gives information about:

- How and why your data will be used for the research;
- What your rights are under GDPR; and
- How to contact UWE Bristol and the project lead in relation to questions, concerns or exercising your rights regarding the use of your personal data.

This Privacy Notice should be read in conjunction with the Participant Information Sheet and Consent Form provided to you before you agree to take part in the research.

## Why are we processing your personal data?

UWE Bristol undertakes research under its public function to provide research for the benefit of society. As a data controller we are committed to protecting the privacy and security of your personal data in accordance with the (EU) 2016/679 the General Data Protection Regulation (GDPR), the Data Protection Act 2018 (or any successor legislation) and any other legislation directly relating to privacy laws that apply (together "the Data Protection Legislation"). General information on Data Protection law is available from the Information Commissioner's Office (https://ico.org.uk/).

## How do we use your personal data?

We use your personal data for research with appropriate safeguards in place on the lawful bases of fulfilling tasks in the public interest, and for archiving purposes in the public interest, for scientific or historical research purposes.

We will always tell you about the information we wish to collect from you and how we will use it.

We will not use your personal data for automated decision making about you or for profiling purposes.

Our research is governed by robust policies and procedures and, where human participants are involved, is subject to ethical approval from either UWE Bristol's Faculty or University Research Ethics Committees. This research has been approved by UWE Bristol's Ethics Committee. The research team adhere to the **Ethical guidelines of the British Educational Research Association (and/or the principles of the Declaration of Helsinki, 2013) and the principles of the General Data Protection Regulation (GDPR).**

For more information about UWE Bristol's research ethics approval process please see our Research Ethics webpages at:
www1.uwe.ac.uk/research/researchethics

## What data do we collect?

The data we collect will vary from project to project. Researchers will only collect data that is essential for their project. The specific categories of personal data processed are described in the Participant Information Sheet provided to you with this Privacy Notice.

## Who do we share your data with?

We will only share your personal data in accordance with the attached Participant Information Sheet and your Consent.

## How do we keep your data secure?

We take a robust approach to protecting your information with secure electronic and physical storage areas for research data with controlled access. If you are participating in a particularly sensitive project UWE Bristol puts into place additional layers of security. UWE Bristol has Cyber Essentials information security certification.

Alongside these technical measures there are comprehensive and effective policies and processes in place to ensure that users and administrators of information are aware of their obligations and responsibilities for the data they have access to. By default, people are only granted access to the information they require to perform their duties. Mandatory data protection and information security training is provided to staff and expert advice available if needed.

## How long do we keep your data for?

Your personal data will only be retained for as long as is necessary to fulfil the cited purpose of the research and in accordance with UWE policies. The length of time we keep your personal data will depend on several factors including the significance of the data, funder requirements, and the nature of the study. Specific details are provided in the attached Participant Information Sheet. Anonymised data that falls outside the scope of data protection legislation as it contains no identifying or identifiable information may be stored in UWE Bristol's research data archive or another carefully selected appropriate data archive.

## Your Rights and how to exercise them

Under the Data Protection legislation you have the following **qualified** rights:

(1) The right to access your personal data held by or on behalf of the University;
(2) The right to rectification if the information is inaccurate or incomplete;
(3) The right to restrict processing and/or erasure of your personal data;
(4) The right to data portability;
(5) The right to object to processing;
(6) The right to object to automated decision making and profiling;
(7) The right to complain to the Information Commissioner's Office (ICO).

**Please note, however, that some of these rights do not apply when the data is being used for research purposes if appropriate safeguards have been put in place**.

We will always respond to concerns or queries you may have. If you wish to exercise your rights or have any other general data protection queries, please contact UWE Bristol's Data Protection Officer (dataprotection@uwe.ac.uk).

If you have any complaints or queries relating to the research in which you are taking part please contact either the research project lead, whose details are in the attached Participant Information Sheet, UWE Bristol's Research Ethics Committees (research.ethics@uwe.ac.uk) or UWE Bristol's research governance manager (Ros.Rouse@uwe.ac.uk)

v.1: This Privacy Notice was issued in April 2019 and will be subject to regular review/update.

### C.1.3 Participant Demographics Questionnaire

Participant ID:

# Demographics Questionnaire

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements.

The information that you provide below will be anonymised and handled in accordance with data protection regulations. The information will be associated with a participant ID and not with any personal data.

**Please circle the most appropriate response:**

**Age range:**

18 – 24 / 25 – 34 / 35 – 44 / 45 – 54 / 55 – 64 / 65 – 74 / 75+ / Prefer not to say

**Gender:**

Male / Female / Other / Prefer not to say

**Previous experience with virtual reality:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Previous experience with robotics:**

| None | | Moderate | | Extensive |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

V1 03/03/2020

### C.1.4 Participant Consent Form

# Consent Form

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care.

This consent form will have been given to you with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet

If you are happy to take part in this study please sign and date the form. You will be given a copy to keep for your records.

**Please read the statements below and sign below to give consent:**

| |
|---|
| I have read and understood the information sheet. |
| I have been given the opportunity to ask questions and have had my questions answered to my satisfaction. |
| I am aware that data collected, including video and audio recordings, will be anonymised, kept in accordance with General Data Protection Regulation (GDPR), and will be viewed and analysed by the research team as part of their studies. |
| I am aware that I have the right to withdraw consent and discontinue participation without penalty before or during the study, up until a week after the end of the study. I understand it will not be possible to withdraw after that point as my data may be used in publication. |
| I have freely volunteered and am willing to participate in this study. |
| I am willing to have any recordings shared with the staff taking part in the follow-up focus group. |

Name (Printed)…………………………………………………………………………….

Signature…………………………………………………. Date…………………….

V1 08/12/2021

### C.1.5 Session One - Initial Interview

Participant ID:

# Case Study: Initial Interview (11th April 2022)

**Study Title:** Immersive Control of a Humanoid Robot Surrogate for Users in Palliative Care

1. **What are your current feelings regarding the study?**

2. **What are your current feelings regarding the system itself?**

3. **Are you looking forward to anything in particular about the study or using the system?**

4. **Are you not looking forward to anything in particular about the study or using the system?**

5. **Do you think the system could be useful now or in the future?**

6. **Any other thoughts or comments?**

V1 09/04/2022

### C.1.6 Session One - After System Demonstration Interview

Participant ID:

# Case Study: After Session Interview (11th April 2022)

**Study Title:** Immersive Control of a Humanoid Robot Surrogate for Users in Palliative Care

1. **How are you feeling about the session now?**

2. **How would you describe your mood following the session?**

3. **Were there any features that you were pleased/disappointed with?**

4. **Any other thoughts or comments?**

V1 28/03/2022

### C.1.7 Session Three - Final Interview

Participant ID:

# Case Study: Final Interviews (21st April 2022)

**Study Title:** Immersive Control of a Humanoid Robot Surrogate for Users in Palliative Care

**USABILITY (Researcher speaking to P1 via system)**

1. **Is the headset comfortable?**

2. **How long do you think you could wear it for comfortably?**

3. **What, if anything, would improve the comfort of the system?**

4. **Do you find the system intuitive to use?**

5. **What would make the system easier to use?**

V2 21/04/2022

Participant ID:

6. **How do you find interacting one on one using the system?**

7. **What, if any, technological changes or adjustments would you make to the system to improve usability?**

8. **Do you feel that the system is usable in its current development phase?**

9. **How are you feeling physically and emotionally following this section?**

10. **Any other thoughts or comments?**

**5 MINUTE GROUP INTERACTION/CONVERSATION (Researcher plus colleague, P2, and P1 using system)**

V2 21/04/2022

Participant ID:

**<u>INTERVIEW P1 AND P2 (in-person)</u>**

1. **How have you found having the system/equipment in your home?**

2. **Have your feelings or comfort with it changed seeing it every day?**

3. **What adjustments, if any, could be made to increase your comfort and the convenience of having the equipment at home?**

4. **What are your current feelings regarding the overall study, how do you feel it went?**

5. **What are your current feelings regarding the system itself specifically?**

6. **Did the system live up to or exceed your expectations in anyway?**

V2 21/04/2022

Participant ID:

7. **Was there anything that disappointed you about the system or study?**

8. **Are there any features you particularly like or dislike?**

9. **What, if any, changes/adjustments would you make to improve the system as a whole?**

10. **Do you think the system could be useful now or in the future?**

11. **Would you use the system by choice if it were available?**

12. **Did you feel there was a difference between one-to-one interaction and group interaction while using the system? Is one “better” than the other?**

V2 21/04/2022

Participant ID:

**13. Do you feel that being able to see loved ones in another location is beneficial?**

**14. Do you think such a system could improve social isolation?**

**15. Do you think such a system could have an impact on quality of life?**

**16. Do you feel, in your opinion, that it is worth continuing to develop the system further, and if so, what should be the next development focus?**

**17. Any other thoughts or comments?**

**VERBAL DEBRIEF AND FINAL CONSENT**

V2 21/04/2022

### C.1.8 Breakdown of Total Number of Times each Code is Mentioned and Total Number of Responses

| Theme | | Individual Differences and Emotions | | | | | | Technical Considerations | | | Presence and Social Interactions | | | | Number of Responses |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Time/Code** | **P** | Use | ID | Fear | Hope | Uncertainty | Generation | Tech Concerns | Existing Tech | Future | Place Pos. | Place Neg. | Social Pos. | Social Neg. | |
| Session One (Initial) | P1 | 0 | 0 | 1 | 1 | 3 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 8 |
| | P2 | 0 | 0 | 4 | 2 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 9 |
| **Total for Session One (Initial)** | | 0 | 0 | 5 | 3 | 5 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 17 |
| Session One (After) | P1 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 7 |
| | P2 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 5 |
| **Total for Session One (After)** | | 0 | 0 | 2 | 5 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 1 | 12 |
| Session Two | P1 | 0 | 0 | 4 | 1 | 2 | 0 | 3 | 3 | 0 | 1 | 0 | 0 | 0 | 14 |
| | P2 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Session Three (Usability) | P1 | 0 | 0 | 3 | 15 | 3 | 3 | 6 | 1 | 3 | 2 | 0 | 6 | 2 | 44 |
| | P2 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Session Three | P1 | 3 | 3 | 1 | 5 | 10 | 6 | 10 | 6 | 3 | 3 | 1 | 7 | 1 | 59 |
| | P2 | 1 | 0 | 3 | 2 | 3 | 0 | 1 | 0 | 0 | 1 | 0 | 2 | 1 | 14 |
| **Total for Session Three (ex. Usability)** | | 4 | 3 | 4 | 7 | 13 | 6 | 11 | 6 | 3 | 4 | 1 | 9 | 2 | 73 |
| **Total for Session Three** | | 4 | 3 | 7 | 22 | 16 | 9 | 17 | 7 | 6 | 6 | 1 | 15 | 4 | 117 |
| Follow-up Focus Group | P3 | 0 | 7 | 1 | 2 | 1 | 4 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 20 |
| | P4 | 0 | 4 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| | P5 | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 10 |
| | P6 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 4 |
| **Total for Focus Group** | | 0 | 13 | 2 | 5 | 1 | 8 | 3 | 3 | 0 | 2 | 0 | 3 | 1 | 41 |
| **Total number of times mentioned overall** | | 4 | 16 | 20 | 36 | 24 | 17 | 27 | 13 | 8 | 10 | 1 | 19 | 6 | 201 |

## C.2 Follow-up Focus Group with Healthcare Professionals

This section of the appendix contains documentation used in the follow-up focus group conducted with healthcare professionals working in palliative car. The participants also took part in the focus groups described in Chapter 2. This focus group aimed to assess the generalisability of findings from the case study to other patients with life-limiting illnesses. The documents contained are:

- Participant Information Sheet
- Participant Privacy Notice
- Participant Consent Form
- Follow-Up Focus Group Interview Questions

### C.2.1 Participant Information Sheet

# Study Information Sheet

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care.

## STUDY SUMMARY:

### What am I looking at?
This study looks at how robots and virtual reality can be used to tackle social isolation for people who cannot always get out and about in person, especially those living with a life limiting illness.

### What will you be doing?
I am running a focus group following an in-depth case study with a patient and their partner. During the focus group you will be shown video and audio recordings taking during the case study. We will discuss the behaviour of the patient and their partner. There will be some semi-structured interview questions. You do not have to have any prior experience with robots or virtual reality.

### Who can participate?
Healthcare professionals from Prospect Hospice who have taken part in previous focus groups with the researcher.

### Where is it?
The focus groups will take place online using Microsoft Teams to ensure the groups are Covid safe.

### How long will it take?
Each focus group should last about an hour, but you can stop any time you want to.

### What's next?
Please email me at bethany.mackey@brl.ac.uk if you would like any further information, or to arrange a time to join a focus group. Please find more detailed information about the study, what it involves, and myself below.

## FURTHER INFORMATION:

You are invited to take part in research taking place online. It is funded by the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following information carefully and if you have any

V3 19/01/2020

queries or would like more information please contact Bethany Mackey, Faculty of Technology, Bristol Robotics Laboratory, University of the West of England, Bristol bethany.mackey@brl.ac.uk.

## Who is organising and funding the research?

The project lead is Bethany Mackey, final year PhD student on the FARSCOPE CDT program, part of the Embodied Cognition for Human-Robot Interactions (ECHOS) group, based at the Bristol Robotics Laboratory, University of the West of England. Paul Bremner and Manuel Giuliani are the supervisors for this PhD research. Please find their details at the end of this document.

## What is the aim of the research?

The research is looking at developing an immersive control system for a robot surrogate for users in palliative care. To assist us in assessing the behaviour and interactions of a patient with a life-limiting illness using the system and their partner, we will show you several recordings of a previously run case-study and ask you to discuss them. We have the patient and their partners permission to show you these recordings. The results of our study will be analysed and may be used in conference papers, peer-reviewed academic papers, and a PhD research thesis.

## Do I have to take part?

You do not have to take part in this research. It is up to you to decide whether or not you want to be involved. If you do decide to take part, you will be given a copy of this information sheet to keep and will be asked to sign a consent form. You are free to stop and withdraw from the study at any time without giving a reason. After you have left the group it will no longer be possible to withdraw as all data collected is anonymous and cannot be identified as yours at a later date. Deciding not to take part or to withdraw from the study does not have any penalty.

## What will happen to me if I take part and what do I have to do?

The focus group will take approximately 60 minutes.

You will first be asked to read a privacy notice, sign a consent form, and provide some basic demographic information. You will be shown recordings of the case-study and asked to discuss them. The researcher will be taking notes throughout the study. All of your data and responses will be fully anonymised.

Data will be gathered using the following:

- ***Semi-structured focus group questions***
  The experimenter will ask you open questions to collect subjective feedback. Any other comments can be made here. You have the option to answer as much or as little as you wish.

## What are the benefits of taking part?

By taking part in this study you will be helping us to gain a better understanding of the usability, effectiveness, and appropriateness of the developed system, highlight any further issues that need to be addressed, and any features that are deemed essential for the system to be successful.

## What are the possible risks of taking part?

We do not foresee or anticipate any significant risk to you in taking part in this study. If you feel uncomfortable at any time you can stop the study without giving a reason. If you need any support during or after the study then the researchers will be able to put you in touch with suitable support agencies. The research team are experienced in conducting studies and are sensitive to the subject area. The focus group has been designed with these considerations in mind.

## What will happen to your information?

All the information we receive from you will be treated in the strictest confidence.
All the information that you give will be kept confidential and anonymised immediately after the completion of the study. Recordings will be transcribed and anonymised, after which they will be destroyed. Hard copy research material will be kept in a locked and secure setting to which only the researchers will have access in accordance with the University's and the Data Protection Act 2018 and General Data Protection Regulation (GDPR) requirements. Your anonymised data will be analysed together with other interview and file data, and we will ensure that there is no possibility of identification or re-identification from this point.

## Where will the results of the research study be published?

A Report will be written containing our research findings. This Report will be available on the University of the West of England's open-access Research Repository. The project funder is the Engineering and Physical Sciences Research Council (EPSRC) funded FARSCOPE CDT, which requires all publications funded through them to be open access. Key findings will also be shared both within and outside the University of the West of England. Anonymous and non-identifying direct quotes may be used for publication and presentation purposes.

## Who has ethically approved this research?

The project has been reviewed and approved by University of the West of England University Research Ethics Committee. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England at: Researchethics@uwe.ac.uk

## What if something goes wrong?

If you have any questions about the ethical conduct of this research, have any complaints or concerns, or are uncertain about any aspect of your participation please contact the project supervisors or the University's research ethics committee.

**Project Supervisors:**
Dr Paul Bremner paul.bremner@brl.ac.uk
Professor Manuel Giuliani manuel.giuliani@brl.ac.uk

## What if I have more questions or do not understand something?

If you would like any further information about the research please contact in the first instance:

Bethany Mackey
Bristol Robotics Laboratory
University of the West of England, T Block, Frenchay Campus
Coldharbour Lane, Bristol, BS16 1QY.
bethany.mackey@brl.ac.uk

Thank you for agreeing to take part in this study.

You will be emailed a copy of this Participant Information Sheet and your signed Consent Form to keep.

### C.2.2 Participant Privacy Notice

# Privacy Notice

**Study Title**: Immersive Control of a Robot Surrogate for Users in Palliative Care.

## Purpose of the Privacy Notice

This privacy notice explains how the University of the West of England, Bristol (UWE) collects, manages and uses your personal data before, during and after you participate in this focus group. 'Personal data' means any information relating to an identified or identifiable natural person (the data subject). An 'identifiable natural person' is one who can be identified, directly or indirectly, including by reference to an identifier such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

This privacy notice adheres to the General Data Protection Regulation (GDPR) principle of transparency. This means it gives information about:

- How and why your data will be used for the research;
- What your rights are under GDPR; and
- How to contact UWE Bristol and the project lead in relation to questions, concerns or exercising your rights regarding the use of your personal data.

This Privacy Notice should be read in conjunction with the Participant Information Sheet and Consent Form provided to you before you agree to take part in the research.

## Why are we processing your personal data?

UWE Bristol undertakes research under its public function to provide research for the benefit of society. As a data controller we are committed to protecting the privacy and security of your personal data in accordance with the (EU) 2016/679 the General Data Protection Regulation (GDPR), the Data Protection Act 2018 (or any successor legislation) and any other legislation directly relating to privacy laws that apply (together "the Data Protection Legislation"). General information on Data Protection law is available from the Information Commissioner's Office (https://ico.org.uk/).

## How do we use your personal data?

We use your personal data for research with appropriate safeguards in place on the lawful bases of fulfilling tasks in the public interest, and for archiving purposes in the public interest, for scientific or historical research purposes.

We will always tell you about the information we wish to collect from you and how we will use it.

We will not use your personal data for automated decision making about you or for profiling purposes.

Our research is governed by robust policies and procedures and, where human participants are involved, is subject to ethical approval from either UWE Bristol's Faculty or University Research Ethics Committees. This research has been approved by UWE Bristol's Ethics Committee. The research team adhere to the **Ethical guidelines of the British Educational Research Association (and/or the principles of the Declaration of Helsinki, 2013) and the principles of the General Data Protection Regulation (GDPR).**

For more information about UWE Bristol's research ethics approval process please see our Research Ethics webpages at:
www1.uwe.ac.uk/research/researchethics

## What data do we collect?

The data we collect will vary from project to project. Researchers will only collect data that is essential for their project. The specific categories of personal data processed are described in the Participant Information Sheet provided to you with this Privacy Notice.

## Who do we share your data with?

We will only share your personal data in accordance with the attached Participant Information Sheet and your Consent.

## How do we keep your data secure?

We take a robust approach to protecting your information with secure electronic and physical storage areas for research data with controlled access. If you are participating in a particularly sensitive project UWE Bristol puts into place additional layers of security. UWE Bristol has Cyber Essentials information security certification.

Alongside these technical measures there are comprehensive and effective policies and processes in place to ensure that users and administrators of information are aware of their obligations and responsibilities for the data they have access to. By default, people are only granted access to the information they require to perform their duties. Mandatory data protection and information security training is provided to staff and expert advice available if needed.

## How long do we keep your data for?

Your personal data will only be retained for as long as is necessary to fulfil the cited purpose of the research and in accordance with UWE policies. The length of time we keep your personal data will depend on several factors including the significance of the data, funder requirements, and the nature of the study. Specific details are provided in the attached Participant Information Sheet. Anonymised data that falls outside the scope of data protection legislation as it contains no identifying or identifiable information may be stored in UWE Bristol's research data archive or another carefully selected appropriate data archive.

## Your Rights and how to exercise them

Under the Data Protection legislation you have the following **qualified** rights:

(1) The right to access your personal data held by or on behalf of the University;
(2) The right to rectification if the information is inaccurate or incomplete;
(3) The right to restrict processing and/or erasure of your personal data;
(4) The right to data portability;
(5) The right to object to processing;
(6) The right to object to automated decision making and profiling;
(7) The right to complain to the Information Commissioner's Office (ICO).

**Please note, however, that some of these rights do not apply when the data is being used for research purposes if appropriate safeguards have been put in place**.

We will always respond to concerns or queries you may have. If you wish to exercise your rights or have any other general data protection queries, please contact UWE Bristol's Data Protection Officer (dataprotection@uwe.ac.uk).

If you have any complaints or queries relating to the research in which you are taking part please contact either the research project lead, whose details are in the attached Participant Information Sheet, UWE Bristol's Research Ethics Committees (research.ethics@uwe.ac.uk) or UWE Bristol's research governance manager (Ros.Rouse@uwe.ac.uk)

v.1: This Privacy Notice was issued in April 2019 and will be subject to regular review/update.

### C.2.3 Participant Consent Form

# Consent Form

**Study Title:** Immersive Control of a Robot Surrogate for Users in Palliative Care: Identifying User Requirements.

This consent form will have been given to you with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet

If you are happy to take part in this study please sign and date the form. You will be given a copy to keep for your records.

**Please read the statements below and sign below to give consent:**

| |
|---|
| I have read and understood the information sheet |
| I have been given the opportunity to ask questions and have had my questions answered to my satisfaction. |
| I am aware that data collected, will be anonymised, kept in accordance with General Data Protection Regulation (GDPR), and will be viewed and analysed by the research team as part of their studies. |
| I am aware that I have the right to withdraw consent and discontinue participation without penalty before or during the study, up until the point that I finally leave the focus group. I understand it will not be possible to withdraw after that point as my data is anonymised and will no longer be identifiable. |
| I have freely volunteered and am willing to participate in this study. |
| I am willing to have my questionnaire responses collected. |

Name (Printed)………………………………………………………………………….

Signature…………………………………………………… Date…………………….

V1 08/12/2021

### C.2.4 Follow-Up Focus Group Interview Questions

Participant ID:

# Case Study: Follow-up Focus Group (4th May 2022)

**Study Title:** Immersive Control of a Humanoid Robot Surrogate for Users in Palliative Care

**Semi-structured Interview**

1. **P2 generally strongly disliked technology, would that be the same for the majority of patients?**

2. **P1 has deteriorated since arranging the original focus group and sleeps more often, does that affect the usefulness of the system?**

3. **There is a disjoint between robots to perform tasks and robots to talk through. Please discuss.**

4. **The participants questioned the need for the robot. What are your thoughts on having no Head-mounted display but with a robot? Does the robot make the system?**

V1 28/03/2022

Participant ID:

5. **What about a non-humanoid robot? Does it need to use limbs to be worth it?**

6. **The participants discussed not being able to see the end user and a lack of visual social cues, the example given was being able to tell a lie from body language. Please discuss.**

7. **Is there anything that patients frequently say they miss or wish they could do?**

8. **Could the system work to improve this if they can't do it in person?**

9. **P1 mentioned children would be better for the system, do you agree? Should the system be targeted towards parents with life-limiting illnesses?**

10. **P1 regretted asking for movement capabilities to be removed. Please discuss.**

11. **The system could be tailored to individuals or more general for use in hospice. Please discuss.**

Participant ID:

12. **Some technology has advanced since starting development of the system, does this override any need for it?**

13. **The participants were overwhelmed by the amount of equipment, could this be tackled by managing expectations?**

14. **Any other thoughts or comments?**

**Verbal Debrief and consent**

V1 28/03/2022

# Appendix D

# Publications

This appendix contains copies of the following publications resulting from the work conducted in Chapter 3, the citations for which are:

- Bethany Ann Mackey, Paul A. Bremner, and Manuel Giuliani. 2020. The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20). Association for Computing Machinery, New York, NY, USA, 349–351. DOI:https://doi.org/10.1145/3371382.3378268

- Bethany Ann Mackey, Paul A. Bremner, and Manuel Giuliani. 2020. Immersive Control of a Robot Surrogate for Users in Palliative Care. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20). Association for Computing Machinery, New York, NY, USA, 585–587. DOI:https://doi.org/10.1145/3371382.3377445

- B. Mackey, P. Bremner and M. Giuliani, "Usability of an Immersive Control System for a Humanoid Robot Surrogate," *2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, Napoli, Italy, 2022, pp. 678-685, doi: 10.1109/RO-MAN53752.2022.9900587

# D.1 The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software (Chapter 3)

## The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software

Bethany Ann Mackey
bethany.mackey@brl.ac.uk
Bristol Robotics Laboratory, Bristol

Paul A Bremner
paul.bremner@brl.ac.uk
University of the West of England, Bristol

Manuel Giuliani
manuel.giuliani@uwe.ac.uk
University of the West of England, Bristol

### ABSTRACT

Telecommunication software is often used to tackle social isolation in those with restricted mobility, but lacks high-level interactions found in face-to-face conversation. This study investigated the use of an immersive control system for a robotic surrogate when compared to Skype. There was no significant difference between the presence and social presence felt between the two systems; however, Skype was found to be significantly easier to use. Future work will focus on identifying user requirements and further developing the control system.

### CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *User studies.*

### KEYWORDS

virtual reality, presence, social presence, robotic surrogate, telecommunications, human-robot interaction

**ACM Reference Format:**
Bethany Ann Mackey, Paul A Bremner, and Manuel Giuliani. 2020. The Effect of Virtual Reality Control of a Robotic Surrogate on Presence and Social Presence in Comparison to Telecommunications Software. In *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20 Companion), March 23–26, 2020, Cambridge, United Kingdom.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3371382.3378268

### 1 INTRODUCTION

Social isolation can have a detrimental effect on the mental health of those with restricted mobility. Thakur and Blazer [18] found that 35% of long-term care residents experience "clinically significant depressive symptoms" and Kissane et al. [11] found that palliative care patients may experience helplessness, demoralisation, and suicidal thoughts; Marie Curie [12] suggests meeting with people or visiting significant places "if physically able to" to tackle this. This research aims to design and implement an immersive control system that would allow the user to feel present in a remote location using telepresence, while also socially interacting with their loved ones, despite not being able to physically travel to that location.

Telepresence by definition is "the use of virtual reality (VR) technology to create the effect of being at a different or imaginary location" [8]; where VR refers to the use of a head-mounted display (HMD) system to become immersed in a virtual environment [2] [1]. This concept of "being in one place or environment, even when one is physically situated in another" is known as place presence [20]. Social presence, on the other hand, was described as "being together with another" [6], where it is possible to access the psychological, emotional, and intentional states of the other person [4]. High levels of both are required for a successful telepresence system.

Research investigating robots as a means of tackling isolation usually involve a companion robot [9][17][3], but there is a lack of research into methods of bringing people with restricted mobility closer to their loved ones. Current telecommunications software lacks the high-level interactions found in face-to-face communication required for social presence [10], and there is a need for a more immersive means of communicating, that will allow for increased social presence and higher quality interactions.

### 2 MAIN STUDY

#### 2.1 Aims and Objectives

This study aimed to design and implement a head-mounted display (HMD) based virtual reality (VR) control system for humanoid, social robot Pepper acting as a surrogate; and investigate the effect the system had on feelings of place presence and social presence, in comparison to telecommunications software Skype [13]. With this in mind, these research questions had been identified:

(1) Can VR be used to create an immersive control system that allows the user to feel present in a remote location?
(2) Can the system create effective, natural, social presence between the user and others interacting with them?

#### 2.2 Experimental Design

A StereoLabs Zed camera was attached to the head of a Pepper robot [16], and the video feed streamed into a HTC Vive HMD [19] using Unity, allowing the user to see into the next room. The Pepper robot's head mimicked the movement of the HMD, allowing the other participant to follow the user's gaze.

A total of 13 pairs of healthy participants (19 male and 7 female) took part in the study, where 73% of participants were aged 25-34. The participants had varying degrees of experience in virtual reality, robotics, and telecommunications software, and were awarded a £10 Amazon voucher for participation.

The within-subject study consisted of two conditions: the HMD condition and the Skype condition. Each trial had a local and a


ACM ISBN 978-1-4503-7057-8/20/03.
https://doi.org/10.1145/3371382.3378268

remote participant. The local participant was required to use the HMD to control Pepper's head movement (the HMD condition (Figure 1)) and also take part in a Skype call with the remote participant (the Skype condition). The remote participant was asked to sit at a table across from the Pepper robot in a separate room and later take part in the Skype call. Participants took part in both conditions, but the remote participant remained consistent.

**Figure 1: HMD Condition**

While in separate rooms, participants completed a joint task ranking 5 words in order of importance to a survival scenario, where the scenario changed between conditions (a desert island [14] and a crash landing on the moon [15]).

Following each condition, the local participants were asked to complete a questionnaire to measure place presence (Witmer and Singer's Presence Questionnaire [20]) and a System Usability Questionnaire [7]. Both participants completed the Networked Minds Social Presence Inventory [5] to measure social presence.

It was hypothesised that the HMD condition would produce higher feelings of place and social presence, but lower system usability scores. Therefore, the null hypothesis was that there would be no difference in the scores produced by the two systems.

## 2.3 Results

A number of two-tailed Paired-Samples T-tests were conducted using SPSS, to analyse the questionnaire responses. The results showed no significant difference for place or social presence felt by those using the HMD system, or those interacting with them, when compared to Skype; therefore the null hypothesis could not be rejected. However, as hypothesised, Skype scored significantly higher for system usability ($t = -2.846$, $df = 25$, $p < 0.05$).

While the results did not hold statistical significance, there was a trend in the data that showed slightly higher place ($M = 4.73$, $SD = 0.70$) and social ($M = 5.10$, $SD = 0.52$) presence for the HMD condition than the place ($M = 4.43$, $SD = 0.43$) and social ($M = 4.86$, $SD = 0.51$) presence for the Skype condition; this was further expressed by verbal feedback from the participants following the study trials.

## 2.4 Discussion

The aim of this study was to investigate the effect that the HMD based system had on place and social presence in comparison to Skype. This is part of a larger objective to design and implement an effective immersive control system for a robotic surrogate, with an aim to reduce feelings of isolation in those with restricted mobility, who may otherwise struggle to go outside and interact with others. Additionally, the system could allow users to be able to visit meaningful places, and take part in experiences that they would not ordinarily be able to do.

As expected Skype was found to be significantly easier to use than the HMD system. However, the null hypothesis could not be rejected, despite some anecdotal feedback from participants expressing higher feelings of presence for the HMD condition, and a slight trend in the data in that direction. It is possible that the subtle effect shown could have been statistically significant had the study been conducted with a larger sample.

Another consideration is the familiarity of Skype, which has been consistently improved since its release in 2003; by comparison, virtual reality (VR) is a relatively new technology that still has limited functionality, and room for improvement. The primitive nature of VR technology was evident during the study, as the participants using the HMD based system had limited physical movement, suffered minor latency in the movement of the robot's head and camera, and commented on slight levels of discomfort caused by the head mounted display.

Furthermore, considering aspects of social presence refer to accessing another's emotional state, it may be necessary to reconsider the task used during the study; as it may have been naive to assume a purely logical discussion task would elicit an emotional response.

Having seen a small, albeit non-significant, effect, further research must be conducted, in order to confirm the trend in data. It should also be noted that the participants consisted of university employees and students, with prior experience of the technologies used, who do not have restricted mobility. Therefore, it is not possible to generalise the findings, and it is imperative that user requirements are identified by intended users going forwards.

# 3 FUTURE WORK

Future work will focus on patients in palliative care as target users, who may not have full mobility, but have the full use of the top of their body. Three focus groups will be run with patients, families, and healthcare professionals. The groups will be presented with system prototypes to assess the appropriateness of the technology for the intended usage, whether HMD based control can be used, and what features are required. These focus groups will identify requirements for a system that would be usable and wanted by the users; the scope of the project will then be narrowed down to focus on some of these requirements.

Later development will focus on implementing semi-autonomous body language that reflects the user's personality and mood, while remaining appropriate for the user's environment. Social signal processing will also be implemented in order to ensure that the user is receiving accurate and useful information. Whether surrogate mobility or a humanoid robot is necessary will also be explored. Finally, large-scale case studies will be conducted, where users will be able to use the surrogate. Interviews with users, families, and professionals, will assess whether the system has fully met the identified user requirements.

The development of the system is likely to adapt as requirements are identified. Ultimately, the system must be effective in allowing palliative care patients to interact as naturally as possible with their loved ones from a remote location, and navigate appropriately, in order to improve their quality of life.

## REFERENCES


[1] [n. d.]. Interactivity Element - Virtual Reality Society. https://www.vrs.org.uk/virtual-reality/interactivity-element.html

[2] [n. d.]. What is Virtual Reality? - Virtual Reality Society. https://www.vrs.org.uk/virtual-reality/what-is-virtual-reality.html

[3] BBC News. 2018. 'Robodog' helping people with dementia - BBC News. http://www.bbc.co.uk/news/av/uk-england-dorset-43479791/robotic-dog-in-dorset-care-home-helps-elderly-residents

[4] Frank Biocca and Chad Harms. 2002. (PDF) Defining and measuring social presence: Contribution to the networked minds theory and measure.

[5] Frank Biocca and Chad Harms. 2003. *Guide to the Networked Minds Social Presence Inventory (Version 1.2): Measures of co-presence, social presence, subjective symmetry, and intersubjective symmetry.* Technical Report. http://cogprints.org/6743/1/2002{_}guide{_}netminds{_}measure.pdf

[6] Frank Biocca, Chad Harms, and Jenn Gregg. 2001. The Networked Minds Measure of Social Presence : Pilot Test of the Factor Structure and Concurrent Validity. https://www.semanticscholar.org/paper/The-Networked-Minds-Measure-of-Social-Presence-{%}3A-of-Biocca-Harms/784977a00148ea24e1a65e6160823305a2ceb95c

[7] John Brooke. [n. d.]. SUS -A quick and dirty usability scale Usability and context. ([n. d.]). https://hell.meiert.org/core/pdf/sus.pdf

[8] Collins. [n. d.]. Telepresence definition and meaning | Collins English Dictionary. https://www.collinsdictionary.com/dictionary/english/telepresence

[9] D. Feil-Seifer and M.J. Mataric. [n. d.]. Socially Assistive Robotics. In *9th International Conference on Rehabilitation Robotics, 2005. ICORR 2005.* IEEE, 465–468. https://doi.org/10.1109/ICORR.2005.1501143

[10] Mowafa Househ, Andre Kushniruk, Malcolm Maclure, Bruce Carleton Cloutier-Fisher, and Denise. 2009. A Case Study Examining the Impacts of Conferencing Technologies in Distributed Healthcare Groups. *ElectronicHealthcare* 8, 2 (oct 2009). https://www.longwoods.com/content/21141

[11] D W Kissane, D M Clarke, and A F Street. 2001. Demoralization syndrome–a relevant psychiatric diagnosis for palliative care. *Journal of palliative care* 17, 1 (2001), 12–21. http://www.ncbi.nlm.nih.gov/pubmed/11324179

[12] Marie Curie. 2018. End of life experiences. https://www.mariecurie.org.uk/help/support/terminal-illness/preparing/end-of-life-experiences

[13] Microsoft. [n. d.]. Download Skype | Free calls | Chat app. https://www.skype.com/en/get-skype/

[14] Gwendolyn Purdom. 2018. 5 Surprising Items that Would Help You on a Desert Island, According to a Survival Expert | Mental Floss. http://mentalfloss.com/article/524300/5-surprising-items-would-help-you-desert-island-according-survival-expert

[15] Association for Psychological Science. 2016. NASA Exercise: Ranking Survival Objects for the Moon. *APS Observer* 29, 2 (jan 2016). https://www.psychologicalscience.org/observer/nasa-exercise

[16] SoftBank. [n. d.]. Pepper the humanoid robot | SoftBank Robotics EMEA. https://www.softbankrobotics.com/emea/en/pepper

[17] Rachel-Hannah Strong and Paulo Guiran Pestana. 2015. Robots at Chelsea and Westminster Hospital - YouTube. https://www.youtube.com/watch?v=xhEsXBV7dFI

[18] Mugdha Thakur and Dan G Blazer. 2008. Depression in long-term care. *Journal of the American Medical Directors Association* 9, 2 (feb 2008), 82–7. https://doi.org/10.1016/j.jamda.2007.09.007

[19] Vive. [n. d.]. VIVE™ United Kingdom | Buy VIVE Hardware. https://www.vive.com/uk/product/

[20] Bob G Witmer and Michael J Singer. 1998. *Measuring Presence in Virtual Environments: A Presence Questionnaire.* Technical Report 3. 225 pages. https://nil.cs.uno.edu/publications/papers/witmer1998measuring.pdf

## D.2 Immersive Control of a Robot Surrogate for Users in Palliative Care (Chapter 3)

# Immersive Control of a Robot Surrogate for Users in Palliative Care

Bethany Ann Mackey
bethany.mackey@brl.ac.uk
Bristol Robotics Laboratory, Bristol

Paul A Bremner
paul.bremner@brl.ac.uk
University of the West of England, Bristol

Manuel Giuliani
manuel.giuliani@uwe.ac.uk
University of the West of England, Bristol

### ABSTRACT

Quality of life (QoL) is especially important for palliative care patients, who can be at risk of mental health issues. This project aims to design and implement an immersive control system for a robotic surrogate, that allows users to interact as naturally as possible with their loved ones from a remote location, and navigate appropriately, in order to improve QoL for those living with a terminal illness.

### CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *User studies.*

### KEYWORDS

Immersive Control,Virtual Reality, Robotic Surrogate, Human-Robot Interaction, Palliative Care, Presence, Social Presence

**ACM Reference Format:**
Bethany Ann Mackey, Paul A Bremner, and Manuel Giuliani. 2020. Immersive Control of a Robot Surrogate for Users in Palliative Care. In *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI '20 Companion), March 23–26, 2020, Cambridge, United Kingdom.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3371382.3377445

### 1 INTRODUCTION

Patients in palliative (end-of-life) care are likely to be at risk of mental health issues, with some experiencing helplessness, depression, demoralisation syndrome, and even suicidal thoughts [14]. While technology, sometimes known as telemedicine [10] or telehealth [13], is being applied to many branches of medicine,these are often administrative; such as data collection and management [11][3], symptom assessment [4][5], or out-of-hours support [13]. However, there is a need for research into improving quality of life (QoL) and addressing the needs of those who are terminally ill [12], which this research aims to contribute to.

It is important that those living with a terminal illness do not become housebound and charity Marie Curie [17] highlight the importance of meeting with people or revisiting significant places "if physically able to". Current research does not typically address QoL or the importance of fulfilling these desires; this research aims to bridge this gap using telepresence.

Telepresence refers to a person feeling virtually present from a remote location [19], often known as place presence. Similarly, social presence refers to the "sense of being with another in a mediated environment", where it is possible to access the psychological, emotional, and intentional states of the other person [6]. Telepresence is frequently combined with virtual reality (VR) control; where VR refers to the use of a head-mounted display (HMD) system to become immersed in a virtual environment [2] [1].

Telepresence has been used successfully in healthcare for the elderly, often combined with robotics [22][15][18][8], in every day tasks such as remembering medication, and enhancing social interaction through feelings of place and social presence [16]. However, these technologies are rarely applied to palliative care, with robotics research focusing on companion robots to tackle isolation [24] or their uses in palliative care education [25]. There are many opportunities for the use of robotics in palliative care that have yet to be explored [20] and could prove pivotal in improving QoL for those with terminal illness.

The following doctoral research aims to explore the use of head-mounted display based immersive control for a robot surrogate, in order to improve QoL for those in palliative care. It is hypothesised that by providing high feelings of place and social presence, the system can produce high quality social interaction between the users and their loved ones. Additionally, the system aims to allow those at the end of life to be able to visit meaningful places and take part in social events.

### 2 RESEARCH QUESTIONS

With the aims and motivation in mind, the following research questions have been identified:

(1) Can a head-mounted display based immersive control system enable a high degree of place presence for a remote operator? What are the design features required to do so?
(2) Can such a system create effective, natural, social presence between the user and others interacting with them?
(3) Can limited body language be semi-autonomously generated to effectively portray the operator's personality and social cues, such that they improve place and social presence?

### 3 INITIAL STUDY

An initial study was conducted comparing a head-mounted display (HMD) based control system for a Pepper robot, with telecommunications software Skype; this study aimed to investigate the first two research questions.

#### 3.1 Experimental Design

A stereoLabs Zed camera was attached to the head of a Pepper robot, and the video feed streamed into a HTC Vive HMD using Unity, allowing the user to see into the next room. The Pepper


*HRI '20 Companion, March 23–26, 2020, Cambridge, United Kingdom*

ACM ISBN 978-1-4503-7057-8/20/03.
https://doi.org/10.1145/3371382.3377445

robot's head mimicked the movement of the HMD, allowing the other participant to follow the user's gaze.

A total of 13 pairs of healthy participants (19 male and 7 female) took part in the within-subject study, where 73% of participants were aged 25-34. Participants had varying degrees of experience in VR, robotics, and telecommunications software, and were awarded a £10 Amazon voucher for participation. This study was approved by the University of the West of England ethics committee.

Participants were seated in separate rooms and required to complete a joint task, ranking a set of objects according to their utility in a given survival scenario, where each scenario was allocated randomly between the HMD and Skype conditions (a desert island [21] and a crash landing on the moon [23]). Participants communicated via Skype or with one participant using the HMD based robot surrogate system (figure 1). Following each condition, the participants were asked to complete a number of questionnaires to measure place presence [26], social presence [7], and system usability [9].

**Figure 1: HMD Condition**

It was hypothesised that the HMD condition would produce higher feelings of place and social presence, but lower system usability scores. Therefore, the null hypothesis was that there would be no difference in the scores produced by the two systems.

## 3.2 Results and Discussion

A number of two-tailed Paired-Samples T-tests were conducted using SPSS, to analyse the questionnaire responses. The results showed no significant difference for place or social presence felt by those using the HMD system, or those interacting with them, when compared to Skype; therefore the null hypothesis could not be rejected. As hypothesised, Skype scored significantly higher for system usability ($t = -2.846$, $df = 25$, $p < 0.05$).

While the results did not hold statistical significance, there was a trend in the data that showed slightly higher place ($M = 4.73$, $SD = 0.70$) and social ($M = 5.10$, $SD = 0.52$) presence for the HMD condition than the place ($M = 4.43$, $SD = 0.43$) and social ($M = 4.86$, $SD = 0.51$) presence for the Skype condition; this was further expressed by verbal feedback from the participants following the study trials. It is possible that the subtle effect that the system had on presence would have been statistically significant had the study been conducted with a larger sample.

Additionally, the system is still primitive and may have produced higher feelings of presence once further developed to include more features. Furthermore, considering aspects of social presence refer to accessing another's emotional state, it may be necessary to reconsider the task used during the study; as it may have been naive to assume a purely logical discussion task would elicit an emotional response. It should also be noted that the participants consisted of university employees and students, with prior experience of the technologies used, who are not in palliative care. Therefore, it is impossible to generalise the findings, and it is imperative that user requirements are identified by intended users going forwards.

# 4 FUTURE WORK

While the initial study aimed to investigate the effect that the HMD based system had on place and social presence in comparison to Skype, the larger objective is to design and implement an effective immersive control system for a robotic surrogate. The aim is to reduce feelings of isolation in palliative care patients by allowing users to visit meaningful places, and take part in experiences that they may not ordinarily be able to.

Future work will focus on palliative care patients who may not have full mobility, but have the full use of the top of their body. Three focus groups will be run with patients, families, and healthcare professionals. The groups will be presented with system prototypes to assess the appropriateness of the technology for the intended usage, whether HMD based control can be used, and what features are required. These groups will identify requirements for a system that would be usable and wanted by users; the scope of the project will then be narrowed down to focus on some of these requirements.

Having formulated a list of requirements, certain aspects may be assessed, such as whether a mobile base is essential or whether a humanoid robot is necessary for the system to be effective. User studies will be conducted to test this, such as comparing a humanoid Pepper robot and another telepresence robot. These aspects of the system will be important for creating a natural interaction, for both user and interactant, and will contribute to the second research question.

Later development will address the third research question by implementing semi-autonomous body language on an appropriate robot that reflects the user's personality and mood, while remaining appropriate for the user's environment. Social signal processing will also be implemented in order to ensure that the user is receiving accurate and useful information. Assessment of these features will be done using two separate studies, one focused on different types of body language, such as beat gestures and mimicry, and another on the balance between the system's auto-generated body language and direct user control.

Finally, case studies will be conducted over several weeks, where users will be able to use the surrogate. Similarly to the original focus groups, the users, families, and healthcare professionals, will take part in interviews to assess whether the system has fully met the requirements identified, and addressed all of the research questions.

The very nature of this research is flexible and delicate, therefore, the development is likely to adapt as requirements are identified. The user studies may also change as requirements become evident. Ultimately, it is important to ensure that the system is effective, to allow those in palliative care to interact as naturally as possible with their loved ones from a remote location, and navigate appropriately, in order to improve quality of life, as is the aim of this research.

## REFERENCES


[1] [n. d.]. Interactivity Element - Virtual Reality Society. https://www.vrs.org.uk/virtual-reality/interactivity-element.html
[2] [n. d.]. What is Virtual Reality? - Virtual Reality Society. https://www.vrs.org.uk/virtual-reality/what-is-virtual-reality.html
[3] Amy P. Abernethy, Jane L. Wheeler, and Janet Bull. 2011. Development of a health information technology-based data system in community-based hospice and palliative care. *American Journal of Preventive Medicine* 40, 5 SUPPL. 2 (may 2011). https://doi.org/10.1016/j.amepre.2011.01.012
[4] Beate André, Gerd Inger Ringdal, Jon H. Loge, Toril Rannestad, and Stein Kaasa. 2008. The importance of key personnel and active management for successful implementation of computer-based technology in palliative care: Results from a qualitative study. *CIN - Computers Informatics Nursing* 26, 4 (jul 2008), 183–189. https://doi.org/10.1097/01.NCN.0000304802.00628.70
[5] Beate André, Gerd I. Ringdal, Jon H. Loge, Toril Rannestad, and Stein Kaasa. 2009. Implementation of computerized technology in a palliative care unit. *Palliative and Supportive Care* 7, 1 (2009), 57–63. https://doi.org/10.1017/S147895150900008X
[6] Frank Biocca and Chad Harms. 2002. (PDF) Defining and measuring social presence: Contribution to the networked minds theory and measure.
[7] Frank Biocca and Chad Harms. 2003. *Guide to the Networked Minds Social Presence Inventory (Version 1.2): Measures of co-presence, social presence, subjective symmetry, and intersubjective symmetry.* Technical Report. http://cogprints.org/6743/1/2002{_}guide{_}netminds{_}measure.pdf
[8] Patrick Boissy, Hélène Corriveau, François Michaud, Daniel Labonté, and Marie Pier Royer. 2007. A qualitative study of in-home robotic telepresence for home care of community-living elderly subjects. *Journal of Telemedicine and Telecare* 13, 2 (mar 2007), 79–84. https://doi.org/10.1258/135763307780096195
[9] John Brooke. [n. d.]. SUS -A quick and dirty usability scale Usability and context. ([n. d.]). https://hell.meiert.org/core/pdf/sus.pdf
[10] P. Garner, M. Collins, S. M. Webster, and D. A.D. Rose. 1997. The application of telepresence in medicine. *BT Technology Journal* 15, 4 (1997), 181–187. https://doi.org/10.1023/A:1018699900499
[11] Arif H. Kamal, Keith M. Swetz, Sydney Dy, Allen Y. Tien, Jennifer S. Temel, and Amy P. Abernethy. 2012. Integrating technology into palliative care research. , 525–532 pages. https://doi.org/10.1097/SPC.0b013e32835998c6
[12] Brian Kelly, Susan McClement, and Harvey Max Chochinov. 2006. Measurement of psychological distress in palliative care. *Palliative Medicine* 20, 8 (2006), 779–789. https://doi.org/10.1177/0269216306072347
[13] Lisa Kidd, Sandi Cayless, Bridget Johnston, and Yvonne Wengstrom. 2010. Telehealth in palliative care in the UK: A review of the evidence. , 394–402 pages. https://doi.org/10.1258/jtt.2010.091108
[14] D W Kissane, D M Clarke, and A F Street. 2001. Demoralization syndrome–a relevant psychiatric diagnosis for palliative care. *Journal of palliative care* 17, 1 (2001), 12–21. http://www.ncbi.nlm.nih.gov/pubmed/11324179
[15] Saso Koceski and Natasa Koceska. 2016. Evaluation of an Assistive Telepresence Robot for Elderly Healthcare. *Journal of Medical Systems* 40, 5 (may 2016). https://doi.org/10.1007/s10916-016-0481-x
[16] Annica Kristoffersson, Silvia Coradeschi, Kerstin Severinson Eklundh, and Amy Loutfi. 2011. Sense of presence in a robotic telepresence domain. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, Vol. 6766 LNCS. 479–487. https://doi.org/10.1007/978-3-642-21663-3_51
[17] Marie Curie. 2018. End of life experiences. https://www.mariecurie.org.uk/help/support/terminal-illness/preparing/end-of-life-experiences
[18] F Michaud, P Boissy, D Labonté, H Corriveau, A Grant, M Lauria, R Cloutier, M.-A Roux, D Iannuzzi, and M.-P Royer. [n. d.]. *Telepresence Robot for Home Care Assistance.* Technical Report. www.aaai.org
[19] Marketta Niemelä, Lina van Aerschot, Antti Tammela, Iina Aaltonen, and Hanna Lammi. 2019. Towards Ethical Guidelines of Using Telepresence Robots in Residential Care. *International Journal of Social Robotics* (feb 2019), 1–9. https://doi.org/10.1007/s12369-019-00529-8
[20] Amara Callistus Nwosu, Bethany Sturgeon, Tamsin McGlinchey, Christian D.G. Goodwin, Ardhendu Behera, Stephen Mason, Sarah Stanley, and Terry R. Payne. 2019. Robotic technology for palliative and supportive care: Strengths, weaknesses, opportunities and threats. *Palliative Medicine* (sep 2019). https://doi.org/10.1177/0269216319857628
[21] Gwendolyn Purdom. 2018. 5 Surprising Items that Would Help You on a Desert Island, According to a Survival Expert | Mental Floss. http://mentalfloss.com/article/524300/5-surprising-items-would-help-you-desert-island-according-survival-expert
[22] Arsenio Reis, Rui Xavier, Isabel Barroso, Maria Joao Monteiro, Hugo Paredes, and Joao Barroso. 2018. The usage of telepresence robots to support the elderly. In *TISHW 2018 - 2nd International Conference on Technology and Innovation in Sports, Health and Wellbeing, Proceedings*. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/TISHW.2018.8559549
[23] Association for Psychological Science. 2016. NASA Exercise: Ranking Survival Objects for the Moon. *APS Observer* 29, 2 (jan 2016). https://www.psychologicalscience.org/observer/nasa-exercise
[24] Rachel-Hannah Strong and Paulo Guiran Pestana. 2015. Robots at Chelsea and Westminster Hospital - YouTube. https://www.youtube.com/watch?v=xhEsXBV7dFI
[25] Bethany Sturgeon, Terry Payne, Stephen Mason, and Amara Nwosu. 2017. O-7 Robotic technology and palliative care education: the development of a 'nao robot' computer program. *BMJ Supportive & Palliative Care* 7, Suppl 1 (mar 2017), A2.4–A3. https://doi.org/10.1136/bmjspcare-2017-00133.7
[26] Bob G Witmer and Michael J Singer. 1998. *Measuring Presence in Virtual Environments: A Presence Questionnaire.* Technical Report 3. 225 pages. https://nil.cs.uno.edu/publications/papers/witmer1998measuring.pdf

## D.3 Usability of an Immersive Control System for a Humanoid Robot Surrogate (Chapter 3)

2022 31st IEEE International Conference on Robot and
Human Interactive Communication (RO-MAN)
August 29 - September 2, 2022. Naples, Italy.

2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN) | 978-1-7281-8859-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/RO-MAN53752.2022.9900587

# Usability of an Immersive Control System for a Humanoid Robot Surrogate

Bethany Mackey[1], Paul Bremner[1], and Manuel Giuliani[1]

*Abstract*— **Social isolation is an issue that effects many people, especially those from ethic minorities, LGBTQIA+ communities, the elderly, those in long-term healthcare, and those living with life-limiting illnesses. It has become increasingly evident during the pandemic, when mental health issues have soared, and the importance of interacting with loved ones has been highlighted. While telecommunication software helped a great deal in these unprecedented circumstances, it does not allow for navigation in remote environments, and lacks high level interactions found in face-to-face communication. Therefore, this system has been developed to address these issues, and this study was being conducted to test the technical usability of the system when being used by healthy participants. It was found that 720p is the highest resolution that can be applied before the camera delay becomes unusable; though participants suggested that they would like the option to switch to 2k resolution should they be looking close up without moving. In addition, it became apparent that overall the participants were positive about the system, but would prefer a less bulky head-mounted display, and that the choice of which robot to use with the system (Nao or Pepper) was entirely down to individual preference based on the task being completed.**

## I. INTRODUCTION

Technology has become increasingly prevalent in the modern world and advances that were once reserved for big corporations are making their way into homes; from artificial intelligence helping with simple shopping lists, to robot hoovers and mops. But while these increasingly popular technologies aim to complete mundane tasks with ease, or provide new and exciting entertainment, research is also being conducted to test the applicability of these types of technologies to other problems.

One problem that the general population is facing is isolation; this can particularly apply to the LGBTQIA+ community, the elderly, and those in long-term healthcare, amongst others. It has been well documented that isolation can lead to a plethora of mental health issues within several age groups [1] [2]; Thakur (2008) found that 35 percent of residents in long-term care may experience "clinically significant depressive symptoms" [3]. This can also apply to terminally ill patients in palliative care who may be experiencing helplessness, demoralisation, and even suicidal thoughts [4]; Marie Curie (2018) suggests that this may be tackled by meeting with people to "resolve unfinished matters from the past" or visiting significant places "if physically able to" [5].

While research has been conducted into using robotics as a means of tackling isolation, this usually involves a companion robot [6][7][8]. There is a lack of research into methods of bringing people closer to their loved ones, rather than just providing them with further companionship. Current systems using basic telecommunications software lack the high-level interactions found in face-to-face communication required for social presence [9]. There is a need for a more immersive means of communicating, that will allow for increased social presence and higher quality interactions between those experiencing social isolation and their friends and family.

Presence, sometimes described as place presence, is described as "the subjective experience of being in one place or environment, even when one is physically situated in another"; this is vital to creating an immersive experience and what most virtual reality developers aspire to when designing a system [10]. Social presence, on the other hand, was described as "being together with another"; both physically and emotionally [11].

This project aimed to design and implement a system that will achieve both place presence and social presence using virtual reality (VR) technology and humanoid robot surrogates (Nao and Pepper). While tackling social isolation forms the original motivation for this system, it can be applied to any task where social telepresence is appropriate, with the aim of providing an immersive means of communication for users and a means of navigating remote environments.

## II. RELATED WORK

The section below covers literature related to the design and implementation of this system: virtual reality and telepresence, the concept of presence and social presence, and social robots and human-robot interaction.

### A. Virtual Reality and Telepresence

Virtual reality (VR) has seen a vast increase in popularity in recent years, despite actually being coined in 1989 by Jaron Lanier [12]. Sherman and Craig (2003) specified that a virtual world can apply to "any content of a given medium", not just VR, and identified four elements that they deemed essential: mental immersion, physical immersion, sensory feedback, and interactivity [13]. They summarised that successful mental immersion left the participant "deeply

[1]Bethany Mackey, Paul Bremner, and Manuel Giuliani are with Bristol Robotics Laboratory, University of the West of England, Bristol, United Kingdom bethany.mackey@brl.ac.uk, paul.bremner@brl.ac.uk, manuel.giuliani@brl.ac.uk

engaged" to the point where they temporarily suspended their disbelief and felt involved in the virtual world; whereas physical immersion described the "synthetic stimulus of the body's senses via the use of technology".

One common application of VR is telepresence, which is defined as "the use of virtual reality technology to operate machinery by remote control or to create the effect of being at a different or imaginary location" [14]. However, the term telepresence was coined by Marvin Minsky in 1980 with no mention of virtual reality [15]. They predicted that it would take a decade to develop the "basic instruments" and a further decade to "make the instruments rugged, reliable, and natural"; however, 40 years later, this technology is still being perfected, improved, and commercialised.

Tsui (2013) created guidelines for successful social interaction when using mobile telepresence, where the end goal should be effective interpersonal communication between the user and remote parties [16]. They identified three vital interactions: the human-robot interaction between the user and the robot's interface, the human-robot interaction between the robot's local human interactants (those who interact with the telepresence robot), and the human interaction between the user and interactants. They suggested that if the human-robot interaction is successful, the human interaction is maximised. They also highlighted that presence and engagement could be reduced if the interactants are unwilling to communicate via the robot; therefore, it is important to consider how the chosen robot is viewed by others, especially when investigating the use of telepresence in social interaction. They commented that if a system has been designed well, the technology "should disappear" for the user and interactants, and the focus should be on communication and interpersonal relationships.

Unlike more physical task-oriented telepresence robots, social robots with the specific goal of human-robot interaction have to be able to successfully act as a believable human proxy, or they will not be accepted by the human interactants, and therefore Tsui (2013) recommended the use of humanoid robots for social roles [16]. Additionally, Adalgeirsson (2010) conducted a study measuring the effects of expressivity and found that a socially expressive robot was found to be more engaging and likeable than a static one, as well as contributing to more psychological involvement and better cooperation [17].

The behaviour of the interactants towards the robot is also important for a successful interaction and Takayama (2012) noted that it was vital that the interactant does not touch the robot; they reported that the user felt that the interaction was as invasive as if they had been standing there in person, suggesting high levels of presence for the user [18]. Tsui (2013) highlighted the importance of perceived presence for the interactant as well, and claimed that the quality of the interaction with the embodied telepresence robot will depend on how present the interactants feel the user is [16].

Having compiled a list of guidelines, Tsui also questioned whether the use of virtual or augmented reality would improve social telepresence and whether the need for more processing power would be worth the extra amount of sensory information provided by a more immersive system [19]; this system aimed to answer that question by breaching the gap between social telepresence and virtual reality.

### *B. Presence - Place and Social Presence*

One of the main advantages of VR, and telepresence in general, is the ability to feel a sense of presence in a remote location. Sherman and Craig (2003) suggested that presence is simply another name for successful mental immersion [13]; while Brockmeyer et al (2009) described it as the experience of being inside a virtual environment [20]. However, despite having a concise description, Samani et al (2013) stated that "the sense of presence is a multi-component and subjective concept that is achieved when a person has the impression of actually being present in a remote environment", making it hard to successfully achieve [21]. Ching (2016) suggested that this could be achieved with "low latency, high frame rate and good calibration of the device" [22]. They also stated that the avatar did not have to resemble the users own body, which could be satisfied by the use of a humanoid robot.

Sparks (2017) described presence in virtual reality as "difficult to create, easy to ruin, and nearly impossible to get back once it's gone" [23]. They went on to explain that if a system is designed well, the mind can forget about the technology being used and even about the environment outside the virtual one. They explained that presence could be broken into three categories: visual, auditory, and sensory or haptic presence, and deemed them to be in that order of importance [23].

Social presence theory, conceptualised by Short, Williams and Christie in 1976, is the "sense of being with another in a mediated environment", where it is possible to access the psychological, emotional, and intentional states of the other person [24]. The majority of studies regarding social presence relate to online learning [25], but VR research can also benefit as Koetsier (2018) found that 77% of VR users, in a survey of over four thousand people, wanted more social engagement from their VR experiences, and described it as "an isolating technology" [26]. Bulu (2012) studied the relationship between social presence, and place presence, and how they related to satisfaction and immersive tendencies in virtual worlds. They found that while social presence effected satisfaction the most, immersive tendencies were more related to place presence [27].

The VR and telepresence industries are consistently working towards providing a greater sense of presence, no matter the intended use of the system. Rogers (2017) claimed that improvements in the ability to create presence would ”push the industry forward”, but also warned of overplaying the expectations of the hardware currently available [28]. They suggested that it is better to aim for realistic successful interactions, rather than pushing the technology and ”breaking the spell”.

### *C. Social Robots and Human-Robot Interaction*

Successful human-robot interaction is hard to achieve and requires the human to trust the robot that they are interacting with [29]. Hancock et al (2011) identified three categories that affect trust, the first being robot-related factors; these are usually performance based. Next, they identified human-related factors, which are based on abilities and human characteristics. Finally, they mentioned environment-related factors, which derive from team collaboration and task-based factors [29]. These categories are vital to take into consideration when designing any system that will be interacting with humans, as if the human does not trust the robot then the system will not be deemed successful. If the levels of trust in a system are inappropriate then there can be negative consequences, such as overreliance or complete disuse of a system, depending on whether the levels of trust are too high or too low [29]. With regards to this system, the surrogate needed to be a believable proxy for the user, as if the interactant did not trust the surrogate, then the interaction between the humans would not be authentic.

With this in mind, inspiration was taken from Bruce (2002) who investigated the impact of certain features and behaviours on willingness to interact with a robot for a short time [30]. They hypothesised that being able to turn towards the person that the robot was interacting with to indicate attention, was one of the minimal requirements of successful social human-robot interaction. They found that this was important for giving a slight increase in performance. This was important for this project as it suggested that connecting the VR HMD movement with the robot’s head movement was critical for interaction. However, they also found that having a robot with the ability to convey expression with a humanoid face produced similar results, and that the two factors together produced the most compelling results. While Pepper and Nao do have humanoid faces, they are unable to convey expression.

As already shown, the design of the robot acting as the surrogate is important to the success of the system. If the interactant does not feel comfortable interacting with the robot, then the control system is irrelevant to the authenticity of the interaction. Leite et al (2013) summarised guidelines for the design of social robots for use in long-term interactions. They specified that when designing the appearance of a social robot, it is important to select the correct embodiment for the robot’s purpose and what capabilities it is expected to have, and that they have to be appropriate for it’s intended environment, such as a home or office. However, they also warned that choosing a humanoid would create higher expectations of social capabilities than a more zoomorphic robot. Additionally, they emphasised the importance of not only understanding the user’s affective state, but also having the ability to react accordingly subject to context, and to mimic empathy [31] . Pepper and Nao have the ability to satisfy the majority of these guidelines through the use of the NAOQI API.

### *D. Summary*

Virtual Reality has proven to be a popular and effective choice for research into presence, and therefore has been applied to a control system that focuses on immersion. Similarly, literature into telepresence provided an insight into how to achieve presence using different systems. Finally, research into successful human-robot interaction using social robots identified the necessary requirements that allow a robot to be deemed trustworthy, therefore helping to result in a successful long-term interaction. It is important to note that although there is an abundance of research into these fields, they are rarely studied together, leaving a research gap for an immersive control system for a social robot surrogate; which is what this system aims to address.

## III. System Overview

The developed system allows users to view a remote environment via a video feed streaming into the head-mounted display (HMD) of a HTC Vive virtual reality (VR) system. They can navigate around the environment by controlling a humanoid robot (Nao or Pepper) via the HTC Vive controller. The robot’s head mimics the movement of the HMD, allowing others to follow the user’s gaze. Pepper and Nao are interchangeable with the system. Users are also able to communicate with others in the environment via a microphone and speakers attached to the robot, and a microphone and speaker on the HMD.

## IV. Prior Work

Pairs of participants took part in an initial study comparing a HMD based control system for a Pepper robot with telecommunications software Skype. The participants completed a joint task while seated in separate rooms (figure 1), communicating via the system or Skype, and were asked to complete a number of questionnaires to measure place presence, social presence, and system usability.

Fig. 1. System setup Showing Virtual Reality HMD and Controls for the User and the Robot Surrogate in a Separate Location.

No significant difference was found for place or social presence when compared to Skype, but as hypothesised, Skype scored significantly higher for system usability ($t = -2.846$, $df = 25$, $p < 0.05$). However, there was a general trend towards higher place and social presence felt for the HMD condition, which was expressed verbally by participants. Therefore, further investigation is warranted.

## V. Aims and Objectives

### A. Aims

This study aimed to assess the usability of the developed immersive control system for two humanoid robot surrogates, Nao and Pepper. The system utilises virtual reality telepresence technology and aims to address the issue of social isolation by allowing for navigation in a remote location and social interaction with others.

### B. Objectives

- Identify the most appropriate robot, Nao or Pepper, to use with the system, based on task performance and qualitative feedback.
- Identify design features that could improve the usability of the system.
- Identify the preferred resolution for the system by comparing the trade-off between higher resolution and increased delay in responsiveness from the system.

### C. Research Questions

- How usable is the system in its current form? Which robot produces the best task performance?
- Which robot is preferred by the participants?
- What is the maximum resolution that can be used without resulting in an unusable delay in responsiveness by the system?

## VI. Methodology

In order to answer the research questions identified above, a usability study was conducted for the developed system. The methodology for the study is described below.

### A. Participants

A total of 20 (N = 20) students and staff from within the University were recruited via internal emails and doodle polls. Participants received a £10 amazon voucher for participation in the study.

### B. Procedure

Before beginning the study the participants were asked to read an information sheet and privacy notice and to fill in a consent form and demographics questionnaire. Following this they were then invited to inspect both Nao and Pepper.

The participants were asked to put on the HMD and complete four tasks as described below. The tasks were completed once with each robot, following a within-subject design. The first robot was alternated to minimise practice effects. Throughout the study participants were asked to use the concurrent think aloud process where they describe their activity and what they are thinking out loud.

Fig. 2. Setup for tasks 1 (Identification) and 2 (Navigation).

**Task 1: Identification**
Each robot was placed in front of 7 identical pictures, but placed in different locations. The participant was asked to locate the picture of the doorbell and say the word ”found” as soon as they located it. The time taken to find the picture and whether or not it was the correct picture was noted.

**Task 2: Navigation**
The participant was given the controller and asked to navigate to the middle of a cross marked on the floor with Pepper or table with Nao. They were asked to get the middle front of the robot into the centre of the cross and say the word ”finished” when they felt they were in place. The researcher then took note of the time taken to complete the task and the distance the robot was from the desired navigation point.

**Task 3: Interaction**
Using a set of 5 pre-defined questions, the researcher interviewed the participant while standing opposite the robot. In turn, the participant asked the researcher a separate set of questions when the researcher was controlling the robot using the headset. The researcher gave pre-determined answers. The question sets were randomised out of a selection of 4.

**Task 4: Resolution/Delay Comparison**
The participant was asked to view 4 different resolutions via the Nao robot, which resulted in 4 different frames per second (fps) values. They were asked to rate the resolution and delay for each pair out of 10, where 10 was perfect vision/real-time movement and 1 was totally unusable vision/movement delay.

Following the tasks, the participants were given a set of open-ended questions shown below where they could answer as much or little as they wished, as well as making any additional comments.

1) What features of the system do you like and dislike?
2) Which robot do you prefer to use overall out of Nao and Pepper? Please explain why.
3) At which resolution did the delay in responsiveness become too unusable?

*C. Hypotheses*

The following hypotheses were identified for each task:

- **Task 1:** Participants would be able to identify the correct picture within a similar time frame equally with each robot.
- **Task 2:** Participants would be able to navigate more quickly and accurately with the Pepper robot.
- **Task 3:** Participants would prefer to interact using the Pepper robot as the person controlling it and when it is being controlled by someone else.
- **Task 4:** Participants would prefer the resolution/delay trade off of 720pp.

*D. Ethical Considerations*

The study was granted ethical approval by the university ethics committee. The recruitment email stated that participants should have the use of their upper body and to contact the researcher if they had any conditions or injuries that may be affected by the use of virtual reality, such as Vertigo or Meniere's disease. They were also informed that they would be compensated with a £10 Amazon voucher.

Having read the information sheet and privacy notice at the start of the study, the participants were able to grant informed consent for their data to be analysed and used. The data was fully anonymised using participant IDs, but not confidential as it may be used for publication. Any audio recordings were permanently deleted following transcriptions. The participants were not at risk of any significant harm; however, VR has been known to cause some motion sickness.

There was a small chance of the robot colliding with the participant as it was being controlled by the researcher, however, the robots are designed for safe human interaction and the likelihood of harm was minimal. As well as being written in the information sheet, the participant was also reminded verbally that they could withdraw from the study at any time, without giving a reason, until leaving the room. As the data was anonymous identifying the participant's information would not be possible after this.

*E. COVID-19 Mitigation*

As well as following the university's official COVID-19 guidance, the following specific items were put in place to mitigate any COVID-19 related risk:

- The headset and controllers were sterilised between each participant.
- A separate foam piece for the headset was used for each participant.
- Social distancing between the participant and researcher was adhered to as strictly as possible.
- Participants were from the university and aware of the risk regarding COVID-19. They had also taken "return to work" safety courses provided by the university.
- Disposable gloves were offered to each participant at the beginning of the study.
- Face coverings were worn by the researcher and participants at all times. New masks were offered at the beginning of each trial.

## VII. Results

This section details both the quantitative and qualitative findings of the study.

*A. Quantitative*

**Task 1:**
Due to technical issues with the Pepper robot, one participant's data could not be used for this task (N = 19). As hypothesised there was no significant difference found for time taken to locate the "doorbell" image with Pepper (m = 3.8063 secs) or Nao (m = 5.4705 secs). All participants correctly identified the right image.

**Task 2:**
Due to technical issues with the Pepper robot, one participant's data could not be used for this task (N = 19). There was no significant difference found for time taken with Pepper (m = 29.7458) and Nao (m = 41.0837) to complete the navigation task to the participants' satisfaction.

In addition, there was also no significant difference found for the distance to the target with Pepper (m = 16.3421 cm) and Nao (m = 16.6842 cm). Therefore the null hypothesis cannot be rejected as there was no significant different difference found between the two robots for the navigation task.

**Task 4:**
A one-Way repeated measures MANOVA was conducted on the data for task 4 (N = 20). A significant difference was found between the resolution (independent variable) and both resolution score and delay score awarded by the participants for each resolution. Mauchly's test of sphericity was significant in both cases, resulting in a Tukey's range test being conducted.

***Resolution Score:*** A significant difference was found between VGA (m = 3.050) and all other resolutions (720p, 1080p, and 2k) where their mean scores out of 10 were 5.350, 6.050, and 6.000 respectively (figure 3). However, there was no significant difference between any of the remaining resolutions.Therefore, the gain in resolution is worth upgrading to 720p from VGA, but not any higher.

***Delay Score:*** There was no significant difference between VGA and 720p, but there was a signifcant difference between

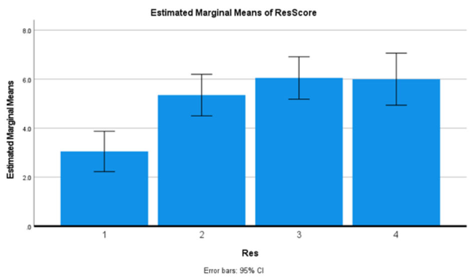



Fig. 3. Marginal means for Resolution Scores (ResScore) for each Resolution (Res).

the scores for VGA/720p (m = 5.675/4.725) and 1080p/2k (m = 3.275/2.800) (figure 4). Therefore the delay is manageable for VGA and 720p resolutions, but not for 1080p or 2k, as hypothesised.

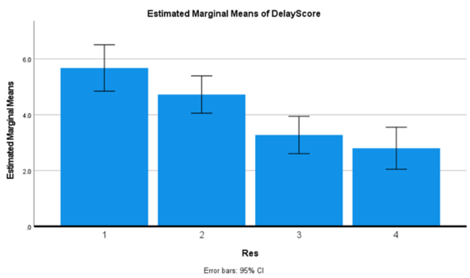



Fig. 4. Marginal means for Delay Scores (DelayScore) for each Resolution (Res).

### B. *Qualitative*

Thematic analysis was conducted for all qualitative data gathered throughout the study. This included overall experience and task 3 (interaction) using verbal (audio recordings) and written (semi-structured interview questions) data.

**Liked Features:**
Overall, participants were positive about their experiences with the robots and the general concept of the system. They spoke extensively about being able to look, move, and explore around the remote environment and feeling much more immersed than when using a screen or phone. Generally participants enjoyed using the system and said the experience was ”fun”.

With regards to the system itself, participants commented specifically on Pepper’s base movement and Nao’s head movement, which they called ”natural”, ”intuitive”, ”cool”, and ”useful”. They liked ”seeing the world from a different perspective” and praised the field of depth of the camera as well as the clarity of the 2K resolution for close up writing; however this was only the case when they were still. They also commented on being able to control the movement of the robot and look around on their own without relying on another person to assist them.

Interactivity was also discussed at length by the majority of participants; they enjoyed being able to interact with others via the system and gain the context of the other person’s environment. Participants talked about a sense of embodiment when being able to move the head and body. They compared the experience to talking on the phone, but said they felt they could speak to people at a greater distance and felt it was a more interactive experience when using the system.

Participants were also impressed with the interactivity experienced when the researcher was controlling the robot. They mentioned being able to interact with a humanoid figure and make ”eye contact”. As well as this they enjoyed the appearance of the robots, their interactivity, and responsiveness - especially the eyes and hands.

**Disliked Features:**
The main aspect that participants seemed to dislike the most was the equipment itself. Multiple participants commented on camera resolution, delay, and ”jerky” movement.

With regards to the control system itself, participants mostly commented on the bulky, heavy headset, and velcro strap; these especially effected participants wearing glasses. They suggested that a more up to date, lighter, headset may assist with these issues. Some participants also mentioned feeling slightly queasy, as can be common with virtual reality, and some audio issues.

When discussing any disliked features of the robots, some participants had mixed feelings. One commented that they preferred looking around and did not like the feeling of moving. A couple commented on not being able to see ”their own feet” or tell their orientation, followed by a suggestion to use augmented reality to show this. Other participants commented on clunky movements and head movement limits, despite this being the case with human bodies also. Some had a preference over which robot they liked interacting with or controlling; this is discussed further below.

**Preferred Robot:**
Overall participants showed no difference between which robot they preferred. However, analysis did show that generally participants preferred the Pepper robot for **navigating** around the environment, and the Nao robot for **looking** around the environment. When interacting with the

robot analysis showed that preference was equal here as well, with some individuals contradicting each other. For example, some participants preferred the ”cuteness” and portable height (on the desk) of Nao and felt ”spoken down to like a child” as Pepper, others preferred the height of Pepper and felt restricted as Nao. How much these findings mattered to participants, and whether it changed their overall preference, varied by individual.

## VIII. Discussion

This study aimed to assess the usability of the immersive control system with two humanoid robots - Nao and Pepper - when being used by healthy adults. Overall the results have shown that the ideal resolution at which to use the system is currently 720p. It was also found that the participants found the system to be bulky and that the headset could benefit from a technical upgrade. Participants also suggested that the ability to switch between resolutions for different ranges of view (far-away vs close-up) would be beneficial.

Additionally, it was found that there was no statistically significant preference or difference in performance present between the two robots. Thematic analysis highlighted the importance of tailoring the system to each individual's needs, based on what they require of the system. For example, whether they would mainly want the system for navigation or interaction. It also became evident that while the system can control either robot, it largely depends on individual differences of the user.

### A. Implications for HRI

What these findings suggest is that social telepresence systems such as these have to be tailored to the users individual needs, and no one system can address all requirements of every possible user. This provides helpful insights for future development of this system and others like it, as well as informing future studies and highlighting the importance of conducting both wider user studies and more in-depth case studies where the system has been tailored for that specific user. However, this does bring into question how commercially available and widely used systems like this could become.

### B. Limitations

While the study itself provided a great deal of insight into the usability of the system, there were limitations. Due to COVID-19 restrictions, only participants from the University who had already gone training were allowed to take part - resulting in a relatively small sample size (N = 20). This was reduced further (N = 19) for tasks one and two due to technical issues with Pepper where the head and base did not move when instructed to by the participant.

## IX. Future Work

Future work will focus on improving the technical capabilities of the system, identifying the needs of the intended end users for this project, and further assessing the success of the system. These are described further below.

### A. Technical Development

As technical issues formed the majority of the disliked features it will be important to address these going forwards. Future work will focus on utilising technological advancements, such as upgrading the camera and virtual reality head-mounted display, to improve the resolution/delay trade-off and range of view. Doing so will also address the issue of the bulky, heavy headset as newer headsets are getting lighter with every iteration.

Another improvement will come from making the system wireless. Removing the need for the headset to be plugged into a computer will remove bulky cables and increase comfort for the user. Additionally, having the camera connected to an on-board computer on the robot will improve the range of navigation and mobility.

Finally, should Pepper be used with the system it will be beneficial to include a picture of the user on Pepper's tablet, which concurs with literature on human-robot interaction and social robotics.

### B. User Studies

Since this study was conducted a focus group has been conducted with healthcare professionals working in palliative care, as well as patients with life-limited illnesses and their family members. The results of this study will inform any user requirements and further development in addition to this usability study.

Following a further period of development a case study with a patient and their partner will be conducted. The choice of robot and certain aspects of the system will be tailored to their individual needs and preferences. This will further assess the usability, benefits, and limitations of the system.

## X. Conclusion

This study addressed the usability of an immersive control system for a humanoid robot surrogates. The findings showed the importance of tailoring systems like these to specific user requirements and how subject to individual differences technology like this can be. Future work will address technical limitations highlighted by the participants in this study. Additionally, a more in-depth case study will be conducted with an intended user - a patient with a life-limiting illness and their family - once the system has been tailored to their needs to further assess any benefits and limitations of the system.

REFERENCES

[1] J. H. Kashani, G. J. Barbero, and F. D. Bolander, "Depression in Hospitalized Pediatric Patients," *Journal of the American Academy of Child Psychiatry*, vol. 20, no. 1, pp. 123–134, 1981.

[2] H. G. Koenig, K. G. Meador, H. J. Cohen, and D. G. Blazer, "Depression in elderly hospitalized patients with medical illness," *Archives of Internal Medicine*, vol. 148, p. 1929, 9 1988.

[3] M. Thakur and D. G. Blazer, "Depression in long-term care." *Journal of the American Medical Directors Association*, vol. 9, pp. 82–7, 2 2008.

[4] D. W. Kissane, D. M. Clarke, and A. F. Street, "Demoralization syndrome–a relevant psychiatric diagnosis for palliative care." *Journal of palliative care*, vol. 17, no. 1, pp. 12–21, 2001.

[5] Marie Curie, "End of life experiences," 2018. [Online]. Available: https://www.mariecurie.org.uk/help/support/terminal-illness/preparing/end-of-life-experiences

[6] D. Feil-Seifer and M. Mataric, "Socially Assistive Robotics," in *9th International Conference on Rehabilitation Robotics, 2005. ICORR 2005.* IEEE, pp. 465–468.

[7] R.-H. Strong and P. G. Pestana, "Robots at chelsea and westminster hospital - youtube," 2015. [Online]. Available: https://www.youtube.com/watch?v=xhEsXBV7dFI

[8] B. News, "'robodog' helping people with dementia - bbc news," 2018. [Online]. Available: http://www.bbc.co.uk/news/av/uk-england-dorset-43479791/robotic-dog-in-dorset-care-home-helps-elderly-residents

[9] M. Househ, A. Kushniruk, M. Maclure, B. Carleton, and D. Cloutier-Fisher, "A case study examining the impacts of conferencing technologies in distributed healthcare groups," *ElectronicHealthcare*, vol. 8, 10 2009.

[10] B. G. Witmer and M. J. Singer, "Measuring Presence in Virtual Environments: A Presence Questionnaire, Tech. Rep. 3, 1998.

[11] F. Biocca, C. Harms, and J. Gregg, "The networked minds measure of social presence : Pilot test of the factor structure and concurrent validity," 2001.

[12] J. Steuer, "Defining virtual reality: Dimensions determining telepresence," *Journal of Communication*, vol. 42, pp. 73–93, 12 1992.

[13] W. R. Sherman and A. B. Craig, *Understanding virtual reality : interface, application, and design*. Morgan Kaufmann, 2003.

[14] Collins, "Telepresence definition and meaning — collins english dictionary." [Online]. Available: https://www.collinsdictionary.com/dictionary/english/telepresence

[15] M. Minsky, "Telepresence," 1980. [Online]. Available: http://web.media.mit.edu/ minsky/papers/Telepresence.html

[16] K. M. Tsui and H. A. Yanco, "Design challenges and guidelines for social interaction using mobile telepresence robots," *Reviews of Human Factors and Ergonomics*, vol. 9, pp. 227–301, 11 2013.

[17] S. O. Adalgeirsson and C. Breazeal, "Mebot: A robotic platform for socially embodied telepresence," 2010, pp. 15–22.

[18] L. Takayama and J. Go, "Mixing metaphors in mobile remote presence," 2012.

[19] K. M. Tsui, A. Norton, D. Brooks, H. A. Yanco, and D. Kontak, "Designing telepresence robot systems for use by people with special needs."

[20] J. H. Brockmyer, C. M. Fox, K. A. Curtiss, E. McBroom, K. M. Burkhart, and J. N. Pidruzny, "The development of the game engagement questionnaire: A measure of engagement in video game-playing," *Journal of Experimental Social Psychology*, vol. 45, pp. 624–634, 2009.

[21] H. Samani, E. Saadatian, N. Pang, D. Polydorou, O. N. N. Fernando, R. Nakatsu, and J. T. K. V. Koh, "Cultural robotics: The culture of robotics and robotics in culture," *International Journal of Advanced Robotic Systems*, vol. 10, p. 400, 12 2013.

[22] T. C. Ching, "The concept of presence in virtual reality – teo choong ching – medium," 2016. [Online]. Available: https://medium.com/@choongchingteo/the-concept-of-presence-in-virtual-reality-6d4332dc1a9c

[23] M. Sparks, "Don't break the spell: Creating presence in virtual reality — learning solutions magazine," 2017. [Online]. Available: https://www.learningsolutionsmag.com/articles/2389/dont-break-the-spell-creating-presence-in-virtual-reality

[24] F. Biocca and C. Harms, "(pdf) defining and measuring social presence: Contribution to the networked minds theory and measure," 2002.

[25] G. Cui, "Evaluating online social presence: An overview of social presence assessment," *Journal of Educational Technology Development and Exchange (JETDE)*, vol. 6, pp. 12–2013, 2013.

[26] J. Koetsier, "Vr needs more social: 77 percent of virtual reality users want more social engagement," 2018. [Online]. Available: https://www.forbes.com/sites/johnkoetsier/2018/04/30/virtual-reality-77-of-vr-users-want-more-social-engagement-67-use-weekly-28-use-daily/edd526318fc0

[27] S. T. Bulu, "Place presence, social presence, co-presence, and satisfaction in virtual worlds," *Computers Education*, vol. 58, pp. 154–161, 1 2012.

[28] S. Rogers, "Why is presence important for virtual reality? – vrfocus," 2017. [Online]. Available: https://www.vrfocus.com/2017/11/why-is-presence-important-for-virtual-reality/

[29] P. A. Hancock, D. R. Billings, K. E. Schaefer, J. Y. C. Chen, E. J. de Visser, and R. Parasuraman, "A meta-analysis of factors affecting trust in human-robot interaction," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 53, pp. 517–527, 10 2011.

[30] A. Bruce, I. Nourbakhsh, and R. Simmons, "The role of expressiveness and attention in human-robot interaction."

[31] I. Leite, C. Martinho, and A. Paiva, "Social robots for long-term interaction: A survey," *International Journal of Social Robotics*, vol. 5, pp. 291–308, 4 2013.

# Bibliography


[1] I. Vitanov, I. Farkhatdinov, B. Denoun, F. Palermo, A. Otaran, J. Brown, B. Omarali, T. Abrar, M. Hansard, C. Oh, S. Poslad, C. Liu, H. Godaba, K. Zhang, L. Jamone, and K. Althoefer, "A suite of robotic solutions for nuclear waste decommissioning," *Robotics 2021, Vol. 10, Page 112*, vol. 10, p. 112, 10 2021.

[2] L. Chan, "Robotics in manufacturing: How robots play a role in the assembly line? | robots.net," 8 2019. [Online]. Available: https://robots.net/robotics/robotics-in-manufacturing/

[3] D. W. Kissane, D. M. Clarke, and A. F. Street, "Demoralization syndrome–a relevant psychiatric diagnosis for palliative care." *Journal of palliative care*, vol. 17, pp. 12–21, 2001.

[4] W. H. Organisation, "Palliative care," 2018. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/palliative-care

[5] J. Lune, "Ceo blog: Why prospect hospice desperately needs more funding - prospect hospice," 4 2024. [Online]. Available: https://www.prospect-hospice.net/ceo-blog/

[6] NHS, "Coping with a terminal illness - nhs," 8 2023. [Online]. Available: https://www.nhs.uk/conditions/end-of-life-care/your-wellbeing/coping-with-a-terminal-illness/

[7] N. Bradley, M. Lloyd-Williams, and C. Dowrick, "Effectiveness of palliative care interventions offering social support to people with life-limiting illness—a systematic review," *European Journal of Cancer Care*, vol. 27, 5 2018.

[8] E. Gergerich, J. Mallonee, S. Gherardi, M. Kale-Cheever, and F. Duga, "Strengths and struggles for families involved in hospice care during the covid-19 pandemic," *Journal of social work in end-of-life and palliative care*, vol. 17, pp. 198–217, 2021.

[9] I. Guemghar, P. P. de Oliveira Padilha, A. Abdel-Baki, D. Jutras-Aswad, J. Paquette, and M. P. Pomey, "Social robot interventions in mental health care and their outcomes, barriers, and facilitators: Scoping review," *JMIR Mental Health*, vol. 9, 4 2022.

[10] N. Joshi, "Companion robots: An innovative ally to reduce social isolation of the elderly," 2022. [Online]. Available: https://www.linkedin.com/pulse/companion-robots-innovative-ally-reduce-social-isolation-naveen-joshi

[11] A. Miles, N. L. Fields, M. Bennett, L. Xu, K. Magruder, M. K. Stringfellow, B. J. Sesay, and S. Handique, "Robotic animal use among older adults enrolled in palliative or hospice care: A scoping review and framework for future research," *Robotics 2024, Vol. 13, Page 92*, vol. 13, p. 92, 6 2024.

[12] S. Howe and K. Florek, "Robots in social care: the human touch at risk," 2024. [Online]. Available: https://www.socialeurope.eu/robots-in-social-care-the-human-touch-at-risk

[13] M. Curie, "Compromised connections," 2024. [Online]. Available: https://www.mariecurie.org.uk/policy/compromised-connections

[14] ——, "End of life experiences," 2018. [Online]. Available: https://www.mariecurie.org.uk/help/support/terminal-illness/preparing/end-of-life-experiences

[15] M. Househ, A. Kushniruk, M. Maclure, B. Carleton, and D. Cloutier-Fisher, "A case study examining the impacts of conferencing technologies in distributed healthcare groups," *ElectronicHealthcare*, vol. 8, 10 2009.

[16] D. K. Anson, *Assistive Technology for People with Disabilities*. ABC-CLIO, LLC, 1 2018.

[17] J. Howard, Z. Fisher, A. H. Kemp, S. Lindsay, L. H. Tasker, and J. J. Tree, "Exploring the barriers to using assistive technology for individuals with chronic conditions: a meta-synthesis review," *Disability and Rehabilitation: Assistive Technology*, pp. 1–19, 2022.

[18] R. Haux, S. Koch, N. H. Lovell, M. Marschollek, N. Nakashima, and K. H. Wolf, "Health-enabling and ambient assistive technologies: Past, present, future," *Yearbook of medical informatics*, vol. 25, pp. S76–S91, 6 2016.

[19] R. F. dos Santos, P. Y. S. Sampaio, R. A. C. Sampaio, G. L. Gutierrez, and M. A. B. de Almeida, "Tecnologia assistiva e suas relações com a qualidade de vida de pessoas com deficiência," *Revista de Terapia Ocupacional da Universidade de São Paulo*, vol. 28, p. 54, 1 2017.

[20] R. Cericola, "The best smart assistive devices for people with disabilities | reviews by wirecutter," 3 2025. [Online]. Available: https://www.nytimes.com/wirecutter/reviews/best-assistive-smart-home-technology-for-disabled/

[21] M. Halpin, "Assistive technology for communication - how it helps," 2025. [Online]. Available: https://reciteme.com/news/assistive-technology-for-communication/

[22] N. Bradley and W. Poppen, "Assistive technology, computers and internet may decrease sense of isolation for homebound elderly and disabled persons," *Technology and Disability*, vol. 15, pp. 19–25, 2003.

[23] G. Dowds, M. Currie, L. Philip, and J. Masthoff, "A window to the outside world. digital technology to stimulate imaginative mobility for housebound older adults in rural areas," *Geographies of Transport and Ageing*, pp. 101–130, 6 2018.

[24] D. Robotics, "Telepresence robot for the hybrid office," 2025. [Online]. Available: https://www.doublerobotics.com/

[25] A. P. Schouten, T. C. Portegies, I. Withuis, L. M. Willemsen, and K. Mazerant-Dubois, "Robomorphism: Examining the effects of telepresence robots on between-student cooperation," *Computers in Human Behavior*, vol. 126, p. 106980, 1 2022.

[26] L. Magnusson, E. Hanson, and M. Borg, "A literature review study of information and communication technology as a support for frail older people living at home and their family carers," *Technology and Disability*, vol. 16, pp. 223–235, 2004.

[27] K. Kim, A. Nagendran, J. N. Bailenson, A. Raij, G. Bruder, M. Lee, R. Schubert, X. Yan, and G. F. Welch, "A large-scale study of surrogate physicality and gesturing on human–surrogate interactions in a public space," *Frontiers in Robotics and AI*, vol. 4, p. 252919, 7 2017.

[28] J. A. Waterworth and E. L. Waterworth, *Distributed Embodiment: Real Presence in Virtual Bodies*. Oxford University Press, 12 2013, pp. 589–601.

[29] D. Gall, D. Roth, J. P. Stauffert, J. Zarges, and M. E. Latoschik, "Embodiment in virtual reality intensifies emotional responses to virtual stimuli," *Frontiers in Psychology*, vol. 12, p. 674179, 9 2021.

[30] A. Hamad and B. Jia, "How virtual reality technology has changed our lives: An overview of the current and potential applications and limitations," *International Journal of Environmental Research and Public Health*, vol. 19, 9 2022.

[31] S. Ohl, "Tele-immersion concepts," *IEEE Transactions on Visualization and Computer Graphics*, vol. 24, pp. 2827–2842, 10 2018.

[32] A. Haans and W. A. Ijsselsteijn, "Embodiment and telepresence: Toward a comprehensive theoretical framework," *Interacting with Computers*, vol. 24, pp. 211–218, 7 2012.

[33] B. G. Witmer and M. J. Singer, "Measuring presence in virtual environments: A presence questionnaire," p. 225, 1998. [Online]. Available: https://nil.cs.uno.edu/publications/papers/witmer1998measuring.pdf

[34] F. Biocca and C. Harms, "Defining and measuring social presence: Contribution to the networked minds theory and measure," *Proceedings of the Fifth Annual International Workshop on Presence*, 01 2002.

[35] N. Savela, T. Turja, R. Latikka, and A. Oksanen, "Media effects on the perceptions of robots," *Human Behavior and Emerging Technologies*, vol. 3, pp. 989–1003, 12 2021.

[36] F. Hegel, C. Muhl, B. Wrede, M. Hielscher-Fastabend, and G. Sagerer, "Understanding social robots," *Proceedings of the 2nd International Conferences on Advances in Computer-Human Interactions, ACHI 2009*, pp. 169–174, 2009.

[37] T. Trailer, "Robots in surrogates movie," 7 2009. [Online]. Available: https://teaser-trailer.com/robots-in-surrogates-movie/

[38] K. M. Tsui and H. A. Yanco, "Design challenges and guidelines for social interaction using mobile telepresence robots," *Reviews of Human Factors and Ergonomics*, vol. 9, pp. 227–301, 11 2013.

[39] B. Preim, R. Raidou, N. Smit, and K. Lawonn, "Introduction to virtual reality," *Visualization, Visual Analytics and Virtual Reality in Medicine*, pp. 355–401, 1 2023.

[40] J. Steuer and B. Reeves, "Defining virtual reality: Dimensions determining telepresence," *Journal of Communication*, vol. 42, pp. 73–93, 1992.

[41] V. Souza, A. Maciel, L. Nedel, and R. Kopper, "Measuring presence in virtual environments: A survey," *ACM Computing Surveys (CSUR)*, vol. 54, 10 2021.

[42] B. H. Channel, "Maintaining your quality of life during a life-limiting illness - better health channel," 2017. [Online]. Available: https://www.betterhealth.vic.gov.au/health/servicesandsupport/Maintaining-quality-of-life-during-a-life-limiting-illness

[43] C. Research, "Managing your symptoms | cancer research uk," 2022. [Online]. Available: https://www.cancerresearchuk.org/about-cancer/coping/dying-with-cancer/last-few-weeks-and-days/managing-symptoms

[44] P. Bremner, N. Trigoni, I. Brown, H. Gunes, C. Bevan, D. Stanton Fraser, and M. Levine, "Being there: humans and robots in public spaces," in *Social Robotics: 5th International Conference, ICSR 2013, Bristol, UK, October 27-29, 2013, Proceedings*, ser. Lecture Notes in Computer Science, G. Herrmann, M. Pearson, A. Lenz, P. Bremner, A. Spiers, and U. Leonards, Eds. Springer, 2013, pp. 581–582.

[45] M. Mara, M. Appel, and T. Gnambs, "Human-like robots and the uncanny valley," *https://doi.org/10.1027/2151-2604/a000486*, vol. 230, pp. 33–46, 2 2022.

[46] M. Bender, "Escaping the uncanny valley," 2022. [Online]. Available: https://remars.amazonevents.com/discover/robotics/article/escaping-the-uncanny-valley/

[47] M. Mori, K. F. Macdorman, and N. Kageki, "The uncanny valley: The original essay by masahiro mori," 2012. [Online]. Available: https://spectrum.ieee.org/automaton/robotics/humanoids/the-uncanny-valley

[48] R. Sakurai, M. Yasunaga, M. Nishi, T. Fukaya, M. Hasebe, Y. Murayama, T. Koike, H. Matsunaga, K. Nonaka, H. Suzuki, M. Saito, E. Kobayashi, and Y. Fujiwara, "Co-existence of social isolation and homebound status increase the risk of all-cause mortality," *International Psychogeriatrics*, vol. 31, pp. 703–711, 5 2019.

[49] NHS, "Changes in the last hours and days - nhs," 2023. [Online]. Available: https://www.nhs.uk/conditions/end-of-life-care/your-wellbeing/changes-in-the-last-hours-and-days/

[50] M. Curie, "Good communication at end of life | information for professionals," 2020. [Online]. Available: https://www.mariecurie.org.uk/professionals/palliative-care-knowledge-zone/individual-needs/good_communication

[51] O. H. P. Studies, "The covid-19 pandemic and the future of telemedicine," Tech. Rep., 1 2023. [Online]. Available: https://www.oecd.org/en/publications/the-covid-19-pandemic-and-the-future-of-telemedicine_ac8b0a27-en.html

[52] T. H. Foundation and N. Trust, "Digital and remote care in the nhs during covid-19 | qualitywatch," 2020. [Online]. Available: https://www.nuffieldtrust.org.uk/sites/default/files/2020-12/QWAS/digital-and-remote-care-in-covid-19.html#1

[53] J. Shaver, "The state of telehealth before and after the covid-19 pandemic," *Primary Care*, vol. 49, p. 517, 12 2022.

[54] S. N. Gajarawala and J. N. Pelkowski, "Telehealth benefits and barriers," *The Journal for Nurse Practitioners*, vol. 17, p. 218, 2 2021.

[55] A. Haleem, M. Javaid, R. P. Singh, and R. Suman, "Telemedicine for healthcare: Capabilities, features, barriers, and applications," *Sensors International*, vol. 2, p. 100117, 1 2021.

[56] C. Wardle, "Telehealth vs in person care – what is the difference?" 2024. [Online]. Available: https://www.theaccessgroup.com/en-gb/blog/hsc-telehealth-vs-in-person-care-what-s-the-difference-and-why-is-it-important/

[57] M. Curie, "We're here to support you | marie curie," 2024. [Online]. Available: https://www.mariecurie.org.uk/help

[58] ——, "Marie curie companions," 2024. [Online]. Available: https://www.mariecurie.org.uk/help/companions

[59] L. Veling and C. McGinn, "Qualitative research in hri: A review and taxonomy," *International Journal of Social Robotics*, vol. 13, pp. 1689–1709, 11 2021.

[60] K. Winkle, P. Caleb-Solly, A. Turton, and P. Bremner, "Mutual shaping in the design of socially assistive robots: A case study on social robots for therapy," *International Journal of Social Robotics*, pp. 1–20, 3 2019.

[61] T. Johnson, L. Bauler, D. Vos, A. Hifko, P. Garg, M. Ahmed, and M. Raphelson, "Virtual reality use for symptom management in palliative care: A pilot study to assess user perceptions." *Journal of palliative medicine*, 1 2020.

[62] A. Nwosu, "Ai in palliative and end of life care: Dr ami nwosu," 2024. [Online]. Available: https://www.mariecurie.org.uk/blog/ai-in-palliative-care/379630

[63] H. L. Bradwell, K. J. Edwards, R. Winnington, S. Thill, and R. B. Jones, "Companion robots for older people: importance of user-centred design demonstrated through observations and focus groups comparing preferences of older people and roboticists in south west england," *BMJ Open*, vol. 9, p. e032468, 9 2019.

[64] K. Niki, Y. Okamoto, I. Maeda, I. Mori, R. Ishii, Y. Matsuda, T. Takagi, and E. Uejima, "A novel palliative care approach using virtual reality for improving various symptoms of terminal cancer patients: A preliminary prospective, multicenter study," *Journal of Palliative Medicine*, vol. 22, pp. 702–707, 6 2019.

[65] W. H. Li, J. O. Chung, and E. K. Ho, "The effectiveness of therapeutic play, using virtual reality computer games, in promoting the psychological well-being of children hospitalised with cancer," *Journal of Clinical Nursing*, vol. 20, pp. 2135–2143, 8 2011.

[66] L. Perna-Forrest and O. Minton, "The potential for virtual reality therapy in palliative care – preliminary findings," *Poster presentations*, vol. 9. British Medical Journal Publishing Group, 3 2019, pp. A63.1–A63.

[67] J. Gershon, E. Zimand, R. Lemos, B. O. Rothbaum, and L. Hodges, "Use of virtual reality as a distractor for painful procedures in a patient with pediatric cancer: A case study," *CyberPsychology & Behavior*, vol. 6, pp. 657–661, 12 2003.

[68] A. C. Nwosu, B. Sturgeon, T. McGlinchey, C. D. Goodwin, A. Behera, S. Mason, S. Stanley, and T. R. Payne, "Robotic technology for palliative and supportive care: Strengths, weaknesses, opportunities and threats," *Palliative Medicine*, 9 2019.

[69] U. R. Group, “Nao: the educational robot | united robotics group,” 2024. [Online]. Available: https://unitedrobotics.group/en/robots/nao

[70] S. Jamshed, “Qualitative research method-interviewing and observation,” *Journal of Basic and Clinical Pharmacy*, vol. 5, p. 87, 2014.

[71] V. Braun and V. Clarke, “Using thematic analysis in psychology,” *Qualitative Research in Psychology*, vol. 3, pp. 77–101, 2006.

[72] T. Leopold, “Hitchbot, hitchhiking robot, gets beheaded in philly | cnn,” 2015. [Online]. Available: https://edition.cnn.com/2015/08/03/us/hitchbot-robot-beheaded-philadelphia-feat/index.html

[73] Aldebaran, “Pepper the humanoid and programmable robot |aldebaran,” 2022. [Online]. Available: https://www.aldebaran.com/en/pepper

[74] E. Arts, “Socibot - engineered arts wiki.” [Online]. Available: https://wiki.engineeredarts.co.uk/SociBot

[75] C. Luo, R. Yuan, B. Mao, Q. Liu, W. Wang, and Y. He, “Technology acceptance of socially assistive robots among older adults and the factors influencing it: A meta-analysis,” *Journal of Applied Gerontology*, vol. 43, pp. 115–128, 2 2024.

[76] O. L. Jacobs, K. Gazzaz, and A. Kingstone, “Mind the robot! variation in attributions of mind to a wide set of real and fictional robots,” *International Journal of Social Robotics*, vol. 14, pp. 529–537, 3 2022.

[77] U. Backonja, A. K. Hall, I. Painter, L. Kneale, A. Lazar, M. Cakmak, H. J. Thompson, and G. Demiris, “Comfort and attitudes towards robots among young, middle-aged, and older adults: A cross-sectional study,” *Journal of Nursing Scholarship*, vol. 50, pp. 623–633, 11 2018.

[78] S. K. Vasudevan, “A cross-cultural comparison of attitudes toward robots among a japanese and us university faculty using implicit and explicit measures,” Master’s thesis, 5 2008. [Online]. Available: https://scholarworks.indianapolis.iu.edu/server/api/core/bitstreams/d8703adf-f9a9-43b6-839c-463facb792e6/content

[79] I. Papadopoulos and C. Koulouglioti, “The influence of culture on attitudes towards humanoid and animal-like robots: An integrative review,” *Journal of Nursing Scholarship*, vol. 50, pp. 653–665, 11 2018.

[80] M. Cheetham, P. Suter, and L. Jäncke, “The human likeness dimension of the “uncanny valley hypothesis”: Behavioral and functional mri findings,” *Frontiers in Human Neuroscience*, vol. 5, 2011.

[81] J. E. Daly, P. Bremner, and U. Leonards, “Robots in need: Acquiring assistance with emotion,” *ACM/IEEE International Conference on Human-Robot Interaction*, vol. 2019-March, pp. 706–708, 3 2019.

[82] I. Leite, C. Martinho, and A. Paiva, “Social Robots for Long-Term Interaction: A Survey,” *International Journal of Social Robotics*, vol. 5, no. 2, pp. 291–308, apr 2013.

[83] S. O. Adalgeirsson and C. Breazeal, “Mebot: A robotic platform for socially embodied telepresence,” *2010 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2010, pp. 15–22.

[84] A. K. Pandey and R. Gelin, “A mass-produced sociable humanoid robot: Pepper: the first machine of its kind,” *IEEE Robotics and Automation Magazine*, vol. 25, pp. 40–48, 9 2018.

[85] L. Takayama and J. Go, “Mixing metaphors in mobile remote presence,” in *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work*, ser. CSCW ’12. New York, NY, USA: Association for Computing Machinery, 2012, p. 495–504.

[86] A. Bruce, I. Nourbakhsh, and R. Simmons, “The role of expressiveness and attention in human-robot interaction.” [Online]. Available: http://www.cs.cmu.edu/~abruce/papers/bruce_icra2002.pdf

[87] K. M. Tsui, A. Norton, D. Brooks, H. A. Yanco, and D. Kontak, “Designing telepresence robot systems for use by people with special needs.” [Online]. Available: http://robotics.cs.uml.edu/fileadmin/content/publications/2011/2011-06-qolt-ktsui-anorton-dbrooks-hyanco-dkontak.pdf

[88] M. Staff, “Research shows htc vive is developers most popular vr platform - mcv/develop,” 2017. [Online]. Available: https://mcvuk.com/development-news/research-shows-htc-vive-is-developers-most-popular-vr-platform/

[89] V. Inc., “A guide to 360º virtual reality: Part 1 - cameras | by visbit inc. | visbit blog | medium,” 2017. [Online]. Available: https://medium.com/visbit/a-guide-to-360%C2%BA-virtual-reality-for-content-creators-part-1-cameras-46131dbbf647

[90] M. Ty, “Best 360 cameras of 2017 in first 360 camera awards presented by life in 360 rumors | 360 rumors,” 2017. [Online]. Available: https://360rumors.com/best-360-cameras-awards-2017/

[91] T. . Guy, “The best 360 cameras of 2018 - ultimate 360 camera buying guide,” 2018. [Online]. Available: https://www.threesixtycameras.com/best-360-camera-2017-buying-guide/

[92] ——, “Pros and cons of every 360 camera: Which one is best for you?” [Online]. Available: https://www.threesixtycameras.com/pros-cons-every-360-camera/

[93] Ricoh, “Theta v - ricoh,” 2024. [Online]. Available: https://us.ricoh-imaging.com/product/theta-v/

[94] Y. Telles, “Unity vs unreal for vr: Key differences and how to choose,” 2022. [Online]. Available: https://ventionteams.com/blog/unity-vs-unreal-virtual-reality

[95] L. Goode, “Pepper the ’emotional robot’ makes its way to Silicon Valley - The Verge,” 2016. [Online]. Available: https://www.theverge.com/2016/8/12/12453770/pepper-emotional-robot-softbank-b8ta-silicon-valley

[96] A. Singh, “’Pepper’ the emotional robot, sells out within a minute - CNN,” 2015. [Online]. Available: https://edition.cnn.com/2015/06/22/tech/pepper-robot-sold-out/index.html

[97] X. Wei, X. Jin, and M. Fan, “Communication in immersive social virtual reality: A systematic review of 10 years’ studies,” *ACM International Conference Proceeding Series*, pp. 27–37, 10 2022.

[98] M. H. Nguyen, J. Gruber, J. Fuchs, W. Marler, A. Hunsaker, and E. Hargittai, “Changes in digital communication during the covid-19 global pandemic: Implications for digital inequality and future research,” *Social Media and Society*, vol. 6, 7 2020.

[99] T. Ying, J. Tang, S. Ye, X. Tan, and W. Wei, “Virtual reality in destination marketing: Telepresence, social presence, and tourists’ visit intentions,” *Journal of Travel Research*, vol. 61, pp. 1738–1756, 11 2022.

[100] M. Niemelä, L. van Aerschot, A. Tammela, I. Aaltonen, and H. Lammi, “Towards ethical guidelines of using telepresence robots in residential care,” *International Journal of Social Robotics*, pp. 1–9, 2 2019.

[101] H. Samani, E. Saadatian, N. Pang, D. Polydorou, O. N. N. Fernando, R. Nakatsu, and J. T. K. V. Koh, “Cultural robotics: The culture of robotics and robotics in culture,” *International Journal of Advanced Robotic Systems*, vol. 10, p. 400, 12 2013.

[102] T. C. Ching, “The concept of presence in virtual reality – teo choong ching – medium,” 2016. [Online]. Available: https://medium.com/@choongchingteo/the-concept-of-presence-in-virtual-reality-6d4332dc1a9c

[103] R. Brown, “Vrcompare - the internet’s largest vr  ar headset database,” 2024. [Online]. Available: https://vr-compare.com/

[104] F. Biocca, C. Harms, and J. Gregg, “The networked minds measure of social presence : Pilot test of the factor structure and concurrent validity,” 2001. [Online]. Available: https://www.semanticscholar.org/paper/The-Networked-Minds-Measure-of-Social-Presence-%3A-of-Biocca-Harms/784977a00148ea24e1a65e6160823305a2ceb95c

[105] F. Biocca and C. Harms, “Networked minds social presence inventory: |(scales only, version 1.2) measures of co-presence, social presence, subjective symmetry, and intersubjective symmetry,” 1 2003. [Online]. Available: https://www.researchgate.net/publication/40700445_Networked_Minds_Social_Presence_Inventory_Scales_only_Version_12_Measures_of_co-presence_social_presence_subjective_symmetry_and_intersubjective_symmetry

[106] V. Forum, “Best camera for streaming into vive headset? - developer discussion - vive forum,” 2021. [Online]. Available: https://forum.htc.com/topic/9092-best-camera-for-streaming-into-vive-headset/#comment-39099

[107] J. Flanagan, S. DeSanto-Madeya, and B. Simms, “Using skype to facilitate presence at the end of life,” *Journal of Hospice and Palliative Nursing*, vol. 16, pp. 489–494, 12 2014.

[108] A. Ljung and E. Wahlforss, “Sensation: a presence enabler for long-distance relationships using skype and visual presence representation,” Master’s thesis, Mediatechnology, Royal Institute of Technology (KTH), 2006.

[109] eztalks, “Top 10 of the best video conferencing of 2017 | eztalks: Business software reviews how-to,” 2017. [Online]. Available: https://eztalks.com/video-conference/top-10-of-the-best-video-conferencing-of-2017.html#google_vignette

[110] P. A. Bremner, O. Celiktutan, and H. Gunes, “Personality perception of robot avatar teleoperators in solo and dyadic tasks,” *Frontiers in Robotics and AI*, vol. 4, p. 16, 5 2017.

[111] G. Purdom. (2018) 5 surprising items that would help you on a desert island, according to a survival expert | mental floss. [Online]. Available: http://mentalfloss.com/article/524300/5-surprising-items-would-help-you-desert-island-according-survival-expert

[112] A. for Psychological Science, “Nasa exercise: Ranking survival objects for the moon,” *APS Observer*, vol. 29, 1 2016.

[113] J. Brooke, *SUS: A ’Quick and Dirty’ Usability Scale*, 1st ed. CRC Press, 6 1996, pp. 207–212.

[114] R. Kirby, “Social robot navigation,” Ph.D. dissertation, 5 2010.

[115] J. Cowling, “A brief history of skype - the peer to peer messaging service,” 2016. [Online]. Available: https://content.dsp.co.uk/history-of-skype

[116] R. Stone, “Virtual reality and telepresence,” *Robotica*, vol. 10, p. 461, 9 1992.

[117] A. Cross, “The evolution of virtual reality: Exploring the past, present and future,” 2023. [Online]. Available: https://www.forbes.com/sites/forbesbusinesscouncil/2023/11/09/the-evolution-of-virtual-reality-exploring-the-past-present-and-future/

[118] A. Ștefania Ghiță, A. F. Gavril, M. Nan, B. Hoteit, I. A. Awada, A. Sorici, I. G. Mocanu, and A. M. Florea, “The amiro social robotics framework: Deployment and evaluation on the pepper robot,” *Sensors 2020, Vol. 20, Page 7271*, vol. 20, p. 7271, 12 2020.

[119] S. R. Documentation, “Dimensions — aldebaran 2.8.7.4 documentation.” [Online]. Available: http://doc.aldebaran.com/2-8/family/pepper_technical/dimensions_pep.html

[120] ——, “Dimensions — aldebaran 2.8.7.4 documentation.” [Online]. Available: http://doc.aldebaran.com/2-8/family/nao_technical/dimensions_naov6.html

[121] C. Office, “[withdrawn] staying at home and away from others (social distancing) - gov.uk,” 2020. [Online]. Available: https://www.gov.uk/government/publications/full-guidance-on-staying-at-home-and-away-from-others

[122] C. Overbeeke and P. Stappers, “The importance of movement for the design of telepresence systems,” *IFAC Proceedings Volumes*, vol. 28, pp. 189–194, 6 1995.

[123] I. D. Foundation, “What is usability testing? — updated 2024 | ixdf,” 2016. [Online]. Available: https://www.interaction-design.org/literature/topics/usability-testing

[124] X. Ji and P. L. P. Rau, “A comparison of three think-aloud protocols used to evaluate a voice intelligent agent that expresses emotions,” *Behaviour Information Technology*, vol. 38, pp. 375–383, 4 2019.

[125] M. R. Fraune, I. Leite, N. Karatas, A. Amirova, A. Legeleux, A. Sandygulova, A. Neerincx, G. D. Tikas, H. Gunes, M. Mohan, N. I. Abbasi, S. Shenoy, B. Scassellati, E. J. de Visser, and T. Komatsu, “Lessons learned about designing and conducting studies from hri experts,” *Frontiers in Robotics and AI*, vol. 8, p. 772141, 1 2022.

[126] H. . C. P. Council, “Communicating during the covid-19 pandemic |,” 2020. [Online]. Available: https://www.hcpc-uk.org/covid-19/advice/applying-our-standards/communicating-during-the-covid-19-pandemic/

[127] S. Rogers, “Why is presence important for virtual reality? – vrfocus,” 2017. [Online]. Available: https://www.vrfocus.com/2017/11/why-is-presence-important-for-virtual-reality/

[128] P. A. Hancock, D. R. Billings, K. E. Schaefer, J. Y. C. Chen, E. J. de Visser, and R. Parasuraman, "A meta-analysis of factors affecting trust in human-robot interaction," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 53, pp. 517–527, 10 2011.

[129] Q. Xu, J. S. Ng, O. Y. Tan, and Z. Huang, "Needs and attitudes of singaporeans towards home service robots: a multi-generational perspective," *Universal Access in the Information Society*, vol. 14, pp. 477–486, 11 2015.

[130] M. M. D. Graaf, S. B. Allouch, and J. A. V. Dijk, "Long-term evaluation of a social robot in real homes," *AISB 2014 - 50th Annual Convention of the AISB*, vol. 17, pp. 462–491, 3 2014.

[131] M. M. A. de Graaf, S. B. Allouch, and J. A. G. M. van Dijk, "Long-term acceptance of social robots in domestic environments: Insights from a user's perspective," in *No. 3: Enabling Computing Research in Socially Intelligent Human-Robot Interaction: A Community-Driven Modular Research Platform*, 2016.

[132] H. Su, W. Qi, J. Chen, C. Yang, J. Sandoval, and M. A. Laribi, "Recent advancements in multimodal human–robot interaction," *Frontiers in Neurorobotics*, vol. 17, p. 1084000, 5 2023.

[133] SpecialEffect, "Specialeffect devkit," 2024. [Online]. Available: https://specialeffectdevkit.info/