Investigating the Effectiveness of Different Interaction Modalities for Spatial Human-robot Interaction

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ABSTRACT

The rapid growth in the fields of social robots and human-robot interaction (HRI) increases the possibility of human-robot close encounter resulting in the ability for a robot to communicate its movement intent becoming important. Based on the existing literature, we integrated eye contact, gaze and head nodding into the design the robot's behaviour and aimed to investigate the effects of these cues as well as their combination with body posture on the efficiency of passing and the quality of HRI. Our results show that the combination of eye contact and turning sideways is the most effective and appropriate compared to other modalities.

KEYWORDS

human-robot interaction, modality, movement intention, gaze, eye contact, nod, body posture

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1 INTRODUCTION

Recent years have witnessed rapid development in social robots. They have been employed in a variety of fields, such as education, service and entertainment [7, 8, 10, 11]. It is possible, as more robots are developed for these purposes, that we will encounter situations in the future where we need to pass by such a robot in close proximity. Even though passing each other is a simple task for two humans, this is not always true for a human and a robot. In human-human interaction (HHI), people usually use some social cues to convey their movement intention. Many researchers also did extensive work on the impacts of these cues on human-robot communication and robot-to-human handovers [1, 5, 6, 9]. However, it remains unclear whether the effects of these cues can be generalised to other scenarios of HRI. Failure to use effective and appropriate cues can lead to a collision or the robot being perceived negatively. Therefore, it is important to investigate how the robot should express its movement intention. For this, we conducted an experiment where people had to pass a robot and the robot communicated its intention of moving in six different modalities (2 (stop vs. turn sideways) x 3 (eye contact vs. gaze vs. nod)).

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2 RELATED WORK

In HHI, people adjust their behaviour and react to others based on social cues. These consist of physical cues (e.g. physical appearance and environment) and behavioural cues that include verbal cues (e.g. speech, laughter and the like) and nonverbal cues (e.g. gestures, eye behaviour and other movements of the body) [12]. To facilitate natural HRI, some of these cues are also used in the design of the robot's behaviour as they are more familiar and understandable to humans [3]. Given that verbal cues are not always used when two people pass by each other, we focus on nonverbal cues in our study. As proposed by [2], the most obvious nonverbal cues are produced body posture, gestures, and head and eye position. It is important to notice the distinction between eye contact and gaze. Gaze can be categorised into mutual gaze, which is also known as "eye contact"; referential gaze: gaze directed at an object or location in space; joint attention: focusing on a common object and gaze aversions: shifts of gaze away from the main direction. As joint attention and gaze aversion were not involved in our study, we investigate mutual gaze (from now on described as eye contact) and referential gaze (from now on described as gaze). [9] conducted an eye-tracking study on collaborative learning and demonstrated that eye contact helped to increase the quality of collaboration and learning gain. In [6], it has been proven that gaze can improve the handover timing and users tend to perceive the robot positively when the robot looking at their faces. [4] stated that people use head nodding to show their acknowledgement and engagement during interactions. Researchers also focus on the design of the robot's nodding to achieve a more natural human-robot dialogue interaction [5].

Given that the time spent in passing can be quite short, if the robot can show its attentiveness and engagement, it may help people to pass by the robot with more confidence so that the efficiency of passing and the experience that people have when they pass by the robot can be improved. Previous studies indicate that the robot's gaze behaviour is able to attract people's attention and guide them in a cooperative task, and nodding can be used as a cue of acknowledgement and engagement. We thus developed an experiment in which the robot showed these cues before passing by people.

3 METHODS

We ran a within-subjects experiment, where participants had to walk past social robot Pepper to enter through a door six times. Each time the robot would show different cues to show its moving intention (the order of these cues was randomised). After each trial, participants were asked to answer three short questions and move back to the starting position. The six conditions are summarised in Table 1.

Table 1: Experimental conditions

Behavioural Design	Description
Stop & Eye contact (SE)	The robot tracked the participant's face while moving. Before passing by the
Turn & Eye contact (TE)	participant, the robot stopped/turned sideways and maintained eye contact.
Stop & Gaze (SG)	The robot rotated its head 15 degrees left first then started to move.
Turn & Gaze (TG)	Before passing by the participant, the robot stopped/turned sideways.
Stop & Nod (SN)	The robot nodded first then started to move. Before passing by the participant,
Turn & Nod (TN)	the robot stopped/turned sideways and nodded again.

Figure 1: The views captured by three cameras.

The experiment was video-recorded to determine the duration of passing the robot for each condition. Three cameras captured the views from top, front and side (see Figure 1). The ground with 0.5m x 0.5m grids for more precise measurements. To simulate the situation where people have to pass the robot in close proximity, we also put two boards on both sides and limit the path to be 1.5m wide. After each trial, participants had to answer three short questions on how comfortable and safe they felt, and how helpful the robot's cues were. Other measurements included demographics (age, gender, familiarity with Pepper and robotic technologies).

4 RESULTS

A total of 22 participants (14 males, 8 females) took part in the experiment. Most participants were from the 18-34 age range and three of them were aged 45 and over. Their average familiarity with robotics technology was 2.86 (SD = 1.08) and that of the Pepper robot was 2.09 (SD = 0.75) based on a 4-point Likert scale ranging from "Not familiar" to "Very familiar".

Data from 2 participants was excluded from analysis due to being outliers. The average time spent in passing the robot for each condition is presented in Figure 2 (left). Compared to the conditions where the robot stopped before passing by participants, participants passed the robot more quickly when the robot turned sideways. This difference is best shown between SG and TG. The time spent in passing is lower when the robot made eye contact with participants as opposed to the conditions that involve head nodding.

As shown in Figure 2 (right), perceived comfort was lowest for TG. In terms of perceived helpfulness, it is noteworthy that when eye contact and gaze were accompanied by turning sideways, participants reported the robot's behaviour being more helpful in communicating its intention to move.

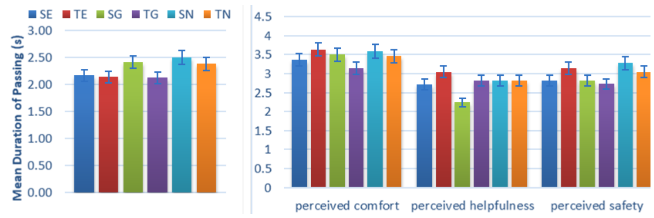

Figure 2: Mean duration of passing when the robot communicated its intent to move in six different modalities (left); mean scores of each dimension in the follow-up questionnaire of each trial (right).

5 DISCUSSION

This study investigated six different conditions for a robot to show its intention to move when passing a human. The results showed that eye contact resulted in the shortest and most efficient passing duration. Additionally, it appears that the robot turning sideways made the passing more effective, especially when it was combined with a gaze. Overall TE appears to be the most effective and appropriate modality in communicating movement intention before passing.

Previous studies have demonstrated the effects of eye contact on the improvement of task performance and quality of HRI [6, 9]. The results obtained in our research indicate that such effects also exist in human-robot close encounter. Interestingly, we found that although the combination with turning sideways tends to be beneficial for the improvement of efficiency, it does not always have a positive impact on the participants' experience. As future work, we will further investigate the effects of the combination with other cues on communicating the robot's intent to move.

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