Towards establishing a 'Cooperation' Measure for Coupled Movement in Close-Proximity Human-Robot Interaction*

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***Abstract*— To achieve safe close-proximity human-robot interaction, particularly for physically assitive tasks, robot motion planning needs to recognize and adapt to the behaviour of humans in the long-term. Generally, motion prediction with probabilistic confidence-awareness models can be used to reason and predict with a degree of confidence the next movement of human in task. As such in order to ensure safety in robot trajectory planning, it is important to learn the variance in the human movement. The variance in the human skill to interact with robots in close proximity can drastically be altered if external distractions or cognitive overloading occur during such interaction. Even if this can be a one-off event, it is critical to evaluate the alteration in the movement to ensure long-term safety over the long-term. For robust long-term human movement prediction and adaption, the overall safety properties of any planner requires collision-free, good approximation and coupling of the robot's movement with that of the human when these type of mistakes occur. In the context of close-proximity human-robot collaboration, the confidence-aware models need to have a measure of cooperation by observing changes in human-robot trajectory comparison because in such interaction collision avoidance is not a requirement of the interaction, but the synchronous movement is. We provide a collaborative measure that represents coupling between the robot movement and the human movement. This measure can provide an additional metric for ensuring overall safety in trajectory planning. We demonstrate this cooperative measure in an assistive dressing scenario, where controlled experiments were performed to study the differences in coupling during learning of the robot-initiated dressing skill by the human, and then introducing cognitive loading and external distractions. This cooperative measure helps to detect the lack of collaboration caused by the one-off events caused by a lack of cooperation rather than just accounting for just the variance in the movement of a learned skill.**

I. INTRODUCTION

The hypothesis on which this dataset was created is based on the fact that there is likely to be a difference between distracted and non-distracted instances of the dressing task, and also there is likely to be a variance in the skill learnt by the human when performing the assistive task movement over time. Modelling and learning these differences can be used to improve safety by preventing or preempting collisions or failures. We created disturbances in the surrounding environment and also cognitively loaded the user, which resulted in failed human-robot interaction, even though the skill for interacting with the robot was already familiar to the user. As part of the initial analysis of the experiments, we found that it is not enough to be able to just map the variance in movement, we also need to precisely measure the nature of the movement. For safety, a measure of collaboration is essential to measure the deviation in trajectory but also can serve as a measure of coupling between the human and the robot. This cooperation measure is represented in the form of a viability kernel which can eventually be used for reachability analysis in similar types of close proximity human-robot interaction. The states in the kernel with the lowest values for the cooperation measure show the instances in which the failures are more likely to happen or will happen. This can enable better confidence-aware robot planning based on the knowledge regarding coupled movement, leading to more appropriate and responsive decision making in the assistive task. Ben Amor et al. [1] present a way of learning the inherent correlations of a cooperative activity to infer the behaviour of the partner and to participate in the cooperation. The authors in [2] present a mixture model of human-robot interaction primitives that allow the infer the human movement from observations. On the other hand, Mainprince et al. in [3] present an interactive re-planning process to capture the adaption to the partner's motion.

Assuming that the motion prediction is pattern-based as explained in[4] and that we need to consider the impact of the dynamic environment cues we need to have a measure of the how the correlation of the movements between the human and the robot varies when the human is no longer focusing on adaption and collaborating to the partner in the interaction due to external disturbances. The HRI experiment carried out showed that failures in the assistive task occur when distraction or cognitive overloading occurs. The contribution of this work visualises the variation in the correlation between the human and the robot in the assistive task when the cooperation and attention are shifted away from the assistive task.

II. APPROACH

In order to evaluate this cooperative measure a dataset of movement generated by humans while interacting with the Rethink Research Baxter robot is created through a set of experiments. The assistive task is that of being dressed with an outer layer of jacket. The human movement is

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recorded through the use of the Xsens Suit. The experiment layout is explained in our previous work presented here [5] . The environment in which the interaction takes places is controlled which allows us to generated a dataset of human movements during which cognitive overloading and distractions, on the human, lead to a lack of synchronisation between the human and the assistive robot. The cognitive overloading and distractions lead to failure in the assistive task. Being able to predict these failures and have a better understanding of what type of variation in the arm movements can be contributed to a lack of cooperation due lessened attention is critical for safety.

The aim of creating the cooperative measure is that of being able to extract the difference in the coupled movement of the human arms and the robot's end effector. The data represent the time-series of the robots' end effector and the human movement properties. Feature engineering is constructed on the trajectories of the human body motion (represented by position and rotations quaternions of 23 joints) using a sliding window along the time series. We are interested into highlighting the difference in the right arm movement of the human with respect to the robot's right arm movement through a cooperation measure extracted from the trajectories. The feature engineering extracted are based on statistical features from the motion of the arm movements with respect to the robot's movement during the close-proximity interaction. The features extracted are: variance, skewness, kurtoisis, reference crossing, wasserstein distance measure between human-robot movement, pair-wise correlation and Probabilistic Movement Primitives (ProMPs) of the trajectories. The comparisons of movement represented as two multivariate Gaussian distribution allows to quantify and compare the variation of human movement with respect to the robots' arm movement when distraction and cognitive overloading lead to failed assistive tasks. A set of distance measures were implement on the dimensional reduction of the feature extracted to derive the cooperation measure. The three distance measurements used are the Mahalnobis, Wasserstein and Bhattacharyya. These are implemented to check if the skill of the human movement can be distinguished from distracted and non-distracted movement. Furthermore, to create the cooperative measure for matching the trajectory distribution in-between participants the Kullback-Leibler divergence will be implemented. This cooperative measure can be used as a natural cost function to minimize,as a reward or a description of the current state of coupled movement for a viability kernel.

III. CONCLUSIONS

By creating this cooperation measure it provides a correlation between human-robot movement in an assistive task, which identifies the states in the attention of the user towards collaborating to perform the assistive task. The cooperation metric as described in this study quantifies how synchronous the movement is and infers the cooperation between the human and the robot through the movement. The dataset created and used in this study allows us to compare an ideally learned skill to one-off events that can hinder safety in long-term movement prediction in close-proximity assistive tasks. Using this measure we have prior knowledge of what type of coupled human-robot movement are performed based on the level of attention of the user. In this way, an evaluation of the adaptive approach can be implemented by creating a safety measure which is based on knowledge about reachable positions based on this historical movement data in which no failures occur. This can serve as a safety measure which will allow a more robust motion planner for the robot established through reachability analysis based on this safety measure because a kernel of all possible state of failures in the interaction will limit the robot to safely interact in the same space as the human.

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