Using Hesitation Gestures for Safe and Ethical Human-Robot Interaction

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***Abstract*— Safe interaction with non-expert users is increasingly important in the development of robotic assistants. Ethical "codes" can serve as a guide as to how this interaction should take place with lay users in non-structured environments. Such codes suggest that robots should behave in a way that is intuitive to users. Previous research has demonstrated that the implicit channel is useful for intuitive human-robot interaction. Our work described in this position paper investigates how a robot should behave when it is uncertain of its human partner's intentions. In this context, uncertainties arising in human-robot shared-tasks should be made transparent to a human user. We posit that hesitant hand motion used by people and animals is a natural modality for a robot to communicate uncertainty. To test our hypothesis we propose to characterize and implement human hesitation gestures onto a robot, and investigate its ability to communicate uncertainty.**

I. INTRODUCTION

EVERY year, increasingly sophisticated robots intended for personal and service applications are showcased. A society in which people routinely interact with robots in home and office environments, while sharing working space, tasks and objects, is becoming a realizable and anticipated future. As a result, increases in autonomy, ability, and complexity of robots are inevitable and gradually requiring more autonomous decision-making capability with minimal human intervention. This raises concerns regarding an expected "code" of conduct that guides robot behavior, namely, robot ethics. In this position paper we uphold the argument of others [1] that ethical robot behavior, as it pertains to interactions with humans, must be considered in order to successfully integrate domestic robots into our society. Unlike traditional ethical questions, which are constantly under debate, robot behavior ethics within a given context can be framed in terms of human safety and social norm adherence [2].

Robots for service and domestic applications pose interesting challenges to issues of safety and ethics [3]. These robots frequently encounter new, uncertain and conflicting situations where any resulting indecision or inaction can bring negative consequences to the user. In such cases, it is important for a robot to clearly communicate its intentions to the user. Take, for example, the annoyance a user may experience with a wheelchair robot when attempting to hang a picture on a wall. Detection of an imminent collision with the wall coupled with the user's command to move forward may introduce uncertainty to the wheelchair's controller. Subsequently, the user may be unable to achieve the desired goal due to inaction or indecision by the robot, and the inability to read the robot's internal state only adds to the frustration experienced by the user. With the possibility that unresolved uncertainties can result in dire consequences, Van der Loos [4] advocates that increase in complexity of robots should be followed by increase in transparency of robot intention in order for human-robot interaction (HRI) to be safe and ethical.

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We posit that the appropriate action of a robot, when faced with uncertainty in an interaction, is to unambiguously demonstrate its internal state. Thus, we hypothesize that such transparency of the robot's inner state can improve user perception of robots. We also postulate that such interaction can initiate a human-friendly human-robot mediation process where the two agents can collaboratively solve the conflict and clarify the uncertainty.

Inspired by the body of work on implicit interaction [5]-[9], which collectively validates the use of nonverbal gesture as an effective communication and interaction mechanism in HRI, we are interested in studying whether a robot's state of uncertainty can be communicated to users via nonverbal gestures. In our study we take the exemplar case of two people noticing that they are reaching for the same object simultaneously. Our pilot studies have shown occurrences of sudden halts or jerky motions of participants' hands before one person yields or persists to resolve the uncertainty regarding who gets the object. Ultimately, with the proposed approach outlined in this paper, the outcome of our study will increase the understanding of how nonverbal gestures such as hesitations can be effective and appropriate in HRI.

II. BACKGROUND

A. Hesitation and Uncertainty

Existing work in psychology indicates that cognitive or internal state of uncertainties and conflicts in animals and humans are often expressed in terms of nonverbal gestures. Such nonverbal behaviors include shrugs, frowns, palm-up gestures and self-touch gestures [10]. Some causes of hesitant nonverbal behaviors are confusion [8], cognitive conflicts [11], difficulty in cognitive processing [12] and reluctance to act [13]. These sources of hesitation manifest themselves in multiple forms of resultant gestures. The previously described jerky motion between two people reaching for the same object arises from cognitive conflict and reluctance to act. We label this kinesthetic gesture a 'hesitation gesture', and it is shown in Figure 1. We are currently investigating hesitation as a potential nonverbal robot gesture that can convey the robot's state of uncertainty to its human collaborator in a human-robot shared-task (HRST) environment.

(a)

(b)

Fig. 1. Hesitation gesture in a human-human shared-task

B. Nonverbal Gestures in HRI

Nonverbal gestures as interaction mechanisms in HRI have been studied in various contexts, types of robots, and modalities [5], [14]-[16]. Among the most studied are gestures used to regulate the flow of conversation between robots and humans [17], [18], and human-robot proxemics [19], [20]. Several studies have investigated the connection between non-verbal gestures and a robot's internal states [15], [21], [22]. However, these studies focused on the expression of emotional state. Nonverbal gestures used to communicate or express the cognitive state of a robot to a person remains relatively unexplored.

As previously mentioned, there are numerous hesitation gestures involved in expressing uncertainty. Breazeal's work on nonverbal robot gestures focused on expression of uncertainties arising from confusing human commands [8]. This study involved a teamwork scenario in which the human took a supervisory rather than collaborative role, instructing the robot to take specific actions. The robot expressed its internal state of uncertainty using shrugs. Her work provides strong evidence that use of nonverbal gestures rather than voice to render a robot's internal state transparent can be effective and helpful in improving task performance with lay users.

However, uncertainty due to cognitive conflict rather than confusion about a command occurs when a robot is interacting with a human as a near-equal partner. In our exemplar case, uncertainty arises regarding who should yield, and how the cognitive conflict between the desire to get the object and the need to meet social norms in being polite to another person is resolved. The gesture manifested from this type of uncertainty is the focus of our study, which we believe will have an impact in creating a human-friendly HRST for lay users when the robot is a near-equal partner in a collaborative task.

III. Methodology

The first phase of a three-phase study is currently underway to investigate the hesitation gesture as a means of handling uncertainties in a HRST. In the first phase hesitation gestures in a human-human shared-task (HHST) are identified and characterized quantitatively in terms of velocity, acceleration, and jerk. These characteristic motions are then implemented onto a robot arm such that the robot will exhibit hesitation gestures when encountering uncertainty or conflict in a HRST. In the second phase of this study, we will empirically determine whether the generated robot motions are also perceived by humans as representing hesitation. The third phase of this study will test the robot gestures' capacity to communicate its uncertainty to a user in a HRST.

A. Phase 1

Under the assumption that a human's hesitation gesture can be characterized in terms of the hand's linear velocity, acceleration and jerk, the first phase aims to quantitatively characterize hesitation gestures frequently observed in HHST environments. In this study, human subjects ($n_1 \cong 5$) are asked to engage in a shared-task with another person, with inertial sensors placed at various locations on one of the participants' dominant arm to collect linear and angular acceleration data. The task involves two people sorting a deck of cards together into appropriate bins according to various sorting rules. A pilot study showed this task to frequently cause hesitation gestures in human subjects. Video recordings obtained from the shared task will be broken down into discrete time-frame labels (A, B, C, etc.) and presented in an online survey in which another set of participants ($n_2 \cong 30$) will be asked to identify the instances where the sensor-equipped hands hesitated. Z-tests will be used to determine whether a given timeframe of a video contains a hesitation motion with statistical significance ($p<0.05$). The set of timeframes identified as containing a hesitation gesture will be the same timeframes of inertial sensor data used to characterize human hesitation gesture in terms of linear velocity, acceleration, and jerk. These characteristics will be used to generate robot hesitation gestures for a CRS robot arm.

B. Phase 2

We hypothesize that a robot motion having the same characteristics as that of human hesitation gestures will be perceived as hesitation. The second phase of this study will statistically test this hypothesis. A video of the robot engaged in a shared task —analogous to the sorting task used in Phase 1—with a human will be broken down into discrete time-frame labels and subsequently shown in an online survey. The video will contain multiple instances of robot hesitation gestures. The participants of the survey ($n_3 \cong 30$) will be asked to identify frames in which the robot hesitated. The same statistical analysis carried out for Phase 1 will be used to determine which timeframes of the video were identified as containing a hesitation gesture. Results of this statistical analysis will be compared with the programmed occurrence of robot hesitation gestures. Any false positives and false negatives found will be tested for statistical significance.

C. Phase 3

Once a visually analogous hesitation motion of a robot is determined empirically in previous phases, we hypothesize that this motion can serve the same communicative function as that of a human's in conveying the robot's state of uncertainty. In Phase 3 of this study, participants ($n_4 \cong 20$) will be asked to engage in a HRST. Half of the participants will be engaged in a shared task with a robot that does not use hesitation gestures when encountering uncertainty or conflict, and the other half of the participants will be engaged in the same shared task with a robot that uses hesitation gestures. A post experiment survey will be conducted in order to study human perception of a robot in a HRST environment when the robot uses hesitation gestures. Likert-scale measurements will be collected to determine whether the HRST with robot hesitation gestures are perceived as friendlier than that of the HRST without hesitation motions.

In the future, we hope to implement a gesture recognition system such that the robot will not only be capable of exhibiting hesitation gestures, but also of recognizing a human's hesitation gesture. This bidirectional hesitation system can be used to mediate the decision of whether the robot or the human should yield the shared space or object. We hypothesize that this bidirectional communication via hesitation gestures will foster safer and friendlier interaction in HRST environments. The robot's actions will be seen as appropriate according to social norms and considerate of the user's internal state.

We believe that this work will aid in developing effective and appropriate methods of conveying a robot's state of uncertainty to a lay user during a collaborative human-robot task.

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