Communicating Robot Intentions for Human Comfort

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***Abstract*—Given a simple cooperation task with an untrained worker we consider the following question: is there a method of declaring the intent of a robotic collaborator that renders a human partner most comfortable with the least distraction? By exploring various methods for communicating the intentions of a cooperator robot in a third-arm scenario and observing the comfort levels and efficacy of the human peer in a simple puzzle-solving task, we can point to needed baselines in terms of effective Cooperative robot communication and meaningfully improve the efficacy and comfort of human partners.**

***Index Terms*—HRI, robot arm, human-robot collaboration, Franka Emika**

I. Introduction

With the fast-growing demand for robotic systems capable of interacting with humans in a safe, seamless, and intuitive manner, the development and integration of these systems in interactive and collaborative tasks has seen an extensive research effort in recent years [1] [2]. Significant progress has been made on advancing the robotic technologies needed to support human-robot interaction (HRI) and human-robot collaboration (HRC) applications. Tasks like environmental perception, task planning and decision making, and human-aware motion planning. Therefore, in this project, we design a research project that involves varying the methods of communication used by a collaborative robot to confer intent to a human partner. A collaborative robot, or cobot, is a type of robot designed to work alongside humans in a shared workspace. Research into cobots is important because of the potential for sophisticated cobots to assist humans in a variety of tasks, allowing for more efficient and cost-effective operation. Intention communication, which refers to the ability of the cobot to provide its intentions to the human operator, is very important to create a successful HRI. Effective intention communication allows a cobot to work alongside the human in an efficient manner, and can potentially render the human participant more comfortable. This possibility is an avenue for research that we hope can be answered by our proposed project. A third-arm scenario is a common example for how cobots could assist humans in everyday tasks. In this scenario, the cobot acts as an extra arm for the human, allowing them to perform tasks that may be difficult or impossible to do on their own. For example, a cobot could assist a human in assembling a complex device or provide necessary tools for an operation. Another aspect of the proposed research project is the inclusion of a dextrous task abstraction in the form of a 3D block puzzle. This type of puzzle involves mentally rotating an object in three-dimensional space in order to determine how it would look from a different perspective. Solving this type of puzzle requires spatial visualization and spatial reasoning skills, which are important for a variety of tasks in both everyday life and in many professions. By including this type of puzzle in the research project, we can extend our findings to a wide variety of jobs and roles that could make use of a third arm, as well as provide a meaningful challenge to participants that will hopefully pull their attention away from the study and the research goals [25]. Given a simple cooperation task with an untrained worker we consider the following question: is there a method of declaring the intent of a robotic collaborator that renders a human partner most comfortable with the least distraction? This question was chosen to build off previous research which questions the connection between robot intent and human comfort, which is described in [3]. In order to test the worst-case scenario the robotic arm will be placed behind the subject outside of their peripheral view. In this way, the human subject will be at their least comfortable with the robot. If the subject is at their least comfortable than anything that renders them more comfortable should have an increased effect. Returning to the main question, if the robot declares their intentions either through audio, textual display, or haptic feedback, will the human subject feel more at ease and which of these options will cause the least distraction. The audio, textual and haptic conditions were chosen as they are distinct yet commonly uses methods of communication that the average public encounters. As such, these conditions will not require a teaching component within the study. We hypothesize the following options for possible outcomes of the above experiment:

- In all cases, the presence of intent declarations will be more beneficial than the control group that does not receive a declaration.
- The audio and textual methods of delivering intent will be effective in providing comfort to the Human partner but will distract the test subject.
- The haptic feedback method will be less effective than audio and text in providing comfort, and less distracting to the subject.

The above hypotheses were considered with the outcome of [3] in mind, where a social robot either did not declare its intentions, declared intentions succinctly, or declared intentions in a drawn out and awkward manner. It was shown that any declaration of intentions was more welcome to participants than none, but the long and excessive declaration resulted in less comfort than the short declaration. This mix of user expectations, form of robotic declaration and user comfort is what led to the development of our research question.

II. Related Work

So far, the Franka Emika robot arm has been used in many studies. Among all the studies, some of them are about handover tasks [4] and some are about task sharing [5] between humans and robots. This robot arm can be used for different tasks, collaborating with humans, or going through tasks on its own. In this study, we are considering this robot arm as a collaborative robot to investigate Human-Robot Interaction for a simple task of puzzle solving in a shared environment. Recent researches aim to develop a new generation of robots that can interact with humans safely and cognitively [6]. Handover is one of the most studied benchmarks in HRI. Although this action could be easily and fast performed by humans in daily life, it becomes challenging and complex in robotic applications [7]. In literature, there exists plenty of research on human-robot handover from different points of view. In [7] the authors give a detailed overview and categorize handover into the physical and social processes. In [4] they focus on the physical process, which could be further subdivided into motion planning [8], handover configuration [R6,R7], synchronization/timing [11] and compliant force-position control [12], [13]. Even though all these issues are crucial for a seamless and safe handover, they were usually discussed separately in different literature. After all, the authors constructed one system that includes human motion prediction, on-line trajectory planning, and robot control. One study with a focus on adaptive task-sharing in human-robot interaction in assembly [5] explains what problems could come up during collaboration with robots and proposes a new adaptive task-sharing model (ATS). To develop this model, the authors studied a series of human-robot interaction (HRI) applications in manufacturing, which represent several ATS features. To compensate for some of the factors leading to a productivity gap in these applications, a new assembly application in a learning factory in cooperation with the same manufacturing company, where HRI applications in manufacturing were observed, was developed. For this paper, the authors reviewed relevant literature on human-robot task sharing and introduce the ATS model together with its six guiding principles and a prototype software solution to enable ATS between a human and a cobot. Human-Robot Interaction (HRI) user studies are challenging to evaluate and compare due to a lack of standardization and the infrastructure required to implement each study. The lack of experimental infrastructure also makes it difficult to systematically evaluate the impact of individual components (e.g., the quality of perception software) on overall system performance. One article [14] proposes a framework to ease the implementation and reproducibility of human-robot interaction user studies. The framework is implemented with four modules: perception, decision, action, and metrics. The perception module aggregates sensor data to be used by the decision and action modules. The decision module is the task-level executive and can be designed by the HRI researcher for their specific task. The action module takes subtask requests from the decision module and breaks them down into motion primitives for execution on the robot. The metrics module tracks and generates quantitative metrics for the study. The framework is implemented with modular interfaces to allow for alternate implementations within each module and can be generalized for a variety of tasks and human/robot roles. The framework is illustrated through an example scenario involving a human and a Franka Emika arm collaboratively assembling a toolbox together. Running full HRI studies is a multi-stage process. During the design and conception stage, researchers must identify the collaborative task or interaction context, decide on the robot's autonomy level, including perceptual and action capabilities, and finally design and plan for the different ways in which the robot will interact with the human. Regarding the design stage, one paper [15] has recently proposed a reference set of tasks for reuse in HRC experiments. The tasks were designed for a collaborative assembly scenario and can be adapted to investigate many aspects that are relevant during collaboration (i.e, role assignment, task allocation, amount of information available to the human and the robot etc.). In the context of human-robot collaboration in manufacturing, one article [16] proposed a Digital Twin (DT) framework that allows for quick analysis and validation of key aspects such as human-robot task allocation, workstation layout, and human ergonomics. Complementary to this idea, in [17], a ROS-based architecture for designing and validating the coordination of tasks that require humans and robots to collaborate was proposed. Using this architecture, human and robot actions defined using off-line programming tools can be executed and tested prior to deployment. To improve the way humans are interacting with robots various factors have to be taken into account. An evaluation framework for Human-Robot Collaboration with humanoid robots addressing usability, social acceptance, user experience, and societal impact (abb. USUS) as evaluation factors is proposed [18]. The theoretical framework of USUS is based on a multi-level indicator model to operationalize the evaluation factors. Evaluation factors are described and split up into several indicators, which are extracted and justified by the literature review. The theoretical factor indicator framework is then combined with a methodological framework consisting of a mix of methods derived and borrowed from various disciplines (HRI, HCI, psychology, and sociology). The proposed method mix allows addressing all factors within the USUS framework and lays a basis for understanding the interrelationship of the USUS Factors. We designed this experiment by getting help from all the frameworks proposed in this field and considering previous papers and their results to enhance the accuracy of our results.

III. Methodology

A. *Robot Arm Implementation*

To build and implement our simulation of the Franka Emika robot using ROS2 Foxy. The ubuntu version used for the Ros2 setup is 20.04.5. A collection of software libraries and tools called the Robot Operating System (ROS) is used to create robot applications. ROS contains the open-source resources you need for the upcoming robotics project, including drivers, cutting-edge algorithms, and robust development tools. Most of the benefits of ROS1 are still there in the second-generation Robot Operation System (ROS2), which offers the required dependability and real-time performance. Hence, we choose to utilize ROS2. For Foxy Fitzroy, which is the sixth release of ROS 2, Open Robotics and the ROS 2 Technical Steering Committee (TSC) have tirelessly added additional crucial functionality, automation, and supporting mechanisms. Due to these new features, ROS 2 Foxy is suitable for use in commercially available robotics systems and products. By carefully following the instructions in the documentation for ROS2 and the Franka Control Interface (FCI), we were able to set up both ROS2 and the Franka Emika Robot. The ROS visualization tool used is RVIZ, a 3D visualization software tool for robots, sensors and algorithms and almost all kinds of data from sensors can be viewed through this tool. We've been able to move our simulated arm to different positions on a workspace by using ROS visualization (RVIZ). We have successfully installed the ROS2 package as well as set up the RVIZ environment. We created a workspace for the robotic arm Franka Emika and moved the joints and end effector to multiple positions. We can move the simulated arm from one position to another by storing the states of motion. We were also able to move some joints about a certain axis by clicking on buttons on the controller. The team has created a simple state machine to keep track of locations and the paths sequestered depending on the state. One of the hurdles that were encountered by the team in preparing the simulation lay in stitching various robot arm movements together into a sequence and being able to save those sequences for later use. Part of the reason for this lay in the way in which the simulation software made use of ROS2. An alternative to programming commands would be to control the arm using a controller.

B. *Text-to-speech voice*

To add speech recognition to our robotic arm, we looked for many approaches to achieve this goal, including text-to-speech software and voice-changer programs. After all, we selected the "Speak4Me" program. It may be downloaded for free from the Apple Store for iPhones and iPads. More than 15 languages can be read aloud, and we can select a different voice (male or female) for each one. It's simple to regulate the reading tempo as well. The texts we want our robot to say can be saved in the "favourites" area, and we can play them in order by connecting the phone to the speaker. Here are some images of the program choices, environment, and icon.

C. *Text output*

The text that the FE-arm is speaking is displayed to the participants at the same time that they are hearing it. We looked into various approaches that were on the market for this aim. Putting the texts in slides or images and displaying them one at a time on a monitor is one of the strategies we can employ. Another method for making it real-time is to enter the text and screen record it so that it may be played back as the participant is listening to the text. This approach makes it sound more authentic and plausible to participants. Additionally, some applications, such as "LED Banner," can display the text we provide them with in real-time. We can utilize an iPad with a larger screen for this strategy.

D. *Experiment Setup*

4 puzzles will be solved by the contestants under these 4 conditions. First, there will be no interaction between the participant and the robotic arm under the null scenario. The presence of audio as a means of communication between the participant and the robot constitutes the second criterion. The third condition is that the participant is also able to see the output of the text visually in addition to the audio. In fourth, their only communication will be through direct physical contact. The measuring of these 4 conditions will be done by 3 metrics, one is through the completion time where the whole interaction under all conditions is video recorded, one is for the pre and post-experiment questionnaires, and another one is through GSR. The GSR sensor gauges the skin's

fluctuating levels of electrical current conductivity. An increase in epidermal sweat causes electrical currents to conduct more readily. Therefore, either good or negative emotional arousal can be inferred from a higher level of skin conductivity following an occurrence.

IV. Metrics

A. Questionnaire

In order to understand the participants' reception and experience of collaborating with robots, we have designed a set of two surveys: the pre-experiment and the post-experiment questionnaire (Appendix A and Appendix B). As Ray stated in What do people expect from robots? [19], one major challenge in designing questionnaires and surveys is to minimize the bias introduced by the experimenter in the way he asks questions. In addition, except for basic information, open questions are avoided as they are difficult to process. Knowing these issues, we decided to use closed-ended linear scale questions.

In the pre-experiment survey, participants will be asked questions mainly about their backgrounds, such as gender, age, and education, together with some questions on their views and experience of working robots. As Schaefer pointed out [22] that prior exposure to robotic technologies will form a mental stereotype of the robot after the future human-robot interactions. The goal here is to understand our participants and ensure that they are comfortable working with robots. This part of the questionnaire will be handed to the participants before the experiment starts, and it should take less than 3 minutes to finish.

In the post-experiment questionnaire, we emphasize on the participant's experience and robot's trustworthiness rating while collaborating with robots in the experiments. Inspired by the framework Three Factor Model of Human-Robot Trust from Schaefer [22] (see fig.1), most questions focus on our participants' experience interacting with robots as well as their attitude towards robots in a team to finish a specific task. This part of the questionnaire will be handed to the participants right after the experiment ends, and it should take less than 10 minutes to finish.

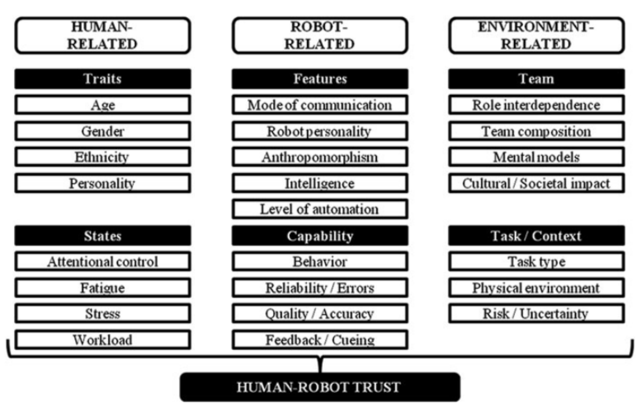

Fig. 1: Three Factor Model of Human-Robot Trust by Schaefer [22]

In the analysis phase, since we are using coded linear scale questions, it will be easier for us to facilitate the statistical results. We will be using ANOVA to determine if any of these factors have significant differences across others in the trustworthiness level of robots.

B. Galvanic Skin Responce

As an indicator of stress level during the experiment, GSR reflects sweat gland activity and changes in the sympathetic nervous system and measurement variables. There are two types of skin conductance defined by their characteristics, tonic skin conductance which is the baseline level without any stimuli and Phasic skin conductance which is the type of change when the environmental stimuli are present. It is believed that there is a certain relation between skin conductivity and emotional arousal, even though the type of emotion is still not able to be verified with the current research [20].

Our team is looking into building a GSR monitoring system based on Arduino. Some previous work has been done by Sugathan et al [20] who built a wearable health monitoring system. Since the voltage change on human skin is too small to be perceived by the sensor and the signal/noise ratio is relatively high, the idea of building a GSR is to apply constant voltage and then detect the current flow which, by Ohm's Law, can be used to calculate the conductance in microSiemens. Following the same method of Sugathan [20], the basic circuit design is cascaded amplifiers to boost the signals as shown in the below figure.

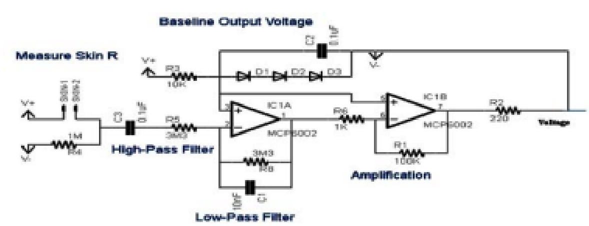

Fig. 2: Analog circuit to build the GSR [20]

With minimal setup preparation needed, the GSR measurements are non-invasive. To get the best results, the sensors/electrodes need to be connected to the participants' fingertips. As Wagner indicates [21], though each person might have a different tonic level, it should fall within the range of 10 to 50 microSiemens. To get the proper tonic level, we will ask our participants to get into the designated position and give them approximately a minute to calm themselves down before the actual experiment starts.

C. Video Recording

As Asan stated [23], it is difficult for researchers to capture all the detail in live settings, especially when it comes to simultaneous minor changes like emotion and hand gestures. Video recording can help to address this problem by capturing all the events during the experiments and allowing researchers to verify the observations and feedback from the participants afterward.

TABLE I: Table for recording social signals during experiments

Head Movements	Count	Speech	Count	Facial Expression	Count	Body Movements	Count	Hand Gestures	Count
Look at Robot		Task Related Sentence		Smile		Lean		Touch Own Body	
Look at Experimenter		Statement		Frimace		Move		Manipulate	
Look in a Direction		Question		Raise Eyebrows		Other		Pointing	
Tilt Head		Laugh						Emblem	
Look at Object		Correction						Other	
Nod		Other							
Shake Head									

In the experiment, we will set up a camera that can capture the whole experiment setup including the robot arm, participants, and the puzzles. It starts recording when the participants start their pre-experiments survey and ends when they finish their post-experiment survey.

In the analysis phase, based on the framework proposed by Giuliani [24], we will count the social signals as the below table (Fig.3). And then we will apply statistical analysis against different variables in our experiments.

V. Ethics

In this study, we will recruit approximately 10 to 20 participants from the local population of undergraduate and graduate students on campus as well as people in the community who may be interested in human-robot interaction. Out of safety concerns, this study will exclude children under the age of 12 and those without an adequate understanding of spoken English. Video recording, email addresses, ages, and gender collected can be used to directly identify participants. However, all collected information will be kept securely and the personal information will be separated from the research data.

Due to the nature of our study, there is a risk of participants experiencing low-speed collisions within the robot's workspace in a lab setting. To ensure safety, Franka Emika has safety features of torque sensing at each joint which is used to detect impacts that can cause the robot to brake immediately, and the robot will operate with a maximum end effector a velocity of less than 2m/s, and be controlled by our team.

Since we are using the Wiz-of-Oz with one of our researchers controlling the robot arm behind the scene, immediately after each experiment ends, we will debrief our participants, and explain the details of our experiment design.

We have prepared an ethics application to the General Research Ethics Board (GREB) at Queen's University as we believe our experiments have a potentially higher than minimum risk to our participants mainly due to the robot arm collision.

VI. Results

This experiment is to be implemented by utilizing the "wizard of oz" technique to control the arm. The purpose of this is to provide the subjects with the illusion of working alongside an intelligent machine. The experience and outcome of the experiment will differ if the robot is perceived to be fully automated, trust and bidirectional understanding of actions are expected to yield a more effective result. The motion and paths of the robot are to be developed by breaking each movement into states. The path the arm takes, the timing of the delivery, as well as the release of the puzzle piece all play a critical role, the robot will follow a certain pre-programed path and actions when requested by the controller. The timing and state of which the robot arm proceeds will be decided by a user behind the screen.

The first action taken will be the retrieval of the puzzle piece. The robot arm and puzzle pieces are to be located behind the user. The necessary piece will be grabbed and lifted, After which the arm will advance towards the participant, either on the left or right side of the participant by random choice, prompting the participant to reach out for a drop-off. After performing this task, the arm will be rotated back to the start location, and the sequence will be repeated until the experiment is completed.

The robot is to be placed in close proximity to the participant. The placement and movement of the arm is positioned in such a way to promote a level of discomfort. The reaction and emotional arousal of the participants recorded using the GSR sensor are expected to be an effective indication of how trusting they are of the robot.

VII. Discussion

Given the nature of this project as largely an in depth proposal, we are unable to thoroughly discuss the results of our experiment, therefore it will helpful to discuss in depth the possible implications of this research as well as possible results as hinted by other research as well as future directions based on possible takeaways from our hypotheses. Taking from further above, our hypotheses for our proposed research project are the following:

- That in all cases, the presence of intent declarations will be more beneficial than the control group that does not receive a declaration.
- The audio and textual methods of delivering intent will be effective in providing comfort to the Human partner but will distract the test subject.
- The haptic feedback method will be less effective than audio and text in providing comfort, and less distraction to the subject.

VIII. Future Work

Evidently, it becomes difficult to expand unfinished research into future directions, however, given how broad the impact of the possible outcomes of this research is, we believe it helps to point towards possible applications or needed investigation based on the hypothesized outcomes. In the event of possible outcomes a, b, d, or e, it is likely that future investigation will be needed to verify the lack of meaningful interaction between the communication of intent and the human partner, especially given the implications of past research [3,4,5]. In the event of possible outcomes G and H, which are contingent on C and F, this research will heavily support the implementation of haptic feedback over audio or visual feedback in the event that a distracted human operator is highly unwanted. On the other hand, if human comfort is paramount then this research would recommend the implementation of audio or visual feedback over haptic feedback. In the event of possible outcomes C and F, without G and H, this research will heavily support further investigation into the exact benefits and disadvantages of each form of intentional communication. In all cases, this research highly encourages the further investigation of similar experiments with more and different forms of intention communication, as well as more complex intentions, and a varied range of minimally or maximally stressful operations.

IX. Limitations

As this research is unfinished, it has heavy restrictions in terms of applicability. However, in the event that this research continues, and meaningful results are found, it remains highly specialized to one-on-one interaction between a collaborative robot and a human partner. The use of the Wizard-of-Oz method to pilot our cobot implies that there will be a lag time between the findings of this research and the implementation of this research in fully autonomous robot actors. Additionally, further research should be done to lessen the abstraction of the puzzle task, not only to strengthen the results of this study, but to affirm the broad findings in highly specialized tasks.

X. Challenges

The challenges faced by this team in creating and preparing this research project largely expressed themselves during the implementation phase. One major hurdle, that transformed the project from experiment into the proposal, was the inability to apply for ethics approval within the time constraints of the project deadline. Ultimately this had the greatest effect on the project. However, it did allow for a greater depth of research into the possible outcomes of the experiment as well as allow the team to expand the knowledge base both on the technical side, like in the coding and control of the robot, but in the ethics approval process and the research-creation process. A lesser challenge faced by the team involved the working documentation of ROS2 and various APIs and software that interacts with ROS2. Largely the issues encountered by the team stem from the still-underway transition away from ROS towards ROS2. Unfortunately, while the transition is underway, much of the burden of knowledge falls to the user to determine whether an interface between the robot and the simulation depends on ROS or ROS2. We found ourselves on several occasions, several hours deep into documentation for a needed application only to discover that it was not compatible with ROS2. While difficult and confusing, I believe that this forced the team to rapidly learn about not only ROS2 but the nature of the difference between ROS and ROS2.

XI. Conclusion

In conclusion, we have thoroughly outlined the importance, feasibility, and possible findings of a research project into the effect of varied intention communication methods on the comfort and effectiveness of human patterns. This project report examined the past literature to carefully build onto, as well as to make use of the best methodologies for this research. It is our belief that this experiment if undertaken, will provide meaningful insight into improving, not only the efficacy of human operators in third-arm work but also their comfort, which will help in acceptance and adoption. We have provided all needed metrics, software, and testing methods in enough depth to start an experiment rapidly after receiving ethics approval. The team behind this proposal is enthusiastic about continuing this research and believes that its conclusions will point to further research into deepening the forms of intentional communication that provide better comfort and efficacy, even in complex task interactions.

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Appendix

Contributions

Equal contributions from all team members