Human-Robot Communication for Collaborative Assembly

Brian Gleeson[†] brian.gleeson@gmail.com
Karon MacLean[†] maclean@cs.ubc.ca
Amir Haddadi[‡] haddadi@ieee.org
Elizabeth Croft[‡] ecroft@mech.ubc.ca
Javier Alcazar* javier.alcazar@ieee.org

[†]University of British Columbia
Department of Computer Science
201-2366 Main Mall
Vancouver, BC V6T 1Z4, Canada

[‡]University of British Columbia
Department of Mechanical Engineering
6250 Applied Science Lane
Vancouver, BC V6T 1Z4 Canada

*General Motors
Research and Development Center
30500 Mound Road
Warren, Michigan, 48090, USA

ABSTRACT

New developments in robotic technology are paving the way for intelligent robots to enable, support, and enhance the capabilities of human workers in manufacturing environments. While few current industrial robots have any direct human interaction, future robots will work in close proximity to support workers in a variety of tasks, move manufacturing quality and processes forward, and increase productivity. However, in this new regime, safety and efficiency require a new form of fluid, transparent communication. In this paper, we summarize ongoing research to develop a system of gestural communication to meet these goals. We observed pairs of participants collaborating on assembly tasks drawn from analysis of our industry partner (General Motors) assembly lines, and analyzed their verbal and nonverbal exchanges. From this we compiled a gestural lexicon of the communication terms required for collaborative work, and the non-verbal gestures that participants used to express themselves. This lexicon provides the basis for a system of human-robot interaction suitable for industrial tasks and environments.

Keywords
Human-Robot Interaction, gesture, industrial robotics.

1. INTRODUCTION AND BACKGROUND

Robotic technology has advanced remarkably in recent decades, and as a result, robotic systems have become commonplace in industrial operations. Robotic devices are used to improve efficiency, increase quality, and reduce ergonomic strain on workers. Currently, there is little direct interaction between humans and robots in industry; industrial robots are generally used for autonomous execution of scripted tasks, conducted behind a safety fence. Industry, however, requires closer collaboration [1]. To meet these needs, we seek to develop new and effective ways for humans and robots to communicate, facilitating human-robot collaboration on real-world tasks.

A human-robot team consisting of a human worker and a robotic assistant (RA) would utilize the strengths of each member: the intelligence, dexterity and perception of the human worker and the memory, strength and precision of the robotic system. An effective RA would help the human worker to improve the quality and efficiency of the industrial process, while the human worker would make possible tasks that could not be executed by a robot alone. Additionally, a RA could significantly improve workplace safety and reduce ergonomic strain by handling heavy items and executing repetitive, stain-inducing, operations.

Recent advances in robotic technology are making it possible for humans and robots to physically interact safely and effectively [2]. Hardware for physical human robot interaction ranges from purpose-build lightweight robots to augmented industrial robots. For such robotic systems to work effectively with humans, we must develop appropriate interaction methods to support communication between people and robotic systems. Interaction methods for human-robot teams have been proposed for application domains ranging from home service (e.g., [3]) to lunar construction [4].

In our research, we develop communication methods for human-robot collaborative work on industrial assembly tasks. Our approach is human-centric, basing our human-robot interaction on observations of human-human interactions, with the aim of producing interaction methods that are natural and intuitive for users. This research is part of the CHARM project (Collaborative Human-focused Assistive Robotics for Manufacturing), a collaborative research effort between the University of British Columbia (SPIN lab and CARIS lab), McGill University (APL group), Laval University (CVSL Lab and The Robotics Laboratory), and General Motors of Canada. The work reported in Section 3.2.1 is discussed in greater length in [5].

2. UNDERSTANDING THE TASK

A necessary prerequisite for effective interaction design is an understanding of the domain in which the interaction will be used. For our study of human-robot interaction (HRI), we work with industry experts to understand the needs of industry, the restrictions imposed by the industrial environment, and the nature of the tasks that human-robot teams will be executing.

When considering a potential RA, our industry partners described worker safety, comfort and ease of use as key priorities. We therefore base our HRI design on human-human interaction, with the intention of designing an interaction experience that is intuitive and does not require extensive training. Important constraints on our interaction design are the noise level of industrial environments, pace, and the continuous attention required. Ambient sound makes verbal communication impractical. Because worker attention must primarily remain on fast-moving assembly tasks, existing robot control interfaces, like control pendants, would be cumbersome. To accommodate these constraints, we focus here on gestural communication, which is unimpeded by a noisy environment and can be executed without stopping work to operate an interface device. When based on natural human gestures, human-robot gestural communication should be easy to learn and simple to use.

To ensure that our communication strategies are well suited to industrial applications, we studied representative assembly tasks provided as examples by our industry collaborators. We analyzed these tasks for key elements and designed abstracted tasks that are appropriate for laboratory experimentation but still capture the characteristic features of the real-world tasks.

3. GESTURAL COMMUNICATION FROM HUMAN OBSERVATION

In designing a lexicon for human-robot communication, we first determined the communication terms that would be necessary to facilitate cooperative work on assembly tasks, and then the gestures that could be used to communicate these terms. That is, we first asked *"what* needs to be said?" (communication terms) and then "*how* can this be said?" (gestures). Our experiments were grounded in tasks abstracted from real-world industrial operations, to assure relevance of the resulting lexicon.

With a goal of designing natural and easy interactions, we observed human pairs conducting our assembly tasks under various conditions and coded the communicative terms and gestures employed. To validate the resulting lexicon, we implemented the gestures on a robot and had participants interpret and rate the gestures in the context of a simulated assembly task.

3.1 METHODOLOGY

Sixteen volunteer participants (8 male average age 26.2; most from an engineering background) worked in pairs to complete simulated assembly tasks. We observed participants' interaction and video-recorded it for later analysis. Participants completed tasks under two experimental conditions: (1) verbal and (2) gestural communication. To prevent communication through facial expression or eye gaze, communication modes that are not easily readable by machine systems, we required participants to wear face masks and dark glasses, as shown in Figure 1. Each pair completed 24 assembly tasks (2 conditions—verbal and gestural, 2 types of task, 6 task variations).

Experimental Tasks: Each experiment involved two separate tasks, simulating key aspects of industrial assembly. The two tasks were meant to represent two envisioned human-robot work scenarios. In the first, one person was responsible for completing an assembly while a second person, playing the part of the robot, supplied parts in the correct order. In the second task, one person placed simulated fasteners in an assembly while the second person, playing the part of the robot, rotated the fasteners in a tightening action. We simulated the assembly with two dimensional shapes, as shown in Figure 1.

Task Variations: To stimulate communication between participants, we introduced task variations that could only be resolved through communication. Once before the execution of each assembly and once after the assembly was complete, each participant privately drew a card that had a chance of containing a task variation instruction. If a participant received a variation instruction, she would have to communicate with her partner to complete or alter the assembly according to the instructions. These variations included moving parts, using different parts, omitting parts, and changing the orientation of parts.

Data Analysis: Using an open coding methodology, we viewed the recorded interactions and classified communication terms and gestures. We first coded the communication terms from the verbal interactions, then coded gestures, independent of semantic meaning, from the gestural communication, resulting in a list of common terms and gestures required to complete the tasks. Finally, we reviewed the videos again to match coded gestures to communication terms, forming a lexicon consisting of the necessary communication terms and the associated gestures.

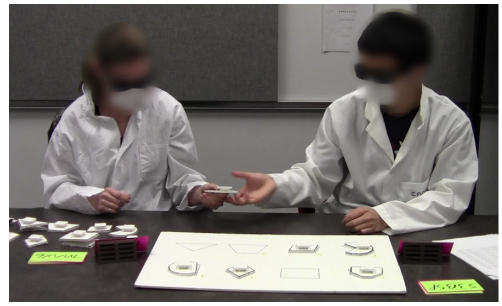


Figure 1. Experimental setup for human-human tasks

To ensure the validity of our analysis, a second researcher coded a subset (25%) of the data with good inter-coder reliability (Cohen's Kappa for terms and gestures = 0.72 and 0.74, respectively).

3.2 RESULTS: THE GESTURAL LEXICON

The primary result of this research is a lexicon listing the communication terms that are required for collaborative assembly tasks and mapping these terms to corresponding gestures.

We separated participants' communication into two primary categories: object manipulation communication and teamwork communication. Object manipulation terms concerned the physical movement of parts in the assembly, for example, communicating "give me part X" (Request Part) or "put it here" (Place Part). Participants used teamwork terms to coordinate actions between partners and to regulate the flow of the task, for example "Are you finished?" (Done?) or "You did that correctly" (Task State OK). We discuss these communication terms and gestures, in brief, below.

3.2.1 COMMUNICATION FOR OBJECT MANIPULATION

We analyzed 276 object manipulation communication events to form our lexicon. Figure 2 depicts the gestures used in this communication and Figure 3 maps gestures to communication terms. Inset pie charts show the frequency of use for each term, i.e., the proportion of the total object manipulation communication accounted for by each given term. While these frequencies are influenced by the specific tasks we used, the data give a generally applicable sense of which communication terms can be expected to be used often in interactions, and which will be used only occasionally. The widths of the lines connecting terms to gestures represent the strength of association between a given term and gesture, calculated as the frequency with which a given gesture was used to express a given communication term; thicker lines imply stronger associations.

Gestures are Physically Simple: The gestures shown in Figure 2 are generally simple and demonstrative. With the exception of one redundant gesture, they require a single hand. Furthermore, participants executed these gestures almost exclusively with their hands, only incorporating eye contact or other face/head signals in

0.7% of events. This physical simplicity is suitable for robotic systems, which may have limited degrees of freedom.

Diverse Ideas from Few Gestures/Terms: Although participants were required to indicate diverse events in different tasks with several variations, they used only a few unique communication terms and gestures. The lexicon is thus simple but broadly useful.

Meaning is Context Sensitive: As can be seen in Figure 3, there is no one-to-one correspondence between gesture and term. Instead, the meaning of a given gesture was interpreted within the context of the task. This ambiguity complicates the task of machine understanding. There are, however, many redundant gesture-term pairs that could be omitted in a machine implementation, gaining clarity at the cost of naturalness.

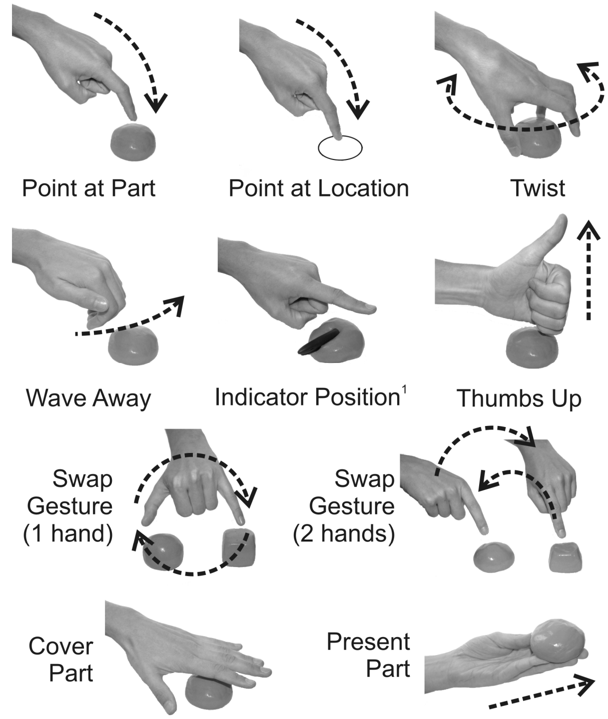
3.2.2 COMMUNICATION FOR TEAMWORK

Teamwork communication was an important part of participant interaction, as illustrated by its prevalence; 79.9% of all observed communication was used to facilitate teamwork. We analyzed these 1085 communication events to form the lexicon in Figure 4-5. The Figure 5 follows the conventions of Figure 3, with two additions of relevance to teamwork communication. Because teamwork communication terms were used as both statements and questions, we show pie charts depicting the proportional use of terms as statements ("!", blue) and questions ("?", red). Unlike object manipulation communication, teamwork communication often involved eye contact. While true eye contact was not possible, as participants' eyes were obscured by dark glasses, participants often demonstrated functional eye contact by turning their head and directing their apparent gaze at their partner. In Figure 5 we plot the frequencies of mutual eye contact ("2-way") and of unreciprocated eye contact ("1-way"), where a participant initiated eye contact but her partner did not return the eye contact.

Some Gestures are Physically Complex: Unlike those gestures used to communicate about object manipulation, teamwork gestures required more than hands. Head nods were frequent, and 16.8% of communication events involved eye contact, with participants sometimes using eye contact alone to communicate and idea. This is somewhat surprising, given that participants could not see their partners' eyes or facial expressions. The complexity of these gestures complicates the task of industrial HRI. While there are robots with expressive faces, industry users may be unwilling to implement such costly features. In these cases, in may be necessary to depart from the natural, human-inspired communication described in our lexicon and develop communication methods better suited to simple robotic systems.

A Few Terms Account for Most Communication: The top three teamwork terms (Done, Go/Next, Task State OK) accounted for 95.2% of all teamwork communication, with 'Done' dominating communication. While this distribution does not mean that the other terms are unimportant (e.g., 'Stop/Pause' may still be a critical term), it can be used to guide interaction design. For example, a simple, efficient signal could be used for 'Done' to save time and effort in the assembly task.

Implicit Communication was Present but is Unsuitable for HRI: Participants often used implicit cues to communicate necessary information. For example, by allow her partner to observe her actions assembly actions, a participant could regulate turn taking and show when to begin the next phase of the task. Similarly, significant pauses in action were used to warn of upcoming changes. While both of our coders observed implicit



[1]Finger used to indicate the desired position of a salient feature on the part.

Figure 2. Gestures used in object manipulation communication

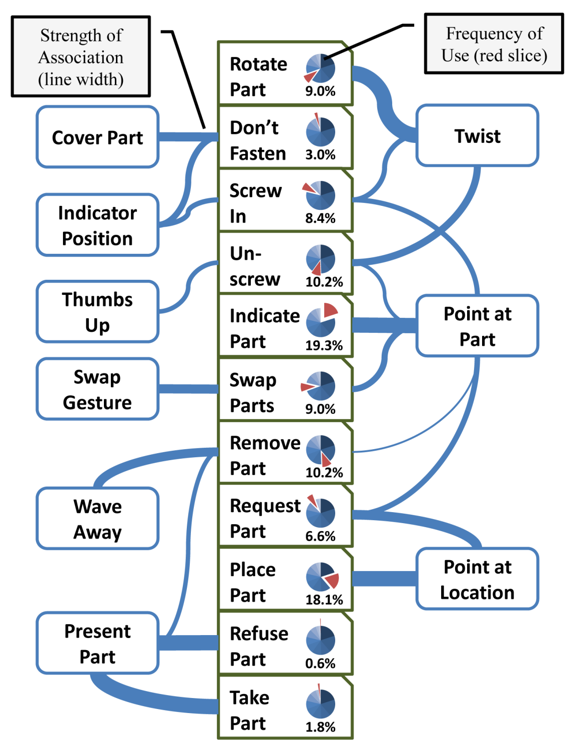


Figure 3. Gestural lexicon for object manipulation, mapping terms (center) to gestures (rounded rectangles). Inset charts show frequency of term use, as fraction of all object manipulation communication.

communication and agreed on the meanings of implicit cues, they were unable to reliably agree on when implicit communication was occurring and when it was not (Kappa = 0.13). Given that our human coders were unable to consistently detect these implicit communication events, we cannot recommend implicit communication as a reliable form of human-robot communication and did not include implicit gestures in our lexicon.

4. ONGOING AND FUTURE WORK

In ongoing work we are validating the effectiveness of our gestural lexicon when used in real human-robot interaction. We have found the object manipulation gestures easily understood when executed by a robot, and participants generally rated the gestures as natural and easy to interpret, within the context of an assembly task. We are currently testing the teamwork lexicon. In addition to the gestures reported here, we are investigating other means to communicate between a human and machine, particularly in the case of teamwork communication where complex and subtle gestures may be impractical for industrial robots. We are exploring simple, symbolic communication such as lights and vibrotactile stimuli for communicating from the robot to the human. For human-to-robot communication, we are investigating touch-based communication, where the user touches and pushes the robot to communicate simple ideas.

5. ACKNOWLEDGMENTS

We thank the other members of the CHARM team who have contributed to this work. This research was funded by NSERC and General Motors of Canada under contract 140570247.

6. REFERENCES

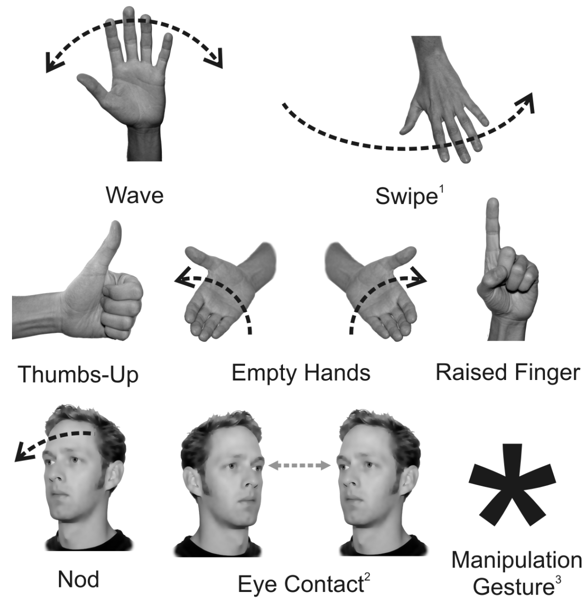
[1] C. Heyer, “Human-robot interaction and future industrial robotics applications,” in *Int’l Conf. on Intelligent Robots and Systems*, 2010, pp. 4749–4754.

[2] S. Haddadin, M. Suppa, S. Fuchs, T. Bodenm, A. Albu-Schaaffer, Hirzinger, and Gerd, “Towards the Robotic Co-Worker,” in *Robotics Research*, C. Pradalier, R. Siegwart, and G. Hirzinger, Eds. 2011, pp. 261–282.

[3] K. W. Lee, H.-R. Kim, W. C. Yoon, Y.-S. Yoon, and D.-S. Kwon, “Designing a human-robot interaction framework for home service robot,” in *ROMAN 2005.*, 2005, pp. 286–293.

[4] T. Fong, J. Scholtz, J. A. Shah, L. Fluckiger, C. Kunz, D. Lees, J. Schreiner, M. Siegel, L. M. Hiatt, I. Nourbakhsh, R. Simmons, B. Antonishek, M. Bugajska, R. Ambrose, R. Burridge, A. Schultz, and J. G. Trafton, “A Preliminary Study of Peer-to-Peer Human-Robot Interaction,” in *Int’l Conf. on Systems, Man and Cybernetics*, 2006, pp. 3198–3203.

[5] B. T. Gleeson, K. E. MacLean, A. Haddadi, E. A. Croft, and J. Alcazar, “Gestures for industry: intuitive human-robot communication from human observation,” in *International Conference on Human Robot Interaction*, 2013, p. In Press.



[1]Horizontal swipe of the hand, as opposed to the vertically oriented ‘Wave’.
[2]No true eye contact was possible, as participants wore dark glasses.
[3]Manipulation gestures (Figure 3) were sometimes used for teamwork.

Figure 4. Gestures used in teamwork communication

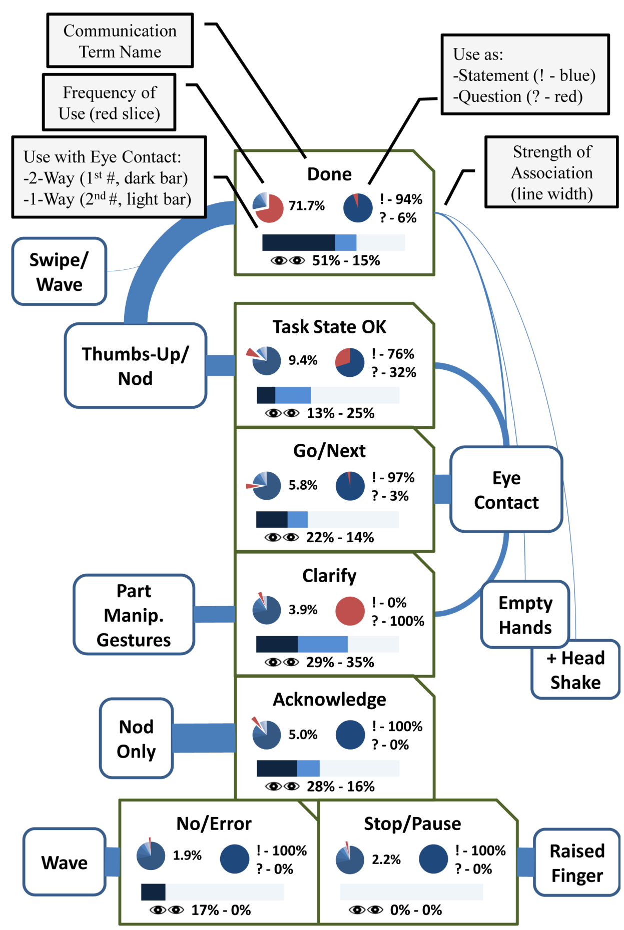


Figure 5. Gestural lexicon for teamwork communication.