Natural Human-Robot Interaction Using Social Cues

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***Abstract*—This paper investigates the problem of how humans understand and control human-robot collaborative action and how to build natural interactions during human-robot collaborative action. We use a 'pick and place' experiment to study collaborative activities between a human and a robot. The results show that even if human participants had a good understanding of the maximum reachability of the robot, they consistently take a surprisingly long time to help and assist the robot when a target object is out of its reach. We implemented a number of social cues in the experiment, analysed their effects in order to identify the role they could play to improve the fluency of human-robot collaboration. The experimental results showed that when the robot uses head movements, two hands or a gesture to indicate non-reachability, people react in a more natural way to assist the robot.**

I. Introduction

Humans are exceptionally good at working in teams, but teamwork is a critical challenge in human-robot interaction. A key problem in this challenge is to understand the capabilities and behaviours both human and robot team members require to work together productively. In particular, we explore how a group of independent co-workers achieve a shared-goal through the development of collaborative behaviours (which we call *joint-actions*) and the achievement of a new state of *we-ness* [6].

Joint or collaborative action, could be described as doing work as a team where the participants share a common goal and jointly execute a series of actions to achieve the goal. Collaborators can use the perception of *affordance* to facilitate the development of joint intention that takes account of the embodiment limitations of partner agents (both humans and robots) creating a more effective natural interaction [2][3]. Affordance relates to the qualities and properties of an object that determine its possible uses, and indicate how it can or should be used. More formally, *affordance* is "an acquired relation between the behaviour of an agent and an entity in the environment such that the application of the behaviour on the entity generates a certain effect" [5]. For example, a robot arm might afford grasping a Duplo block, or pushing a Duplo block.

Perceiving affordances of another agent is important in collaborative activities, because it provides critical information about the available resources and constraints of the environment; possible interactions and collaborative actions [1]. For example, perceiving that a robot's arm cannot reach an object beyond a certain distance allows a human partner to not rely on the robot to pick up an object beyond this distance. In the same way as two people working to achieve a joint goal take each others capabilities and limitations into consideration in predicting what they can contribute, so too when a human works with a robot. For example, humans must use affordance to predict a robot's intention, and the consequences that follow in order to achieve cooperation and natural collaboration [4].

The research reported in this paper attempts to understand how an agent chooses to engage in a joint-action depending on the perceived changes in the affordance of another agent, and the kinds of cues (gaze, gesture, arm position) that if introduced could help to develop a more natural (efficient and effective) interaction. We designed a simple `pick and place` experiment to explore this insight.

II. Experiment

In this experiment, we used four Duplo blocks with four distinct colours. The shared-human-robot goal was to build a tower with the blocks of an agreed configuration and colour sequence (see Fig 1). We implemented different gestures on a PR2 robot and tested their effectiveness in creating natural interactions using a two-staged experiment.

Stage 1 of the experiment investigated how precisely human participants were able to determine (i) the maximum reachable distance of the robot, and (ii) the maximum reachable distance of another human facing them directly across the work bench that was used later to build the tower. To do this, the participants were asked to draw a boundary line that showed the maximum reachability region where the robot and the human, respectively, could reach an object on a table. This line represented the region beyond which the robot could not reach with its arms.

Then, for Stage 2 of the experiment, participants were asked to build a tower of a specific sequence of coloured blocks in collaboration with the robot. The following five different scenarios **A** - **E**, illustrated in see Figure 2, were used to test how well the human was able to work with the robot.
Scenario A: half the blocks are located on each side of a table;
Scenario B: two blocks are located within reach of the human, but out-of-reach of the robot, and two within reach of the robot.
Scenario C: two blocks are located within reach of the human, but out-of-reach of the robot, one within reach of the robot; the robot moves its head to look at blocks it cannot reach;
Scenario D: blocks are arranged in a straight line; the two hands of the robot are fully occupied each holding a block;
Scenario E: all the blocks are placed on the side of the participant, and the robot uses an 'unable to reach' gesture to indicate it cannot reach a specific block to reach the goal.

We added social cues in scenarios **C**, **D** and **E** to observe how humans engage in the collaborative action with robots, and how social cues could change and improve the interaction.

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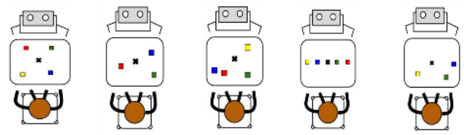

Fig 1: **A** **B** **C** **D** **E**

We recorded the time that each participant took to act after the robot completed its action. The experiment involved 10 participants of different gender (3F; 7M), ages (20-40) and professions (1 undergrad, 3 grads, 3 engineers, 3 others).

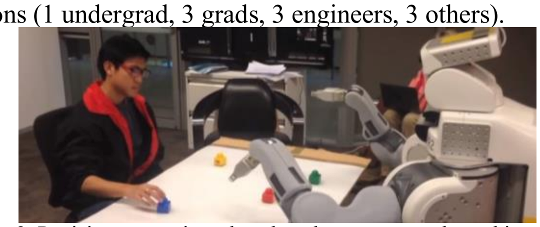

Fig 2: Participants reaction when the robot cannot reach an object.

III. RESULTS

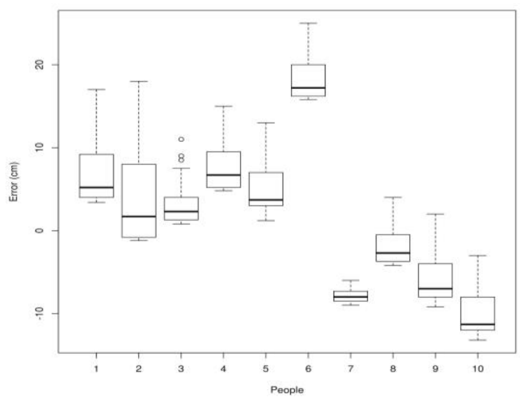

Fig 3: Accuracy of determining the reachability area of the robot

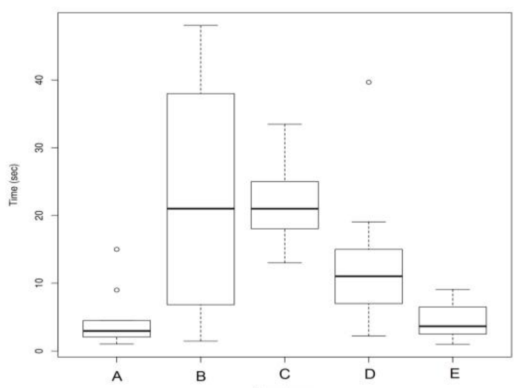

Fig. 4: Time spent by participants when the robot cannot reach an object.

For Stage 1 of the experiment, we evaluated the accuracy of the participant's assessment of the robots reachability given by their drawing on the table of their estimate of the robot's reachability by comparing it with the real reachability of the PR2, which was physically measurable. Fig. 3 shows all the participants were able to accurately determine the reachability of the robot, even if they had not seen the PR2 robot previously. Most of the participants achieved an error margin less than 10 cm. Fig. 4 shows the time that the participants spent in Stage 2 of experiment under the five scenarios. The time taken for Scenario **B** was the longest with the largest variances. The other scenarios (**C**, **D**, **E**) have the same range of time (~10 sec). Participants engaged quickly in the joint action (~5 sec) in Scenario **A**, when all blocks are reachable. When the arrangement of blocks is more complicated (as in **B** - **D**), they take more time to collaborate.

IV. CONCLUSION & DISCUSSION

When the robot was unable to reach an object, and did not offer a cue, the human took a surprisingly long time to respond, and participate in the joint action. It is also surprising that participants with more accurate determinations of the maximum robot reachability (Fig 3) did not perform better. There are several possible explanations for this behaviour: some participants (i) were unfamiliar with the PR2 and unsure what it will do, (ii) may not have wanted to make a "mistake".

Stage 2 of the experiment was designed to evaluate to what extent the simple robot social cues would help to build a more natural (efficient and effective) interaction. The variation of response time is halved in scenario **B.** Regarding the head movement, when PR2 head points to the object that it could not reach, the response of the participant time decreased significantly (by ~15sec). The use of two hands (scenario **D**) is better understood by participants as they waited around only 10 sec before responding. Holding blocks in both hands simultaneously provided a valuable cue to human participants. The robot cue that human participants understood best were the special gestures indicating the next required block as unreachable as evidenced by the most significant reduction in response time (<8sec). Clearly, the use of this gesture gives a valuable clue that leads to a more natural interaction and conveys important information for collaborative action.

In this paper, we have demonstrated that judgments of affordance are not sufficient for natural interactions and cues are necessary during a collaborative action. Moreover, we identified the most important and most useful cues to indicate an unreachable object. We also demonstrated that a robot can naturally interact with objects and humans, using simple social cues without voice commands. Furthermore, we have shown that humans can participate responsively in real-time joint actions with a robot using social cues, and not as passive agents following instructions such as verbal commands that are not always possible and slow down the collaborative process. It is our intention to make the robot physical behaviours more similar and natural to a human working with another human in a collaborative setting. According to Norman [4] the human needs continual feedback about the state of the robot to build a better more natural interaction.

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