# Promoting Collaboration with Social Robots

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***Abstract*—As robotic technology becomes more robust and interactive, robots are increasingly stepping into the role of a collaborator to humans in various contexts. In addition to performing collaborative tasks accurately and efficiently, robots should also contribute socially by improving team effectiveness and cohesion. This work is a first step toward developing a high-level reasoning model of the motivations and strategies held by each individual of the team. With this model, social robots will be able to promote more efficient and enjoyable collaboration by suggesting improvements to specific actions, aligning diverging strategies, and encouraging actions that promote higher team cohesiveness.**

## I. Introduction

In our increasingly interactive world, collaboration is an essential human skill, critical to learning, work, and everyday social interactions. In a similar way that collaboration skills are necessary for humans, robots will also need to be equipped with the skills to be a productive and valuable collaborator in a wide variety of contexts.

There has been a substantial focus in human-robot interaction research on improving the competency of a robot to complete tasks that a human would find beneficial. Robots can now learn tasks from demonstration [1], determine what part of a task a human is in and offer appropriate assistance [2], and teach or tutor humans [3]. While focusing on improving the proficiency of robots performing particular actions is important, robots can also improve a multiple human and robot teaming experience by enhancing human-human collaboration. Improving the quality of human interactions in a collaborative scenario is fundamentally different than improving task performance, as it impacts the social dynamics of the team to further enhance the collaborative experience.

We believe that providing social robots with an increased ability to perform team orientation and coordination actions will significantly increase the value of robots as collaborators. Social robots that promote pro-social and collaborative actions among their colleagues can increase team cohesiveness, an essential component to collaborative success [4]. Additionally, social robots that can perform higher-level strategy, suggesting improvements and ideas for new directions to colleagues, could drastically improve the effectiveness of teams.

We are in the process of conducting exploratory work into developing a robot that promotes collaboration among its colleagues through direct inquiry. We have plans to further develop this work of promoting collaboration by developing high-level reasoning models to formulate and find optimal strategies.

## II. Related Work

To develop rich and informed autonomous collaborative interactions between robots and humans, we believe understanding and contributing to group high-level strategy formation is a necessary skill for robots seeking to promote collaboration. Strides have been made toward equipping a robot to perform hierarchical task analysis in a human-robot collaborative context. Hayes has developed an algorithm that builds hierarchical representations of tasks from physical demonstrations so that a robot can anticipate the needs of a collaborator (and offer a supportive behavior) [2], [5]. These hierarchical representations are useful in that they are symbolic representations of how a task is being completed, from which strategy could be derived. Others have developed autonomous coordination algorithms for multi-robot systems [6], [7]. These algorithms are useful, in that we can derive ways that a robotic agent can collaborate with its colleagues once a strategy has been determined. These methods are excellent steps toward autonomous high-level strategy formation; however, we still lack the ability to determine a high-level strategy given a set of inputs, update that strategy, and suggest optimizations to that strategy.

## III. Proposed High-Level Reasoning Model

We plan to develop a model of higher-level reasoning and strategy so that we can provide a social robot with the ability to promote collaboration autonomously. The strategic reasoning model that we propose has two main components: 1) maintaining a model of the groups current strategy and 2) searching for optimizations to the current strategy.

To begin, the model will take as input some specific features of the task and task domain. In the beginning of the interaction, the robot would determine how to measure the outcome measure as well as factors that influence the outcome measure through observation and posing questions to collaborators. Once the robot can measure success and influencing factors, the model will use these features to determine what the current strategy of the group is. From this data, the model should be able to detect trends. Additionally, the robot will listen to what its other team members say to derive strategy. For example, in a construction task, the robot should be able to parse phrases like "let's expand the foundation so we can make it taller." This model will continually update and keep track of trends and the success associated with each trend.

Once the robot has a model of the current strategy of the group, it can both 1) contribute to discussion on strategy and 2)

Fig. 1. A social MyKeepon robot, tries to promote collaborative behavior between two children while playing an interactive build-a-rocket game (on a touch-screen monitor).

understand better the strategy formation dynamics to promote better collaboration. To contribute to discussion on strategy, the robot can perform optimizations to try and determine if there are better strategies that the group is not executing (exploitation) or strategies that the group has not tried to execute yet (exploration). To use this strategy formation model to promote collaboration, the robot will comprehend what the current strategy is and which parties have been the most influential in its formation, and use this information to improve the collaborative dynamics. For example, the robot may recognize which individuals are driving decisions and take note if certain parties' opinions are being ignored. Then, the robot could employ repairing actions to include and promote the use of strategies proposed by the participant whose opinions are being ignored.

## IV. Current Work

Before starting to construct this proposed high-level reasoning model, we conducted a study to examine the effects of different strategies of promoting collaboration a social robot employs in a group playing a game. By studying the responses and effects of these robot interventions, the high-level reasoning model we construct will be able to suggest which strategy to employ to achieve the desired result. Additionally, we will be able to use the observational data from this first study to inform and train our high-level reasoning model.

For this first study, we sought to promote the growth and use of collaborative skills in children by building a robot that promotes collaboration through direct inquiry. We decided to focus on children between the ages of 6 and 9 years old because a child's ability to plan and collaborate emerges around age 5 [8]. Thus, children between the ages of 6 and 9 would likely benefit from interventions to improve children's collaboration. During the experiment, two children and a robot play an interactive tablet build-a-rocket game, shown in Figure 1, during which the robot will either attempt to promote collaboration between the two using one of three strategies. These are the following strategies that the robot employed:

1) **Relational**: The robot asks questions during pauses in the rocket building game that are targeted at developing and reinforcing the relationship between the participants, for example, "[Participant 1], is there a way for you to help [Participant 2] better next time?"
2) **Task**: The robot asks questions during pauses in the rocket building game that aim to better focus the participants on the task they are working on, for example, "[Participant 2], which pieces do you want to change for next time?"
3) **Control**: The robot does not say anything during pauses in the game.

We have run the described study with a total of 88 participants. We are currently in the process of analyzing and making conclusions from this data. In addition to running this study with children, we are also running this study with adults to study the differences in reactions to the robot's questions. We are measuring performance and collaboration quality by each pair's task success, the type of utterances used (discussing strategy, encouragement, feedback, etc.), and nonverbal behaviors.

## V. Conclusion

As robots becoming increasingly common as collaborators with humans, it is important that robots become better social collaborators through their promotion of collaborative behaviors in the group. We seek to build a high-level reasoning model to achieve this goal. We are in the process of a first study that examines the effectiveness of robot interventions to promote collaboration using different strategies. After this study, we plan on constructing this high-level reasoning model that will maintain a model of the groups current strategy and search for optimizations to the current strategy.

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