Anticipatory Communication Strategies for Human-Robot Team Coordination

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Increasing prevalence of autonomous systems has generated interest in effective inclusion of robots as team members in many domains, especially where complex and safety-critical tasks must be performed. I envision a world where autonomous systems can be seamlessly integrated into high performing human teams. In order for team members to successfully work in concert to achieve a goal, the team must establish a common understanding of the task expectations and communicate effectively. In my dissertation, I draw inspiration from studies of effective human teamwork, which show that best performing human teams exploit anticipatory coordination strategies (referred to as implicit coordination) to selectively communicate information based on the perceived needs of the other members in the team instead of requesting for information (referred to as explicit coordination). I elaborate upon prior characterizations of communication as implicit versus explicit by dividing implicit communication into two subtypes: (1) goal-based information (referred to as deliberative-implicit communication) and (2) status updates (referred to as reactive-implicit communication). Based on an empirical study conducted using 13 teams of 4 people working on a collaborative search-and-deliver task, I find that the best performing teams exhibited higher rates of deliberative communication than reactive communication compared to the worst-performing teams ($p = 0.039$). In other words, the best performing teams proactively shared goal-based information with their teammates.

By gaining insight into how high-performing human teams communicate effectively, I developed a computational model using a Maximum Entropy Markov Model (MEMM) that selects the appropriate communication type (i.e., deliberative, reactive, explicit or no communication) for the autonomous agent using human teams' data. I show that my model accuracy was high when the model was trained and tested using the best-performing teams' data (73.3%) and all 13 teams' data (92.3%) from the previously studied human-human teams. I further validate this model by assessing team performance in an empirical study where teams consisting of 2 human and 2 autonomous agent worked on a collaborative task. I compare the performance of teams with agents using the MEMM communication model to performance of teams with agents communicating using only deliberative-implicit communications or reactive-implicit communications. Results from this study showed that team performance with agents using the MEMM communication model was statistically better than team performance with agents using reactive-implicit communication model ($p < 0.001$) and deliberative communication model for the fastest five teams ($p < 0.001$). I also found that mean task completion time for agent using the MEMM model was equivalent to the mean task completion time of human-human teams study within 95% confidence. For these reasons, I recommend that a human inspired communication model be further investigated and implemented in human robot teams meant to work in cooperation with human teammates. This is one of the first studies to empirically demonstrate that teams consisting of humans and autonomous agents, where the agents are designed to emulate communication strategies of human teams, performs equally as well as teams with all humans.