Automated Planning for Peer-to-peer Teaming and its Evaluation in Remote Human-Robot Interaction

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ABSTRACT

Human factor studies on remote human-robot interaction are often restricted to various forms of supervision, in which the robot is essentially being used as a smart mobile manipulation platform with sensing capabilities. In this study, we investigate the incorporation of a general planning capability into the robot to facilitate peer-to-peer human-robot teaming, in which the human and robot are viewed as teammates that are physically separated. One intriguing question is to what extent humans may feel uncomfortable at such robot autonomy and lose situation awareness, which can potentially reduce teaming performance. Our results suggest that peer-to-peer teaming is preferred by humans and leads to better performance. Furthermore, our results show that peer-to-peer teaming reduces cognitive loads from objective measures (even though subjects did not report this in their subjective evaluations), and it does not reduce situation awareness for short-term tasks.

Categories and Subject Descriptors

H.1.2 [**Human factors**]; I.2.8 [**Plan execution, formation, and generation**]; J.7 [**Command and control**]

Keywords

Robot design principles; Autonomous robot capabilities; User study/Evaluation; Teamwork & group dynamics

1. INTRODUCTION

In supervised human-robot teaming, the human creates the plan to achieve the global goal, and then either directly provides motion commands or breaks the plan into sub-plans

(or sub-goals) for the robot to handle. In peer-to-peer (P2P) teaming, the human and robot share the same global goal and collaborate to achieve it. While increasing robot autonomy is generally viewed as desirable, humans may feel uncomfortable at the loss of control entailed by such autonomy in P2P teaming, which can potentially reduce situation awareness for humans and affect teaming performance.

In this study,[1] we mainly concentrate on remote interaction and perform our investigation for emergency response in an urban search and rescue (USAR) task. Here, the task cannot be fully specified a priori due to incomplete information about the models, goals or settings in such scenarios. Furthermore, information can be continuously changing throughout the task and may not always be synchronized between the human and robot (e.g., goal updates and human preference models) due to communication or interpretation delays. The goal of this USAR task is to explore areas of the disaster scene to provide real-time information, which is then used to aid the management team to create rescue plans (e.g., identifying locations of casualties). The aim of our study is to compare P2P and supervised teaming in terms of objective measures as well as subjective measures such as situation awareness and mental workload.

Related Work: In most previous works on human-robot and human-machine interactions (e.g., [1]) for teaming, the human always plays a supervisor role. While there are works that incorporate general planning capabilities into robots to achieve P2P teaming (e.g., [3]), as yet, there exists no empirical investigation of its influence on the teaming performance. In this study, we implement P2P teaming in which the human and robot are viewed as teammates, and the robot exhibits autonomy through automated planning capabilities. In terms of automation in human-robot interaction, it is well known that it can have both positive and negative effects on human performance [2].

2. STUDY DESIGN

Fig. 1 presents the simulated environment and human-robot interface used in our USAR task, which represents the floor plan of an office building before a disaster occurs (e.g.,

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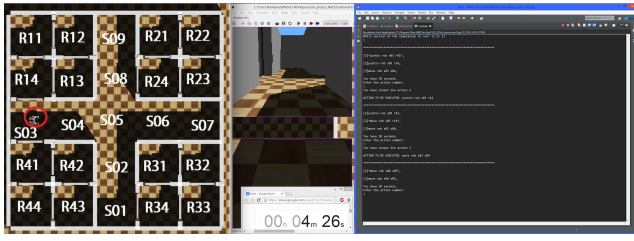[1] A longer version at rakaposhi.eas.asu.edu/hri15-long.html.

Figure 1: Environment (left) and interface (right) used in the USAR task with a simulated Nao robot.
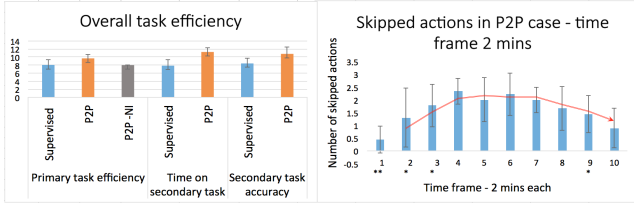

Figure 2: Results for objective measures.

a fire). The study was performed over 4 weeks and involved 19 volunteers. Each subject took part in one experimental trial of either P2P or supervised teaming. Both the human subject and robot had access to the floor plan before the disaster. The robot in P2P teaming could use the planning capability (based on SapaReplan [3]) to independently create its own plan based on the floor plan and current status of the task. In both teaming scenarios, the robot displayed a list of applicable actions that it could perform given the current state. The interaction interfaces were the same except that the robot in P2P teaming also recommended the next action (from along the applicable ones) in its plan. The global goal was to report the number of casualties in as many rooms as possible in 20 minutes.

The incomplete task information was assumed to be a result of blocked doors. We provided the information regarding which doors might be blocked to the human subject, but only after the task had run for 1 minute to simulate dynamic information. This information, however, remained unknown to the robot. The human subject could interact with the robot at specific times to reduce the influence of this information asymmetry, or the robot had to learn this information by pushing the door and failing (which could reduce the teaming performance).

In a real USAR task, the human would also have other information to process and analyze. To simulate this, the human subject was also assigned to a secondary task. This secondary task involved solving three-dimensional spatial visualization puzzles. The performance of the team was evaluated on both the primary and secondary tasks. Each trial ended when the given time elapsed. Finally, the human subject completed a questionnaire (in Likert scale) that included questions for evaluating situation awareness, mental workload and other subjective human-robot interaction aspects.

3. RESULTS AND CONCLUSIONS

The results for objective measures are presented in Fig. 2. Overall, subjects in P2P teaming outperformed subjects in supervised teaming in terms of the number of rooms visited
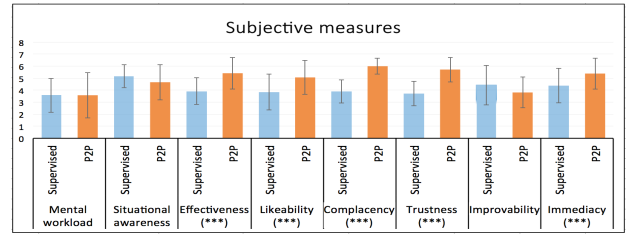

Figure 3: Results for subjective measures. $*$ denotes $p < 0.05$, $**$ denotes $p < 0.01$, $***$ denotes $p < 0.001$.

within 20 minutes and the secondary task performance (left part of Fig. 2). In fact, performance for the primary task in supervised teaming was no better than the robot with a planning capability executing the task alone (i.e., P2P-NI). Results for subjective measures as assessed by the survey questionnaire are presented in Fig. 3. Our analysis on mental workload did not show any significant difference due to the fact that most humans preferred to rely on themselves at the beginning even in P2P teaming, which might be a result of the lack of trust in the robot for handling the task initially. This effect can be seen from the right part of Fig. 2, which shows how many robot recommended actions were followed by the human subjects in P2P teaming. Even though the workload was seen to be almost the same based on subjective measures (Fig. 3), the objective measures suggest that the cognitive load was indeed reduced (based on the time spent on the secondary task (left part of Fig. 2)). Our analysis on situational awareness did not show any significant difference either. This might be partially due to the fact that the recommended action of the robot from the planning capability during execution provided situation awareness to the human subject, since the same action would likely be chosen by the subject in the same situation. This is interesting since it suggests that humans in P2P teaming can maintain situation awareness, at least for short-term tasks such as our USAR task. Our analysis on likability, improvability, and complacency showed that the subjects generally preferred and felt more satisfied working with the robot in P2P teaming.

Our conclusions from this preliminary study are that humans prefer working with robots with a planning capability for P2P teaming, and the planning capability helps reduce cognitive load and maintain situation awareness for short-term tasks.

4. REFERENCES

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