Human-Autonomy Teaming and Agent Transparency

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ABSTRACT

We developed the user interfaces for two HRI tasking environments based on the Situation awareness-based Agent Transparency (SAT) model: dismounted infantry interacting with a ground robot (Autonomous Squad Member) and human interacting with an intelligent agent to manage a team of heterogeneous robotic vehicles (IMPACT). User testing showed that as agent transparency increased, so did human operator performance and trust calibration effectiveness. The expanded SAT model, which includes Teamwork Transparency, is also briefly described.

1. INTRODUCTION

We developed the SA-based Agent Transparency (SAT) [1] model—based on the theory of situation awareness (SA) [2], the Beliefs-Desires-Intentions Agent Framework [3], and other relevant previous work [4][5]—to support human operator's SA of the mission environment involving the autonomous agent (Fig. 1). Agent transparency is defined as the "quality of an interface pertaining to its abilities to afford an operator's comprehension about an intelligent agent's intent, performance, future plans, and reasoning process" [1]. At the *first* level of the SAT model, the operator is provided with the basic information about the agent's current state and goals, intentions, and proposed actions. At the *second* level, the operator is provided information about the agent's reasoning process behind those actions and the constraints/affordances that the agent considers when planning those actions. At the *third* level, the operator is provided with information regarding the agent's projection of the future state, such as predicted consequences, likelihood of success/failure, and any uncertainty associated with the aforementioned projections. Incorporating all three levels should allow an operator to gain understanding of an agent's reasoning process behind its actions and help the operator make informed decisions as to whether he or she should intervene. Recent research programs such as the U.S. Department of Defense Autonomy Research Pilot Initiative (ARPI) have started to investigate some of the key human-agent teaming issues that have to be addressed in order for mixed-initiative teams to perform effectively in the real world with all its complexities and unanticipated dynamics. This paper summarizes two efforts supported by the ARPI to investigate the effects of agent transparency on human-agent team performance in two military contexts. Also briefly summarized is the expanded SAT model (Sect. IV), which incorporates Teamwork Transparency.

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Situation awareness-based Agent Transparency

Level 1: *Agent's current status/actions/plans*
- Purpose: Desire (Goal selection)
- Process: Intentions (Planning/Execution); Progress
- Performance

Level 2: *Agent's reasoning process*
- Reasoning process (Belief/Purpose)
- Environmental & other constraints/affordances

Level 3: *Agent's projections/predictions; uncertainty*
- Projection of future outcomes
- Uncertainty and potential limitations; Likelihood of success/failure
- History of Performance

Figure 1: SAT Model

2. AUTONOMOUS SQUAD MEMBER

The objective of the Autonomous Squad Member (ASM) project is to investigate enabling agent capabilities to support military squad-level performance in dynamic mission environments. The SAT model provided a framework for how to organize and implement the information coming from the ASM to the human squad members (Fig. 2; the "*At-a-Glance*" Transparency module is displayed in the upper left corner).

Figure 2: ASM user interface

Ecological Interface Design (EID) and Cognitive Systems Engineering (CSE) principles were used to develop the visualizations of the SAT model-based information [6]. One of the principles of EID and CSE is to design an interface using metaphorical symbology that is based on principles that the user would already be familiar with [6]. After the initial user interface was developed, in order to ensure the effectiveness of the designs, we conducted two usability evaluations: the pluralistic usability walkthrough [7] and the card sorting task [8]. The purpose of the pluralistic usability walkthrough is to have users and usability experts observe a typical use case of the interface and garner feedback on the tasks performed using the interface [7]. This feedback can be commentary on the design of the interface, areas of the task that the user might be having difficulty performing, or if the presentation of information in the training materials was unclear. The card sorting task was used to examine the mental models evoked by the symbology utilized in the interface [8].

A human-in-the-loop experiment with sixty participants was subsequently conducted to test the effects of ASM transparency on operator performance, workload, and trust in the ASM [9]. In four different SAT model-based display conditions, participants used the ASM's interface to gain information about the ASM and simulated squad's status as they completed a route containing obstacles. Results indicated that participants had greater trust in the ASM and were most effective at maintaining SA when the ASM provided all three levels of SAT information (without uncertainty). No significant difference in participant workload was observed among different levels of ASM transparency.

3. IMPACT

In the IMPACT study, we examined the level of information necessary to create an effective and transparent interface to support human teaming with an intelligent agent (IA) for multi-robot management in a series of simulated military missions (Fig. 3).

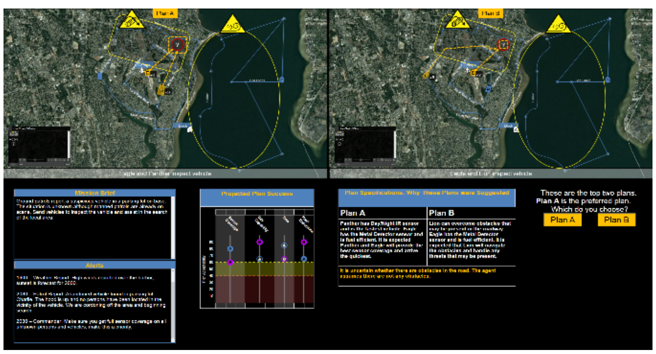

Figure 3: IMPACT user interface

For each mission, the IA provided two recommended plans utilizing the robots (including ground, aerial, and surface platforms). Plan A was always the agent's top recommendation, and plan B was the back-up plan. About 1/3 of the times, Plan B was actually the better option—the agent was incorrect due to external information (changes in Commander's Intent, intelligence, etc.). A within-subjects design with three levels of agent transparency (based on the SAT model) was employed: Level 1+2, Level 1+2+3; Level 1+2+3+U (uncertainty information). Fifty-three young adults participated in this study [10]. Participants' task was to choose between Plan A and Plan B based on the information presented by the IA and additional information that was provided (e.g., Commander's intent/instructions, etc.). Results indicated that proper IA use and correct rejection were both significantly greater when L1+2+3+U was presented compared to L1+2. The greatest rates of proper IA use and correct rejection were found with L1+2+3+U, suggesting that operators were more likely to make correct decisions when they were presented with all three levels of transparency as well as uncertainty. As we found in a previous study [11], no significant difference was found for workload, indicating that operators did not experience more effort as the agent transparency increased. Participants' subjective assessment of their trust in the IA indicated that they trusted the IA's ability to *analyze* information most when presented with L1+2+3+U, while they trusted the IA's ability to suggest *decisions* most when presented with L1+2+3.

4. TEAMWORK TRANSPARENCY

Since the SAT model was first introduced in 2014, progress in artificial intelligence and in the capabilities of autonomous systems has continued to advance. To capitalize on these advances in machine learning and their potential applications in mixed-initiative teaming, we have expanded the SAT model by incorporating aspects of Teamwork transparency and Bidirectional communications between human and machine agents [1]. To facilitate the creation and maintenance of a shared understanding between the human and machine agents, the machine must communicate not only *taskwork* information (e.g., task procedures, likely scenarios, environmental constraints) but *teamwork*-related information as well (e.g., role interdependencies, interaction patterns, teammates' abilities). Specifically, the updated model moves beyond characterizing and framing transparency with regard to an agent's communication about *itself* (i.e., current state, goals, reasoning, projections) and encompasses transparency as it applies to an agent's understanding of its *teammate*'s roles and responsibilities and its *interaction* with its teammate as well. In a model incorporating these types of transparency, both human and machine agents are responsible for maintaining transparency regarding their own tasks as well as their contributions to *shared tasks*. This bidirectional transparency allows the human and machine agents to take each other into account when making decisions. It would also allow them to use each other's behavior and reasoning as a resource in their own decision making process.

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