Human Autonomy Teaming for the Tactical Edge

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Abstract. The U.S. Army is currently working to integrate artificial intelligence (AI)-enabled systems into military working teams, in the form of both intelligent embodied agents (i.e., robots) and computer agents, with the express purpose of improving performance during all phases of the mission. This is largely uncharted territory, and it is not yet clear how to do this effectively, nor is it clear how to measure the effectiveness of such human-AI integrated teams. This paper provides an overview of the Combat Capabilities Development Command Army Research Laboratory's Human-Autonomy Teaming Essential Research Program to address this critical gap and the associated implications on effective teaming.

Problem Statement

Artificial intelligence (AI) is a core component of the U.S. Army's modernization strategy. The Combat Capabilities Development Command Army Research Laboratory's Human-Autonomy Teaming Essential Research Program (HAT ERP) directly supports this emerging capability. While relevant research in AI tends to focus on limited aspects or isolated functional snippets of the overall task, for our work to be effective, the research must cover Soldier-autonomy teams completing all phases of the mission and adapting to any situation along the way. Advancing forms of AI will continually change the nature of the battlefield and the very nature of the tasks that Soldiers perform. A common pitfall when developing autonomous systems for human-autonomy team is to trivialize the human component when modeling the characteristics of such a system. Our approach for Soldier-focused AI development focuses on how to optimize the synergistic employment of Soldier intelligence with AI to address the volatile dynamics and complexity inherent to multi-domain operations (TRADOC, 2018).

Thrust Areas and Associated Research

Our research is predicated on the idea that in order to manifest the full potential of advancements in intelligent technology, such as AI, we will need to truly team human and AI capabilities. We expect that the nature of interaction between humans and AI will need to change dynamically in order to be sensitive to changes in context, including different time constraints, levels of certainty or the amount of data available, and complexity of the problem. Effective and intelligently designed and applied bidirectional teaming mechanisms (Marathe et al, 2018) will allow us to overcome the limitations of both human and artificial capabilities and achieve a level of performance and ability that is currently not possible. Broadly, in order to do this, we need to understand how and where human and machine capabilities complement each other and how and where they fundamentally differ.

While the U.S. Army has employed smaller ground robots for dull, dirty, and dangerous tasks at the tactical level for decades, we are starting to see new possibilities for standoff with the introduction of large autonomous combat systems. These larger combat systems are expected to exhibit autonomous (or semi-autonomous) mobility, situation awareness (to include target recognition), and communication. While the introduction of autonomous capabilities for complex combat systems offers new operational possibilities, the effective integration of such systems from a teaming perspective, from the tactical all the way to strategic levels, is still an area of open research. Our research can be described within four major research thrusts: enabling Soldiers to predict AI, quantifying Soldier understanding of AI, Soldier-guided adaptation, and characterizing Soldier-autonomy performance. The following provides a review on a subset of projects that address critical gaps to integrate AI-enabled systems into military working teams**.**

Enabling Soldiers to predict AI actions

Enabling Soldiers to predict AI provides Soldiers with insights into evolving mission-dependent AI capabilities to ensure Soldiers can effectively predict AI actions. For effective and trusted teaming to be developed and maintained, Soldiers must be able to understand the AI's decisions or actions (Level 1) and the reasoning by which these decisions are made (Level 2) within the mission and environmental context in order to predict (Level 3) future decisions or actions (for more information about the levels of the Situation awareness Agent-based Transparency or SAT Model, see Chen et al., 2014). While there are a number of AI approaches to make AI more "human-like" in its decision-making processes, including use of neural networks, reinforcement learning, and cognitive architectures, to name a few, this critical need for advanced teaming cannot be solved from technology development alone. The difficulty is that there is not one single "human way" of making a decision or solving a problem (e.g., route planning; Perelman, Evans, & Schaefer, in press), resulting in associated algorithms that still may not be trusted by human team members. Therefore, appropriate user interface design and communication strategies can be used in conjunction with algorithm development to effectively communicate decisions made by the AI, its reasoning for making those decision, and support prediction of future decisions or actions.

User Interface Design to Enhance Autonomous Mobility. Mobility is a central component of military operations, especially with respect to the modern maneuver-centric multi-domain battlefield. Prior research in autonomous mobility has shown that AI-enabled agents must behave predictably in order to function effectively as teammates. This predictability can be facilitated by manipulations designed to make the AI's behavior more transparent. In order to improve crew members' awareness of the AI's mobility behaviors in both planning and execution, we implemented multimodal transparent crew interface design concepts. First, a Transparent Route Planner, consisting of modifications to the existing route planning functionality of a crew user display, enabled supervisory control of the vehicle in environments where terrain data is available. In testing with Soldiers, this capability improved the users' understanding of the AI's future mobility actions by over 60% (Perelman et al., 2020). Second, a Comparator Display was designed based upon prior work in unmanned vehicle operations (e.g., Behymer, Mersch, Ruff, Calhoun, & Spriggs, 2015; Stowers et al., 2016) showing that displays designed to improve plan transparency can help commanders make better decisions regarding tradeoffs in mission criteria (Chen et al., 2018). With this display, users were able to improve their understanding of courses of action proposed by AI agents by over 25%, while simultaneously reducing the time spent interpreting the AI by over 35%. Finally, in order to reduce crew workload and improve crew members' local situation awareness and understanding of vehicle autonomy status during mission execution, we implemented a multimodal cuing system, which presented auditory and vibrotactile cues to crew members when the vehicle neared dangerous areas of the environment and when the vehicle's autonomy encountered mobility challenges.

Commander's Interface. The reduction of Soldier crew size makes it necessary for AI to move from tools to teammates. This creates the need for a new level and type of organization and coordination for a commander with his or her crew and AI assets. A Commander's Interface can be operated within a vehicle on the battlefield, providing the commander with command and control capabilities through tools to coordinate execution of human-autonomy team responses to an evolving mission and situational needs. This interface is being designed to maintain a commander's situation awareness and ability to organize and coordinate Soldier and AI crew by providing a consolidated view of information related to: vehicle state (ground and small UAS), crew state (information about tasking, activity, and state of individual crew members), autonomy state (status of autonomous agents including mobility, AiTR, decision support tools, etc.). This will allow a commander to quickly and easily maintain SA of the mission and all of their crew and assets within one interface and communication mode.

Cognitive-centric Display Design. Aided target recognition (AiTR) and other intelligent algorithms for dismount systems uses virtual content overlaid on the real world (augmented reality) as a primary means through which to communicate and effect Soldier-AI team performance. There has been and continues to be a lot of important work on cognitive-centric display design, where principles of cognition are leveraged to optimize displays for intended targeted performance. However, this top down approach may only lead to incremental improvements in performance, as it optimizes what is currently possible. Our research under this area instead focuses on how a better understanding, and therefore targeting, the mechanisms and processes that underpin both the desired performance, as well as the relevant visual cognitive performance. Through the usable field of view of dismounted Soldier systems there is the potential to create levels of joint human-AI target acquisition and engagement decisions; if we alter the way that Soldiers see the world, we are also altering the input that we are opportunistically sensing.

Quantifying Soldier understanding of AI

In order to *quantify Soldier understanding of AI*, it is necessary to be able to incorporate Soldier experience, intelligence, and intent within a mission context, without overburden to ensure effective communications from Soldiers to AI. Whereas the previous research topic was primarily looking at the information being communicated *to* the Soldier, this area focuses on the Soldier. By leveraging Soldier behaviors and actions it is possible to provide AI-enabled systems with specific team constraints and environment-specific data necessary to adapt models of the world needed to improve responses and enhance team situation awareness in a way that is specifically tailored to the Soldier and team's needs.

The Soldier as a Sensor. The continued research into wearable technologies has made it possible to start to consider the Soldier as a sensor within human-autonomy teaming operations. This has the potential to help provide additional understanding of the relationship between operator states, such as trust, and performance and how this relationship varies across different team types and operational contexts (Schaefer et al., 2019; Metcalfe et al, 2017). Therefore, we are developing tools to objectively characterize natural interactions between the human and the AI to account for the behavior and performance of the entire team in order to provide a more objective, continuous, real-time assessment. With more robust models of human states, actions, intentions, and goals built around real-time, machine-consumable physiological measures, we expect to push the boundaries of what's possible with human-machine teams. Development of these novel tools will require creating an integrated system capable of combining wearable sensing with advanced machine learning approaches for real-time state estimation (Marathe et al., 2020). Outcomes will allow systems to adapt to individual Soldier capabilities leading to enhanced Soldier-AI team SA, greater awareness of unknowns and blind spots, an overall system learns and adapts to the Soldier reducing Soldier burden and providing sustained support, and enhanced teaming.

Integrating Soldier Knowledge into AI. Accuracy of AI within highly complex and dynamic terrains is difficult to the nature of the dynamic environment and continuously changing threat. In addition, current AI training processes require a significant volume of labeled data to accurately describe the world, making it incredibly difficult to adapt to adversary actions or situational abnormalities, or even make decisions informed by situational context -- unlike the intelligent, experienced, and highly adaptive Soldier. As such, under this area of emphasis, our research focuses on the understanding how we can link Soldier knowledge to Soldier action, and use opportunistically collected behavioral and biomechanical data to characterize actions or action states (e.g., acquisition of a new target unrecognized by the algorithm, or tracking a target) in order to either create new sources of labeled training data to reflect an evolving threat, or include the data as an additional source for current algorithms to complement the computer vision that it is currently exclusively relying on. On a larger scale, our work is looking at developing tools that support tactical awareness via collective knowledge. By combining passive sensing from multiple individuals it is possible to maximize situational understanding while identifying the gaps in information awareness. From this, we will be able to task AI based on inferred mission objectives.

Soldier-guided AI adaptation

Soldier-guided AI adaptation enables Soldiers to interact with and adapt AI technologies in response to evolving mission demands, commander's intent, and adversarial dynamics. Outcomes of this research should be used to refine algorithms with Soldier interaction and reinforcement learning to continuously improve and adapt capabilities for dynamic and adversarial missions. This supports the development of decision aids that are capable of dynamically orchestrating the tasking and flow of information across a distributed Soldier-AI team. However, complex, dynamic, and data-sparse combat environments can limit the tractability and success of many of the learning strategies, such as deep reinforcement learning, used in civilian settings to produce remarkable AI behaviors and capabilities. Research in Soldier-guided training of AI assets is being undertaken to overcome these constraints and leverage the intelligence and experience of non-expert human users to rapidly imbue learning agents with desired behaviors through data efficient and naturalistic interactions that can be more easily utilized by Soldiers in training and on the ground.

The optimal orchestration of resources in heterogeneous human-AI teams is a critical to effective team operation. Decision aides and transparency tools will need to be utilized to fluidly integrate distributed teams of Soldiers and AI-enabled systems to manage the high volumes of information needed to coordinate their actions to prevent breakdown of team effectiveness, improve resiliency, and increase decision making speed and quality in the presence of dynamic combat environments. One research aim is to learn policies for autonomous task assignment through demonstrations of exemplar team allocations by a commander, given the current mission context. Figure 1 represents the notional concept for such a closed loop orchestration system that dynamically allocates these resources of the Soldier-AI team, via decision aides integrated within the user interface, to maintain desirable or optimal values of measures of interest (e.g. performance metrics, team states, and communication dynamics). With this goal in mind, studies are currently being conducted to assess the open loop effects on these measures of interest of when modulating the team's resources (e.g. team member tasking, information flow, and physical movement and formations) in military-relevant but controlled experimental settings to inform these decision aides to drive toward and maintain more optimal and resilient Soldier-AI teams.

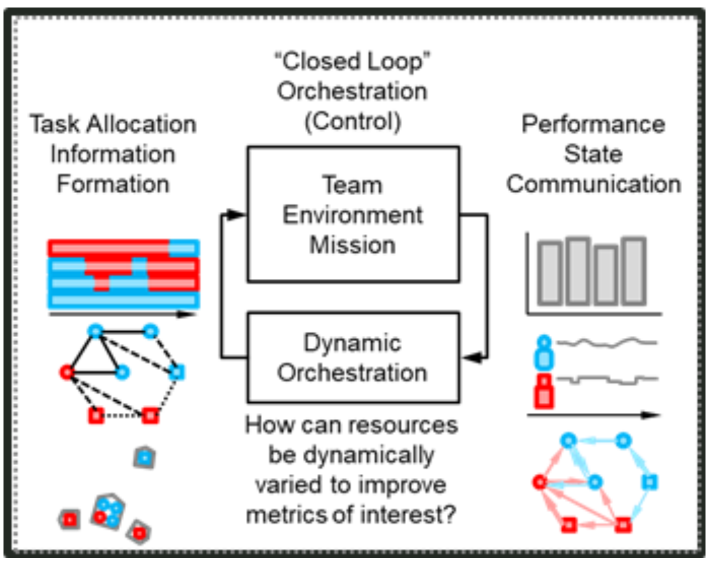

Figure 1. Visual depiction of the multiple factors that influence task allocation.

Characterizing Soldier-Autonomy Performance

Finally, *characterizing Soldier-autonomy performance* research focuses on the development of techniques to measure (and thus intervene to improve) performance in the face of dynamic operational environments. Decades of research on human teams have produced a wealth of literature on factors that are useful for predicting performance outcomes for these teams. However, as the U.S. Army moves to integrate AI, there are several existing deficiencies that must be overcome in order to enable effective teaming. First, the majority of this literature describes qualitative factors; that is, we can currently describe effective teaming very well with words, but not with numbers. Second, attempts to quantify factors that are predictive of team performance frequently employ data and data collection techniques that are not compatible with AI; for example, a great deal of the literature on human team dynamics employs questionnaires. Third, the types of data that might be useful for predicting the performance of integrated human-AI teams may require the rapid processing of high-dimensional or large packet size data, collected at a high sampling rate from spatially distributed agents, by computationally-expensive algorithms. There is the potential for these data to quickly exceed bandwidth limitations; that is, we should not expect to have access to *all the data, all the time.* To overcome these challenges, we are developing novel techniques and technologies for estimating human-AI team outcomes. The products developed during the course of this research project include software applications and sampling techniques intended to characterize, and ultimately allow us to improve, performance in the face of dynamic operational environments.

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