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Assisting Collaborative Decision Making in Complex Environments

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ABSTRACT

Distributed teamwork is becoming increasingly common in many complex task domains, resulting in critical decisions often being made between remotely-located task operators. Many of these operators rely heavily on distributed collaboration technologies, such as email, instant messaging, and desktop conferencing, for communication and information sharing. However, reliance on these "explicit" communication tools for maintaining awareness of remote collaborator's ongoing activities and status requires effort from both parties and can be disruptive. To address this issue an activity-centric design approach has emerged that aims at helping people remain apprised of remote colleagues' activities, while minimizing disruption. To illustrate the utility of this approach for complex domains, activity-centric interfaces developed for unmanned aerial vehicle (UAV) operations are described.

Keywords

Human-computer interaction, interface design, activity awareness, command and control, collaborative decision support

INTRODUCTION

Teamwork and collaborative decision making is a critical component of many complex task environments, such as military command and control, and emergency and disaster response. Advances in computing technologies, information sensors, and network infrastructure have lead to a significant increase in distributed teamwork in many of these environments. A basic tenet of such networked operations is that enabling individuals and groups to leverage information both locally and globally will result in more efficient and effective decision making. However, the abilities of humans to access volumes of previously unavailable information, filter and understand the information, share it between groups, and come to a consensus all under the added stress of the time-pressure introduces significant challenges for collaboration in networked operations.

To help operators communicate and exchange information in network-centric environments, remote team members are beginning to rely on collaboration technologies such as email, instant messaging (or 'chat'), and video and desktop conferencing applications (Boiney, 2005; Klein & Adelman, 2005). These technologies can be very helpful for conversing and sharing files with remote collaborators. Yet, teamwork studies have shown that such explicit communication and information sharing, while an important aspect of collaboration, is often accompanied by more subtle group interactions to help people communicate and coordinate during joint work (Tang, 1991; Gutwin & Greenberg, 2004; Scott et al., 2004). When physically distributed, though, it is difficult to engage in subtle group behavior because remote operators' activities are not visible. Instead, operators must rely on explicit methods, such as requesting an update on a team member's current task activities. Explicitly asking for such information requires effort from both parties and can be disruptive. To address these issues, more sophisticated information sharing methods have begun to emerge. These methods aim to facilitate overall team performance and to reduce the costs associated with collaborating at a distance. One such method attempts to minimize the effort required from remote collaborators to share information related to their ongoing and planned task activities to help with group planning and coordination. This activity-centric technology design approach is based on the notion of providing better "activity awareness" across distributed teams, and is described in more detail in the following section.

ACTIVITY-CENTRIC TECHNOLOGY DESIGN

Remote teams suffer from the lack of support for the overall collaboration process in common collaboration technologies (Carroll et al., 2003; Mark et al., 2003; Mark & Abrams, 2004; Powell et al., 2004; Carroll et al., 2006). Teams must expend effort in addition to their ongoing task activities to provide status updates or to interrupt busy team members to ask for assistance. This effort also introduces barriers to team members attempting to provide their teammates assistance. For example, someone who has completed an assigned activity has no unobtrusive way in current collaboration technologies to find out if or how they could assist a teammate who is currently overwhelmed and unlikely to meet an upcoming team deadline.

To mitigate these issues, collaboration technologies have begun to emerge that better support the shared activity process (Carroll et al., 2003; Mark et al., 2003; Mark & Abrams, 2004; Millen et al., 2005; Scupelli et al., 2005; Carroll et al., 2006). This design approach is aimed at providing collaborators ongoing *activity awareness* information. Carroll et al. (2003) define activity awareness as:

> "the awareness of project work that supports group performance in complex tasks. … It involves coordinating and carrying out different types of task components, such as assigning roles, making decisions, negotiating, prioritizing and so forth. … Activity awareness implies an awareness of *other people's plans and understandings*. Complex, long term, coordinated activity cannot succeed without on-going interpretation of current goals, accurate and continuing assessment of the current situation, and analysis and management of resources (including time) that constrain execution of possible plans."

Though the formal concept of activity awareness is a recent development (Carroll et al., 2003; Carroll et al., 2006), several collaboration technologies have already been developed that support the underlying notion of facilitating the shared activity process.

Two essential concepts in these technology designs are 'visibility of action' and 'feedthrough of action' (Hill & Gutwin, 2003; Dabbish & Kraut, 2004; Scupelli et al., 2005). Within the context of collaboration technologies, these concepts refer to the system playing an active role in the collaboration process by automatically providing some indication of a person's system actions to their remote collaborators (feedthrough of action) in order to increase the visibility of these actions, thus increasing their collaborators' awareness of these actions. For example, Scupelli et al. (2005) developed an enhanced instant messaging system to visually indicate whenever a remote collaborator is currently interacting with a group-related file. Providing such real-time activity information can help teams coordinate their interactions with shared file resources, as well as keep them apprised of who is working on what, giving them an overall sense of the project status.

While this approach supports the moment-by-moment awareness of remote team members' relevant activities, it gives little indication of the overall progress and status of the shared activity. Thus, visibility and feedthrough of action alone are insufficient for providing activity awareness. In order to increase collaborators' awareness of the ongoing activity process, Carroll et al. (2003) developed several mechanisms for situating team members' activities within the context of the overall shared activity. In an application developed to assist the joint development of a large science project by groups of students from different schools they provided two types of displays to facilitate the shared activity process: a desktop interface for students to perform their individual task activities and a project summary interface, designed for large-screen wall displays located in the separate classrooms.

The desktop interface provides a timeline of recent and ongoing activities of all members of a student's class, or 'team', including upcoming class milestones and overall project deadlines. On the project summary interface, the past and ongoing project activities and deadlines for all students, organized by classes, are shown on a project timeline. This summary view enables team members to maintain awareness of the current status of the overall shared activity, of which sub-activities are progressing on schedule, and of which sub-activities need more work. This information can help team members' prioritize their own task activities and help the group as a whole make task delegation decision. Their system provides team members an activity-centric space for organizing their shared virtual resources. Such activity-centric collaboration spaces have been found to help team members coordinate related task activities and to foster opportunistic collaboration in a variety of task domains, including corporate (Muller et al., 2004).

In summary, providing feedthrough and visibility of team member's actions within the context of the overall shared activity process enables team members to maintain activity awareness, which can help them interpret remote collaborators' goals and actions, anticipate collaborators' future plans and actions, manage their shared resources, and stay apprised of the overall team situation.

Although the activity-centric design approach shows promise for enabling remote collaborators to engage in ongoing information sharing with minimal effort, thus far, it has only been explored in relatively low risk, low tempo application areas such as educational and corporate task environments. An important issue that arises in complex task environments is the sheer volume of information operators must deal with, particularly in networked environments where they must process both local and remote information gleaned from data sensors and collaborators. This raises questions related to the ability of operators to process automatically provided remote activity information, and effectively incorporate this information into their decision making processes. In order to investigate the utility of the activity-centric design approach in a complex task domain, we have begun developing activity awareness display concepts in unmanned aerial vehicle (UAV) mission operations. Based on our preliminary investigations, this design approach shows promise for improved decision making and teamwork in this task domain; however, these investigations also indicate that determining what information to share and how the information should be provided are critical design issues to ensure that an appropriate balance is obtained between awareness and information overload. The following sections describe an experimental UAV mission task environment and some initial activity awareness display concepts developed for this environment.

COLLABORATIVE UNMANNED AERIAL VEHICLE (UAV) OPERATIONS TASK

In order to better understand how to develop activity-centric collaborative display technologies for complex task environments, a representative complex task scenario was developed. The task scenario involves a team of operators working together to secure a large geographic area (the team's area of interest (AOI)) to ensure the safe passage of an important political convoy traveling through the area. The UAV team must surveil the area for potential threats. Once hostile targets have been identified, the team must coordinate with an external strike team to engage these hostile contacts before they are within firing range of the convoy.

The UAV operations team consists of three UAV operators, each responsible for controlling multiple UAVs, and one mission commander overseeing the team's mission progress. The UAV operators are responsible for supervising the progress of several semi-autonomous UAVs surveilling the AOI, confirming potential targets identified by the UAVs' onboard automatic target recognition (ATR) systems, and coordinating with a strike team to destroy confirmed targets. This task scenario assumes advanced onboard ATR capability.

The mission commander is responsible for ensuring the safety of the convoy and for managing the workload of the UAV operators on his or her team, along with the tasking of their assigned UAVs, throughout the mission. To achieve these mission objectives, the mission commander can make several types of strategic decisions, which include requesting the convoy to hold its current position if its intended route is not deemed safe, requesting supplementary surveillance data from a nearby joint surveillance and target attack radar system (JSTARS), and re-tasking of a team's UAV asset to a different sub-AOI (requiring the handoff of the UAV between operators).

In order to explore some initial activity awareness display concepts, the current phase of this research is focused on developing supervisory-level, large-screen display interfaces, similar to those available in many command centers, to support the decision-making and task performance of the UAV team's mission commander. The following section overviews these supervisory-level, large-screen display interfaces and the activity awareness display concepts used in this context. These interfaces are an updated version of those first presented in Scott et al. (2007), and incorporate some refined activity awareness display concepts based on an preliminary users study.

ACTIVITY-CENTRIC UAV MISSION COMMAND DISPLAYS

Based on information requirements generated from a cognitive task analysis (CTA) of the mission commander's role in the UAV mission scenario described above (see (Scott et al., 2007) for details), two large-screen display interfaces were developed to support supervisory-level decision making in the task scenario: a map display and a mission status display. The Map Display visualizes positional information of relevant contacts and assets in a geographical context and critical status information related to convoy status (Figure 1). The Mission Status Display visualizes current and expected mission status information, including surveillance progress of the team's UAVs, current UAV-related activities of each operator, communication links to external resources, and scheduled strikes on known targets (Figure 2). The symbology used on these display is primarily based on standard military display symbology from MIL-STD-2525B (DOD, 1999), modified to satisfy the information requirements generated by the CTA. These modifications were primarily made to investigate activity awareness display concepts that were informed by the information requirements.

Activity-Centric Display Concepts

This section describes the main activity-centric display concepts included in the Map and Mission Status command displays.

UAV status and UAV-related operator tasking. To keep the mission commander apprised of the current tasking of the team's UAV assets, and of its corresponding UAV operator's tasking, the UAV symbology color is updated for certain UAV tasking state changes. For example, when a UAV's onboard automatic target recognition (ATR) system detects a potential target the UAV's symbology is displayed as orange. When the UAV operator finishes their target confirmation, the UAV's symbology is returned to its nominal blue color. To provide further details about the UAV and its corresponding operator tasking, the Mission Status Display contains a visual summary of each

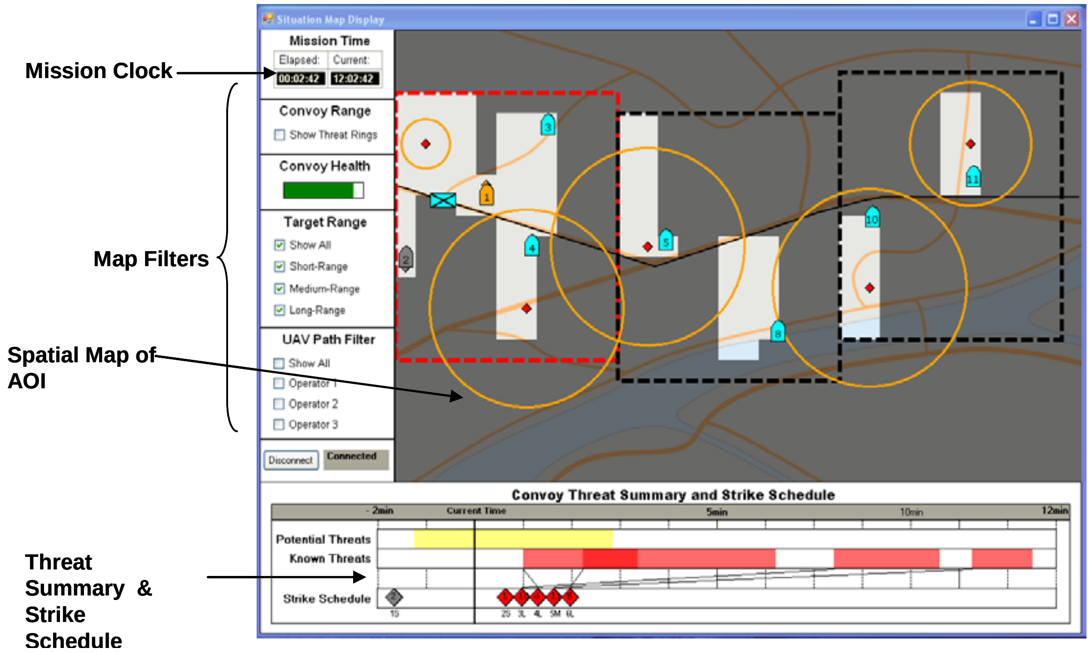

Figure 1. Map Display.

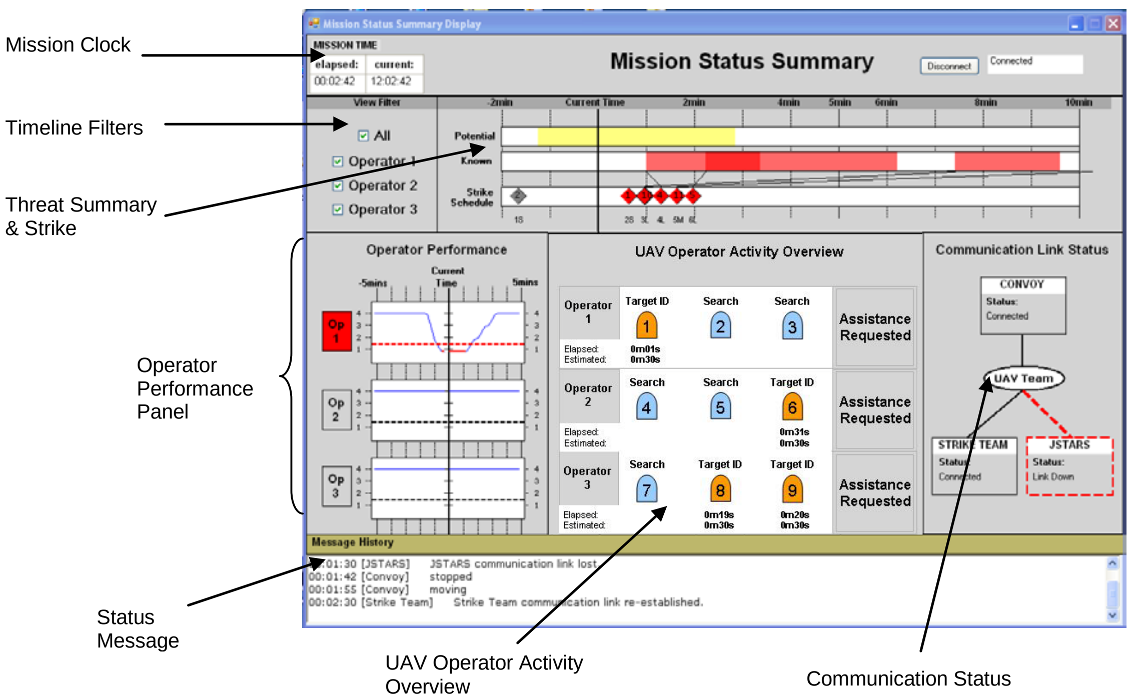

Figure 2. Mission Status Display.

operator's activities for each UAV under their control. For each UAV that had detected a possible threat and is awaiting their operator to complete the necessary target identification task, the UAV operator's time-on-task is shown, along with a system estimated expected task completion time. Preliminary display evaluations indicated that this information may help mission commanders better manage operator workloads by helping them determine which task activities operators are struggling with.

Current and expected convoy safety status. The command displays also provide updated information on the current and expected safety level of the convoy, based on the ongoing activities of the UAV operations team and the external strike team, upon which they rely to destroy any identified convoy threats. This information is provided in

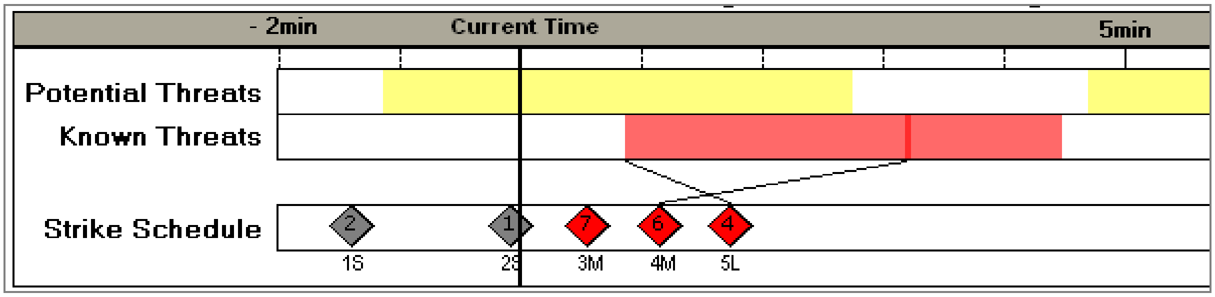

Figure 3. Strike schedule example: Threat 4M is scheduled to be destroyed 2 minutes before *the convoy will be within its weapons range. Threat 5L is scheduled to be destroyed 1 minute* after *the convoy will be within its weapons range. Threat 3M is far enough away from the convoy's route that the convoy is not expected to pass within its weapons range, thus no corresponding 'threat window' is shown.*

the form of an integrated activity timeline, called the Convoy Threat Summary and Strike Team Schedule timeline, provided on both command displays (Figure 3). This timeline indicates when the convoy is or is expected to be in range of any unsurveilled areas (i.e., a potential threat, shown as a yellow time window) or in range of a known threat (shown as a red time window). The timeline also shows the updated target strike schedule in the context of current and expected convoy threats. Known threats are shown as red diamonds in the bottom row of the timeline. The position of a known threat on the timeline indicates the scheduled time when it will be destroyed by the external strike team. If the convoy is or is expected to be within weapons range of a known threat, a black line is displayed between the target's symbol in the strike schedule and the beginning of its corresponding threat envelope in the row above. Preliminary display evaluations have shown this timeline to be particularly useful for assisting in command decision-making in this environment.

Current and expected operator task performance, relative to convoy safety. The Mission Status Display contains a time graph for each UAV operator that shows the current and expected operator performance, currently based on the operator's (and their assigned UAVs') surveillance performance and its current and expected impact on convoy safety. If an operator's surveillance performance begins to degrade, placing the convoy's safety in jeopardy, the operator's performance score decreases. When an operator's performance is or expected to become critically low (i.e., their surveillance performance is putting the convoy in critical risk of being attacked), a visual alert beside the corresponding time graph turns reds. Also, the corresponding operator AOI boundary will turn red in the Map Display.

CONCLUSIONS

As critical decisions in complex environments become increasingly reliant on information sharing between networked collaborators, new information technologies that complement the currently available explicit communication tools are needed. In particular, technologies are needed that help minimize the effort required from busy operators to share context-appropriate information, in a manner that is easily and effectively interpreted under time pressure. This paper has described a promising design approach, activity-centric technology design, that aims to facilitate planning and coordination in teamwork through intelligent sharing of group activity information. The paper overviewed an ongoing project focused on exploring the feasibility of this design approach for complex task environments, such as UAV mission control operations. Preliminary results from this project suggest that the activity-centric design approach may improve decision making, and teamwork overall, in complex task environments. However, many open questions remain related to understanding what information should be shared and what information representations best enable remote collaborators to interpret this information and effectively integrate it into their decision making activities.

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