Cognitive Task Analysis of Distributed Network-Centric Information for the Promotion of Shared Situational Awareness Within Collaborative UAS Operations

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A hybrid model of cognitive task analysis coupled with activity theory and team cognition was evaluated to determine human-computer interface (HCI) design factors that promote Shared Situational Awareness (SSA) within a collaborative unmanned aerial system (UAS). A computer testbed simulation was created for use with participants in a time-sensitive Intelligence, Surveillance, and Reconnaissance (ISR) and weapons engagement mission testing scenario. A cognitive analysis was performed which consisted of a Hierarchical Task Analysis (HTA), Applied Cognitive Task Analysis (ACTA), time-sensitive activity analysis, and coordinated team cognition. Results from testing indicated that the promotion of situational awareness (SA) was enabled by network-centric updates among users in a collaborative UAS. The major cognitive task determined was maintaining SA of the big picture while performing the mission task at hand. Recommendations include the automation of a region of interest for network-centric updates, active filters for decluttering, and the synchronization of entities portrayed on HCIs.

The utilization of the Global Information Grid (GIG) and the introduction of functional concepts such as Horizontal Fusion (HF), Enterprise Services (ES), and the Distributed Common Ground Control Station (DCGS) 10.2 will enable Network-Centric Warfare (NCW) in the 21st century. Additionally, the implementation of complex adaptive systems will assist in the fusion of ISR data from multiple collection platforms and enable multi-INTElligence (INT) data fusion products. The effect of publishing and consuming data from a Network-Centric Environment (NCE) by a UAS assists in the identification and tracking of targets or points of interest.

The collaboration and synchronization of multiple heterogeneously located UAS Command and Control (C2) will enable optimum time on station and sensors on target for identification and persistent surveillance (DoD, 2007). One of the key components to these functional concepts is a NCE with HCIs for increased SA and collaborative decision making. To enable this effect networked team members must maintain a shared understanding of the battlefield as dynamic events occur without overloading their workload or cognitive process.

Figure 1 illustrates a Concept of Operations (CONOPS) of multiple collaborative UASs identifying and tracking a target for persistent ISR within a C2ISR Community of Interest (COI). Network-centric information updates within
the COI from ISR data and multi-INT fused data products promote the creation of a Common Operational Picture (COP) among the HCIs of the networked users in the system. To realize the benefits of a NCE, a user processes individual and shared situational awareness (SSA) in their cognitive domain for knowledge building and situational understanding of the battlefield. However, the sheer magnitude and type of data that can be presented to a user at one time could potentially overwhelm the user’s cognitive process adding to the “Fog of War.” This paper presents a cognitive demands analysis methodology for the promotion of UAS SSA and testing results for HCI design considerations.

**HCI Analysis Methodology**

A review of various testing methods of cognitive demands, user inputs, time-sensitive performance, and system functionality was performed to determine an optimum yield of a hybrid HCI analysis methodology. The following are overviews of the determined high opportunity researched methodologies.

The HTA methodology is beneficial in determining the goals and inputs a user takes on a system. This system-centric approach lends itself well to Universal Modeling Language (UML) Use Case creation for requirement generation and for interface design analysis. However, the limitation of the narrow focus of the task and no high level view of the cognitive aspects on the user usually requires this methodology to be coupled with other analysis methods (Crystal & Ellington, 2004).

The next analysis methodology investigated was the ACTA. This analysis method is a streamlined version of the more robust Cognitive Task Analysis (CTA) and consists of three interview methods of test participants and/or subject matter experts (SMEs). The interviews are composed of a task diagram, knowledge audit, and simulation overview. The task diagram interview identifies the demanding cognitive elements of the task in relation to an overview performance of the task. The knowledge audit elicits probes of a user’s experiences, prediction of events, situational awareness, and perception of the environment. The simulation interview enables visibility into the cognitive process of a user through a challenging simulation scenario. The ACTA methodology captures the cognitive elements of the participants and task skills required for judgment and decision making (Militello & Hutton, 1998). A cognitive demands table highlights the difficult cognitive elements from the three interview methods in relationship to system goals and functionality. Analysis of the table focuses on determining relationships which input into HCI design criteria recommendations. Overall, this methodology provides inputs to cognitive demands of a task. However, this methodology lacks the capability to represent the mental model of the participant in relationship to individual and shared situational awareness and team coordination and cognition.

The third analysis method investigated was activity theory. This methodology views the activity rather than the performance of individual tasks and can be conceptualized as a work process method. The activities performed are related to other activities to yield an effect. This methodology seemed promising in uncovering new behaviors and activities in relation to the time-sensitive Joint Targeting Cycle (JTC) and dynamic targeting model. Limited in scope and new in implementation, this methodology requires coupling with known existing task methodologies.

The last analysis method researched was team coordination and cognition in relationship to shared SA among team members. The Endsley model of situational awareness (Endsley, 2000) and the Office of Naval Research’s (ONR) structural model of team collaboration were analyzed as a potential cognitive process models for team collaboration. Figure 2 illustrates the resultant hybrid cognitive process model for team collaboration. The individual and system level task factors are not represented in order to focus on the components of SA, collaboration, perception, communication, decision, actions, and the cognitive process.

During collaborative team problem solving, the team utilizes SSA, collaborative knowledge, and shared understanding to propose different Course of Actions (COAs). Individual team members use their own mental models and knowledge to assist in building collective team
cognition. Within the team consensus state, team members negotiate to determine the best COA and utilize team shared understanding and collaborative knowledge from SSA. In the last structural stage, the perception of the team mission goal is evaluated in relation to the chosen COA. Measurement of the cognitive process of team members is enabled through the introduction of a roadblock transformation (Cooke, DeJoode, Pedersen, Gorman, Connor, & Kiekel, 2004) to normal operations to observe coordinated perception and action of team members.

Bonaceto and Burns’ (2003) roadmap for cognitive engineering in system engineering was utilized in the creation of a hybrid analysis method from the above researched methodologies. The ranking of UAS C2 challenges of “smaller” organizations, “better” coordination, and “faster” execution to high opportunities for cognitive measurement methods was employed to create the resultant hybrid HCI analysis methodology model.

Figure 3 illustrates the resultant HCI cognitive task analysis methodology for determining design factors, levels of automation, and portrayal of information from network-centric updates. Within the Venn diagram is HTA for representation of the goal-oriented system view of tasks a user takes on the system. Additionally, ACTA aids in determining the cognitive elements of a user employing the system (e.g., decision making and judgments). A task diagram interview, knowledge audit, simulation interview, and cognitive demands table are performed for the ACTA. Activity theory takes into account the workflow process and relates to the time-sensitive targeting model (Office of the Joint Chiefs of Staff, 2007): Find, Fix, Track, Target, Engage, and Assess.

The researched hybrid model of team collaboration is utilized to determine the team cognition and coordination and the amount of SSA achieved. A roadblock transformation within a simulation scenario is presented to observe and measure the coordinated team efforts and shared SA. All these analysis methods are related to the information, cognitive, and physical domain to create design criteria for an HCI with network-centric updates. Also determined from the analysis is the level of software automation required to account for workload and projection of future status.

HCI Simulation Testbed

Because access to actual USAF UAS operations is limited to research, a simulation testbed was created to initially test the HCI analysis methodology and to serve as the simulation for the ACTA. The created testbed is a modification of a Phase II Small Business Innovative Research (SBIR) Distributed UAV Access System that was integrated with the Vigilant Spirit Control Station (VSCS) lab at the 711 HPW/RHCI at Wright-Patterson Air Force Base. It should be noted that the created cognitive task model, specifically ACTA, can be utilized to contrast expert and novice participant groups by conduction testing using the same simulation. Therefore, a second sample group of Predator Operations Center (POC) personnel is planned to be performed and contrasted to the initial sample group results presented in this paper.

Illustrated in Figure 4 is the created simulation testbed with emulated components of a POC. Connected to the simulation are a Joint Terminal Attack Controller (JTAC) and simulated network-centric data updates from multi-INT data fusion. Contained within a POC are a Mission Coordinator (MC), Senior MC (SMC) and Mission Commander (MCC). For testing purposes the MC role was selected to analyze due to the tasks of mission planning, coordination of imagery collection, threat detection, and communication with the personnel within the Ground Control Station (GCS). Within the GCS the pilot and sensor operator share a Tactical Situational Display (TSD) for updates of the battlefield and promotion of a COP.

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Testing Scenario

The sample participant group consisted of commercial airline pilots, a small UAV pilot, RC pilot, FAA DER, and engineers with a background in UAV CONOPS. The participants were asked to play the roles of a MC and a sensor operator or pilot in the GCS. Previous research of a POC task overview (Drury & Darling, 2007) has shown that the high level task of targeting has the most cognitive demands on a user. The research performed concentrated on tasks in relationship to team collaboration for ISR and target engagement. The knowledge audit consisted of participants utilizing a 2D/3D HCI displaying threats and friendlies and interview probes in relation to the promotion of a COP. The participants were allowed to utilize the HCI for a set time then asked to recall from memory the battlefield environment and relate it to a collaborative ISR or weapons engagement UAS mission.

A human-in-the-loop simulation was performed for a time sensitive scenario. This simulation was utilized to probe the participant’s cognition and decisions relating to the hybrid model of cognitive tasks. From a previous Situational Awareness Global Assessment Technique (SAGAT) with a computer testbed simulation it was determined that freezing the simulation to probe for questions was a hindrance to the overall simulation tempo. Therefore, for the cognitive task simulation participants were actively engaged and challenged for questions probing their knowledge with a textual dialog for input of their answers.

The simulation scenario consisted of five main events with interview questions probing the participant’s cognition after the occurrence of the incident in the simulation (see Figure 5). The first event consisted of an imagery request of video along a mountain road (1). The second event was the discovery of a SCUD launcher threat from the video and posting of the entity data to the GIG. This update was displayed in the HCIs of the participants with an audible cue (2). The first UAS maintained persistent surveillance and tracking of the target while the second UAS created a mission route for target engagement (3). During ingress to the target, a threat of a SA-6 from multi-INT data fusion was posted into the system and displayed on all participant’s HCIs within the Collaborative Unit (CU) (4). Finally, after a modified mission route was created avoiding the SA-6 and the UAV was enroute to the SCUD target a friendly force was posted into the system and displayed in close proximity to the target of interest (5). In addition to the interview questions, team coordination and collaboration was observed during the simulation events.

Testing Results

The task overview interview resulted in five steps in relationship to the performance of a UAS CU: entering the group, status and location, communication within and out of the CU, joint operational roles, and notification to exit the group. The most cognitively demanding steps were the joint operations of surveillance and weapons engagement while maintaining situational awareness of the big picture and location of other UASs.

The Endsley SA model was coupled with the ACTA components of the big picture, job smarts, and self monitoring in the analysis of the participants performance of the knowledge audit. Figure 6 represents the 2D view of the Tactical Situation Display (TSD) HCI utilized for testing. From analysis of the results, participants utilized roads from topographic features for recall and spatial relationship of entities to form a mental picture. Also, satellite imagery and a 3D digital elevation model assisted in the perception of entities in current environment. The comprehension of the current situation in relation to an ISR or weapons engagement mission highlighted the need for entity positional updates and indicators of last direction traveled. Some participants perceived the UN truck was in danger
while others thought the friendly M1 tank was moving to strike the SA-6. Additionally, to assist in the comprehension of the current situation route traces of UASs within the CU were utilized. In order to maintain a COP a task that was identified as important was the comparison of video to the TSD. To optimize the performance of tasks between members of a CU the entities display on the TSD should be synched, thus enabling a COP among the HCI of the users. Participants projected that ISR or a weapons engagement in the area should take into account the SA-6 in the close proximity to the SCUD launcher with friendlies and neutrals in the area. Active filters also were employed on the TSD to filter friendlies and threats on the battlefield to assist in decluttering the display. Testing results indicated that the automation of entities displayed to a dynamic region of influence based on the UAV’s position would assist in promoting a COP.

For each event in the simulation interview, participants were asked questions to query their judgment, decision making, and SA. These questions consisted of assessment of the current situation, items which led to actions, error a person could potentially make, future projection of the battlefield, and next actions to perform. Results from the probing of the participants during the simulation are listed in Table 1.

Table 1. Simulation Summary

<table>
<thead>
<tr>
<th>Event</th>
<th>Actions</th>
<th>Assessment</th>
<th>Critical Cues</th>
<th>Potential Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Imagery Request</td>
<td>Approve the imagery request based on security and priority.</td>
<td>No threats in area of imagery request route.</td>
<td>Situational awareness display of entities and terrain.</td>
<td>Does not know availability of UAS in CU for tasking.</td>
</tr>
<tr>
<td>(2) SA of Scud Launcher</td>
<td>Post NC update of location of target and communicate status.</td>
<td>Analysis of video stream for status of entity.</td>
<td>Current operational state of target (i.e., moving, preparing to launch, or abandoned).</td>
<td>Missing identification of target in video.</td>
</tr>
<tr>
<td>(3) SCUD update and route request</td>
<td>Creation of mission route for target engagement.</td>
<td>Location of threat, communication with JTAC.</td>
<td>Location of SCUD in HCI. Location of other UAS flight patterns.</td>
<td>Does not know terrain feature in area or location of other UASs in CU.</td>
</tr>
<tr>
<td>(4) SA-6 Threat</td>
<td>Change route continue communication with JTAC, CU, and higher command.</td>
<td>Comparison of threat location to mission route.</td>
<td>Location of threat zone to UAV mission route.</td>
<td>Creating a route that violates the threat zone of the SA-6.</td>
</tr>
</tbody>
</table>

Table 2 illustrates a cognitive demands table for HCIs among a collaborative group of UASs based on the testing results. This table relates the cognitive elements to difficulties, HCI cues and strategies, and common errors.

Table 2. Cognitive Demands

<table>
<thead>
<tr>
<th>Cognitive Element</th>
<th>Why difficult</th>
<th>Cues and Strategies</th>
<th>Common Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintaining a COP</td>
<td>Dynamically changing battlefield with multiple threats and friendlies.</td>
<td>NC updates and communication between UAS CU.</td>
<td>Unaware of battlefield entities from the performance of the task at hand.</td>
</tr>
<tr>
<td>Projection of future status of battlefield</td>
<td>Require knowledge of narrow focus picture in relation to larger view.</td>
<td>Updates of the status of entities.</td>
<td>Not having the current state of the entity.</td>
</tr>
<tr>
<td>UAS coordination and collaboration</td>
<td>Multiple skill levels and members in CU. Some personnel are only told on a need to know basis.</td>
<td>Tone of dialog in communication of team members.</td>
<td>Incorrect data due to relaying of information.</td>
</tr>
</tbody>
</table>
Discussion and Conclusions

One of the most cognitively challenge tasks determined was maintaining situational awareness of the big picture and determining how it related to the task at hand (e.g., planning a mission route, tracking a target). Analysis of the testing results in relation to the time-sensitive targeting model identified the activity of communication as a key component in reducing the cycle time of target detection to engagement. Specifically, the automation of communication between the pilot, MC, and JTAC for weapons engagements based on rules of engagement (ROE). Maintaining a COP between CU team members was enabled through network-centric updates to their respective HCIs. During the dynamic events of the SA-6 and friendly force update within the test simulation the coordination among team members was observed. Key elements determined were the ability to communicate among the team members, share information, and collaboratively come to a team consensus of the COA to take. One of the enablers of team collaboration and decision making was the positional display of an entity on the HCI with a unique identifier (e.g., Global Unique ID) among team members.

Recommendations

Based on the analysis of the testing results and participant feedback, a supervisory HCI for use with a UAS CU within a COI is recommended. This HCI should employ an automated smart pull of data from the GIG from the UAVs region of interest. Additionally, it is recommended that the HCI contain automated communication links to members within the CU and JTAC, automated and manual declutter filters, and the ability to send data and display received data from a user’s HCI. These NC HCIs could be utilized by a MC or functional components created and incorporated with legacy HCIs (e.g., FalconView). The realized effect of the utilization of collaborative UAS operations with cognitively developed HCIs is a robustly-networked Air Force performing information sharing and decision making at an increased tempo for accomplishment of mission goals.

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References


