Space Situation Awareness Human Effectiveness Research Trends

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Abstract – *Space situation awareness (SSA) is a process performed by humans for humans. Humans have the need to know about past, current and possible future situations in space and humans task the sensor systems and other sources to collect the information. Unfortunately in the process of pulling off this extremely difficult task of SSA, the needs of the human are often overlooked. Recognizing this, the Air Force is conducting human-systems research to accommodate the needs and limitations of the human in the SSA process. This paper will outline past and current research trends related to this area.*[1]

Keywords: Human factors, human-computer interfaces, work-centered support, cognitive science, space situation awareness, space operations.

1 Introduction

DoD space assets are susceptible to numerous anomalous conditions. Austin [1][7] discusses some of the unique hazards that can quickly and permanently disable a spacecraft. These include the extreme natural radiation environment in space, and collisions with other satellites or the ever-increasing amount of space debris. There is the potential for either intentional or unintentional disruption of space services as the result of radio frequency interference. As the interfering signal can originate from almost anywhere on the portion of the Earth visible to the satellite, quickly determining the problem and locating the source of the interference is challenging. Other threats include laser dazzling and anti-satellite weapons. Near real-time intelligent methods are needed to detect and distinguish between environmental, man-made, and unintentional acts.

The Combat Operations Division of the Joint Space Operations Center (JSpOC) maintains space situation awareness in support of the Joint Functional Component Command for Space (JFCC-SPACE) [2]. Many of the tasks, therefore, involve monitoring, aggregating and reporting current status of various US space resources, as well as the relationship of US resources to various red and gray space objects and/or capabilities.

SSA is a process performed by humans for humans. Humans have the need to know about past, current and possible future situations in space and humans task the sensor systems and other sources to collect the information. Unfortunately in the process of pulling off this extremely difficult task of SSA, the needs of the human are often overlooked which can lead to inefficiencies or erroneous conclusions. This is why the research of the Air Force Research Laboratory (AFRL), Human Effectiveness Directorate (RH) is important and the potential "bang for the research dollar" is high. We simply must ensure that critical information coming from terrestrial and space-based sources is exploited to the maximum extent.

2 Past Research

RH's SSA research started 2002 with a Small Business Innovative Research (SBIR) effort to investigate how new fusion technologies can be integrated into the workflow. This research lead to a series of maturing research efforts including a dual directorate (Space Vehicles and Human Effectiveness Directorates) collaboration, a rapid response effort (using AFRL's Core Process 3), and eventually became a foundational technology for the Joint Space Operations Center (JSpOC) Mission System (JMS). Key elements of this technology included:

(1) Enhanced orbital catalog processing for all-on-all conjunction prediction and proximity awareness.

(2) A satellite information database with pertinent satellite information, archiving and net centric information.

(3) Multi-level distributed data fusion of satellite telemetry, space weather, and space catalog.

(4) Advanced visualization system for intuitive display and interface for information tailoring.

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Of course, this effort alone did not address all JSpOC needs and several key long-term research areas were identified. These included threat characterization and assessment, intelligence for SSA, data fusion performance metrics, dynamic sensor tasking, and optimal cognitive environments to work in.

More recently, in an attempt to begin addressing the need to optimize cognitive environments, RH has conducted a widely regarded Cognitive Task Analysis (CTA) of the JSpOC and National Air and Space Intelligence Center (NASIC) to lay the foundation for future SSA and space command and control (C2) work. This work will not only provide a foundation for RH research but research of other directorates. The JSpOC has found the CTA report useful documentation for their operations.

3 Research Trends

The future of RH's research in SSA is tightly coupled with the other AFRL directorates. Information Directorate, for example, has efforts involving multi-sensor fusion and space command and control (C2) that RH will leverage and feed. Directed Energy Directorate, Space Vehicles Directorate, and Sensors Directorate are also integral to sensor exploitation thus it will continue to be beneficial for all to work together to develop solutions.

When it comes to SSA human factors there are a number of needs that have been deemed as highest priority (Figure 1). Many of these needs are in response to Air Force leadership's desire to "do more with the data we have" or "make use of the data that is falling on the floor." These needs are the result of numerous visits to AFSPC, SMC, ESC, external space organizations, and, of course, to most of the AFRL directorates. These needs include:

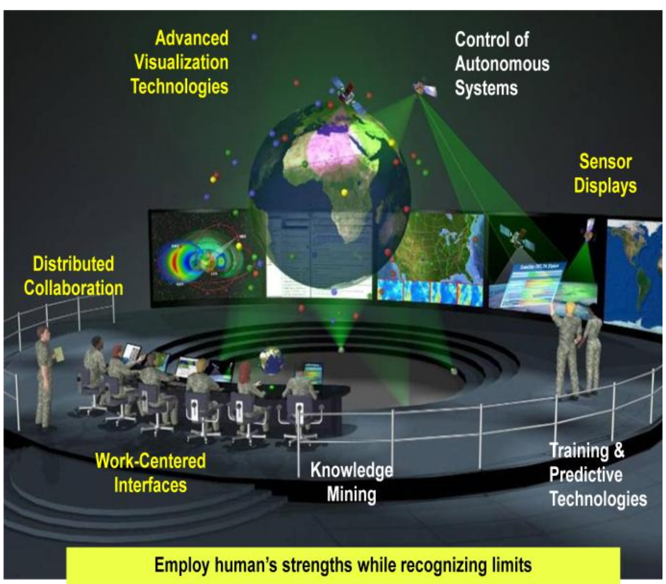

Figure 1: Concept for future Joint Space Operations Center

(1) Better exploitation of existing SSA tools
(2) Improved flow of tasks performed
(3) Interpretation of sensor data
(4) Space weather displays
(5) Training technologies
(6) Collaboration technologies
(7) Improve human use of automation
(8) Modeling adversary behavior

These technical needs are discussed in more detail below.

3.1 Better exploitation of existing SSA tools

Today most web users do not realize when they are actually using complex software products. Those who do some banking online may query Oracle databases in ways that would have required weeks of training just a short time ago. By understanding user's needs and the tools available to fulfill these needs, we can make these tools easier to use, improve workflow, reduce cognitive loads, and empower the users to perform tasks that were not previously possible [3,4].

A similar paradigm is needed across the SSA enterprise. Supporting organizations often have tools that could be of use in operations centers but the personnel do not have time to learn how to use them. They therefore must contact supporting organizations for the information spending manpower and cognitive capital from both organizations. If an analysis is highly iterative or time critical, it may not be practical to constantly call on the supporting organization. Therefore an environment that supports cognitive processes could have a significant impact during urgent situations (Figure 2).

During a recent CTA of JSpOC operators in the Combat Operations Division, RH researchers identified more than 70 different tools over three levels of security. Each workstation had three computers, each with its own monitor, keyboard and mouse. Operators switched from one system to another, depending on the tool they needed to use.

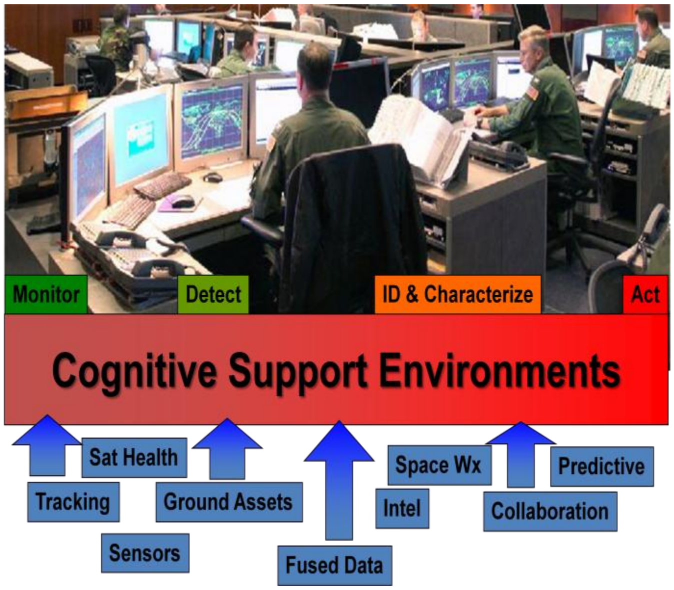

Figure 2: Cognitive Support Environment

The types of tasks to be supported imply the need for certain types of tools and the requirement for information sharing or copying (between tools) and collaborating (between and among individuals and organizations). Particularly problematic is the moving of information across multi-level security systems. This entails transcribing data to compact disks, moving disks from machine to machine, copying data to the new machine and then destroying the disk. Information flow from low to high is possible; the reverse is not.

With a more work-centered approach, the user thinks in terms of work performance rather than performance of disjoint tools (i.e., separate computer applications). By dividing work among several unified tools a user is sidetracked by tool operation rather than accomplishing their ultimate goal. A unified cognitive environment better permits users to isolate a problem, make sense of a situation, or develop a plan.

Brown [5] emphasizes that SSA is developed by integrating, fusing, exploiting, analyzing and displaying traditional and non-traditional space surveillance, reconnaissance, intelligence, and environmental sensor information and data sources along with system health and status information.

3.2 Improved flow of tasks performed

Through our studies we have found that SSA is achieved through many processes, performed by many organizations, with an evolving set of tasks that are sometimes modified or created to accommodate a specific situation [6]. Therefore human factors technology that facilitates the flow of task could possibly yield a much timelier and more accurate SSA picture. If we look at task flows, we often find that there are bottlenecks that can be alleviated by the insertion of automation. This can be as simple as the transfer of data from one tool to another or alerting an operator when new data is available.

The JFCC Space User Defined Operational Picture (JSIP UDOP), part of ESC's JSpOC Mission System (JMS) program, is intended to bring data from several tools into a single visualization interface. By accomplishing the research of exploiting existing tools more efficiently (1), we may improve the flow of tasks performed. However this is not the only aspect needed to improve task flow. When we understand how people perform their work (often by performing a cognitive task analysis), we can build work environments that allow the user to focus on the task at hand rather than on the idiosyncrasies of the tools.

3.3 Interpretation of sensor data

An overwhelming amount of SSA data comes from sensors all around the world. To complicate the situation, different types of sensor sources (e.g., electro optics, inverse synthetic aperture radar, and thermal) each have their own imaging characteristics with certain benefits and limitations. Given the quantity and complexity of the information, the study of image processing is receiving increasing attention to create actionable information from these sources.

Several research questions related to sensor exploitation are being addressed by the Battlespace Visualization Branch at Wright-Patterson Air Force Base [7]**Error! Reference source not found.**. How can we best display these to extract details that otherwise would have gone unnoticed? How can we exploit stereoscopic vision or best use flicker to highlight a "hot spot"? Is it beneficial to give the user control over the balance between multiple sensor sources?

Empirical studies at AFRL [7] have been conducted to determine the effectiveness of corner filters and flicker methods. The latter result suggested that flickering a part of an image holds considerable promise as a new technique for combining (fusing) data from two or more (e.g., multi-spectral) images. This is further evidence of the strength of the magnocellular subsystem within primate visual systems. The magnocellular pathway detects motion in an image to gain attention as opposed to the parvocellular which detects color – a weaker subsystem to alert the user. This is not to say that color is not useful, rather that movement, such as flicker, gains attention more effectively than color. Motion, however, needs to be used judiciously to maintain effective alerts.

3.4 Space weather displays

Most space weather phenomenology cannot be seen, felt, heard, or smelled like we can with terrestrial weather. Given this and the limited audience for space weather analysis, our visualizations of space weather are far from the maturity of terrestrial weather displays. So what are the best ways to convey the current and future space weather situations, and what will the impact be to space assets?

Through a Small Business Innovative Research (SBIR) effort (currently in Phase II) with The Design Knowledge Company and Aptima, new visualization technologies to better understand the space environment (including weather) are being developed. Much of the research has been based on the Space Environmental Effects Fusion System (SEEFS) developed by Air Force Space Command. SEEFS is actually a collection of space environment models [8]. The new visualizations will better enable space components to assess overall space environmental conditions and determine impacts through intuitive visualizations that are integrated into the workflow.

3.5 Training technologies

This area of AFRL research includes technology that allow operators, analysts and decision makers to better understand the space environment, potential threats, and effectiveness of certain options. Ideally, space professionals should be nearly as familiar with the space domain as we are in terrestrial battlespace. Today, however, the analysts rely on mental models of the environment since there are few computer-based models available to them. These mental models may not accurately account for factors such as atmospheric drag or the sheer vastness of the space domain.

RH's Warfighter Training Division in Mesa, Arizona has initiated research in the use of gaming technology for training of the space analyst. Working with Sonalysts, Inc., specifications for applying a gaming environment were developed for training, rehearsing, and exercising of defensive counterspace (DCS) operations. By applying a commercial gaming engine, they developed a training system specification that supports both individual- and team-level operations [9].

3.6 Collaboration technology

Additional research is being conducted under another SBIR topic to bridge the divide between the many organizations that collect SSA data with those who need it. Most knowledge of the space environment is not stored electronically. It is stored in the collective minds of individuals who operate the telescopes, analyze intelligence data, control satellites, and make use of the services satellites provide. How can we find people with the knowledge that we need? How can we better enable people to share information and work collaboratively in assessing situations? How can we improve collaboration in a multi-level security environment? How can the collective knowledge be optimally conveyed to the decision maker (Figure 3)?

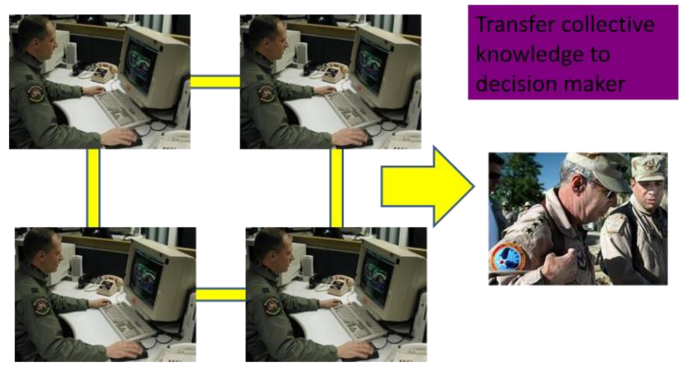

Figure 3: Transfer of collective knowledge to decision maker

In order to maintain SSA and conduct C2 of space assets, JSpOC operators must collaborate both with others in their own facility and with those in other organizations. Within the JSpOC, those in Combat Operations Division must have a clear understanding of the Joint Space Tasking Order (JSTO) produced by the Plans Division and the tasks to be performed. Strategy, Plans and Combat Operations Divisions all rely on the Intelligence Surveillance and Reconnaissance Division (ISR-D) to support their functions. The ISR-D, in turn, relies upon reach back to NASIC and other intelligence production and analysis agencies for a complete understanding of space activity worldwide. Combat Ops Division personnel must coordinate the activities of ground stations to be sure ground stations are operational when needed. JSpOC personnel must respond to Theater Support Requests, providing information about status of space assets that may impact theater operations and, perhaps directing satellite or ground station operators to provide support.

By the nature of space operations, there is arguably a greater reliance on information from external organizations than most other types of operations centers. This observation is based on our studies of various Air Force operations centers that often have direct feeds from the theaters of interest (e.g., Predator and satellite imagery) [6].

AFRL has ongoing SBIR research to investigate the unique human-human collaboration needs for SSA and develop computer-based technologies to address these needs. One of the goals of the effort has been to link up those with certain expertise or with specific knowledge that is needed by someone else in the enterprise. For example, a certain anomaly may be observed by a radar site that is, unknown to them, relevant to an event investigation at the JSpOC. Multilevel security issues are an additional challenge of developing such collaboration technologies.

With the growing number of satellites as well as considerable debris in space, it has become increasingly important to collaborate with commercial and foreign entities in order to avoid collisions in space. Boltz and Owen [10] discuss issues associated with establishing international SSA.

3.7 Improve human use of automation

SSA tasks are often too complicated, fast, difficult, or tedious for a human to accomplish effectively. In these cases, automation (e.g., intelligent agents) can be a great tool. But how can we best allow humans to invoke an agent? How can we give the human visibility into the progress of the agent? When is it appropriate for the agent to provide results or alerts?

Many of these research questions are being addressed by RH's System Control Interfaces Branch through their focus on unmanned aircraft systems (UAS). Although there are some distinct differences between human interaction with UAS and automation for SSA, we plan to highly leverage this research.

3.8 Modeling adversary behavior

Whenever something is launched the world watches. Some things are not controversial but, on occasion, there are things that other countries can view as aggressions. These may result in diplomatic incidents or, worse, as a trigger for a counter action. Therefore it is desirable to know in advance what reaction may take place to certain space options.

RH's Anticipate and Influence Behavior Division at Wright-Patterson is conducting research to model foreign entity behavior and help in the forecasting of cascading effects. These behavior models may eventually feed other simulations and models for a more comprehensive forecasting capability.

4 Plans to address these issues

The Human Effectiveness Directorate has several efforts planned to address some of the needs identified above. In 2010, a Cognitive Task Analysis of NASIC's Space and Missile Systems Group will be completed and will lay the foundation for the further development of visualizations and work-centered technology to be inserted into JMS. This will improve sharing and interpretation of intelligence information for space object identification and other analyses in support of the JSpOC.

RH also has several Phase I and Phase II Small Business Innovative Research (SBIR) efforts underway which address visualization and collaboration issues for space operations as well as the integration of space operations with air and cyber operations. These include Multi-Modal Collaboration Environment, 4D Common Operating Picture, Visualization of Disparate Domain Operations, Collaboration for Space Situation Awareness and Visualization for Distributed C2ISR Operations.

Perhaps most significantly in RH's space research portfolio is an Advanced Technology Development (funded with money set aside for applied research) to demonstrate a work-centered visualization environment for the JSpOC and supporting organizations. This effort will build on previous basic and applied research performed by AFRL and other research organizations. The aim of the research is to provide the human-system interface for the JSpOC Mission System (JMS) which is the next generation space SSA and C2 system being developed by the Electronic System Center (ESC) 850th Electronic Systems Group based at Peterson AFB, Colorado.

5 Conclusions

The space environment is becoming increasingly complex; today many nations as well as private companies have satellites in orbit. Maintaining space situation awareness requires the coordination of both space and ground-based assets as well as analysis and correlation of huge amounts of data in order to gain insight into potential impacts of space events. As Lt Gen Larry James pointed out during a panel discussion on Space Situational Awareness (SSA) held as part of the 2009 United States Air, Trade, and Technology Exposition, much of the required data fusion takes place in the gray matter of the human.

Given the critical role for the human in the space situational awareness process, it stands to reason that research into better human accommodation could have a great payoff. This may become even more evident in a crisis situation when many people around the world need to cooperatively determine what has happened, who can be attributed, and what to do about it. We feel that the areas covered in this paper that are being research by AFRL, are at least a good start toward addressing the need for better human-system integration.

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