Human Interfaces For Space Situational Awareness

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Abstract

United States defense operations are greatly enhanced by satellites, however these key assets are vulnerable to perils such as space weather or acts of aggression. Unfortunately it is not only difficult to defend against such threats, it can be difficult to determine the cause from the ground. What may at first appear to be a routine system glitch may in fact be something much more serious. This situation is aggravated by the fact that Air Force satellite control centers use antiquated technology requiring multiple human controllers per satellite, each viewing alphanumeric displays that degrade situational awareness, increase crew workload and invite confusion during demanding wartime scenarios. The Air Force Research Laboratory (AFRL/HECP) in conjunction with various organizations at Schriever Air Force Base are conducting research to increase situational awareness of the orbital battlespace by allowing operators to navigate through three-dimensional displays with voice-activated commands. This speech interface to Satellite Tool Kit – which will be discussed in this paper – is intended to be an initial step at enabling operators to quickly gather information from satellites or constellations. Future research plans call for applying usability engineering techniques to the satellite attack identification and reporting process, and then applying the optimal configuration of human interface technologies.

Introduction

Satellites are highly autonomous systems that usually require relatively little control from the ground. When human intervention is required, controllers rely on information transmitted between the satellite and their control station via telemetry links. Many of today's Air Force controllers are still viewing telemetry on antiquated 1960's vintage workstations with alphanumeric text displays that degrade situational awareness, aggravate crew workload and invite confusion during on-demand wartime scenarios. Often multiple controllers are employed to ensure erroneous inputs are not made. Figure 1 shows a typical screen used by satellite controllers that are often cluttered with cryptic mnemonics and inconsistent data values. A new generation of human interface technologies is sorely needed and indeed some efforts are being made to improve the situation. However few of these efforts use proven human factors engineering principles.

Figure 1: Example of a satellite operator screen employing ineffective use of color and inexplicit mnemonics

Improved human-computer interface technologies will be particularly needed during critical mission events such as when satellites are attacked. For this reason and others, Air Force Space Command (AFSPC) is undergoing a paradigm shift from space surveillance to space situational awareness. (AFSPC, 2002) In other words, there is a need to fully understand in near real-time what is happening with all space assets as opposed to passively monitoring individual satellites. The ultimate goal is to allow warfighters to have a clear understanding of the space landscape to confidently discriminate between intentional and unintentional effects on space systems and the capabilities they provide. (General Dynamics, 2001) The

warfighter must be able to perform "intel preparation of the battlefield" by characterizing friendly and adversary space system status, capability and actions. When the availability of one or more satellites is compromised – whether innocent or intentional circumstances – it will be critical to effectively detect, identify, locate, classify, assess and report the incident. For brevity's sake I will refer to these actions collectively as "processing" the incident. This processing needs to take place at several organizational levels from the satellite operator up to the commander in chief (figure 2).

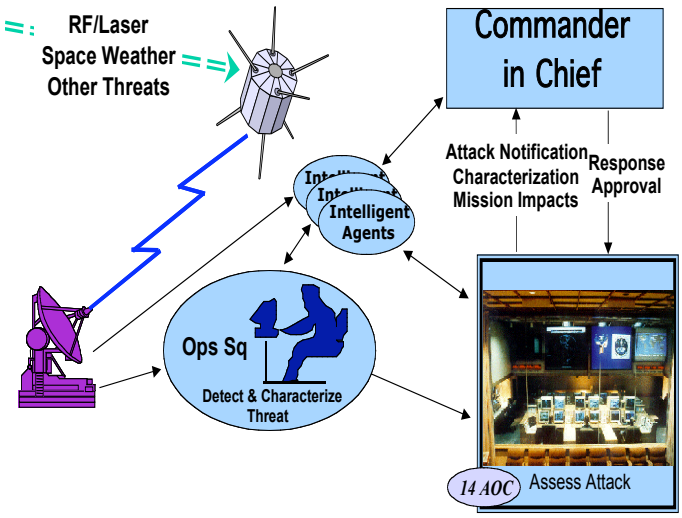

Figure 2: Satellite Threat Warning and Attack Reporting process with the conceptual integration of intelligent agents

This concern for space capability protection is not unfounded. The events of September 11, 2001 showed the American people that, in the blink of an eye, our enemies could significantly impact our national security. If a coordinated act of aggression would be directed at our space assets, our defense capabilities could be hindered and it would likely come at a time when these capabilities are most needed. Granted, a space attack requires much more sophistication than hijacking a commercial airliner, but the steaks are too high not to be ready for such an event. New technologies in space vehicle design, sensors and materials are clearly important for future space protection but the ability of the warfighter to understand the situation could be just as critical. If we are not able to head off an attack, we must at least be able to know how much our capability has been degraded, what advantage is trying to be gained, and who or what is responsible. Taking days to process the information will likely cause us to lose critical time to react to an incident.

Past Research

With any form of applied science, it is important to thoroughly understand the area in which technology will be applied before coming up with a technological solution. Therefore before conducting research in space situational awareness, the Air Force Research Laboratory, Human Effectiveness Division (AFRL/HE) has conducted research in routine satellite operations. This research and other relevant research are summarized below.

Research in Satellite Operations

Although space capability protection is a relatively new thrust, research in crew interfaces for satellite control is not new. From April 2000 to August 2002, AFRL/HECP (Human Interface Technology Branch) worked with Monterey Technologies, Inc. (MTI) on a Small-Business Innovative Research (SBIR) program to develop innovative interface concepts for satellite controllers. In this task MTI videotaped a task analysis of a typical, unclassified satellite "pass" (i.e., the time when a controller has a real-time telemetry link) then developed new interface concepts and implemented a testbed in which to test these concepts. As shown in figure 3, this analysis revealed that manual (mouse clicks and keyboard input) and visual modalities were heavily loaded whereas the speech and hearing modalities were light.

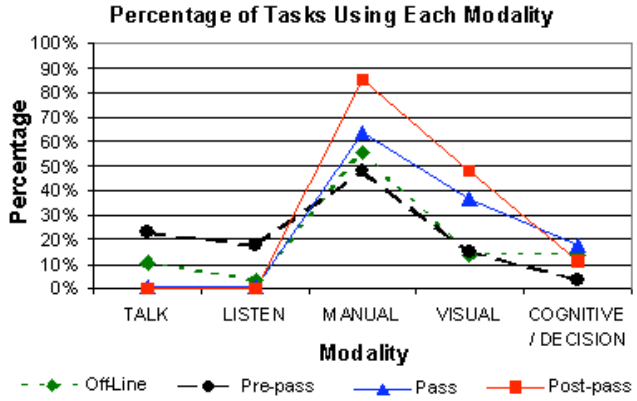

Figure 3: Satellite Controller Modality Analysis

Once the task analysis was completed, interface concepts were developed on the testbed that consisted of better graphical user interfaces, touch screens, speech input and synthetic voice feedback. Once completed, the new interfaces were tested in relation to the baseline system. The results showed a marked improvement in operator performance with approximately one sixth the number of

steps required and less than half of the time to perform the tasks. (Sharkey, et al 2002)

Research with Speech Interfaces

Long before the research by MTI, the Air Force has investigated speech interfaces for communication between an aircraft pilot and the "electronic crewmember." (Williamson, 1996) These studies showed that speech was a viable technologies even in this less than serene environment of a fighter cockpit which can be noisy and put stresses on the pilot that are typically not experienced by satellite controllers. In the relatively tranquil environment that a satellite controller works in, speech input has demonstrated considerable potential to streamline interfaces, reduce task times and cut down the learning curve. Although the research at AFRL/HE is just underway, space organizations have expressed considerable interest in applying speech recognition in the near term for satellite control.

Recent advances in this technology have allowed speech recognition without customizing or training the software for an individual's voice. Although many of us complain that we seldom talk to real support people anymore, these advances have made it possible for commercial organizations to use speech recognition on a massive scale to lessen the burden on live telephone operators. We believe it is only a matter of time when speech input will be used for personal computers including new tablet computers.

Autonomous Systems

Few systems today are fully autonomous. There is typically a need for humans to interact with the system in certain circumstances. Table 1 from Sheridan (1992) breaks automation out into ten discrete levels. Note that all but level 10 involve some human involvement. The further down the scale, the more continual attention is required from the human. This scale can be useful for designers of human interfaces for autonomous systems of all types to better understand how to approach the interface design.

Clearly autonomy can allow humans to accomplish things never before possible but one common mistake in developing highly autonomous systems is to overlook the needs of the human when things go wrong. AFRL/HE has gained a much better understanding of this problem in our work with unmanned air vehicles (UAVs). UAVs – many of which are highly autonomous – are increasingly important to our national security. With their automation, UAVs are very much like satellites – especially from a controller's standpoint. This fact may make it possible in the future for one person to control vehicles in the air and in space.

Table 1: Levels of Automation

Level		Action performed by the computer. The computer…
HIGH	10	Decides everything and acts without human involvement
	9	Informs the human only if it, the computer, decides to
	8	Informs the human only if asked to
	7	Executes automatically then must inform the human
	6	Allows the human a restricted time to veto before automatic execution
	5	Executes the suggestion if human approves
	4	Suggests one alternative
	3	Narrows selection down to a few
	2	Offers a complete set of alternatives
LOW	1	Offers no assistance: human makes all decisions and performs all actions

In designing an optimal interface to support UAV operations, experiments have been conducted to determine the value of basic two-dimensional (2-D) displays, flat perspective view displays and multi-sensory, 3-D immersive displays promoting "virtual presence." Just as with our satellite research, our UAV research initially focused on enhancing existing ground stations by improving existing interfaces. Ultimately, a new perspective view and immersive interface concepts supporting future unmanned vehicles may be developed. This advanced interface is expected to reduce operator workload, increase operator situational awareness, and improve overall system performance in current and future UAVs. (Draper 2002)

Relevant Activity In Space Situational Awareness

Research at CERES

The Center for Research Support (CERES) at Schriever Air Force Base, Colorado is developing concepts for future Satellite Operations Squadrons (SOPS) to effectively react to satellite attacks. In this effort, called the Defensive Counterspace Testbed (DTB), CERES is aiming to improve the process of satellite threat identification and

attack reporting. But since satellite problems will rarely be attributed to acts of aggression, methods will be needed to clearly distinguish critical events from normal system problems or space weather incidents. The current thinking is to use data fusion and artificial intelligence to derive a "best guess" as to the cause and assign a confidence or certainty factor. But to my knowledge there have been no studies as to how this information should be displayed.

Although human interface design is not the focus of the DTB effort, CERES is creating a prototype system to investigate some possible displays. For satellite state-of-health monitoring, in-house developed screens are being used. These satellite operations screens are a major improvement over the screens shown in figure 1 because they are much more intuitive and graphically friendly. To improve the controller's situational awareness of the space environment, Satellite Tool Kit® (STK) by Analytic Graphics, Inc. is to provide two-dimensional and/or three-dimensional (3-D) displays of constellations or individual satellites. MATLAB® by The MathWorks Inc. is currently being proposed to display space weather. CERES believes it will be best to allow the user to have some screens persistent so they are currently proposing to use a wall of displays.

When a significant event occurs that causes a change in the satellite's health, the plan is for an STK window to automatically pop-up to show the affected satellite in 3-D. In addition to depicting the location and orientation of the satellite with respect to Earth, it is also possible to display information such as uplink and downlink status and possibly unfriendly satellites in the vicinity.

Research at AFRL

AFRL/HE is working closely with CERES to provide expert human factors support. The first phase of HE's research will draw on the experience gained through previous interactions with space organizations and the MTI SBIR. Depending on the type of attack, the Satellite Operations Squadrons are likely the first place where a satellite attack will be detected. AFRL researchers are therefore aiming to improve the accuracy and tempo to process a satellite attack.

The specific goal of the AFRL research this year will be to apply human interface technologies to allow a controller to manipulate visual display using spoken commands. This is an important capability to allow the controller to see exactly what they need to see without frustrating keyboard commands or menu options. One of the biggest benefits of speech interfaces is the ability to encapsulate multiple commands into one logical phrase. For example, if multiple satellites are attacked, the controller could be inundated with windows showing each satellite under attack. Rather than traverse through pull-down menus or sift through overlapping windows, the speech interface will allow the user to ask the computer to display a certain satellite or to tile certain windows. As shown in figure 4, a controller may ask to see satellites that have certain suspicious behaviors such as low power or telemetry transmission problems.

Specifically these are the first questions AFRL is addressing in this research:

1. How can voice input improve the operations? The hypothesis is that voice input will eventually be more intuitive and will free up the hands for other interactions such as manipulating objects or views (cameras) in the virtual 3-D displays. Voice input will be used for commands such as "show a close up of satellite X" or "show all satellites on orbital plane Z" or "tell me what subsystems have been affected on satellite Y."
2. Should the STK windows of individual satellites pop up automatically when the computer detects an abnormal state or should the user request the information using keyboard/mouse or voice commands?
3. How should these windows be displayed in relation to other windows that CERES has determined to be important for the controller? These other windows include STK worldview, MATLAB-based space weather display, satellite control screens developed at CERES, and the view for higher headquarters (on up to the Commander in Chief).

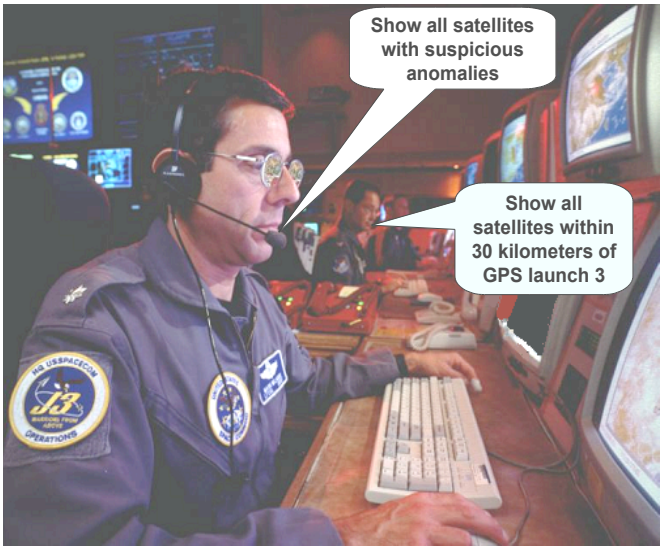

Figure 4: Speech Input for Satellite Operations

Future Research. In future phases of this research, we hope to apply proven usability engineering methodologies to the satellite threat warning and attack reporting process. Usability engineering is a structured process to both develop new interfaces and improve existing interfaces. (Nielsen, 1994) Many major companies have found that the cost to perform usability engineering is worth the investment for their Internet screen designs and other

human interfaces. As with these companies, it may not be practical to perform all of the steps in the complete usability engineering process, however it should at least be possible to do a quick task and functional analyses and a couple iterative designs.

We also hope to:

1. Investigate the utility of virtual reality displays and interactivity. The CAVE – a fully immersive virtual reality room (Figure 5) – is one possibility for this research. The CAVE will allow an operator or commander have a god's eye view of all space and ground-based assets. In addition, body tracking and gesture recognition may be investigated.

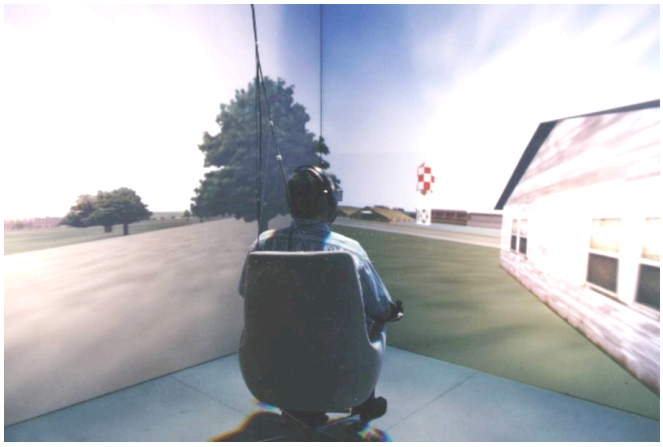

Figure 5: The CAVE provides fully immersive virtual reality

2. Investigate the utility of head-mounted displays to increase screen "real estate" as was done in AFRL/HECP's ongoing Airborne Warning And Control System (AWACS) research.
3. Investigate HCI concepts for higher headquarters including North American Aerospace Defense Command (NORAD) and U.S. Space Command. It is believed that providing 3-D views would be beneficial to these organizations but they will probably require the ability to get more detailed information on demand.
4. Determine how the High Level Integrated Team Training Environment for Space (HILITE) software can be used for Space Situational Awareness and Defensive Counterspace. In particular HILITE uses intelligent agents and automated message routing that could prove to be invaluable for SSA. Intelligent agents are virtual personal assistants who act autonomously, adaptively and cooperatively to seek information over a network. Intelligent agents can tirelessly act on behalf of the user by continually monitoring situations, performing certain tasks, and adapting to new work patterns and unanticipated operational events.
5. Apply Work Centered Support System (WCSS) concepts. AFRL/HEC and the Sustainment Logistics Branch (AFRL/HESS) are jointly developing this technology, which also applies intelligent agents. Intelligent agents are applied using work-centered analysis and design techniques after conducting process task and cognitive work analyses. Process task analysis involves applying traditional physical and information processing analyses. Cognitive work analysis involves analyzing mental work, problem solving, and dynamic work behavior for the job. Work-centered design aims to support work in context through appropriate display and aiding techniques. It provides "decision quality" information that is context tailored, aids the user in performing routine tasks, and rapidly adapts to atypical work patterns. (Eggleston and Whitaker, 2002)

Conclusions

Current crew interfaces for Air Force satellite operations are considered by many to be insufficient for routine use let alone during stressful mission critical situations. For critical situations, interfaces are needed that allow users to gain situational awareness quickly about the orbital battlespace to differentiate between routine and critical situations. If a situation is deemed critical, the warfighter needs to be able to assess the impact and intent so that appropriate actions can be taken. The research being performed by space organizations and AFRL are important steps in making this happen.

Acknowledgements

The author would like to thank Maj. Robert Hessin, Mr. John Balke and Mr. Chad Oster at CERES, and Mr. Jeff Akers for their satellite control expertise. Special thanks also to Mr. Sam Kuper for his input on WCSS.

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