2002-01-2312

Investigation of EVA Information Interface Technology in a Mars Analog Arctic Field Science Setting

Michael F. Boucher, Edward Hodgson and Sean K. Murray
Hamilton Sundstrand Space Systems International

Pascal Lee
SETI Institute and NASA Ames Research Center

Stephen Braham
Simon Fraser University

ABSTRACT

Hamilton Sundstrand Space Systems International *(HSSSI)* participated with the National Aeronautics and Space Administration (NASA), the Search for Extraterrestrial Intelligence (SETI) Institute and Simon Fraser University in the 2001 field season of NASA's Haughton-Mars Project *(HMP)* to study information technologies concepts and hardware systems for advanced Extravehicular Activity (EVA). The research was focused on developing an improved understanding of the uses of the interface in an exploration / field science context. Interface integration with communication, navigation and scientific data systems, and the special challenges posed by the expeditionary environment were investigated.

This paper presents a discussion of the field test systems, test activities and results. Recommendations for future, higher fidelity research are included.

INTRODUCTION

Access to, recording, managing, analyzing, sharing and interpreting information is at the very heart of exploration science. The unique operational environment of an EVA (Extravehicular Activity) system makes this a special challenge to NASA's mission for the human exploration and development of space (HEDS). In an EVA system, the challenging environment of space - vacuum, thermal extremes, radiation, extreme lighting conditions – are compounded by system design constraints – weight, volume, power consumption, oxygen compatibility, mobility, dexterity, and tactility restrictions. Together, these challenges have heretofore severely restricted the information support and management options for EVA astronauts (Figure 1). NASA has managed this very successfully during the Apollo missions and space shuttle operations through a combination of training and extensive support from the Earth and from IV (Intra-vehicular) personnel using voice communications (Reference 1). However, future, more ambitious missions will make these approaches less effective and less desirable. Information transfer and management requirements will be increased at the same time that opportunities for ground support and the effectiveness of prior training are decreased. Our research is intended to help develop a basis for the design and development of systems and techniques that will better meet these needs.

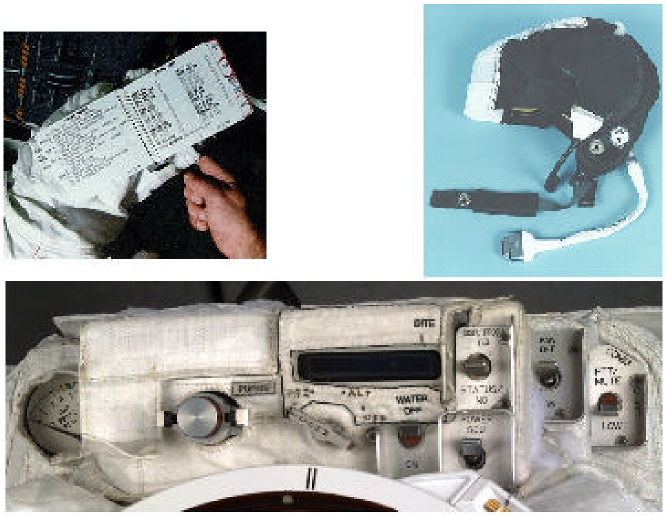

Figure 1: Current Extravehicular Mobility Unit (EMU) information interfaces are limited.

The complexity of information transfer and management has grown through NASA's history as more complex missions have been undertaken and as robotic elements have been introduced and used more pervasively. Still, the ability of the EVA crew person to participate directly in this process has remained limited and relatively rudimentary. Information is still provided to the crew person in real time by verbal communication, written checklists and limited capacity text displays. A far more robust capability including digital transfer and flexible presentation of a variety of data, graphic display of information, and a wide range of data management and command interactions is envisioned (Figure 2). Numerous research activities ranging from NASA studies of intelligent agents (Reference 2), studies of wireless networking technology (Reference 3), and studies of potential EVA information interfaces at Hamilton Sundstrand and elsewhere (References 4, 5), are aimed at providing these capabilities.

History makes it clear that this will entail difficult compromises and trade-offs. To arrive at the best total capability, these must be made based on a clear understanding of the most important tasks and of what design parameters are critical to meeting those needs. Since the systems involved and the functions they will perform are far removed from present and past practice, experience with the use of early development test articles in relevant settings is vital to achieving this understanding.

STUDY DESCRIPTION

OBJECTIVES

The principal objective of the field research program described in this paper was to improve our understanding of requirements and design optimization parameters for a future EVA information interface. We sought to achieve this before committing substantial development funds by working with pre-prototype hardware and current state-of-the-art software in the field science setting of a NASA Mars analog research program.

There has been a wealth of prior research dealing with the design of EVA information interfaces (References 6 - 8) and with information system needs for field science and exploration (References 1, 2, 9). However, these have depended on experience derived from systems and contexts far removed from those realistically expected in a future Mars mission. For example, the Apollo missions were accomplished with simple EVA information interfaces and relied on extensive verbal communication and support from Earth for information access and management tasks. More recent field studies have operated in significantly different contexts and made use of systems that do not reflect the unique interface constraints and requirements for EVA.

EVA System Interactions
Added Interaction Capabilities Under Study

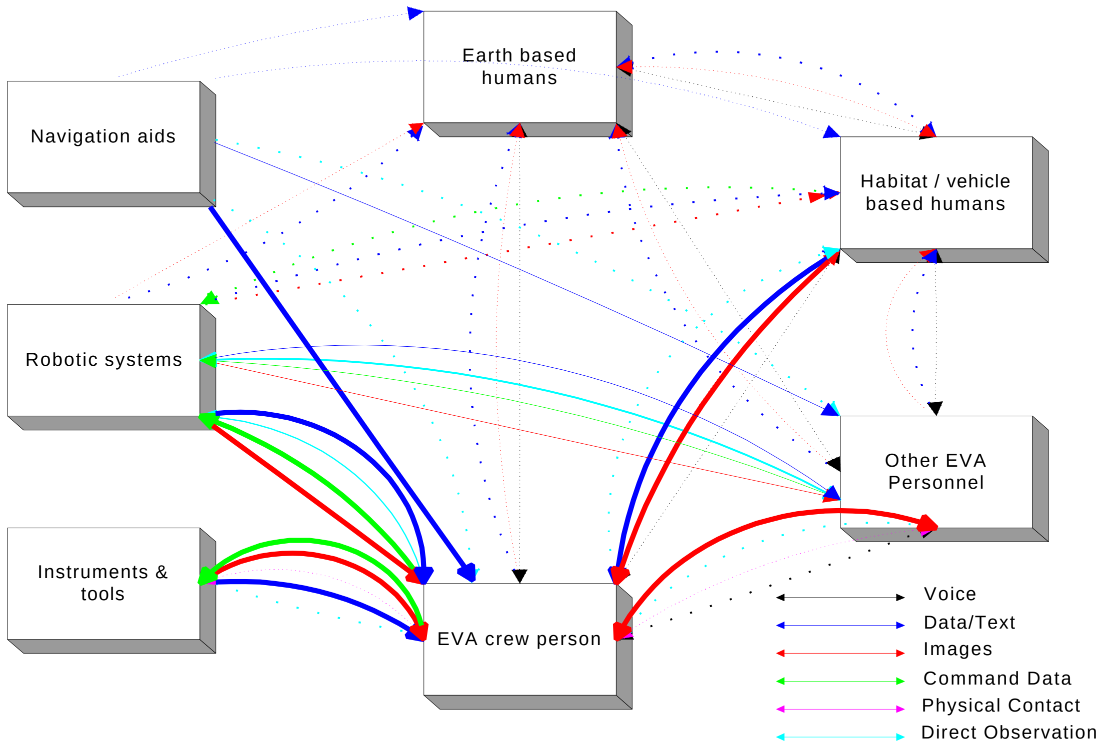

Figure 2: A rich set of EVA information interfaces is envisioned to support complex exploration tasks and scenarios.

Our research was intended to combine some of the unique constraints of an EVA operating environment with science objectives and infrastructure representative of a planetary exploration mission.

Additional objectives of the collaboration included providing a user interface that would support the evaluation of communication and field science techniques from the perspective of an EVA crew person. We expected that by working together in this way, some of the most promising avenues of attack and some of the most critical design issues for all of the systems and operations involved would be identified early. In this way, greater progress could be made toward the development of the required integrated mission capabilities than would be possible through separate, parallel development of systems for later integration at a higher level of maturity.

HMP NETWORKS AND SYSTEMS

The EVA information systems were operated as components in the evolving HMP experimental planetary exploration computing and communication infrastructure. Simon Fraser University, the NASA Ames Research Center, and the SETI Institute have been collaborating under a series of Canadian systems development programs, working in partnership with corresponding research at NASA. The result has been an increasingly deep understanding of the requirements of field exploration communication systems, and the computing requirements of sophisticated scientific investigations in remote and hostile locations. The 2001 field season information system research was the first stage in the latest of these ongoing research projects, a new program called MarsCanada. MarsCanada focuses on direct support of field exploration activities in Canadian Mars analog locations, such as the Haughton Crater region.

The lead group in the high-speed regional networking research has been the PolyLAB Advanced Collaborative Networking Laboratory at Simon Fraser University (SFU), working in collaboration with the Canadian Federal government’s Communications Research Centre (CRC) and Canadian communications company Wi-LAN Ltd. Research has been funded by the Canadian Space Agency (CSA) Space Exploration Program. It is intended to determine the requirements for information systems technologies that support both robotic and human planetary surface exploration.

Starting in 1999, a range of technologies have been integrated, delivered, and tested in the HMP field environment. Studies have taken place on range and speed requirements for data communication, in the context of underlying power and space requirements for various field systems.

Human planetary exploration demands mobile computing systems that interface with communications delivering and receiving voice, data, and potentially video, to and from vehicle computing systems, and from systems in planetary orbit and on Earth. The vehicles can vary in complexity and size and may be either crewed or robotic. These different applications require different levels of communications availability and quality of service (QoS) parameters. In addition to average bandwidth, parameters such as peak bandwidth, latency, latency variation, bandwidth variation, and bit-error and telemetry, frame-error rate may be significant. Various control and experiment requirements on the mobile elements determine the required QoS parameters for the communications systems.

The environment that will be experienced by modern information systems in human lunar and Martian surface exploration poses significant issues for communications components. Large amounts of high quality data must be moved over great distances. Wireless data communications across the exploration region are essential.

Line of site loss and multipathing can produce severe problems in implementing these regional data networks. Multipathing results when the same signal reaches a receiver by multiple paths as a result of terrain reflections and interferes with itself. It is the primary limiting factor in high-speed communication systems, being the only problem that cannot be reduced by changes in communication frequency or power usage. The more topographically complex a region, the higher the probability that both multipath and line of site fading will interfere with communication to an EVA site. However, the most interesting geological and biological research can be expected to take place in the most topographically rugged locations, such as in valleys and in close proximity to cliffs and hills. The HMP wireless communications and data networks have been created to support experiments to better understand these conditions and improve our ability to deal with them

The goal has been to evolve systems that provide:

- Highly efficient bandwidth utilization to support high data rate needs with low power consumption.
- Resistance to multipathing in complex terrain.
- The ability to support operations where line of site communications with primary vehicles or space communication segments are difficult or unavailable.

This requires advanced radio modulation techniques and a complex network topology.

In response, the HMP communication system has evolved into a layered approach consisting of static space communication segments linked to regional high-speed advanced radio networking systems, including static or vehicle-carried regional repeater nodes. The regional network infrastructure then terminates in simpler low-power, low weight, local communication links providing outbound and inbound network data streams to highly power-constrained and mass-constrained elements, such as EVA crews and robotic systems.

In addition to these high-speed systems, lower speed data is used to provide GPS location services, in emulation of future advanced positioning data systems. Finally, simple VHF and UHF communications are used to provide long-range safety audio communications. These systems will be integrated into the data communications network in the future to provide a single, consistent, and easily maintained flexible communications and networking environment.

HMP computing systems are integrated over the communications network simulating anticipated exploration systems. A field-hardened server supports a wide range of wireless network clients including robotics, vehicles and EVA crews. The network protocols used are designed to tolerate anticipated communications delays for a planetary exploration scenario, and the system includes provisions for simulating these delays to support experimentation. Experiments with this system have included interaction with remote mission control facilities and collaborating investigators through satellite links as well as regional network operations.

Communication experiments in the 2001 Field Season included the use of conventional IEEE 802.11b Direct Sequence (DS) wireless local area network (LAN) technology to provide medium-scale communications from the EVA test system to a fixed simulated rover, relayed to a base camp network, and then on to a satellite communication facility via a high-performance Multicoded Direct Sequence Spread Spectrum (MC-DSSS) radio network link The MC-DSSS system thus provided the regional networking infrastructure with lower-power local communications being provided by the IEEE 802.11b system.

Although IEEE 802.11b DS was known to provide only limited resistance to multipathing, equipment for its use with available wearable computers was readily available for use this summer. As described later in the paper, multipath sensitivity was evident in the field and limited the scope and location of test activities. They can be significantly reduced with more advanced wireless networking systems that will be deployed in the field in future seasons. With the more advanced systems in place, we expect that EVA traverse activities will be possible in geologically and biologically significant locations, and at great range from base camp facilities.

HMP Context and Operations

The NASA Haughton-Mars Project (HMP) provided the scientific and exploration context for our study. The HMP is an international interdisciplinary field research project centered on the scientific study of the Haughton impact crater and surrounding terrains, Devon Island, Nunavut, Arctic Canada, viewed as a possible Mars analog. Integration of the information systems research with HMP scientific studies ensured relevance of the results to real field science needs.

Mars analogs may be defined as settings in which environmental conditions, geologic features, biological attributes, or combinations thereof offer opportunities for comparisons with possible counterparts on Mars and for simulations of partial Martian conditions. While climatic and environmental conditions on Devon fall short of the extremes encountered on Mars, aspects such as topography, terrain types, geologic features and their variety, and the overall lack of logistical infrastructure save that brought in by field investigators represent unique combinations of analog attributes. Research on the HMP presents two areas of thrust: Science and Exploration Research. Studies are conducted in a multi-disciplinary approach as intimate ties exist between the many disciplines involved.

The HMP Science program seeks to*:*

1. *Compare the Earth and Mars, in particular the many apparent similarities in geology between Devon Island and Mars*
2. *Study the effects of meteorite impacts on the Earth*
3. *Study life on Earth in the extreme environment of the high Arctic including the preservation and mode of exposure of biosignatures, and practical issues of planetary protection.*

The Science program is intended to lead to a better understanding of the nature of Mars and that of the Earth as a planet, of possibilities of finding life on other planets, and of how to go about looking for any evidence of such life. These goals are central to NASA's astrobiology and planetary exploration programs.

In addition, field science activities on the HMP serve as the basis on which the HMP's Exploration Research program is built. This program seeks to use the opportunity of ongoing scientific field research on Devon to develop new technologies, strategies, and experience in human factors relevant to the future exploration of Mars and of other planets by both robots and humans.

The Exploration Research program is divided into three areas of research with substantial overlap between them:

1. Information Systems (IS) *studies of communications architectures and information technologies including studies in Human-Centered Computing (HCC) and the development of Mobile Exploration Technologies.*
2. Robotic *exploration technologies and strategies including field tests of robotic vehicles and*

components, definition of the requirements for robotic systems to support human Mars exploration, and the deployment and evaluation of operational robotic systems in response to the exploration and survey needs of the HMP Science program.

3. Human Exploration Research *investigates many aspects of field studies in support of the human exploration of Mars and other destinations in space. Studies to date have addressed exploration logistics and operations requirements, the planning and execution of EVAs, EVA systems (e.g., spacesuits, field instruments, tools, roving vehicles, robotic assistants), field science protocols, interactions with "Mission Control" (incorporating 4 to 20-minute time delays), field medical equipment and telemedicine procedures, nutrition in exploration environments, habitability, greenhouses, and human physiological and psychological monitoring.*

The research reported here is interdisciplinary, resulting from combining investigations on information systems and human exploration in the context of supporting field geology studies.

EVA INFORMATION INTERFACE TEST SYSTEMS

SUITED ENVIRONMENT SIMULATOR

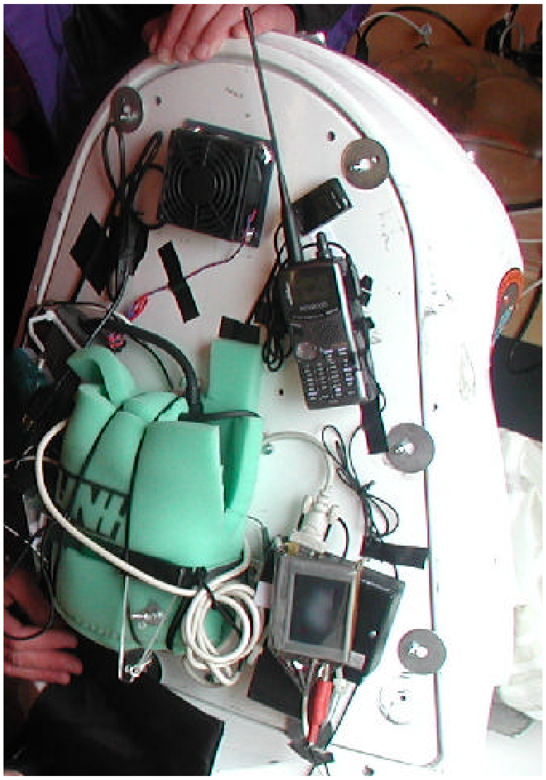

Figure 3: Rear view of the simulator showing CPU, optical display system, video converter box, brushless DC motor, batteries, mouse pad, GPS, and two way radio.

The Suited Environment Simulator (Figure 3) is part of a system concept mockup designed and built in 1997 to investigate an exploration system concept that used a field-replaceable life support system. The hard upper torso (HUT) was modified for this field season to support test integration of a display, computer and control devices, communications and GPS. A field season consists of several months each summer when researchers work on Devon Island at the HMP. The polycarbonate bubble assembly simulates the visual deficits that may occur during planetary exploration operations and acoustic environments inside a closed spacesuit helmet. The bubble provides impact resistance and in case of emergency can be removed quickly. Two removable arm units were used on the simulator during this field season. Each arm uses a Stereolithography Apparatus (SLA®) scye bearing and an SLA upper arm bearing to provide representative arm geometry and deformation of the arm cloth elements, and includes a standard Extravehicular Mobility Unit (EMU) glove interface. The HUT uses a harness system obtained from a commercially available backpack. The harness system distributes the system weight toward the hips and can be adjusted to fit a variety of suit subject sizes. When properly fitted to the suit subject, the harness effectively controls center of gravity (C.G.) shifts that might occur during field activity,

The simulator employs a brushless DC fan to provide ventilation to the suit subject without generating electromagnetic interference (EMI) that would interfere with the test electronics. Although the system is open and ventilation can occur through the open waist bearing, the fan provides up to 36 cubic feet per minute (cfm) of airflow inside the HUT. A minimum flow of 6 acfm is required for safe operation of the suit. A flow diverter is mounted inside the HUT to direct the fan flow over the top of the test subject's head. This provides for adequate CO2 washout and moisture removal from the inner bubble surface. For power, the simulator ventilation system shares a 12V, 18 amp-hour lead-acid battery mounted on the lower portion of the harness below the HUT. An indicator light mounted on the inside of the HUT is continuously illuminated during safe battery operations (above 11.5 VDC). Below this voltage, the light will turn off indicating that it is time to terminate test operations with the bubble assembly in place. This is illustrated in Figure 4.

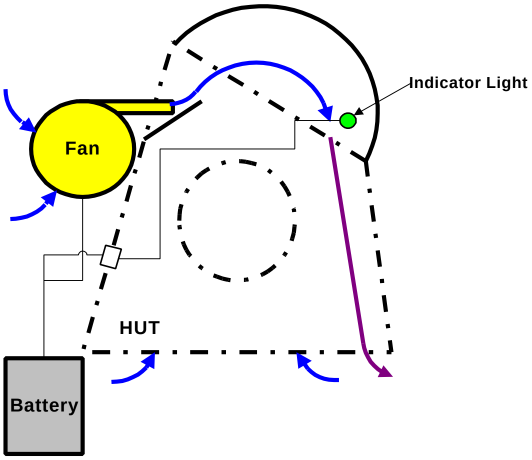

Figure 4. The simulator is configured to represent suited information interface operating environments and ensure test subject safety.

3000 Series EMU glove thermal micrometeoroid garments (TMG's) were used in conjunction with standard issue cotton EMU comfort gloves to simulate dexterity and tactile deficiencies associated with pressure suit gloves.

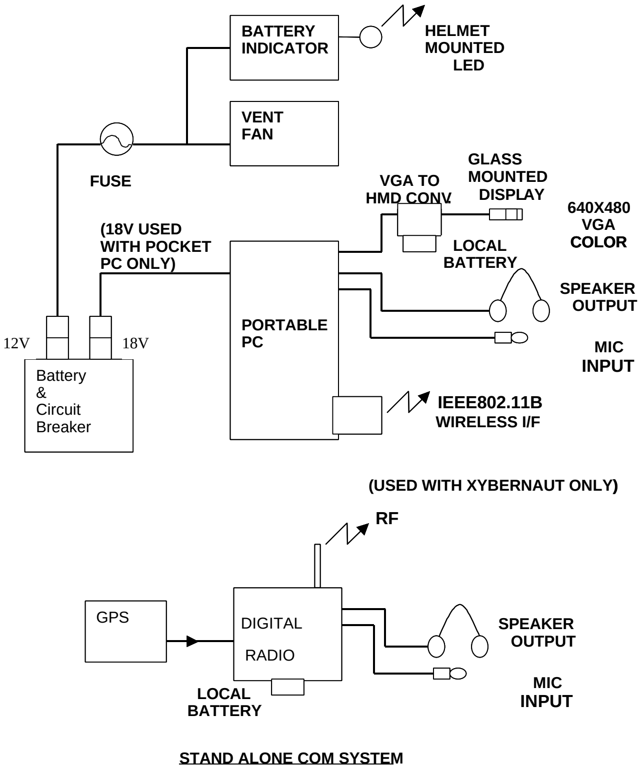

Figure 5: The test system integrates commercially available components to provide a complete wearable information interface test bed

Commercially available electronic components were integrated with the simulator to support the research as illustrated in Figure 5. All electronic hardware is mounted on the rear of the HUT. An outer covering encases the electronics and protects the electronic equipment from inadvertent contact. Through the use of air inlet filters mounted inside the enclosure, some protection from particle contamination is maintained. The electronics are accessible only when the cover is removed. However, a simple system was installed to support cycling the Central Processing Unit (CPU) on and off, while suited, if a hard reboot was necessary.

Two simulator computer systems were used during the field tests. One was assembled from discrete components using a wearable size CPU with a Pentium 3, 800 MHz processor and 256M of RAM. It provided desirable operational characteristics for speech recognition system control and display integration experiments, but was not fully ruggedized for extended field use and could not be adapted for connectivity with the HMP wireless networks during this field system. The other unit, an integrated, ruggedized, Xybernaut MA-IV wearable computer, was equipped for network connectivity and was used during many field activities. Specific characteristics of each of theses options are discussed in subsequent paragraphs. Both PC's provided serial, PCMCIA and USB ports to interface with various types of peripherals. Computer output was presented to the test subject through a head-mounted micro-display that could be variably positioned.

Two micro-display formats were studied, a glasses mounted display from Micro-Optical® Corporation (Figure 6-1), and the head-mounted Xybernaut® optical display, (Figure 6-2). Comparison and evaluation of operational characteristics of these options was a primary focus of the research.

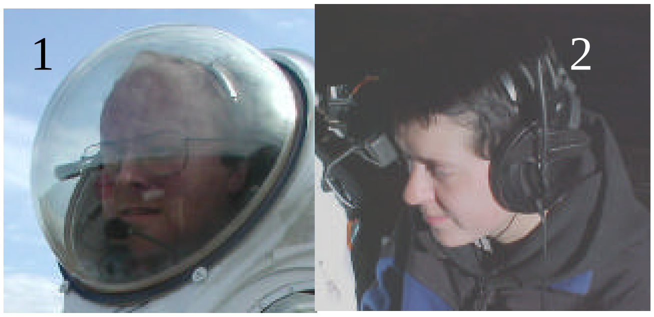

Figure 6: 1) MicroOptical GMD worn by Dr. Steve Braham (Photo courtesy of Pascal Lee 8061953) and 2) Xybernaut® optical display worn by Trish Garner

During test operations, the subject manipulated the computer system using either voice commands or a variety of manual input devices mounted to portions of the suit simulator. The speech recognition system used an 'off-the-shelf' microphone headset and plugged into the computer through the sound card.

One of the manual control interface studies was a commercially available mouse pad system. Laboratory experiments confirmed that this device would not respond to a gloved hand. To solve this difficulty, the pad was enclosed in a typical anti-static metalized mylar bag. (Figure 7) The bag was grounded to provide the electrical conductivity necessary for gloved operations. This configuration was shown to respond well to a spacesuit gloved hand and provided environmental protection for the mouse pad as well. As a result it was included for evaluation in the field study.

Figure 7: Mouse pad enclosed in a metalized Mylar bag.

Voice communications were conducted though a portable two-way radio mounted to the suit simulator. For this study, separate headphone and microphone interfaces supported the voice communications and computer control voice interactions requiring two devices to be worn inside the helmet simultaneously for some tests. This compromise simplified hardware preparation for the tests, but was quite inconvenient during test operations. Suit subject interface was accomplished using the radio's VOX function or a push to talk (PTT) button soft mounted to the front of the HUT just below the bubble interface for accessibility during suited operations.

Tracking was conducted through the use of a small Global Positioning System (GPS) receiver. The GPS made use of a connection to the two-way dual-band (UHF/VHF) radio to transmit a position every few minutes.

COMPONENT-BASED SYSTEM AND SELECTION

An information display compatible with the physical and operational constraints of a space suit was perceived as the most challenging hardware element of the system. Consequently, system development began with the display and proceeded from there to other components consistent with the display and planned test objectives. In addition to operational capabilities, component selections for the test bed were based primarily on the key parameters of power, weight, volume and adaptability. Power for the various components had to be kept to a minimum due to the use of a battery during the experiments and the desire to provide for a minimum of four-hour EVA scenarios.

Display Selection

Multiple display options were evaluated before the final selection of the MicroOptical display for the fieldwork. Attributes of the MicroOptical display which traded favorably against the competition were the small size and light weight of the optics when mounted to the glasses, low power requirements (300mW), ease of use and PC interfaces.

It provided a full-color, VGA resolution suitable for presenting the range of text and graphics information envisioned in the test program. In the full color mode, it provides a display brightness of 50fL but can be switched to a high-bright (240fL) monochrome mode in high ambient brightness conditions. The optical display can be positioned at various locations with respect to the wearer's eye providing a 16° field of view and an effective focal adjustment distance of 2 to 15 ft providing comfortable display use despite its close proximity to the wearer's eye.

The display was configured to clamp to the temples of conventional prescription glasses. Where the user does not wear glasses, a pair with non-prescription lenses supplied with the display can be used. These had temples that wrapped around the ear to prevent the glasses from moving on the subject's head during use. Laboratory testing verified that it could be accommodated within the envelope of a spacesuit helmet without severely restricting the wearer's head motions and could be comfortably viewed in positions that did not interfere with direct vision for normal activities. This was considered a key requirement for EVA use.

The display optical unit connects to a VGA conversion box through a custom pigtail. The VGA conversion box has a dedicated power supply and a standard VGA interface connector, which was connected to the VGA output of the test computer. Test system assembly was complicated by the fact that the pigtail between the display and the conversion box was of only modest length and hardwired with no interface connector. Newer versions of the equipment provide a connector, a change that will significantly aid future research.

PC Selection

The computer for these experiments was intended to support delivery of multiple data formats and representative content to the display during field science activities and to permit experiments with a variety of interface control concepts. In particular, speech recognition was envisioned as a particularly attractive interface for system control and for field science documentation. As a result, primary factors in selecting the computer unit were size, weight and power consumption, compatibility with the selected display, compatibility with candidate control interfaces, adequate processing power and memory for speech recognition software and compatibility with standard software tools for display generation and software control.

Various portable PC vendors were evaluated with the final selection being a device offered by SaintSong, a division of Samsung from Korea. The PC provided the basic attributes required for the field test, VGA format display, Windows operating system, and an 18 VDC power interface. Additional benefits were that the floppy disk drive and keyboard were add-ons, which could be removed during fieldwork. One drawback to the PC selected was the lack of a PCMCIA slot for use with the wireless Internet card. For future work USB wireless interfaces will be evaluated. For wireless testing, the PC was swapped out for the Xybernaut system, which had the PCMCIA card capability.

Xybernaut MA-IV Integrated Wearable Computer

Many of the system tests were based on the use of a Xybernaut MA-IV wearable computer, providing 300 Mhz of processing power with 192 MB of RAM and 10- GB storage. These devices support PCMCIA cards, providing a convenient interface for wireless networking tests. Input/Output can be provided by a range of devices, ranging from high-resolution color Head Mounted Displays (HMD), wrist-mounted keyboards and displays, and handheld touch-sensitive daylight readable flat panel displays (FPD). Two different head-mounted display configurations were tested with this system as shown in Figure 6. With the use of an I/O expander port, we were able to use the MicroOptical display as an alternative to the somewhat larger, although higher-resolution, display provided with the Xybernaut system.

The configuration tested during the HMP 2001 Field Season used Microsoft Windows © 98 Second Edition as the installed operating system base, combined with IBM's Via Voice Millenium Edition © speech recognition product and the ESRI ArcExplorer © Geographical Information System (GIS) product. A range of IEEE 802.11b DS PCMCIA cards were used for local communications off the suit.

Testing was also performed using a simple vest and/or external monitors and keyboards, providing a development and base system test environment that could operate independently of the integrated suit mock-up. Testing in the vest included use of advanced server-based voice-driven interface access.

FUNCTIONAL EVALUATION

This year's field study objectives concentrated mainly on the human interface requirements for an advanced spacesuit information interface for exploration missions. Testing was performed with a commercially available, wearable CPU and evaluated the ability to present useful information in various formats to an explorer in a spacesuit and the ability to control the information processing and display system in several modes. These included speech recognition control, manual control interfaces and remotely operating the CPU using conventional wireless LAN technology while in an environment that resembled the Martian landscape. The simulations evaluated the performance of current helmet mounted displays (HMD), in-helmet mechanical and electrical integration strategies, software application issues, and task interface requirements.

Prior to the start of testing, several persons were chosen based on technical background, size, age, and gender. The test subjects included both geologists and engineers. Subjects were both male and female and ranged in age between approximately 20 and 50. The physical differences among the test subjects challenged systems for establishing and maintaining required head and display positions within the simulator helmet. This was accomplished through the use of an adjustable harness adapted from an internal frame backpack. After each test subject donned the simulator, support personnel adjusted the harness to fit. Harness adjustment supported proper head positioning and provided long-term comfort and stability to the subject during test operations.

Each subject was asked to develop a voice model using the speech recognition software. Voice models were developed while wearing the simulator, with bubble in-place, to account for the acoustic effects of the helmet and air flow environment. Because most test subjects were not identified or familiarized with the test hardware in advance, the voice models had to be develped in the field at Devon Island in a single session for each subject. This proved to be a tedious and uncomfortable process, particularly with the Xybernaut computer in which the slower processor speed resulted in a lengthy post-processing period for the voice model data file. Creating voice models over time before going into the field in future research studies is expected to make better use of field time and to improve the performance of speech recognition systems.

However, subsequent laboratory tests have shown that the need for higher processor speeds was primarily driven by the use of dictation-driven context-free speech recognition. Advanced speech recognition tests using the Xybernaut vest configuration with a context-driven, speaker-independent voice interface model produced excellent access to remote data resources, even in highnoise environments. This is based upon moving the intelligence from brute-force speech model processing to process and context-driven processing. The result is less required processing time, speaker and accent independence, fast recognition time, and sophisticated human-computer interaction. This provides an available, robust command interaction technology, but still demands further advances to address the desired capability to use the information interface as a flexible field documentation aid.

During the field study, the test subjects participated in several activities typical of what scientists would undertake during a planetary exploration. Activities included climbing, walking, bending, grasping, rover interface operations, and tool manipulation while interfacing with the simulator's CPU. The simulator, (HUT, Bubble, Arm Assemblies, Gloves…etc), was intended to provide a representative environment for display and control interactions (mechanical interferences, optical barriers, acoustic environments, etc) while performing these activities. The research team recorded feedback from the suit subjects and documented events photographically.

The first phase of the research began with testing the suit CPU, peripherals, including the MicroOptical® GMD, mouse pad, and microphones, and optimizing their integration with the simulator. This phase of the testing was conducted close to base camp to make it easy to make necessary adjustments while debugging the system. This phase included evaluation of the voice recognition software for both field documentation and system control. Results for field dictation were encouraging, but showed the need for greater training of the voice model than was practical during the field program. It was especially notable that the training protocol for the commercial package used did not establish reliable recognition of scientific terms required for field geology and biology. Speech recognition errors in these tests were too frequent for reliable display and system control, forcing users to rely on a back-up mouse pad system.

The mouse pad system worked well with an ungloved hand but the metalized Mylar bag did not provide sufficient grounding for consistent mouse operation in the field making some further refinement necessary. A layered approach with a sheet of aluminum foil sandwiched between two metalized Mylar bags worked the best. Several possible mouse pad mounting locations were also evaluated to identify the best locations for this type of manual user interface. Three locations, the wrist, top of the hand, and front of the HUT were found to be suitable for effective operation.

Comparative evaluations of mouse pad control use in these locations (Figure 8) led to the conclusion that a wrist or forearm position was best. Users were able to control the system based on the cursor position on the screen without direct vision of the mouse pad, but found this more difficult. Although the top of the hand seemed to be a good location for the mouse pad it was thought that it could interfere with hand operations in confined spaces possibly becoming dislodged. The forearm and wrist locations generally offered good control and minimal potential interference. However, this interface location permitted significant changes in relative orientation of the mouse pad and display axes as a result of head and arm mobility. At times, cursor movement control was noticeably more difficult as a result. Experiments in this test series were not extensive enough to determine if this difficulty would be significantly reduced through learning and experience. This requires further study in the future.

Figure 8: Alternative mounting locations for mouse pad a) top of hand, b) wrist, c) front of HUT, d) forearm.

Evaluations of the MicroOptical® GMD were promising. Because of its small size and mounting location on the eyeglasses, most users felt that normal head movement within the confines of the bubble were not obstructed. When correctly positioned, the display provided comfortable readability without obstructing the wearer's view of outside objects and task areas. Testing was performed in daylight and without the use of a sunvisor. As a result, most users preferred the display in bright mode, which improved viewing while in bright sunlight. Suit subjects commented negatively about the need for readjustment of the display position during suited operations. The positioning adjustment device on this model allowed some movement when locked, causing a reduction in the view of the screen. This mechanical linkage must be improved or replaced with another design for long-term use in a pressurized space suit.

The larger Xybernaut® optical display was also evaluated. Because of the size restrictions caused by the helmet bubble, the Xybernaut® optical display could only be used without the bubble attached. Subjects found that the parabolic reflector adequately displayed the computer screen in all conditions but noticeably obstructed the wearer's field of view. Substantial changes would be required for successful integration into a spacesuit.

The second phase of test activities focused on wireless network system integration. The suit simulator was outfitted with a Xybernaut MA-IV wearable computer. A IEEE 802.11b DS PCMCIA card with radio antenna was inserted into the PCMCIA slot and supported the RF LAN signal. A suit-mounted radio antenna provided a radius of exploration of approximately 400 yards from an intermediate transmitting station intended to represent a rover mounted relay station. (Figure 9) The intermediate transmitting station included another 802.11b wireless Internet adapter with an additional 802.11b PCMCIA card with radio antenna connected to a Linksys® wireless adapter point. High and low frequency parabolic antennas were connected to the Linksys® adapter point and transmitted the LAN signal to the base camp CPU.

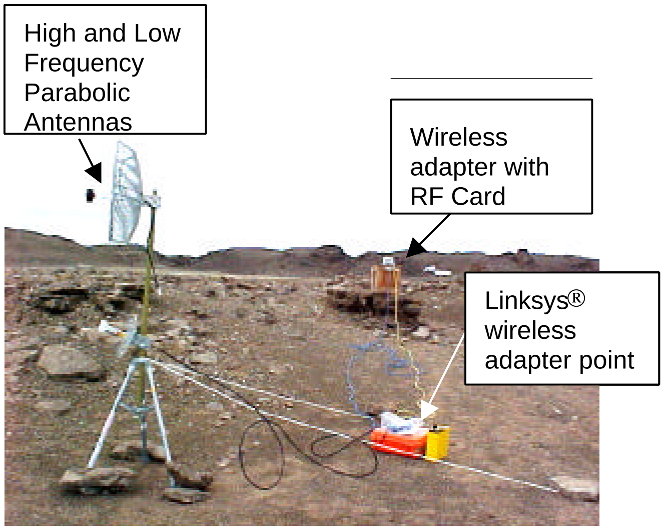

Figure 9: Intermediate Transmitting Station

The second phase of testing was done in two stages. The first, preliminary stage focused on establishing and characterizing the wireless network links between base camp computers, mobile relay station, and personal exploration system. The second stage attempted to apply the system in more realistic exploration scenarios.

In the first stage, the transmitting station was assembled on a hill approximately 0.5 km from base camp. The site was geologically uninteresting; so, the efforts concentrated on establishing QoS parameters and environmental interferences. If a line of site was kept between the transmitting station and the suit computer, the LAN signal was maintained with a range of approximately 400 yards. Orientation of the suit subject relative to the transmitting station to maintain a direct line of site between the 802.11b radio cards was required for reliable data communications. This will require further work on antenna integration with the EVA suit in the future to avoid constraints on field science activities.

When a repeatable, strong LAN connection was established the second stage of testing commenced. A location 1.9 km away from base camp was selected based on its distance and geological interest. Several attempts were made to establish a strong LAN signal, but one could not be established. Signal failure was due to multipath interference caused by the vertical rock face of the prospective exploration site. The relay site was moved 0.1 km away from the vertical rock face to eliminate the interference. At the closer site, a strong LAN signal could still not be established. Signal failure here was also attributed to multipath arising from signal reflection caused by changes in elevation between the base camp and transmitting station. The transmitting station was moved to a new location approximately 1.7 km from base camp with fewer elevation changes along the line of sight. A strong signal was established from this site. With a direct line of site between the radio cards, the transmitting station permitted the simulator to establish a network link as far as 1.9 km from base camp.

CONCLUSION

This year's field-testing showed that the simulator could support field test use. Both displays were visible and useable during exploration activities, however, the Xybernaut® optical display did not support operations with the bubble installed on the HUT. Suit subjects thought that both displays provided adequate presentation of text and graphics data without special software, although better resolution and visibility are desirable. The larger size of the Xybernaut® optical display provided more interference with external environment visibility when compared to the smaller MicroOptical® GMD. This field trial shows that an enhanced vision system could potentially be located within the suit but hardware should be better integrated with the helmet to minimize helmet strikes during head maneuvering and eliminate the need for adjustment.

Testing with the wireless LAN system demonstrated that commercially available wireless LAN components could be assembled in the field and carried the LAN signal nearly 2 km. However, the commercially available equipment was not designed to operate in the field and was susceptible to environmental interference. One obvious shortcoming of the system was the Loss of Signal (LOS) caused when the suit subject came between the intermediate transmitting station and the IEEE 802.11 PCMCIA radio card. Effective antenna integration with the suit is needed to eliminate this problem. Future field experiments should include evaluating solutions to this problem that will be robust without interfering with mobility. The communication system on the next generation interplanetary exploration suit could use similar wireless technology, but higher processing speed and better software compatibility coupled with a larger bandwidth would be necessary to support typical data transfer. Smaller packaging and more robustness would be important to meet weight and volume constraints and survive the expected abuse.

FUTURE PLANS

Based on the results of the field-testing described in this paper, continuing research is planned during 2002 to build on and extend what has been learned to date. This will include development of more fully integrated systems with expanded capabilities, further field tests in the context of ongoing scientific research at Devon Island, and expansion of the collaboration to include testing the EVA information interfaces in higher fidelity EVA hardware systems. This may be accomplished by supporting a NASA JSC field test program using an advanced EVA prototype pressure suit.

Field tests at Devon Island during 2002 are expected to support a more complete and realistic suite of human science activities and field science collaboration tests as a result of the implementation of more robust wireless networks and more capable human information interface systems. These are expected to enable transfer of the types and amounts of data envisioned for ultimate uses of the system and to extend the terrain and distance over which testing can be accomplished. More capable human interface systems are expected to support effective use of system control by the EVA scientist in various modes envisioned for an ultimate flight design supporting the evaluation of their usage characteristics in a realistic field research setting. These tests will also play an important role in maturing the human information interface hardware, software, and control concepts prior to their use in higher fidelity hardware as part of the NASA JSC-led field test program.

The NASA JSC-led field test program is expected to provide an opportunity for the evaluation of system field performance in a functioning pressure suit environment. It will also permit the evaluation of robotic system interaction applications of the interface in the context of NASA research on EVA robotic cooperative exploration research tests and provide actual experience with long distance collaboration over satellite data links.

ACKNOWLEDGMENTS

The research described in this paper was supported by NASA, the Canadian Space Agency, and Hamilton Sundstrand Corporation. Field research activities were conducted under the auspices of the NASA Haughton-Mars Project (HMP). The HMP is managed by the SETI Institute. Logistical support in the field was provided in part by the Polar Continental Shelf Project (PCSP) of Natural Resources Canada and by the United States Marine Corps (USMC). Permits to carry out research on Devon Island were issued by the Nunavut Research Institute (NRI). The northern communities of Grise Fiord and Resolute Bay are thanked for their overall support of the HMP. Xybernaut Solutions, Inc. donated the Xybernaut wearable computers used in this research to the SETI Institute. Kawasaki Motors USA sponsored the ATVs.

The authors would also like to thank many individuals who supported the research in the field and during the sometimes difficult process of preparing field systems and getting them to Devon Island. Joel Goldfarb, Clark Dean, Pete Kinsman, and Peg Pozdol of Hamilton Sundstrand and Colleen Lenahan of the HMP worked tirelessly to ensure that functioning EVA simulator and information interface hardware were available to support the research at Devon Island when needed. John Schutt and Gordon Ozinski provided capable and essential support as knowledgeable test subjects in the field. We would also like to acknowledge the support of NASA personnel, notably Richard Fullerton of the EVA Project Office and Joe Kosmo at the Johnson Space Center who provided valuable input on desirable interface design characteristics, anticipated usage patterns and testing approaches. Geoffrey Briggs, Brian Glass, and Anthony Gross of the Center for Mars Exploration at NASA Ames Research Center also provided instrumental support.

REFERENCES

1. Carr, Christopher E., Newman, Dava J., “Supporting Martian Field Geology”, Geological Society of America, Boston, MA, November, 2001.
2. Clancey, W.J., “Human Exploration Ethnography of the Haughton Mars Project – 1998 – 1999”, Mars Society Annual Meeting, Boulder, CO, 2000.
3. Braham, S.P., Anderson, P., Alena, R., Glass, B., Lee, P., “Internet Communications for Planetary Exploration”, Proceedings of the Space internet Workshop, 2000.
4. Carr, Christopher, E., Newman, Dava J., “Applications of Wearable Computing to Exploration in Extreme Environments”, MIT, August, 2000.
5. Gernux, Carolyn G., Blaser, Robert W., Marmolejo, Jose, “A Helmet Mounted Display Demonstration Unit for a Space Station Application”, SAE 891583.
6. Goodman, Gail, “Information requirements for Space Station Freedom EVA”, SAE 919526, 1991.
7. Carr, Christopher, E., Schwartz, Steven J., Newman, Dava J., “Preliminary Considerations for Wearable Computing in Support of Astronaut Extravehicular Activity”, MIT, 2001.
8. Simonds, Charles H., Chen, Hsiang Chen, “Design and Testing of An Electronic Extravehicular Mobility Unit (EMU) Cuff Check List”, SAE 911529, 1991.
9. Cohen, Marc M., “Mars Surface Science Laboratory Accommodations and Operations”, SAE 1999-01-2142, Danvers MA, July, 1999..

CONTACT

For more information on the NASA HMP, visit www.marsonearth.org

DEFINITIONS, ACRONYMS, ABBREVIATIONS

EVA: Extravehicular Activity

CPU: Central Processing Unit

CSA: Canadian Space Agency

DS: Direct Sequence

EMU: Extravehicular Mobility Unit

ESA: European Space Agency

GMD: Glass Mounted Display

GPS: Global Positioning System

HMD: Helmet Mounted Display

HMP: Haughton-Mars Project

HSSSI: Hamilton Sundstrand Space Systems Intl.

HUT: Hard Upper Torso

IS: Information Systems

JSC: Johnson Space Center

LAN: Local Area Network

LOS: Loss of Signal

NASA: National Aeronautics and Space Administration

PC: Personal Computer

PCSP: Polar Continental Shelf Project

PTT: Push to Talk

QOS: Quality of Signal

SETI Institute: Institute for the Search for Extraterrestrial Intelligence

SLA®: Stereolithography Apparatus