ABSTRACT

With a renewed focus on manned exploration, NASA is beginning to prepare for the challenges that lie ahead. Future manned missions will require a symbiosis of human and robotic infrastructure. As a step towards understanding the roles of humans and robots in future planetary exploration, NASA headquarters funded ILC Dover and the University of Maryland to perform research in the area of human and robotic interfaces. The research focused on development and testing of communication components, robotic command and control interfaces, electronic displays, EVA navigation software and hardware, and EVA lighting. The funded research was a 12-month effort culminating in a field test with NASA personnel.

INTRODUCTION

The research activity focused on four main areas pertaining to human and robotic interaction or informatics. The areas of research were array microphone system development, robotic command and control system comparisons, use of an electronic helmet mounted display for EVA, evaluation of a prototype mapping software for extravehicular terrain navigation (EVA), and an evaluation of modified commercial lights for nighttime EVA traversing. Clear communications is critical to the success of any EVA activity but it is considerably more important if the system is utilized for human and robotic interface. The research performed on the development of an array microphone system is laying the groundwork for a voice recognition quality spacesuit communication system. This system will allow command and control capability between astronauts and their robotic assistants. Research was also performed in the area of command and control capability through the development and testing of physical touch based systems. These systems included robotic control using joystick, electronic textile, and gestural control methods. The development and integration of visual displays into future spacesuits will also play a critical role in enhancing the astronauts capability to efficiently interact within an information rich environment. The research performed included the evaluation of an existing commercially available display and ultimately the integration and testing of this helmet mounted visual display in the I-Suit prototype EVA spacesuit. Display testing included robotic control without line of site and viewing EVA procedures. EVA astronaut terrain navigation research was also performed. This portion of the project looked at mapping software, computer interfaces, and
utilization of the EVA display. The final research area is EVA lighting for nighttime traversing. This includes spacesuit and rover lights. This research involved the modification, integration, and testing of state of the art LED lighting technology.

ARRAY MICROPHONE DEVELOPMENT

The array microphone system development began with audio testing at Johnson Space Center (JSC) to characterize the noise in the helmet of a pressurized spacesuit. Pressurized spacesuits have significant internal noise from air supply vent flow as well as other secondary sources such as the water pump and subject breathing. The array microphone development focused specifically on the NASA H-Suit and ILC Dover I-Suit Advanced EVA prototype spacesuits. Audio testing was performed with both suits pressurized to 4.3 psid with and without test subjects.

The suits were pressurized using a test panel at the JSC Advanced Suit Lab. Air enters both suits through a vent duct at the rear of the helmet. The inlet air requirement is 6 acfm minimum. The air supply flows into the suit and across the interior surface of the helmet bubble. Excess air and expelled CO2 from the subject is removed from an outlet valve at the rear of the upper torso. Individual microphones were plumbed into the suits and positioned at critical locations near the subject’s mouth where the array microphone system would be installed in the future. The noise signatures for both suits were recorded and later analyzed by a communications system design engineer at Kennedy Space Center (KSC).

The communications expert at KSC developed an array microphone system for both spacesuits including the array microphone, pre-amp electronics, and digital signal processor. The complete array microphone communications system was fabricated in a collaborative effort between NASA JSC, NASA KSC, and ILC Dover. The completed H-Suit and I-Suit array microphone systems can be seen in Figures 1 and 2.

The communications system performed well in both suits during the field trials at Meteor Crater Arizona. The system provided clear uninterrupted communications during sending and receiving voice from both suits for a total of twelve one hour suit test events. The only anomaly experienced was a defective battery on one radio during week one of the field testing. Future research in 2005 will begin to provide more definitive data on the communication system performance through testing of voice recognition software developed at NASA Ames Research Center.

ROBOTIC COMMAND AND CONTROL

Background

This area of research focused primarily on the development, integration, and evaluation of touch based interfaces that will allow a suited astronaut to have command and control capability of his or her robot and or rover. The vehicle chosen for the testing was a prototype six-wheel drive electric EVA tractor designed and built at the JSC Advanced Suit Laboratory. The tractor was designed with autonomous astronaut tracking capability. Once at a work site, it is envisioned that a suited EVA
astronaut would need local command and control capability. Hardware was developed to evaluate three different interfaces that can provide control input with a pressurized EVA gloved hand. This hardware includes an electronic textile control pad, a commercial joystick controller, and a prototype video capture gesture control system.

The EVA Tractor was controlled by integrating a commercial robotic controller into the existing vehicle drive systems. This robotic controller allowed for wireless control via a commercial multi-channel radio frequency transmitter. Three separate transmitters were modified to provide an interface to the E-textile touch pad, joystick controller, and gestural control system.

The command and control devices were developed and or modified to provide the best interface to a pressurized spacesuit glove. The field testing included using the latest evolution of the EVA gloves currently used on Space Station. The E-textile pad was designed specifically to operate the EVA tractor that drives like a tank. The three wheels on each side are linked to one another. Each set of three wheels is powered by one electric motor. A four-button control layout was developed to provide the most efficient one-handed operation of the vehicle. The E-textile pad was designed with adequate size and spacing of the four buttons to allow operation with a gloved hand. The joystick controller toggles were modified by adding larger custom knobs to improve pressurized glove interface. The gesture system utilizes a helmet camera that, in attempting to focus on a colored marker on the EVA Glove, proportional control of the EVA tractor thin film sensors were embedded in the fingers. The system was turned on by flexing the fingers and affecting a resistance change in the sensors. The University of Maryland researchers developed custom hardware and software to complete the gesture system.

Field testing was performed at Meteor Crater Arizona with the NASA Desert RATS Team. The command and control tests involved driving the EVA Tractor along a preplanned traverse path using each type of control method. The tests were performed by two spacesuit subjects that the NASA Desert Rats Team utilizes for their remote field activities. NASA personnel defined and placed 8 traverse path landmarks for the command and control tests as well as other NASA experiments. The eight landmark points were placed approximately 25 meters apart. The landmark points increase in elevation from location 1 until the terrain plateaus at location 8 and transitions to a steep down hill grade back to the suit donning area. The command and control test plan involved driving the EVA Tractor from the suit donning stand to each of the 8 landmarks and back to the suit donning area. Due to hardware anomalies with the gesture control system, the suited subjects did not use it and it was only tested on level ground about 50 meters from the traverse path landmarks. A University of Maryland researcher in plain clothes performed this testing. Drive tests were also performed using the E-textile and joystick control methods but without a line of site to the EVA tractor. The purpose of this testing was primarily to evaluate the EVA display and will be discussed in a later section.

The first test utilized the E-textile control pad. The control pad was designed specifically to operate the EVA tractor that drives like a tank. The three wheels on each side are linked to one another. Each set of three wheels is powered by one electric motor. A four-button control layout was developed to provide the most efficient one-handed operation of the vehicle. The E-textile pad was designed with adequate size and spacing of the four buttons to allow operation with a gloved hand. The joystick controller toggles were modified by adding larger custom knobs to improve pressurized glove interface. The gesture system utilizes a helmet camera that, in attempting to focus on a colored marker on the EVA Glove, proportional control of the EVA tractor thin film sensors were embedded in the fingers. The system was turned on by flexing the fingers and affecting a resistance change in the sensors. The University of Maryland researchers developed custom hardware and software to complete the gesture system.
During a long traverse scenario, the subject tended to provide increasing amounts of pressure on the buttons unknowingly until fatigue set in. The test was rerun unsuited to determine how much the EVA gloves played in this lack of tactile feedback. The same fatigue was experienced and in about the same amount of time unless the subject was consistently reminded to reevaluate their contact pressure. Figure 3 shows two views of a suited E-textile control pad test.

The second series of tests utilized the modified commercial joystick controller. Initially the same arm fatigue was experienced as with the E-textile control pad. This was a result of the subject attempting to hold the controller higher in front of them than necessary. The test was continued with the subject holding the controller down in front of the suit with the arms extended and relaxed. A two-stick control system is very common for tank type driving and in this test, the joystick control was found to provide good feedback and made controlling the EVA tractor easy. Figure 4 shows two views of the joystick control test.

The third series of tests evaluated the gestural control system. During initial testing with the sensor equipped EVA glove, the sensors were damaged beyond field repair. This eliminated the possibility to perform suited evaluations. Backup electronics were procured to allow for a hand held switch to be used to activate the system. Once activated, the gesture vision system was used to turn the EVA Tractor right or left. Initial trials were performed to determine the change in system reliability with different color markers against the natural daylight conditions and terrain color. The trials showed that a different color marker was required than was chosen during laboratory tests. The UMD team had prepared numerous markers for the field testing as part of the evaluations and ultimately chose a red marker over other colors such a black, orange, and blue. The gesture system was used to successfully demonstrate basic driving maneuvers on flat terrain. Figure 5 shows two views of the gestural control tests.
EVA DISPLAY EVALUATION

Background

This NASA funded research was a continuation of previous work performed using in-house research and development funds. The previous work included an investigation into the current state of the art in head mounted displays. The displays investigated were compared based on factors such as size, display resolution, power requirements, performance in varying lighting conditions, and cost. A single display was chosen and laboratory testing was performed. The initial testing utilized the head-mounted display attached to a pair of eyeglasses. Suited and non-suited evaluations were performed to evaluate factors such as display clarity, display size, eye fatigue during extended use, and operation in bright sunlight. A spacesuit system level test was also developed to evaluate the display function. This test involved mounting a camera on a radio controlled vehicle and driving the vehicle while pressurized in the I-Suit without having a direct line of site to the vehicle. This initial laboratory test was the basis for the experiment developed for the EVA Display field test performed at Meteor Crater Arizona.

The display used for the in-house research and development was also used for this current research. The display is a VGA optical display with a 640 x 480 resolution. Viewing video through the display is approximately equivalent to viewing a 17-inch computer monitor at an average office workstation. Viewing video from a wireless camera was accomplished with commercial camera hardware, software, and a small laptop computer mounted on the suit. The display was modified with an articulated arm and mounted directly to the inside of the I-Suit helmet. The integration of the display can be best seen in Figure 11 later in this paper.

Field Testing

The field test consisted of driving the EVA Tractor without a line of site on flat terrain within a large open field adjacent to the EVA traverse path previously mentioned. As previously stated, two different NASA suit subjects performed the testing. For the field tests, the display was mounted in the helmet of both the H-Suit and I-Suit. A camera was mounted on the front of the EVA Tractor with a tinted filter to provide better visibility in bright sunlight (Figure 6). The video from the EVA Tractor camera was visible through the helmet-mounted display via a wireless transmitter. Test 1 was performed by subject 1 unsuited...
using the E-textile control pad (Figure 7). Test 2 was performed by subject 2 pressurized in the I-Suit using the joystick controller. Test 3 was performed by subject 1 in the H-Suit again using the E-textile control pad. The goal of each test was to drive the EVA Tractor approximately 25 yards from the start point and turn the vehicle around and return to the start point.

Test 1 was performed unsuited. It consisted of the suit subject viewing the EVA Tractor video feed through the I-Suit helmet mounted display and driving the tractor via the E-textile control pad. The Test 1 was completed but not without difficulty. The test started with the vehicle driving into the sunlight. Once at the turn around point, subject 1 found it difficult to turn around due to a lack of visual queues. The vehicle and camera were both facing into the sun and the camera was positioned such that it was pointed directly inline with the plane of the horizon. These two factors made it virtually impossible to determine the vehicle position rotationally in order to turn it around and bring it back to the start point. In order to provide a physical reference for subject 1 a person was used as a visual marker to provide a reference point for turning the vehicle around 180 degrees. One significant lesson learned is that the camera should have been placed high and to the rear of the vehicle with a view of the front of the vehicle. Subject 1 also noted a desire for a larger viewing window on the helmet mounted display. For Tests 1 through 3, the video camera software limited the viewing window to approximately 50% of the full EVA display screen capability.

Test 2 was completed while pressurized in the I-Suit with subject 2. The subject remained in the donning station for the duration of the test. The I-Suit helmet was covered to eliminate the subject visibility to the EVA Tractor (Figure 8). This test consisted of the same parameters as Test 1. The results of this test were consistent with Test 1.

Test 3 was performed with subject 1 pressurized in the H-Suit on the donning station (Figure 9). The H-Suit helmet was covered as in Test 2 to eliminate the subject’s visibility to the EVA Tractor. In this test, subject 1 drove the EVA Tractor from EVA traverse location 1 to 3. This test was performed with the E-textile pad as in Test 1. Subject 1 noted that the E-textile control pad could be improved if the buttons were gated and/or provided some tactile feedback. Just as with previous driving tests, the subject noted hand fatigue due to a tendency to supply excessive pressure to the control pad.
After the vehicle drive tests were completed, another test of the EVA Display was performed. This test consisted of viewing geologic science trailer procedures (Figure 10). The purpose of this test was to evaluate the subject’s ability to read text from the helmet-mounted display. This test was performed in bright sunlight conditions and with only one subject.

NASA’s science trailer is a prototype mobile geologic analysis laboratory. It includes the type of analysis tools that would be needed to perform science on a planetary surface. The science trailer procedures were developed in a presentation format in Microsoft PowerPoint. The procedures were saved on the spacesuit computer and viewed by a subject using the helmet-mounted display in the H-Suit. The subject commented at the end of the test that the helmet mounted display worked well for viewing science trailer procedures and that it was preferred over viewing written procedures from a notebook. The ability to page through the procedures was accomplished via a commercial track ball. The subject commented that a better computer pointing device or voice control was needed. As a result of normal body movement and vibration, the track ball would not maintain the pointer in PowerPoint. This caused the suit subject to expend an unacceptable amount of time reacquiring the pointer, moving it to the on-screen scroll bar, and clicking the track ball button to page down through the procedures.
EVA ASTRONAUT TERRAIN NAVIGATION

Background

One of the lessons learned from the Apollo missions was the need for astronaut personal navigation capability. The ability to navigate on a planetary surface is not only a productivity issue but a safety issue as well. A test was developed to evaluate the suit interfaces required for successful terrain navigation. This includes among others EVA displays, mapping software, and computer interface or pointing devices (Figure 11). The test utilized a global positioning system (GPS) device. The GPS device provided a convenient vehicle for testing the EVA display, navigation software, and computer pointing device. For this test, commercially available mapping software was modified and the I-Suit with the integrated helmet mounted EVA display and computer track ball pointing device was used.

Field Testing

NASA personnel at the remote field site defined a traverse path. As previously discussed, the traverse path included 8 critical landmark points. The traverse path consisted of translating up and down a hill over uneven terrain. The GPS receiver was used on the suit with the modified mapping software to send a real-time spacesuit position marker onto a modified satellite image of the remote field site. The first part of the test was to record the 8 landmark points onto the terrain map. This function is envisioned in the future to be performed by a robot prior to EVA. The second phase of the test was to complete the traverse path unsuited attempting to find the most direct path between each landmark point. This first test was then rerun with a subject pressurized in the I-Suit. The suited run consisted of the subject traversing along the traverse path while regularly looking at his position using the helmet mounted display and mapping software (Figure 12). The second test not only provided an evaluation of the navigation components but also an indication of the impacts the pressurized suit has to the subject’s ability to stay on the traverse path. Subjective comments were provided as to the display position, general map visibility (day/night), and on screen controls visibility.

8 Landmark Points with Short Sleeve Traverse Path Recorded

8 Landmark Points with I-Suit Traverse Path Recorded

Figure 12: Map Record from Navigation Tests
The test subject noted that the map satellite image and map markers were difficult to see in bright sunlight. The map visibility was improved when the display was switched to its high bright mode. This mode changes the display to black and white and increases the display light intensity. The test subject commented on a need to improve the maps color clarity and contrast. The navigation system was evaluated during a nighttime test and the map was found to be very visible in the absence of bright ambient lighting. As with the science trailer procedure test, the subject noted the need for a better computer pointing device to allow for map function manipulation.

EVA LIGHTING

A lightweight lighting system was developed for the I-Suit by modifying state of the art commercial high intensity LED lights. The lighting system was developed to support a planned nighttime EVA traverse test during the Meteor Crater field testing. This test consisted of the suit subject remotely piloting the EVA tractor from traverse points 1 through 8 while accessing whether the suit and EVA Tractor lighting systems were sufficient. Two separate light systems were developed for use on the suit simultaneously (Figure 13). Upper helmet lights were designed for long distance light projection. This set of lights utilized 2 hyper-bright white LEDs set in projector cones and 4 high-bright white LEDs. These lights were controlled by either a standard toggle switch or alternately a flexible printed circuit switch attached to the upper arm cover layer. The lower helmet lights were designed for local suit lighting to illuminate the area around the boots and in the normal work envelope in front of the chest. This set consisted of two pods of 6 high-bright white LEDs. These lights were positioned to ensure adequate light was supplied to the area in front of the suit to ensure easy identification of changes in terrain. The lower helmet lights were designed with an E-textile control pad similar to the one utilized for the EVA Tractor control tests.

Along with the I-Suit lighting system, EVA Tractor lights were provided that consisted of commercial hand held floodlights modified for attachment to the front of the EVA Tractor (Figure 14). Custom brackets were designed and fabricated to allow quick release of the tractor lights by the suited subject. The planned scenario was that the EVA Tractor lights function as vehicle driving lights until at a work site and then one or both lights could be removed by the EVA crewmembers to provide additional suit lighting.

The suit lights worked well with the exception of a bad circuit in the lower light pods that caused these lights to turn off automatically about every 3 to 4 minutes. The lights could be quickly turned back on by touching the E-
Textile control pad. When traversing from landmarks 1 through 5 with both suit and tractor lights on, the suit subject noted the lighting was sufficient and possibly more than what was required. From landmarks 5 through 7, the EVA Tractor lights were turned off. The suit subject noted that the suit lights alone provided enough light to accomplish the task of driving the EVA tractor along the traverse path.

CONCLUSION

This initial field test of human and robotic interface technologies was successful. All test equipment and support systems functioned as planned. Within a 4 day period, 6 pressurized suit runs were accomplished, meeting the planned goals for the project. A considerable amount of information was learned about the integration, function, and robustness of spacesuit informatic systems. This development and field test was just the first step in an ongoing effort to identify, develop, and test all the informatic elements required to perform future EVA on the Moon and Mars. There remains room for improvement. In the area of EVA displays, providing user visibility in bright ambient light conditions will be crucial to mission success. For robotic command and control activity, improvements to E-textile control pads that can be embedded into the spacesuit layers as well as incorporating voice recognition with the new suit array microphone communication system will be required. Improvements to mapping software and on-suit computer interface devices are also required. EVA lighting will continue to be an area for further development as EVA mission requirements are defined.

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REFERENCES

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