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Development and Testing of Advanced Pressure Suit Technologies and Analogues for Earth-Based Simulations

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The University of Maryland (UMd), along with Arizona State University (ASU), initiated a research effort in August 2010 under the support of the NASA Lunar Advanced Science and Exploration Research (LASER) program. In order to fulfill the objectives of this grant, the UMd Space Systems Laboratory (SSL) Human Systems team has been continuing its on-going development of advanced controls and displays for planetary surface EVA. In addition to advanced avionics, two space suit simulators have been designed and built with the purpose of serving as test beds to aid the evaluation of human-robot cooperative surface operations, as well as providing novel additional capabilities to the suited astronaut. The space suit simulators, dubbed MX-A ("Alpha") and MX-B ("Bravo"), attempt to emulate the constraints typical of a pressurized suit in an unpressurized environment. By reducing the system complexity, support equipment overhead, and required operating protocols, we are able to open access to a wider range of test subjects; this allows faster, more accessible, and more conclusive experimental procedures. In this paper we will describe in detail the design and assembly process of these two suit simulators, with specific focus on avionics and advanced controls and displays. Field tests under this program focus on the use of the suit simulators and an astronaut support rover previously built in collaboration between UMd and ASU. For the current test cycle, several rover control interfaces were prototyped and tested, including speech recognition and synthesis, head tracking, gestural control, and suit-integrated joystick teleoperation. This paper documents the experimental evaluation process adopted in this study to compare all the above interfaces, and presents experimental results and conclusions.

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Nomenclature

D-FLEAS	Desert Field Lessons in Engineering And Science
DOF	Degree(s) of Freedom
EVA	ExtraVehicular Activity
EVVA	ExtraVehicular Visor Assembly
HMD	Head-Mounted Display
HUD	Head-Up-Display
IDE	Integrated Development Environment
IMU	Inertial Measurement Unit
LASER	Lunar Advanced Science and Exploration Research
MEMS	Micro Electro-Mechanical System
MX-3	Maryland eXperimental spacesuit, mark III
NBRF	Neutral Buoyancy Research Facility
PLSS	Personal Life Support System
RAVEN	Robotic Assist Vehicle for Extravehicular Navigation
SSL	Space Systems Laboratory
UMD	University of Maryland
VR/AR	Virtual Reality/Augmented Reality

I. Introduction

In August 2010, the University of Maryland and Arizona State University were awarded a grant under the NASA Lunar Advanced Science and Exploration Research (LASER) program. This four-year program is meant to enable the development and testing of both robotic technologies and operating protocols to increase the ability of humans to perform extended science missions on the Moon and Mars. This paper will exclusively focus on the development and initial evaluation of the human interfaces that enabled the above research, while leaving to a separate manuscript[1] to expand on the field trials.

We will describe in detail the MX-A and MX-B unpressurized space suit simulators, their avionics and capabilities, and how they contribute to the wider research scope. We will give an overview of all the interfaces that were developed, and describe the experimental procedures that were used to evaluate their performance and user response. Lastly we will cover plans for future work and experimentation, and will discuss observations and conclusions on the current state of the art in EVA/robotic surface scientific exploration.

II. MX-A/B Unpressurized Space Suit Simulators

In the last year and a half, two space suit simulators were designed and built at the University of Maryland with the goal of producing a simple system that would simulate the mobility constraints of a planetary pressure suit. The extensive history of space suit design and testing at the SSL with the Maryland Experimental (MX-x) series of suits[2] was branched in two different directions. The first, numbered series, refers to pressurized space suit analogues (MX-1, MX-2) while the phonetic series refers to unpressurized space suit simulators (MX-A, MX-B). The rationale behind the branching was to avoid confusion given the significant difference in the two architectures. In this work we will focus on the phonetic series of suits, leaving the pressurized suit analogues for future publications. It is our vision to converge back to a single branch and produce MX-3, a high mobility planetary space suit analogue that will be the result of all the advancements made in both current branches.

Figure 1. MX-Alpha

The unpressurized series of suit simulators is envisioned as a simple platform that enables the rapid prototyping of advanced controls, displays, measurement, and monitoring systems for field evaluation in an

environment as close as possible to the pressurized suit environment, but without the overhead complexity associated with pressure suits. By adding physical bulk around the wearer and providing a realistic helmet and ventilation system, we are able to constrain their range of motion, tactile feedback and visual perception in a manner similar to current pressure suits. These unpressurized suit simulators will be used in this study to perform field tests of planetary surface geological exploration with and without robotic support; in a larger sense, they will also be used to identify functional requirements for future pressurized space suit systems under development in the SSL.

MX-A and MX-B were designed to accommodate a very wide range of subjects, mainly with the intent of enabling test subjects from very different backgrounds without incurring strict mission or safety protocols. It is our assumption that future planetary EVAs will inevitably be highly autonomous and unchoreographed. By allowing subjects to follow their normal field study procedures during our trials, we obtain a better understanding on what a scientist might do or need to do in planetary surface exploration activities. This approach allows us to add important operational requirements to our design processes, as well as informing future scientists on the the current technological limitations that are associated with planetary EVA.

Figure 2. MX-Bravo

In the following sections we will describe in detail all the various subsystems that make up both MX-A and MX-B. These two suits were equipped with a backpack incorporating an on-board computer that would interface with any enabled surrounding systems via WiFi such as astronaut assistant rovers, control stations, other suits, or robotic manipulators. At the same time they provide the user with cartographic elevation GPS-base moving maps, and voice feedback when commands are executed. The suits also include a two way radio for communications with the ground station, a digital microscope and a helmet mounted camera whose video output can be streamed over the network. A high definition helmet mounted video camera for capturing the user workspace for post analysis of the simulated EVAs was also provided, along with a head tracking system, a gestural recognition system, a speech recognition interface, and a visual feedback wristpad controller.

A. Pressure Garment Simulators

MX-A and MX-B share the same design approach when it comes to the pressure garment system. An outer nylon garment simulates the external micrometeoroid and thermal insulation layer, while an internal layer acts as both a comfort layer and a backing plane for an interstitial layer of polyester stuffing. The rigidity of the external and internal nylon layers, along with the interstitial stuffing, provides a significant mobility constraint. We do not claim a high fidelity emulation of the constraints associated with pressure suits, but merely attempt to simulate the concept. The purpose of these suit simulators is not to evaluate the performance of the mobility system but, as stated before, to provide a platform for avionics and user perception evaluation.

Figure 3. Donning MX-B

The pressure garment simulator is also the main interface for cable routing and the backpack connection interface. The main difference between the first and second iteration of this series resides in the entry type and size. MX-A is a waist entry suit, divided in two separate sections. MX-A was our first attempt in CAD assisted design, and early versions of design techniques resulted in a smaller suit than initially anticipated. MX-B, on the other hand, is a body seal closure suit; resulting from the experience gained from its

predecessor, it was redesigned completely and is able to accommodate a much wider range of subjects. The change in entry type was the result of the fact that with MX-Alpha we were unable to achieve autonomous donning and doffing, especially when it came down to closing the two zippers. With MX-B we were able to significantly increase the ease of donning and doffing of the suit, allowing for semi-autonomous operations and reducing entry time.

B. On-Board Computer and Audio Loop

Both suit simulators are equipped with an ASUS EeePC 1215N netbook that serves as the main processing unit in the avionics package. As we learned from the MX-2 pressurized suit, by delegating all the crucial but simple processing to embedded systems, we can ensure a much higher level of reliability of the overall system. In the suit simulators we have taken the same approach, leaving to the on-board computer only those tasks that are either graphics intensive or that require more computational power. The netbook in these two cases serves as the main driver for the head mounted display, GPS cartographic moving map, video interface for the digital microscope and the helmet mounted camera, as well as the receiver for any other streaming video feed. It also functions as the main network hub, since all the embedded electronics are connected to it. The on-board computer parses the data from all the connected devices, translates it into commands, and sends those commands to the appropriate system be it a rover, a control station, or a robotic arm. In addition to the above features, the on-board computer is tied in the suit audio loop and can function as an audio recording system; via text-to-speech technology it also gives audio feedback on the current suit systems status and on commands received or sent. As part of the top-level avionics, MX-B also includes an advance audio loop that, through the use of a 4 channel active mixer, was able to feed to the user headset all audio transmissions from the on-board two way radio, on-board computer, speech recognition board, and audio feedback from the suit subject microphone. The other side of the audio loop includes a 4-way audio splitter that splits the microphone input to the on-board radio, computer and speech recognition board, and through a line amplifier feedback to the headset mixer loop. All audio inputs and outputs have volume controls to equalize all the audio streams.

Figure 4. MX-A and MX-B backpacks

C. Helmet Assembly

Helmet assemblies play a critical role in enabling a high-fidelity suit simulation, by constraining the user's head mobility and field of view. MX-A uses an 1/8 inch initial thickness vacuum formed polycarbonate ellipsoidal bubble, 6 inches tall with an 8 inch semi-major and a 6 inch semi-minor axis . Over the main pressure bubble, the assembly includes a second clear visor, a simulated sun shield and a outer fabric cover. The main purpose of the second clear visor is to enable the projection of see-through synthetic images, and is currently under development. Given the dimensions of the desired bubble, we were unable to acquire a COTS element; therefore we were forced to build our own from scratch, resulting in a usable but optically suboptimal element. The helmet assembly encloses the user's head, but does not seal it from the external atmosphere. The helmet does however increase the risk of CO_2 pooling. In order to mitigate this issue, a set of box fans was mounted inside the helmet which ensured adequate airflow to both reduce the likelihood of CO_2 pooling and

Figure 5. Helmet Assembly

fogging of the visor. The helmet assembly severely impinges the ability to conduct unaided communications with the suit user, therefore a communication headset was developed which will be described later.

As of now the two simulator suits share the same helmet assembly. The SSL is currently engaged in the design and assembly process of the MX-B helmet assembly, which process and description will be included in future publications.

D. Backpack Assembly

MX-A used a backpack assembly that was made from two acrylic bins that were cut to the desired size and joined together via a wood cross beam assembly. Adjustable shoulder straps were connected to a second wood cross beam structure that also prevented the open side of the larger, lower bin from deforming under load. The resultant shell served as mounting frame for the embedded suit avionics, and also included an outer fabric layer for aesthetic purposes. The backpack assembly was designed to be lightweight and impact resistant to protect the electronics within. The outer fabric layer included two zippers and a series of Velcro pads that covered the access ports of the backpack. From initial testing we immediately noticed that the lack of an access port wide enough to access the suit computer when the backpack was being worn was a significant design flaw. The use of two different non-connected volumes in the backpack was also inconvenient for debugging purposes. Lastly, the suit's exteriorized shoulder straps made donning and doffing the backpack very easy, but were aesthetically unpleasing since they induced strange bulging of the stuffing in the lower torso and shoulder sections.

These design flaws in the first iteration were the main driver for the design of the MX-B backpack. This implementation uses a 1/2 inch PVC pipe structure that defines the backpack envelope and serves as a mounting frame for all the embedded electronics and adjustable shoulder straps. It is covered by a fabric layer that includes two main access panels to the interior, one on the back and one on the front of the unit. The access windows allow access to the entire content of the backpack even when the backpack is in use, mitigating one of the mayor design flaws of its predecessor. Secondly it allows for quick connect and disconnect of the adjustable shoulder harness that is interior to the suit simulator. Both backpacks also served as the mounting point for the helmet assembly. This last feature will likely be removed from future implementations, given the constraints it imposes on the alignment and position of the suit. In later iterations, the helmet assembly will be integral to the suit and not to the backpack.

III. Advanced Controls

In the past micro-controllers and embedded systems were reserved to limited niches due to their complexity, cost and size. Today's micro-controller based systems are smaller, cheaper and easier to use by allowing for more intuitive development environments and standardized communication protocols. These systems allow researchers, engineers and students to implement rapidly and efficiently a wide array of devices that are limited only by one's imagination and experience. MX-A was our first attempt at suit-integrated embedded micro-electronics; although very successful, MX-A's avionics were not very reliable, and had limited capabilities. MX-B was the result of this experience, where a much better understanding of the Arduino microcontroller platform and its IDE (Integrated Development Environment) resulted in more complex, stable and performing interfaces. This section will describe in the detail the interfaces that were developed, integrated and tested in the MX-Alpha, and Bravo suit simulators. Figure 6 gives a general overview of the two suits' avionics architecture. The figure identifies additional functionality incorporated into the MX-B avionics package; we expect this trend to continue in the future.

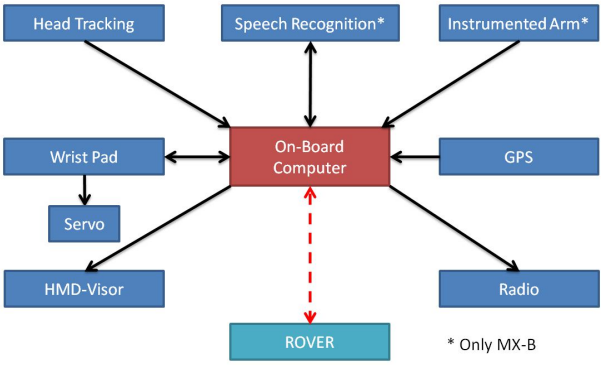

Figure 6. Avionics Architecture

A. Multi-Functional Wrist Pad

Figure 7. MX-A and MX-B Wristpads

The main control interface for both the Alpha and Bravo platforms resided in a wrist mounted button pad. The first iteration of the wristpad included a series of conductive pads connected to the digital readouts of an Arduino Mega board. To limit noise and false positives, all the inputs were grounded through pull-down resistors. The wristpad was mounted on the left wrist, while a modified right glove included two conductive pads on the index and middle fingers connected to two different digital output lines. Pressing a finger on a button would close a specific digital circuit, allowing the Arduino to identify if a button was pressed, and with which finger it was pressed. Finger differentiation was obtained by pulsing one finger high and the other low, and reading from the digital inputs of the board. Our implementation was restricted to two fingers since there was no need for more input commands in our specific application, but the principle applies to any arbitrary number of sensed fingers, and is limited only by the desired sampling rate and microcontroller performance. The system had its advantages and disadvantages: it is a very reliable concept, since it does not allow for accidental button press, and due to its simplicity it can be packaged in a very low profile wristpad. On the other side, it does not allow any sort of visual feedback, and it is sensitive to dust and corrosion since the contacts are exposed and the finger contacts are located right on the finger tips, which are usually subject to wear and contamination. This last issue was the main driver for moving away from the concept. During field trials we experienced several failures of the finger contacts which reduced the reliability and user confidence in the system.

For MX-B, we expanded on the initial wristpad concept by building a much more advanced interface that includes an analog thumbpad, nine buttons, eight of which include an RGB LED; these can be commanded to any desired color, allowing for visual feedback of the button press. The ability to color code each button independently opened the doors for a layered user interface, allowing a much broader control authority. In the second iteration wristpad, accidental button presses are possible, but they are mitigated on the procedural level. The wristpad layered interface requires a button sequence to be pressed in order to execute a command; following each button press, the user receives an audio message that relays what button was pressed and what it does, along with visual feedback on the wrist pad. For example, initially the wristpad is in the top menu layer with all the buttons lit white, except for the stop command, which is a dedicated button and is always red. The user can now select the a mode of operation; in this example, we will assume the user wishes to teleoperate a rover via the embedded thumb pad. The user will select the thumb pad button and the computer will feed to the local audio loop a synthesized voice saying "Thumb pad mode enabled". A series of buttons will light up. In this specific case, the pressed button will turn green, the "send commands" button will turn orange and blink while the "exit" command will turn blue and the "stop" command will remain red. The remaining buttons will not be lit, indicating that no functions are associated with those in the currently active mode. At this point, no commands are sent to any paired system; in order to begin transmission, the user will have to press the "send commands" button, at which point that button will turn off and the "stop sending commands" button will start blinking orange. The user will be notified by an audio message that reads "Thumb pad mode active". From now on commands are sent to the paired system until either the "exit" command or "stop" command is pressed. Two buttons never change location: those are the "exit" and the "stop" buttons. The "stop" command is the only button that doesn't require any secondary press; regardless of the mode, it immediately sends a signal to all paired systems to stop. Audio feedback is also provided. The "exit" command on the other side is enabled only after a mode has been selected; when pressed, it returns the wrist pad to the top level layer and interrupts any transmission of commands. This approach was very successful in the field, since any accidental button press was readily recognized; there were no instances of unwanted commands being sent to any paired system. It was also observed that the intrinsic stiffness of the buttons, along with the position of the wristpad, made accidental presses infrequent.

B. Head Tracking

MX-A had a very basic head tracking interface that relied on a single two-axis MEMS accelerometer mounted on the communication and visor headset. The accelerometer allowed us to measure pitch and roll angles of the user's head, and translate those to forward and lateral velocities that were than used to control rovers. In MX-B we have brought the concept further by replacing the accelerometer with a 9 DOF MEMS IMU (3-axis accelerometer, magnetometer and angular rate sensors). The IMU includes a microcontroller that filters the data from the three sensors via an extended Kalman filter, and then communicates over serial to the MX-Bravo's on-board computer. The filter and the dual redundant sensors allow us to have a much smoother and more accurate reading of the pose of the user's head in the Earth's magnetic reference frame. The IMU is also able to evaluate the pose of the head in a highly dynamic environment; it allows the user to access readings from the three sensors separately (before filtering and mixing is executed) allowing for a rough estimate of the dynamics of the user's head.

Figure 8. MX-A and MX-B head Tracking System

C. Gestural Control Interface

One of the current research topics at the SSL is robot-actuated space suits. The first step towards the implementation of an active exoskeleton or "powered suit" is to better understand the dynamics of the human inside the space suit, the limitations that the suit imposes on the person, etc. Current measurement systems that allow for such an analysis either require an extensive infrastructure (e.g., arrays of motion tracking cameras), and/or do not grant accurate and repeatable measurements (e.g., resistive bend sensors). In a novel approach to this problem, the SSL has developed a measuring system capable of determining the attitude of the human arm and the bend angle of each finger on the hand while still remaining portable and nonintrusive. This initial prototype is purposely restricted to the arm for simplicity, but will be extended to the entire body once the initial evaluation of the concept has been conducted and the appropriate revisions on the embedded electronics are finalized. As of now the measurement system includes a microcontroller, three 9 DOF MEMS IMUs located each on the back of the hand, forearm and upper arm, and 10 piezo-resistive bend sensors (two for each finger). By initially measuring the lengths of the subject's arm sections we are able to determine the position and pose in earth-magnetic reference frame of the subject's arm and hand. Currently, the embedded micro-controller is only responsible for parsing the data from the various sensors and sending it to the MX-B on-board computer, which executes filtering and data manipulation.

Figure 9. Arm pose measurement System

D. Speech Recognition

Speech recognition was not implemented on the MX-A platform, but it was initially introduced earlier in MX-2. In MX-B we added an embedded speech recognition board that communicates to both the embedded on-board microcontroller and suit computer. Its main purpose is to provide the user with a more natural primary control interface while still allowing the wristpad to be used as a redundant interface. This subsystem is still in the development and evaluation phase.

IV. Advanced Displays

MX-A and MX-B shared the same head-mounted display. Based on a stripped down z800 visor from eMagin, we adapted the visor mount to include a small radio controlled model servo to swivel the visor in and out of the user's field of view. To actuate the servo, the user is required to input a button sequence on the wristpad, and the Arduino microcontroller commands the servo. The user also has the ability to incrementally tilt the visor up and down to adapt it to his or her preference. The same commands have been implemented via speech recognition, therefore allowing the user to adjust the head-mounted display without pressing any buttons.

The visor is able to display a maximum resolution of 800x600 pixels at 60Hz; although compact, the visor assembly does not always fit inside the helmet depending on the suit subject. This interface is extremely useful, but it is not likely to be an option in future implementations. The visor, when down, completely obstructs the user's field of view, resulting in an unacceptable loss of situational awareness. Also, if for any reason the visor swivel would fail to function, the visor would remain locked in its last position, possibly compromising the astronaut's ability to see outside. Current effort is concentrated in the development of a similarly capable system, but with a different approach. Instead of using a head mounted display, we are in the process of testing an in-helmet projection system that would enable the astronaut to pull down an external helmet visor to see the projected images, while at the same time retaining the ability to see outside. The synthetic images would be displayed as overlays on the physical world, therefore limiting the overall distraction and loss of situational awareness. The authors are currently engaged in developing this two-way mirror and micro-projector based head-up display that will be integrated in the next iteration helmet assembly.

Figure 10. Modified z800 visor

A. Night Operations and Lighting

If we were to consider extended lunar missions, we would have to take into account that for half of the time the crew will be required to operate in the dark during the 14 days of lunar night. That would be true as well for Mars, although Mars has a day/night cycle much more similar to the familiar Earth cycle. In order to enable night operations with MX-B, we incorporated helmet mounted light sources and a flashing beacon. We evaluated this system in a night run in the Arizona desert, where a moonless night allowed us to verify that the brightness levels provided by our LED-based system were sufficient to enable science operations in the dark. The MX-B lighting system is composed of two modules, each including an array of three high intensity RGB LEDs. By turning on all three LEDs we obtained a cold white color light beam approximately 40 degrees wide. The lights are enabled, disabled and color tuned from the wristpad or speech recognition system. When the lights are enabled, a beacon located on the top of the backpack also begins to flash; the flash color and frequency can be modified, to allow an easy identification of the crew members in the dark. Lastly, the light modules are housed on both sides of the helmet on a swivel mechanism, allowing the user to turn the beam wherever necessary. The right light module also includes the two helmet mounted cameras which are rigidly mounted on the assembly, therefore providing light for the video devices as well.

Figure 11. Night Operations and lighting system

V. Rover Control Interface Evaluation

During the latest Desert Field Lessions in Engineering and Science (Desert FLEAS) field trials, we had the opportunity to run a pilot study to address the usability of each rover control mode that MX-Bravo offered. A simple course, depicted in figure 12 was set up in the Arizona desert where eight subjects participated in the experiment. The RAVEN rover was the controlled platform to be run across the course. Measurements taken were course completion time, videos and user feedback. Each subject was briefed on a single control interface, and then asked to perform the course as fast as comfortable. Once each subject ran the course in a given control mode, we would repeat for the next control mode.

Three control modes were tested in sequence. The first mode was the wristpad, the second was head tracking, and the third was gestural control. No additional training was provided for any of the control modes, so each subject was at a similar point in the learning process. The figure below shows the completion times that were recorded during this preliminary test. All test subjects recorded higher times in the initial wrist pad run, and on average, their times were better with the head tracking than with the gestural control. We believe that the learning process played a significant role in this preliminary test; therefore randomizing the controller sequence and granting some familiarization time with all the interfaces will be a must in future implementations of the test. Statistically we are not able, with this preliminary data set, to draw any significant conclusions; qualitatively the rover was easy to control in all three modes tested.

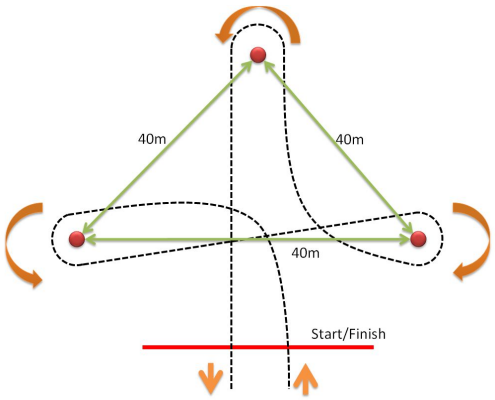

Figure 12. Course diagram

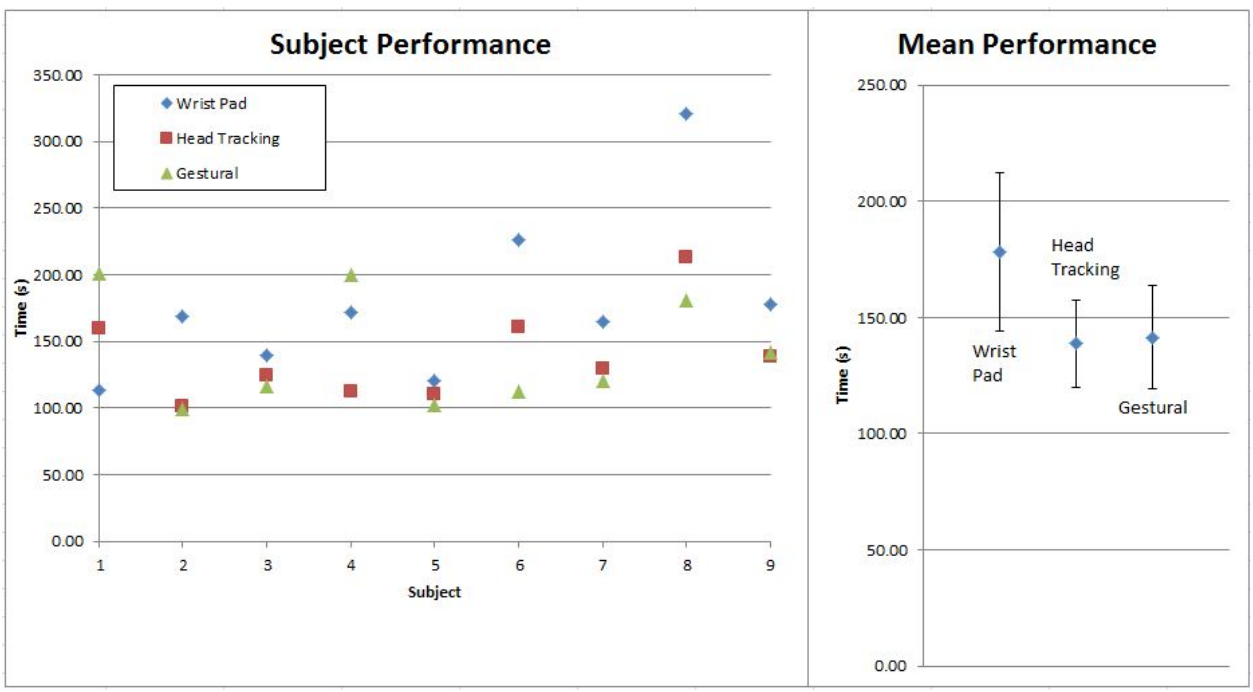

Figure 13. Experimental results: Execution times

User feedback was perhaps the most valuable of all the collected data elements. Users were very helpful in giving us feedback on the various control modes. In summary, the general consensus was that all three modes were perfectly feasible, but subjects tended to like the gestural control strategy best, followed by head tracking and (lastly) the wristpad. Subjects thought that the commanded output from the wristpad was very different from the one in the latter two modes. From a software perspective, the output commands followed the same translation process for each interface, and the control range for each interface was also

similar. Following this initial pilot test, a more extensive study was conducted. 15 test subjects, 12 males and 3 females participated in a more rigorous study where the three interfaces (wristpad, gestural and head control) were compared. Test subjects had an average age of 22.2 and an average experience with videogames of 4.2 on a scale from 1 to 7. All were currently enrolled students.

A similar course to the previous test was implemented at the University of Maryland. Three obstacles were placed in a corridor and a slalom course was identified by arrows taped on the corridor floor 14. Subjects were asked to run the course as fast as comfortable while standing in a predetermined location near the control station. Since the RAVEN platform was not available, a simpler but similar rover was built. Mini-RAVEN is a three wheel vehicle with two powered front wheels and a free-swiveling third wheel. The rover uses an Arduino based microcontroller with an X-Bee module for wireless serial communications. The rover was programmed to emulate the input-output data structure used on the RAVEN platform, therefore eliminating the need to modify the interfaces control software. Its speed and handling performance are comparable to it's "bigger brother", but since the data acquired during this test is not going to be compared to the data acquired in the field trials, the difference in platform will not impact our conclusions. The data acquired included course completion times, obstacles hit (either corridor walls or markers), a Cooper-Harper evaluation, a NASA Task Load Index (TLX) survey, and finally an analytical hierarchy process (AHP) survey to rank pairwise comparisons. As learned from the previous test, the interface sequence was randomized between subjects; all subjects were asked to perform up to three runs with each interface to mitigate learning curve and order bias on the acquired data.

Figure 14. Indoor test course and mini-RAVEN

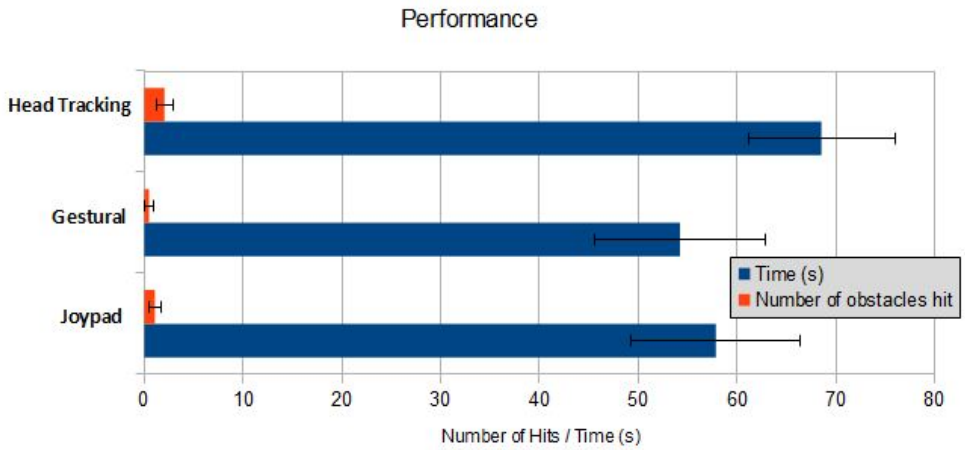

Figure 15. Mean course performance

Data was acquired for all runs, and outliers were excluded from the post processing. The results from the test are summarized in the figures 15, 16 and 17 below.

The last metric that was evaluated was a simple AHP analysis that, through three pair-wise comparisons,

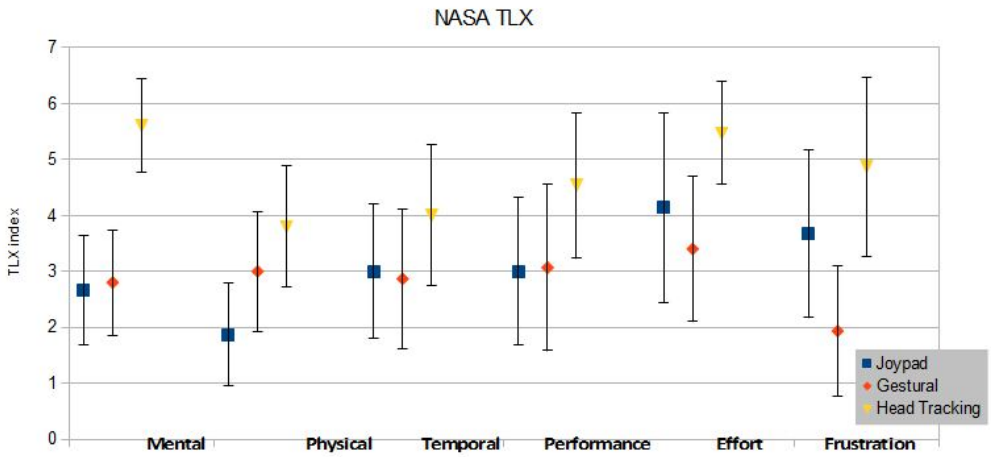

Figure 16. NASA TLX test results

gave a ranking of the three interfaces. Subjects were asked which interface they liked better overall, and the results show a wide preference for the gestural control (60.88%), followed by head tracking (25.68%), and lastly by the joy pad (13.44%). The result is probably biased by the novelty of the interfaces over the more standard joypad.

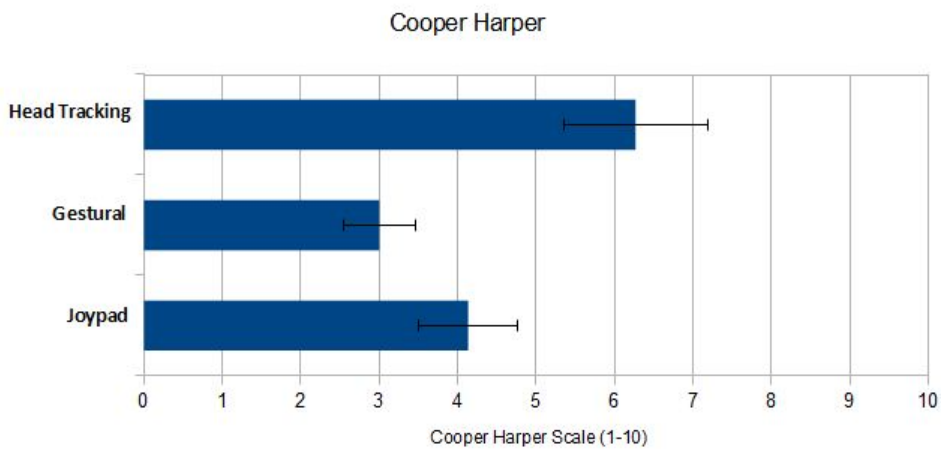

Figure 17. Cooper Harper

Otherwise, from the summary above, we can see that overall the users preferred and had better performance with the gestural control interface, followed by the joypad, and finally the head tracking system. All the metrics except for the AHP show this trend. Unfortunately, the limited population of test subjects and relatively wide spread of data points does not allow us to make a statistically conclusive assessment. It is however safe to state that the user response to the gestural control interface was very positive, and at least comparable to the more standard joypad, and that such control interfaces can be very promising for future applications.

VI. Conclusion and Future Work

This work has greatly expanded our capabilities in, and understaning of, space suit avionics and command and control interfaces. The next step forward to continue this effort will be modifying the MX-B platform for neutral buoyancy operations for micro- and partial-gravity simulations in the SSL Neutral Buoyancy Research Facility, as well as finally continuing the development of the third iteration of our pressurized series of suits. The birth of the MX-3 space suit analogue will not imply the conclusion of our work with our simulated suits branch; instead both will progress in parallel given our firm belief that there are a series of scenarios where the two suits branches can contribute significantly in different ways. MX-A and MX-B are ideal platforms for an initial concept test; they allow for a very rapid turn-around time when developing innovative avionics and user interfaces, as well as simple integration of subsystems. They open the doors for more extensive experimental studies where we do not have to worry about custom fitting a pressure suit on every potential trained subject, and all the safety concerns associated with pressurized suit operations. On the other side, their reduced fidelity does not allow us to draw significant conclusions when it comes down to scenarios where suit pressurization is a critical factor. We will compensate for the reduction of fidelity by providing a more complex, pressurized platform that will fill in the gap in the previous studies.

MX-3 is expected to be operational by the end of 2011, and will be designed to be a highly instrumented, lightweight planetary space suit analogue to be used in our future Desert FLEAS studies, simulating lunar and Mars EVAs in Earth analogue sites like parts of the Arizona desert. MX-3 has also been envisioned to be compatible with neutral buoyancy operations, although this latter feature might require a few modifications on the platform, such as incorporation of ballast systems. In future research, we plan to incorporate into MX-3 all the embedded systems that are currently prototyped in the MX-Bravo platform, and to expand upon the IMU based measurement system with extended metabolic workload studies, by adding on electromyographic (EMG) sensors, oxygen uptake (VO2) measurements, a heart rate monitor and pressure sensors on the hands and contact points between the suit and subject's limbs. The proposed measurement system may very likely open the doors for a more in-depth understanding of suit-demanded workload on astronauts in a high fidelity simulation environment. Three more Desert FLEAS test series are planned in Arizona analogue sites through 2014, and the SSL is always receptive to additional opportunities for analogue studies.

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Figure 18. The SSL 2011 Human Factors Team

References

[1]Akin, D. L., Saripalli, S., Di Capua, M., Davis, K., Hodges, K., and Young, K., Field Analogue Simulations Investigating EVA/Robotic Collaboration in Lunar Exploration, 41th International Conference on Environmental Systems, Portland, Oregon, July 2011.

[2]Di Capua, M., Akin, D. L., and Brannan, J. C., MX-3: Design and Technology Development of an Advanced All-Soft High Mobility Planetary Space Suit, 40th International Conference on Environmental Systems, Barcelona, Spain, 2010-761311, July 2010