

Incorporating Advanced Controls, Displays and other Smart Elements into Space Suit Design

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ABSTRACT

The MX-2 neutral buoyancy space suit analogue has been designed and developed at the University of Maryland to facilitate analysis of space suit components and assessment of the benefits of advanced space suit technologies. The MX-2 replicates the salient features of microgravity pressure suits, including the induced joint torques, visual, auditory and thermal environments, and microgravity through the use of neutral buoyancy simulation. In this paper, design upgrades and recent operations of the suit are outlined, including many experiments and tests of advanced space suit technologies. This paper focuses on the work done using the MX-2 to implement and investigate various advanced controls and displays within the suit, to enhance crewmember situational awareness and effectiveness, and enable human-robotic interaction. An advanced interface has been built into the suit which includes a speech recognition system, augmented reality and several different displays, which provide information to the crewmembers through images which incorporate status updates, electronic checklists, diagrams, camera feeds, video, etc. This system allows the suit subject to choose the information on the displays using voice, as well as to control various robotic systems with voice commands. The system also provides auditory feedback. This hands-off, eyes-off interface could make future servicing tasks, such as satellite repairs or construction of structures in space or on the moon, simpler and more time-effective, reducing the demands on the EVA astronaut while taking advantage of the extensive benefits of human-robot teams. By significantly en-

hancing the capabilities of a suited astronaut, this system will enable astronauts on the surface of the Moon or Mars to explore more effectively, safely, efficiently, and autonomously. The system reduces reliance on external communications, which has the potential to reduce operational costs and crewmember workload.

INTRODUCTION

The next generation of extravehicular activity (EVA) space suits must enable astronauts to explore the surface of the moon efficiently and effectively. In addition to designing the suit itself to be as mobile and lightweight as possible, interfaces, displays and controls must be designed to provide the suit subject with high bandwidth information, simple communications, and fluid, reliable and intuitive control of robots and other support systems. While today's typical EVAs are scripted, well-rehearsed and relatively infrequent, and are assisted every step of the way by IVA crew and teams of ground personnel, future lunar EVAs will occur on a daily basis [1], be relatively autonomous from ground operations, and must involve less overhead. Lunar astronauts must have far greater autonomy; they must be able to explore, change course as they see fit, and monitor themselves and each other [2]. To make this possible, they must have easy access to navigational information, their own position, the status of their suit and consumables, as well as databases of information which are easily accessible.

Today's typical cell phone user is able to communicate easily with anyone in the world, obtain real-time

navigational data in the form of maps and location, and has access to the entire internet providing endless information at the click of a button. Similar functionality could also be integrated into space suit design, so that an astronaut exploring the moon could easily and instantly obtain his/her position on a lunar map, speak to fellow EVA astronauts, crewmembers in the habitat, and individuals back on earth, check geological databases for information pertaining to the rocks and formations they are looking at, watch instructional or informational videos in real time, and monitor their own consumables, suit status and physiological data quickly and easily.

There are several challenges, however, to integrating such a system into a lunar EVA spacesuit [3]. Small buttons or touchscreen interfaces are very difficult to use while wearing spacesuit gloves [4]. Current navigational methods used on Earth, such as the Global Positioning System (GPS), or navigation based on proximity to cell-phone towers and/or wireless locations, clearly will not work on the moon. While some have proposed satellite systems for navigation on the moon, this infrastructure is not currently available, and thus other means must be devised for lunar exploration. Additionally, the system should be designed such that it does not place additional burden on the astronaut, so that it is easy and intuitive to use and provides additional functionality and capabilities, and so that it significantly increases lunar EVA autonomy.

The first concept that serves this goal is a speech recognition system, which can be used to obtain information and to control various systems, including displays, cameras, scientific instruments, and robots. Speech is a promising means of control because it is a “hands-off, eyes-off” interface. It will not additionally fatigue the astronaut by requiring them to move their hands and it will not interrupt them from their current task. For example, no matter what the astronaut is working on, without interrupting their task they could simply say “Oxygen remaining” and the suit would provide the answer, or they could say, “Rover come here” and the nearest rover would begin to autonomously drive near, within a safe distance. Much work has been done in the field of supervising semi-autonomous robotic assistants [5–9].

The speech interaction system can be combined with advanced displays for even more functionality. Several display modalities are under investigation, including chest-mounted, wrist-mounted, mounted within the helmet, and a semi-translucent visor. Each can be used to display various information to the subject, including maps, videos, live camera-feeds, checklists, consumables status, etc. Using speech, the user can change what is displayed, asking for a specific camera-angle or checklist to aid in the current task. Again this allows for a fluid work flow, and does not additionally exert the astronaut. These displays will provide far greater functionality than the Display and Control Module (DCM) currently used in the Extravehicular Mobility Unit (EMU) [10].

The purpose of this research is to test these concepts and determine the utility of the various functionalities. The best way to do this is to integrate the technologies into an operational pressure suit, which in itself provides valuable information on the systems level challenges inherent in this design, and then test the technologies in simulated EVA operations. Using these technologies within a space-suit in a challenging environment provides a great deal of information as to which of these systems are most useful.

Neutral buoyancy is universally accepted as one of the best methods of simulating microgravity EVA. Parabolic flights provide excellent simulations of the microgravity environment; however, the short time-span of each parabola makes long-duration testing almost impossible. Neutral buoyancy, combined with a pressure suit test bed, provides an environment in which long duration testing of advanced space suit technologies can be performed. This is the underlying concept of the MX-2 (Maryland eXperimental suit 2), a neutral buoyancy pressure suit which serves as an experimental platform for investigations of advanced controls, displays, and other smart elements. These elements can be integrated into the suit and tested to determine their integrability, utility, and optimum usage.

This paper will first describe the design of the MX-2 and the overall suit architecture, detail the specific advanced systems which have been tested in pressurized neutral buoyancy manned operations, and provide an overall vision for the future of space suit controls and displays technology. The advantages of speech interaction, heads up displays, augmented reality, human-robotic interaction and advanced informatics are discussed in detail. Finally, anticipated further steps in this work, including an architecture to be used in the development of the next generation MX-3, are proposed.

MX-2 ARCHITECTURE OVERVIEW

The MX-2 is an operational pressure suit designed to simulate EVA in the neutral buoyancy environment. The MX-2 is an outgrowth of the MX-1 [11], a first generation design that served to refine fabrication techniques for the fully operational MX-2. The current suit significantly improved on the MX-1 design; it utilizes the original Hard Upper Torso (HUT), while new soft goods as well as an open loop portable life support system have been designed and incorporated. The suit became fully operational in 2005 [12], and it continues to be enhanced and upgraded as a testbed. The suit now includes an electronics box which houses several integrated suit and subject sensors, and a computing platform which communicates via Ethernet to the deck station. The MX-2 has the capability of integrating a series of displays, which enable the suited subject to display video feeds and text checklists, and can be controlled via voice through a speech recognition system.

SUIT MATERIALS

The torso is a rear-entry fiberglass HUT with integral planar scye bearings. The torso interfaces with the arms and lower torso assembly (LTA), which combined are termed the “soft goods”. The soft goods are made of three layers: the first layer, termed the pressure bladder, is made of a urethane coated nylon, which is heat-sealed together to form the air-tight bladder. The pressure bladder is constrained by the restraint layer, which is sewn, as well as high strength restraint lines located along the lines of non-extension. The outermost layer is the integral ballast garment (IBG) which protects the suit from any sharp edges or other hazards, and includes many pockets to allow for ballasting in the underwater environment. The amount of ballast added to the suit must be adjusted prior to each dive to account for the weight of the test subject and the suit configuration. Figure 1 shows the structure of the entire suit.

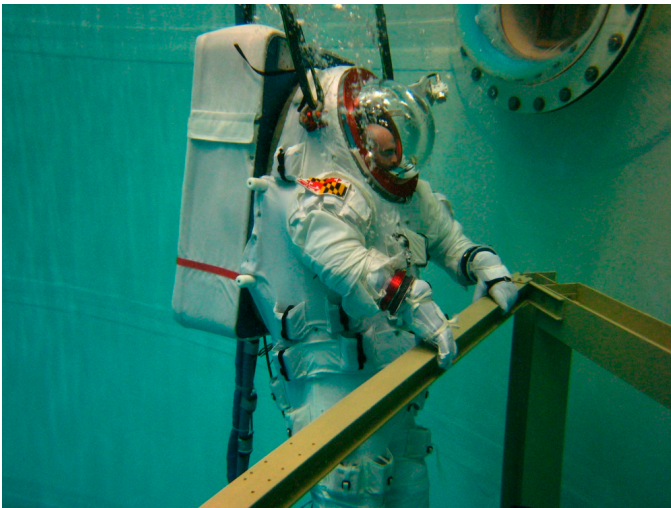


Figure 1: The MX-2 suit before the incorporation of advanced controls and displays.

LIFE SUPPORT

An open-loop life support system is used to provide the suit subject with air and cooling water. Air is provided from the surface at a rate of 6 cubic feet per minute (170 Liters per minute), and regulated with a back-pressure regulator to a nominal pressure of 3 psi differential (psid) (0.2 atm). As the suit is lowered into the water, the ambient pressure increases at a rate of approximately 0.5 psi/foot depth (0.1 atm/meter), thus the back-pressure regulator correspondingly increases the suit pressure to keep the differential at 3 psi (0.2 atm). The suit can operate anywhere in a pressure range of 2-4 psid (0.14-0.27 atm). Exhaust air is returned to the surface where sensors measure the CO₂ and O₂ concentrations to allow metabolic workload measurements. Backup air supplies are housed within the backpack in the event that the primary air supply fails.

COMMUNICATIONS, AVIONICS AND INFORMATICS

The subject wears a Communication Carrier Assembly (CCA), also known as a “snoopy cap”, with integrated microphone and speakers, which provides full duplex high-bandwidth communications to the suit technicians as well as the safety divers, who use full face mask dive gear as well as an underwater speaker. The voice signal from the suit is additionally input directly into an onboard computing platform, which performs the speech recognition, and then the auditory feedback from the computer is spliced into the headphones. In the event of a computer malfunction, communications to the divers and technicians will not be interrupted. Onboard sensors monitor the suit pressures and in-helmet CO₂ concentration, as well as the subject’s heart rate. The signals from the sensors are processed by the onboard computer, logged for offline analysis, and also relayed to the surface via Ethernet where they can be monitored in real-time by suit technicians. The display of the computer can be shown in a helmet-mounted LCD or a semi-translucent visor. A camera mounted on the suit’s shoulder provides suit technicians with a view of the subject’s workspace, and an in-suit camera is mounted on the snoopy cap.

SIZING

The MX-2 was designed to accommodate a large range of test subjects, and has some integrated design features which allow for resizability. The torso is very large and as such almost any subject can fit inside. The downside of this design feature is that once inside the subjects’ centers of rotation of their shoulders are not co-aligned with the scye bearings, unless their shoulders are very broad. The interscye distance in the MX-2 is approximately 19” (0.48 m). The soft goods are designed to accommodate up to the 95th percentile male, which dictates the maximum length of the pressure bladder layer. The restraint layer is designed with several different sizing inserts which can be integrated into the suit for different subjects. These dictate the actual length of the soft goods and can be matched to the subjects’ arms and leg dimensions. The gloves are also designed for 95th percentile male hands, and have adjustable restraint bars and cuff restraint lines which can resize the glove to fit smaller hands. The boots have a series of four adjustable straps which allow dynamic comfort fitting of the boots to any size foot.

Several sizes of liquid cooling garment (LCG) have been designed, each able to accommodate a small range of sizes of test subject. Each LCG can interface to the suit through a common set of quick disconnects, which connect the LCG to the cooling water inlet and outlet hoses. A valve on the front of the suit allows the subject to control the flow rate of the cooling water. An adjustable internal harness and stirrup system supports the subject within the suit, distributing the subject’s weight around the HUT.

To date, five different subjects have experienced simulated EVA using the MX-2. These subjects range in height

from 5'8" to 6'4" (1.7-1.93 m) and have a weight range of over 150 lbs (68 kg). This is an extremely wide range of subjects for a single suit, which demonstrates the advantages of the resizable design elements. The fixed size of the torso implies that the fit is worse for smaller subjects; however, smaller subjects have still had success operating the MX-2. A smaller HUT would have precluded most subjects from MX-2 operations.

OPERATIONS

Manned operations of the MX-2 require careful planning, preparation and execution. Every effort is made to protect the safety of the suit subject and all the people involved in the dive, which includes divers, suit technicians, dive directors and test directors. Detailed nominal checklists are followed at all times, while emergency checklists are prepared, rehearsed, and on hand to be used in the event of an off-nominal situation. Suit technicians test the suit components prior to each dive, and monitor the suit and suit subject during the dive. Divers monitor the suit and subject, and can relay information to the surface using a full-face mask dive mask which allows bidirectional voice communications while diving. All divers can also hear the suit subject and all suit technicians through the underwater speaker.

SPEECH RECOGNITION AND SYNTHESIS

The speech recognition system implemented in the MX-2 is a unique and valuable addition to the suit system. The signal from the suit subject's voice is split inside the suit, through a passive analogue signal splitter, with one line sent directly to the surface, and the other sent directly to the onboard computer. The system is connected in this way for two reasons: the first is that if the computer were to malfunction or turn off, the communications link between the subject and the crew is not lost. Secondly, because communication between the subject and the computer runs in parallel to the exterior communication, the channel to the subject is always open, even when the computer is talking. This has proven very useful when the suit technicians need to speak to the subject while a speech test is ongoing.

The computer is listening at all times for recognizable words or phrases, which have been preprogrammed into the system. The system is break-activated, meaning that it will only recognize one of these phrases if they are preceded by a small pause. This helps prevent false positives, and also prevents unwanted interruptions by the system in the normal conversation between subject and dive crew. As mentioned the system does not completely interrupt the communications channel, but rather the computer voice is "on top" of all other communications. For example, a subject can query the system for their suit pressure, by pausing and then stating "suit pressure". The system will recognize the phrase and return the current data from the suit pressure sensor.

Currently, the system can be used to query for information, change what is displayed on the various displays (discussed in the next section), and to control various robotic platforms. The user can for example call up specific checklists applicable to the current task, by saying phrases such as, "donning checklist" or "servicing checklist". The user can also ask for a specific camera view: by saying "South Porthole Camera", that camera feed is shown in the display. This is incredibly useful as it provides multiple sets of eyes within the workspace, from all different angles, for the subject to use as they see fit. If the subject can not see behind or below something, but knows that a camera can, they can simply stay where they are and call up that video into their display, rather than removing themselves from their foot restraints, traversing to a new location just to look at something, and then returning. This can significantly save time and energy. Additionally, since the subject can use voice to control robots (discussed below), they can control robotic camera platforms to dynamically move cameras exactly where they need them.

ROBOT CONTROL

In "Direct Control Mode", which must be switched on using a speech command, the user can control both robotic arms and a robotic positioning platform. This technology has been integrated both on the Ranger Dexterous Robotic Servicing System, capable of both 1-G and neutral buoyancy operations, and a planar version of the Space Station Remote Manipulator System at the NASA Goddard Space Flight Center. Subjects can give commands such as "forward five" or "roll right", while watching the robotic arm both in the helmet and in the additional displays. Additional layers of safety have been built into the speech system to prevent accidentally commanding the robot to do something unwanted. For example, the system can ask for confirmation of any command before executing the movement. As well, the rate and duration of each movement is limited, so that to control a large motion requires several successive speech commands. This is not an ideal control architecture, but represents an important step towards being able to command complex robotic motions by voice.

Overall the speech system has been designed to be very flexible and extensible. It is very easy to add in new terms and phrases, and to synchronize them with new functionalities. Any word or phrase can be linked to virtually any command. Thus far, the speech system has been used to control cameras, obtain auditory information, change displays, start applications, start a phone call, and even restart the computer. The possibilities are only limited by the computing platform. The speech system does not need to be "trained" to listen for certain words or pronunciations; rather, the subject must essentially "train" his or her own voice to speak in a way that the system will recognize. Once the subject has a good feel for how fast to speak, how long to pause, etc. then any command can be programmed to be recognized by the system.