Designing Extended Reality Interfaces for Spacesuits

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ABSTRACT

Since the final Apollo mission in 1972, no humans have set foot on the moon. In 2024, through the next generation Artemis Missions, the National Aeronautics and Space Administration (NASA) aims to land the first woman and the thirteenth man on the lunar surface. This paper deals with research and speculations on how an Extended Reality (XR) interface within spacesuits could help astronauts conduct mission objectives such as geological sampling and assist with navigation on the moon. Opportunities for design changes and development to current astronaut interfaces with data streams and commands arise when exploring the challenges astronauts face during their interactions with the spacesuits and the lunar environment. Our research focuses on four main challenges outlined by NASA: lunar navigation, sample collection of lunar material, interface with the telemetric stream of vitals data and spacesuit status, and high-contrast lighting conditions [1]. Our approach also considers how to control the user interface (UI) and a tutorial system that would allow astronauts to train on the system before their mission to the moon.

Author Keywords

Lunar landing, Artemis, augmented reality, mixed reality, heads-up display, human-computer interaction, lunar exploration, telemetry display, user-interface control

ACM Classification Keywords

H.5.2 User Interfaces: User-centered design, H.1.2 User/Machine Systems, I.3.6 Methodology and Techniques

CCS Concepts

Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Mixed / augmented reality

INTRODUCTION

In order to meet NASA's aspirational goals for larger-scale missions on the lunar surface and extreme extraterrestrial environments, it is crucial to utilize the power of modern technology. As NASA prepares for a return voyage to the moon, a significant challenge the association faces is the integration of new technologies that did not exist during the Apollo missions. As part of a submission for NASA's Spacesuits User Interface Technologies for Students (SUITS), Rhode Island School of Design's (RISD) Space Design team examines how MR technology may be used to provide help with various Lunar tasks: navigating on the lunar surface, communication between astronauts and the Mission Control Center (MCC), displaying the extravehicular activity (EVA) spacesuits system state and telemetry, and more. Working with Microsoft's HoloLens 2, our team will design, code, and prototype a UI to present to NASA in the Spring of 2022.

RELATED WORK

While exploring ways to utilize XR in extreme environments and within the various design constraints, our team came across many instances of work that tried to solve the same problems with which we are now tasked.

Astronaut Heads-up Displays

As a part of its Early Career Initiative, NASA developed the Integrated Display and Environmental Awareness System (IDEAS) and the Joint Augmented Reality Visual Informatics System (JARVIS) projects to design an augmented reality (AR) heads-up display (HUD) and UI to assist astronauts during EVAs [2][3][4]. Building off of the 2015 IDEAS project, the JARVIS team is addressing three challenges: 1) solving the unique optical problems associated with having a near-eye display compatible with the Exploration Extravehicular Mobility Unit (xEMU) helmet configuration, 2) integrating with the informatics systems currently employed in the xEMU design, and 3) demonstrating the utility and value of including the JARVIS system on future missions [2]. Our team's HUD design has a similar purpose to these existing experiments, from strategically displaying task lists in a user-friendly way to organizing the biometrics and telemetry systems in an unobstructive manner.

Navigation Tools

Navigation is one of the most important aspects of lunar exploration. However, there are currently no navigational systems used during lunar expeditions. On Earth, Global Positioning System (GPS) navigation is used quite frequently and can easily be found within apps such as Google Maps, Waze, and Apple Maps. All three of these apps use the global navigation satellite system. The process of locating a user starts with the trilateration between four or more Medium Earth orbit, sometimes called the intermediate circular orbit, satellites. The satellites transmit highly accurate positional data to a device that in turn displays the positional information to the user. No such satellites orbit the moon currently, but this positional system of trilateration could be useful if we discover a cost-effective and worthwhile way to get satellites in orbit around the moon. So far, NASA and its competitors around the globe have only successfully tested temporary satellites in Selenocentric orbit [5].

Wayfinding Tools

NASA is working on getting a GPS-equivalent satellite system to help aid navigation on the moon. The moon's lack of an atmosphere makes navigation difficult. We found that astronauts have trouble determining the size and distance of specific landmarks. NASA hopes to create a receiver that will signal all the way from lunar-orbiting crewmembers. This method is very similar to how GPS satellites orbit around the Earth [6].

Motion and Gesture Detection

Another critical aspect of the XR design is the control interface. It is essential to our design's success that we have streamlined and practical control methods that do not impede an astronaut's ability to carry out tasks and interface with the UI.

Hand Gesture Control

In the prototype that RISD Space Design will be building to present our designed user experience with AR, we will make use of the hand gesture and eye-tracking functionality of Microsoft's HoloLens 2. Hololens 2 is the display technology that we will use for showcasing our UI design even though NASA may use a completely separate HUD technology for the final iteration of this project [7][8].

IMU

In order to add motion and gesture detection functionality to the spacesuit, an Inertial Measurement Unit (IMU) containing gyroscopes and accelerometers will be embedded into our design. With it, we will be able to better understand an astronaut's positional data [9].

Antilatency

Antilatency is a multipurpose positional tracking system that we intend to test for use as gesture control. Antilatency offers a much higher level of precision in positional tracking than the HoloLens can offer on its own. This system's increased accuracy will allow astronauts wearing large pressurized gloves to be far more articulate with gesture controls [10].

DESIGN

Designing an XR interface for spacewalks poses unique problems. Besides considering how the lunar environment affects the human body and interferes with technology use, design teams also need to consider many other factors when creating their designs. The difficulty of performing tasks in a microgravity environment, the constraints caused by a pressurized spacesuit, and accommodations of the astronauts' needs are crucial to create a successful, unobtrusive, and human-centered design. As outlined by NASA's challenge requirements, we focused on addressing the four challenges mentioned in the abstract: Navigation, Geological Sampling, EVA System State, and Auxiliary Considerations (lighting conditions, control systems, and a system tutorial). Our team separated into subgroups; each focused on one of the four challenges.

Research

All the teams outlined above researched and developed ways to address the specific challenges. Below is a summary of our research and preliminary design ideas developed from each of the core subgroups.

Navigation

Our design will guide the astronaut in real-time during lunar navigation. The destinations astronauts would reach include multiple EVA sites and designated geology excavation sites [11]. Data provided by HoloLens' internal sensors, spatial mapping capabilities, and appropriate imagery from cameras would be used to help guide astronauts during navigation on the lunar surface [1][11]. Potential design ideas include a mini-map idea where we utilize the data from the proposed lunar position system or the use of spatial mapping to define a localized coordinate system. To assist in wayfinding, we are investigating the use of geolocational pinpoints. This proposed pin-based wayfinding method would be very similar to that of Google Maps, as it could drag and drop a pin on a specific location. These pins would be displayed on a mini-map to keep track of positioning, as well as on a false compass to help with bearings. The mini-map would always be shown in the corner of the HUD, along with the compass shown along the top of the HUD. Additionally, there would be a system for any alerts or emergencies the astronauts may run into by having a blinking light or notification. This would better notify the astronaut of their suit status as well as alert them to the quickest way back to home base if they run into an issue with their suit.

Geological Sampling

For geological sampling, our primary focus has been to identify the differences in geological fieldwork on terrestrial and lunar surfaces. Our design will aid in science sampling and geological research to study the lunar surface and help prep future missions for a long-term stay on the moon. In order to best facilitate sample collection, our design will provide spatial map tagging multiple camera options, note-taking capabilities, and recording devices for voice memorandums [1][11].

The process and experience of fieldwork are directly affected by the specialized lunar sampling tools and the astronauts' restricted mobility due to their pressurized suits. Some of the limitations of astronauts are "rapid build-up of hand and forearm fatigue," "reduced mobility of the legs preventing safe bending to kneel down," and the "minimal internal volume of the helmet, limiting the astronaut's upward and downward visibility" [12]. Our design aims for our XR technology to reduce movement required in these restricted scenarios based on these concerns. For example, labeling collected samples is much different on Earth, as "flat labels laying on the ground would get covered with the very adhesive lunar dust" [12].

To avoid having physical labels that would be subject to the regolith, our interface will geotag each sample bag and map every sample location with a virtual pin, removing the need to carry physical markers or signs. It would be highly beneficial for data recorded of geo-samples during Artemis missions to be tagged with their spatial and time contexts with the help of remote sensing datasets (aerial imaging) and NASA's Lunar Positioning System [14]. Geotagging photos and videos of samples with their origins allow accurate hypotheses to be drawn from them. On occasions without access to said Positioning Systems, astronauts on sampling activities would benefit from binoculars and microscopic technologies that substitute for the lack of atmospheric perspective.

EVA System State

During EVA tasks, the XR device will assist astronauts execute airlock maneuvers. The device would provide suit telemetry and vital data to the astronauts. This data must be easy to access while at the same time remaining unobtrusive [1][11]. For future missions to the moon, NASA requires our XR device to be compatible with a suit port in order to execute airlock activities such as the Umbilical Interface Assembly (UIA), interact with the Display and Control Unit (DCU), and conduct Intra-vehicular spacesuit prep [11]. Moreover, the AR device must interact with the suit telemetry stream (which will be provided by NASA) and display vitals in a way that does not obstruct the astronaut from performing other tasks [11]. From requirements from NASA and through considerations of the tasks that astronauts must perform while on lunar missions, an opportunity lies in how RISD Space Design may synthesize telemetry streams to derive actionable insights for astronauts while not overloading them with information.

Auxiliary Considerations

There are high contrast lighting conditions on the moon. The User Interface (UI) must consider how displays would be seen in both bright and shadowed regions of the moon [1][11][13]. We have to consider how the UI would be learned by the astronaut and what our learning tutorial would look like [11]. We also have to consider the type of control systems that interact with our UI. The Auxiliary Controls subteam has been doing research on different methods for system control, from voice control to eye gaze technology to gesture control [7][8][9][10].

Hardware and Software

HoloLens 2 and Magic Leap were the two best XR-supporting hardware technologies. HoloLens 2 stood out to us because it has full functionality embedded directly in the headset and a robust hand gesture tracking system. Considering the computing power accessible and the nature of user interaction design to prefer simple and straightforward communication, we decided to implement our design in Unity with C#. Microsoft's Mixed Reality Toolkit will also be used to enable the full functionality of the HoloLens 2's features.

PROGRESS AND INTERVIEWS

Our current design progress is minimal, and we are just now working on wireframes and design structure for our UI. We have secured funding for a HoloLens to begin to prototype with. We have just onboarded a software team to help with the backend development. We are also working with professionals within the disciplines and have conducted interviews with astronauts and other leading experts.

Interview Insights

Our team has conducted many interviews with authorities in the fields related to our research. We have listed the insights gleaned from a select few from these interviews.

Insights from Astronaut Steve Swanson further informed us on current and future lunar navigations. Currently, there is no GPS location on the moon, so navigation has to rely on the astronaut's memory and mission control as a guide. There is also no magnetic field, so a compass can not be used. Right now, astronauts plan to use pictures of landmarks to help get from point A to B. However, NASA hopes to put 5G on the moon and create ways to develop an astronaut's situational awareness. Regarding the EVA's telemetric streams of system state data, our interview with NASA designer Skye Ray informed us that redundancy of telemetry display on the Mission Control side is always wanted. Therefore, the display of vitals on the astronaut side should focus on unobtrusive communication, and the relay of telemetry data should remain at a minimum. Next, our interview with geologist Peter Schultz suggested that we fully replace traditional field-note taking commonly seen in terrestrial sample collection with multimedia technology embedded in the HoloLens. Proposed means of note-taking include videotaping, audio recording, and hand gesture annotating. Doing so will minimize the astronaut's unnecessary movements and facilitate data exchange with NASA mission control. We also interviewed Isabel Torren, a NASA UI designer, and Alejandro Romero, a NASA VR/AR intern, for navigation solutions insights. We learned from the interviews that setting up localization with pin tracking for the astronaut, rover, and destination navigation could be significantly improved. Lastly, after speaking with cartographer Jonathan Levy, we began playing with color grading and iconography ideas to support our topographical map display. Color grading would help distinguish landmarks and points of interest. Iconography would help draw the astronaut's eye in a quick, easy but unobtrusive way. Both of these would significantly improve the accuracy of navigation.

CONCLUSIONS

From our findings and considerations thus far, RISD Space Design will be moving forward with a HUD designed using HoloLens. The main opportunity areas that we will be exploring include an easily accessible task list, localization with pin tracking to aid navigation, geotagging for geological samples, and a clear display of vitals. Moreover, we must be mindful of the constraints the astronauts' suits pose and design in ways that necessitate only the bare minimum of hand gestures. Preliminary ideas for how this might be achieved include videotaping, audio recording, and hand-gesture recording.

Acknowledgments

RISD Space Design thanks all who participated in the initial research phases, including all interviewees and faculty advisors. We also wish to thank Naomi Tomlin from Vassar College for offering last-minute proofreads of this paper.

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