NASA S.U.I.T.S. Report

TopSUITS

Introduction

The NASA Spacesuit User Interface Technologies for Students (NASA S.U.I.T.S.) design challenge is a mission-driven project in which university student teams design and create spacesuit informatics using the augmented reality (AR) Microsoft HoloLens platform. The University of Miami, University of North Florida team was one of nine teams participating in the challenge. The University of North Florida/University of Miami named *Topsuits*, designed, tested and coded the AR interface. The challenge culminated at NASA Johnson Space Center, where they went into a third set of testing with an EVA (Extra Vehicular Activity) crew trainer and expert.

Abstract

The goal of this project was to design a user-friendly mixed reality experience that increases the efficiency while performing a set of given tasks during an EVA. In order for a Mixed Reality (MR) Heads Up Display (HUD) to be effective, the the team designed an interface with the goals that it should be simple and intuitive. To ensure safety and flexibility, the interactions are hands free with the option of using gesture controls. Voice commands show and hide elements of the UI on demand. The user retains control over the user interface (UI) with user initiated interactions that show and hide obstructing overlays. The user is prompted for interaction with the system using an intuitive interface, that incorporates guided step by step instructions and a schematics overlay. Usability testing was performed to ensure that the design implementation meets our requirements, followed by iterations of development and design updates. The third set of testing at NASA Johnson also revealed some interesting features that could be added to the interface to enhance usability. These features are voice guided instructions along with the written interface and animations, as well as audio cues for warning alerts.

Statement of the Challenge

The current EMU (Extra Mobility Unit) was designed forty years ago and has technical limitations. Astronauts are only able to view their Primary Life Support System (PMLL) status through a monitor that can display only one data point at a time. Astronauts primarily receive their suit status from mission control, which can present a challenge if astronauts have the need to work more autonomously. With NASA’s mission to travel to Mars, there will be an even longer communication delay than the one that currently exists.

Working with the spacesuits presents a challenge for the interface. The hololens primarily supports voice recognition and gesture controls. Within the constraints of spacesuits there are two types of challenges that exist. The sound of the fan from the PLSS in the suit can prevent the astronauts from hearing audible cues, so sounds that can counteract the loud noise of the suits are preferable. There is also the added challenge of finger-based gesture controls. Since astronauts primarily use their hands to perform maintenance tasks and guide themselves around the spacecraft, it would be beneficial to have less reliance on demanding hand gestures to execute functions in the interface. Solutions need to address these two issues extensively for AR to become a viable solution for deeper space travel.

These new challenges will force us to adapt to new limitations. That is at the heart of what NASA has been doing for years; finding creative ways to solve problems we have never encountered before. Ideally, this opportunity will help uncover and explore these new challenges, creatively tackle them, and push the boundaries of what is possible for future generations.

History of the Challenge

For years astronauts conducting EVAs outside of the space station have relied on ground control to monitor not only the EMU through a telemetry data stream, but also to give step by step detailed instructions on how to fix or install mechanical components. During current operations on the International Space Station (ISS), data feeds to ground control have to toggle between suit data and voice communications. This will present a challenge when operating further away from Earth, with a longer communication delay. The essence of this NASA S.U.I.T.S design challenge, is to create an augmented reality interface that could potentially address these issues and create robust solutions that can be implemented into the new generation of spacesuits.

The designs this team implemented include detailed task instructions ingested in a step by step format, animations on actionable steps that help guide the user on how to perform the task, schematics for an overall view of the panel board, and easy to use intuitive interface. The augmented reality interface will also includes a viewable panel of telemetry data for the space suit itself, allowing astronauts to view their suit data collectively.

Sources

Astronauts are equipped with a mirror to read some of data off of the panel in the image to the left. The panel consists of a display screen and switch to allow the astronaut to scroll through the PLSS data. The team’s AR interface includes a color-coded dashboard with PLSS data that the astronaut can get an at-a-glance update of various critical components of the suit.

FIG 1. Current EMU data display.

The figure to the right is the cuff checklist that are used to help perform EVAs. However, Mission Control typically reads each task to the astronauts. With the AR interface the team has developed, the astronauts will have at a glance step by step instructions.

FIG 2. Cuff Checklist

Methods

Interface Design:

The team implemented the User-Centered Design (UCD) process to ideate, create, and iterate throughout the project. The design process began with background research about EVA missions, tasks, and equipment in order to inform design ideation sessions. The team met for a brainstorming session that inspired the initial designs. Each week, the group met to discuss the progress of the design and provide feedback. Throughout the project, there were four main iterations of the design. The team used Sketch, Adobe Illustrator, and Adobe XD to create prototypes and final assets.

Software Testing:

To test the functionality of the user interface acceptance testing was performed. This type of testing is done by the customer to ensure the application meets their requirements. Since the developers were creating the interface to meet the requirements given by the designers they acted as the customers. Once a new version of the interface was developed the designers tested the interface and gave the developers feedback.

Usability Testing:

Prior to test week, inspection methodology and comprehensive user testing were completed to identify usability problems and provide design recommendations for improvement. The UX research team conducted 1) an expert heuristic evaluation of the interface design, as well as two different usability tests: 2) testing of telemetry panel design and 3) comparative study of task completion using the EVA task board with the HoloLens application versus paper instructions.

The heuristic review was completed using Nielsen and Molich's Ten Usability Heuristics to evaluate the usability of the system's interface design (Nielsen & Molich, 1990). Issues were identified, assigned a severity score, and provided a recommendation for improvement.

The usability study that focused on telemetry panel design and information saliency was conducted with six participants recruited at the eMERGE AMERICAS Conference on Miami Beach, Florida. The test moderator recruited participants who were interested in the project and had time to complete the test. Each individual session lasted approximately twenty-five minutes. During the session, the moderator explained the test session and asked each participant to complete a short demographic questionnaire. Participants completed a Microsoft HoloLens tutorial before interacting with the EVA application. Once in the application, the task scenarios were read and participants were prompted to locate the requested information. The information was displayed on a static telemetry panel and participants were asked to locate the following values:

- Pressure reading for oxygen
- Remaining battery life
- Outside temperature
- Pressure in your spacesuit

At the completion of the task, users were asked to complete a single-ease questionnaire (SEQ) to assess the participant's perceived difficulty of completing the task. Additionally, participants were encouraged to provide feedback about their experience with the interface.

The final usability study was conducted to identify usability problems while also comparing values of efficiency, effectiveness, satisfaction, and perceived workload around completing tasks using paper instructions and instructions provided using the augmented reality application. Six participants completed the usability test with each individual session lasting approximately one hour to one hour and fifteen minutes. During the session, the moderator explained the test session and asked each participant to complete a short demographic questionnaire and an informed consent. The participant then completed the Microsoft HoloLens demo and the moderator gave a short introduction to the EVA task board in order to familiarize the participant with its layout and capabilities. The participant then completed tasks using paper instructions and instructions in the mixed reality application. After each task, the participant completed a SEQ and NASA-TLX, and provided qualitative feedback. Additionally, the moderator collected data around time on task, number of assists, and task completion pass/failure metrics. After completing tasks with each platform, the participant completed the system usability scale (SUS). At the conclusion of the usability test, the participant completed a post-study interview with the moderator. Each session was screen captured with the consent of participants.

Results

Usability Testing

The results from the heuristic evaluation revealed the importance of creating an interface that displayed vital information intuitively and minimally. A second iteration of the interface was created using the feedback from the evaluation, which was then tested informally with attendees at the eMERGE AMERICAS conference. The findings were used by the team to create a third iteration of the interface, the version that underwent the most rigorous usability testing before test week.

The results of the comparative paper versus AR usability study show that participants using the AR method when completing the disabling alarm procedure experienced a lower success rate than when using the paper method. When completing the rerouting power task, participants experienced seemingly equivalent success when using paper or AR. As for time on task, more time was spent on completing tasks using AR versus using paper. SEQ mean data suggests that participants found completion of the disabling alarm task more difficult using AR, while completing the rerouting power task was found easier using AR. A table of the results are shown below. Given the small sample size across the usability, we did not conduct statistical analysis of the results. Table 1 provides descriptive statistics of the task based metrics.

Table 1: Results for success rate, time on task and SEQ

		Success Rate (%)		**Time on Task (sec)**		**SEQ**	
Task	*N*	*Rate*	*95% CI (Adj Wald)*	*Geometric Mean*	*95% CI*	*Mean*	*95% CI*
AR-Disable Power	6	0.50	0.1876- 0.8124	363.26	187.5- 703.9	4.83	3.66- 6.01
AR-Reroute Power	6	0.38	0.0925- 0.7043	510.64	387- 673.8	6	5.59- 6.41
Paper-Disable Power	6	0.63	0.2957-0.9075	226.58	146.9- 349.6	5.5	4.29- 6.71

Paper-Reroute Power	6	0.38	0.0925- 0.7043	387.33	218.1- 687.9	5.17	4.75- 5.58

The System Usability Scale (SUS) SUS ratings collected from the usability tests were converted to obtain the usability score for the AR method and the paper method (see Table 2). The AR method received a SUS score of 81, above the industry standard average (68) and in the direction of favorable perceived usability. Conversely, the paper method received a score of 60, revealing unfavorable perceived usability. NASA-TLX evaluations were also collected to evaluate participants perceived workload. Final NASA-TLX scores were not calculated as we did not collect category weight data from the participants.

Table 2: SUS scores

SUS Scores	
AR	81
Paper	60

Interface Design

The final designs were created based on the system requirements and results of the usability evaluations. The interface consists of two main panels with EVA time as fixed object, available across panels. The EVA time is presented at the top right of the user's point of view providing how long a user has been conducting the EVA.

The two main panels are visible when a user first opens the interface, Telemetry Panel and Task Selection Panel. On the Telemetry Data Panel are data sets grouped into 5 categories Battery, Oxygen, Water, Suit, and Environment. Data sets are considered optimal when that are colored in blue. When data set is not in an optimal state, it is highlighted and turned red. A fixed waring panel appears under the EVA time indicating which data set is not in an optimal state. Switches are grayed out when off and red when on, similar to warnings on car dashboards.

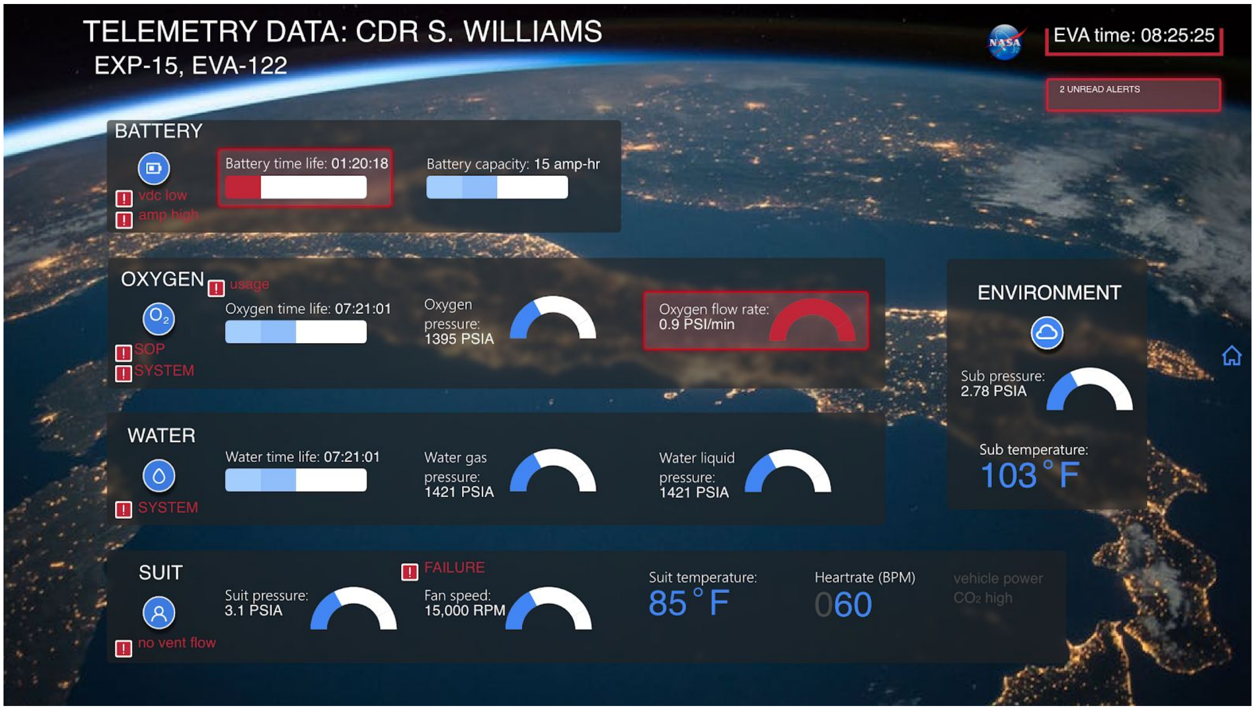

Figure 3. Telemetry Data Panel

On the Task Selection Panel are tabs indicating what tasks are available for the user to complete. Once the user selects desired tabe using a one figure click gesture or says "Start [Name of Procedure] the Instruction Panel will appear.

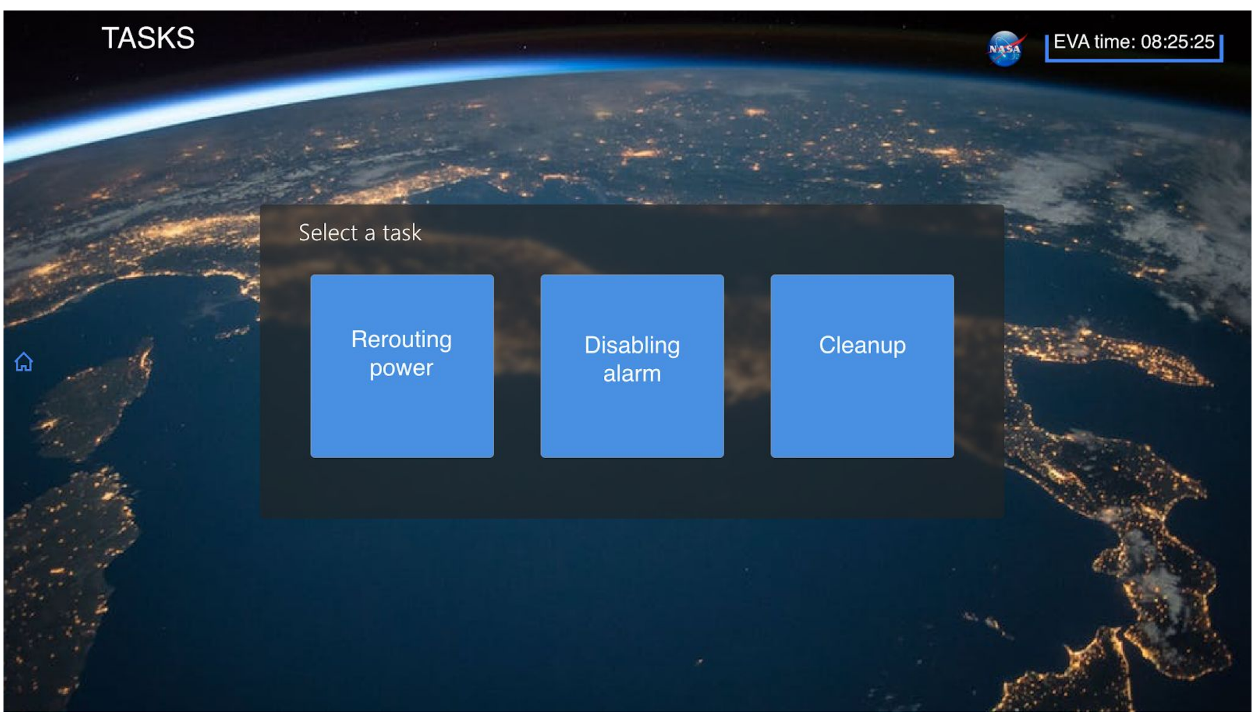

Figure 4. Task Selection Panel

On the Instruction Panel the title of the panel includes the name procedure and pagination. The content of the panel includes the step number, instructions, animation on how to complete the step, directional button, and schematic button. Users can use voice commands such as “Next” “Previous” and “Open/Hide Schematic” to select designated buttons.

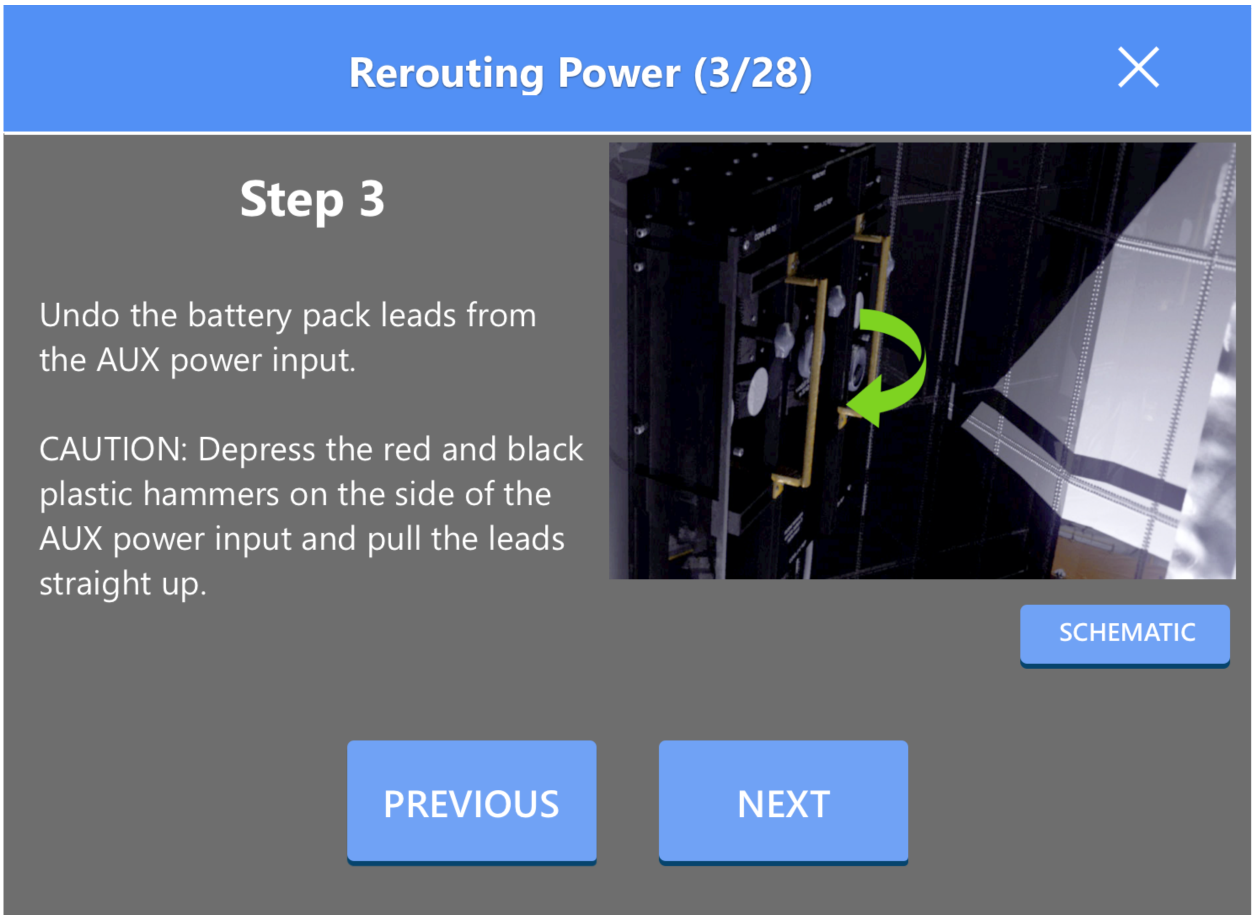

Figure 5. Task Instruction Panel

Discussion

Challenges we faced when designing this user interface included limited information about the EMU and the astronaut’s conditions when performing EVAs. Similarly, lack of design standards for augmented reality, limited Hololens functionality, and steep learning curve for operating the Hololens for test participants also contributed to the challenges experienced in completing the project.

When using a User Centered Design approach to development a product the first step is to identify the people who will use the product, what they will use it for, and under what conditions they will use it. This allows for the creation of a user profile that leads to specifying requirements for the product. But this information was hard to come by which forced us to make a lot of assumptions about an astronaut's conditions when completing EVAs. These assumptions caused our user profile to be slightly off base and important conditions were not taken into consideration. For example, we did not consider that astronauts are always speaking with mission control or their partner when conducting EVAs. If the user were to say a built in voice command while conversing with either the system would hear said command and then proceed to implement it.

Augmented Reality technology is relatively new. With all new technological advances there has not been any tried and tested design rules, which made creating design for such an environment difficult because a number of assets would be created, implemented then discarded because of visibility issues or a different number of things. This extended the design timeline and left little time for development.

The Hololens is prototype in and of itself so there were some limitations on what could be accomplished with the device. Hololens only has three recognizable gestures built into the unit with no way to integrate new ones. This was a curse and a blessing in disguise, because we found that astronauts have limited mobility and are continuously using their hands to complete physical tasks when conducting EVAs a gesture free environment is more idyllic. Another challenge we face when using the Hololens is that fixed object in the user's point of view disappear when recording sessions. After doing some research we found that this happens because the field of view becomes large in recording, which places the fixed object outside the view of the user.

Conclusion

Future implementations should include a warning sound to indicate that an anomaly has occurred with the telemetry data, clear distinction that said anomaly has been cleared, and branding element similar to Siri that would allow for more usability.

In the end we created a product that exceeds the requirements for the challenge. Our uniform design is a gesture free environment that is conducive to gesture free interface that achieves a low mental workload for the user.

Peer Review

Test week provided teams the opportunity to view and test other designs, encouraging innovative collaboration and ideation. We identified a few noteworthy features from the other teams that would assist in creating a better version of the AR system.

1) CSU Boulder's interface received positive reception from NASA employees as their design mimicked an interface familiar to pilots and astronauts. Their design considered the typical user which was reflected in their design. It aligned with users' mental models, making learning of the system easier for the user.
2) MIT implemented "chirp" noises as audible feedback from the system as well as the option to have the system read the task instructions aloud to the user. This function

afforded the user more options for completing a task as well as providing real-time feedback.

Works Consulted

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