Owl SUITS

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1 Technical Section

1.1 Abstract

Our team proposes an augmented reality (AR) system integrated with the HoloLens2, designed to enhance astronaut performance during extravehicular activities (EVAs). Utilizing human factors and user-centered design principles, our system focuses on streamlining routine EVA tasks, providing just-in-time (JIT) instructions to minimize cognitive load, and reducing potential errors. By leveraging the AR capabilities of the HoloLens2, we aim to improve the visibility of critical data, enable efficient navigation, and support mission success.

The system is tailored to meet the unique challenges of the EVA scenario, including managing suit telemetry, guiding astronauts through navigation and sampling tasks, and ensuring safety with integrated caution and warning systems. The user interface (UI) provides real-time telemetry updates, offering clear visibility of critical vitals, such as oxygen levels and heart rate, while also delivering intuitive navigation tools through an integrated map system. The map supports real-time tracking of both astronauts and assets, enhancing situational awareness.

Our prototype will undergo human-in-the-loop (HITL) testing to ensure its usability and effectiveness in a mission setting. The testing will include task analysis, cognitive walkthroughs, and user failure modes and effects analysis (uFMEA), followed by high-fidelity prototype testing. We will utilize 60 participants in iterative usability evaluations, ensuring feedback informs system improvements. The HoloLens2 loan program will provide the primary hardware for testing, with no additional peripheral devices planned. Through iterative development and testing, this AR system aims to enhance astronaut performance, reducing workload and enabling efficient mission execution.

1.2 Software and Hardware Design Description

1.2.1 Pressurized Rover

The pressurized rover (PR) interface (Fig R.1) is designed to provide comprehensive control and monitoring capabilities while maintaining operational simplicity. The interface is divided into four main quadrants, each serving specific functions essential for mission success.

Primary Display Layout

The **primary monitoring center (upper left)** for all telemetry and visual data. A configurable display shows real-time telemetry streams from both the rover and EVA systems. The interface allows operators to monitor multiple camera feeds simultaneously, including views from both EV crew members and the Lunar Terrain Vehicle (LTV), with the ability to switch between feeds as needed. Critical biomedical data for both EV1 and EV2 is prominently displayed, including heart rate, oxygen levels, suit pressure, and battery status. These vital signs are presented with clear visual indicators that make it easy to identify any concerning trends or values that approach critical thresholds. The **mission's command center (upper right)**, providing immediate access to current task procedures and requirements. A prominent mission elapsed time display keeps track of overall mission duration, while individual station elapsed time counters monitor specific task durations. This quadrant also houses the primary caution and warning notification system, which displays clear, color-coded alerts for any biomedical or resource-related concerns. The notification system uses a hierarchical structure to ensure the most critical alerts receive immediate attention while maintaining awareness of lower-priority issues.

The **vehicle control interface (lower left)** combines manual and autonomous operation capabilities in an intuitive layout. A virtual joystick provides precise manual control when needed, while dedicated controls allow seamless engagement of autonomous navigation features. The interface displays real-time feedback on vehicle speed, heading, and power consumption, enabling operators to make informed decisions about vehicle operation. The **mapping and navigation quadrant (lower middle)** features a sophisticated 2D map display that serves as the mission's situational awareness hub. The map dynamically tracks the positions of all assets - the pressurized rover, both EV crew members, and the LTV - in real-time. It visualizes planned and actual traverse paths, marks geological sampling locations, and displays user-placed pins that can be customized to indicate various points of interest or hazards. The system includes a terrain analysis overlay that helps identify potential obstacles or areas of interest, and an integrated path planning interface that supports both manual and autonomous navigation decisions. The **XRF data management interface (lower right)** provides real-time visualization of geological samples collected by EV crew members. When samples are scanned, the interface immediately displays spectroscopy results through both numerical data and an intuitive color-coded mineral composition visualization. Each sample is automatically tagged with metadata including timestamp and GPS coordinates, while the interface maintains a scrollable history of collected samples for quick comparison. Operators can add notes to sample records and filter the data by various parameters, supporting efficient geological survey documentation and mission planning.

Key Operational Features

Autonomous Systems

The autonomous navigation system integrates advanced pathfinding algorithms that consider multiple factors simultaneously. The system continuously analyzes terrain data, identifies potential obstacles, and optimizes routes based on resource consumption. Real-time route adjustments are made automatically when new obstacles or better paths are identified. A sophisticated resource management system provides predictive analytics on power consumption and life support systems, calculating optimal turn-around points based on current usage rates and remaining resources. This system helps ensure mission safety by maintaining adequate margins for return journeys.

Interoperability

Our interface implements comprehensive data sharing capabilities with EV systems, ensuring all mission assets maintain synchronized awareness. Pin placements, position tracking, and telemetry data are shared in real-time across all platforms. XRF data collected by EV crew members is immediately displayed and stored in the rover's system. The integrated communication system ensures clear data flow between all mission elements, while the shared caution and warning system guarantees that critical alerts are recognized across all platforms simultaneously.

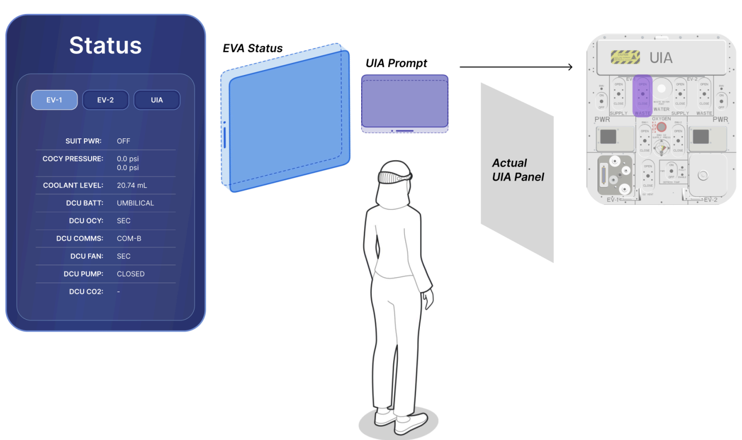
Scientific Data Management

The scientific data management system provides robust capabilities for collecting, storing, and analyzing geological data. XRF data collected during EVA operations is automatically stored and organized, with immediate access available through an intuitive interface. The system maintains detailed records of sample locations and analysis results, allowing for easy review and comparison of collected data. This information is seamlessly shared between EV and rover systems, ensuring all team members have access to the latest scientific findings throughout the mission.

1.2.2 Space Suit

<u>Egress</u>

The Egress UI will effectively facilitate completion of egress procedures, enabling crewmembers to safely exit the airlock to begin the EVA. It will provide clear communication and feedback while minimizing workload.



This design minimizes cognitive workload by emphasizing "information in the world" rather than relying on "information in the head." It provides just-in-time instructions, with the current step and specific subtask (e.g., the immediate instruction) always displayed on the screen at the top of the display. The progress bar for the immediate task with key task-relevant metrics (ex. oxygen and battery levels) will always be in view in the top right corner. A "Device/Interface" indicator will always be visible, clarifying whether the current task requires using the UIA, DMU, or both. Additionally, the interface will include a progress map of the entire egress procedure that will always be in view, ensuring clear visibility of system status.

The HMD interface will also feature a visual replica of the UIA that highlights the specific switch or component the crewmember needs to focus on to complete the current task. This diagram will be visible upon turning slightly to the left or side-by-side to the UIA in the physical environment, requiring minimal head movement and ensuring it does not obstruct the crewmembers' view of the actual UIA.

The overall status of both crewmembers (EV1 and EV2), including oxygen levels, carbon dioxide levels, suit pressure, and more, will be shown on a panel that becomes visible when a crewmember turns slightly to the left of the actual UIA (in close proximity to the visual replica), facilitating effective safety monitoring. Placing both the status panel and UIA replica on the same side of the actual UIA allows for quick, intuitive access to information while minimizing head motion, reducing potential confusion about where to look and lowering cognitive workload. As illustrated in Figure 1, the status window and UIA image will appear to the left side of the user. Figure 2 shows the enlarged image of the status window.

Navigation

The navigation system is essential in ensuring crewmembers can safely and efficiently traverse the lunar surface during their EVA. Given the challenging low-light conditions expected at the lunar south pole, the design emphasizes the use of bright green and yellow in the interface to maintain high visibility against the dark environment. This color scheme ensures that critical information from the UI stands out clearly while blending seamlessly into the physical surroundings. Additionally, the system leverages the DCU's built-in GPS, which feeds real-time location data to the TSS, allowing for accurate tracking and synchronization of all assets during the mission.

Map

The map system consists of the minimap and the floating map, both critical for EV1's navigation. The minimap (Figure N.1) appears when EV1 gazes at the back of their left hand and provides a condensed, real-time view of nearby spatial information for EV1, EV2, and the rover. It dynamically adjusts based on EV1's orientation, ensuring the map always aligns with EV1's direction. The minimap is designed to avoid clutter, showing only relevant pins and markers within close proximity, such as nearby waypoints or hazards. Its location and conciseness ensures quick access to essential data while maintaining a clear, unobstructed view of the environment.

The floating map (Figure N.0) offers a larger, more detailed overview of the entire terrain, accessible through voice commands or the handheld menu. It displays routes, pins, breadcrumbs, and the rover's projected path, based on real-time communication with the rover team. The floating map uses grid lines for easy navigation and keeps all assets in sync, ensuring that EV1, EV2, and the rover are accurately represented.

Together, the minimap and floating map provide both quick-reference navigation and comprehensive terrain overviews, ensuring efficient and informed navigation during the EVA.

The map uses a range of **icons** to represent key mission elements. EV1's current position is shown with an arrow indicating their direction, while EV2's location is marked without an arrow to indicate its static nature. The rover is represented by an icon that includes both its position and its projected path, determined in coordination with the rover team. Specimen locations are marked, showing both previously collected samples and those awaiting collection. Breadcrumbs and waypoints are visible as dashed lines, with each distinguished by a different color to ensure clarity during navigation. Other pins, such as hazard or general pins, are also displayed on the map.

HUD

The heads-up display (Figure N.2) provides EV1 with critical information necessary for navigation and monitoring suit status. It ensures that essential data is always accessible while minimizing cognitive load and maintaining the crewmember's focus on the EVA.

The **compass** is an integral part of the HUD (Figure N.2), providing directional awareness for EV1 throughout the mission. It displays the locations of EV2 and the rover, ensuring that EV1 can easily orient themselves in relation to other assets. The airlock is always visible on the compass, offering a constant reference point for safe return. The direction of the currently targeted pin is also displayed, with icons shifting to the left or right if EV1 is not facing the correct direction, helping them reorient. A small distance indicator next to each icon shows the proximity to the target. Home and target locations are represented as distinct logos on the compass, keeping critical objectives within view.

The HUD (Figure N.2) continuously displays real-time biomedical **telemetry** for both EV1 and EV2, covering key metrics such as battery life, oxygen levels, and heart rate. The telemetry system also calculates the amount of time remaining based on current battery consumption, providing EV1 with an accurate estimate of how long they can continue operating. This range estimation ensures that the crewmembers can plan their tasks effectively, avoiding any risk of exceeding their suits' power limits. The **routing** system (Figure N.0) provides EV1 with optimal paths, using breadcrumbs and waypoints to guide navigation. These floating objects are visually distinct, with breadcrumbs and waypoints represented by different colors to differentiate them. Breadcrumbs mark the path EV1 has already traveled, while waypoints highlight the intended route forward. Routes are continuously updated in real-time, adjusting for newly detected hazards or changes in terrain. Waypoints are placed at fixed intervals along the path and dynamically adjust if EV1 strays from the route, ensuring the most efficient and safe navigation throughout the EVA.

The **pin** system is a crucial part of the navigation interface, allowing EV1 to mark and interact with important locations throughout the EVA. Pins can be placed manually or automatically, depending on their type, and once placed, they are synced across EV1, EV2, and the rover. This ensures all team members and equipment have access to the same spatial information. Pins can be viewed either on the map or as fixed objects within the physical environment, providing real-time, consistent navigation and location tracking throughout the mission. The **handheld menu** (Figure N.3) appears when EV1 gazes at their right hand and provides access to the pin selection options. From the menu, EV1 can choose the appropriate pin type for marking locations or hazards. After selection, the pins are placed in the environment or on the map based on the crew member's actions.

<table>
<tr><th>Pin Type</th><th>Description</th><th>Placement Method</th></tr>
<tr><td>Hazard Pins</td><td>Red triangles used to mark dangers, such as craters or hazardous areas.</td><td rowspan="3">Manually placed by EV</td></tr>
<tr><td>General Pins</td><td>Used to mark points of interest for navigation or mission objectives.</td></tr>
<tr><td>Specimen Pins</td><td>Marks locations of samples. Two subtypes: already collected or to be inspected.</td></tr>
<tr><td>Breadcrumbs</td><td>Marks the path EV1 has traveled for backtracking purposes.</td><td>Automatically dropped by the system at regular intervals as EV1 moves, without manual input.</td></tr>
<tr><td>Waypoint Pins</td><td>Guides EV1 along the intended route, automatically adjusting if EV1 goes off course.</td><td>Automatically placed by the system along the route, updating dynamically as EV1 navigates.</td></tr>
</table>

The process of **placing pins** is intuitive and relies heavily on finger tracking and gaze-based interactions. EV1 selects the type of pin to place through the hand menu (Figure N.3), which is activated by gazing at the right hand. Once the pin type is chosen, EV1 can place pins directly in the physical environment by pointing to the desired location, with finger tracking guiding the placement. The pin is confirmed either by using a voice command or a pinching gesture with the left hand. This system allows for quick and efficient pin placement during exploration. Pins can also be **placed on the map** by pointing to a specific location and confirming in a similar manner.

For more precise placement, coordinates can be manually input through the hand menu. Additionally, labels can be attached to pins using voice commands or the keyboard, providing further context or notes about the marked location. This flexible system ensures that EV1 can easily interact with the environment and keep track of important mission elements.

Geological Sampling

Scanning (Figure G.A)

To initiate the scan, the "Start Scan" button on the floating pop-up menu (Figure G.0) will be selected and the "Stop Scan" button will terminate the scan process. Once the scan is completed, two options, "Rock" or "Regolith," will be available for selection via a toggle, allowing the documentation process to proceed based on the chosen type. Once selected, the floating status tracker (Figure G.2) will be activated and updated dynamically throughout the scan.

In order to document the characteristics of the rock scanned, the **field notes** feature will be a floating window (Figure G.1) accessible to the astronaut after the scanning procedure is completed. To facilitate effective documentation procedure, the interface will utilize **toggles and sliders** as they are highly accessible and low error prone controls to document the geological samples scanned. Additionally, the **voice feature** also allows the astronaut to easily toggle characteristics on the field note without physically interacting with the interface. **Photographs** of geological samples will be taken and stored to the Material Library as a part of the geological collection procedure. To take a photo, a *voice command* will be used to capture the image. For each recording taken, photographs will be saved with its respective field notes. Photographs will be used for further analysis, examination, and validation of observations in the future. **Voice notes** provide astronauts with a flexible solution for recording initial observations and further comments on a geological sample that go beyond the standardized survey in the floating field notes window. Utilizing voice allows for the astronaut to record observations while actively interacting with the geological sample.

To facilitate accurate documentation, astronauts are also able to toggle a **reference sheet** window which allows cross referencing between the collected sample and characteristic descriptions. This reduces errors and standardizes the descriptions across all collected samples.

Material Library (Figure G.B)

The material library (Figure G.3) stores all recorded materials, allowing astronauts to review previous collections. It becomes accessible when entering geological sample mode, where the recorded materials are displayed as a list of images, each accompanied by essential information such as the logged time, date, location, and material properties. Astronauts can easily access detailed information by clicking on a sample in the list, which opens additional details in a pop-up window (Figure G.4), similar to a webpage. This setup enables multiple recorded materials to be viewed side by side and closed when no longer needed. To return to the geological sampling mode homepage, astronauts can click the exit library button located in the top right corner of the interface. Overall, the library functions similarly to a computer file system for managing and reviewing geological data.

Ingress

To ensure a safe and efficient return to the airlock after completing the EVA, the Follow-Path Mode feature of breadcrumbs will be used. When the crewmember activates Follow-Path Mode through the HMD's hand menu, the navigation system initiates, providing vital guidance for the journey back to the airlock. As the crewmember progresses along the designated path, sequentially numbered breadcrumbs will be displayed within their field of view, clearly indicating the route leading back to the airlock. Upon reaching the airlock, the crewmember will perform a procedure similar to what is outlined in the egress section.

Caution and Warning system

The caution and warning system is integrated into the user interface to continuously monitor spacesuit and biometric telemetry. It provides real-time alerts when any parameter enters off-nominal ranges, such as oxygen levels, heart rate, or suit pressure. These alerts will be displayed regardless of the current mode the crewmember is in, ensuring that warnings are always visible whether the user is navigating, sampling, or performing other EVA tasks.

The system generates both visual and audio alerts to ensure immediate attention to critical conditions. Visual alerts will appear in a consistent location on the HMD, while audio alerts will be triggered to emphasize high-priority warnings. This dual-modality ensures that critical telemetry data, such as suit pressure or heart rate anomalies, are promptly addressed.

In addition to monitoring EV1's status, the system also tracks the telemetry of EV2. If either crewmember's suit or biometric data enters off-nominal ranges, the system will trigger warnings across both HMDs. This synchronized alert system ensures that both EV1 and EV2 are aware of potential issues, allowing for immediate response to hazardous conditions. Caution warnings are consistently provided across both assets to maintain situational awareness and ensure mission safety.

1.2.3 Interoperability

The system ensures full interoperability between EV1, EV2, and the rover, supporting seamless communication and data sharing throughout the EVA. **Telemetry data** from both spacesuits and the rover is continuously shared between all assets. This includes real-time biometric telemetry, such as oxygen levels, heart rate, and suit pressure, as well as the rover's system status. This shared telemetry provides synchronized data across all interfaces, ensuring that any issues detected are known to both crewmembers and rover operators. The **caution and warning system** is designed to provide alerts across both EV1, EV2, and the rover. If either spacesuit or rover telemetry enters off-nominal ranges, the system triggers synchronized alerts across all assets. This ensures that any hazardous condition detected in one system is immediately communicated to all team members.

Waypoints, asset locations, and points of interest (POIs) are shared between EV1, EV2, and the rover, ensuring that all team members have access to the same navigational data. Waypoints are automatically placed and updated as EV1 or EV2 progress along the route, while POIs marked by any asset are immediately visible to all. Asset location data is synchronized in real-time, allowing each team member to know the positions of all assets at any given time. **Scientific data**, such as spectroscopy results or sample scan information, is shared between both spacesuits and the rover. This enables the rover team to view and analyze the same data collected by EV1 and EV2 during geological sampling or other scientific activities, ensuring consistency and collaboration. The system supports the ability to display the **camera feed** from either EV1 or EV2 on the rover interface. This allows the rover team to view the surroundings of the crewmembers in real-time, improving situational awareness and enhancing collaborative efforts.

1.3 Concept of Operations

1.3.1 Assumptions

Our design has four main assumptions. First, the AR technology and functionality available in the HOLOLENS II will be built into the spacesuit helmet. Second, all astronauts using this UI are English speakers, as our design is optimized for individuals who are fluent in English and hold Western-based cultural, mental models of colors and symbols. Third, the AR overlay will begin once the helmet has been connected to the spacesuit's built-in power system.

1.3.2 Overview of the Envisioned System and Claims

Our team proposes a system design that is rooted in human factors (HF) and user-centered design (UCD) principles. We propose building an AR system with the primary goal of being a tool to aid the crew in the execution of their mission while undergoing an EVA. The crew has complicated jobs that could be streamlined through the use of AR. Our design aims to function as a tool to streamline menial routine tasks that are part of the EVA, to be a memory aid to reduce the amount of information That the astronauts must remember, and to reduce overall errors during the EVA process. This will reduce astronaut workload during EVAs and allow them to focus greater attention on other aspects of EVA tasks that require greater problem-solving or precision.

Our design prioritizes **two main features**: The first is the **usability** of the user interface (UI). The "10 Usability Heuristics for User Interface Design" (Nielsen, 2020) are broad rules of thumb that provide principles for usable designs. Our design embodies the principle of "visibility of system status" by providing information about the current state of the mission, the environment, and the spacesuit in easily accessed locations. For example, the most important suit vitals information is displayed on the top right of the astronaut's field of view. This ensures that this information is easily accessible when needed but does not clutter the astronaut's center of focus or impair their vision for current tasks. Our design uses the principle of "match between

system and real world" by using phrases and concepts that we believe will be familiar to the crew, and presents them in an easily understandable format. Our design also utilizes conventions that American astronauts will be familiar with. In accordance with the "recognition rather than recall" principle, information required to use the design will be visible and easily retrievable when needed. For instance, during egress/ingress, the "Device/Interface" indicator communicates what devices/interfaces are involved in the task at hand, and the UIA replica clearly highlights which switch/component is pertinent, eradicating the need for effortful memorization.
The second main feature our design prioritizes is **just-in-time (JIT) instructions**. Instructions for completing procedures and the next steps to be accomplished for the mission are only presented to the user as needed. This format of presenting information supports performance, particularly under time pressure constraints, by providing simple, clear instructions for each subtask at the time that subtask is being executed (Drews et al., 2007). This will reduce the cognitive load of the crew and thereby reduce the likelihood of errors. JIT instructions will also improve overall performance and increase success rates of tasks because decision points in task execution are eliminated (Drews et al., 2007).

1.3.3 Operational Description and Workflows

Workflow diagrams (workflow figures) were created to illustrate the capabilities of our design and how our design would function in each of the aspects of the EVA scenario during testing.

1.4 Human-in-the-loop testing

The objective of human-in-the-loop (HITL) testing is to enhance system usability and minimize operational risks by employing appropriate user-centered testing methods. As such, we aim to conduct testing in multiple phases (see Table 1). Before HITL testing begins, we will conduct preliminary assessments, including task analysis, cognitive walkthroughs, and use-related Failure Modes and Effects Analysis (uFMEA), to gain a comprehensive understanding of the users' tasks, expectations, and potential challenges. Based on the information gathered from the initial assessment, we will construct an interactive, high-fidelity prototype for testing on human subjects.

The HITL testing will be implemented in three phases to enhance the development of the AR HMD based on real user feedback. The human factors methods that will be employed include qualitative and quantitative evaluation techniques, such as think-aloud protocols and formal usability testing as recommended in ISO 9241-11. This multifaceted approach allows us to capture both user feedback and potential design flaws, ensuring a more robust interface and interaction experience. Our testing will focus on **evaluating the usability** of the current system design while also comparing it to designs from previous iterations. This comparative analysis will help identify areas for improvement, particularly in light of the updated mission requirements. The goal is to optimize the interface to better support operator tasks and mission success, refining functionality and user experience.

Participants will be recruited from Rice University using the SONA platform, an internal system that offers course credit for research participation. The undergraduate population at Rice University has roughly equal numbers of genders, a wide range of ethnicities, and is from all across the United States (Rice University, 2021). Approximately 60 participants will be selected, representing diverse academic backgrounds and fields of study. This diversity is crucial for increasing the external validity of our findings, ensuring that the usability improvements apply to a broader user base. All testing procedures will be approved by the Institutional Review Board (IRB). We expect this undergraduate population to have a reasonable understanding of the basic perceptual and task elements being evaluated, serving as suitable proxy users without the need for additional recruitment funding. As participants engage with the AR HMD system, general safety measures for using VR/AR headsets will be followed (Microsoft, 2022).

Table 1. HITL Testing Phases

Testing Phase	Fidelity	Sample Size (*N*)	Human Factors Methods
Phase 1: Conceptual Design	Low-Fidelity Wireframe / Whiteboard / Figma	N/A	Task Analysis, Cognitive Walkthrough, uFMEA
Phase 2: Iteration 1	High-Fidelity Prototype / Figma	20	Usability Evaluation, Think-Aloud
Phase 3: Iteration 2	High-Fidelity Prototype / Unity	20	Usability Evaluation, Think-Aloud
Phase 4: Iteration 3	High-Fidelity Prototype / Unity	20	Usability Evaluation, Think-Aloud

1.4.1 Preliminary Testing

A **task analysis** will be performed on the egress, navigation, geologic sampling, and ingress procedures to break down and understand how participants complete these tasks. The outputs of this analysis will inform the subsequent testing.

Before testing with participants, a **cognitive walkthrough** will be completed to detect potential issues users might encounter. This method allows us to identify potential usability issues in the system and understand how well the system design supports users in achieving their goals. By identifying these issues early, we can address them and minimize the likelihood of confusion or inefficiencies.

A **use-related Failure Modes and Effects Analysis** will be conducted to discover potential failures and use errors related to human action, cognition, and perception, along with their implications and possible remedies. This approach enables us to identify and prioritize failures by risk level and implement targeted mitigations to enhance the usability of our integrated systems.

1.4.2 HITL Testing

Usability Evaluation

The **usability** of the AR head-mounted display (HMD) will be measured using the metrics recommended by ISO 9241-11: effectiveness, efficiency, and satisfaction. Key effectiveness metrics include task completion rate, error rate, assistance rate, and cognitive workload assessed by the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988). Efficiency will be measured by the time taken to complete the predefined tasks and scenarios using the AR heads-up display system. Satisfaction will be measured based on participants' responses to the modified System Usability Scale (SUS) questionnaire, which captures voters' perceptions on the ease of use of the system (Bangor, Kortum & Miller, 2008; Brooke, 1996), and the added Adjective Rating Scale (ARS), which captures subjective usability based on adjective ratings to better interpret the SUS scores (Bangor, Kortum & Miller, 2009). In order to identify usability issues and refine the AR HMD, a series of **iterative usability tests** will be implemented. We will recruit 20 participants for each iteration, aiming for a total of 60 participants over three iterations. Participants will be immersed in a simulated EVA and asked to follow the instructions on the HMD to complete specific tasks. Data will be collected through direct observation methods, post-test questionnaires, and think-aloud protocols.

Think-Aloud

Participants will verbalize their thought processes as they interact with the system using the think-aloud protocol. This method allows us to gather real-time insights into how users perceive and engage with various design elements, highlighting areas where users may encounter difficulties or confusion. Additionally, it enables us to observe how design changes from previous iterations affect user performance, perceived workload, and satisfaction.

1.5 Project Management

Our project management approach follows a structured timeline spanning from December 2024 to May 2025 (also see: Gantt Chart + Timetables), with development tracks for both the spacesuit HMD and pressurized rover interfaces running in parallel. The development process is divided into four main phases: Setup & Design (December-January), Core Development (January-March), Testing & Integration (March-April), and Final Optimization (April-May).

Key integration points between the two systems are scheduled throughout the development cycle to ensure seamless interoperability. We've allocated specific time for human-in-the-loop testing and low-light condition testing to validate our design assumptions. The schedule includes buffer periods for addressing unexpected challenges and incorporating user feedback. Regular checkpoints with both development teams will help maintain synchronization between the spacesuit and rover systems.

1.6 Technical References

Bangor, A., Kortum, P., & Miller, J.A. (2008) The System Usability Scale (SUS): An Empirical Evaluation. International Journal of Human-Computer Interaction, 24, 574-594. https://doi.org/10.1080/10447310802205776

Bangor, A., Kortum, P., & Miller, J.A. (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. Journal of Usability Studies, 4(3), 114–123.

Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability Evaluation in Industry*, *189*(194), 4-7.

Charters, E. (2003). The use of think-aloud methods in qualitative research an introduction to think-aloud methods. *Brock Education Journal*, *12*(2).

Drews, F. A., Picciano, P., Agutter, J., Syroid, N., Westenskow, D.R., & Strayer, D.L. (2007). Development and evaluation of a just-in-time support system. *Human Factors, 49*(3), 543-551.

Federal Aviation Administration. (2010). *Advisory circular: Flight crew alerting*. Retrieved from: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_25.1322-1.pdf

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in Psychology* (Vol. 52, pp. 139-183). North-Holland.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, *3*(3), 203-220.

Lee, J. D., Wickens, C. D., Liu, Y., & Boyle, L. .N. (2017). *Designing for people: An introduction to human factors engineering*. Charleston, S. C.: CreateSpace.

Microsoft. (2022). *Product safety warnings and instructions*. Microsoft Support. Retrieved October, 2022, from https://support.microsoft.com/en-us/topic/product-safety-warnings-and-instructions-726eab87-f471-4ad8-48e5-9c25f68927ba

Microsoft. (2022). *Hand menu.* Microsoft Mixed Reality. Retrieved October, 2022, from https://learn.microsoft.com/en-us/windows/mixed-reality/design/hand-menu

Nielsen, J. (2020). *10 usability heuristics for user interface design.* Nielsen Norman Group. Retrieved October, 2022, from https://www.nngroup.com/articles/ten-usability-heuristics/

2 Outreach Section

2.1 Poster at HFES

A poster outlining our design and development process will be created and displayed at the HFES Houston conference in Spring 2025. It will cover the implementation of Human-in-the-Loop (HITL) testing, key UI considerations, and how the system is designed to alleviate astronauts' workload. This poster will provide an opportunity for feedback from industry experts and fellow students, helping to further refine our design. It will also facilitate productive discussions, encourage creative thinking about research, and inform others in our field about a dynamic research area of interest to NASA.

2.2 Publication of Technical Paper

The goal of this outreach activity is to publish a technical paper summarizing the development and testing of our interface. We plan to submit this paper by June 15th, 2025. By submitting this to a technical journal, we hope to inform other researchers and developers about the capabilities of our design so that they may take inspiration for their own prototypes. Innovation occurs with the sharing of scientific findings. It is therefore important for us to partake in the scientific discourse. Potential journals of interest include the Journal of the Association of Computing Machinery and the Journal of User Experience.

2.3 Club Event Through Rice University

The goal of this public club event is to showcase AR/VR technologies and the widespread application of these systems. We will demonstrate 4 different AR/VR scenes within these devices—a multimodal traffic environment, a realistic sun glare scene, a central vision loss simulation that is based on the user's eye movements, and our NASA SUITS design. We hope to educate the undergraduate population as to the power of AR/VR technologies, the elements that power these devices, such as coding and graphic interfaces, as well as the applicability of these devices in different environments, such as Mars and the lunar surface. This event will be hosted during the second week of April 2025 and advertised through Rice's Human Factors Student Chapter mailing list and website, Rice University's student engagement platform (OwlNest), and various Rice University mailing lists.

2.4 K-12 Student Outreach Event

Our team aims to inspire and educate K-12 students about the role of AR in space exploration through engaging classroom lessons. Our primary objective is to introduce students to AR technology and its application in real-world space missions, with a particular focus on NASA's development of AR systems for astronauts. We plan to conduct outreach activities in local

elementary, middle, and high schools throughout the upcoming school year, scheduling visits in collaboration with interested teachers.
During each visit, the team will lead a hands-on lesson that introduces AR concepts using age-appropriate materials, including interactive demonstrations and simple coding exercises related to NASA's SUITS Challenge. The activities will include an "Hour of Code" where students can create basic AR interfaces, aligned with state STEM standards to ensure educational value. The lesson will highlight how astronauts use AR to perform tasks during extravehicular activities (EVAs) and explore the connections between AR technology and NASA's ongoing space missions.

We will seek letters of agreement from participating schools, implement a social media campaign to share our outreach efforts, and link the lessons to the curriculum standards for STEM education. This plan aims to spark interest in space exploration and technology careers among young students, while providing teachers with resources to further integrate space science into their classrooms.

3 Administrative Section

3.1 Institutional Letter of Endorsement

RICE UNIVERSITY

Marcia K. O'Malley
Thomas Michael Panos Family Professor and
Chair, Department of Mechanical Engineering

October 28, 2024

As the department chair of the Mechanical Engineering department at Rice University, I am aware of Rice University students' participation in the NASA SUITS 2024 Challenge and endorse their involvement.

Sincerely,

Marcia K. O'Malley

Marcia O'Malley, PhD
Professor of Mechanical Engineering
Chair, Department of Mechanical Engineering
Rice University

Email omalleym@rice.edu • Office 713-348-3545 • Fax 713-348-5423
Rice University Department of Mechanical Engineering-MS 321 • P.O. Box 1892 • Houston, TX 77251-1892 • mech.rice.edu/users/omalleym

3.2 Statement of Supervising Faculty

RICE

Raudel Avila, Ph.D.
Assistant Professor of Mechanical Engineering
George R. Brown School of Engineering
Department of Mechanical Engineering
PI: Computational Mechanics and Bioelectromagnetic Lab
Applied Physics Program

Mechanical Engineering Building, 224
6100 Main St
Houston, TX 77005-1827
(713) 348-2427
roavila@rice.edu
avila.rice.edu

Oct 24th, 2024

Dear NASA,

I am pleased to support Benjamin Rubin, Yining Zhang, Mert Culcu, Titan Chen, Yining (Elena) Zhang, Cameron Huang, Israel Cantu, Annlyle J. Diokno, Xiaoxuan “Alicia” Cheng, Alexandra Hu and Sahitha Vuddagiri in their NASA SUITS 2024-2025 Challenge.

As requested in the proposal guidelines, I certify that as the faculty advisor for an experiment entitled "Owl Suits" proposed by a team of higher education students from Rice University, I concur with the concepts and methods by which the students plan to conduct this project. I will ensure the student team members complete all project requirements and meet deadlines in a timely manner. I understand any default by this team concerning any project requirements (including submission of final report materials) could adversely affect selection opportunities of future teams from their institution.

Please let me know if you require any additional information.

Sincerely,

Raudel Avila, Ph.D.,
Assistant Professor of Mechanical Engineering | Rice University

3.3 Statement of Rights of Use

As a team member for a proposal entitled “Owl SUITS Proposal” proposed by a team of higher education students from Rice University, I will and hereby do grant the U.S. Government a royalty-free, nonexclusive and irrevocable license to use, reproduce, distribute (including distribution by transmission) to the public, perform publicly, prepare derivative works, and display publicly, any technical data contained in this proposal in whole or in part and in any manner for federal purposes and to have or permit others to do so for federal purposes only. Further, with respect to all computer software designated by NASA to be released as open source which is first produced or delivered under this proposal and subsequent collaboration, if selected, shall be delivered with unlimited and unrestricted rights so as to permit further distribution as open source. For purposes of defining the rights in such computer software, “computer software” shall include source codes, object codes, executables, ancillary files, and any and all documentation related to any computer program or similar set of instructions delivered in association with this collaboration. As a team member for a proposal entitled "Owl SUITS Proposal" proposed by a team of higher education students from Rice University, I will and hereby do grant the U.S. Government a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States Government any invention described or made part of this proposal throughout the world.

Yining Zhang

Yining Zhang

Annlyle J. Diokno

Mert Culcu

Israel Cantu

Cameron Huang

Sahitha Vuddagiri

Titan Chen

Alexandra Xu

Alicia Cheng

Benjamin Rubin

3.4 Funding and Budget Statement

The table below shows a summary of our estimated funding needs. We anticipate receiving funding from the following sources: Rice University's Student Chapter for the Human Factors and Ergonomics Society, the Rice University Psychological Sciences Department, and the Texas Space Grant Consortium. We are located in Houston and have found housing options that are alternative to hotels.

Items	**Costs**
Transportation	$50
Outreach Events	$100
Hololens2 purchase (in the event that loan is not granted)	$4000
Total:	$4150

3.5 Hololens2 Loan Program

We need a loaned device from NASA SUITS to participate.

4 Appendix

4.1 Figures

4.1.1 Pressurized Rover

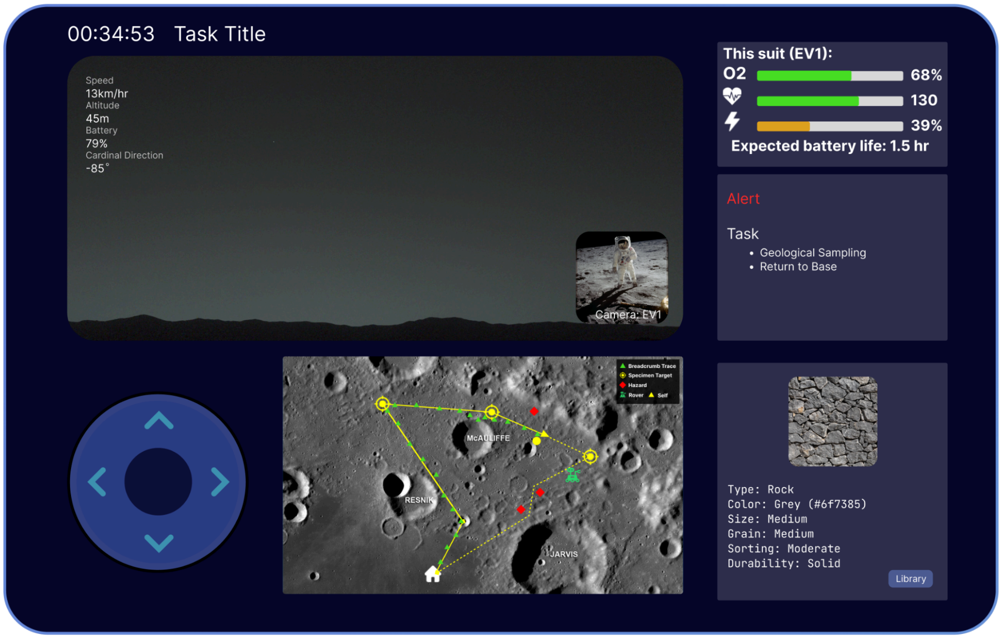


Figure R.1

4.1.2 Navigation

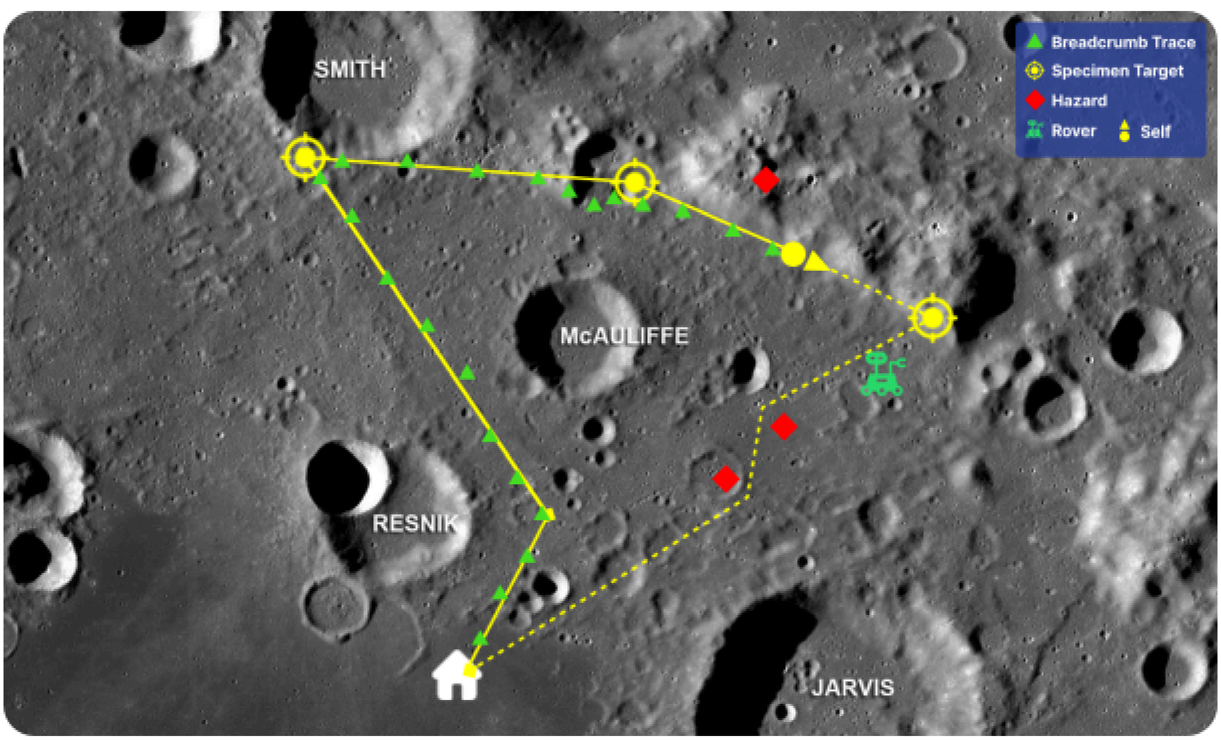


Figure N.0

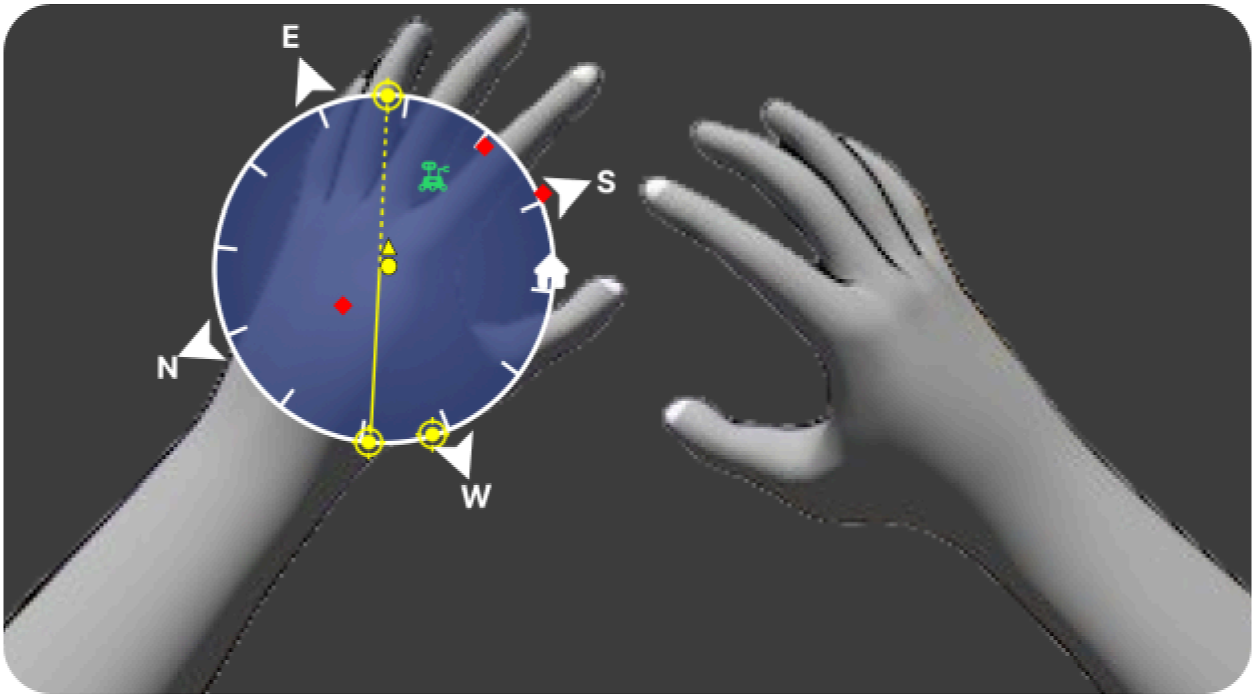


Figure N.1

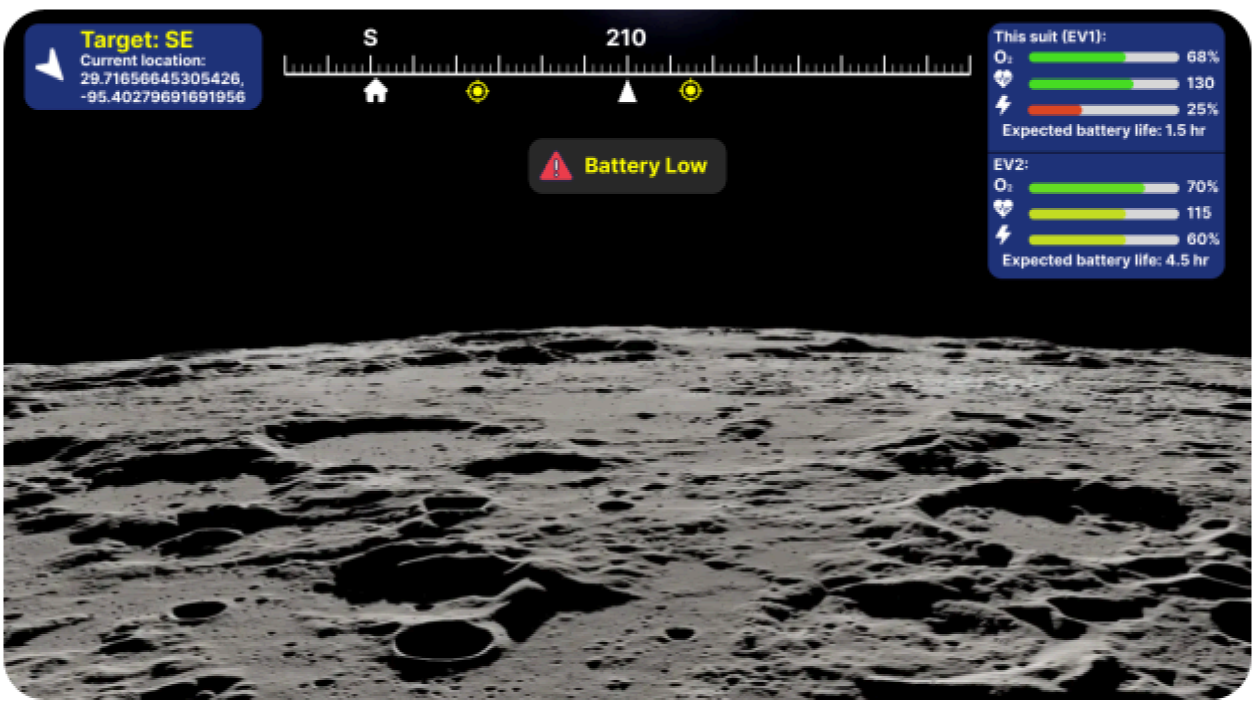


Figure N.2

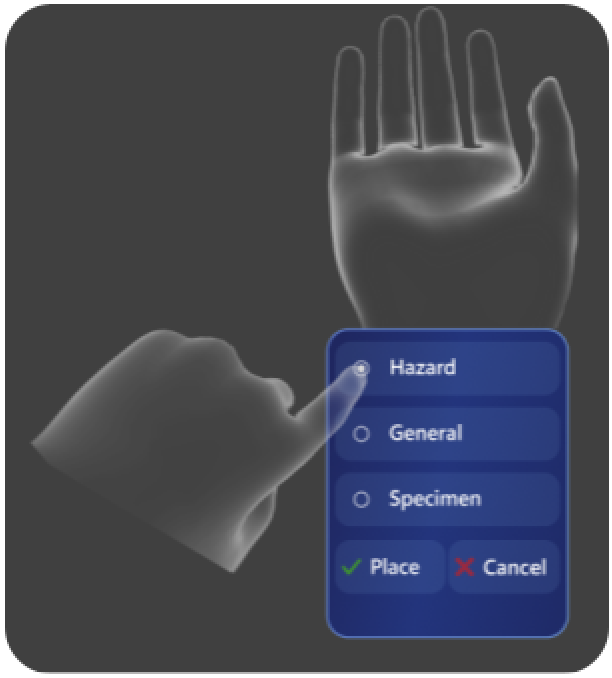


Figure N.3

4.1.3 Geological Sampling

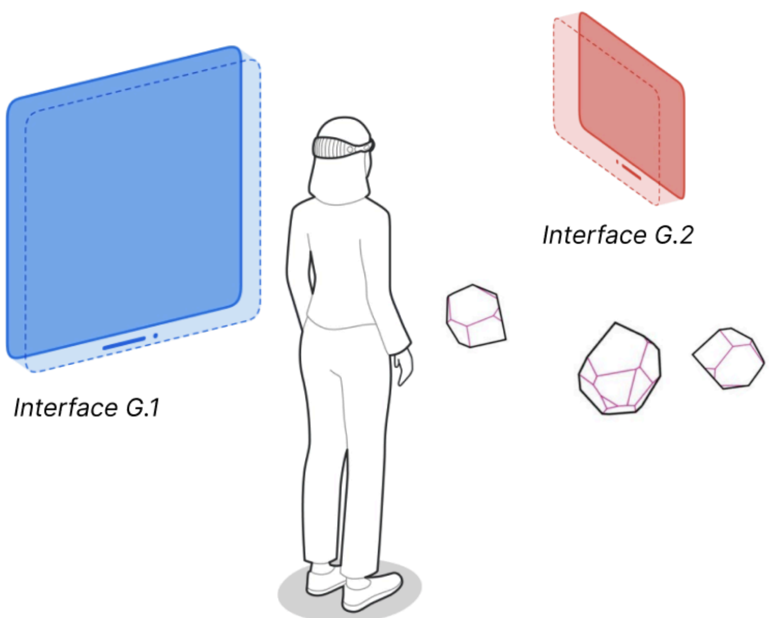


Figure G.A

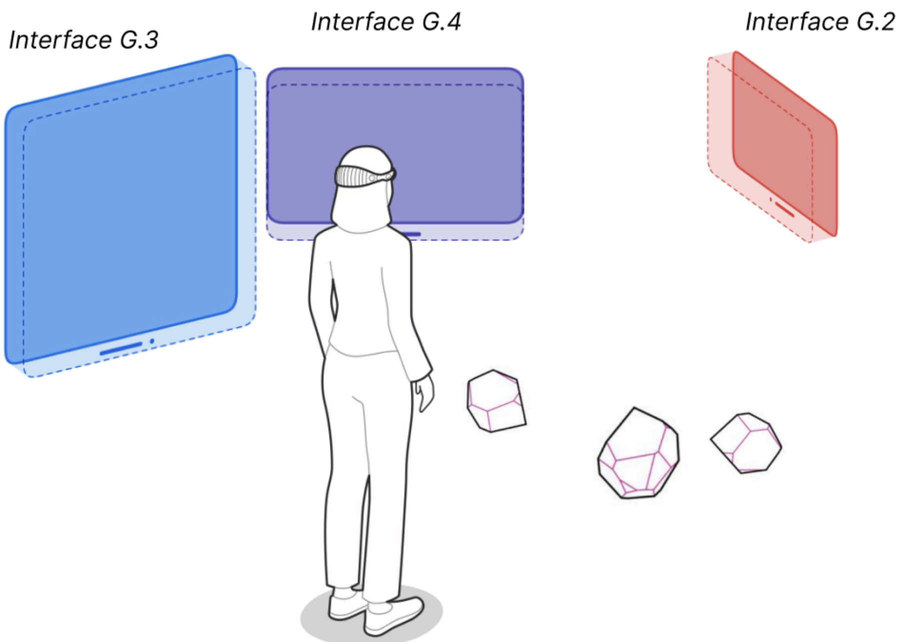


Figure G.B

Figure G.0

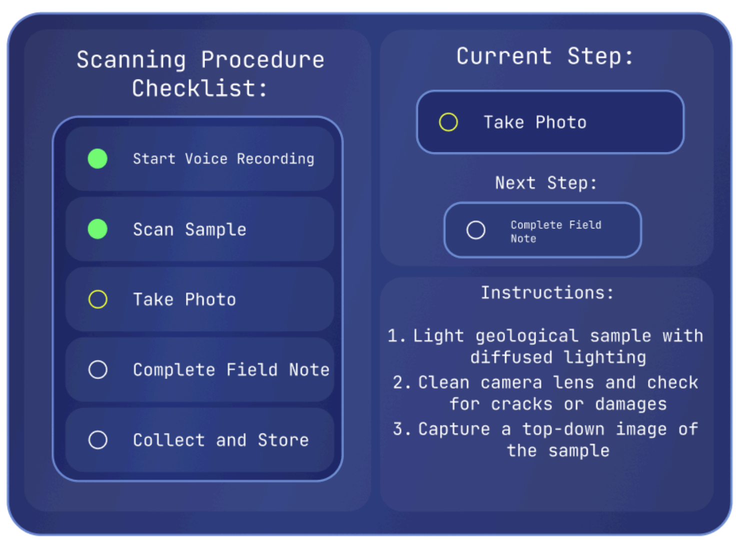


Figure G.2

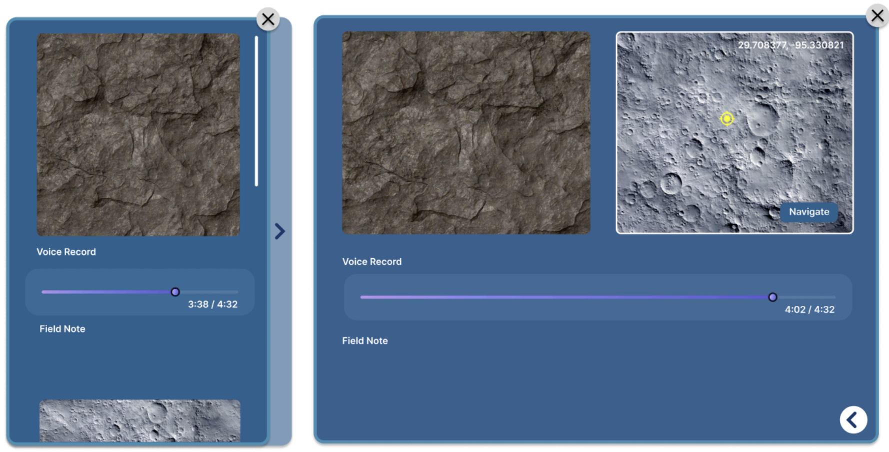
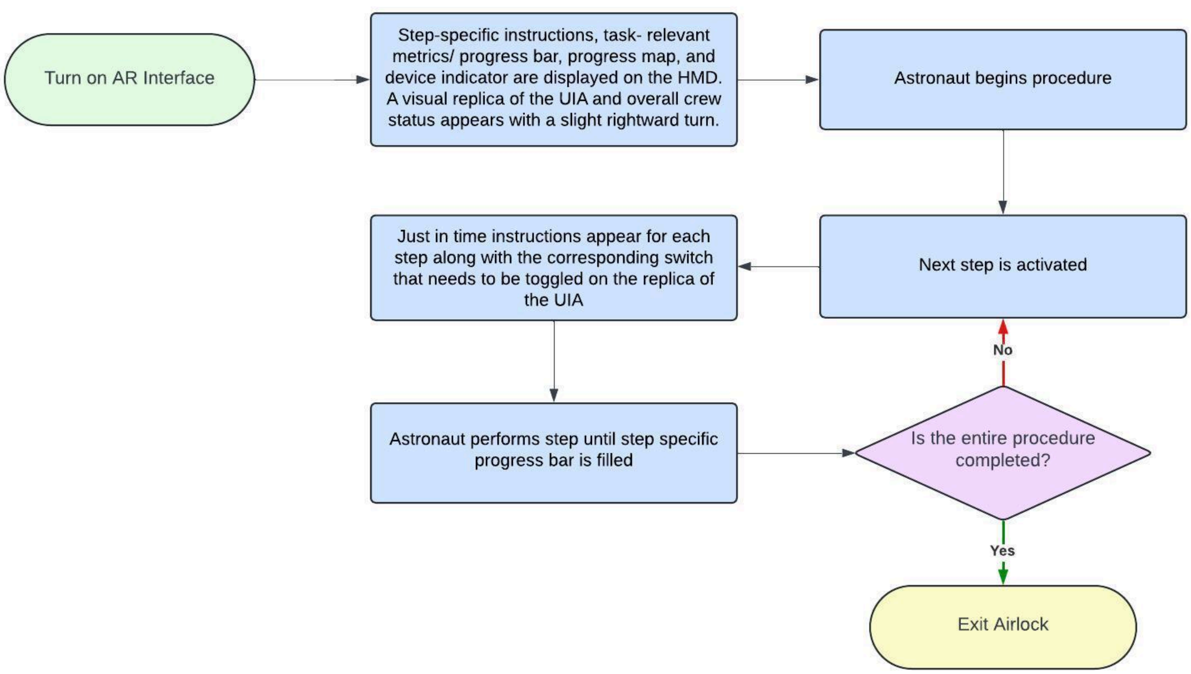


Figure G.3

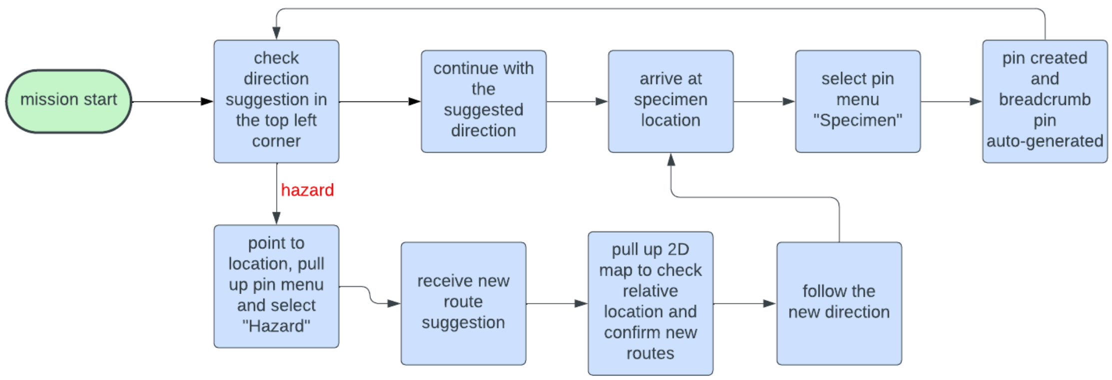
Figure G.4

4.2 Workflows

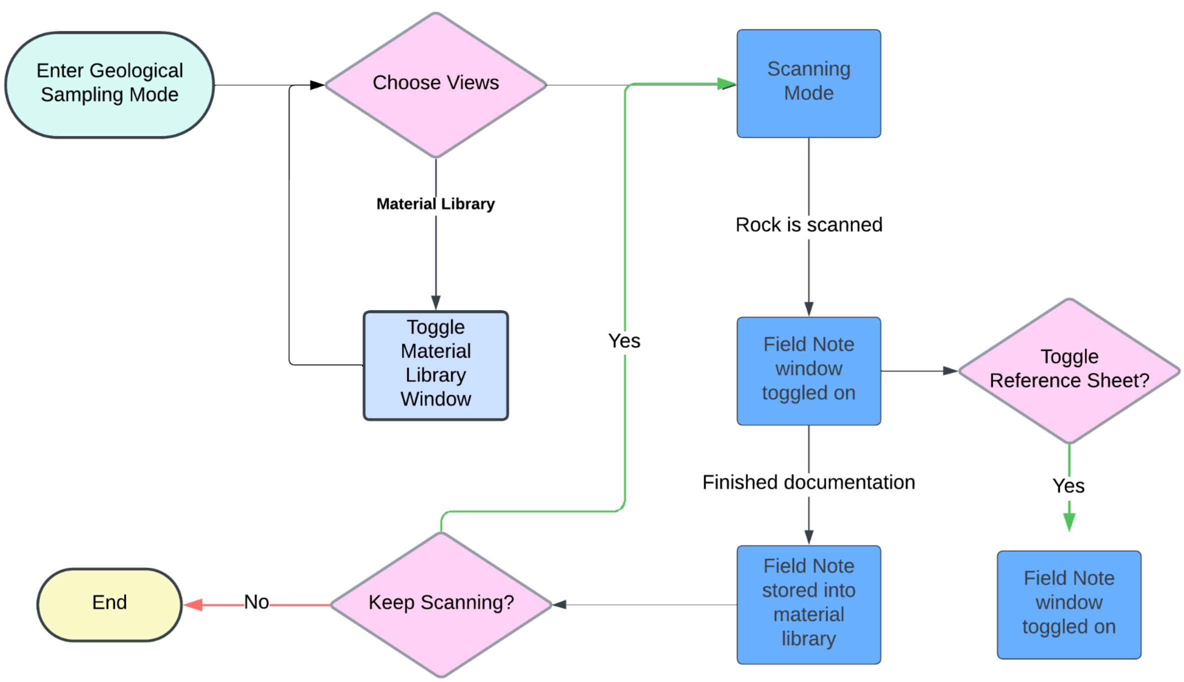
4.2.1 Workflow for Egress



4.2.2 Workflow for Navigation



4.2.3 Workflow for Geological Sampling



4.3 Project Management

4.3.1 Pressurized Rover (PR)

Start Date	End Date	Phase	Milestone/Activity	Team	Deliverables
12/12/24	1/15/25	Setup	Set up DUST environment and TSS integration	Dev	Working simulation environment
12/19/24	1/29/25	Design	Design rover control interface and layout	Dev	UI mockups, control scheme
1/2/25	2/5/25	Core Development	Implement autonomous navigation system	Dev	Path planning algorithm
1/16/25	2/19/25	Core Development	Develop resource management system	Dev	Resource tracking interface
1/30/25	3/5/25	Core Development	Create camera feed integration system	Dev	Multi-camera display
2/13/25	3/12/25	Integration	Implement interoperability with spacesuit team	Dev + HMD	Data sharing protocol
2/27/25	3/26/25	Core Development	Develop hazard detection system	Dev	Hazard visualization
3/13/25	4/9/25	Testing	Test autonomous features and controls	HITL	User testing results
3/27/25	4/23/25	Testing	Integration testing with spacesuit team	Dev + HMD	System integration report
4/10/25	5/7/25	Optimization	Performance optimization and refinement	Dev	Performance metrics
5/1/25	5/15/25	Final	Final integration and demonstration prep	Dev + HMD	

4.3.2 Spacesuit HMD

Start Date	End Date	Phase	Milestone/Activity	Team	Deliverables
12/12/24	1/15/25	Setup	Set up HMD development environment and TSS integration	Dev	Working development environment, TSS connection
12/19/24	1/22/25	Design	Design basic UI components and information architecture	Dev	UI mockups, component library
1/2/25	1/29/25	Core Developm	Implement UIA procedure display system	Dev	UIA interaction system

		ent			
1/9/25	3/5/25	Core Developm ent	Develop 2D mapping and navigation interface	Dev	Map system, navigation controls
1/16/25	2/12/25	Core Developm ent	Create biometric and system data displays	Dev + PR	Real-time data visualization
1/30/25	2/26/25	Core Developm ent	Implement XRF data collection and display	Dev	Sample analysis interface
2/13/25	3/12/25	Integration	Develop interoperability system with PR team	Dev + PR	Data sharing protocol
2/27/25	3/26/25	Core Developm ent	Create caution & warning system	Dev	Alert system
3/13/25	4/9/25	Testing	Test navigation and procedure execution	HITL	User testing results
3/27/25	4/23/25	Testing	Integration testing with PR team	Dev + PR	System integration report
4/10/25	5/7/25	Optimizati on	Low-light testing and final optimization	Dev + PR	Performance metrics
5/1/25	5/15/25	Final	Final integration and demonstration prep	Dev + PR	Demo-ready system

4.4 Gantt Chart