Boise State University NASA SUITS Challenge Team Proposal 2021 - ARSIS 5.0

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I, Dr. Karen Doty, faculty supervisor, endorse this proposal.

Karen Doty, 10-24-21

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Technical

Abstract

Augmented Reality Space Informatics System (ARSIS) 5.0 is a prototypal system designed to help an astronaut on an Extravehicular Activity (EVA), in accordance with the 2022 NASA SUITS (Spacesuit User Interface Technologies for Students) Challenge.

The main objectives of ARSIS continue to be navigation and information display. To this end, ARSIS contains interactive menus, a realtime biometric display, augmented reality (AR) procedures and geology sampling workflows. Additionally, the use of AR annotations facilitates communication between Mission Control and the astronaut.

This year's focus on Lunar Search and Rescue, better navigation options, external robotics, and increased usability have led the team to focus on improving ARSIS with instant messaging and distress signals, realtime map updates with mission objective markers, a self-driving rover, and persistent holographic arm-mounted menus.

Design Description

Systems

Note: ARSIS frequently has multiple users. Unless otherwise specified, the term "user" in this section refers to the person using the Augmented Reality Display

Head Mounted Display (HMD)

The Head Mounted Display (HMD) provides access to ARSIS's features. ARSIS displays information on demand and connects the user with the interface tools and options.

Notifications

Notifications are short, contextual messages that appear in the user's HMD for the purpose of providing awareness about a situation.

AR Annotations

AR Annotations are objects or paths rendered on the HMD that conform to local topography [Arora].

Interactive Menus

The core of the ARSIS system is in its Interactive Menu Navigation. Menus are implementations of the MRTK [Polar-kev].

Minimap

The minimap is a persistent, dismissible panel that displays real-time information about the nearby environment [Mahalil].

ARMs

Arm-Retained Menus (ARMs) are virtual objects that are displayed over the user's arms. ARMs provide additional access to commonly used features and functions.

Interactive Menus

Interactive Menus are the bulk of ARSIS's functionality. Menus can be pinned in place or set into "follow mode" to follow the user. Important menus can be accessed either through the main menu or through the ARMs. *See Figure B.1.*

Procedures Menu

The Procedures Menu has information concerning various procedures, including text and image data. Users can navigate through the procedures using either gesture or voice [Polar-kev]. A stretch goal this year is to enable the Ground Station to Create, Rename, Update, and Delete (CRUD) procedures during the mission. *See Figure A.2.*

Biometrics

Biometrics connects to NASA's provided Telemetry Stream in order to provide real-time data on the state of the simulated space suit. When a metric is out of acceptable range, it will have an indicator showing the user that there is an anomaly. A stretch goal this year is to convert the biometric data display to charts that display the levels over time, allowing the user to identify worrying trends at a quicker pace. Another stretch goal is to allow the user to "pin" these charts to their HMD or another persistent place – allowing for faster checking of metrics that the user might think are important to know at the moment. *See Figure A.1.*

Geology Sampling

A Geology Sampling menu exists to record information about samples. The first section of the menu is an interactive questionnaire to ensure that all important data is gathered. Next, the user has the ability to add an optional voice sample. Finally a picture of the sample can be taken. This information is saved to the system. A stretch goal for this year is to develop the ability to automatically update the map when a sample is taken. Another stretch goal is to use computer vision to identify the sample automatically. *See Figures A.3 - A.6.*

Mega Map

The Mega Map is a menu that provides a map of the surrounding areas, as well as functions to manage beacons and the RC Car Rover. See the *Locational and Situational Awareness Package (SLAP)* section below.

LunaSAR

The LunaSAR Menu shows the current state of any LunaSAR activities, and provides tools to be used during these activities. For more information, see the *LunaSAR* section below.

Notifications

Notifications allow for contextual information to be displayed to the user automatically via the HMD. There has been some study of notifications in XR, so we plan on implementing some better practices, such as making the obtrusiveness of the notification correspond to the urgency of the task, and the expected engagement of the user when the notification arrives [Ching-Yu].

Biometrics Out of Range

This notification appears when a Biometric is outside of the acceptable range.

Biometrics Time Left

This is a persistent notification that displays the lesser value of the Oxygen and Battery values, allowing the user to understand time constraints when working in an EVA.

Record Path

This notification appears while the user is actively using the Record Path tool. More information on this tool is included in the *Miscellaneous Tools* section

LunaSAR Message Received
This notification appears when a LunaSAR message is received. It displays a relevant icon, as well as the content of the message.

RC Car Destination Unreachable
This notification appears when the RC Car Rover cannot reach its destination. It disappears when no longer relevant.

Ground Station

The Ground Station is a pair of portals for Mission Control users. The Virtual Reality Ground Station is a robust tool for telestration and other functions. The Desktop Ground Station is an alternative way to access the VR functionality and the user can choose either option depending upon their preferences. The Ground Station functionality is described below. *See Figure B.3.*

Topology Recording and Transfer over Network
The user's HMD records topological data about the user's surroundings and transmits that data to the Ground Station. Using point cloud matching, a low-resolution version of the environment is rendered. This provides the Ground Station user the ability to better understand the immediate environment [Yoshinaga]. We also plan on using cloud anchors to increase the accuracy of this simulated environment to combat the problem of drift. *See Figures A.8 - A.9.*

Realtime Telestration
The primary purpose of the Ground Station is to provide Telestration (tele-illustration) to the user. The Ground Station user is able to create icons or paths, which are then placed in the user's field of view via AR Annotation. These annotations are placed in accordance with the topology received by the Ground Station—making sure that the annotations are placed properly in the user's environment [Arora]. These Telestrations can be placed in real-time, allowing for powerful communication techniques with the user.

Realtime Mission Updates
The Ground Station User is able to add and remove Navigational Beacons from the user's map. Additionally, the Ground station user will be able to create new user procedures and update current ones.

Situational and Locational Awareness Package (SLAP)

Situational and Locational Awareness Package (SLAP) is a bundle of functionalities that allow for the user to understand their current environment, and how it relates to their current objectives.

Navigation Beacons
Navigation Beacons are points of interest to the current mission. They render in realspace via the AR Annotation feature [Arora]. They are also displayed on both the Mini Map and the Mega Map. In addition to beacons, waypoints can be placed to aid in particularly obtuse navigation scenarios. *See figure B.2.*

One beacon at a time can be designated as the Primary Beacon. Until this designation is changed or removed, navigation systems will prioritize that beacon. This prevents distractions from irrelevant beacons, especially during LunaSAR.

Navigation Beacons can be added or removed from either the Mega Map menu, or via the ARM. In addition, the Ground Station can add and remove beacons. Finally, the LunaSAR feature will automatically add a beacon (and set it as the Primary Beacon) if it receives the appropriate message.

Mega Map
The Mega Map displays the user's real-time environment. An indicator shows the user where all current Navigational Beacons are located. If

there is an active Primary Beacon, it will be highlighted and have a different appearance.

Another indicator shows the current location of the user. For the test at JSC (Johnson Space Center), the map will be one provided by NASA. It will be augmented with current data about the user's local topology.

The Mega Map also provides an interface to add and remove Navigational Beacons, or to set one Beacon as the Primary Beacon. This interface can also be used to set the destination for the RC Car Rover.

The Mega Map provides options to pan, zoom, grow, or shrink the map as the user needs.

Mini Map

The Mini Map is mostly a smaller version of the Mega Map, but is designed to be used during the actual movement of the user.The Mini Map is a purely visual tool, and does not contain any options for interacting with other parts of ARSIS.

In addition, the Mini Map cannot be panned, and is always centered on the user. The top of the Mini Map does not always point in the same direction, but rather always corresponds to the forward direction of the user. Finally, Navigation Beacons that are too far away to display on the Mini Map will be designated by an arrow in the appropriate direction, as well as a label displaying its distance from the user. *See Figure A.2.*

If a beacon is designated as the Primary Beacon, it will become larger and a brighter color than usual, and the other beacons will slightly fade. If the Primary Beacon is too far away to show on the Mini Map, then a similar effect will happen to the arrow that points to it.

RC Car Rover

The Remote Controlled (RC) car contains an attached camera and Raspberry Pi computer.

Destination Setting and Self-Driving Capabilities

The user is able to select a destination for the RC car from the Mega Map, and the car will use its self-driving capabilities to attempt to reach the destination. If it cannot, it will stop moving and send the user a notification [Barnes].

Visual Feedback from RC Car

The user will be able to receive visual feedback through a specialized menu. Suggestions for visual feedback type include static images or a video feed.

Other Considerations

As per the guidelines of this design challenge, the RC Car Rover will not have any functions essential to the mission.

We considered many applications for the RC car, including: mapping terrain, serving as a mobile hotspot, serving as a mobile cloud server for ML tasks, being a toolbox or “pack mule”, or fetching items from far-off locations.We decided the most appropriate functionality for this test is communication with, control of, and visual feedback from the RC car.

LunaSAR

Receive LunaSAR Messages

ARSIS automatically receives LunaSAR Messages from a Telemetry Stream. It then parses this information into a format usable by its features.

Contextualize Message Information

The LunaSAR Message body displays as a notification to the user.

Simultaneously, the locational information included in the message is used to create a new Navigation Beacon, which is then set as the Primary Beacon. The user can then use existing navigation tools to navigate to this beacon.

Facilitate LunaSAR Activities
ARSIS is able to receive follow-up messages, as well as send its own preformatted LunaSAR-compliant messages. These messages can be read in real-time via notifications or in aggregate via the LunaSAR menu. Tools to send pre-formatted messages can be accessed via the ARM or LunaSAR menu. Ground Station will also see these messages.

Arm-Retained Menus (ARMs)

ARMs provide a persistent way to access commonly-used features, without requiring constant voice commands which could disrupt communications with the other astronaut or Mission Control. ARMs are AR menus that become enabled when the user looks at the appropriate part of their body, and are disabled at all other times [Polar-kev]. ARMs follow the user's actual arms, ensuring that they do not obstruct vision.

There are four ARMs: one on each palm, and one on the back of each hand. *See Figure C.1.*

System Access ARM
The System Access ARM is located on the right palm. It provides quick access to the Main Interactive menu, as well as the Procedures and Geology Sampling menus.

It also has two buttons that are keyed to the "next" and "previous" options in the Procedures Menu, allowing for faster navigation of that menu.

Emergency ARM
The Emergency ARM is located on the back of the right hand. It provides quick access to the biometrics and LunaSAR menus, as well as functionalities related to the LunaSAR system.

The Emergency ARM has a one-button push option to open either of those two menus.

In addition, the user can read the last LunaSAR Message received or send their own message without opening any additional menus. The user will also be able to "pin" specific biometrics to this ARM, so that they can view the current state of the specific biometric information without going into the Biometrics Menu.

Navigation ARM
The Navigation ARM is located on the back of the left hand. It provides quick access to the Mega Map, as well as functionalities related to the Map, Navigation Beacons.

The Navigation ARM has a one-button push to open the Mega Map. In addition, the user can enable or disable the Mini Map with one button..

While Facing a Navigation Beacon, the user can push a button to set that beacon as the Primary Beacon. Similarly, the user can delete beacons by pushing another button and selecting a confirmation. The user can place a beacon anywhere within line of sight using this ARM. Placing beacons in other places requires using the Mega Map Menu.

Tools ARM
The Tools ARM is located on the left palm. It provides quick access to various tools.

These tools include the Record Path tool, the Measurement Tools, and the controls for the dynamic light shutter. These tools are described in more detail in the Miscellaneous Tools section below. In addition, the user can press a button to pull up or dismiss a visual feedback panel from the RC Car Rover.

Miscellaneous Tools

ARSIS has a variety of tools that are not designed as part of a larger system. Those are listed below.

Path Recording
The Paths functionality allows the user to record their path as they then walk along. This path is then displayed as an AR Annotation [Arora]. A potential use of this is backtracking, especially through hazardous terrain. *See Figures A.7, B.2.*

Measurement Tools
ARSIS includes a tool that will tell the user the distance between two points, which can be placed in AR. This can be used for measurement, especially of rock samples.

ARSIS also includes a tool that will tell the user the angle between their forefinger and thumb. This can be used for measurement or, in emergencies, for navigation.

Lighting Considerations
ARSIS includes photochromic film to prevent high-light issues, as well as attached lights that will allow topology-mapping and vision up to 10 feet in dark conditions. A stretch goal this year is to build a shutter that will control the amount of light allowed into the system as needed.

Redundant User Input

Voice
All options for the user have a corresponding voice command to access. The keyword "Adele" prefaces all ARSIS voice commands. The team decided to include this functionality due to accidental activations that occurred during previous versions.

This keyword was previously removed due to concerns about the annoyance of its frequent use, but persistent navigation tools in the ARMs reduce the need for constant voice direction.

Gesture
Interactive Menus can be interacted by "touching" them in AR. Menus can be made to follow the user, be opened or closed, or have their buttons activated in this way [Polar-kev].

ARMs
ARMs are a subset of gesture controls. They are persistent, rather than contextual, and provide quick access to commonly used features—without having to navigate through the menus

Design Challenges

Challenge	Proposed Solution System(s)
Navigation	SLAP, LunaSAR, Ground Station
Position Localization	SLAP
Terrain Sensing	Native HMD Functionality, Ground Station
EVA System State	Biometrics Menu
User Interface and Controls	Interactive Menus, Redundant User Input, ARMs

Tele-Robotics	RC Car Rover
Peripheral Devices	Ground Station, Misc. Tools - Lighting Considerations, RC Car
Geology	Geology Sampling Menu, Misc. Tools - Measuring Tools

Concept of Operations (CONOPS)

This section describes, at a high level, how ARSIS will meet the expectations and requirements of this design challenge. The methodology of this section is to present a number of scenarios from the perspective of the astronaut, along with the expected behavior from ARSIS.

Scenario #1 Uneventful Geology Sampling

You exit your vehicle. The persistent Mini Map says that the Primary Beacon is 730 meters in a direction to your right. You turn until the map says that the beacon is up----forward You see an indicator in front of you that the beacon is in the distance. You begin walking, taking care to avoid any hazards.

The walk is uneventful. Over time you notice that your time left meter (persistently at the bottom of your vision) declines, but not more than expected. Occasionally you notice that you've drifted slightly off-course, so you turn slightly to correct. The arrow on the Mini Map points straight up again – you're headed in the right direction. Eventually you get far enough away from your vehicle that it falls off the Mini Map. Instantly, an arrow appears at the bottom, pointing down. 200 meters in that direction to the vehicle. It's a little hard to make out, but that's expected. It's meant to be unobtrusive until it's needed.

You reach an area of hazardous terrain. Mission Control warned you about it, so you weave through it, using waypoints put there in advance by Mission Control. While you're moving, you look at the virtual button on your left palm and hit it. A path appears as you walk. That will make backtracking faster.

Eventually you make it to the sample site. You want to have better vision (and don't need the Mini Map any more) so you look at the back of your left hand and hit a button. The Mini Map disappears. The beacon – a blue orb, floating in space -- is also no longer needed. You hit another button on the same panel. The orb disappears as well. When you open your Mini Map again, you'll notice that the arrow on the bottom of your minimap is now clear.

You look at your right palm and hit a button on it to open up the Geology Sampling menu. After answering some questions about the sample's characteristics, you get to a question about the angle of its crystalline formations. You hit a button on your left palm to pull up an angle measure, and quickly get the answer. You skip the voice sample option; there is nothing out of the ordinary. Finally you snap a picture to complete the sampling.

After you finish up at the site, you turn your Mini Map back on. You turn around until you face the arrow on your Mini Map. It's a bit of a walk ahead, but you know you won't get lost.

Scenario #2 Unexpected Hazardous Terrain

As above, except that, due to extenuating circumstances, mission control has not already told you how to navigate the area of hazardous terrain.

As you approach the hazardous terrain, mission control tells you to slow down. From the Ground Station, somebody begins consulting the data that they have on the area. After making absolutely certain that they're correct, they begin marking out the safe path. Arrow icons show up in your field of vision, telling you exactly where to go. In addition, big splotches of red appear, warning you of particularly dangerous areas. With this warning, you are able to continue the mission without incident.

Scenario #3 LunaSAR

As scenario #1, except that, on your way back, you receive a LunaSAR message.

As you get closer to your vehicle, a notification appears in your field of view. A message is there, along with some coordinates, indicating that your crew mate is having trouble and needs assistance. You don't really need the coordinates, as your minimap automatically shows a new arrow, pointing off to your left. This new arrow greys out your home beacon, the same way that the sampling mission did it earlier. If you were more pressed for battery or oxygen, you could switch the Primary Beacon back very easily—but that is not the case and your crew mate needs you, so you need to determine how to get to them.

First you hit a button on the back of your left hand, pulling up your Mega Map. You see that the distress beacon is on the other side of a cliff. From this menu, you set a waypoint to navigate to first, allowing you to save some time. You hit an option on the back of your right hand, sending a LunaSAR message that help is on the way. You hit the first button again to close the map.

With mission control's concurrence, you navigate over there uneventfully.

Scenario #4 New Point of Interest

As Scenario #1, except that mission control determines a new point of interest while you're still sampling.

While you're sampling, mission control determines that there's an opportunity for another sample very close by. From the Ground Station, somebody opens up the list of active beacons and adds a new one at the appropriate place. It appears on your maps automatically.

Scenario #5 Damaged Spacesuit

As Scenario #1, except that 200 meters out you realize that one of your biometrics is abnormal.

A notification appears as you're walking. It's warning you that something is off, so you check the biometrics panel. One of the metrics is slightly lower than usual, so you decide to monitor it.

In the Biometrics Menu, you select 'pin' on that metric. When you close the menu you see that a graph representing that metric's value over time is now visible on the back of your right hand.

Over the next few minutes you verify that it is declining and notify Mission Control and your EVA crew member. The decision is made to abort the EVA and head back to your vehicle. You change your Primary Beacon to the vehicle and turn back.

Scenario #6 RC Car Rover Navigation

As Scenario #1, except that you notice another potential sampling site during your activity.

From your current work location, you notice some potentially interesting rock formations. After consulting with Mission Control, you decide the best option is to have the RC Car go over to the site while you continue to work, so you open your Mega Map.

You select the option to move the RC Car Rover to a location. You then drag the little icon to the appropriate place on the map. The car makes its way to the location. When it gets there, you look at the menu on the back of your left hand, and hit the button to send visual feedback. Mission Control determines that the rocks are of interest.

Human-in-the-loop (HITL) Testing

Testing of our integrated system will be conducted by team members, community members, and university level students. The majority of our testing will take place on the Boise State University Campus, and will follow the strict COVID-19 guidelines of the University. There are three main development areas that we intend to test, starting as early as the eighth week of development.

Testing Sprints

Our plan is to test ARSIS in three sections: Navigation, Tools, and User Interface (UI). These testing sections correspond to where we will be in the development process at the time of each test. The goal is to get feedback in a timely manner thus providing opportunities to make changes while also testing existing interface capabilities.

Test Protocol

1. Testing environment is prepared. Cleaning, loading, connection testing, etc.
2. Participant fills out a pre-test survey, providing the researchers information on participant familiarity with XR systems.
3. Participant wears HoloLens 2 and ski gloves during testing procedure
4. Tester is briefed on basic controls
5. Tester is given a series of tasks to complete, depending on the test.
6. Tester attempts to complete the tasks
7. Tester completes a post-procedure survey

Testing of ARSIS 5.0 will be recorded from three different sources to allow for as much metric data as possible. This includes the VR ground station, the HoloLens 2, and an external camera either held by a tripod [Appendix B.3, B.4]. Each perspective will provide visualization of user activity to ensure that our design meets the project goals and incorporates test results in our iterative design process. Visualization of metrics will include where users are looking on the GUI, the position and detection of articulated hand tracking, and the location and mapped spatial data around the user along with all user interface control interactions. This allows the team the ability to analyze and track the effectiveness of certain functionalities. This includes the ease of navigation between interfaces and ability to identify parts of the interface that draw more or less attention than intended. Benchmarking provides the ability to optimize the experience further.

Goals

The primary goal is to get information that will help design a better system. The team is looking to remove areas of confusion and unintuitive features.

Subject Pools and Expected Demographics

With most pandemic restrictions being lifted, testing of ARSIS 5.0 allows for a broader demographic of users. The subject pool will consist of team members, Boise State University faculty and staff, university students, and community members. Ideally, diversity in testing leads to the end goal of universal usability in technology.

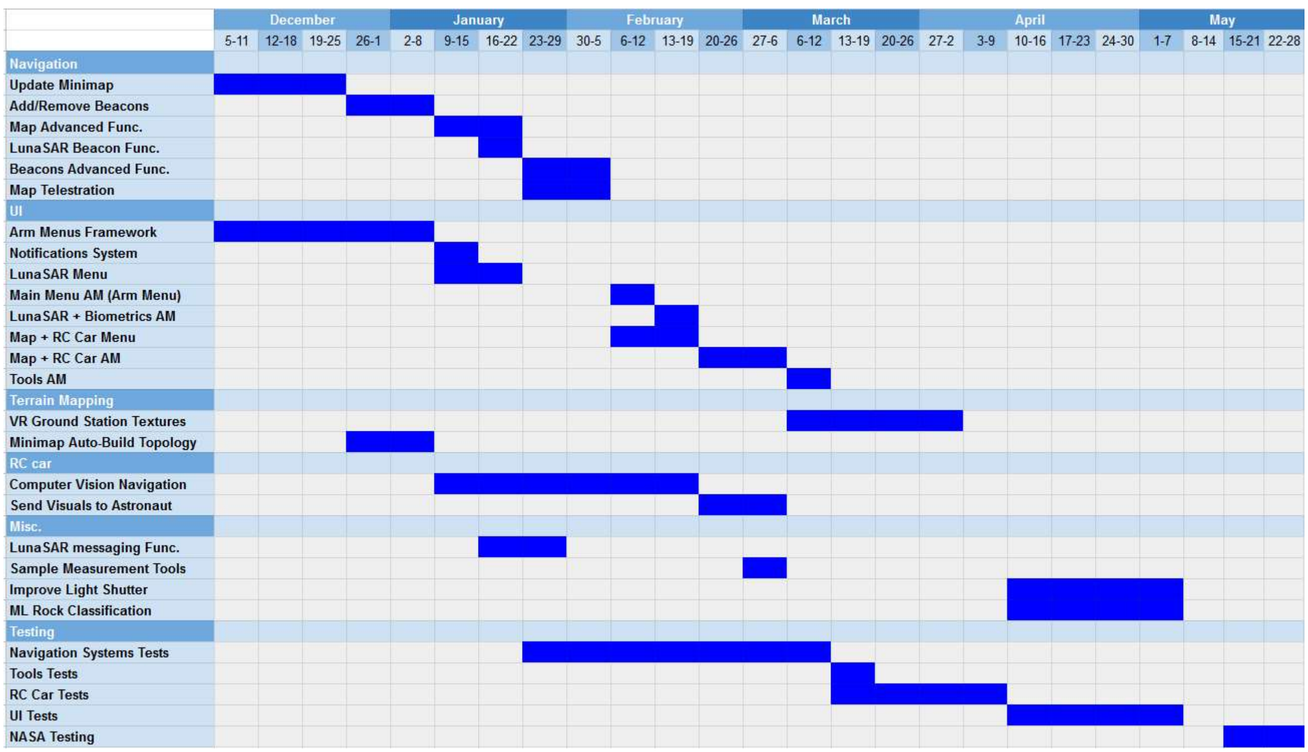
Safety Measures

The majority of testing will take place on campus in an open, clean, and well ventilated area which falls under the strict covid guidelines of the University. The team also plans to follow these guidelines in external testing scenarios such as outreach events. To limit contamination, the use of disinfectant spray and wipes will be used to sanitize the equipment between each use of the HMDs. The RC car will not require the same sanitation process due to the minimal contact it receives and the seamless integration with new testers/users.

Spot Testing

The team intends to continue the tradition of randomly- inspired testing on the hardware and software capabilities of our system. These tests are not as robust, but can frequently lead to new insights. For example, the team recently took the system to the Bruneau Sand Dunes to test controllers vs hand tracking in reflective, sandy environments (*see Figure B.2)*. The team discovered that the irregular light reflecting off the sand interfered with Oculus Touch controllers, but not hand tracking. The team also took ARSIS to Craters of the Moon Idaho to test how the topology transfer feature worked in caves [Appendix D].

Team Project Schedule



Boise State University NASA SUITS project schedule

The Team Schedule is separated into three "pushes". The first push is to complete all the navigation requirements, including lunaSAR requirements. The team intends to be finished with this push by February 19 in order to begin testing that section of ARSIS. The second push includes finishing the UI and RC Car requirements, as well as building the measurement tools (size and angle). The team intends to be finished with this push by March 12, and will test at that time. The final push is finishing up testing as well as adding quality of life features: including rock classification, improved light shuttering, and textures for the VR ground station. This push is focused on less essential, quality-of-life features that can be omitted depending on the results from testing of core features.

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