Skylight

Semi- Autonomous Exploration of A Lunar Skylight Cavity

Executive Summary

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Abbreviations

GCS Ground Control Station

1 Introduction

Cavities on the Moon are of specific scientific interest. They can provide insights of the moons geological history as well as provide shelter for future manned missions. The challenging part is to evaluate caves on the moon whether they are suitable for such mission, as satellite images only provide pictures of the entry. To explore the inside there is no other option that actually go there of send a robot.

The probability of actually finding a cave is very high where a roof of a lava tube is collapsed (a "Lunar Skylight"). Lava tubes are very long cavities that were created by volcanic activity. While the probability of finding a cave in these places are very high, entering these trough the collapsed roof is very challenging.

This study evaluates the feasibility of a robotic mission to a Skylight located in the Marius Hills region on moon (14.091N, 303.223E, see Fig.1). The pit has an diameter of 48-57 meters and a depth of 45-55 meters. The goal is to reach the ground of the pit and explore the cave for at least 200 meters.

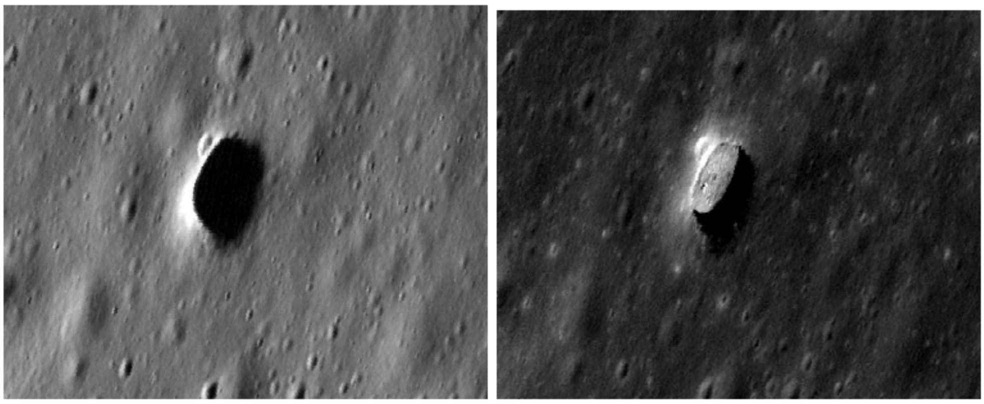

Figure 1: *Marius Hills Skylight, picture by Lunar Reconnaissance Orbiter (LRO)[1]*

2 Mission Description

This section gives a first overview of the aspired subsystems in the Skylight exploration system in Section 2.1. With the understanding of the components, the mission is presented in Section 2.2 by the main steps as planned for this study.

2.1 Components Overview

The overall system consists of three major hardware subsystems. This study focusses on the surface operations, hence the lander is excluded from detailed analysis. Consequently, the major subsystems are:

1. *Surface rover.* This is the biggest subsystem. It transports all equipment and mobile elements from the lander to the designated entry spot of the lunar cave opening. In the phase of tethering down the exploration rover (see next point) it might serve as anchor and communication relay

either directly to earth or to the lander. As anchor, the surface rover needs to generate energy or have energy stored for transmission to the exploration rover.

2. *Tethering subsystem*. The tethering subsystem serves the purpose of safely lowering the exploration rover into the lava tube. It further can be used to transmit power and/or data between the anchor and the exploration rover. The tethering subsystem includes also a wireless communication device to be able to communicate with the surface without docking to the exploration rover.

3. *Exploration rover*. This is the rover that is lowered into the cave. It has the task of exploring the interior of the lava tube. It needs to have at least a certain degree of autonomy as temporary communication loss is very likely.

2.2 Mission Steps

The aspired mission can be subdivided into several individual steps. Our study contains the following main phases:

1. Descent Phase: Tether the exploration rover down.
2. Settlement Phase: Deploy Base Station within the lava tube.
3. Exploration Phase : Semi-autonomous, guided exploration.

We expect that the tether is anchored near the rim of the skylight in a save place, in order to reduce the risk of a mission failure due to further collapsing of the roof. The exploration rover traverses the last distance by itself, laying down its tether itself. The anchor also holds the connection to earth, either directly or using the lander as relay station.

The following Figure 2 shows a potential mission sequence in detail

2.2.1 Descent Phase

For descending we propose a hybrid approach using tethering and actively controlled legged-wheels. The first step will be to approach the rim of the collapsed roof with the exploration rover. During the approach, the legged-wheels minimize the risk of pushing the soil in front of the wheels. Thus also minimizing the risk of pushing soil over the rim or destabilizing it. The tether spool is located on the rover that will descent into the skylight itself to avoid abrasion by the lunar regolith by pulling the tether through it. Doing this, the active tether management attached to the rover also allows the selection of a suitable location for the descent. When a location is found, the rover starts the descent while the wheels will be actively controlled in order to be able to avoid obstacles and cliffs. The tether also contains power supply and communication, so this part of the mission may also be remote controlled. The rover uses local path planning to avoid big obstacles on its way down, the legged wheels of the robot are actively driven. This way, the rover can also overcome overhangs and parts of the traverse where it is only hold by the tether itself. The study will contain different solution for tether management and look for solutions for autonomous assistance systems to make the descent safer and possibly the ability to retract the system to the surface. Close range data sampling of the walls of the pit is identified as highly valuable in terms of scientific gain, since the composition of the different outcrops can provide insights for understanding the different geological stages of the moon [2]. During Descent Phase this data acquisition could be performed. In order to keep the exploration rover light as possible, additional sensors could be mounted on the docking station for this particular

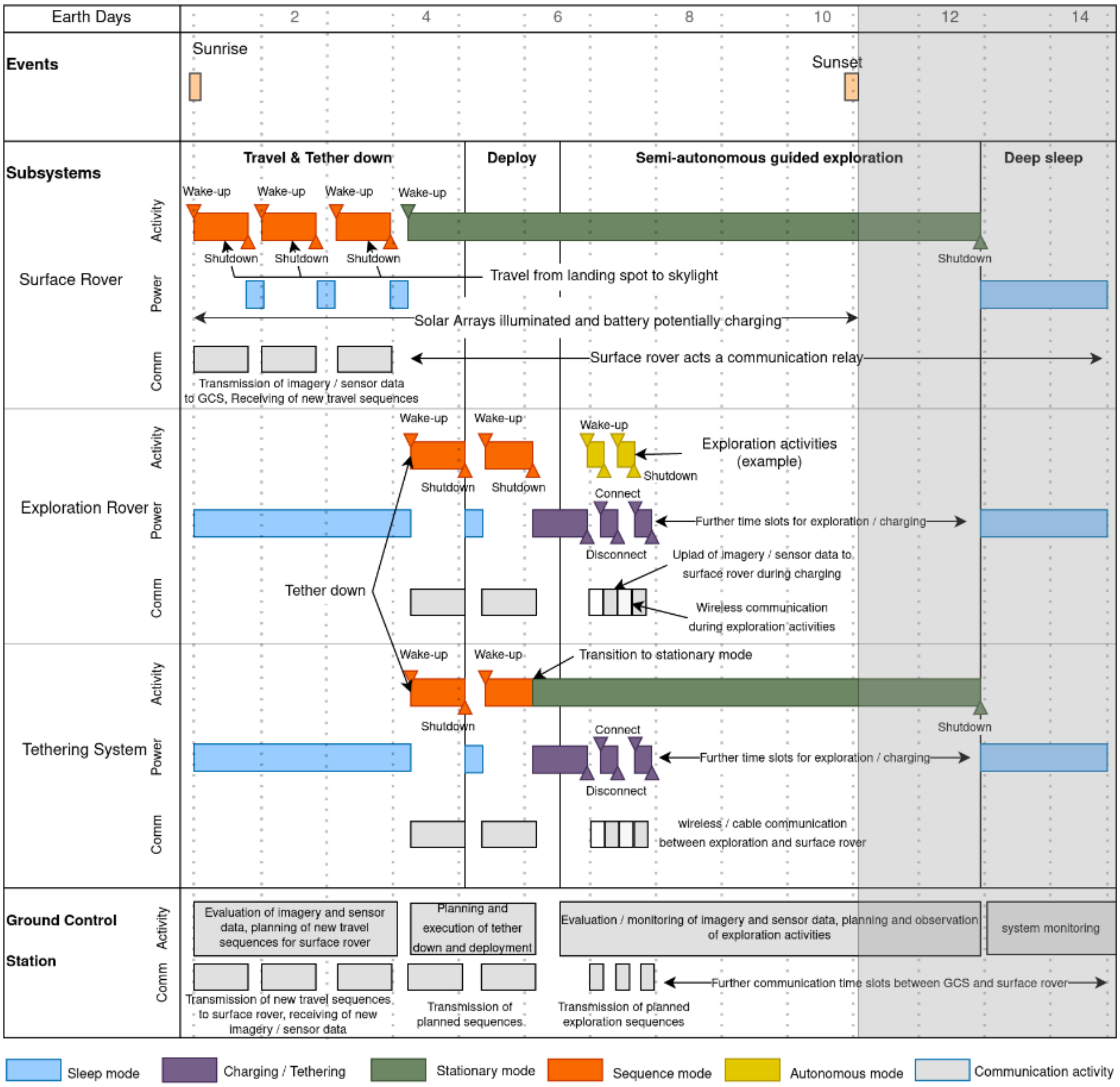

Figure 2: *Example mission sequence comprised of the three main mission steps on the lunar surface: Travel and tether down, deploy, and semi-autonomous guided exploration followed by a deep-sleep. The shown activities are separated into the subsystems: surface rover, exploration rover, and tethering system, as well as communication activities of the ground control station. The activities are categorised according to energy, communication and activity. The period shown extends over 14 earth days. The exposure conditions depicted take into account the estimated light conditions at the landing site Marius Hill pit 14.09 N 303.31 E.*

operation. On Descent Phase communication with Ground Control Station (GCS) is available with small delays. Thus, results from computationally expensive simulations executed on GCS -using data recently acquired by the systems- can be used to optimize the descent operation. This approach can help to maximize safety and scientific gain.

2.2.2 Settlement Phase

When the bottom of the skylight is reached, the rover deploys the tethering part in a suitable location and disconnects from it. The tethering part is still connected to the anchoring point on top and thus can now serve as recharging and data relay station for the battery driven rover. The base station (tethering part) also provides a wireless communication module to hold connection to the rover. This way the rover can wirelessly operate and navigate in the lava tube, while still be able to communicate for larger periods of time, as the uplink to earth is located at the surface and has a wired connection to the bottom of the lava tube. Creation Time: Jan 14 at 11:41 AMOur study will investigate docking mechanisms for recharging and data transfer and also evaluate wireless communication methods to be used in the lava tube.

2.2.3 Exploration Phase

At the floor of the tube, even in the area of the collapsed roof, we expect a high possibility of wireless communication loss. This might already happen, if a big boulder is shadowing the line of sight to the base station. Our approach is to enable the rover to autonomously explore, map and navigate the environment. This autonomous mode can be started and configured as long the wireless communication is available. In case of a communication loss, the rover is able to plan a path back to a covered area, send its updated map and wait for further commands once the connection is re-established.

This behavior can be parameterized, and thus the mission safety can be directly controlled during the different exploration phases by adjusting the maximum allowed time without communication. This way, the rover can be either remote controlled or an autonomous exploration goal can be set. This exploration goal can be area or time limited, the software will try to explore as much as possible and return to the initial position, where a communication link was available.

Then the next action can be selected. This can contain following actions: Deploy an communication relay station, explore further into areas without communication or the deployment of a relay station in a suitable point, based on the already mapped area.

In some situations, communication may be re-established later from another position while exploring and thus ease the need for a relay station at that point. For example when the rover moved around a boulder and is able to communicate after it was surrounded. Then the Operator can decide, it a relay is needed to cover that area or not.

The strategy for safe return of the rover to the base station is to mostly navigating in known terrain, and keeps the exploration phases to extend the map as short as possible. As soon new map parts are discovered, the rover returns to the base and uploads the map.

The Mission Command can the decide where to extend the map by selecting a suitable waypoint in the known map or to allow a autonomous exploration, where the risks taken can be controlled by the duration and parameters to the path planner, like maximum slope that the robot is allowed to traverse in autonomous mode.

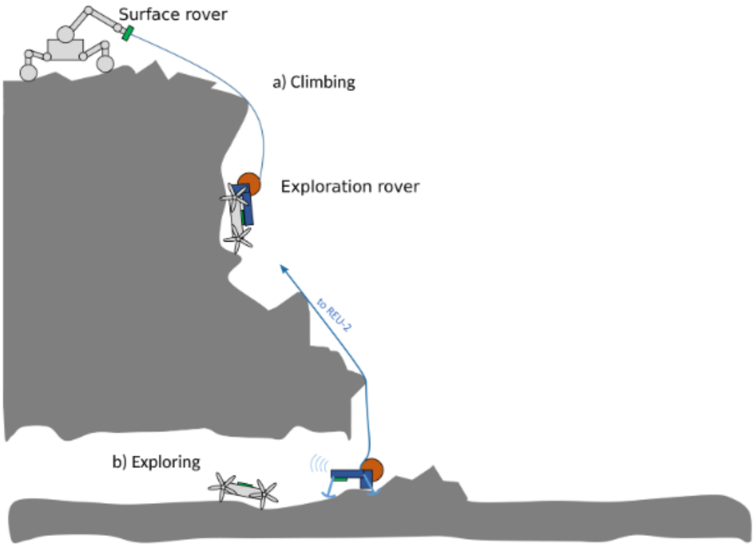

Figure 3: *Proposed Descent and Exploration Strategy*

References

[1] *LROC Quickmap*, 2020. [Online]. Available: https://quickmap.lroc.asu.edu

[2] R. V. Wagner and M. S. Robinson, "What to expect in lunar pits," in *Lunar and Planetary Science Conference*, ser. Lunar and Planetary Science Conference, 3 2020, p. 1163.