IAC-20-A3.2B.3

BUILDING A PIECE OF THE MOON: CONSTRUCTION OF TWO INDOOR LUNAR ANALOGUE ENVIRONMENTS

Philippe Ludivig[a]*, Abigail Calzada-Diaz[a], Miguel Olivares Mendez[b], Holger Voos[c], Julien Lamamy[a]

[a] *ispace, Inc, Rue de l'industrie 5, Paul Wurth InCub, 1811, Luxembourg*, p-ludivig@ispace-inc.com
[b] SpaceR Research Group – University of Luxembourg, 2 Avenue de l'Universite, L-4365 Esch-sur-Alzette, Luxembourg, miguel.olivaresmendez@uni.lu
[c] Automation & Robotics Research Group – University of Luxembourg, 2 Avenue de l'Universite, L-4365 Esch-sur-Alzette, Luxembourg, holger.voos@uni.lu
* Corresponding Author

Abstract

Developing and testing autonomous systems to ensure that they work reliably on the moon is a difficult task, as testing on location is not an option. Instead, engineers rely on simulations, testing facilities and outdoor lunar analogues. Due to the lack of lunar analogue testing facilities in Europe, ispace Europe and the University of Luxembourg have teamed up to build two of these facilities with the goal of designing new vision-based navigation systems. These systems will enable autonomous long-range traverses for lunar rovers. These two facilities have a surface area of 64 and 77 square meters, respectively. Regarding the type of testing needed for vision-based systems, the optical fidelity of the environment has been considered as the most important factor. Thus, different types of Basalt have been used for the two facilities to create a larger number of possible landscapes, such as craters, hills, rocky areas and smooth planar surfaces. Regolith simulant was also considered but, due to the health restrictions and the cost factor, basalt was selected instead. As a result, this has allowed for larger testing areas. The illumination setup has been designed to simulate the highland regions of the Moon, with a single light source positioned low above the horizon, casting long shadows over the entire area. To mitigate problems with feature detection algorithms picking up features at the edge of the facility, the walls have been painted black. This also produces high contrast shadows, which is exactly what makes vision-based navigation challenging in the polar regions. The outcome of this research is a set of lessons learned which will enable other researchers to replicate similar facilities and to reproduce the same fidelity in indoor testing for future vision-based navigation systems.
Keywords: Moon, Testing, Facility, Autonomy, Regolith, Lighting

1. Introduction

Fifty years after the first moon landing, agencies and companies have set their sights to go back to the lunar surface permanently. To facilitate this, autonomous robotic systems will be a crucial tool. This will be required for a range of tasks, including detection and mapping of resources, but also to build up supply chains for resources and power before the arrival of human settlers.

However, developing reliable autonomous systems for the lunar surface is not a trivial task, as testing on location is not an option. Instead, engineers must rely on exploring different solutions, such as creating simulations, testing facilities and outdoor lunar analogues. Due to the lack of lunar analogue testing facilities in Europe, new updates are essential where researchers may test the performance of their work. To support this endeavour, ispace Europe and the University of Luxembourg have combined their collaborative efforts to build two of these facilities with the goal of developing reliable navigation systems. These facilities will enable autonomous long-range traverses for lunar rovers. As the current state of the art in planetary navigation relies on computer vision systems, we have designed these facilities to greatly consider optical fidelity. The two facilities that were built are both located in Luxembourg, where the ispace lunar yard has a surface area of 8 x 8 meters and contains 3 tons of surface material while the University of Luxembourg facility boasts 7 x11 meters with 20 tons of surface material.

Fig 1. ispace rover in the University of Luxembourg LunaLab

In this paper we will investigate multiple existing lunar facilities, before moving on to the different elements to consider when trying to recreate lunar surface with a high degree of optical fidelity. We will discuss the different issues and challenges encountered, as well as elements that we plan to enable to improve in future work.

2. Existing facilities

Before exploring the details on building an indoor testing facility, we are listing several existing facilities which were considered based on their features before construction.

2.1 NASA Ames - US

The NASA Ames Lunar Testbed [1] has a 4 x 4 metre footprint with a depth of 0.5 metres. In order to have a high material fidelity, it uses JSC-1A Regolith Simulant. In addition, the facility uses a setup of 12 lights to facilitate changes in illumination conditions for dataset generation. In the past, it has been used for rover excavation tests, as well as testing of sensor payloads for localisation purposes. The POLAR stereo dataset has been produced here with a stereo camera and a LIDAR as ground truth [2].

2.2 DFKI - Germany

While this facility does not use stimulant or even sand, it has a large slope that is used to demonstrate the climbing capabilities of multi-legged robots to crawl up the steep slopes of craters [3].

2.3 GMRO - US

Granular Mechanics and Regolith Operations (GMRO) laboratory in Florida, US. It is an 8 x 8 metre enclosed chamber filled with regolith up to 1.5 metres. Its primary purpose is to test mechanical systems of regolith mining robots. It is filled with Black Point-1 lunar-regolith simulant [4].

2.4 Sagamihara - Japan

The space exploration expert building is owned by the Japanese Space Agency (JAXA). It has a 22.6 x 17.7 metre sandbox filled with 425 tons of coarse and fine silica sand. Because of the height of the facility and amount of sand, one can also simulate rough terrain with steep slopes. The sand however, is not mimicking the optical properties of lunar regolith [5].

2.5 DTVC – South Korea

The Dirty Thermal Vacuum Chamber (DTVC) facility [6] in South Korea can host up to 25 tons of soil with a surface area of 4.0 x 3.8 metres for roving operations. The environment can be held at vacuum and at temperature ranges between -190℃ and +150℃. This facility represents the closest conditions to replicating the actual environment on the lunar surface. This, however, also limits the size of the testing ground due to the large equipment needed to produce a vacuum.

2.6 Future ESA facility - Germany

The European Space Agency (ESA) has been planning to build a 1000 m² indoor facility named Luna at the European Astronaut Centre (EAC) in Cologne, Germany [7].

2.7 Mars Analogue facilities

In addition to Lunar testing facilities, we also looked at Mars analogue testing facilities, which face similar problems. While the illumination on the moon conditions are significantly different for Mars, the unstructured desert-like environment is similar and therefore, a good starting point to test vision-based navigation systems. Two notable facilities in this field are the Astrium Mars Yard in Stevenage [8] and the Mars Dome at UTIAS, Canada [9].

3. Construction Process

For all of the existing facilities mentioned in the previous section, none are operated or owned by a private company and therefore, are not as cost effective as needed for our R&D process. The DFKI facility come the closest to what we require for testing. To specify, our requirement is a facility where daily testing can be done with a high degree of optical fidelity, but without the need of complex health and safety requirements.

During our experiments, we found that the single biggest factor for optical fidelity is the scene illumination. Having a strong single light source is required, while the matte black surroundings give much more accurate shadows. The surface material is the next element to improve the image quality. Lastly, the surface shape depends on the area of the moon the facility is supposed to mimic.

Fig 2. Opposition effect with washed out terrain features observed on lunar surface (NASA)

3.1 Surface Material

The ideal material to use for the surface material is regolith simulant, which is a fine ground basalt rock that is ground to the size of the particles found on the moon. The material is however, expensive to procure, and it is also a health hazard, as the tiny sharp particles can be carcinogenic when inhaled [10]. Instead, we are using regular basalt-type rocks and sand at a size of 0.2-1mm and gravel of 2-5mm in size. The benefit to this is that this type of material can also be procured locally and does not need to be produced specifically for this application. However, the downside is that the material is not as powdery and does not have the same retro-reflective properties as regolith. As a result, the "opposition effect" (Fig 2), which can be observed on the moon with the sunlight directly behind the camera, cannot be reproduced in our facilities.

3.2 Lighting

Regarding the illumination, we focused on a single light source for both lunar yards, in order to achieve single and high contrast shadows. We have experimented with two different lamps, a simple 2000W

Fig 3. 2000W Light source with barn doors used to simulate the solar illumination

tungsten bulb and a 1000W tungsten bulb with a focussing lens. Tungsten bulbs can also produce radiation in the UV and IR spectrum, and they mimic the radiation of the sun reasonably well. They can produce an intensity of up to 100 000 lux (at a one-metre distance), which is lower than what the 135 000 lux we expect as solar constant on the lunar surface [11]. The field of view of the light should also be considered when planning the possible placement options of the light, and the space needed between the testing terrain and the lamp to illuminate the complete scene. For this reason, we generally operate the lights in flood mode with their widest field of view. The height of the light should also be considered when simulating equatorial regions, as the sunlight must be position above the terrain. In our case, we are primarily considering cases in the polar regions, where our issue is the minimum height of the light-stand.

For sensor-specific tests, such as active IR sensor resistance to sunlight, we use spot mode as it produces a higher intensity illumination for a smaller field of view. In order to perform specific illumination tests, we have plotted (Fig 4) the illumination intensity falloff for the

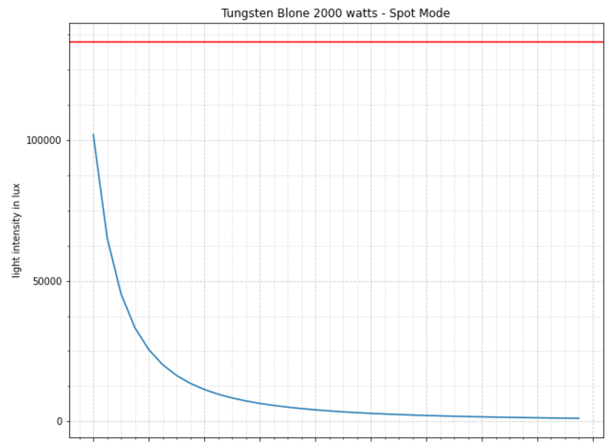

Fig 4. Light-source intensity fall-off over distance

different lights. For more accurate results, however, the use of a light metre is recommended to measure the intensity of the illumination including, the light reflecting off the ground.

3.3 Shadows

One particular issue we encountered is that the shadows in our facility were not as pitch-black as they are on images from the lunar surface. One reason for this is the lack of tall structures on the moon that can bounce light into the shaded areas. In an indoor testing facility, the primary sources of reflected light are the walls and the ceiling. In order to mitigate this issue, we have painted both areas black, which results in darker shadows, but also a much darker overall environment. This difference can be clearly observed between *Fig5* and *Fig6*. Another way to improve this problem is to make use of barn doors on the light-source, to limit the direct lighting to the surface area, without illuminating the walls or the ceiling.

3.4 Surface Shape

The surface shape of the testing facility depends on the target area we are trying to mimic. The lunar surface varies widely between smoother areas, such as the maria regions and the rougher highland regions. As surface observations are not available for most landing sites, we need to make assumptions based on the distributions of larger craters and rocks in the targeted area [12]. In addition to the distribution of craters and rocks, we have also considered the shape of the craters and have replicated several in different sizes. When designing these craters, we have tried to be as accurate as possible in mimicking their circular shape and their rims [13]. Overall, the type of surface should be considered before the construction, as this dictates the amount of surface material needed.

3.5 Other considerations

Another issue we have encountered with the finer surface material is the need for ventilation. The powdery nature of the fine particles leads to dust cloud during the removal of rover tracks, or the reshaping of the surface. Before continuing with testing, we have to wait for the dust to settle. The fine particles also cause problems for robotic systems, as the grains tend to enter any openings, including inside mechanical systems.

Lastly, when testing localisation systems, a ground truth localisation system should be considered. To address this, we are making use of *Optitrack* motion capture systems, which are mounted on the ceiling. As they operate in the IR spectrum, they are not interfering with most of our camera tests. Alternatively, active IR markers can also be used on the rover, which greatly reduces the overall IR scene illumination of the motion capture system.

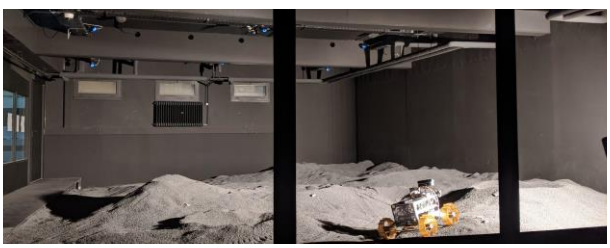

Fig 5. LunaLab with localisation system mounted on the ceiling.

Fig 6. ispace lunar yard facility with sunlight and different terrain features

4. Conclusion

In this paper, we presented the construction of two facilities to test vision-based navigation systems and remote operation for lunar surface rover systems. We have introduced the different technical challenges and how they were overcome to build an easy to use and cost-efficient solution for daily testing opportunities. Through trial and error, we have built these facilities from scratch and learned how to improve the optical fidelity of the environment trough, light-sources, surface material, and other modifications to the facility.

As future work, we are currently considering a stronger light-sources in order to mimic the full strength of the sun. We area also working towards covering any remaining areas of the facilities in matte black, to improve the contrast of the shadows. Lastly, we are looking into acquiring additional volcanic rocks of different sizes, so that we can change the environment based on scenario needs of randomly distributed rocks.

Acknowledgements

This research was completed with the support of ispace Europe and the University of Luxembourg and was funded by the Luxembourg National Research Fund (FNR grant number 11824057).

References

[1] M. Everingham and N. Pelster, “Lunar analog creation: Preparation and operation of a lunar regolith simulant testbed,” *AIAA Sp. 2009 Conf. Expo.*, no. September, 2009, doi: 10.2514/6.2009-6510.

[2] U. Wong *et al.*, “Characterization of Stereo Vision Performance for Roving at the Lunar Poles,” *ntrs.nasa.gov*, 2016. https://ntrs.nasa.gov/search.jsp?R=20160011187 (accessed Feb. 17, 2020).

[3] F. Cordes and F. Kirchner, “Heterogeneous Robotic Teams for Exploration of Steep Crater Environments,” *Planet. Rover Work. ICRA’10*, no. February, 2010, [Online]. Available: http://ewh.ieee.org/conf/icra/2010/workshops/PlanetaryRovers/.

[4] I. Lane, John and Mantovani, James and Mueller, Robert and Nugent, M and Nick, A and Schuler, J and Townsend, “Optical Extinction Measurements of Dust Density in the GMRO Regolith Test Bin,” vol. 2011, no. 2865, pp. 1–9, 2016.

[5] JAXA, “Space Exploration Experiment Building.” http://www.ihub-tansa.jaxa.jp/afse.html (accessed Oct. 17, 2019).

[6] Y. Yoo, T. Chung, H. S. Shin, E. Patrick, R. Graham, and G. Fletcher, “The KICT Dirty Thermal Vacuum Chamber (DTVC) : Large-Scale Space Environment Simulation of the Moon and Mars,” p. 10223, 2017.

[7] European Space Agency, “Luna facility brings Moon to Earth,” 2018. https://www.esa.int/About_Us/EAC/Luna_facility_brings_Moon_to_Earth (accessed Sep. 17, 2019).

[8] P. Meacham, N. Silva, and R. Lancaster, “The

Development of the Locomotion Performance Model (LPM) for the ExoMars Rover Vehicle," *ASTRA 2013 - 12th ESA Work. Adv. Sp. Technol. Robot. Autom.*, no. 1, 2013, [Online]. Available: http://robotics.estec.esa.int/ASTRA/Astra2013/Papers/meacham_2811294.pdf.

[9] C. H. Tong, D. Gingras, K. Larose, T. D. Barfoot, and É. Dupuis, "The Canadian planetary emulation terrain 3D mapping dataset," *International Journal of Robotics Research*. 2013, doi: 10.1177/0278364913478897.

[10] S. J. Indyk and H. Benaroya, "A structural assessment of unrefined sintered lunar regolith simulant," *Acta Astronaut.*, vol. 140, no. April, pp. 517–536, 2017, doi: 10.1016/j.actaastro.2017.09.018.

[11] S. Darula, R. Kittler, and C. A. Gueymard, "Reference luminous solar constant and solar luminance for illuminance calculations," *Sol. Energy*, vol. 79, no. 5, pp. 559–565, 2005, doi: 10.1016/j.solener.2005.01.004.

[12] T. Fong, "Lunar Robotics Update," pp. 1–32, 2018, [Online]. Available: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190001347.pdf.

[13] B. Hager, "Dynamic thermal modeling for moving objects on the Moon," 2013.