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Location selection and layout for LB10, a lunar base at the Lunar North Pole with a liquid mirror observatory

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ABSTRACT

We present the site selection process and urban planning of a Lunar Base for a crew of 10 (LB10), with an infrared astronomical telescope, based on the concept of the Lunar LIquid Mirror Telescope. LB10 is a base designated for permanent human presence on the Moon. The base architecture is based on utilization of inflatable, rigid and regolith structures for different purposes. The location for the settlement is identified through a detailed analysis of surface conditions and terrain parameters around the Lunar North and South Poles. A number of selection criteria were defined regarding construction, astronomical observations, landing and illumination conditions. The location suggested for the settlement is in the vicinity of the North Pole, utilizing the geographical morphology of the area. The base habitat is on a highly illuminated and relatively flat plateau. The observatory in the vicinity of the base, approximately 3.5 kilometers from the Lunar North Pole, inside a crater to shield it from Sunlight. An illustration of the final form of the habitat is also depicted, inspired by the baroque architectural form.

1. Introduction

The Moon is the closest celestial body to the Earth and therefore an establishment of a small settlement on the Lunar surface may happen in the foreseeable future. Even though the Moon is, for now, not a target for any clearly defined human exploration initiative, this does not mean that in future decades it will not be under consideration once more.

1.1. Lunar architectural concepts

There are a number of architectural concepts proposing establishment of a settlement on the Moon. A very motivational but currently unrealistic concept by Kraft Ehricke proposes a fully sustainable city for thousands of people called "Selenopolis" [1]. There are of course more modest concepts, such as the modular elevated bunker lunar base of Jan Kaplicky and David Nixon; mobile bases such as "Habot" [2], "Mobitat" [3], the modular Human Lunar Surface Base [4], the SICSA lunar base concepts [5] and others, such as the concepts in [6] or on-line.[1]

The more "traditional" lunar base concept is based upon pre-fabricated modules that will be transported to the lunar surface (for example the concept in [7]). These concepts tend to be heavy and therefore costly. Inflatable structures have been proposed as a way to construct a base with less material. The modules or parts of the base are carried to the lunar surface as inflatable structures to be pressurized in situ (Inflated-Torus concept by Larry Toups and Kriss Kennedy [8]). Further gains in mass can be achieved by using lunar materials for construction, especially for radiation shielding.

Regolith solidification can be realized through bonding of regolith particles below the melting point by emitting

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[1] For example the on-line archive of the National Space Society at http://www.nss.org/settlement/moon/library/

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directed microwave radiation or by heating and compacting the regolith. This process is a construction technique that is unique to the lunar environment. Fast solidification of the lunar dust is possible mainly thanks to the very thin atmosphere on the Moon and the high abundance of iron in the lunar dust. The sintering may be performed in a number of layers according to power source capacity or technique used [9]. The surface layer can also be melted to create a glass-like surface and become easily cleanable from lunar dust [10]. The sintering technique will be essential for lunar settlement construction. A well designed robotic vehicle enabling moving and sintering of the regolith [11] is essential.

For an outline of different lunar base proposals and construction methods, the reader is referred to the review of lunar construction methods by Benaroya and Bernold in [12].

1.2. Lunar operations

An equally important aspect of Lunar base construction is the operational framework on the Lunar surface. Activities can be performed either manually, robotically (fully or partially autonomous robotic systems) or with a tele-operated robotic system, guided from the Earth [13]. Tele-Robotics and Autonomous Systems can reduce the risk and cost associated with human activities on the lunar surface. High level of robotic autonomy would also offer significant time advantages with regards to tele-operations [14].

A framework for semi-autonomous tele-operation of multiple cooperative robots for lunar exploration was proposed by Lee and Spong in [15]. It consists of two control loops, a local autonomous control and integral communication node on the Moon and a bilateral tele-operation loop which enables humans to remotely control operations. This framework is created to ameliorate the problem of communication latency and window contact duration, for robots on the Moon operated from the Earth.

The desire to minimize human involvement in lunar construction operations has its roots in risk minimization and cost reduction. The preferred operational framework is to have as many automated operations as possible. If the complexity of the task is high, then tele-operated machinery could take over. Human involvement should be reserved for the absolutely critical tasks, although considerations should be given to the overall planning to allow humans to be able to be involved in any task, if the necessary conditions arise. An extensive analysis of the integration between architecture, operations and exploration can be found in [16].

Lunar Base 10, or LB10, is an architectural concept of a robotically constructed base located on the Lunar North Pole [17]. LB10 should be for the most part deployed and constructed without human presence on the Moon, to minimize risk and overall cost. The concept also explores the coupling of a permanently manned lunar habitat (designation: LB10-H) with a major astronomical observatory (designation: LB10-T). We have chosen an infrared observatory on the lunar poles, a concept highlighted by Angel et al. in [18] as our baseline, since it is detailed enough to provide functional requirements for the LB10 siting and construction. Our purpose was to investigate the interaction between the two elements: the instrument that requires darkness and the habitat that is better served if placed in highly illuminated areas.

We present in this paper the location selection study and the extended base layout design, based on the selected location. The deployment strategy, the exterior and interior design of the base as well as structural analysis for the main elements, will be described in future work.

2. Methods

We analyzed areas of the North and South Lunar Poles to find out the most appropriate site for the lunar settlement. The analysis was based on Lunar Reconnaissance Orbiter (LRO) data. More specifically, we used data from:

(i) Polar Mosaics from the LRO Narrow Angle Camera (NAC) at 2 m/pixel resolution.
(ii) LRO Lunar Orbiter Laser Altimeter (LOLA) polar maps at 5 m/pixel resolution.
(iii) LRO NAC illumination maps.[2]

For the location selection process, analysis was performed using the NASA ISIS3 software package for reading the spacecraft data. Spatial and geographical analysis was performed with the Geographic Resources Analysis Support System (GRASS-GIS). Finally, the visualization of the data and 3D representations of the selected sites were performed with GRASS-GIS and Quantum-GIS software packages. The map projection ellipsoid for the Moon used was a stereographical polar projection with ellipsoid parameters $a = 1\,737\,400$ and $b = 1\,737\,400$.

The concept design and the urban design drawings with contour lines were done in Autodesk AutoCAD and ADOBE software. Merging of the vector drawings and photography or figures produced by GRASS GIS was performed in ADOBE Indesign, and the figures' quality and compression was optimized in ADOBE photoshop. Some vector artwork was also done in the ADOBE InDesign software working with standard formats JPG.

3. LB10: definition

3.1. Mission objectives and timeline

The primary goal is to establish a permanent human presence on the Moon, by constructing a lunar base

[2] The data release used was the LRO MOON LROC 5 RDR V1.0, from the NASA Planetary Data System (PDS). For the Altimeter data, we used the 2009 Lunar Orbiter Laser Altimeter Raw Data Set from the LRO-L-LOLA-4-GDR-V1.0 2010 release. The polar mosaics were obtained from NASA/GSFC/Arizona State University on-line archive from http://wms.lroc.asu.edu/lroc/nac_polar_mosaic (last accessed March 2011). The illumination maps were taken from the LRO website http://www.nasa.gov/mission_pages/LRO/multimedia/lroimages/lroc-20110316-north.html and http://www.nasa.gov/mission_pages/LRO/multimedia/lroimages/lroc-20101215-south.html, last accessed March 2011.