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Mission architecture decision support system for robotic lunar exploration

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ABSTRACT

It is common practice in the landing site decision process for planetary or lunar exploration to limit the choice of sites to locations that strictly meet the technical and safety requirements of the lander. The science objective is ultimately implemented within the operational requirements of the mission strategy.

In this paper, we present a study that derives the technical requirements of the landing strategy by considering proposed landing sites. The study reviewed the objectives of the future robotic exploration of the Moon and proposed targets from the Apollo era to our time. Three types of strategies are defined, namely, rover missions, immobile landing stations, and impacting probes. The capabilities and restrictions of each system are taken into account and compared to the science objectives of the proposed landing sites. A Geographic Information System (GIS) with lunar datasets was developed and the methodology was implemented. The study concludes with a description of the resulting mission scenarios that were assigned to the targets. The technical requirements for each landing system to fulfil these scientific objectives are derived and the feasibility, based on the technological readiness, is discussed.

1. Introduction

For surfaces which have been examined by many orbital instruments and landers, such as the one of Moon or Mars, it is the choice of the landing site that bears the key to the scientific results of a mission. The most sophisticated planetary exploration system (either robotic or even human) will only return little novel results if deployed on the wrong spot of the surface. Despite this fact, practice in space exploration shows that the process of landing site selection comes at a stage when the engineering of the landing system is already forced to deliver a strict frame of operational parameters to the overall mission design. Hence, the choice of the final site leads to a compromise or a trade-off between the multiple scientific goals of a mission and its operational restrictions (Grant et al., 2004; Chamitoff et al., 2005). The scientific potential or scientific rationale of an exploration mission is ultimately adapted to what is technically feasible with an a priori given hardware platform.

In this paper, we describe the development of a landing strategy decision support system that works the other way around. A methodology is presented to derive exploration strategies based on the scientific objectives for previously proposed landing sites on the lunar surface.

A brief review of exploration objectives for the lunar surface is given. Landing sites that offer the potential to meet these scientific goals are considered in this process. The site proposals reach back to the Apollo era until more recent proposals. The list of proposals is certainly not exhaustive; there are numerous spots on the lunar surface of high scientific interest. However, the method of this approach is presented through these examples for discussion and eventual later refinement. Each site is evaluated and an adapted landing strategy is proposed that meets the scientific goal. To assure the technically feasibility of the mission, three categories of robotic missions are defined: rovers, landing stations, and impacting probes. Each of these systems has its capabilities and restrictions. The landing strategy decision process was implemented into a Geographic Information System (GIS) with lunar data. It merges the three mission types and the proposed sites as a function of their respective objectives and constraints. In the final part of this paper, the result of this process is described, which led to different mission scenarios. We conclude with the description of some technical requirements for future exploration systems to fulfil the scientific objective of the landing site proposals studied here.

2. Review of the objectives of robotic lunar exploration activities

A concise overview of the benefits and the need for a return to the Moon by humans or robots can be found in Crawford (2004).

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Neal (2009) summarizes how much was learned during the first stage of lunar exploration and what is left to explore in the post-Apollo era. The author compiled a comprehensive list of reasons to return to the Moon, with reference to the space policies of leading space-exploring nations. Robotic exploration was, and will again be, the precursor in the preparation of crewed interventions on the lunar surface (Boyle et al., 1962; Wilhelms, 1985; Spudis and Taylor, 1992; Wargo and Hill, 2007; Plescia et al., 2007). In this function, its primary mission goals are as follows: (i) the reconnaissance and cartography of safe, hazard-free landing sites (Jolliff et al., 2009; Chin, 2007), (ii) the study of the chemical composition of the surface in order to locate resources and evaluate the feasibility of the in-situ use of elements, such as water, hydrogen, oxygen, and helium, and the mining of rare elements (Haskin, 1985; Podnieks and Roepke, 1985; Meek et al., 1985; Matsumoto et al., 2007; Kulcinski et al., 1992; Spudis and Hood, 1992; Swindle, 1992), (iii) the characterisation of the radiation environment, the lunar atmosphere, and space hazards (Gerzer, 2007; Plescia et al., 2007; Foing and Ehrenfreund, 2008); and more generally, (iv) the test of new technologies needed for human exploration (Foing and Ehrenfreund, 2008). The ultimate goal of lunar robotic development is supposed to lead to a teleoperated infrastructure that supports human exploration. However, apart from this precursor function, robotic missions can also help unravel other questions concerning the Moon or its space environment, such as (i) the lunar origin (National Research Council, 2006), (ii) the identification of the geological processes that formed the surface (i.e., cratering, space weathering, volatile delivery, or volcanism) to establish comparative Earth-parallels and estimate the absolute surface age (Wilhelms, 1987; Crawford, 2004; Foing and Ehrenfreund, 2008; Flamini and Ori, 2007), (iii) the composition at sites of known stratigraphy context in order to extrapolate and model composition at unsampled sites and to allow calibration of orbital measurements (colour and gamma-ray) (Wilhelms, 1985; Wilhelms, 1987), (iv) the crust, the composition, and the state of the lunar core (National Research Council, 2006; Wilhelms, 1985; Lognonne et al., 2007; Schmitz et al., 2007; Tanaka et al., 2007), and (v) astronomy from the lunar surface, eventually on the Far Side, shielded from the electromagnetically noisy Earth (Spudis and Hood, 1992; National Research Council, 2006; Tanaka et al., 2007).

Numerous landing sites were proposed that offer the potential to reply to the above stated scientific wish list. Fig. 1 shows an overview of the locations that were proposed in the references listed in Table 1. The perimeters around each landing site have a radius of 50, 100, and 200 km and show a theoretical operation perimeter of robotic or manned vehicles, which will be discussed later.

Three categories of exploration activities are derived from the objectives and will be used for further consideration (see Table 1): (CP) reconnaissance, cartography, and high-resolution photography of the location, (IS) in-situ science using instruments such as microscopic imagers, spectrometers (Mössbauer, APXS, thermal emission, laser emission), or seismic instruments, and sample return (SR), which represents the highest effort either by manned or robotic means. The minimum requirements are stated per landing site. These were derived from the recommendations of the references cited in the last column. No priority is given in the order of the table, but the number of references for similar sites can provide a feedback on the scientific considerations of a site.

All sites that are discussed by Head (1970) and Greeley (1974) represent original Apollo mission landing site proposals which were never reached. Taylor (1992) argues for a return to the Apollo 17 landing site at Taurus-Littrow. While the author underlines the importance of a return by astronauts (and not robots), he also gives some considerations about the scientific value of a robotic mission to this site. This study concentrates on robotic missions either with scientific objectives or as a precursor to human activity. The two mission site proposals for manned missions are the South-Pole Eternal Light Region (ELT) (Spudis et al., 1985) and Mare Smythii (Spudis and Hood, 1992; Swindle, 1992).

3. Restrictions of robot lunar exploration activities

The second step in the mission strategy decision process is providing the definition of the parameters for each site that

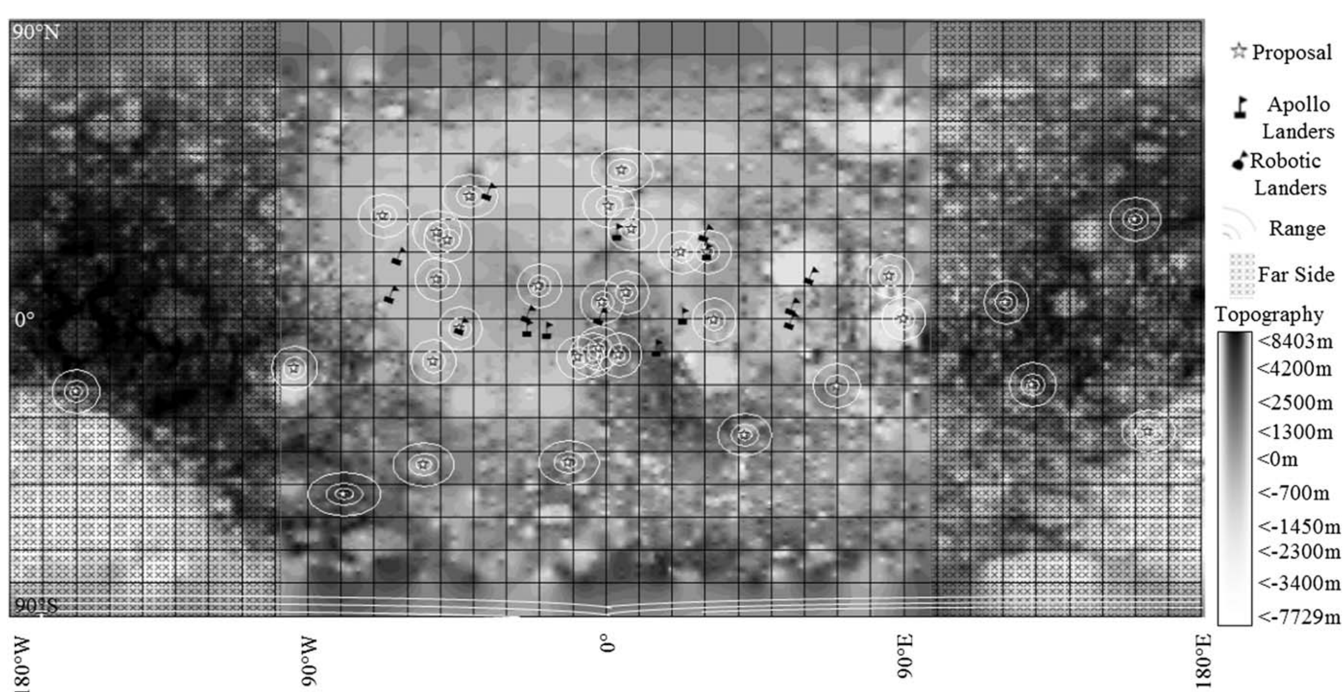

Fig. 1. Previous and proposed new landing sites on a topographical chart of the lunar surface. (The topographical data courtesy of the PDS Geoscience Node).