Planetary and Space Science 58 (2010) 893–903

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Feasibility study of a lunar landing area navigation network deployed by impacting micro-probes

P. Weiss *[,1], K.L. Yung

Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, DE406, 1Yuk Road, Hung Hom, Kowloon, Hong Kong, People's Republic of China

ARTICLE INFO

Article history:
Received 29 December 2009
Received in revised form
11 February 2010
Accepted 12 February 2010
Available online 3 March 2010

Keywords:
Moon
Penetrator
Navigation network
Beacon
Impact

ABSTRACT

Exploration activities on the lunar surface will require precise knowledge of the position of a robotic or manned vehicle. This paper discusses the use of radio beacons as method to determine the position of a mobile unit on the surface. Previous concepts consider the installation of such equipment by the robot itself. A novel idea is discussed here, namely to use miniaturized radio beacons which are deployed (released) during the descent of the lander on the surface. This idea has three major advantages compared to previous proposals: (i) it avoids the time costly and energy consuming installation of the equipment by a rover. (ii) The impact velocities of the probes are in reasonable range since the probes are deployed at low altitude from the main lander that approaches its final landing site. (iii) The probes can take reconnaissance pictures during their free-fall to the surface. This method will therefore deliver charts of the proximity of the landing area with higher resolution than those done by orbital means. Such information will enable scientists and mission operators to precisely plan robotic excursions (and later Extra Vehicular Activity) through the identification of hazardous areas and spots of interest.

The paper will study the feasibility of this system from different aspects. The first section will outline the application scenario and the potential outcome of such a system for the coming phase of lunar exploration. A technological readiness review was done to evaluate if the payload instrumentation for these high velocity impacting probes is available. The second section presents the simulation of the impact process of a preliminary probe model in nonlinear transient dynamic finite element analysis using the Lagrangian hydrocode LS-DYNA. The purpose of this simulation was to evaluate if the beacon is able to communicate with the mobile unit even when buried into the soil.

The integration of this payload into coming lunar missions will contribute to the international efforts of lunar exploration with a landing site ad hoc navigation system for robotic or manned excursions.

1. Introduction

A return to the Moon with robotic vehicles is currently planned in the 2013–2020 time frame by various nations. Four decades after the last human presence on the lunar surface, most of these missions aim to develop and test the technologies that are necessary to establish a permanent outpost. These missions will deliver precious data for the development of facilities that could enable a long-duration human presence on the Moon (Foing and Ehrenfreund, 2008; Gerzer, 2007; Plescia et al., 2007). Geochemical in-situ soil analysis will complete current sample databases. More than 40 years after the end of the "Apollo" and "Luna" program, these measurements can be done with improved instruments. This knowledge will allow a more precise evaluation of the ISRU elements in the soil, leading to concepts for the retrieval, processing and usage of such resources by future lunar inhabitants (Mendell, 1985; Matsumoto et al., 2007; Kulcinski et al., 1992; Spudis and Hood, 1992; Swindle, 1992).

Life support technologies will include navigation and communication infra-structures to assure the security of personnel and robots during surface expeditions and EVA (Extra Vehicular Activity). New strategies need to be developed to explore sites that could not have been assessed before, such as permanently shadowed craters, near–Far-Side regions, shadowed from Earth, and areas of rugged topography (Spudis et al., 1985; Spudis and Hood, 1992; Swindle, 1992). Reconnaissance and cartography of the local region around the landing site will allow to plan excursion efficiently, and to search for safe, hazard-free locations for exploration (Chin, 2007).

The concept of an ad-hoc landing navigation network is discussed in this paper. The objective of such a payload is to

* Corresponding author. Tel.: +852 65489334; fax: +852 23625267.
E-mail addresses: weiss@cppm.in2p3.fr, peter.weiss@polyu.edu.hk (P. Weiss).
[1] Present address: Centre de Physique des Particules de Marseille (CPPM), CNRS, Case 902, 163 Avenue de Luminy, 13288 Marseille Cedex 9, France.

0032-0633/$ - see front matter
doi:10.1016/j.pss.2010.02.007

build a navigation network based on radio beacons by the use of impacting micro-probes: a series of four impacting micro-probes is proposed which is deployed during the descent of the lander onto the lunar surface. Each probe will consist of an optical system for site reconnaissance and a telecommunication beacon. The probes could also feature geochemical analysis instruments to analyze the soil and search for ISRU elements. The probes are deployed in sequence during the landing approach. In free fall, without deceleration system, those will impact prior to the touchdown of the main lander. The vision system will deliver high resolution photography of the area surrounding the landing site of the main lander, which can be used to assess the local environment for potential hazards to the mobility of a later deployed rover, and identification of locations of interest. While the optical system will not survive the impact, the telecommunication device will continue working after the impact. This device will serve as ad-hoc navigation beacon network to determine the location of a mobile unit during its excursions.

An option to this scenario is to equip the probes with instruments that can identify buried water ice. In this configuration, the probe can be deployed into permanently shadowed areas, where its instruments would identify buried water ice, if present. The impact sites of one or several probes will be in the reach of the rover. It is therefore possible to examine the impact site of the probe by the robot later. This will deliver insights about the impact condition of such instrument as technological assessment for future penetrator mission. The possibility to "revisit" impactor-type mission sites is only given in the constellation with a landing mission. The analysis of the impact site will enable scientists to examine fresh ejecta. Models later discussed show that this would give the opportunity to analyze ejecta from several meters depth through the instruments of the rover.

This work describes the feasibility study of such a low-altitude penetrator payload: the technological readiness for its main components is studied in the first section. The ruggedness and degree of miniaturization are of highest priorities for this application scenario. The report will review different beacon technologies. The feasibility of the deployment method is then evaluated by simulating the impact of a design model onto lunar regolith. The penetration depths were derived from empirical formula and hydrocode simulations. The objective of this effort was to evaluate the capability of the probe to communicate with the mobile unit even when buried into the soil.

2. Literature review

2.1. Mission objectives

The purpose of this manuscript is to describe the concept of micro-penetrators as deployment method of a surface navigation network. In this section, it will be explained how such a system could meet different objectives of the coming phase of lunar exploration.

2.1.1. Positioning and navigation

Excursions of robotic vehicles and ultimately EVA by astronauts will require accurate positioning systems to perform a secure exploration of the areas in proximity of the landing site. The idea of using standalone radio beacons for such task is not new, and was proposed for lunar and planetary applications (Beggins et al., 1988; Abelson and Satter, 2005). The novelty in our concept is the idea, to deploy such equipment in low altitude during the descent of the landing craft. The positional beacons are designed to survive the impact. Such beacons can be used to determine the location of a rover (longitude, latitude and altitude), and positioning system will be ultimately necessary to allow operations out-of-sight from the lander, a relay satellite or Earth.

The proposed deployment through penetrators solves several problems related to the installation of surface equipment: (i) it avoids the time and energy consuming setting up of such beacons by rovers or astronauts on different, distant locations. (ii) The fact that the system will be buried partly in regolith through the impact will decrease the problem of the thermal management of its components: at a depth of -50 cm virtually no temperature fluctuation between the lunar day and night has been measured (Vaniman et al., 1991). However, the penetrators will still need a thermal protection mechanism, since the isolating layer will be disturbed through the impact. (iii) As a solution of the problem of surface navigation, this concept also serves as penetrator technology verification within the time frame of coming lunar missions.

2.1.2. Landing site reconnaissance

The main objective of the proposed payload is to enhance the capabilities for secure surface operations and navigation: it is proposed to deploy a series of four micro-impactors during the landing phase of the main vehicle. It is assumed that the main lander is actively decelerated by retro thrusters. The probes are released at different instances of the approach. During their descent, they transmit surface pictures of the local landing area at increasing resolution. The result of this method will be to produce accurate charts of the surrounding area. Those can be used to identify locations of scientific interest for exploration activities by rover, once the lander is landed: the imagery will help to visually identify surface spots that call for further investigations in the perimeter of the landing site.

2.1.3. Identification of potential resources

One major goal of coming lunar missions will be to measure abundances of resources that are needed to sustain life during long duration missions. Potential candidates for sites with high abundances of water ice are permanently shadowed craters. Although these locations will be a primary mission target for robotic vehicles, their exploration will come with a high risk for the vehicle, and a high price in terms of energy consumption (the rover will be driven by battery or Radioisotope Thermoelectric Generator, and will require artificial illumination). The here presented concept offers the potential to deploy micro-impacters into these regions during the landing of the main craft at the poles. The deployed beacon could identify water ice in the soil of its impacting site. Upon confirmation on its presence, it could serve as radio pinger to lead the rover to the spot where the ice was found.

2.1.4. Measurement of the properties of the lunar dust

Conclusions on the soil's geo-mechanical characteristics can be drawn through investigation of the impacting site by a rover. The ballistic impact will excavate fresh subsurface material which can be examined in-situ. Such material hosts the possibility of not having been substantially altered by space weathering processes and would therefore be in a rather pristine state.

2.2. Review of the technological readiness

The development of the impact-deployed radio beacons can be achieved by using technologies which have reached technological maturity. Some of these were tested either in real space missions or through terrestrial trials in the last years. The following section