EPSC Abstracts
Vol. 7 EPSC2012-931 2012
European Planetary Science Congress 2012

A Proof of Concept for a Lunar Spherical Rover

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Abstract

Planetary environments are harsh and not well-characterized, thus imposing important constraints on the design of exploration rovers.

A new conception (at least for lunar and planetary rovers) that avoids the detrimental effects of lunar regolith is proposed: a spherical rover with no moving parts in direct contact with the ground.

1. Introduction

Up to now, planetary and lunar rovers have been wheeled-driven, and there are plans for legged exploration rovers. While this is usually seen as an advantage –due to the flight experience– in some cases, the unavoidable presence of gears and mobile parts can be a significant hazard to the mission. The abrasive lunar regolith has been the origin of substantial problems with Apollo rovers, and is a serious hazard even for modern ones.

Here we propose a completely different configuration: a spherical rover in which all the moving parts are protected from the environment by an external spherical shell.

2. Roving mechanism

The rover moves by displacing a mass from its equilibrium position. Once the equilibrium of this ballast is perturbed, the whole rover rotates to reach again its equilibrium configuration. By continuously perturbing this equilibrium the rover can move and even climb slopes. There are two important figures of merit of this kind of rovers: the ratio between the counterweight mass and the total mass of the rover (μ), and the ratio between the position of the center of mass of the ballast and the radius of the spherical shell (δ). Then, the maximum slope that can be climbed is given by:

$$\beta_{\max} = \sin^{-1}(\delta\,\mu) \qquad (1)$$

$$\delta = \frac{R_{CM}}{R} \qquad (2)$$

$$\mu = \frac{M_{CW}}{M + M_{CW}} \qquad (3)$$

It must be noted that both δ and μ are less (or equal in the extreme, unfeasible, case) than 1, and that to obtain this expression we have assumed that the sphere does not slide. For typical cases, δ≈0.7 and μ≈0.5 which allows the rover to ascend slopes of less than 21 degrees. Our goal is to design the rover in such a way that it would be able to climb slopes up to 35 degrees, near the limit slope for regolith. This can be done, for example, by using the ballast to house batteries and/or other massive components in order to increase both δ and μ as much as possible.

The rover can also steer by displacing the counterweight perpendicularly with regard to the translation path. In this way we can control the direction in an effectively manner.

By its simplicity, the propulsion mechanism is very robust, and hence it offers a high level of safety at a minimum cost. It is also easily scalable to allow large payloads.

There are several similar, independent designs in the literature, as can be seen in [1,2]. The origin of this roving mechanism can be tracked as far as 1893.

3. Applications

This kind of rovers can be employed in several ways. The first one is as stand-alone exploration rovers, carrying experiments and cameras to points up to several hundreds of meters to the vehicle used to make a soft landing. Even if the lander is the main scientific vehicle, the engines will perturb the state of the regolith near to the landing site, thus modifying to some degree the scientific results. Having the possibility to move a few tens of meters (well beyond the reach of robotic arms) would ensure the access to pristine materials. They could also act as scouts –or navigation aids– for larger, more advanced rovers. These rovers, probably wheel- or leg-driven, have a typical speed much lower than spherical rovers, and safety issues would preclude its use on rough environments, like inside craters, where these small rovers could extend the mission's operational capabilities. The algorithms [6] used to align the coils in the case of using resonant inductive coupling would easily allow pointing the experiments carried on the spherical rover if necessary.

5. Open issues

There are still some open issues. The most important is related to the endurance, as the spherical shell is not very apt as a solar cell substrate (even for thin, flexible cells). In any case, even if we had solar cells on the surface of the rover, they would be partly darkened by regolith, and their efficiency would be severely diminished. To deal with this problem we are exploring the possibility of employing wireless power transmission [3]. In this case, the lander (mandatory for our rover design) would act as the energy provider; the energy could be relayed by laser means (with the problem again of the regolith covering the outer surface of the spherical shell) or by resonant inductive coils [3,4,5]. To do so with a good efficiency, it is essential to control the relative orientation of the resonant coils; this is not a problem, as the classical ball-plate problem has been satisfactory solved, and efficient algorithms are provided by [6]. With current technologies, an efficiency of 80% can be achieved at a distance equivalent to a few coil diameters [5].

There is also an issue with the communication subsystem that we have solved by using small antennas with controlled phase shifts to modify the antenna pattern and make it more directive. The lander, provided with a high gain antenna, would then be used as a radio relay.

Thermal control will be provided by a completely passive system employing surface coatings (affected again by the regolith and its thermal properties) and by an interior shell of aerogel. Nevertheless, selected parts of the surface of the rover can be designed to change its reflectivity in a controllable manner with the use of liquid crystals, in a similar manner to the Ikarus solar sail [7]

6. Summary and Conclusions

We have shown that a spherical rover can be used with profit for some specific tasks in lunar and planetary exploration. By its simplicity, robustness and scalability, it can be a valuable addition to future missions where mobility is of paramount importance.

Acknowledgements

This work has been supported by the MITYC under the contract reference TSI-020100-2010-138 as a part of the grant AVANZA Competitividad I+D+i 2010.

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