A Spherical Robot for Planetary Surface Exploration

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Abstract

This paper presents the concept of a spherical robot that moves by making its external shell rotate. The spherical shape allows the robot to operate on all kinds of operating surfaces and obstacles. A rolling robot naturally follows the path of less resistance, and it has less chances of getting stuck on top of an object. The characteristics and capabilities of such robot is presented, along we some ideas on how such design can be beneficial for planetary exploration.

1 Introduction

Planetary exploration missions have always – and will still for many years – rely on unmanned automated spacecraft and robots to acquire the scientific data we need to advance our knowledge of the universe. Earlier exploration missions typically involved remote-sensing satellites that gathered scientific measurements from orbit. With the growing need from the science community to acquire samples for in-situ analysis or return to Earth laboratories, planetary mission planners are now concerned with the requirements to land a mobile vehicle on the surface of the planetary body for sample acquisition. Mobility is a critical element of the mission; the collection of samples from a single site might bring erroneous scientific conclusions on the nature and history of the whole planetary body. The missions of current interest (Mars, polar craters of the Moon) will require a mobile robot that can face difficult operating conditions, having to move in a dusty environment, filled with obstacles of various shapes and sizes. In such environments, wheeled robots have limited mobility capabilities and special care must be taken to avoid having them flip over when moving on an uneven terrain. The Sojourner rover with its six wheels was carefully controlled by an Earth-based operator to stay clear of such conditions and to make sure the robot did not get stuck somewhere. A robot design with wheels larger than its body is one solution but, with the constraints of low mass and low volume imposed by the launch vehicle, this increase in size cannot be accommodated. Even a larger size does not prevent the robot from blocking in elevated position onto an object.

One promising design configuration for a robot that could operate in such difficult terrain is to encapsulate the robot inside a spherical shell, and use this shell to make the robot move around in the environment. The spherical shape allows the robot to face all kind of obstacles and operating surfaces, since a rolling ball naturally follows the path of least resistance.

The objective of this contribution is to present the characteristics and capabilities of such spherical robot, and see how such design can be beneficial for planetary exploration. The paper is organized as follows. Section 2 describes the locomotion mechanism of the spherical robot. Section 3 presents the characteristics of the prototype built to demonstrate the capabilities of such robot. Section 4 addresses how such design can be beneficial for planetary exploration. Section 5 presents related work, followed by the conclusion of the paper in Section 6.

2 Locomotion Mechanism of a Spherical Robot

The locomotion mechanism of our spherical robot is fairly simple. The idea is to have a robot encapsulated inside a spherical shell, and to make this shell rotate to make the robot navigate in an environment. The purpose of the shell is to protect the robot's circuitry against shocks, dirt, thermal variations and other environmental effects that electronic devices and mechan-

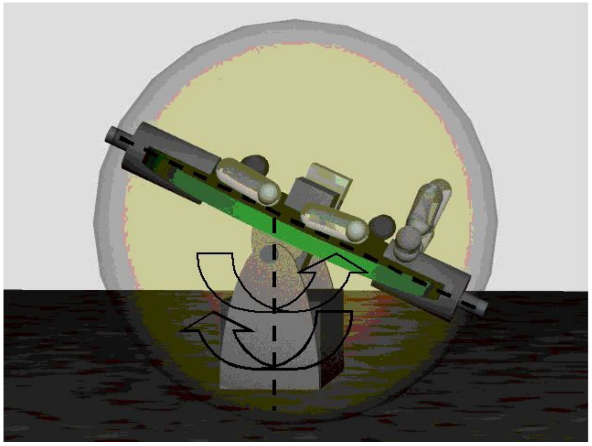

Figure 1: Rear view of the propulsion and steering mechanisms, as the robot turns to the right.

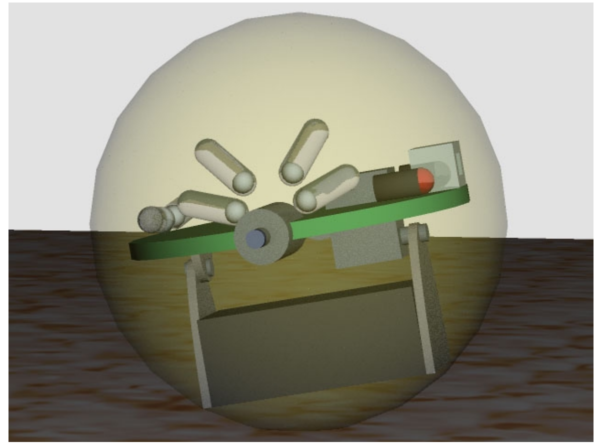

Figure 2: Right side view of the propulsion and steering mechanisms.

ical components are sensitive to. Having no external components, the shell can completely seal the robot internal circuitry and mechanisms. Figures 1 and 2 illustrates the locomotion mechanism of the robot.

The robot is not a separate device that is rolling inside the shell like a hamster ball toy. The robot is made of an internal plateau on which all components are attached. This plateau is attached to both sides of the shell on a rotating axis, and one or two motors can be used to make the shell rotate around this axis. By using the motors, the robot's shell can move forward or backward. An inclinometer measures the inclination of the plateau in the direction perpendicular to the rotation axis, so that the robots controller can regulate the speed of the motors. The speed of the motors is regulated based on longitudinal inclination of the internal plateau to keep the center of gravity of the robot close to the ground, allowing it to move.

Steering is done using a counterweight mounted on a servo-motor. This counterweight, which can be the battery of the robot, is attached to the internal plateau, mounted on a pivot axis transversal to the axis of rotation. This way, the counterweight can be moved from one side to another using a servo-motor, displacing the centre of gravity of the spherical robot and thereby changing its trajectory. An inclinometer allows regulating the transversal inclination of the robot.

When the robot collides with an obstacle, the internal plateau flips over, which can be detected by monitoring the plateau inclination. The robot can then back up and turn in a direction that would make the robot move away of the obstacle. A micro-controller is used to control the robot and to interface electronic devices like sensors, RF communication links or special actuators. Using such moving platform, various types of sensors can be installed on the plateau to make the robot do various tasks (like for instance a camera and a microphone for remote surveillance). A wheel encoder can also provide useful information like monitoring the acceleration of the robot to regulate its speed going down a hill.

3 Proof-of-Concept Prototype

In 1998, we built a first prototype of such spherical robot using off-the-shelf components, to demonstrate the feasibility of the design. This first prototype is shown in Figure 3. Our prototype uses a 68HC11 microcontroller board, a plastic sphere (simply bought in a pet store), standard motors and a 12 Volts 1.2 Amp.hr nonspillable rechargeable SLA battery. The overall cost of material used is less than 100$US. The prototype is 6 inches in diameter and weighs about 4 pounds. With this first prototype we wanted to validate the locomotion and control mechanisms of such type of rolling robot. We tried to optimise the weight of the robot by minimising the number of components and exploiting them (like the battery) for the dynamics of the robot. This also limited the cost of the robot. No complicated mechanical parts were required.

This prototype was used to do experiments aiming at designing an intelligent mobile robotic toy for young

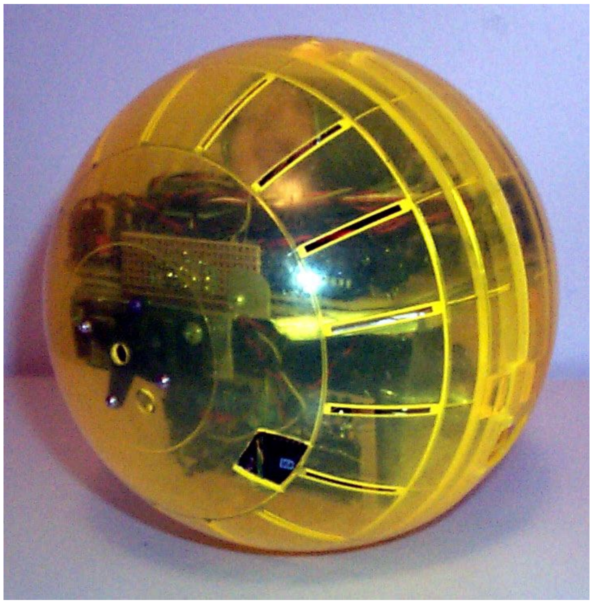

Figure 3: First prototype of our spherical robot.

children that could operate in a household environment filled with all kind of objects (other toys, shoes, clothes, etc.), obstacles (walls, couch, table, chairs, stairs, etc.) and entities (dog, cat, people, etc), and on different operating surfaces (wooden floor, ceramic, shaggy carpets, etc.) [3, 4]. Children are extremely hard on their toys: they grab them, throw them, kick them, put them in places they should not be in (dirt, water, modeling compound, ...), etc. So they are a good testbed to validate the physical robustness and versatility of such robot design. The prototype was also used in a first set of experiments involving the use of mobile robotic toys to help children with autism develop social and interaction skills [3].

4 Spherical Robot for Planetary Exploration

Our trials demonstrate that the robot is able to operate in diverse conditions, and that this concept has many characteristics that, with the proper adaptations, would make it suitable for planetary exploration. Space missions that are currently in the planning stages include the exploration of permanently-shadowed craters near the South Pole of the Moon and the exploration of Mars. These missions scenarios have in common the following constraints:

- operation in an environment of dust and (on Mars) wind;
- locomotion through rough and hazardous terrains;
- large obstacles (boulders, rocks) to avoid or overcome;
- loose surface material that makes traction difficult for small vehicles;
- no atmosphere or low-density atmosphere that makes heat rejection by conduction or convection difficult;
- large temperature extremes between day and night;

and the following mission requirements:

- mobility to increase the quality of the scientific returns (as briefly presented in Section 1);
- low mass, low cost, low complexity and high reliability, as is the case for all space missions.

In terms of protection from a harsh environment, a spherical design is optimum : it presents the minimum surface for a given volume of equipment. With the possibility to enclose its mechanical and electrical components in a sphere that can be filled with an artificial atmosphere (much like the drive system of the Apollo Lunar Rover), design problems associated with dust penetration, lubrication and thermal regulation are much simplified. The shell can also serve as an efficient thermal protection in a way similar to the Lunokhod design for survival during the 14-day long lunar nights. By following the paths of least resistance, locomotion through difficult terrain might be easier for the spherical robot than for a wheeled or legged robot. The size of the robot and the material of the shell can be adapted in accordance with the type of mission and the type of terrain. An inflatable shell could also be designed.

Current research activities are directed at adapting this basic concept to the requirements of planetary missions. These adaptations include:

- Power generation from solar cells.
- Heat rejection through radiators.
- Accommodation of navigation sensors.
- Accommodation of a science payload.

The concepts under investigation take advantage of the rotation-axis attachment points on the sphere where "despun" instruments platforms and solar panels could be fixed. Other concepts are looking at mechanisms that would open the shell, allow scientific instruments to take measurement or sample the surface, then close the shell again for further travelling.

5 Related Work

We discovered other similar designs of spherical rolling robots after having built our first prototype. The Solar Ball Kit commercialized by Images Company Inc. (not sold anymore) is a spherical robot that uses solar energy in its first version. In the second version, when light is detected a battery is activated and the robot moves. No steering mechanism is provided. Released in 1998, the BEAM MiniBall is also a rotating robot that has a similar behavior. It is based on a design by Richard Weait of Toronto who built, in the 1993 BEAM Robot Olympics, a self-contained solar-powered robot in a pet store hamster ball like the one used for our first prototype. The Orbot rollerbot is a rolling sphere robot teleoperated using a TV remote control. Toy Biz Inc. [1] also has a patent on a self-propelled toy ball which plays musical tunes and generates sound effects. Once energized, the electronics of the ball operate to propel the ball and simultaneously activate an integrated circuit sound effects chip which plays a musical tune. When the ball bumps into something, the propulsion mechanism is disengaged and the circuit then plays a randomly selected pre-programmed sound effect. Thereafter, the propelling mechanism is again activated and the ball resumes playing the musical tune. Our spherical robot significantly differs from these products by using a microcontroller and sensors to make the robot navigate autonomously in the environment.

A similar concept is the teleoperated robot named Cyclops [2], designed in 1998 by the Field Robotics Center of Carnegie Mellon University. Cyclops uses a similar rolling mechanism to ours. However, instead of using a counterweight for steering, Cyclops use a rotational mass to make the robot pivot in place. While this actuator makes Cyclops holonomic, the authors report some difficulty in making the robot rotate with precision. Our design is non-holonomic and uses much simpler components and offers a less expensive design. The rotation actuator can also be added to our design if required by the application. Our locomotion mechanism also differs from other round-shaped robots like Gyrover [8] in that it can rotate on all of its external surface, and not on a wheel.

Another interesting robot for planetary exploration is the Scout robot [6, 7]. It is a small size robot (11cm long and 4cm wide) of about 200g that uses differentially-driven wheels, and design for indoor use. It has the shape of a cylinder, with two narrow wheels on the extremities. The robot can climb a 20° slope, and can jump over small obstacles (like a stair case) by winching a leafspring tail around its body and snapping it out. Compared to our design, the Scout has the advantage of being holonomic. However, our design allows to have a robot completely sealed inside the shell, only one motor can be necessary for locomotion, and a spherical shape may be more efficient in navigating on soft surfaces (i.e., not hard-pressed such as dirt). Finally, compared to a hopping rover [5] that is not always in contact with surfaces features, our spherical robot requires simpler control algorithms.

6 Conclusions

This paper describes the concept of using a rolling spherical robot for planetary exploration. As explained in the paper, the first prototype of such spherical robot has been designed for entertainment purposes in a household environment. Our objective with this paper is to present the idea and explore the potential benefits and interests of using such robot for planetary exploration. If such concept reveals to be interesting enough to the research community, we would like to refine and adapt the design with the collaboration of specialists in space exploration. Further analyses and breadboard developments will address the adaptations, from a functional point of view (solar cells, sampling device, cameras, etc), to the scientific requirements of typical planetary missions. Follow-on developments will address the qualification for a given planetary environment.

Acknowledgments

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