Final

Inflatable Technology for Robotics

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Abstract

The Inflatable Rover uses novel, large, inflatable wheels to climb over rocks, instead of traveling around them, thus enabling it to traverse over 99% of the Martian surface. Preliminary tests using commercial nylon balloons as tires, a rigid metal chassis, and a simple, joy-stick control, have shown great promise. Tests have been successfully conducted in rugged rocky canyons, on giant sand dunes, and on calm lakes (simulating the liquid methane lakes anticipated on Saturn's moon Titan). Future work will be concentrated in the areas of materials research for the inflatable tires, development of a collapsible chassis, and adaptation of existing algorithms for image recognition and hazard avoidance.

Introduction

The general purpose of designing a large, lightweight, inflatable rover is to allow the rover to travel over rocks instead of around them, as present planetary rovers are required to do. This can greatly increase a rover's versatility, speed, and range. It has been estimated that in the 5% rockiest regions of Mars, approximately 1% of the surface is covered by rocks of 0.5 m or higher (Golombeck and Rapp 1997). Early tests with scale models of inflatable rovers showed that this type of vehicle could easily scale rocks that were 1/3 the diameter of the wheels. Thus a wheel size of 1.5 m diameter was chosen to allow the rover to traverse well over 99% of the Martian surface. In order to minimize mass and complexity, a three-wheeled vehicle was chosen with a wide wheel base to enhance stability in rugged and steep terrain.

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Design specifications

The first full-size bench model of the Inflatable Rover (Figure 1) has two 1.5-meter diameter rear-drive wheels with a forward steering wheel of the same size. It is shown with an inflatable solar array that is sized to produce over 100 W of electrical power on Mars. The 20 kg prototype rover has two Micro Mo coreless motors with planetary reduction gears. The two motors propel the rover at 2.0 km/hr, using only 18 W of power on level terrain. Considering Mars' reduced gravity of 0.38 g, the available 100 W of power could propel the vehicle at almost 30 km/hr in level terrain.

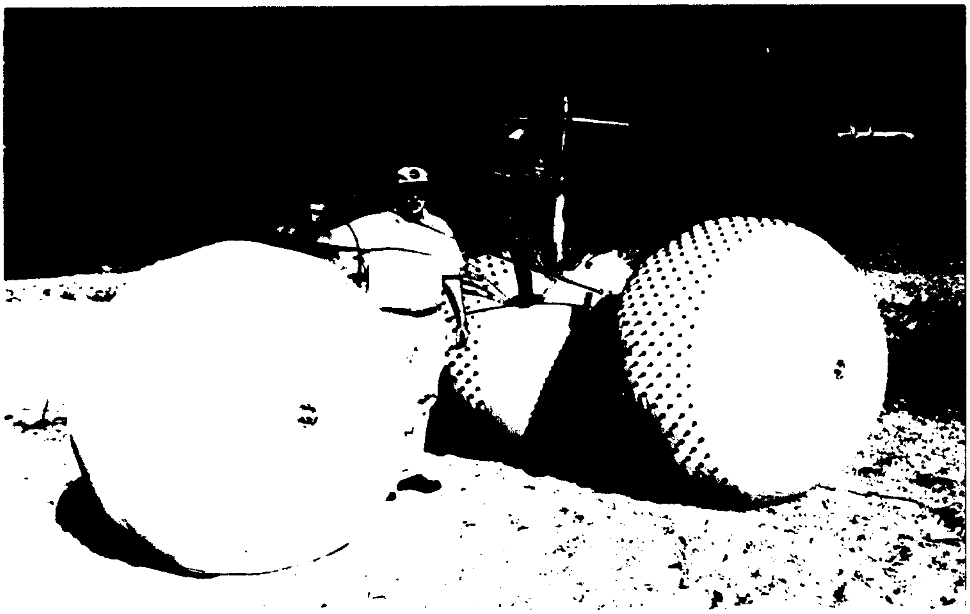

Figure 1. Early Inflatable Rover with Commercial Nylon Balloons as Tires.

The forward-steering tire is driven in direction by a simple motorized worm gear and provides excellent control. All motors are operated at 12 V DC and are battery-powered for the bench model. The large, inflated spherical wheels allow the rover to swallow most small rocks, while providing a large contact surface to climb steep hills or over larg rocks, and to maintain excellent ground contact during wind storms (Jones, 1998; Jones et al. 1998a, 1998b, 1999). In fact, the present prototype, uses commercial nylon balloons as tires and has stood up well to 30 MPH (13m/sec) gusts, which are equivalent in force to 130 m/sec gusts in the extremely thin Martian atmosphere (0.006 bar pressure).

Field testing

Thus far, the rover has been successfully tested in a wide range of conditions including on giant sand dunes in the Mojave desert; in very rugged, rocky canyons simulating Martian terrain (Figure 2); and on calm lakes simulating liquid methane seas anticipated to exist on Saturn's moon, Titan (Figure 3). The rover has successfully climbed rocks as high as 0.75 m, and has traversed well with ascents and descents on hills and slopes as high as 30°. JPL has prepared a videotape (Jones 1999) that demonstrates operation in these various terrains.

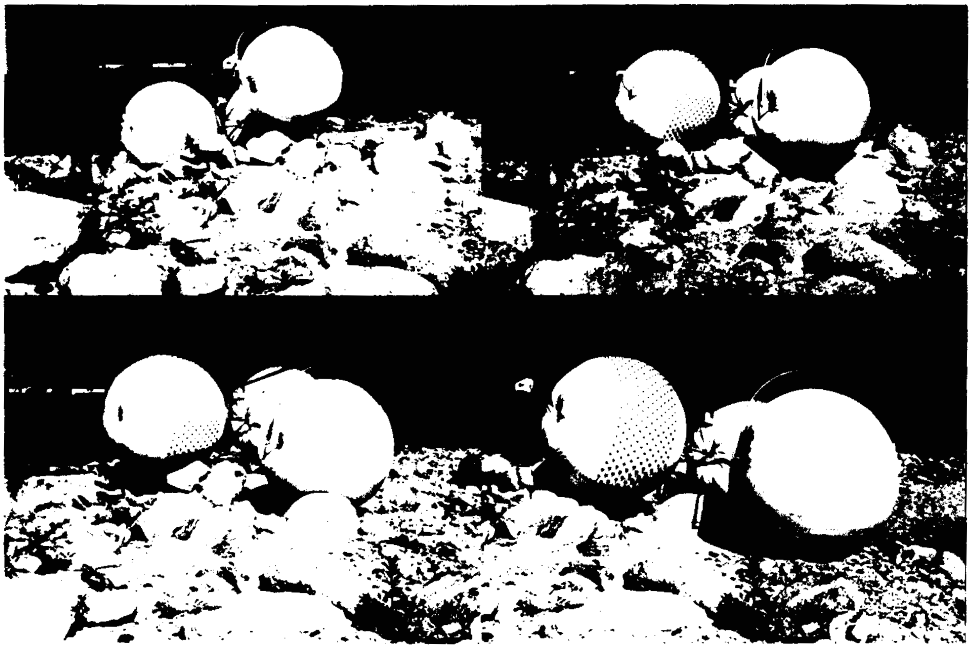

Figure 2. The Inflatable Rover Traversing Rocky Terrain.

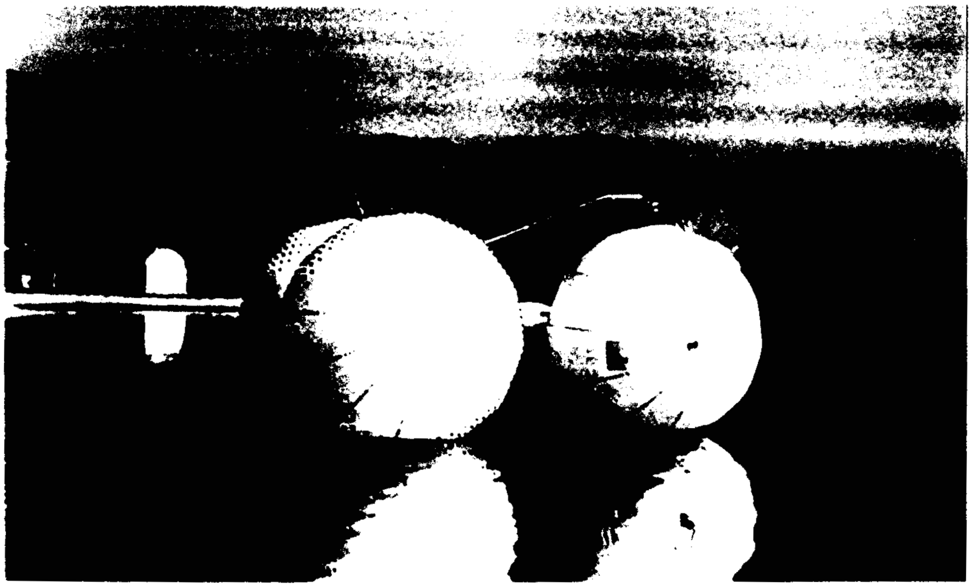

Figure 3. The Inflatable Rover Operating on a Calm Lake.

Testing has also been conducted using a novel, commercially available, color-tracking Sony TV video camera (model EVI-D30). The camera can be locked onto a specific color target and can update tracking of this target five times per second. Furthermore, it can track angular changes as high as 80° per second. Preliminary tracking tests have thus far been very successful and will be reported in a subsequent paper (Jones and Wu 1999).

Future work

Assuming funding is available as planned, significant work will be conducted in the upcoming financial year, FY'00. More rugged kevlar or PBO wheels with a silicone or polyurethane inner bladder will be developed, along with a scale model collapsible chassis for the rover. All materials will be selected to withstand the Martian 170 K nights, as well as Titan's 90 K surface. Also, an image recognition system will be integrated, as available from Rocky (Volpe 1999) or FIDO (Schenker et al. 1994), and the rover will demonstrate the ability to travel to pre-selected objects or follow an astronaut while carrying supplies, tools, or rock samples. In addition, the rover chassis will be modified to allow the Inflatable Rover to collect, transport, and deploy at least three nano-rovers to pre-selected sites (Wilcox 1999).

Summary and conclusions

All present flight planetary rovers are based on the standard Pathfinder Sojourner concept of a four- or six-wheeled vehicle that must generally travel *around* most obstacles. To give a specific example, during a month of operation, the 35-cm tall Sojourner rover only traveled a total of about 100 meters, and never more than 7 meters per day. Other development rovers, such as Athena, Rocky, and FIDO, are all somewhat larger, but still are not intended to travel more than about one km from the landing point, and that would be over a period of weeks. And, of course, the 1 kg nano-rover presently in development, although very capable, would have a substantially shorter range. Development of the Inflatable Rover would allow rovers to travel tens of kilometers in a single day, with a range of hundreds of kilometers or more. The use of inflatables to increase speed and range is a critical enabling technology that will allow robotic outpost development (transporting other rovers to distant sites); transportation of astronauts; and long-distance transfer of heavy equipment or in situ resources, such as water ice from the Martian north pole. Several new technology areas must be developed, including more rugged, ultra-lightweight, inflatable tires (stronger for long distances), a compactable chassis to fit into small planetary entry capsules, and revised autonomous control algorithms that allow much larger distances to be traversed.

Acknowledgments

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References

Golombeck, M. and Don Rapp. 1997. "Size-Frequency Distribution of Rocks on Mars and Earth Analog Sites: Implications for Future Landed Missions," *Journal of geophysical Research.* Vol. 102, pp. 4117–4129, February 25.

Jones, Jack. 1998. "Inflatable Rovers," Space Inflatables Workshop, May.

Jones, Jack et al. 1998a. "Balloons for Controlled Roving/Landing on Mars," IAA International Conference, April.

Jones, Jack et al. 1998b. "Inflatables for Mars Sample Return," Mars Micromission Conference, May.

Jones, Jack. 1999a. "Inflatable Rover Demonstration," JPL Photolab Video #9905_10B (3 minutes), May.

Jones, Jack and Jiunn Jeng Wu. 1999. "Inflatable Rovers for Planetary Applications," SPIE International Symposium on Intelligent Systems and Advanced Manufacturing, September 19-22, Boston, Massachusetts.

Schenker, Paul S., Stephen F. Peters, Eric D. Paljug, and Wen S. Kim. 1994. "Intelligent Viewing Control for Robotic and Automation Systems," Photonics East '94, Sensor Fusion VII, Boston, Massachusetts, October.

Volpe, Richard. 1999. "Navigation Results from Desert Field Tests on Rocky 7," *International Journal of Robotics.*

Wilcox, Brian. 1996. "Nanorovers for Planetary Exploration," Madison, Wisconsin, AIAA Robotics Technology Forum, January.