NANOROVERS FOR PLANETARY EXPLORATION

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Recent advances in microtechnology and mobile robotics have made it feasible to create extremely small automated or remote-controlled vehicles which open new application frontiers. One of these possible applications is the use of nanorovers (robotic vehicles of the order of 10 grams or less) in planetary exploration. Such vehicles could be used, for example, to survey areas around a lander, or even to be distributed along the lander descent trajectory, and to look for a particular substance such as water ice or microfossils. The objective of this activity is twofold: to create a useful nanorover system using current-generation technology including mobility, computation, power, and communication in a 10 gram package, and also to advance selected technologies which offer breakthroughs in size reduction.

NASA planetary missions have been under increasing pressure to reduce their launch mass requirements so that less expensive launch vehicles can be used. For example, the Delta launch vehicle is less than one-fifth the cost of the Titan, and the Taurus is less than half the cost of the Delta. In order to launch on these inexpensive vehicles, significant reductions in mass must be achieved. For example, the Science package on post-Pathfinder landers is expected to be 20 kg or less. To achieve those aspects of scientific exploration requiring mobility, any rover component of the science payload must compete effectively in terms of mass against other payload options. Microrovers (<~10kg) were conceived partly in response to this [Wilcox, 1987], and soon after nanorovers (<~ 10g) were proposed for the same reasons [Brooks and Flynn, 1989]. Nanorover technology would allow some mobility-based science surveys, such as the search for water ice or other volatiles, microfossils, or other entities at or very near the surface with a small, perhaps negligible fraction of the science payload. This latter point makes it conceivable that nanorovers could fly on most landers using whatever mass margin is left over at launch time. This paper describes the science, power, computation, control, thermal and mobility issues related to nanorovers.

The most attractive science data which a nanorover could gather would be compositional information about the terrain over which it passes. There are large and cumbersome instruments on Earth for this, and there are those which involve radioactive particle penetration of the material. Both are poorly suited to an Earth-based development program. One instrument which is potentially small, low mass, low power, and can distinguish between hundreds of different likely mineral types is a near-IR point spectrometer. When combined with a multiband visual imager, it can give the planetary scientist a wealth of knowlege about the surface morphology and composition.

However, the size and power requirements of a spectrometer with adequate resolution to distinguish among similar minerals leads to a rover dimension of -10 cm and a power budget of -200 mW. Fortunately, the power delivered by a solar panel on Mars is about 10 mW/cm^2, so that 20 cm^2 of area is adequate in full sun, or about 30 cm^2 is needed to give reasonable performance over a useful daytime operating range.

The processing on-board the vehicle accomplishes several functions: 1) to maneuver the vehicle as determined by autonomous goal-seeking or as desired by the human operator, 2) to acquire the most relevant images and other sensor information, 3) to manage the communication link, power system, and other resources, and 4) to handle loss-of-communication events or other anomalous situations. We address these in sequence.

The simplest mode of control which is desirable for the vehicle is some form of direct human control analogous to teleoperation. In this mode, images and other sensor data are returned from the rover or lander, displayed to the operator, and the operator decides what motion the vehicle should take, if any. Since the data bandwidth from the vehicle is going to be very limited, the operator will need to decide what action the vehicle should take based on only one image or subimage. Over the past decade JPL has demonstrated the effective control of planetary rover and military vehicles on rough terrain using frozen images. In the Pathfinder rover, scheduled for launch to Mars in Dec '96, stereo 3-D images are taken and displayed to the operator, where he or she can designate path coordinates or other activities by maneuvering an icon of the vehicle in the 3-D image. For the nanorover it is desired not to require that the lander have a pair of stereo cameras. In this case the nanorover will be servoed to a path which is designated in the image plane of a monocular lander camera.

Autonomous goal-seeking would be another mode of operation of the nanorover. In this mode, the rover would use some simple sensor, such a seeking a particular mineral spectra, to guide the vehicle toward a region which meets the science objective.

Hazard avoidance would be based on simple behaviors. One simple behavior would be to use the focus adjustment of the camera to determine range to objects, which can then be avoided with behavior-control similar to that used on the Pathfinder rover

The last and most open-ended function which the on-board processor must perform is to provide autonomous behaviors under extenuating circumstances. Probably the most important of these circumstances is to re-establish communications when commands are no longer received. It must detect that no communication has been sent for an excessive period of time, it must have or be able to detect which direction is likely to increase the signal strength, and it should have a way of measuring signal strength. The kind of actions which the vehicle can take would include heading in a pre-established direction which should increase the signal strength, or to servo toward higher signal using the signal-strength sensor.

The data link is expected to have a capacity of about 1000 bits per second of data. However, the severely limited power budget makes moderate-range (30 meters), moderate-bandwidth (1000 bits/see). As an example, some types of remotely- actuated car alarms use a surface acoustic wave (SAW) resonator at about 300 MHz to transmit about 1 milliwatt of power, are roughly 4070 efficient and requires 2.5 mW.

For mobility, a small four-wheel drive, skid-steered vehicle has been selected. Small motors are used in a wide variety of mass/power sensitive applications, such as autofocus cameras. These motors are available with integral gearheads which give the low speeds and needed torque which mobility requires.

References:

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