Robotic Vehicles for Planetary Exploration

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Abstract. Future missions to the moon, Mars, or other planetary surfaces will use planetary rovers for exploration or other tasks. Operation of these rovers as unmanned robotic vehicles with some form of remote or semi-autonomous control is desirable to reduce the cost and increase the capability and safety of many types of missions. However, the long time delays and relatively low bandwidths associated with radio communications between planets precludes a total “telepresence” approach to controlling the vehicle. A program to develop planetary rover technology has been initiated at the Jet Propulsion Laboratory (JPL) under sponsorship of the National Aeronautics and Space Administration (NASA). Developmental systems with the necessary sensing, computing, power, and mobility resources to demonstrate realistic forms of control for various missions have been developed and initial testing has been completed. These testbed systems, the associated navigation techniques currently used and planned for implementation, and long-term mission strategies employing them are described.

Key words: Mobile robots, terrain sensing, terrain modeling, path planning

1. Introduction

The exploration of the planetary surfaces of the solar system undoubtedly represents one of the most exciting endeavors that humans will undertake in the next century. Literally dozens of diverse and scientifically unique planets and moons await detailed scientific exploration and mapping, as glimpsed by the flyby missions of Voyager and other spacecraft. Robotic missions may be efficient precursors and alternatives to the more traditional exploratory technique of using piloted vehicles. In some cases, such as for the inner moons of Jupiter or the surface of Venus, the radiation or thermal environment makes human exploration essentially impossible. In other cases, such as for the outer solar system, round-trip missions with current propulsion technology would last almost a human lifetime. Thus the use of robotic rovers is an attractive option if this activity is to go forward.

Research on planetary rovers has been conducted at JPL since the mid-1960′s, and in the late 1970′s there were Mars rover research programs at JPL and at Rensselaer Polytechnic Institute with results of that research reported at the time [1-5]. In general, the conclusions of that research were that the computing requirements of autonomous hazard avoidance were very high compared to the performance of then-available space-qualified computers. In fact, both projects used large off-board mainframe computers for most computation. Even with these large computers, the vehicles could navigate only very slowly, so that Earth-based human control would still have given similar or higher overall system
performance despite the long signal time to Mars (varying from 6 to 41 minutes round trip at the speed of light).

Because of this long signal time to Mars and other planets, it is impractical to have a rover that is teleoperated from Earth (that is, one in which the lowest-level feedback control is mediated through the real-time perception of a human being). Therefore, some autonomy on the rover is needed. On the other hand, a highly autonomous rover (which could travel safely over long distances for many days in unfamiliar territory without guidance from Earth and obtain samples on its own) is significantly beyond the present state of the art of artificial intelligence, even using computers vastly larger than those envisioned for deep space missions in the next two decades (which must be small, light, low-power, fault-tolerant, and radiation hardened). In between the two extremes just mentioned, various degrees of autonomy are possible. Three in particular that have been studied at JPL are called Computer Aided Remote Driving (CARD), Semi-autonomous Navigation (SAN), and behavior control.

One of the most promising Earth-based control schemes is called Computer-Aided Remoted Driving (CARD). With CARD, stereo pictures from the rover are sent to Earth, where they are viewed by a human operator using a stereoscopic display. The operator designates a path using a 3-D cursor, giving a safe path for the vehicle to follow as far ahead as he can see accurately in three dimensions. A ground-based computer computes the turn angles and path segment distances that correspond to the designated path. This information is sent to the rover, which executes the path by dead reckoning, perhaps aided by computer vision. A new stereo pair of pictures is taken from the new position, and the whole process repeats. Depending on the terrain, the rover might travel about 20 meters on each of these iterations, each of which would take at least the speed-of-light delay (typically 30 minutes), plus whatever time is spent on the ground designing and approving the proposed path. This results in an average speed somewhat less than one centimeter per second. The basic benefit of CARD is a relatively reduced information transmission requirement compared to continuous teleoperation (2 frozen images versus an image stream). CARD has been discussed in detail previously [6, 7].

With Semi-Autonomous Navigation (SAN), local routes are planned autonomously using range information obtained on the vehicle, guided by global routes planned on Earth using a topographic map which is obtained from images produced by a satellite orbiting Mars. The orbital images are used by a human operator (perhaps with computer assistance) to select an approximate corridor for the vehicle to follow, which avoids large obstacles, dangerous areas, and dead-end paths. The topographic map for the corridor would be transmitted from Earth to the rover.

The rover then views the local scene and computes a local topographic map by means of some sensor system such as stereo vision or laser scanning. This map is matched to the local portion of the global map sent from Earth, as constrained by knowledge of the rover’s current position from other navigation devices or previous positions, in order to determine the accurate rover position and to register the local map to the global map. The local map (from the rover’s sensors) and the global map (from the Earth) are then registered statistically [8], and combined to form a revised map that has high resolution in the vicinity of the rover. This map is analyzed by computation on the rover to determine the safe areas over which to drive. A new path then is computed, revising the approximate path sent from Earth, since with the local high resolution map small obstacles can be seen which might have been missed in the low-resolution pictures used on Earth. Using the revised path, the rover then drives ahead a short distance (perhaps a few to ten meters), and the process repeats. If sufficient computational and power resources exist on the rover, this cycle might repeat every few minutes for an average speed of approximately 10 centimeters per second. SAN has been discussed in detail previously [9, 10, 7].

In behavior control, an approximate range and heading to a goal location are determined by a human operator. These are transmitted up to the vehicle which then attempts to reach the goal by combining heading or beacon sensor information with (typically) short-range obstacle sensor information. At JPL this has been implemented in