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Environment–robot interaction—the basis for mobility in planetary micro-rovers

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Abstract

Planetary exploration through the deployment of robotic rovers on planetary surfaces such as mars imposes unique constraints on mobile robotics. In particular, I examine the issue of mobility across a hostile planetary surface as an oft-neglected aspect of robotic autonomy. I compare the traction performance of a wheeled concept (the rocker–bogie springless system adopted on Sojourner), a tracked vehicle concept and a novel concept called the elastic loop mobility system (ELMS). I highlight some limitations of the Bekker theory analysis used here in the determination of mobility characteristics of any vehicle locomotion system.

Keywords: Mobile robotics; Planetary exploration; Mars rover; Bekker theory; Mobility analysis; Robot–environment interaction

1. Introduction

Most terrestrial mobile robotics platforms are operated in relatively benign environments such as office corridors and the like despite recent emphasis on "embodied" or "situated" robotics paradigms which emphasise the necessity for dealing with realistic (and so uncompromising) environments [2,10]. Evolutionary robotics has focussed on robotic control systems with some considerations of robot body morphology but still within artificial environments. Planetary robotics does not have that luxury—planetary environments are rugged, hostile and a priori unknown. Indeed, for such applications, the environment and its characteristics are fundamental in determining robotic behaviour. Although planetary surfaces are static (though the motion of the rover introduces a dynamic component) unlike those encountered by terrestrial robots, they are unstructured and rocky, requiring robust mobility over a hostile and challenging surface (Fig. 1).

The agent–environment interaction involves the dissipation of energy which ensures physical energy transfer between the two systems. It is this approach of modelling the energy transfer of the environment and the robot that I take here. I explore some issues relating to

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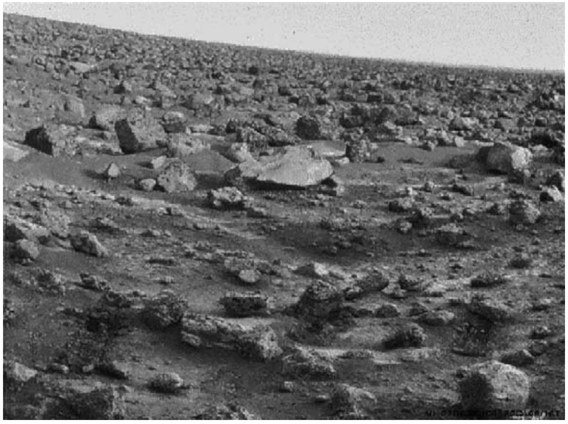

Fig. 1. The Martian terrain (from NASA).

environmental complexity which are relevant to planetary exploration, namely the interaction of the robot's mobility system and the planetary terrain. The hostility of planetary terrains make this aspect of robotic autonomy somewhat peculiar to planetary robotics, though of relevance to any terrestrial robot designed to function in natural environments (e.g. military environments). The NATO Reference Mobility Model (NRMM) emphasises performance characteristics based on [20]:

(i) maximum speed and turning radius;
(ii) traction for overcoming resistive forces to motion;
(iii) vehicle maneouvrability for obstacle avoidance;
(iv) ride comfort.

Performance parameter (iv) is not considered further as suspension is not generally regarded as a high priority for robotic rovers and the traversal speeds of planetary rovers are low ~10–20 cm/s. Performance parameters (i) are difficult to clarify in any quantitatively comparative sense but are determined by parameters (ii) and (iii). Maximum speed will be determined by the motor torques, slope, incidence of obstacles (which determines mean free path), and the surface traction on the soil. Turning radius will depend on the geometry of the vehicle and the nature of the turning mode and strongly influences parameter (iii)—skid steering which is adopted in tracked vehicles and small micro-rover vehicles offers the highest turning maneouvrability at the expense of power consumption. Most vehicles with forward and aft motion capability can turn through skid steering and indeed, elimination of explicit steering motors substantially reduces the mass of the vehicle. Hence, the analysis presented here consider precisely these parameters to determine the performance of robotic planetary rovers.

In this paper, some of the results are presented from a study of different mobility systems for the European Space Agency under the Aurora programme [14].

2. Planetary rover mobility systems

Many of the proposed locomotion systems for planetary rovers have paid little attention for the need to accommodate significant payload capacity for scientific instruments and to act as a stable platform for the delivery of those instruments to their selected targets—the scientific payload of a typical rover is ~5–15% of the total rover mass but it is desirable to maximise this mass fraction as the primary *raison d'etre* of the rover. Mobility performance is a defining characteristic for the choice of scientific targets available to the scientific instruments. There are five classes of locomotion system in mobile robots which are applicable to planetary exploration rovers:

(i) wheels, e.g. automobile locomotion;
(ii) tracks, e.g. armoured vehicle locomotion;
(iii) legs, e.g. animal locomotion;
(iv) body articulation, e.g. snake undulation;
(v) non-contact locomotion, e.g. hopping.

The chief advantage of legged robots is that they are required to overcome only the compaction resistances at the point of contact while wheels and tracks must overcome these forces continuously. Furthermore, legs use these resistive forces to aid movement rather than hinder movement. However, legged motion involves considerably more complex control algorithms than wheeled and tracked systems. Of these types of mobility system, I have considered only the first two from which I have selected three candidate mobility systems for study:

(i) the wheeled rocker–bogie suspension system (as exemplified by the Sojourner rover);
(ii) a tracked system (as exemplified by the Nanokhod rover suitably scaled);
(iii) the elastic loop mobility system (ELMS).