Path Planning for Mars Rovers Using the Fast Marching Method

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Abstract This paper presents the application of the Fast Marching Method, with or without an external vectorial field, to the path planning problem of robots in difficult outdoors environments. The resulting trajectory has to take into account the obstacles, the slope of the terrain (gradient of the height), the roughness (spherical variance) and the type of terrain (presence of sand) that can lead to slidings. When the robot is in sandy terrain with a certain slope, there is a landslide (usually small) that can be modelled as a lateral current or vectorial field in the direction of the negative gradient. Besides, the method calculates a weight matrix $W$ that represents difficulty for the robot to move in certain terrain and is built based on the information extracted from the surface characteristics. Then, the Fast Marching Method is applied with matrix $W$ being a velocities map. Finally, the algorithm has been modified to incorporate the effect of an external vectorial field.

Keywords Path planning · Fast Marching · Planetary exploration

1 Introduction

Planetary exploration with robots has increased in the last decades. Different robots, such as the the Mars Exploration Rovers (MER) [1], Spirit and Opportunity [2], have been placed in planets, like Mars, and asteroids, like Ceres and Vesta, in order to obtain valuable samples for the scientific community and enlarge our knowledge of the universe. These activities require safe and accurate movements to be executed...
combined with on-board decision making, specially due to the long time the information needs to travel. These robots are equipped with different sensors to evaluate their environment. Stereo-vision system are commonly used [3], although other type of sensors such as active vision LIDAR systems and six-axis Inertial Measurement Units are also being tested [4].

Once the environment is recognised, path planning is essential for exploration and reaching interesting goals. The objective of a path planner for a mobile robot operating in environments with obstacles, is to calculate collision-free trajectories with the best possible characteristics. General desired path characteristics are safety (in terms of obstacle avoidance) and shortness (for energy optimization). Besides, in the case of planetary exploration, it is common to take into account the height [5, 6, 7, 8], the roughness (unevenness) [6, 7, 8] of the terrain, and the possible sliding of the robot due to, i.e. sandy slopes (height gradient) [6].

The path planer presented is based on the Fast Marching Method (FMM), which essentially computes the time of arrival of a wave to the different points in the environment. Then, the gradient descent method is used for path extraction. The intrinsic nature of FMM and a proper definition of the velocities at which the wave (robot) can move, makes the computed path to assure safety, and shortness [9]. In order to define the speed over the environment, the method uses the height information and evaluates the roughness of the surface based on its spherical variance. It also takes into account the gradient of the height of the area, and the distance to obstacles. Then, it combines these data with the robot movement limitations to generate a weighted matrix. This matrix can be seen as a cost function and defines the different velocities at each point of the map.

Finally, robots not always can avoid difficult terrains. This may lead to small slidings while moving. An approach for considering these slippings is presented. These undesired movements are modelled as a vectorial field which depends on the terrain and the height gradient of the surface, and its effect is considered using the Fast Marching Method subjected to a vectorial field (FMVF).

**Statement of Contributions:** This work introduces a method for considering important characteristics of the environment (in planetary exploration) and taking them into account by the path planning method, Fast Marching. Besides, new considerations in the computation of Fast Marching subjected to a Vectorial Field are presented, and its application to the robot sliding modelling is detailed.

The remainder of the paper is organised as follows. Section 2 introduces an explanation about the FMM and how this algorithm can be implemented. Next, section 3 explains the formulation of the Fast Marching method subjected to a Vectorial Field. Following, section 4 details the velocities matrix and how it is formed. Section 5 presents numerical simulations that show promising results. Finally, the main conclusions of this paper are summarised in section 6.