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Fast marching subjected to a vector field–path planning method for mars rovers

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A R T I C L E I N F O

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A B S T R A C T

Path planning is an essential tool for the robots that explore the surface of Mars or other celestial bodies such as dwarf planets, asteroids, or moons. These vehicles require expert and intelligent systems to adopt the best decisions in order to survive in a hostile environment. The planning module has to take into account multiple factors such as the obstacles, the slope of the terrain, the surface roughness, the type of ground (presence of sand), or the information uncertainty. This paper presents a path planning system for rovers based on an improved version of the Fast Marching (FM) method. Scalar and vectorial properties are considered when computing the potential field which is the basis of the proposed technique. Each position in the map of the environment has a cost value (potential) that is used to include different types of variables. The scalar properties can be introduced in a component of the cost function that can represent characteristics such as difficulty, slowness, viscosity, refraction index, or incertitude. The cost value can be computed in different ways depending on the information extracted from the surface and the sensor data of the rover. In this paper, the surface roughness, the slope of the terrain, and the changes in height have been chosen according to the available information. When the robot is navigating sandy terrain with a certain slope, there is a landslide that has to be considered and corrected in the path calculation. This landslide is similar to a lateral current or vector field in the direction of the negative gradient of the surface. Our technique is able to compensate this vector field by introducing the influence of this variable in the cost function. Because of this modification, the new method has been called Fast Marching (subjected to a) vector field (FMVF). Different experiments have been carried out in simulated and real maps to test the method performance. The proposed approach has been validated for multiple combinations of the cost function parameters.

1. Introduction

The study of robot motion in rovers used for exploration in Mars or asteroids (Ceres,Vesta) has special difficulties because it is necessary to take into account multiple variables such as the obstacles, the changes in height, the slope of the terrain, the surface roughness, the uncertainty of the measurements, the composition of the ground (proportion of sand), possible small landslides due to the sand, and even the insolation level at each point of the path in order to increase the duration of the batteries. Some of these characteristics (slope, roughness, height) present scalar values, but other s (landslides due to the sand) have to be represented by vectorial parameters.

The path planning problem for a mobile robot operating in environments with unknown obstacles (dynamic or not) consists of computing a collision-free trajectory from an initial point to a goal location. The planning module has to optimize its performance depending on the objectives of the vehicle. Different parameters can be used to check the behavior of the system. For example, the smoothness of the path, the system safety, and the gradient or slope are important when navigating outdoors.

In this paper, we have examined how to implement a path planner for a rover that is exploring Mars. These vehicles need expert and intelligent systems to make the best choices in order to survive on a hostile planet. The method has to consider the available information and the factors that influence navigation to compute the most adequate paths.

The Mars height map[1] (Fig. 1) obtained by the Mars Orbiter Laser Altimeter (MOLA), an instrument aboard NASA's Mars Global

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[1] http://mola.gsfc.nasa.gov/topography.html.

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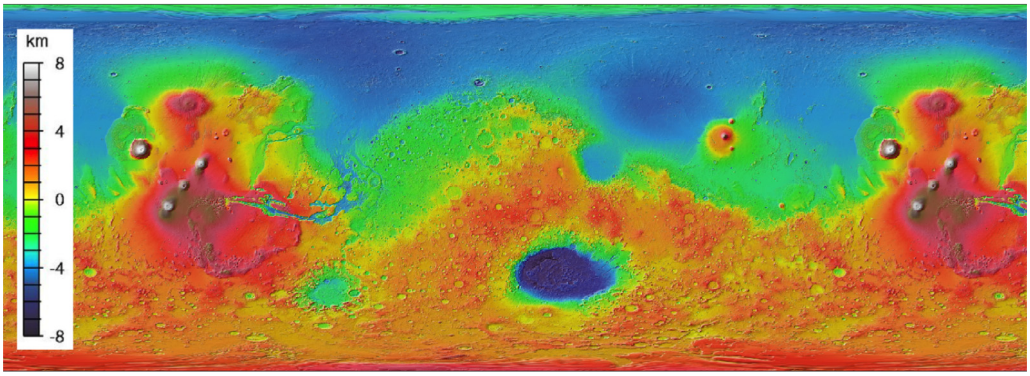

Fig. 1. Mars height map. Size: 46,080 × 23,040 pixels: Scale: 1: 25, 0000, 000. Projection: −180E to 180E, 90N to −90N.

Surveyor, is the source of information that is used to compute the robot's path. The best paths will be calculated over zones of this map depending on different variables. Different factors have to be considered according to the type of environment where the method will be applied. In our approach, these factors are classified into scalar and vectorial variables. In order to introduce these characteristics in the path planning module, a technique that optimizes a scalar cost function subjected to an external vector field is proposed. Due to our previous experience (Garrido, Moreno, Abderrahim, & Blanco, 2009; Garrido, Moreno, & Blanco, 2008; Valero-Gómez, Gómez, Garrido, & Moreno, 2013), we have chosen the Fast Marching (FM) method (Sethian, 1996) as the basis of the path planner. A modified version called Fast Marching (subjected to a) vector field (FMVF) has been implemented in this work to deal with factors that can be represented by scalar parameters and an external vector field.

This paper investigates how to apply the FMFV algorithm in different situations to obtain optim al paths for Mars rovers, but it is possible to extrapolate the same technique to other vehicles used for space exploration on planets and asteroids.

This new method consists of several steps. First, a map of the environment is created using the available information. After that, the cost or potential of each location has to be computed. Finally, the optimal path is calculated applying the FMVF method. These steps are introduced below.

The input data is the point cloud of the surface. This cloud can proceed from the rover laser sensor, from a known map, or from a mixture of both sources of information. The Mars height map is used here, but the algorithm is not limited to this option. The initial map is discretized in an orthogonal grid. As will be explained in Section 3, the planning algorithm can be applied to the initial map or to a three-dimensional triangular mesh that represents more accurately the planet's surface.

Although any scalar property could be taken into account, the change with respect to the initial height, the slope of the terrain, and the surface roughness are extracted in this work to build the scalar component of the cost value. These parameters can consider the robot's limitations (characteristics and environment conditions) to generate a cost value for each cell of the map. As will be described in Section 4, the slope or the roughness can be saturated to reduce the speed to the minimum when navigating hazardous areas. Besides, the FM method returns smooth paths, which is helpful when applied to nonholonomic vehicles. This cost value can be viewed as a difficulty or viscosity map which is situated on the planet's surface. Once the cost value is computed for the whole grid, the method is ready to apply the FM algorithm over the surface to generate the path. In other words, the initial map is modified and a potential is given to each cell. The potential field represents the influence of the scalar properties.

Without using the new potentials, the shortest path between two points would be obtained (i.e., the geodesic distance). When the potential with the scalar properties is included, the path considers the features of the surface and the limitations of the robot. Moreover, it gives us information about the speed of the robot based on the FM wave propagation speed (Garrido et al., 2009).

One of the crucial problems of the Mars rovers when navigating is caused by the presence of sand on the ground. This sand can produce two different phenomena. First, sand banks in which it is better not to enter could be formed in specific zones. In this case, these areas could be classified as dangerous terrain using a scalar parameter. This variable could be included in the previously explained scalar component of the cost function. Second, small landslides can change the position and direction of the previously calculated trajectory. The current approach models these lateral currents by using an external vector field that is also included in the cost of the planning module. This idea relies on the solution published in Petres et al. (2007). In this way, the planning method is based on a cost function that combines scalar and vectorial properties.

The path planning method has been tested using simulated and real input data. The objective is to demonstrate that the proposed strategy is a suitable technique and it takes into account the most typical factors that could influence navigation on the surface of Mars. Since different parameters can be introduced in the cost function, the experiments will validate our method under different circumstances that result in different cost functions. Smooth and safe paths are obtained in all cases.

This paper is organized as follows. The state of the art is reviewed in Section 2. Section 3 details the implementation of the FM method. After that, the FMVF algorithm is explained in Section 4. The experimental results are presented in Section 5 and, finally, the most important conclusions are summarized in Section 6.

2. State of the art

Path planning is one of the most widely studied problems in robotics. It consists of finding a path from an initial point to a goal location. The most typical algorithms are reviewed in this section. There are multiple methods that have been successfully applied and classifications depending on the objectives followed by the planner. For example, a classic approach classifies the algorithms according to the completeness, which means that the planning method would find a path if it existed. The increase of the computing power makes it possible to consider many different challenging goals such as the optimization of the path length or the safety.

An interesting division is proposed by LaValle (2011). Two groups of algorithms are defined depending on how the informa-