

Path Planning for Planetary Rover Using Extended Elevation Map

N95-23689

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ABSTRACT : This paper describes a path planning method for planetary rover to search for a path on planetary surface. Planetary rover is required to travel safely over a long distance for many days in unfamiliar terrain. Hence it is very important how planetary rover processes sensory information to understand the environment and to make decisions. As a new data structure for a map information, an extended elevation map(EEM) has been newly introduced, which includes the effect of the size of the rover. The proposed path planning can be conducted in such a way as if the rover were a point while the size of the rover is automatically taken into account. The validity of the proposed method is verified by computer simulations.

KEY WORDS AND PHRASES

Path planning, planetary rover, elevation map.

INTRODUCTION

In recent years many researchers have extensively studied and developed mobile robots (planetary rovers) for unmanned surface exploration of planets[1][2][3]. Planetary rover is required to travel safely over a long distance for many days in unknown terrain. Due to the communication delay between the earth and the rover, round trip propagation time, and bandwidth limitation, autonomous capability of rover is essential.

One of the important functions for a planetary rover is to plan a path from a start point to a goal without hitting obstacles. Path searching in a structured world with polygonal obstacles has received considerable attention as part of the general problem of robot motion planning, and various algorithms have been proposed [4][5][6][7]. However, there are few outdoor guidance systems that can create a path plan in such unknown and unstructured environment as planetary surface[8][9]. There have also been proposed only few practical path planning

methods that consider the size of the robot.

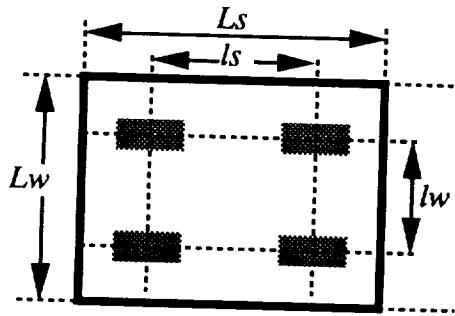
This paper describes a path planning method for planetary rover to search for a path on planetary surface. The model of a rover is introduced to consider the size of planetary rover. This model can be easily modified into any other rover architecture. A planetary rover makes an elevation map by observing the environment. The conventional elevation map was based on the implicit assumption that a rover can be described as a point[10]. We have newly introduced an extended elevation map, which includes the effect of the size of the rover. By using an extended elevation map, path planning can be conducted in such a way as if the rover were a point while the size of the rover is automatically taken into account. The difference of the height in accordance with the different rover orientation is also taken into consideration. The proposed path planning algorithm is based on grid search method.

This paper is structured as follows. In 2nd Section, modeling of the planetary rover is discussed. Then a method to make an extended elevation map is explained in 3rd Section. In 4th Section, a path planning algorithm based on extended elevation map is proposed. Computer simulations are given in 5th Section. Final Section is for discussion, conclusion, and future work of the research.

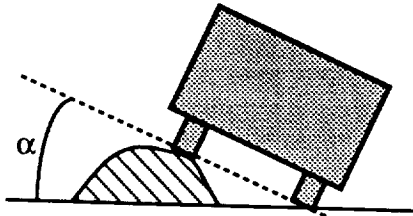
ROVER GEOMETRY

The performance of a rover moving in unstructured environment depends upon the geometry, such as suspension, size, the number of wheels etc. To consider the size of a planetary rover, a model of the rover is introduced as shown in Fig.1. Rover geometry is expressed by three parameters, roll angle criterion, pitch angle criterion, and height criterion.

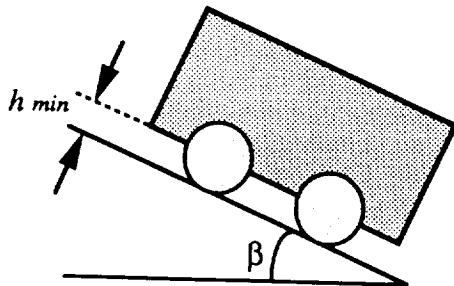
The maximum roll angle α_{max} is corresponds to the capability to clear obstacles. The maximum pitch angle β_{max} means the maximum angle of inclination for a rover to go over. The height h_{min} means the minimum distance between the body of a rover and the ground to avoid hitting the ground. Though this model shows the case for a four wheel rover, it is easy to adapt such a modeling to any other rover with different geometry.



(a) rover geometry



(b) roll angle



(c) pitch angle

Figure 1. Model of a rover

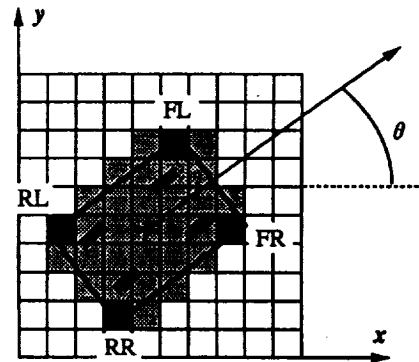
EXTENDED ELEVATION MAP

Map Data Structure

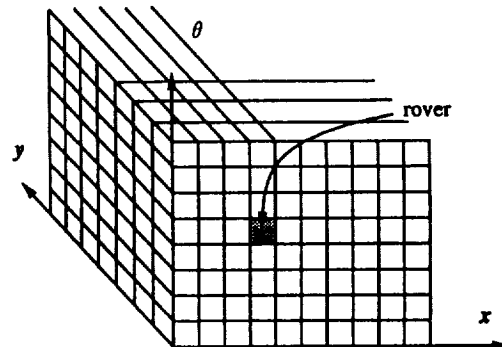
The planetary rover plans a path based on an elevation map which consists of many square grids. Each grid $G(x,y)$ has the height information z of that point (x,y) .

$$z = h(G) = h(x,y) \quad (1)$$

An elevation map shows the terrain data in front of the rover detected by a sensor. The conventional elevation map is based on the implicit assumption that a rover can be described as a point. Here a new map concept is proposed to include the effect of the size of the rover as shown in Fig.2. A rover actually occupies some grids on the elevation map. So virtual map with the information on the position and the attitude of a rover is proposed. The authors call this map an Extended Elevation Map (EEM). The information about the traversability is added to each grid on EEM. By using EEM, path planning can be conducted in such a way as if the rover were a point while the size of the rover is automatically taken into account.



(a) occupied grids(elevation map)



(b) extended elevation map

Figure 2. Extended elevation map

Judgment of Traversable Area

Traversable area means the area where a rover can stay stably. Now suppose that the position of four wheels of a rover are FR, FL, RR, and RL respectively. And then the position of the center of gravity and the orientation (azimuth angle) of a rover on EEM is to be expressed by (x, y, θ) respectively. The stability conditions for a rover roll angle and pitch angles are,

$$\frac{|h(\text{FR}) - h(\text{FL})|}{l_w} \leq \tan(\alpha_{\max}) \quad (2)$$

$$\frac{|h(\text{RR}) - h(\text{RL})|}{l_w} \leq \tan(\alpha_{\max}) \quad (3)$$

$$\frac{|h(\text{FR}) - h(\text{RR})|}{l_s} \leq \tan(\beta_{\max}) \quad (4)$$

$$\frac{|h(\text{FL}) - h(\text{RL})|}{l_s} \leq \tan(\beta_{\max}) \quad (5).$$

The condition for the rover body to avoid hitting the surface of the ground is

$$h(G_i) < P(G_i) \quad (\forall i=1, \dots, N) \quad (6),$$

where P denotes the plane constructed by the contact points of the wheels with the ground. N is the number of grids occupied by the rover. If all the conditions from (2) through (6) are satisfied, that area is defined as traversable one. Otherwise such a area means non-traversable one.

The height H of a rover on EEM is expressed as follows.

$$H(x, y, \theta) = \frac{1}{4} \{h(\text{FR}) + h(\text{FL}) + h(\text{RR}) + h(\text{RL})\} \quad (7).$$

PATH PLANNING

Extended grids on EEM are searched in the proposed path planning algorithm. Here suppose that the rover can move in eight kinds of directions ($\theta = \frac{\pi}{8} \cdot j$ ($j = 0, \dots, 7$)). The following two action patterns for the rover are selected.

Action_1 : move to the neighboring grid without turning

Action_2 : turn to a different direction at the same place

In the case of a 2-1/2 dimensional environment like the surface of Mars, simple distance does not provide a correct required traverse time since the slope of the terrain can drastically affect the time. A cost function is

required for estimating the time and power of motion over a 2-1/2 dimensional terrain. So the path from a start point to a goal is determined in such a way as the following cost function be minimized. The cost function E consists of two energy functions, the motion energy E_{hor} for horizontal movement and the potential energy E_{ver} for vertical movement.

$$E = E_{\text{hor}} + E_{\text{ver}} \quad (8)$$

where

$$E_{\text{hor}} = K_1 \cdot \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (9),$$

(in case of Action_1)

$$E_{\text{hor}} = K_1 \cdot \frac{\pi}{8} \sqrt{l_w^2 + l_s^2} \quad (10),$$

(in case of Action_2)

$$E_{\text{ver}} = K_2 \cdot |H(x_1, y_1, \theta_1) - H(x_2, y_2, \theta_2)| \quad (11),$$

K_1, K_2 : constant.

SIMULATION RESULTS

In order to investigate the validity of the proposed method, path planning in a terrain environment shown in Fig.3 is simulated. Table 1 shows the parameters for this simulation. Traversable areas and untraversable areas are obtained as shown in Fig.4. White regions mean traversable areas, and black regions mean non-traverse areas. Gray regions show the areas where a rover can stay stably or not depending upon the orientation of the rover. Figure 5 shows that a reasonable path can be planned by the proposed algorithm. Calculation time is about 3.0[s] (CPU: SPARC IU/FPU 40MHz).

Table 1. Parameters for a rover

map size	9.0 × 9.0 [m]
grid size	0.3 [m]
width of rover	1.1 [m]
length of rover	1.3 [m]
wheel base	1.1 [m]
distance between right wheel and left wheel	1.3 [m]
start point	(4, 4)
goal point	(25, 25)
K_1, K_2	10

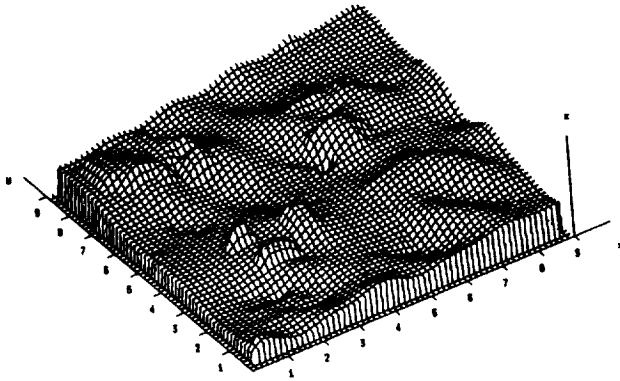


Figure 3. A terrain map

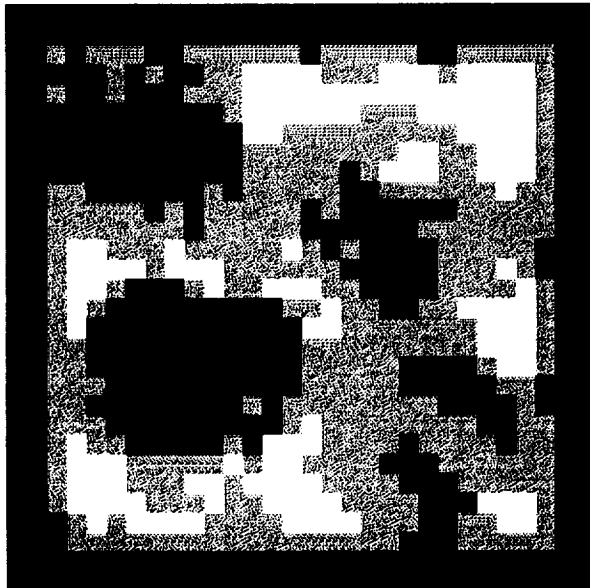


Figure 4. Traversable area

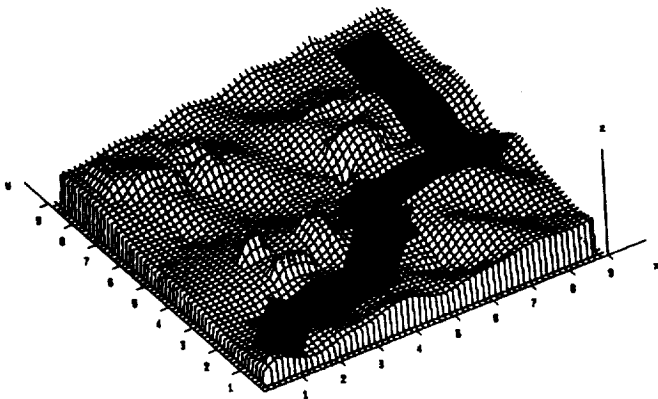


Figure 5. Simulation result

CONCLUSION

A new path planning for a planetary rover has been presented in this paper. The validity of the proposed method is confirmed by computer simulations. Experiments of mobile robot in an outdoor environment are under planning.

REFERENCES

- [1] D.P.Miller, M.G.Slack, R.J.Firby, "Path planning and execution monitoring for a planetary rover," Proc. of IEEE Int. Conf. on R&A, pp.20-25, 1990.
- [2] D.Lavery, R.J.Bedard, "NASA planetary rover program," Proc. of i-SAIRAS'90, pp.119-122, 1990.
- [3] A.Baiget et al., "Rover: Autonomous concepts for Mars exploration," Missions, Technologies et Conception des Vehicules Mobiles Planeraires, pp.313-326, 1992.
- [4] T.L.Perez, "Spatial Planning : A Configuration Space Approach", IEEE Trans. on Comp., pp.108-120, 1983.
- [5] D.Gaw, A.Meystel, "Minimum-Time Navigation of An Unmanned Mobile Robot in A 2-1/2D World With Obstacles", IEEE Int. Conf. on R&A, pp.1670-1677, 1986.
- [6] Z.Shiller, H.H.Lu, "Robust computation of path constrained time optimal motions," Proc. of IEEE Int. Conf. on R&A, pp.144-149, 1990.
- [7] T.T.Lee, C.L.Shih, "Robust path planning in unknown environments via local distance function," Proc. of i-SAIRAS'90, pp.251-254, 1990.
- [8] M.Amara, J.P.Friconneau, A.Micaelli, "Bond graph modeling, simulation and reflex control of the mars planetary automatic vehicle," Missions, Technologies et Conception des Vehicules Mobiles Planeraires, pp.509-529, 1992.
- [9] R.Morlanss, A.Liegeois, "A D.T.M-based path planning method for planetary rovers," Missions, Technologies et Conception des Vehicules Mobiles Planeraires, pp.499-507, 1992.
- [10] M.Hebert, T.Kanade, I.Kweon, "3-D Vision Techniques for Autonomous Vehicles", ICMU-RI-TR-88-12, CMU 1988.