Terrain Data Real-time Analysis Based on Point Cloud for Mars Rover

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Abstract. With the development of space exploration, more and more aerospace researchers pay attention to Mars, and Mars rover that has a capability of autonomous navigation will gradually become the focus of the study. Above all, we need to realize real-time modeling and analysis of unknown environment, providing necessary real-time information for Mars rover motion planning, and ultimately achieving autonomous navigation. Firstly, briefly introducing the research content. Then, using visual sensor on Mars rover to acquire 3D point cloud area in real-time environment. And creating 3D grid map to reduce the complexity of 3D map for real-time analysis. Thirdly, relying on the established 3D grid map, analysing and identifying terrain and environmental information and providing necessary information for Mars rover motion planning.

Keywords: vision sensor, 3D point cloud, 3D grid map, obstacle crossing possibility, obstacle feature.

1 Introduction

The research is to achieve modelling and terrain data real-time analysis of environment based on point cloud for Mars rover. The target is to establish stereo vision sensor system on Mars rover, and to achieve 3D point cloud creating, modelling and real-time environmental analysis. According to the particular rover model, establishing stereo vision sensor and connecting to the rover on-board computer, writing the program by using open source PCL library based on Microsoft Visual C++. Then combining with Mars rover motion planning in Webots robot simulation environment, finally running the program on the Mars rover.

And the research is to study the methods to solve the problem about terrain point cloud data analysis for Mars rover. And finding the method to reduce the complexity of the 3D point cloud map, and creating 3D grid map which have amount of sufficient

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information in a short time [1]. According to the complex environment on Mars, studying how to get further information on the environment analysis to identify the area which can be passed through or not, while calculating the area part of the characteristic data by obstacle features analysis, and then provide the data to motion planning for Mars rover [2].

The main framework for modelling and terrain data analysis system as follows.

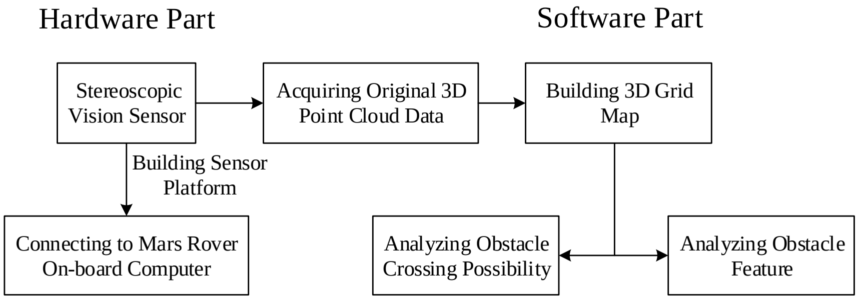

Fig. 1 Modelling and terrain data analysis system of environment for Mars rover

2 Original 3D Point Cloud Data Acquisition and Processing

The research is to study the methods to solve the problem about terrain point cloud data analysis for Mars rover, and we can utilizes stereo vision sensor to acquire original 3D point cloud data, for example, Bumblebee2 [3]. The research mostly focuses on the 3D point cloud processing, and using Kinect sensor as stereo vision sensor temporarily. And the sensor platform is built on the Mars rover which is six wheeled rocker type mobile robot. And the stereo vision sensor platform can adjust the vision angle in a certain range.

2.1 Original 3D Point Cloud Data Acquisition

Firstly, using stereo vision sensor can get depth image and color image of current environment in general. And the original 3D point cloud map can be built by depth image and color image [4]. The research also proposes a method to build the original 3D point cloud map. The research uses stereo vision sensor to acquire depth image and color image of original environment, as follows.

Fig. 2 Original environment data acquisition

The left is depth image and the right is color image. The research builds the 3D point cloud by integrating depth image and color image, as follows.

In general stereo vision sensor coordinate system, Z-axis is the normal axis of lens, the depth value of each pixel in the depth image represents the Z value of the actual coordinate space, and X, Y is the index position of the depth image of each pixel (X is column, Y as row), so X, Y coordinate space needs to be converted to the actual X, Y value.

Firstly, acquiring the field of view of stereo vision sensor, including horizontal and vertical viewing angles.

Secondly, calculating the proportion of unit conversion.

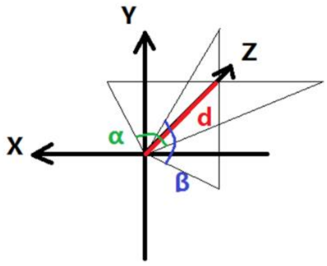

Fig. 3 Proportion of unit conversion

Angle α is horizontal viewing angle and angle β is vertical viewing angle.

$$RealWorldXtoZ = 2tan(\alpha/2), RealWorldYtoZ = 2tan(\beta/2) \quad (1)$$

Thirdly, calculating the actual environment of X, Y values. And nXRes is the pixel value in the depth image in the width direction, nYRes is the pixel value in the height direction.

$$NormalizedX = X/\ nXRes - 0.5, NormalizedY = 0.5 - Y/nYRes \quad (2)$$

$$X = NormalizedX \times Z \times RealWorldXtoZ \quad (3)$$

$$Y = NormalizedY \times Z \times RealWorldXtoZ \quad (4)$$

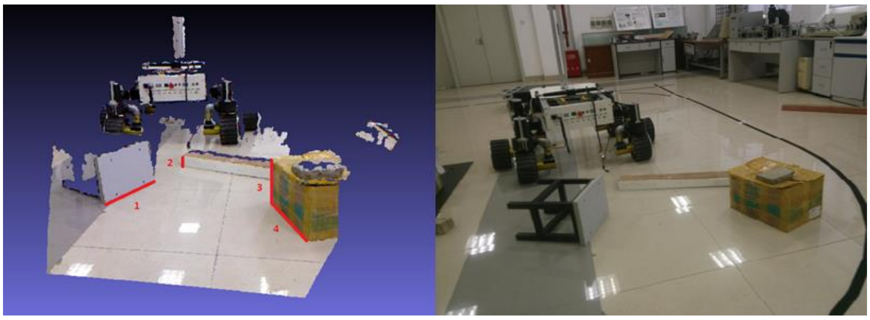

Fig. 4 Comparison between actual environment and 3D point cloud

Table 1 Errors between actual value and 3D point cloud value

Feature	Actual value (m)	3D value (m)	Errors (%)
1	0.3530	0.35182	0.33433
2	0.0600	0.05927	1.21667
3	0.2260	0.22435	0.73009
4	0.3820	0.38104	0.25131

2.2 Building 3D Grid Map

Mars rover motion planning needs large amounts of real-time environment data [5]. Therefore, it is necessary to build 3D grid map, in this way, it can reduce the complexity of creating maps, and reduce running time of the algorithm.

Fig. 5 3D grid map (size 0.1m left, size 0.05m right)

PCL open source library filter module has filter function that can remove unwanted point in the 3D point cloud data with different filters [6]. And the research uses filter module class ApproximateVoxelGrid to simplify 3D point cloud map. Class

ApproximateVoxelGrid can generate 3D grid map with the input of original 3D point cloud map, and the research takes advantage of all the center of the grid to approximate point sets that are contained in the grid.

The research choices for 3D grid size is 0.05m. The data points are reduced from 163 209 points to 2440 points, and the size of point cloud file reduce from 7078KB to 82KB, ensuring the environmental characteristics of the information simplify data.

3 Terrain Data Analysis of Single-frame 3D Grid Map

As for terrain data analysis, the coordinate system of 3D grid map needs to be changed [7]. Due to the current coordinate values obtained 3D grid map is based stereo vision sensor coordinate system, must be transformed into a coordinate system of Mars rover.

3.1 Analysing Obstacle Crossing Possibility

The research gained some motion data of Mars rover about obstacle crossing from physical experiments, namely the rover's wheels cannot pass through slope of about 30 degrees or more, and the height of the obstacle radius rover wheels (11cm) above. So the research needs to search all of the data points on the 3D grid map, to detect whether obstacle whose slope angle is more than 30 degrees exists or not. So, we need to search all the data points of the 3D grid map and find out point sets (two points) that meat some requirements. Firstly, the difference between X values of the two points is less than 0.1m, while the difference between Y values of the two points is greater than 0.05m. In this way, the two points in the point set are closest with each other in the 3D grid map (grid size 0.05m), and they have different Y values.

Then, calculating the slope between two points in all point sets. If the point set whose slope angle is more than 30 degree, the algorithm will judge whether the point set is located on the area that the wheels of Mars rover will pass through or not. And X value of the area is more than 0.2m or less than -0.2m.

And if X value of points is less than 0.2m and more than -0.2m, the algorithm will judge whether Z value of these points is less than the bottom height of Mars rover or not, namely if Z value is more than 0.32m, the area could not be passed through. In addition, if the point set whose slope angle is more than 30 degree is located in the area whose X value is less than 0.2m and more than -0.2m, the current terrain cannot be passed through.

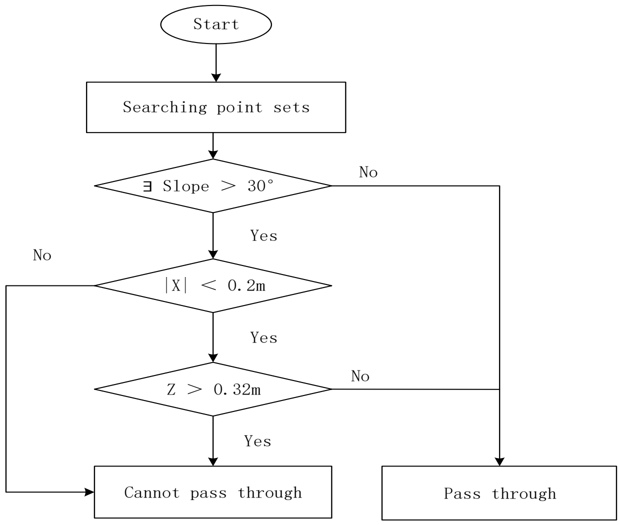

Fig. 6 Flow diagram of obstacle crossing possibility analysis

3.2 Analysing Obstacle Feature

After analyzing obstacle crossing possibility, if the current 3D grid map is can be passed through, it is necessary to analyze obstacle feature. In this way, Mars rover could take a different strategy under different condition of obstacle feature.

In the algorithm, the input is pointer of point cloud, and the output is a variable named “workcase”. During the experiment, the main analysis is about some relatively simple obstacle feature. If the value of “workcase” is 1, it indicates that the ground is flat; 2 indicates uphill straightly; 3 indicates uphill straightly on left side; 4 indicates uphill diagonally on left side; 5 indicates uphill straightly on right side; 6 indicates uphill diagonally on right side; 7 indicates uphill diagonally; 8 indicates downhill straightly; 9 or 10 indicates downhill on one side (left and right).

Firstly, the algorithm will judge whether the area is “workcase” 1 or not by average and variance of Z value. Then the algorithm selects four arrays of data points whose X value are -0.45m, -0.25m, 0.25m and 0.45m respectively. And the Y value of data points in every array are sorted by size. In addition, the algorithm will search the points whose Z value is more than 0.05m in every array and assign the least Y value to variable distance. Secondly, the algorithm will judge whether the difference between distances (X value -0.45m and 0.45m) is less than 0.1m or not. And the difference can be signed by Diff (-0.45 to 0.45). The other terrain data analysis is as follows.

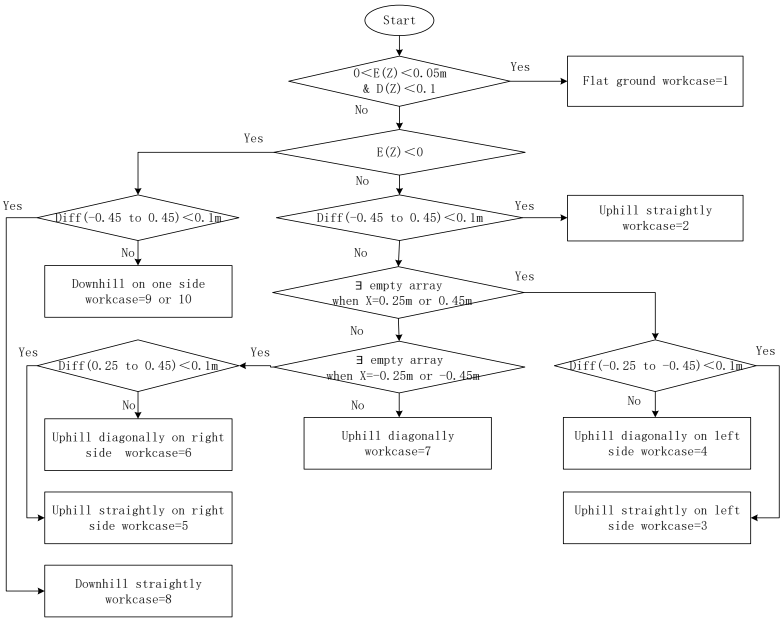

Fig. 7 Flow diagram of obstacle feature analysis

3.3 Experiments under Webots Robot Simulation Environment

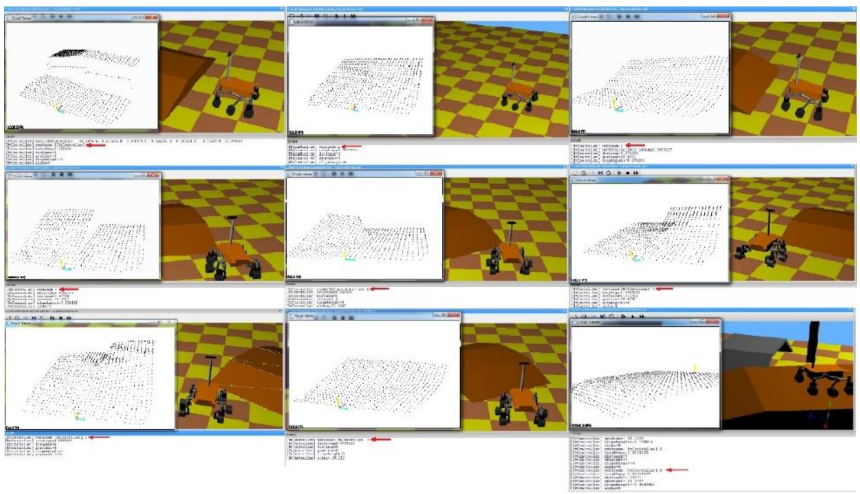

Fig. 8 Algorithm experiments under Webots robot simulation environme

Table 2 Errors between actual value and analysis value in experiments

Obstacle	Feature	Actual value	Analysis value	Errors (%)
2	distance	0.6750m	0.6763m	0.1926
	gradient	20.0°	20.0021°	0.0105
3	distance	0.4740m	0.4750m	0.2110
	gradient	20.0°	20.0014°	0.0070
4	alpha	-26.0°	-26.6887°	2.6488
8	distance	1.2950m	1.3007m	0.4402
	gradient	-11.5°	-11.4787°	0.1852

4 Conclusion

Considering the size of Mars rover, Errors between actual value and analysis value are within an acceptable range. According to figure 8, the algorithm can realize obstacle feature recognition and get result in a short time about 0.5s. In conclusion, simulation experiments verify the accuracy and real-time of the algorithm.

Acknowledgment

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References

1. Andreasson, H.,Treptow, A.,Duckett, T. Localization for mobile robots using panoramic vision, local features and particle filter[A]. In 2005; 3348-3353
2. Bajracharya M, Maimone M W, Helmick D. Autonomy for mars rovers: Past, present, and future [J]. Computer, 2008, 41(12): 44-50
3. Kim I H, Kim D E, Cha Y S, et al. An embodiment of stereo vision system for mobile robot for real-time measuring distance and object tracking[C]//Control, Automation and Systems, 2007. ICCAS'07. International Conference on. IEEE, 2007: 1029-1033
4. Matthies L, Kelly A, Litwin T, et al. Obstacle detection for unmanned ground vehicles: A progress report [M]. Springer London, 1996
5. Manduchi R, Castano A, Talukder A, et al. Obstacle detection and terrain classification for autonomous off-road navigation[J]. Autonomous robots, 2005, 18(1): 81-102
6. Nguyen D V, Kuhnert L, Schlemper J, et al. Terrain classification based on structure for autonomous navigation in complex environments[C]//Communications and Electronics (ICCE), 2010 Third International Conference on. IEEE, 2010: 163-168
7. Su L, Luo C, Zhu F. Obtaining obstacle information by an omnidirectional stereo vision system[C]//Information Acquisition, 2006 IEEE International Conference on. IEEE, 2006: 48-52