Research Article
Development of a Mars Rover with Mapping and Localization System

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Abstract: In order to provide the research foundation for future exploration of the unknown world, a mars rover prototype is developed for studying the related technologies. In this study the development of a mars rover prototype with mapping and localization system is presented. At first, the architecture of the mars rover is designed to meet the motion requirement on rough terrains. The sensory system with stereo vision is introduced, which is responsible for environmental modeling. The experiment shows that the developed prototype is able to explore in unknown environments and the mapping and localization system proved to be feasible.

Keywords: Mars rover, mapping and localization system, stereo vision

INTRODUCTION

There is growing international interest in a global exploration of the surface of Mars. Up to now, more and more countries have put forward their own mission to Mars. Most of them are concerned about the development of the rover and hope to learn more about Mars by rover's application.

Since 1997, JPL has successfully landed four rovers on the surface of Mars, including the Sojourner rover (Team, 1997) in 1997 and the Spirit (Squyres *et al*., 2004a) and the Opportunity (Squyres *et al*., 2004b) in 2004 and the newest one is the Curiosity (Richard, 2012) in 2012.

Corresponding to such growing attention, there are an increasing number of research papers being published to deal with technological issues on exploration rovers. The research area is very broad from rover designs (Iizuka *et al*., 2006; Lindemann and Voorhees, 2005), motion control (Karl, 2000; Yoshida and Hamano, 2002), path planning (Tarokh *et al*., 1999) and so on.

However, among all the research cases, map building for the unknown environment is the first work should be done before moving. The Spirit and the Opportunity successfully built the 3D map for the environment around them, using two monochromatic navigation cameras (Navcams) mounted on the mast. Some machine vision technology (Squyres *et al*., 2005; Cheng *et al*., 2005; Maimone *et al*., 2007) was presented, which is applied for navigation and hazard avoidance.

However, there are also many technical difficulties with the Simultaneous Localization and Mapping (SLAM), especially for the unstructured 3D environment. Therefore, it is necessary to have more research for mars rover.

In order to study the mapping and localization problems for the robot moving in the unstructured environment, we developed the prototype of mars rover as experimental platform for validation of algorithms.

THE SYSTEM FRAMEWORK

In planetary exploration, rovers are required to move on rough terrains such as in craters and rear cliffs where it is scientifically very important to explore. Further, rovers must avoid tip-over and stack even though they move on rough terrains. According to the mission demands, we design the rovers with following characteristics.

Mobility:
- Rover dimensions:
- 110cm(L)*130cm(W)*46cm(H) (Not including the height of the mast)
- Weight 80Kg
- 6-wheel, all wheels independently driven
- Max speed 20 cm/sec, 25 cm wheels
- Obstacle performance: 200 mm
- Climb a 30-degree slope
- Navigation and control:
- Industrial Personal Computer: Onboard Pentium M 1.6 GHz, 1 GB DDR2 SDRAM, PCI-104 expansion
- Software architecture under Linux
- Mast-mounted Binocular stereo vision: Bumblebee2, 1/3" CCD sensor, 15FPS

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Fig. 1: The photo of the mars rover

- Panoramic camera: SONY RPU-C251
- Operability: autonomous control and teleoperation control
- Navigation and obstacle avoidance performance

In order to meet the functional requirements, we proceeded with the rover design, which is shown in Fig. 1. The rovers are six-wheel-drive, four-wheel-steered vehicles with a rocker-bogie suspension system similar in design to the Curiosity. All 6 wheels of the rover are independently driven by their own DC motor and the front two wheels and rear two wheels are also steered by identical DC motor as are the wheel drives.

With the rocker-bogie design, it allows the traversing of obstacles of at least a wheel diameter 25 cm) in size. The binocular stereo vision and panoramic camera is mounted on the mast at the top of the rover. The controller and other sensors are installed in the rover chest.

The rover control system is composed by the System on Robot and the Tele-operator & Monitor System (Fig. 2). The System on Robot includes the main controller, mapping module, motion control module, sensor module, path planning module and wireless transmission module.

The motion controller is designed on the STM32 and All of them are connected together by the CAN bus. The mapping module includes the Binocular stereo vision and the processor and the Sensor module includes the inclinometer and the laser. The Tele-operator & Monitor System is mainly used to control and monitor the state of the Mars Rover.

MAPPING AND LOCALIZATION SYSTEM

The mapping and localization system for the rover is mainly used to set up the 3D map of surrounding environment when the Mars Rover remains still,
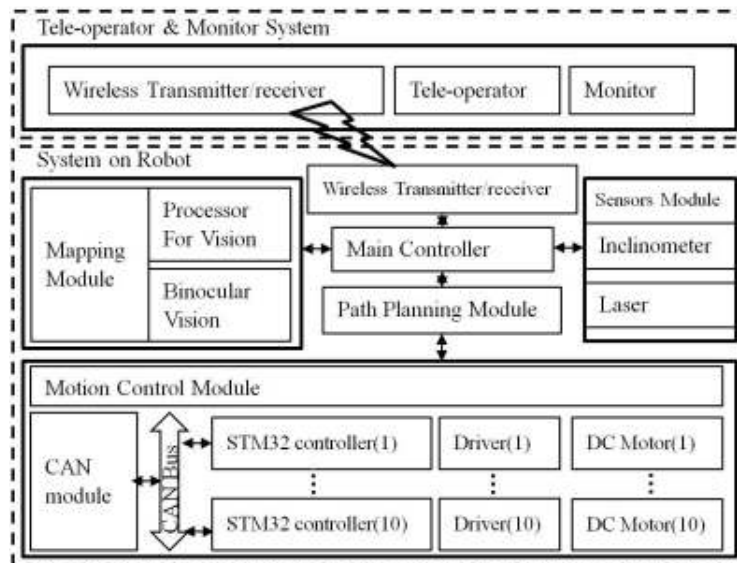

Fig. 2: The framework of the rover control system

Fig. 3: The components of the stereo vision system

simultaneously create 3D map and locate itself when Mars rover moves. The basic components of Mars Rover's binocular stereo vision sensor system are shown in Fig. 3: They mainly include binocular stereo camera (Bumblebee2) for acquisition of environment image, an IPC (Model: Advantech UNO-2172-P22E), PCMCIA card, IEEE-1394 line which are used to connect the IPC and binocular stereo camera, battery to provide power for IPC and also DC-DC voltage converter utilized between battery and IPC.

THE METHOD FOR SIMULTANEOUSLY 3D MAPPING AND LOCALIZATION

Binocular stereo camera system acquires real-time environmental gray scale image. Images are read into IPC's memory via PCMCIA card hardware interface. After using image calibration data to rectify the left and right image of each frame, we obtain 3D point cloud map from disparity image.

According to the parallax principle of binocular vision, disparity of each pixel in the images can be computed through the two images at both left and right side, then after arranging disparity value based on pixels of reference image (left image), we can get a disparity image (a gray scale image). Also the 3D coordinate values of each image feature pixel point in the camera coordinate system can be computed by using camera parameters. Therefore, all the feature points are restored to 3D space and form a 3D point cloud with equal proportion. Furthermore, through coordinate transformation, we are able to obtain 3D point cloud map of the environment collected by image in any coordinate system. Left image, disparity image and 3D point cloud are shown respectively from left to right in Fig. 4.

After obtained 3D point cloud map from disparity image, we extract the feature point and estimate the camera movement. The main process is shown in Fig. 5.

SURF (Bay *et al.*, 2006) is mainly adopted here to conduct feature point extraction and feature matching. The relative visual odometry procedures in open source ROS system [14] are used to enable acquisition of relative positioning data during camera movement, in which least square method is applied. The actual acquisitions are a rotation data expressed in quaternion and a displacement vector. Every two frames' positioning data are calculated to get each frame's rotation and translation relative to initial coordinate system. Therefore we get the positioning of the camera movement.

With 3D point cloud of each frame and positioning data of each frame, an incremental 3D point cloud map can be built by the method presented.

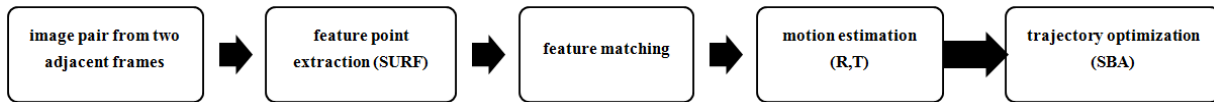Fig. 4: From disparity image to 3D point cloud map

Fig. 5: Feature point extraction and estimation of camera movement

Fig. 6: Mars Rover's travel environment (left) and created incremental 3D map (right)

EXPERIMENT AND CONCLUSION

An experiment has been carried out to build an incremental 3D map of complex outdoor environment. The environment and 3D map are shown in Fig. 6 and the white line shown in the two pictures is an approximate route the Mars rover moved. By gradually expanding the range of Mars Rover's 3D reconstruction, Mars Rover can achieve autonomous positioning and movement in certain range.

In this way, during the movement of binocular stereo camera system, a continuously expanding 3D map of the real environment is constructed, in the meantime, the Mars Rover's mobile data is also calculated, which can be used to positioning during the movement of Mars Rover.

According to the experiment, we found following problems:

- For the binocular stereo vision sensors, the less environment characteristics, the greater the difficulty of feature matching and the positioning error will increase. Also the point cloud becomes sparse and it affects the quality of the incremental map. Therefore, it is necessary to apply multi-sensor information fusion method to achieve environmental perception by using other depth sensors.
- Due to the massive calculation for image processing, it is difficult to meet real-time requirements. The future research will focus on the algorithm optimization, so as to improve the real-time of rover control.

In this study, the prototype of mars rover with mapping and localization system has been presented. By the experiments, the feasibility of the mechanism system and electronic system was proved. Also the 3D map information for the surrounding environment was obtained by the mapping and localization system. The results are foundations of the further study of mars rover.

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