RESEARCH ON THE METHOD OF STEP FEATURE EXTRACTION FOR EOD ROBOT BASED ON 2D LASER RADAR

Qiang Yin
College of Mechanical Engineering
Wuhan Polytechnic University
Wuhan 430023, China

Gongfa Li*
College of Machinery and Automation
Wuhan University of Science and Technology
Wuhan 430081, China

Jianguo Zhu
School of Mechatronic Engineering
Beijing Institute of Technology
Beijing 100081, China

ABSTRACT. Considering the requirements of climbing obstacle and stairs for Explosive Ordnance Disposal (EOD) robot, a method about step feature extraction based on two-dimensional (2D) laser radar is in great demand. In this paper, we research the three-dimensional (3D) environment feature extraction (EFE) method including the 3D point clouds map construction, the line feature extraction and the plane feature extraction. The EFE method can be applied to feature extraction of the step vertical plane. Based on the method, we construct a 3D feature recognition system (FRS) using 2D laser radar. FRS can help us extract quickly the step vertical planes from 3D laser radar line map, thus can provide necessary environment information for the decision and action of EOD robot. We demonstrate the ability of FRS by applying it to some typical step environment.

1. Introduction. Stair-climbing in complex environment is an important functional requirements of Explosive Ordnance Disposal (EOD) robot[7, 3, 1]. At present, in order to manipulate the robot to climb the stairs, the robot operators need to observe the robot real-time video images. A single two-dimensional video image is not sufficient to describe the three-dimensional feature of 3D space, thus multiple cameras are usually used to guide the operation. The analysis of multiple video information is a heavy mental work even for a skillful operator. Therefore, in a complex environment, it is a big challenge for controlling the robot to avoid obstacles or grasp explosives accurately. Sometimes operators need to try several
times to finish the task. In a bad situation, a failed attempt may cause serious consequences, such as the overturn of the robot and the trigger of the explosives. Thus, in this kind of operation mode, the operator is in an intensive and inefficient state all the time[2]. In an alternative mode, we can enhance the 3D sensing capability of the EOD robot and integrate some autonomous functions, such as obstacle surmounting and stair climbing. In this paper, we will propose a method of step feature extraction for EOD robot under complex environment.

2. Feature extraction of 3D environment.

2.1. The limitations of traditional feature extraction method. At present, there are very few studies on climbing stairs of mobile robot[9, 11, 5]. Previous researches are mainly concentrated on improving the obstacle-striding mechanism of robots, and robots with ability of autonomous climbing stairs have not been widely used[4, 15, 6, 14]. S. Stepflight et al propose to use a variety of sensors to identify the robot posture, and help the robot to ascend and descend stairs [8]. This method uses individual sensor modules including sonar, visual and acceleration sensors. The sonar sensor returns a distance measurement, the vision sensor calculates a heading angle, and the accelerometers on the robot give forward and lateral acceleration. At any moment, no more than one sensor will be used, and a rule-based judgment is adopted to extract information from the suitable sensor. In another work, Y. Xiong and others use a camera as the basic navigation sensor to detect the edge of steps, consequently, they can identify the current offset angle and offset direction for the robot[13]. But due to the complexity of the algorithm, the robot control cycle is long, leading to a slow movement of the robot. Then, limitations of camera-based environment detection are analyzed. The advantages of the method is that, the operators can obtain high-resolution images, and do not require the data of the stair edge. However, when the light is too strong or the loss of environmental information is intolerable, the fidelity of images would become very low and it’s difficult to figure out the accurate location and scope of the robot on the stair. One possible remedy is that before steps edge feature extraction, one may use some algorithms to eliminate the distortion and noise of the images. However, the whole process cycle is too long, and it is difficult to extract the step feature information rapidly.

On the basis of the above considerations, we need a rapid method to extract the environment feature information for EOD robots. We would like to mention that, laser radar is not restricted by all kinds of light conditions, and it very accurate for step environment automatic detection. 3D laser radar is capable of obtaining 3D space information [16, 12]. However, 3D laser radar is expensive, bulky and heavy. Especially, the imaging speed is slow, which restricts its application. Compared with the 3D laser radar, 2D laser radar has the advantages of fast response, simple structures and stable performance, thus is widely used in indoor mobile robot[10].

In this paper, based on 2D laser radar and a pan-tilt device, we design a kind of 3D feature recognition system (FRS) for EOD robot. The main processes are, (1) obtain the 3D spatial point cloud data, (2) transform the coordinates, (3) extract line and plane and (4) recognize step characteristic in a complex 3D environment. FRS can provide accurate data for the robot autonomous function. Our research is mainly focused on the extraction of the navigation information of climbing stairs for EOD robot, where the stair environment is treated as an unstructured environment.
2.2. 3D feature recognition system based on 2D laser radar. For the construction of 3D feature recognition system based on 2D laser radar, we select URG-04LX-UG01 laser radar produced by HOKUYO company. The system consists of the 2D laser radar, drive motor for pan-tilt-device, data acquisition card and computer control unit, as shown in Figure 1.

![System structure diagram](Image)

The main performance index of the system are as follows:

1. Horizontal scanning range: 240°;
2. Horizontal scanning time: 100 ms;
3. Horizontal angle resolution: 0.36°;
4. Pitching scanning range: 180°;
5. Pitch scanning speed: 5°/s;
6. Pitching angle resolution: 0.5°;
7. Measuring distance: 20 mm to 5600 mm;
8. Ranging accuracy: 30 mm (60 mm to 1000 mm); 3% of the measured distance (1000 mm to 4095 mm);

For the convenience of the observation and manipulation for the robot operator, PC machine can realize human-machine interaction by using visualization software. The environment around the robot is expressed with the help of OpenGL 3D graphics software. The operator can monitor the robot from multi-angle, and send instructions to the robot when necessary. Figure 2 shows the reconstruction of 3D environment by using OpenGL.

![3D environment reconstruction](Image)

3. Step feature extraction process based on 2D laser radar. The main steps of extracting step vertical plane from the 3D point cloud map are as follows:

1. Generate 3D point cloud map;
2. Create the 3D line;
extract 3D line of step vertical plane;
(4) generate step vertical plane by the fitting algorithm.

3.1. **Construction of 3D point cloud map.** We construct the 3D stair scene around the EOD robot by gathering data step-by-step. In a single scanning of the laser radar, only the information of one plane in the scene is obtained. In order to build a complete 3D scene, the environment should be scanned from different point of view. The 3D point coordinates of these scanning images are in different coordinate systems. Therefore, in order to obtain a complete 3D data, it is necessary to transform the 3D points of all the distance images into a common coordinate system.

The EOD robot could build the 3D point cloud map with laser scanning data by using a 2D laser radar. We use Visual C++ as the platform to develop the robot software system, including 3D data acquisition, display and preservation. The system uses OpenGL technology to display the 3D point cloud map. OpenGL is a powerful software interface used to produce high-quality, computer-generated images and interactive applications. Combined with Visual C++, OpenGL is independent of the window system and operating system.

We select a typical stair environment, as shown in Figure 3. In order to scan 3D data of the environment, firstly, the robot remains stationary, and the laser radar scans from minus 90 degrees to 90 degrees to collect 3D data from a single view point. Secondly, the laser radar data is processed through a coordinate transformation procedure, and then is visualized with OpenGL. Finally, the 3D point cloud map of the environment is reconstructed, as shown in Figure 4. By associating the heights of the points with various colors, we can display the gradient of the scene visually.

3.2. **Create the 3D line.** When the 3D point cloud map has been generated, each row of data frame is converted into the corresponding line with a line feature extraction algorithm. The whole scene map of 3D line is shown in Figure 5.

3.3. **Extract 3D line of step vertical plane.** In Figure 5, lines which are parallel to the ground should be regarded as the line of the step vertical plane. Therefore, we can easily extract all 3D line belongs to step vertical plane from 3D line map of the entire environment. The 3D lines of step vertical plane from different perspective are as shown in Figure 6.

3.4. **Fit step vertical plane.** 3D lines are classified according to their projections on the ground, that is, lines sharing the same projection should belong to the same group. All the lines in the same group are fitted into a plane until the whole step vertical plane is completed. The 3D scenes of step vertical plane from different perspective are shown in Figure 7.

Finally, some important parameters for the step plane (such as the step height, the width and the slope angle) can be obtained after extraction of vertical plane, which are the necessary environment information for the decision and action of EOD robot.

The above results show that the method of step extraction in complex environment presented in this paper is reasonable and effective. Step vertical planes are quickly extracted from 3D line map, which provide the step information necessary for robot stair-climbing.
4. **Conclusions.** Aiming at the Stair-climbing function demand of EOD robot, this paper proposes a kind of step feature extraction method to identify 3D stairs environment information based on 2D laser radar. We construct a 3D environment FRS using 2D laser radar. And demonstrate the ability of FRS by applying it to some typical step environment. The main processes of extracting step vertical plane...
Figure 6. 3D lines of step vertical plane from different perspective

Figure 7. Step vertical plane from different perspective

are, (1) obtain the 3D spatial point cloud data, (2) generate 3D line, (3) extract 3D line of step vertical plane and (4) generate step vertical plane by the fitting algorithm. Finally, 3D reconstruction of step vertical plane shows that this method is efficient and convenient.
In future work, we plan to rebuild an 3D environment in real-time, and develop new control strategies and path planning algorithm of autonomous stair-climbing for EOD robots.

Acknowledgments. This research reported in the paper was supported by Wuhan Polytechnic University Research Grant(No.2014RZ37). The research was also supported by the National Natural Science Foundation of China (Grant No.51575407).

REFERENCES

[1] X. G. Duan, Q. Huang and J. T. Li, Design and implementation of a small ground mobile robot with multi-locomotion modes, *China Mechanical Engineering*, 18 (2007), 8–12.
[2] L. Q. Fan, X. F. Yao and H. N. Qi, An automatic control system for EOD robot based on binocular vision position, *Proceedings of the 2007 IEEE International Conference on Robotics and Biomimetics*, 2007, 914–919.
[3] Q. Giuseppe, B. Luca and B. Giorgio, Epi.q-TG: Mobile robot for surveillance, *Industrial Robot: An International Journal*, 38 (2011), 282–291.
[4] S. Jiang, Service robot, *Robot Technique and Application*, 3 (2004), 10–14.
[5] R. Labayrade, C. Royere and D. Gruyer, et al., Cooperative fusion for multi-obstacles detection with use of stereovision and laser scanner, *Autonomous Robots*, 19 (2005), 117–140.
[6] Y. W. Li, S. R. Ge and H. Zhu, et al., Obstacle-surmounting mechanism and capability of four-track robot with two swing arms, *Robot*, 32 (2010), 157–165.
[7] A. I. Mourikis, N. Trawny and I. R. Stergios, et al., Autonomous stair climbing for tracked vehicles, *International Journal of Robotics Research*, 26 (2007), 737–758.
[8] S. Steplight, G. Egnal and S. Jung, A mode-based sensorfusion approach to robotics stair-climbing, in *Proceedings of 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Vol. 2, 2000, 1113–1118.
[9] S. Thrun, A personal account of the development of stanley the robot that won the DARPA grand challenge, *AI Magazine*, 27 (2006), 69–82.
[10] J. F. Vasconcelos, C. Silvestre and P. Oliveira, et al., Embedded UAV model and LASER aiding techniques for inertial navigation systems, *Control Engineering Practice*, 18 (2010), 262–278.
[11] S. Wender and K. Dietmayer, 3D vehicle detection using a laser scanner and a video camera, *IET*, 2 (2008), 105–112.
[12] Y. Wang, Z. Ma and Y. Hu, et al., Novel free-form surface 3D laser scanning system, *Journal of Mechanical Engineering*, 45 (2009), 260–265.
[13] Y. Xiong and L. Matthies, Vision-guided autonomous stair climbing, in *IEEE Int. Conf. Robotics and Automation*, Vol. 2, 2000, 1842–1847.
[14] P. Yang, J. Chen and C. M. Li, et al., Design of gravity center regulation system of stair climbing intelligent service robot, *Journal of Mechanical Transmission*, 38 (2014), 102–104.
[15] H. L. Zhuang, *Control System of Specialized Mobile Robot and Obstacle Performance Study*, Ph.D. thesis, Shanghai Jiao Tong University in Shanghai, 2013.
[16] G. J. Zhang, *Machine Vision*, 1nd edition, Science Press, Beijing, 1994.

Received July 2015; revised September 2015.

E-mail address: ydqking1210@sina.com
E-mail address: ligongfa@wust.edu.cn
E-mail address: hlrobot@163.com