Proceeding of the 2015 IEEE
International Conference on Information and Automation
Lijiang, China, August 2015

The Obstacle Detection and Obstacle Avoidance Algorithm Based on 2-D Lidar

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***Abstract* - Obstacle avoidance ability is the significant embodiment of the ground mobile robot, and the basic guarantee of the ground mobile robot to perform various tasks. Obstacle avoidance technologies are divided into two kinds, one is based on the global map and another is based on sensors respectively. This paper mainly aims at the local obstacle avoidance method based on sensors. The study of obstacle detection and obstacle avoidance are two inseparable parts in the research of obstacle avoidance ability. This paper proposes an efficient obstacle detection and obstacle avoidance algorithm based on 2-D lidar. A method is proposed to get the information of obstacles by filtering and clustering the laser-point cloud data. Also, this method generates the forward angle and velocity of robot based on the principle of minimum cost function. The obstacle detection and obstacle avoidance algorithm has advantages of a simple mathematical model and good real-time performance. The effectiveness of the proposed algorithm is verified on MATLAB simulation platform.**

Index Terms* – *2-D lidar; obstacle detection; obstacle clustering; obstacle avoidance

I. INTRODUCTION

Obstacle avoidance technology is a hotspot in the field of the ground mobile robot, also is one of the most important embodiment of the intelligent robot. Good performance of obstacle avoidance is the basic premise of robot on a particular task.

The technology of obstacle avoidance can be divided into two parts, one is global obstacle avoidance method based on the known environment information and another is local obstacle avoidance method based on the information from sensors. This paper is mainly focused on the local obstacle avoidance method based on the information from 2-D lidar.

Lidar has the advantages of high precision, large detection range, and fast sweep frequency. It is widely used in the obstacle detection field of the ground mobile robot [1]. Lidar can be divided into 2D lidar and 3D lidar. 3D lidar can get the height information of obstacles, so it is suitable for bumpy environment, such as the sea, field, etc. But its data is large which costs more processing time, meanwhile the price of 3-D lidar is higher than 2-D lidar [2-4]. This paper is focuses on the 2-D lidar for its low price and more fast processing time.

The most commonly used local obstacle avoidance method is the artificial potential field method (APF) and visible graph method, they all have the advantages of a simple mathematical model and good real-time performance. The theory of artificial potential field (APF) was proposed by Khatib, he defined the influence of the target on the robot as virtual attractive force, and the influence of obstacles on the robot as virtual repulsive force, the direction of the resultant force is also the direction of the next movement of the robot [6]. The traditional artificial potential field method has some problems, such as local optimal solution, and target inaccessible when robot is near to the target. There are some improved artificial potential field methods combined with the fuzzy rules [7], genetic algorithm [8], and regression search method [10] respectively. The visual graph method can be used to judge if the line between the robot and the target cross the obstacle, no cross represents the target is visible, the robot can reach the target point directly, Otherwise, choose one of the connecting line from the robot to the ends of obstacle as the direction of traffic [12][14].

This paper proposed a simple and practical obstacle detection method based on the 2-D lidar LMS511 from SICK SENSOR, and also designed an obstacle avoidance algorithm in the light of the results of the obstacle detection, which is based on visibility graph method, and the validity of the algorithm is verified on the MATLAB simulation platform.

II. 2-D LIDAR

LMS511 is a two dimensional lidar of SICK SENSOR used in field (Fig. 1), measuring range up to 80 meters. Its horizontal scan range from -5° to +185°, angle resolution is set to 1°, once scan can get 191 laser points, also called laser-point cloud (Fig. 2). Assume that the distance of the laser point *I* is *Ri*, The position of this laser point in Rectangular coordinate system with the origin of lidar can be obtained as *(Xi, Yi)*:

$$\begin{aligned} Xi &= Ri * \cos(i - 5) \\ Yi &= Ri * \sin(i - 5) \\ i &\in (0,190) \end{aligned} \tag{1}$$

Since the lidar is in single plane scanning, considering the lidar is installed on the ground mobile

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robot may encounter low obstacles. Install the lidar in a slightly downward sloping way when use it, set the sloping angle as *a* (Fig.3). Therefore, the distance value need to be revised, the revised point coordinates of laser can be expressed as following:

$$
\begin{aligned}
& Xi = Ri * \cos(i - 5) * \cos(a) \\
& Yi = Ri * \sin(i - 5) * \cos(a) \qquad (2) \\
& i \in (0,190)
\end{aligned}
$$

Fig. 1 SICK LMS511

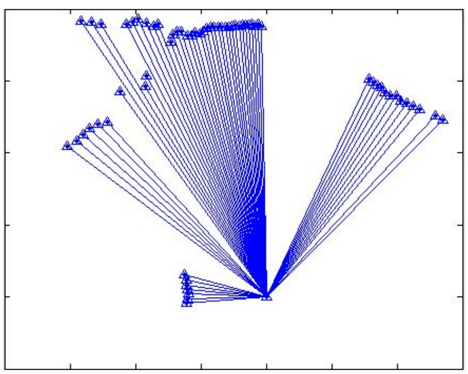


Fig. 2 Origin data of lidar.

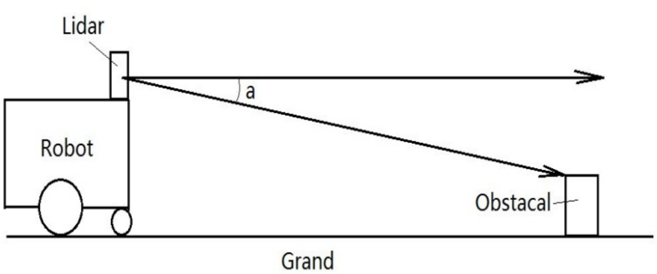


Fig.3 Lidar downward sloping angle a

III. OBSTACLE DETECTION ALGORITHM

Combined with the characteristics of laser-point cloud data, this paper proposed an obstacle detection algorithm and its process is shown in Figure 4:

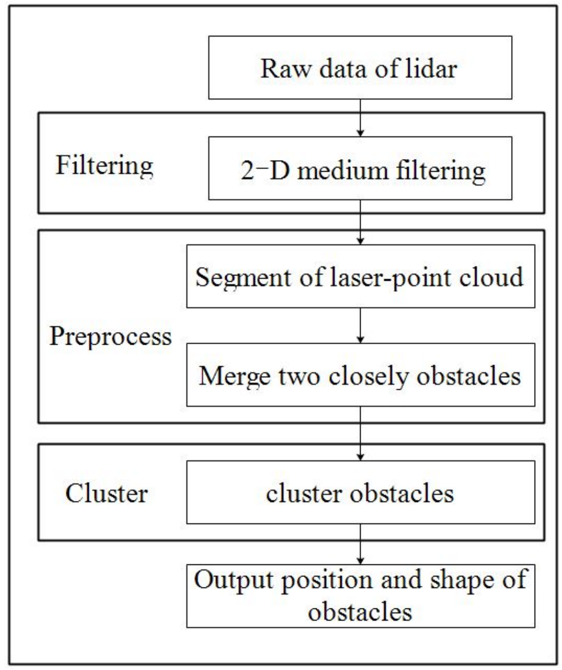


Fig.4 Obstacle detection algorithm process

Obstacle detection process is mainly divided into three steps: the filter, preprocess, and obstacle clustering.

A. Median filtering

Using a 3*3 median filtering window at the laser-point cloud data, set the current time as *t*, and the value of laser point *i* is *R(t, i)*, Then build the 3*3 median filtering window shown as following:

$$
\begin{aligned}
& [R(t-1, i-1), R(t-1, i), R(t-1, i+1) \\
& R(t, i-1), R(t, i), R(t, i+1) \\
& R(t+1, i-1), R(t+1, i), R(t+1, i+1)]
\end{aligned}
$$

Take the median of the 9 numbers as the value of the distance between robot and the laser point *i* at the time *t*, this method can give attention to both space and time, filtering out the occasional noise points, reducing the complexity of the obstacle clustering.

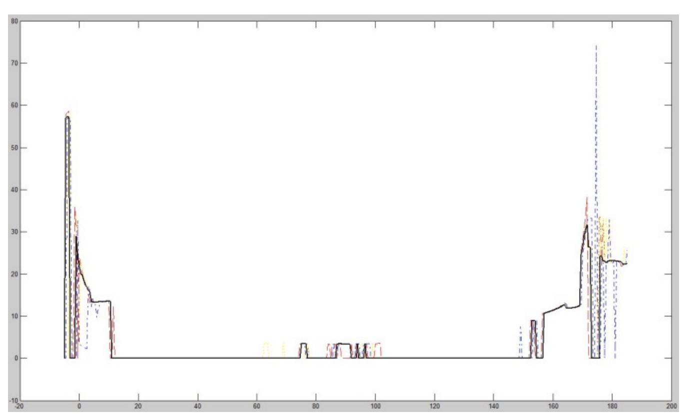


Fig.5 Effect of Median filtering

B. Preprocessing of laser-point cloud data

The progresses in preprocessing the laser-point cloud data is expressed as follows:

(i) In space order, for segmentation of the 1*381 laser-point cloud sequence, set i as the index value of those 381 laser points, $R(i)$ is the distance value of the laser point i, so the starting index and the termination index of each block of independent laser-point cloud blocks are *start(i)* and *stop(i)* respectively, among which *start(i)* satisfies

$$(R(i-1) == 0) \&\& (R(i) != 0) \tag{3}$$

In the same way, *stop(i)* satisfies

$$(R(i) != 0) \&\& (R(i+1) == 0) \tag{4}$$

(ii) Assuming the 381 laser points are divided into N blocks at the step (i), splitting each of the laser-point cloud blocks, the conditions for separation is when the distance between point i assumed to be $(x(i),y(i))$ and point $i+1$ assumed to be $(x(i+1),y(i+1))$ is greater than the value of the width of the robot multiply the amplification factor k.

$$d = \sqrt{[x(i) - x(i+1)]^2 + [y(i) - y(i+1)]^2} \tag{5}$$

If distance d satisfies the condition: $d > k * Width$, where $Width$ means the width of the robot. Then break the current laser-point cloud block into two pieces, and the amount of laser-point cloud block plus one time.

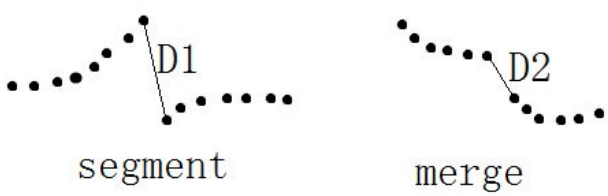


Fig.5 Segment and merge

(iii) If there are N laser-point cloud blocks, the value of L is the space distance between the termination point of laser-point cloud block i (set its index value as p in the 381 laser points) and the starting point of laser-point cloud block $i+1$ (set its index value as q in the 381 laser points). If the value of L satisfies the condition: $L < Width$, which means the robot cannot pass this narrow gap, so consider them to be merged into one laser-point cloud block, the calculation just like step (ii). Finally, the total number of laser-point cloud block minus one time. To make the two combined laser-point cloud blocks spatially continuous, we need to give value to those laser points cloud between p and q, assuming that there are *num* laser points required the assignment, and the distance value of point p is $R(p)$, the distance value of point q is $R(q)$, so $i \in [1, num]$, the calculation method of $R(i)$ can be expressed as following:

$$R(i) = R(p) + i * \frac{R(q) - R(p)}{num} \tag{6}$$

C. Obstacle clustering

Assuming after filter and preprocess of the 381 laser points, the laser-point cloud is divided into N independent laser-point cloud blocks, clustering each block of laser points, $i \in (0, N)$, set the starting point index value and termination point index value of block i are p and q respectively. Clustering methods can be divided into three types: circular, linear and rectangle. The judgment condition is expressed as following:

(i) If the amount of laser points in a laser-point cloud block is x, and x is less than 5, the clustering method is circular, get the intermediate point $O(Xo,Yo)$ between starting laser point p and termination laser point q as the center of a circle, Dj is distance between those x laser points and point O, $j \in [p,q]$,chose the maximum of Dj as the radius of the circle. As shown in the figure 6.

$$\begin{aligned} Xo &= \frac{Xp + Xq}{2} \\ Yo &= \frac{Yp + Yq}{2} \\ r &= max(Dj) \\ j &\in [p,q] \end{aligned} \tag{7}$$

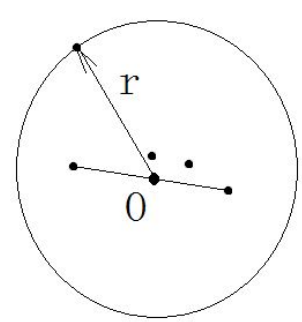


Fig.6 Circular clustering

(ii) If x is greater than 5, set the line L: $y=ax+b$ which connecting the starting point p and the termination point q as the benchmark, calculate distances between the line L and each point between point p and point q, get the maximum value as $Dmax$, $|s|$ is the distance between point p and point q, if $Dmax < 0.2 * |S|$,the clustering method is linear, returns the information of two endpoints which named *Point1* and *Point2*.

(iii) If $Dmax \geq 0.2 * |S|$, the clustering method is rectangle, returns the rectangle's four endpoints which named *Point1*, *Point2*, *Point3* and *Point4*. In practice, this method can be treated as 4 lines. As shown in Figure 7.

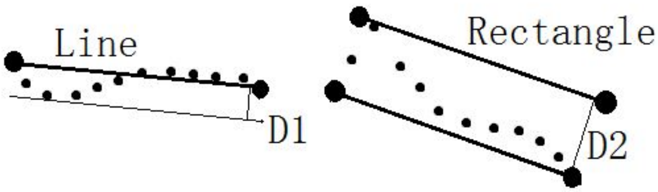


Fig.7 Linear and rectangle clustering

IV. OBSTACLE AVOIDANCE ALGORITHM

Set the robot's current traveling direction angle to be θ, the termination point is destination, when there is no obstacles, the optimum direction is from robot to the Destination, set as α ,we get

$$\alpha = actan(\frac{y_D - y_r}{x_D - x_r}) \tag{8}$$

Among which (x_D, y_D) is the terminal point coordinate, (x_r, y_r) is the current coordinate of the robot. At this point the robot's next steering angle is $\alpha - \theta$.

When obstacles are detected in the process of moving, and if they are without prejudice to the robot's steering angle which make the robot reach the terminal point from the current position, the steering angle remains: $\alpha - \theta$.

In the process of moving, if robot will collide with an obstacle in the direction of α , we need to search for a turning angle β_i at the both sides of angle α which can help the robot avoid obstacles. To speed up the search speed, take 1° as the interval, ie

$$\begin{aligned} &\beta_i = \alpha + i \\ &i \in [-90, 90] \end{aligned} \tag{9}$$

In all feasible directions, construct a cost function as following:

$$\beta = min\{\left|\beta_i - \alpha\right|\} \tag{10}$$

So the turning angle which can help the robot avoid obstacles is $\alpha+\beta$. As shown in the Figure 8 and Figure 9.

The difference between Fig. 8 and Fig. 9 is the laser range, for it adopt 50 meters laser range in Fig. 8 compared with it adopt 60 meters laser range in Fig. 9.

Set the laser range to be 50 meters, there are a linear obstacle in the left front of the robot and a circular obstacle in the right front. Only the right part of the linear obstacle is beyond the detection range of lidar, so the robot chose a direction as shown in Figure 8. When increasing detection range of lidar to be 60 meters, all of the linear obstacle and circular obstacle are in the detection range of lidar, so robot chosed the right side of the circular obstacle as the optimal traveling direction. As shown in Figure 9.

According to contrast turning angle generated by Fig. 8 and Fig. 9, we found that the turning angle in Fig. 9 is more reasonable because robot could get more environment information with laser range set to be 60 meters.

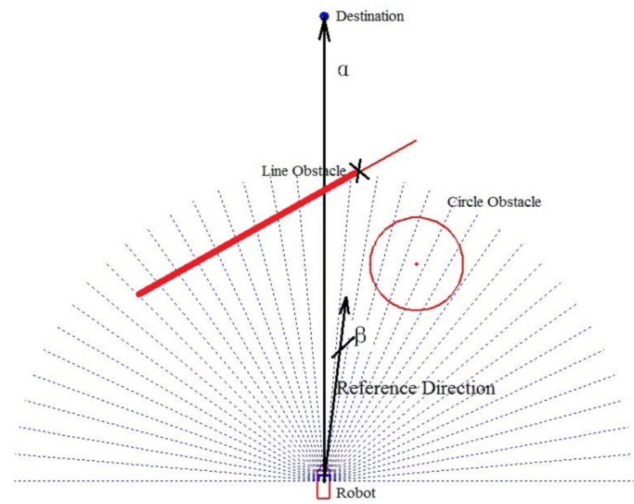


Fig.8 The selection of the optimum direction

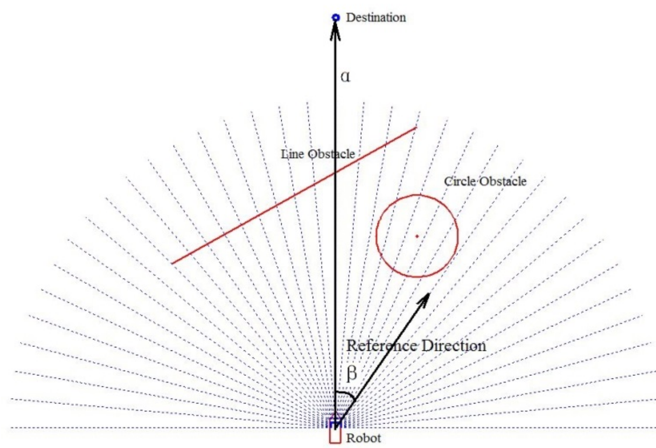


Fig.9 The selection of the optimum direction after increasing lidar's detection range

Simultaneously, the speed control of robot is also designed in consideration of running safety. Assuming that L_{safe} is the safe distance, and L_{danger} is the dangerous distance, so the speed control rate can be expressed as following:

$$V = \begin{cases} V_{max} & Dist >= L_{safe} \\ (0.2 + \frac{Dist - L_{danger}}{L_{safe} - L_{danger}} * 0.8) * V_{max} , & L_{danger} <= Dist < L_{safe} \\ 0.2 * V_{max} & Dist < L_{dangeer} \end{cases} \tag{11}$$

V. SIMULATION TEST

In order to verify the effectiveness of the above-described obstacle detection and avoidance algorithms, some robotic obstacle detection tests are conducted. The test field is shown in Figure 10.

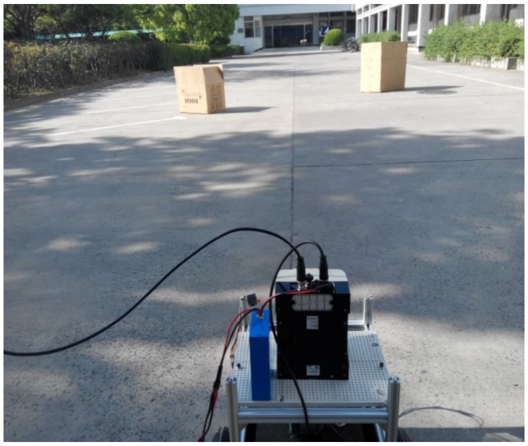


Fig.10 The test scenarios

It contains bushes, walls and wooden boxes in the test scene. The laser-point cloud data obtained by lidar was shown in Figure 11.

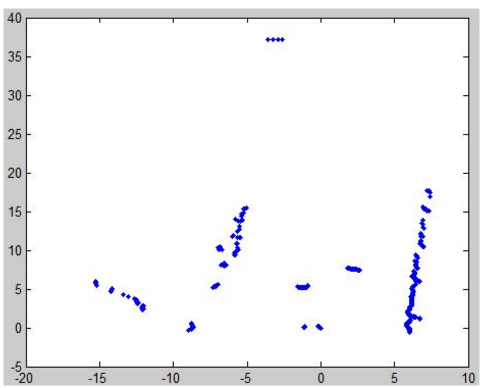


Fig.11 The laser-point cloud data of lidar

Import the collected raw data into the obstacle detection algorithm, obstacle information after extraction was shown in Figure 12.

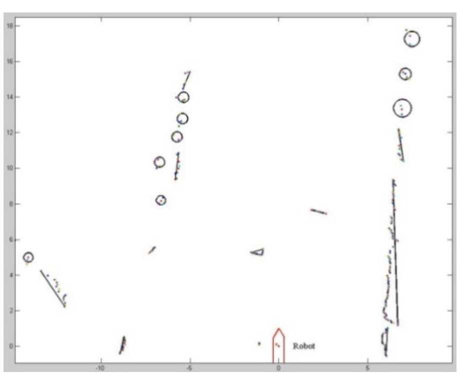
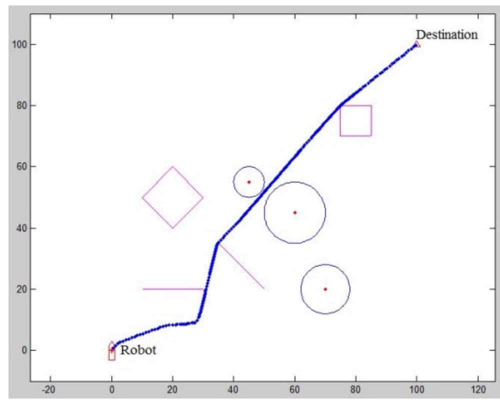


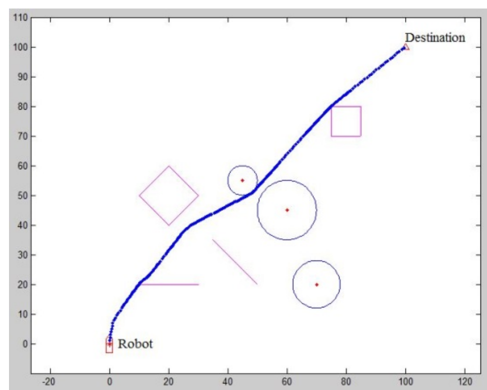
Fig.12 The obstacle information after extraction

It can be seen from the Figure 12, the obstacle detection algorithm proposed in this paper could filter and split the laser-point cloud data quickly and effectively, and cluster the laser points into linear obstacles and circular obstacles.

Meanwhile, some simulation tests were carried out on MATLAB simulation platform about the robot's obstacle avoidance algorithm. Simulation scenario is an area of 100m * 100m, *(0, 0)* is the starting point, *(100, 100)* is the termination point. Setting detection range of lidar to be 50m and 80m respectively, a series of circular and linear obstacles were set up in those tests, and the results of those tests with the obstacle avoidance algorithm proposed in this paper shown is shown in Figure 13:



(a)



(b)

Fig.13 The obstacle avoidance tests in complex environment
(a) lidar's detection range is 50m (b) lidar's detection range is 80m

It can be seen that the greater the detection range of lidar was, the more the environmental information could be got, and the better the obstacle avoidance path was.

In obstacle avoidance process, when the obstacles are located after the target, destination unreachable problem is arisen, the reason is when the robot approaches to the target, some obstacles after the target are detected, then robot makes an evasive action, so it can't reach to the target directly, as shown in Figure 14. The solution is setting a circular area, of which the center is the target point, and *r* is the radius. When moving into this area, the robot begins to estimate whether the obstacle on the path blocks robot and target point. If there is no obstacle across the path, the robot could reach to the target directly. Or the robot will apply the avoidance strategy to avoid obstacles, as shown in Figure 15.

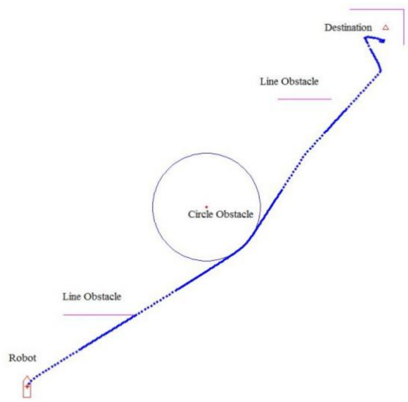


Fig.14 Destination unreachable problem

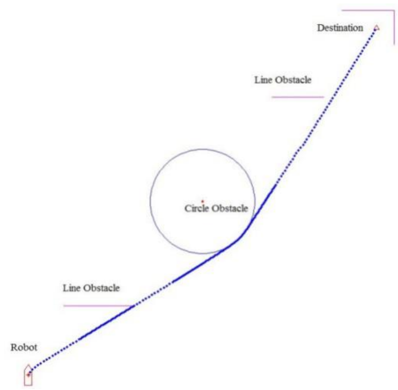


Fig.15 The solution of destination unreachable problem

VI. CONCLUSION

In this paper, the obstacle detection method based on SICK LMS511 outdoor lidar can effectively filter the noise from raw laser data, segment and cluster the laser-point cloud by means of filtering, preprocessing and clustering. The test result acquired from an outdoor environment show that the obstacle information can be obtained by using this method. Meanwhile, this paper proposed a simple obstacle avoidance method based on visibility graph method with a MATLAB simulation platform which proved its effectiveness in a complex scene. Future job will focus on dealing with dynamic obstacles with 2-D lidar.

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