Obstacle avoidance for unmanned vehicle based on a 2D LIDAR

Zeyu Ma
ISCTE – Instituto Universitário de Lisboa
Shanghai Martime University
Lisbon, Portugal
zmaue@iscte-iul.pt

Octavian Postolache
Instituto de Telecomunicações ISCTE – Instituto Universitário de Lisboa
Lisbon, Portugal
opostolache@lx.it.pt

Yongsheng Yang
Institute of Logistics Science & Engineering
Shanghai Maritime University
Shanghai, China
yangys_smu@126.com

***Abstract*—In recent years, international trade ports have become increasingly busy. As the most important form of transportation in international trade, container shipping plays an important role in reducing the labor cost of terminals, improving port capacity and reducing the energy consumption of loading and unloading operations. AGV is gradually becoming the main tool for container handling in large international ports. It can work continuously and continuously, improving the efficiency of container operation. Due to the complex port environment, the technical requirements for unmanned vehicles are highly demanded. Unmanned vehicle obstacle avoidance technology is an important part of many related technologies. The detection and avoidance of surrounding obstacles is to be achieved by unmanned vehicle in safety condition. How to get environmental information and plan the route is very important. In this paper, we design and develop a laser-based avoidance system for autonomous guided vehicle materialized in this work by two-wheeled robot. This system can quickly collect obstacle distance information and effectively avoid the obstacles and determine the new direction and a new path after information processing on the level of computation platform. The local processing on the edge platform expressed by a Raspberry Pi is followed by cloud processing. Experimental results are presented that validate the capability of the system. on navigation based on 2D LIDAR.**

Keywords—LIDAR, obstacle avoidance, Autonomous Robot

I. INTRODUCTION

In recent years, new generations of unmanned vehicles such as AGVs, unmanned vehicles have gradually replaced inefficient container trailers as the main tool for container handling in large international ports that improves the efficiency of container operations. Due to the complex port environment, the technical requirements for unmanned vehicles are highly demanded. The obstacle avoidance technologies are developing every day to realize the safety operation of unmanned vehicles. Obstacle avoidance is a very important function of an unmanned vehicle. In this article, are discussed how robots can avoid obstacles distributed in their operation environment.

In order to acquire information of the surroundings and build a 2D/3D model of the environment, it is used accurate optical measuring instrument, such as a LIDAR. LIDAR is an optical measurement instrument with high that operates free from electromagnetic waves and light interference. The LIDAR permits wide measurement range, and it is a common solution for mobile robots. The basic working principle of LIDAR is to measure the time interval from the emission of the laser beam to the reception of the reflected light from the surface of the obstacle (target object). Raspberry Pi is used to control through a step motor the LIDAR orientation to avoid obstacles autonomously. The Raspberry Pi is a microcomputer that can be used in conjunction with a variety of sensors is part of Internet of Things implemented architecture.

The goal of the work is to develop a system for indoor/outdoor distance measurement to obstacles and surrounding environment modelling for unmanned vehicle. This can improve the operational safety and to reduce collision rate of unmanned vehicles. A study obstacle avoidance strategies and robot motion control in multiple scenarios it is also considered.

II. RELATED WORK

In order to solve this navigation and obstacle avoidance related problems, a variety of sensors are applied. In [1], the author developed an alternative position estimation method and implementation of LIDAR sensor and Raspberry PI for 2D space mapping. In [2], they have developed a new emergency obstacle avoidance module for moving robots that uses Laser Imaging Detection and Ranging (LIDAR) to detect static and moving obstacles. They developed a LIDAR rotation platform and detects low height objects. In [3,4] they describe the performance evaluation of obstacle detection and segmentation algorithms for automatic guided vehicle (AGV) navigation using a 3D real-time ranging camera. In [3] the author verified measurements obtained using a partially accurate 2D scanning laser range finder. In [4] they use PMD camera to measure the obstacle, Pixel-Mixed-Device Technology (PMD) offers a small, light-weight camera generating 3-D images, based on time-of-flight The particular characteristics of the sensor characteristics and application potential for mobile robots. In [5], This paper describes a navigation and control system that uses a differentially driven magnetic point to guide the AGV. In addition, Hall effect sensors, encoders and counters are used for control and continuous guidance. The specific implementation of the magnetic spot navigation method in Shanghai Yangshan Port is presented in [6]. As an inexpensive and simple distance sensor, ultrasonic sensors are widely used in unmanned vehicles. In [7,8] In these two papers, the fuzzy logic obstacle avoidance method based on ultrasonic sensor is introduced. In [7] the author introduces an approximate fuzzy inference method based on KH interpolation in the fuzzy environment of fuzzy rule base. This method can be realized as practical direct fuzzy logic. Control the application. In [9] are described algorithms applied on single 2D laser imaging detection and ranging (LIDAR) sensor to perform autonomous 3D reconstruction of the environment and a robotic operating system (ROS) to implement it on a robot. This paper [10] describes an algorithm that performs an autonomous 3D reconstruction of an environment with a single 2D Laser Imaging Detection and Ranging (LIDAR) which can create a

3D model of the robot's surroundings without prior information or human intervention. In [11], the authors combine LIDAR with the Mecanum drive system. The Mecanum wheel is a design for a wheel that can move a vehicle in any direction. Set the robot to protrude and protrude from the wall along the wall (doors, posts, and other features). The robot scans at an angle to clear the object, pass the object, and then scan the wall to restore its original path. In this paper [12], an efficient obstacle detection and obstacle avoidance algorithm based on two-dimensional lidar is proposed. The algorithm provides obstacle information 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. In [13] they investigated the trajectory tracking control of a wheeled mobile robot using a laser rangefinder sensor to estimate the robot position and orientation. In [14], the authors completed a real-time automated robotic system for monitoring, enabling simultaneous robot positioning, mapping and navigation with virtually no human intervention. In [15] the authors present an inexpensive 2D LIDAR system using LIDAR-Lite v1 for obstacle detection in self-driving vehicles with a scan angle of 360 degrees. The acquired data is filtered by median and detected by obstacle clustering of point cloud data. A point cloud is a set of data points in space. Point clouds are generally produced by 3D scanners, which measure many points on the external surfaces of objects around them. The results show that near obstacles can be detected at close range. In [16], aiming at the expensive solution for simultaneous positioning and mapping (SLAM) of mobile robots. The authors designed a low-cost mobile robot solution, which uses laser imaging to acquire 2D laser scanning matching data and SLAM's open source GMapping software package, using RVIZ (ROS visualization tool). Realizing the indoor mapping it can build high-precision maps. In [17] the author uses an autonomous mobile robot with a robotic operating system (ROS). The system uses 2D LiDAR and RGB-D cameras with a ROS 2D navigation stack and is implemented on the Raspberry Pi 3 and intel NUC respectively. Comparative usability testing was performed on two systems in multiple experiments. The results show that the robot can avoid objects in the path or stop in the unavoidable situation.

III. System Description

The obstacle avoidance system includes an autonomous mobile robot. The prototype acrylic plate as the chassis of the robot and two-wheel differential structure. The front half has a drive caster with support that combines lidar and Raspberry Pi, controllers and power modules. The main components of the implemented prototype are described in detail.

A. *Localizaton sensor - Lidar*

The localization of obstacles is performed using LIDAR-lite v3, that is a compact optical distance measurement sensor from Garmin. This device measures the distance to object by calculating the time delay between the transmission of a Near-infrared laser signal and its reception after reflecting from the target. Effective range is 40 meters, the measurement accuracy within 5 meters is 2.5 cm. The LIDAR transmits data to the Raspberry Pi through the I2C (Inter-Integrated Circuit) communication protocol and operates at 5V DC, which means it can work well with raspberry pi computation platform.

A two-dimensional rotating platform for LIDAR was designed that allows LIDAR to measure obstacle position in multiple directions. The rotating platform consists of a stepper motor and a link plate. The stepper motor is controlled by the Raspberry Pi, and its rotation frequency and rotation mode can be set by code.

B. *Computation platform - Raspberry Pi*

To operate the robot, a Raspberry Pi 3B+ was used. The Raspberry Pi is a series of small single-board computers, it can read multiple sensor data at the same time. With a network interface, users can remotely control raspberry using Secure Shell (SSH) however it is also considered the autonomous navigation algorithms.

C. *Actuators - Motors and controller*

In this robot, a set of two DC motors and an Adafruit-motor-hat as a controller were used. This Adafruit-motor-hat can control two DC motors and one stepper motor simultaneously. The power supply is based on 6V batteries and a power bank for the raspberry. A block diagram of the hardware connections is presented in Figure 1, where the fully assembled robot is presented in Figure 2.

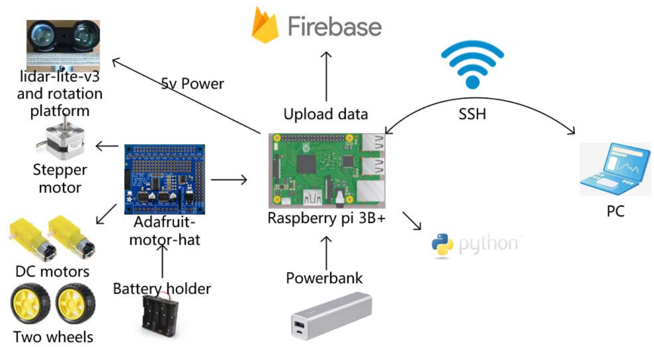

Fig. 1. Hardware connections diagram.

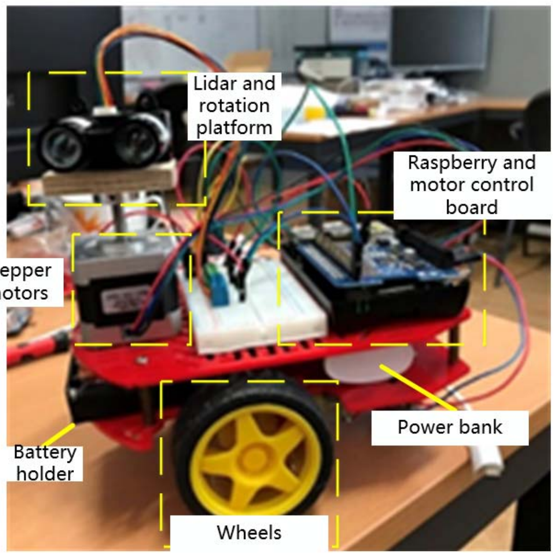

Fig. 2. The implemented Robot prototype

D. Firebase real-time database

Firebase is a mobile and web application development platform developed by Firebase, Inc. The firebase database was used to store the distance to obstacle data. Connect the Raspberry Pi on the robot to the Internet via WI-FI. two properties for each piece of data: the measurement angle and the distance value. When a measurement cycle ends, the distance values for all angles are uploaded.

IV. Obstacle Avoidance Method

In this chapter, the kinematics model of the robot is introduced to illustrate how it moves forward and turns. How the robot moves next is based on the distance measured by the lidar at different angles. The obstacle avoidance method outputs a DC motor command based on these distance values.

A. Robot kinematics model

The motion control of the robot is closely related to the motion model of the robot itself. The kinematics model of the robot is introduced to illustrate how it moves forward and turns. The robot used in the study is a two-wheeled robot with two drive wheels and a universal wheel. The following figure shows the pose of the mobile robot at two adjacent moments, θ_1 is the angle at which the mobile robot moves around the arc at two adjacent moments, and θ_3 is the amount of change in the heading angle (toward the head head) of the moving machine at two adjacent moments. L is the distance between the left and right wheels, which is the distance between the right wheel and the left wheel. d is the distance that the right wheel travels more than the left wheel. R is the radius of the circular motion of the mobile robot.

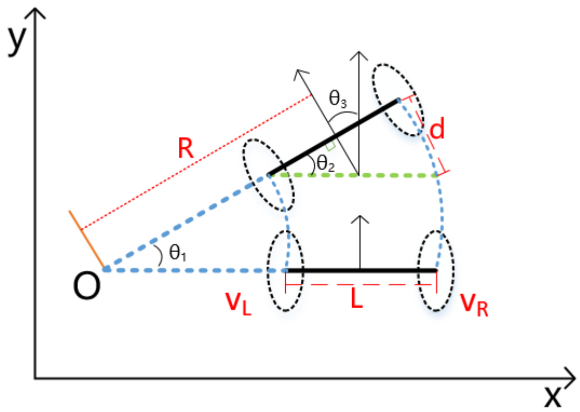

Fig.3. The kinematic model of two wheels robot.

The moving speed of the mobile robot v is equal to the average of the left and right wheel speeds :

$$v = \frac{v_R + v_L}{2} \tag{1}$$

How to calculate the robot's heading angle and how to calculate the angular velocity. As shown in the figure, by superimposing the positions of the robots at two moments, it is clear that the amount of change in the heading angle of the mobile robot is. From the geometric relationship in the figure we can get:

$$\theta_1 = \theta_2 = \theta_3 \tag{2}$$

Identify applicable funding agency here. If none, delete this text box.

When the robot makes a circular motion, it starts from the starting point and returns to the starting point around the centre of the circle. In this process, the cumulative heading angle of the robot is 360 degrees, and it also moves 360 degrees around the centre of the trajectory, indicating the angle of change of the heading angle of the robot equal to the angle at which it rotates around the centre of the motion trajectory. Among these three angles, θ_2 is easy to calculate. Since the robot is in continuous motion, the time interval between two adjacent moments is very short, and the angle change is small, so there is the following approximate formula:

$$\theta_2 \approx \sin(\theta) = \frac{d}{L} = \frac{(v_R - v_L)\Delta t}{L} \tag{3}$$

The angular velocity of the robot around the centre of the circle can be calculate, which the speed of the robot's heading angle is also:

$$\omega = \frac{\theta_1}{\Delta t} = \frac{v_R - v_L}{L} \tag{4}$$

Therefore, the radius of the circular motion of the mobile robot can be introduced.

$$R = \frac{v}{\omega} = \frac{L(v_R + v_L)}{2(v_R - v_L)} \tag{5}$$

B. Safety operation distance

The settings for safe distance for UAV is performed as following. First the array to store the data of each LIDAR measurement cycle was considered.

After the data is sorted, the largest and smallest data are marked as the maximum distance and the minimum distance. The next action of the unmanned robot depends on the values of the maximum distance and the minimum distance. If the maximum distance is less than 35 cm, the robot will rotate 180 degrees. When the maximum distance is greater than 35 cm and the minimum distance is less than 100 cm, the robot turns to the direction of the maximum distance to avoid obstacles.

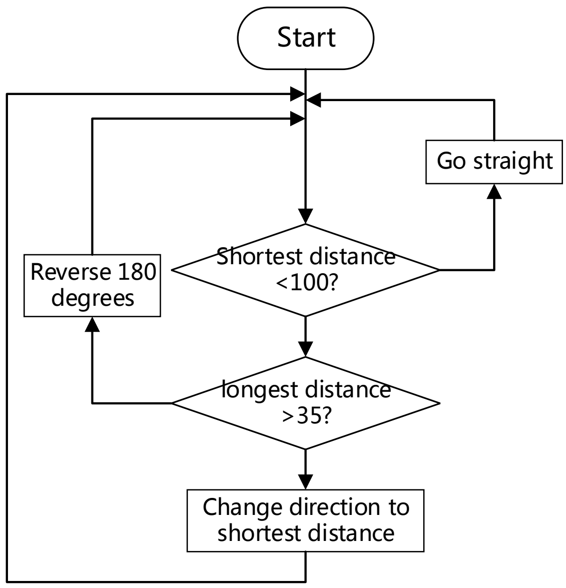

Fig. 4. Safety distance block diagram.

The data is sorted, and the largest and smallest data is marked as the maximum distance and the minimum distance. Whether the unmanned robot is in safe operating mode depends on the maximum distance and the minimum distance.

When the maximum distance is less than 35 cm, the unmanned robot will rotate 180 degrees. When the maximum distance is greater than 35 cm and the minimum distance is less than 100 cm, the unmanned robot can turn to the direction of the maximum distance to avoid obstacles.

C. Stepper motor rotation mode

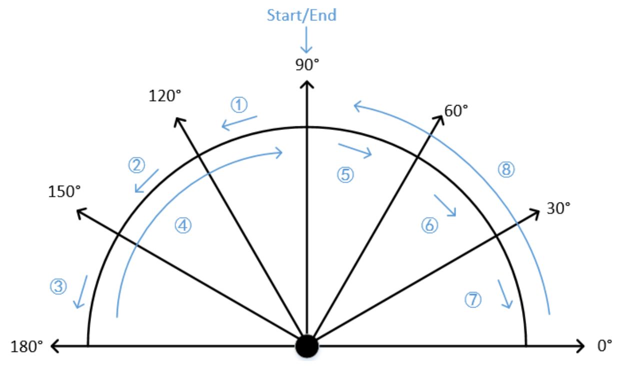

Fig. 5. Stepper motor rotation mode.

The LIDAR and stepper motor are connected by a rotating platform to form a two-dimensional distance measuring system. When the stepper motor rotates, the lidar will also rotate with the stepper motor. In this system, how to make the lidar measure the obstacles in the 180 range in front of the robot is an important issue. First I set the rotation mode of the stepper motor. The rotation mode can be seen in Figure 3. The starting and ending positions of the rotation are the centre of the robot's orientation. In one cycle, the stepper motor rotates a total of 8 times, mark the number of steps of the stepper motor as 1 to 8 and when the cycle is over, the start position coincides with the end position. According to the stepper motor driver`s function, The stepper motor is characterized by 300 steps/rev, which means the stepper motor rotates 300 times in 360 degree, every step rotates 1.2 degree. The LIDAR work sequence can be seen in Figure 4. The settings of the stepper motor rotation sequence were1-3, 4-7 rotates 30 degree, equal to 25 steps, sequence 4 and 8 rotates 90 degree, equal to 75 steps. When the 1-7 step is over, the lidar will work.

TABLE. 1. LIDAR WORK SEQUENCE.

sequence	LIDAR work?	angle
1	Y	120
2	Y	150
3	Y	180
4	Y	90
5	Y	60
6	Y	30
7	Y	0
8	N	

V. EXPERIMENTAL RESULTS ABOUT DISTANCE AND OBSTACLE AVOIDANCE

First, considering the time required for each measurement cycle and the measurement accuracy, I tested the pause time after each rotation of the rotating platform. The length of the pause will affect the travel efficiency of the car and the measurement accuracy of the LIDAR.

In order to test this pause time, I set up a scene: set the car to stand still, set different pause time, measure multiple cycles, compare the accuracy of the measurement results with the measurement time. Measuring distance values at different angles using an angle ruler and a laser range finder. The distance value of each angle has shown in Table II. The distance measured by the laser range finder was accurate as a benchmark for monitoring comparisons.

TABLE II. DISTANCE MEASURED BY LASER RANGE FINDER AND ANGLE RULER.

angle	Distance(cm)
0	110
30	70
60	45
90	39
120	45
150	32
180	30

The distances in different directions were measured in sequence at different pulse times and the result can be seen at Table III

TABLE III. DISTANCE VALUES OF DIFFERENT PULSE TIME.

Pulse time(s) Angle	1.5	1.25	1	0.75	0.5	0.25	0.1	0.05
0	90	87	92	91	85	100	67	101
30	4	69	69	72	68	55	56	80
60	45	47	43	47	44	46	38	42
90	40	41	39	37	38	50	34	32
120	44	45	44	47	38	55	56	34
150	33	31	34	32	38	29	29	35
180	31	31	32	29	30	34	21	42

Different measurement results corresponds to different pause times. Considering the two factors of measurement accuracy and pause time, it is best to set the pause time to 0.5 seconds. The comparison of measurement results is shown in Figure 7.

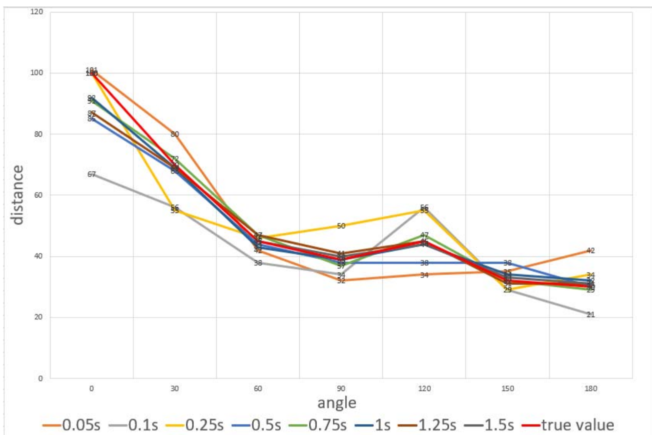

Fig. 7. Distance measurement of different pulse time accuracy comparison chart.

In order to test the obstacle avoidance performance of the robot, various test scenarios were established. First, how the lidar detects obstacles and the specific error comparisons are presented.

TA.BLE IV. MEASURED VALUE OF 7 DIRECTION (0 ° - 180 °)

position	P1(0 °)	P2(30 °)	P3(60 °)	P4(90 °)	P5(120 °)	P6(150 °)	P7(180 °)
true value	100	63	36.4	31.5	36.7	52.6	45.5
measured value	100	61	38	30	36	54	45

Fig. 8. Measurement error

According to the distance measured by lidar in 7 directions, the approximate shape of the obstacle can be drawn, the robot as the center of the surrounding environment can be established.

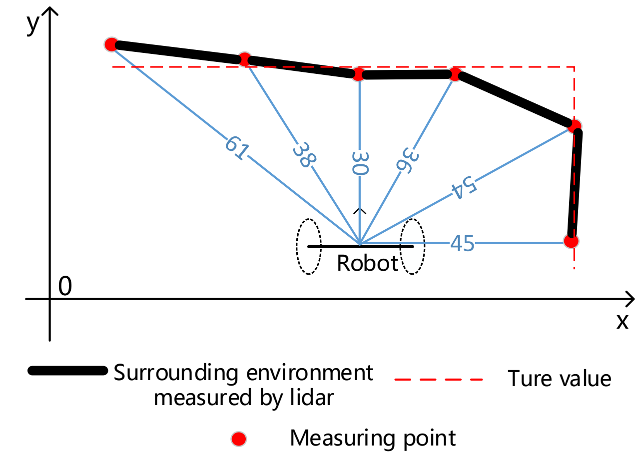

Fig. 9. Surrounding environment established by measurement value

Then, three scenarios were established: (a) corner; (b) obstacles at various angles; (c) dead ends. In Fig. 10, D1 is the maximum value and is greater than the safety distance determination value, and the remaining D2-D7 are smaller than the safety distance determination value. At this time, the robot turns 90 degrees to the left.

In Fig. 11, D3 and D4 are both greater than the safety distance determination value, D1-D2, D5-D7 are smaller than the safety determination distance, and the robot will turn to the direction of D3 because D3 is larger than D4.

In Fig.12, D1-D7 are both smaller than the safety distance determination value, and the robot will reverse the direction by 180 degrees in this case.

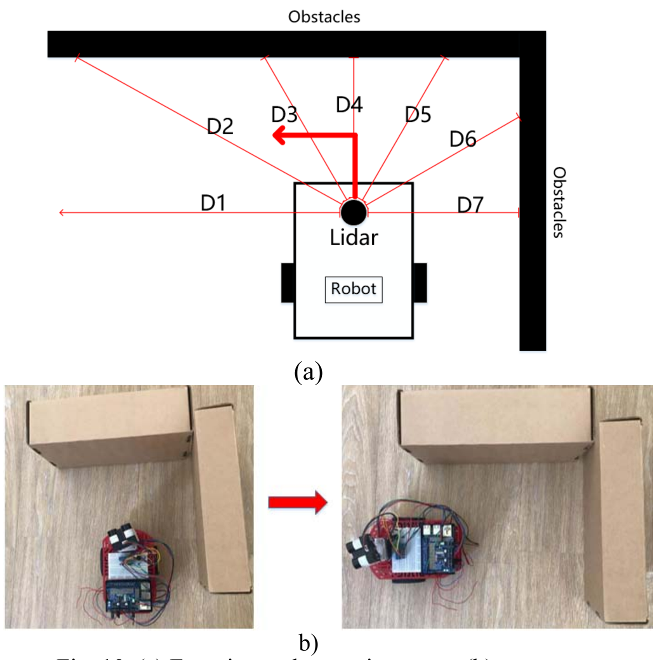

Fig. 10. (a) Experimental scenario: corner (b) corner experimental setup

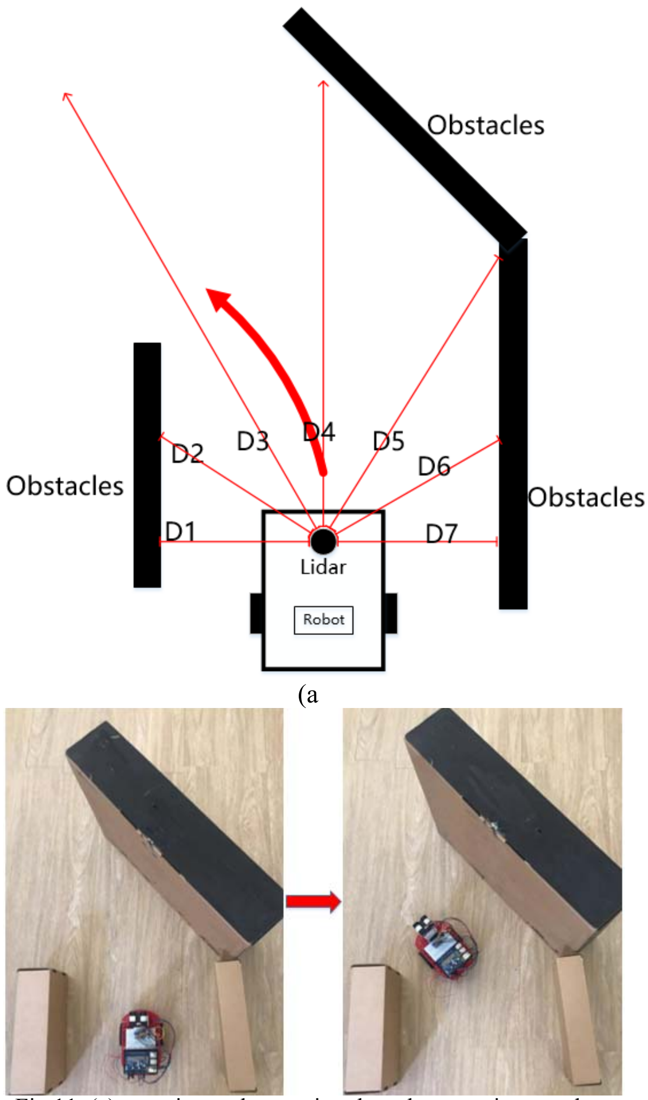

Fig.11. (a) experimental scenario: obstacles at various angles (b) various angles test result

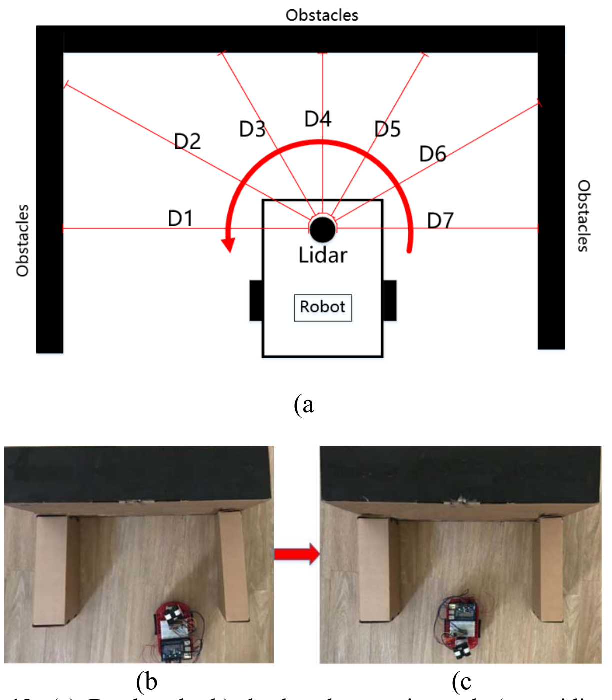

Fig. 12. (a) Dead ends, b) dead ends experimental, (c avoiding obstacles experimental.

VI. Conclusion and Future Work

This work uses a LIDAR and Raspberry Pi to build a small robot with obstacle avoidance capability. It is designed to improve the accuracy and safety of robot during autonomous operations. The robot can obtain the distance information of the surrounding environment, and the information can specify the obstacle avoidance strategy and upload it to the real-time database. Some obstacle avoiding scenarios are set and tested, In the future work, new obstacle avoidance algorithm will be carried out, and the ability of the algorithm to respond to various scenarios will be improved.

Acknowledgements

This research is supported by Instituto de Telecomunicações (IT-IUL) at ISCTE-IUL, Lisbon, Portugal and Fundação para Ciência e Tecnologia (FCT). This work is also supported by the Shanghai Science and Technology Commission (No. 19595810700, 18295801100, 17595810300) and Yunnan Science and Technology Program (No.2018IB022)

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