Design and implementation of a mobile robot with autonomous door opening ability

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***Abstract*— there are many services and security robots have been implemented in public areas, such as shopping malls, hospitals. However, it is difficult to let such robots to be used in a usual home environment. In order to let robots walk through multiple rooms, the robot must have the ability to open doors. In order to improve this issue, this paper presents a mobile robot design, which is based on the computer vision technology, therefore, the proposed robot could correctly recognize the door and the door handle, and complete the action to open the door with their own mechanical arm.**

Keywords- Computer vision, mobile robot, door opening.

I. Introduction

With advances of technology, there are more and more autonomous robots in usual home and office environment, such as floor cleaning, shopping services, security patrol and so on. Mobile robots in a single room, indoor navigation and map construction technology has been used widely. However, when a robot want to move in a building, autonomous robots need to be able to pass through the multiple rooms, to achieve this goal, autonomous robots must have the ability to open doors.

Since the doors and door handles are presented as variety of shapes and looks, to locate the door and opening it, could be a challenging issue in this study. In order to improve this problem, we designed a mobile robot with 6-DOF manipulator, combined with computer vision technology, therefore, the robot could determine the position of the door handle and force points, and then reach the goal of door opening.

In this paper, we focus on the design and implementation of mobile robots to open the door, we designed a new mobile robot system, which is powered via ESP32 plus and Raspberry Pi 3 as the control core, and equipped with the sonar sensor, LiDAR, gyroscope, accelerometers. This mobile robot has basic indoor navigation capabilities. The computer vision technology is used to try to locate the door handle, and implement a mechanical arm to open the door.

II. Related Work

Indoor positioning and scanning indoor maps are one of the topics that mobile robots focus on [1-4], and some research attempts to classify the doors in the map[5, 6]. Further, we hope that after the door is located, the robot could open a door autonomously, allowing the robot to perform various tasks whish are require across the rooms.

There are some researches already studied on the issue of open doors [7-9], including the use of images, tactile or laser scanning to detect doors and handles. The most of these articles are using commercial service robots, and even military mobile robots. With the proposed designing a mobile robot, the chassis components are made of aluminum extrusion, and the arm is printed by 3D printing technology. This configuration not only significantly reduces the cost of purchasing commercial machines, but also has improved flexibility and expansibility.

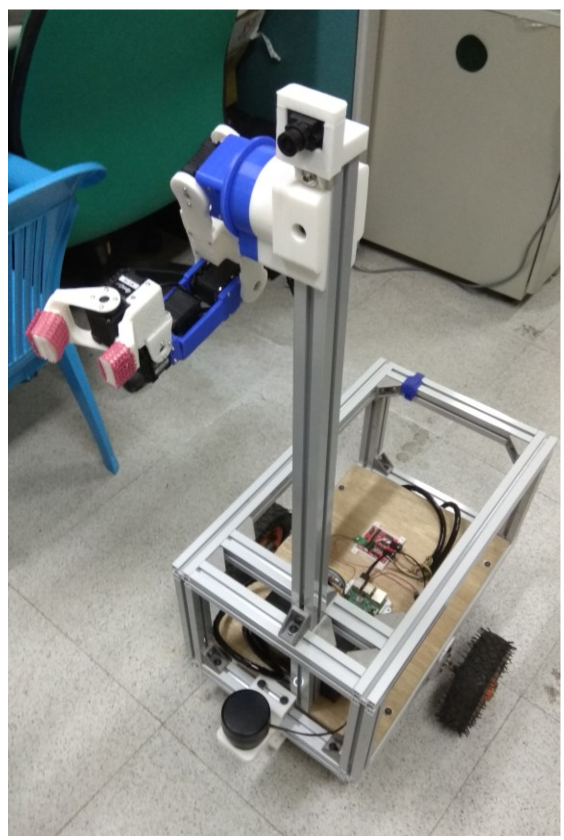


Figure.1 Mobile robot system

The studies with the use computer vision to try to open the door is shown in [10], the proposed method uses a sliding window to detect the image blocks and uses the K-means classifier to improve the accuracy, however, the method is only focused on the flat door lock. Another method uses the Hough transform to extract the line from the Canny edge and uses a fuzzy system to identify the gates with lengths, directions and distances between two segments. Furthermore, the use of door handles for tactile detection requires complex robots and force feedback systems.

We hope that our design could autonomous determine the door lock for the doorknob or flat lock, and according to the situation to implement the action to open the door. Our trategy is to use sliding windows to roughly define the door handles and add histogram of oriented gradient (HOG)[11] features as well as SVM classifiers to increase accuracy, and the robot with force feedback can confirm the condition of the fixture grasping the door knob.

III. Hardware Design

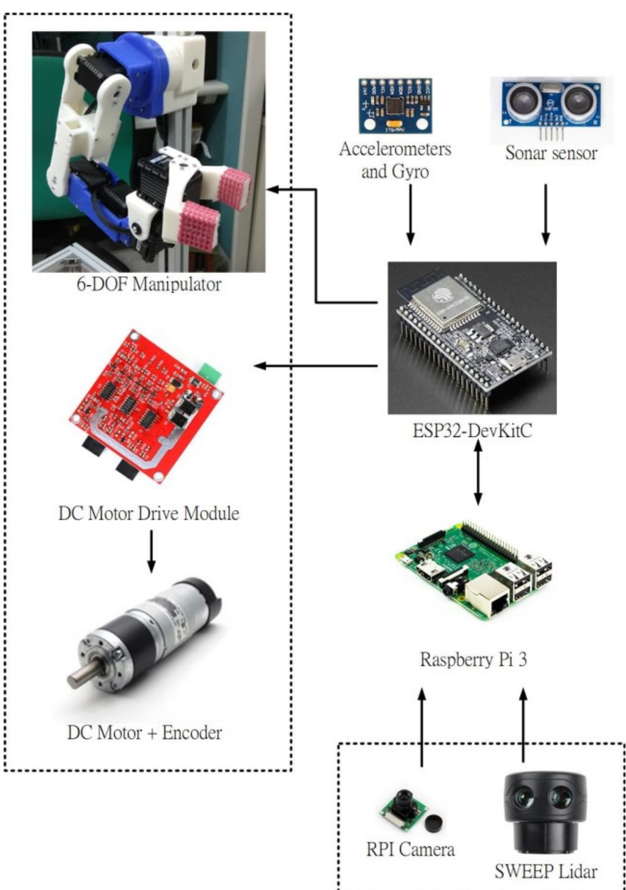
This design of the autonomous mobile robot is shown in Figure 1. The hardware configuration is shown in Figure 2. The mobile platform uses two active casters and two passive casters to allow this robot to move in all directions. The chassis has a maximum load of 50KG. Robots are also equipped with laser radar and ultrasound, therefore, that mobile robot has the ability to build indoor maps and obstacle avoidance.

Mobile robot is equipped with a 6-DOF mechanical arm, and the use of AI motor by ourselves design, the machine can be based on the feedback angle and torque to estimate the current position of the arm and jaw grip state. Each arm component is printed them out by a 3D printer, the Manipulator are designed to fit the possible door handles and knobs.

The arm and mobile robot are connected to the top of the installation of a camera to identify the object to manipulate. The visual identification and map scanning software are developed with the raspberry pi 3. The robot and arm movement are mainly controlled by the esp32 development board with the motor drive boards.

IV. Methodology

The major goal of this paper is to perform a door opening action on a mobile robot. However, due to the limitations of the arm, that the door movement requires the coordination of the various components. The motion parameters of the manipulator and the mobile chassis are shown in the Table I. The working range of the arm is limited by its length, while



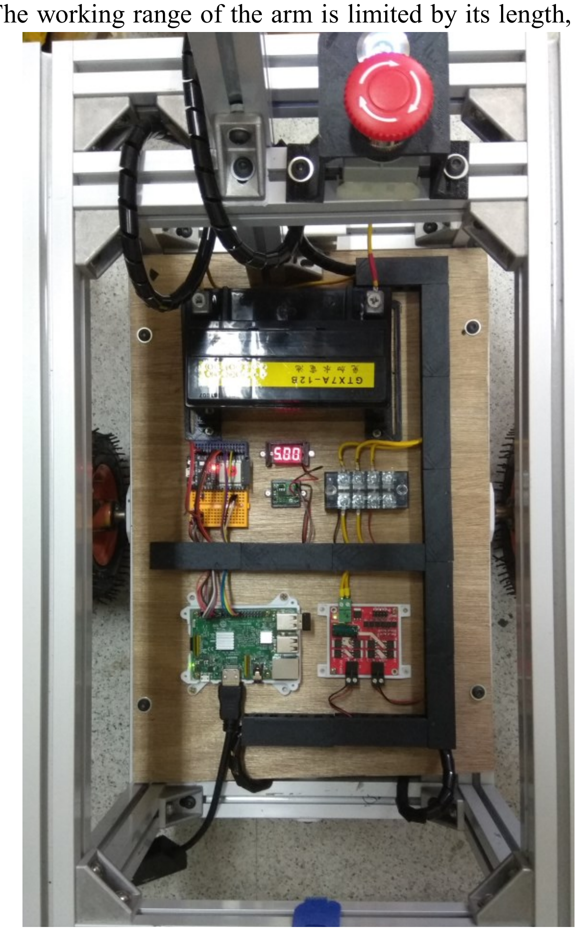


Figure.2 Hardware architecture

the movable chassis has a large range of motion.

It is worth noting that the reasonable allocation of the task of each component is essential. Basically, the arm is only responsible for a small range of motions (e.g grasping the door knob), the implementation of the door to open the coherent action requires the arm and chassis at the simultaneously.

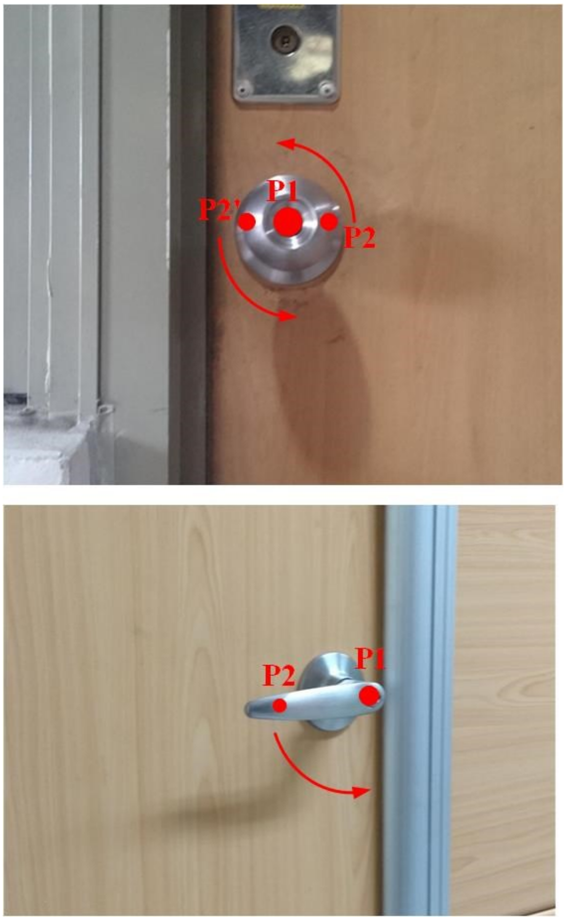


Figure.3 The locating points found in the perceptual algorithm are in the circle / flat handle. Point 1 indicates the pivot axis of the door handle, usually on the keyhole. Point 2 indicates a point that can be grasped. With Point 1 as the axis, the action of opening the door is done by applying a circular motion relative to Point 2.

In order to control the power of grips to adapt to various door knot/handles, the motors of grips would be controlled with the *max-min operation*. With the pressure sensors of motors, the fuzzy set could be considered as two values of pressure sensors (x, y), and the rotated angles of door knot/handles (R). The power of motor could be set as A. The composition could be shown as follows.

$$\mu_B(y) = \max_{x \in X}\left[\min\left(\mu_A(x), \mu_R(x, y)\right)\right]$$

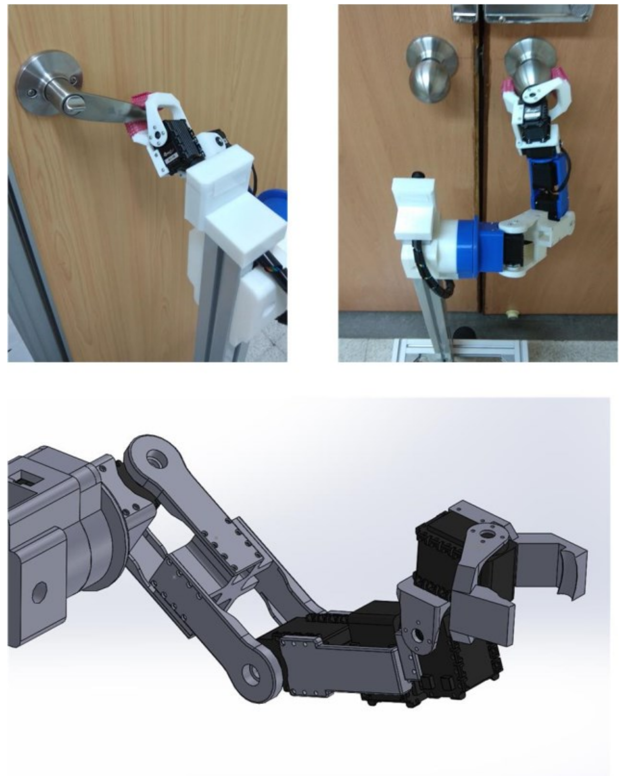


Figure.4 The arm clamp is designed to grip the flat handle and the round handle, the arm can stretch up to a distance of 30cm.

In this composition (relation-relation), the max and min operators could be replaced as t-conorm and t-norm. With the fuzzy rule. The *center of gravity defuzzifier* or *center of area defuzzifier* could be applied to generate a fuzzy set. When the area is continues, the defuzzifier could be presented as follows.

$$y^* = \frac{\int_Y \mu_C(y) \cdot y dy}{\int_Y \mu_C(y) dy}$$

On the other hand, When the area is discrete, the defuzzifier could be presented as follows.

$$y^* = \frac{\sum_{i=1}^{L} \mu_C(y_i) \cdot y_i}{\sum_{i=1}^{L} \mu_C(y_i)}$$

Based on these defuzzifiers, the power and sensor values (pressure level) could be computed with the modified center average defuzzifier to reach the better performance as follows.

$$y^* = \frac{\sum_{j=1}^{J} \bar{y}^j \mu_{C^j}(\bar{y}^j) / \delta^j}{\sum_{j=1}^{J} \mu_{C^j}(\bar{y}^j) / \delta^j}$$

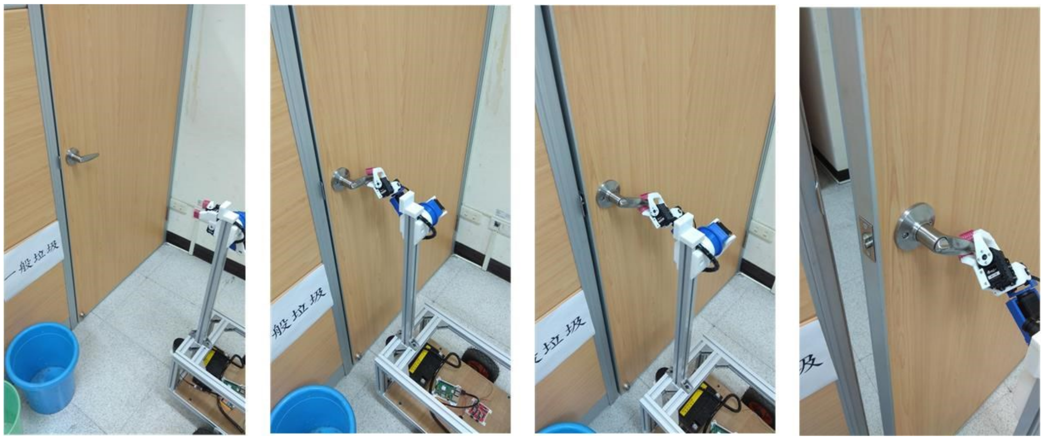


Figure.5 Door opening motion

With the approach of the fuzzy control, the grip power could be controlled with the defuzzufuers with more accuracy. Instead of plain linear increasing, the performance improvement of grips leads to the usability of robot arms significantly.

Computer vision is mainly used to identify objects, and to find out the points for the arm to grasp. The rectangular area in the image is sampled through the sliding window and an attempt is made to determine whether each of the holding areas roughly defines the door knob. It would try to place a rectangle on the door handle by sliding the window, with an accuracy of about 70%.

Since the height of the door handle is usually 80 to 110 cm above the bottom of the door, we can add this to the test condition, in simpler words, the door handle will not be located near the top and bottom of the door position, we can focus on the detection of the middle of the location, so you can save the calculation time.In addition, the direction of the door opening can be determined by the observed door hinge shaft (usually the door opens to the side where the door hinge shaft is mounted).

In order to improve the accuracy of the identification, we also use the Histogram of oriented gradient (HOG) feature and support vector machine (SVM) to post-process the target image. The gradient feature of each partial image is taken, and the obtained values are classified by SVM. The rectangles containing the door handles are classified in the positive examples and the rectangles without the door handles are classified as negative examples.

TABLE I. FUNCTIONAL CATEGORIZATION OF SUBSYSTEMS

	ARM	MOBILE
Workspace dimension	Smaller than 30cm	Unlimited
Weight capacity	1kg	50kg
Positioning accuracy	10 ~ 25 mm	100 ~ 200 mm
Cycle time of motion control	20ms	100 ~ 200 ms

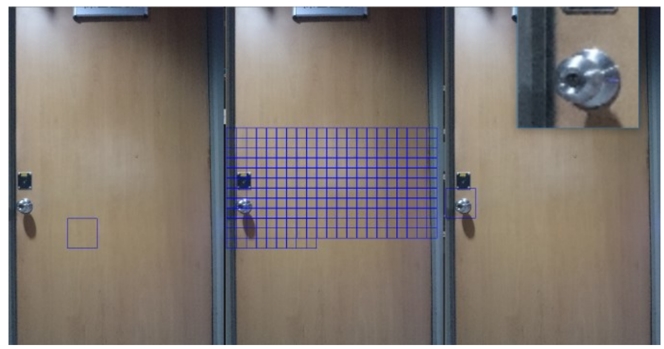


Figure.6 Sliding window method reveal. (Left) detection window from the upper left to the lower right, according to the set parameters to repeat the test. (Medium) sliding window to move the trajectory. (Right) The last window places the detection frame in the position most likely to be the door handle.

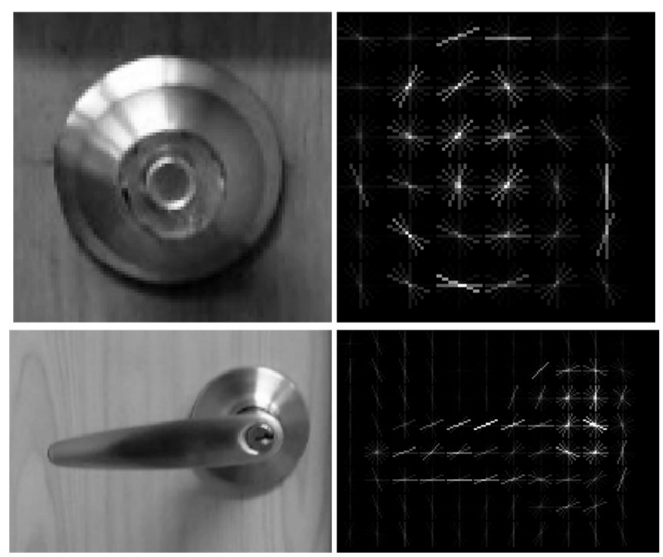


Figure.7 HOG features of circle / flat handle view

The process of opening the door is shown in Figure 8. A brief explanation of each phase is given as follows:

1) First, the robot will locate the door of the room and move to the door 100cm from the location, the maximum positioning inaccuracy of about 200mm, this error is sufficient to be used in the general indoor navigation, however, this range might not provide enough information for us to grasp the door handle.

2) The camera will take a shoot of the front view. If the door handle is successfully searched, the robot is repositioned so that the door handle and arm are positioned as a straight line to correct the error of (1). If the door handle is not found, it will return to (1), and then e-search the location of the door.

3) The robot will move 80 centimeters, the camera re-shoot the door handle to locate the positioning point can be grasped, and then the robot will grasp the door handle and rotate.

4) After the grasping, the robot moves of 20 cm (forward / backward) in towards the door open direction, and the arm is shifted by 45 degrees toward the door chain direction. After reaching the position, the robot is released at the end of the robot and the arm is returned to complete the door opening action.

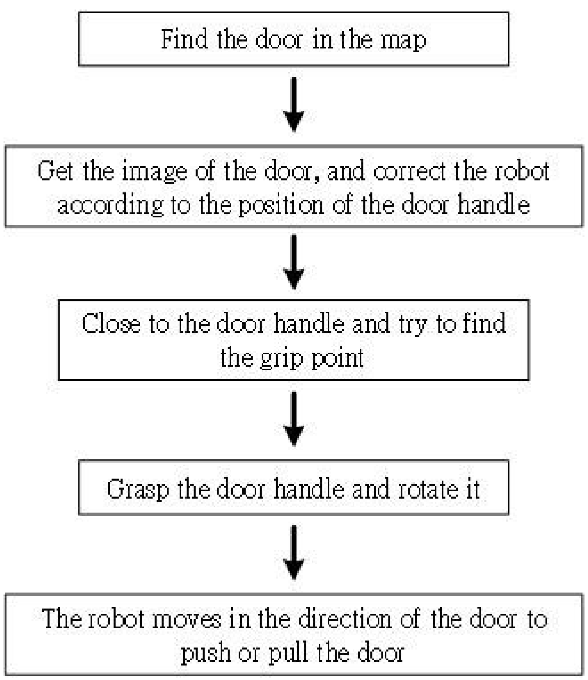


Figure.8 Flowchart for automatic door opening evaluation

V. EXPERIMENTS AND RESULTS

In this section, the experimental result is shown. The visual detection mainly run on raspberry pi3, and with OPENCV 3.1 to complete the job. Our experiment was conducted in a hallway (about 30 doors), the robot moved to the front of each door and tried to find the door handle. Due to the arm torque is insufficient, the experiments with the round handle could not be successfully completed in the most of time. Therefore, when the robot can successfully hold the round door handle, we will considered as a successful example.

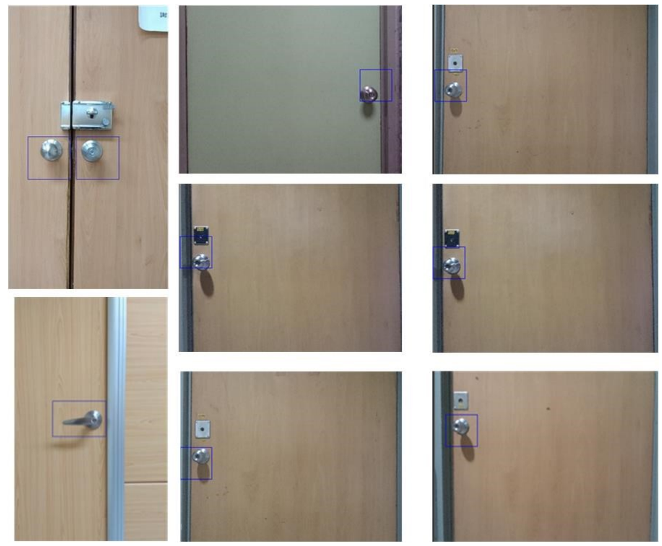


Figure.9 The door handle detects the test results

The results of the experiment are shown in Table II, including the results of using the sliding window to detect and join the SVM classifier. The accuracy rate of to use of sliding window alone only reaches 74%. And after adding the SVM classifier, the accuracy of the door handle detection can be increased to 88%. Some detection results shown in Figure 9.

TABLE II. DOOR HANDLE CLASSIFICATION ACCURACY

	Total number	Correct	Accuracy
Sliding window	35	25	71%
HOG+SVM	35	31	89%

According to the results, with the addition of the classifier detection, the modification could significantly improve the detection accuracy of the door handle. However, there are some conditions to lead to detection failure, such as glass doors, ambient light, limited space corridor. Due to the lack of strength of the proposed arm (especially the gripper part, not enough to grasp the round handle and rotate it), the situation by the mobile robot to open the handle would be shown independently.

Figure.10 Try to open the example of the circle handle. Due to lack of power output of the arm, therefore, the round handle unable rotated successfully, causing the door opening to fail.

VI. CONCLUSION

In this study, we propose a mobile robot to open the door for the multiple rooms roaming solution, the method of our designed robot significantly reduces the cost of mobile robot construction. With using the sliding window to retrieve the joint operation performed with the arm also demonstrated the ability to open the door independently when dealing with flat handle and round handle.

In the experiment, we showed an attempt to help the robot arm grasp the door handle with computer vision, the experimental results show that the accuracy of the door handle detection is 89%. However, the lack of strength of the arm lead to the short of the experiments of round knobs. The mobile robot also has the basic indoor navigation capability.

This proposed platform provides a good foundation for mobile robots that are used indoors, and aluminum extrusion has a great deal of flexibility in changing design or functional expansion. Based on this research, we will combine more mobile robot applications, such as map overlap in the future. To fit the commercial robot requirements, such as indoor service / navigation / patrol robots.

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