Journal of Computers Vol. 29 No. 2, 2018, pp. 118-135
doi:10.3966/199115992018042902013

Indoor Omni-directional Mobile Robot that Track Independently

Kaibo Zhang[1*], Lei Zhang[1]

[1] Department of Electrical and Information Engineering, Beijing University of Civil Engineering and Architecture, Beijing, China
alvisaccount@163.com

Received 24 July 2017; Revised 19 September 2017; Accepted 19 October 2017

Abstract. Service robots want to achieve intelligent interaction, self-tracking is the foundation. At present, the tracking of indoor robots is mainly for human body tracking or object tracking with auxiliary markers, only one type of target can be tracked. In order to solve the above shortcomings, this paper designed an automatic omni-directional robot, using a common camera, according the different target using different strategies to achieve the tracking of any tracking, regardless of their status. The tracking strategy can be divided into two broad categories. One is tracking the human. Using based classifier face tracking and feature point tracking, Set the face tracking as a high priority of tracking, and the feature point tracking is added to ensure the tracking integrity when face blind spots appear. Another is the tracking of objects in any state. In this case, the feature points are used to track the target feature points, using Shi-Tomasi algorithm and Lucas-Kanade algorithm. The 2D coordinates of target sub-pixel level accuracy are obtained. Combined with laser range finder, build three-dimensional coordinate positioning. Finally, this paper verifies the feasibility of the system through experiments. The success rate of tracking is over 90%, which has high reliability.

Keywords: arbitrary target tracking, face detection, feature point detection, omni-directional mobile robot, visual tracking

1 Introduction

With the breakthroughs in artificial intelligence and computer vision, robots are receiving more and more attention and more robots are appearing in people's fields of vision. At the same time with the aging population and the demand of smart home, indoor service robots become a hot issue. Advances in computer vision enable robots to better perceive the environment. In the future, in-indoors service robots are expected to be part of our lives. These robots will need to have a full understanding of the environment, with the least amount of guidance, high quality, and high-precision detection and tracking of personnel [1-3].

In the research of tracking, many scholars had achieved an ideal tracking [4]. Such as use laser range finder based on human leg movement model tracking [5]. Human body tracking based on color camera [1]. Human body tracking based on Kinect sensor [6]. However, their tracking can only track a certain type of object, and there is no strong universal for the human body or the labeled object, and most of them are based on powerful sensors such as RGB-D or laser range finder [7]. The effect is better but the cost is higher. Therefore, this paper designs an indoor service robot that can track any target in any state of motion and has low cost. In the design process, we not only consider use the the common sensors that achieve a wide range of applications, but also refer to the research results of others, considering the robot structure, tracking algorithm, tracking angle, Impact on people, etc., as follows:

The intricate indoor environment that robots want to exercise and complete human instructions requires not only sufficient flexibility but also some intelligence to interact with humans. Researchers

[*] Corresponding Author

have always wanted to solve this problem based on bionicism, especially imitation. Because of the evolution of tens of thousands of years, mankind has excellent ability, which is reflected not only in intelligence but also in the flexibility of movement. Humanoid robot has always been a hot area of robotics. However it is difficult to balance of the two feet compared to the multi-legged creature. How to keep the humanoid robot stable and fast moving has always been the key to humanoid robot applications. Scholars have proposed many ways to solve this problem, including pressure center (COP) [8], zero moment (ZMP) [9-11], dynamic gait control [12-13], gait reference generation [14-15] and so on. This has made a significant contribution to humanoid robotics planning. But, there are currently no mature and universally applicable methods for achieving the autonomous and highly-complex task of humanoid robots moving in complex habitat environments.

Therefore, in view of the fact that current humanoid robots can not be widely used indoors at present, some scholars think that if we can achieve human flexibility by another method and still have some stability and intelligence, can we solve the above problems?

Some scholars had focused their attention on the wheeled. Wheel can be divided into differential drive and omni-directional drive. Want to achieve the flexibility of movement, two-wheel differential drive and omni-directional drive are better choices. Two-wheel differential drive can be moved back and forth, rotate in place, has more flexibility than the ordinary wheeled, so researchers conducted some research in the two-wheeled machine [4, 16]. In order to obtain a sufficient field of view to capture the surrounding environment, it is generally necessary to support the visual capture sensor with a support rod on the top of the robot so that the two-wheeled robot essentially becomes a two-wheeled self-balancing mobile machine with an inverted pendulum which has three DOF (Pitch elevation, azimuth and displacement of the mobile platform), but only two wheels control the input torque so that these mobile robots are under-driven systems. Due to the extra degree of freedom, the control design of these robots is challenging [4]. Omni-directional drives are mainly omni-directional wheel and Mecanum wheel, composed of three or four, in the case of the installation of the camera, it still has better stability. And compared with the differential drive, which has horizontally and diagonal movement can make the movement greatly enhanced flexibility, and it also has been more widely used the indoor mobile robot. Therefore, based on the above comparison, this paper uses four independently driven Mecanum wheels to form a mobile robot chassis, and a certain height of the support rod is installed on the center of the vehicle body to place the camera.

Indoor service robot want to play an increasingly important role they must behave in ways that humans can accept [17]. Following is the foundation of robot service, in many cases, the robot needs to follow the person, for example, presenting to a robot, giving a robot instruction, or cooperating with a man to carry an object. Therefore, the robot's follow-up behavior must be robust, easy to understand and acceptable.

Research on tracking has focused on robot algorithms, and few studies have examined the effects of robot motion paths and tracking angles on humans [18-20]. But the fact is that when humans walk with each other, they often go side-by-side [21], As the robot moves toward the person, the approach from the side is less threatening than the frontal approach [22]. These findings illustrate the importance of direction in human interaction. Follow the angle of human-machine motion research are Yang et al. [23], the study found that in the following process, the angle formed by the connection between the robot and the user and the direction of the human body is different, which has different advantages and may affect the user's preference. At 0 degrees (ie, the robot follows directly behind) is the most compact in space. Human robot teams occupy only one aisle instead of two, providing more room for others. This may be helpful in a busy or narrow environment. Below 60 °, in contrast to 0 ° and 30 °, the user can see the robots without turning their torso. This may be preferable when the robot falls or when the user wishes to interact with the robot while walking. Gockley, Forlizzi & Simmons [3] in the study, it was found that people felt that robot's follow-up behavior was most natural as they moved directly to destination, while ignoring their exact path of walking.

Therefore, the direction of human-computer interaction is very important. Different angles have different advantages, the impact on people is not the same, after reference to the above study, this paper eventually use 0 degrees (ie, just behind) tracking. The goal of such a choice is not only to adapt to the flexibility of following in the indoor complex environment but also to locate and avoid the tracking target.

Our goal is to create a robust and adaptable robot for autonomous tracking. Robots must be flexible enough to handle scene clutter, multiple moving objects, and any other transformation in their environment. For tracking the choice of goals, we are not limited to moving or stationary people, but also include any movement of any item. On the one hand, people who are recognized and follow do not need to wear special clothes or locate gadgets in order to achieve more natural human-computer interaction. To achieve this goal, we employ visual inspection of face. In order to achieve the versatility of the system, we did not use a powerful RDB-D camera or a dedicated sensor such as human body capture. Instead, we used a web camera commonly used, with the detection algorithm to achieve. On the other hand, for any shape object tracking any state of motion, it is not necessary for an object to label the object, but the feature point of the object is tracked.

In this work, we built an indoor mobile robot to achieve real-time tracking of objects of any shape and status. Apply different tracking strategies for different tracking goals. The application of the McNum wheel to achieve a full range of robot movement, so complex and ever-changing living environment is feasible. In addition, the movement of the robot in translation, rather than rotation, keeps the vision acquisition sensor always on the target of tracking, allowing for maximum tracking. The visual sensor on the robot uses a common network camera, application of visual processing algorithm, achieved the face detection and feature points extraction, through the Shi-Tomasi algorithm and Lucas-Kanade algorithm for target feature point tracking, and can get the target The two-dimensional coordinates of the sub-pixel level accuracy in the video acquisition coordinate system. In order to reduce the processing time of the system and improve the recognition and tracing ability of the target, the visual analysis and the underlying motion control are divided into two modules and run simultaneously. The data transmission between them through the virtual serial port for real-time communication.

2 Robot Design

2.1 Robot Structure

The structure of indoor omni-directional robot is shown in Fig. 1. Robot structure is divided into three layers. The first layer is the visual capture sensor, which is supported by the rod, the purpose is to obtain the maximum field of view to capture the surrounding image Information. In order to achieve a wide range of robot applications, this article does not use a powerful dedicated camera instead of using a common Ordinary camera. The second layer is the robot's control center, mainly composed of a notebook, which is simultaneously implemented visual capture and motion control procedures program. Connected to it is video capture sensor of first layer and CAN module to communicate with the third layer. The third level is the robot chassis, including all electronic components, motors, motor drives, laser range finders, power supplies, etc(located in the chassis). Chassis consists of four Mecanum wheels, each wheel is controlled by a servo motor, each motor is connected to a drive, each driver has a different node, the drive connected to a CAN bus, the notebook through the USB port to connect a CAN Controller, in the CAN bus to send and receive data to different nodes, to achieve the control of the movement. In the living environment, in order to pass the obstacles flexibly, the robot's own volume can not be too large, at the same time due to set a certain height of the camera, in order to obtain the field of vision but also to avoid the formation of inverted pendulum structure, and ultimately determine the size of the robot chassis For 4500 * 4500mm.

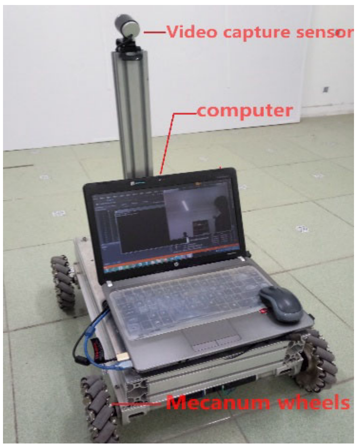


Fig. 1. Robotic entity

2.2 Sports Model

The desire to achieve robot mobility in complex indoor environments requires precise control of the robot's motion. The chassis with the Mecanum wheel is highly flexible therefore the control is also more complex than the traditional differential drive.

Since the invention of the wheel of Mecanum, many scholars have conducted in-depth studies on the wheel geometry and the motion model. A well-established kinematic model has been established. Therefore, the relationship between the movement speed of the robot and the speed of the motor can be determined after the distribution method of the wheels and the size of the robot are determined. The establishment of the chassis as shown in Fig. 2, the coordinate system, you can get the motion model.

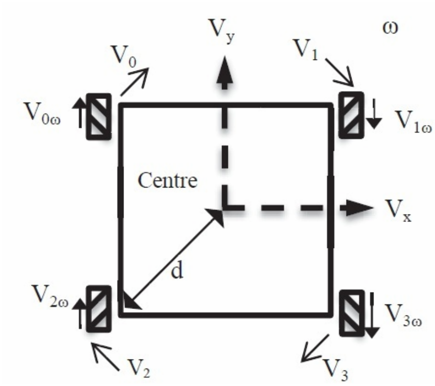


Fig. 2. Chassis coordinate system

In the coordinate system of Fig 2, v_x, v_y respectively denote the robot's linear velocities (m/s) in the x and y directions, ω denotes the angular velocity of the robot (rad/s), d denotes the distance between the wheel and the center of the chassis (m), and v_0-v_4 denotes the linear velocity of the wheel (m/s), respectively. Because rollers are turned 45° to the circle of the circumference of the biggest wheel, therefore, we can get Equations 1-3.

So the relationship between the robot speed and the motor can be determined. Fig. 3 shows the relationship between the robot's movement direction and each motor's movement direction.

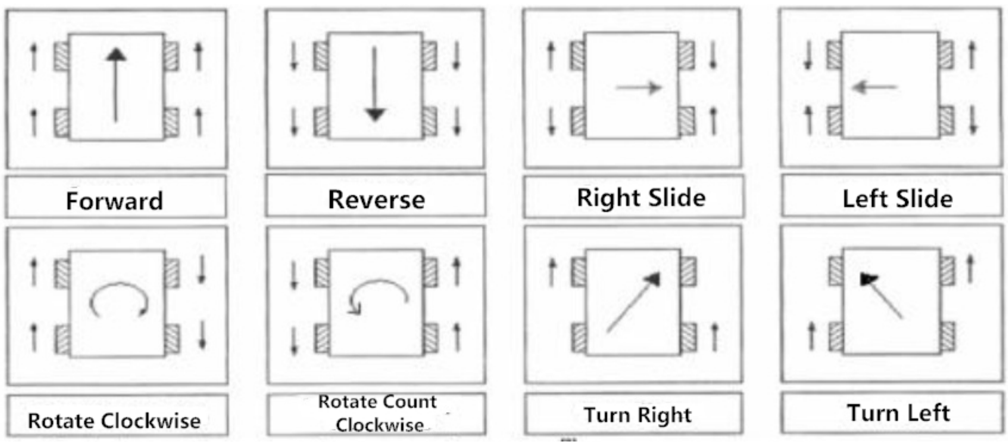


Fig. 3. The relationship between the direction of movement of the robot and each motor

In this paper, the wheel diameter is 152mm. RM35 DC motor is adopted, the reduction ratio is 16:1, the expected forward speed of the robot is 1m/s when moving at a constant speed, so the motor speed should be 3376r / min.

$$V_X = 2\sqrt{2}(V_0 + V_1 - V_2 - V_3) \quad \textbf{(1)}$$

$$V_y = 2\sqrt{2}(V_0 - V_1 + V_2 - V_3) \quad \textbf{(2)}$$

$$\omega = 2\sqrt{2}(V_0 + V_1 + V_2 + V_3) \quad (3)$$

2.3 Visual Tracking Process

Visual tracking is the focus of this article. This article sets out different tracking strategies for different goals. One is tracking the human body. Using of face tracking and feature tracking, tracking the face as a high priority, in the face blind spot use the feature point tracking to supplement, to ensure the integrity of tracking. Another is the tracking of objects in any state. In this case, we utilize the feature point tracking strategy, as shown Fig. 4.

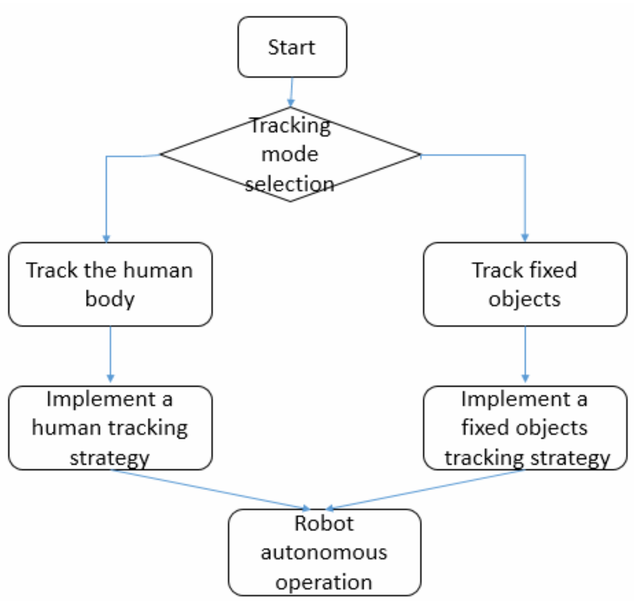


Fig. 4. Robot overall control process diagram

Tracing objects in any state using feature points. Feature point detection is a method of obtaining image features in computer vision systems, also known as corner detection, which plays an important role in motion detection, image matching, video tracking and object recognition [24]. A feature point is a feature point of an image and is a two-dimensional feature that can be precisely located, and can even achieve sub-pixel level accuracy. Habitat environment in the service robot work, the corner can be seen everywhere，As shown in Fig. 5, colored dots indicate detectable corners or feature points. With the help of corner points, the target tracking can be pinpointed accurately. Therefore, this paper adopts feature point tracking for objects.

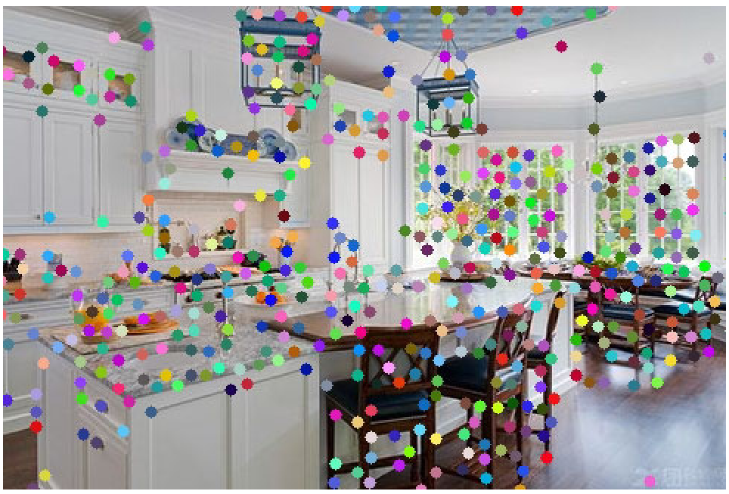


Fig. 5. Living Environment characteristic point detection

When carrying out target tracking for feature points, the user can randomly select the tracking target in the visual interface of the robot visual acquisition program to perform the operation, and detect several best feature points on the selected target for tracking. The process of tracing the feature points is to track the best feature points with Shi-Tomasi algorithm in real time. The process shown in Fig. 6.

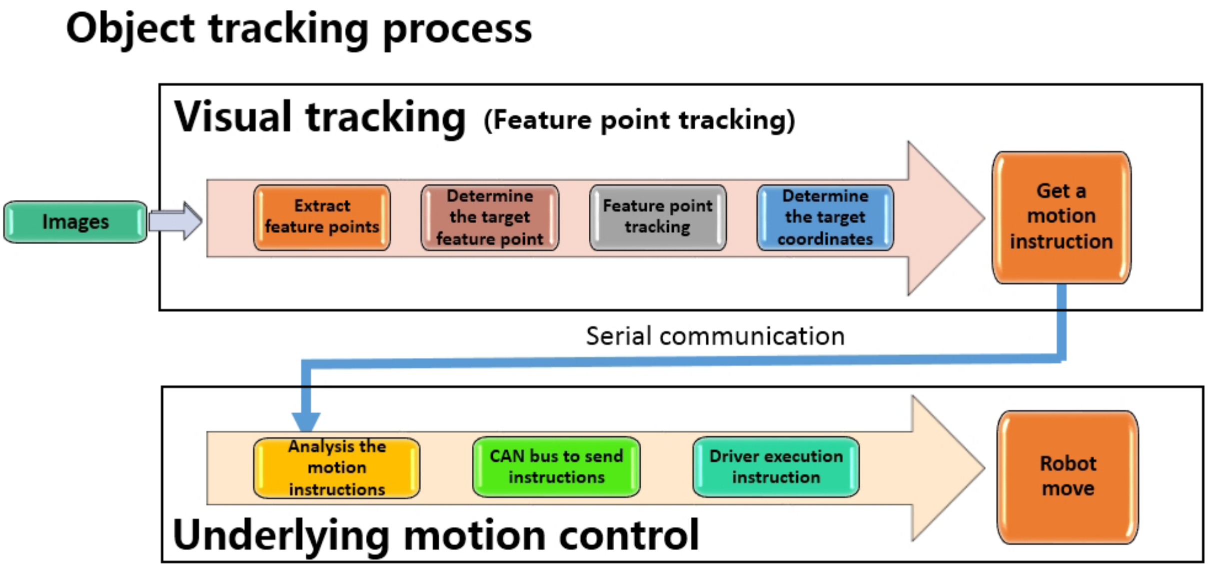


Fig. 6. Object tracking process diagram

Shi-Tomasi algorithm is an improvement of Harris algorithm. The Harris algorithm subtracts the determinant of M from the determinant of M, and then compares the difference with a predetermined threshold. Based on the Harris algorithm, Shi-Tomasi analyzes the eigenvalue of M, and if The smaller of the two eigenvalues is greater than the minimum threshold, the feature point is obtained.

When tracing the feature points, the paper uses the iterative Lucas-Kanade method in the pyramid to calculate the optical flow of a sparse feature set and track the point coordinates of the vector in a frame-by-frame manner. The concept of optical flow is first proposed by Gibson. It is the instantaneous velocity of the pixel motion of the space moving object in observing the imaging plane. It uses the change of the pixels in the image sequence in the time domain and the correlation between adjacent frames to find the difference between the previous frame and the current frame Correspondence, thus calculating the movement of objects between adjacent frames a method of information.

When the user selects the area to be tracked, the program will select the best feature point in a 16 × 16 pixel area and read the coordinates and print in real-time on the background. The coordinates of the read-out feature points exist in the vector container. The Lucas-Kanade method traces the point coordinates of the vector in a frame-by-frame manner and calculates the coordinates of the feature points in the current video frame in real time to determine the target area and control the movement of the robot according to the position of the target in the area.

The Lucas-Kanad method of tracking begins by building a Gaussian pyramid for each frame, with the largest scale at the top and the original at the bottom. Then, calculate the optical flow from the top level, as the initial position of the next level, search down the pyramid, and repeat the estimation until it reaches the bottom of the pyramid. Finally, the feature points in the vector container can be obtained accurately in each frame Pixel coordinates. Knowing where the feature coordinates are, you know where the target is in the camera to capture the video. The coordinate system and area division of the image video capture are shown in Fig. 7.

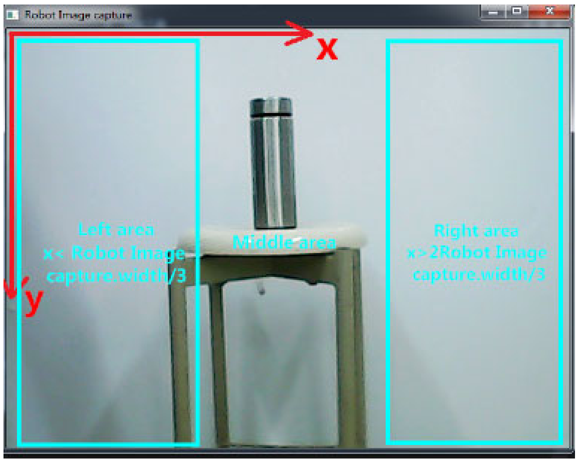


Fig. 7. Video coordinate system and area division

In complex indoor environments, to achieve face tracking, we must take into account the situation that user can not face the camera from time to time, so the detection procedures must meet the requirements of human side of the face detection tracking requirements.

Face detection process is as follows. Firstly, the image preprocessing is performed on the collected color image to reduce the noise point and also to enhance the image. The preprocessed image is converted into a grayscale image, the purpose of which is to remove the influence of illumination on the face detection algorithm, and then face detection is performed, as shown in Fig. 8.

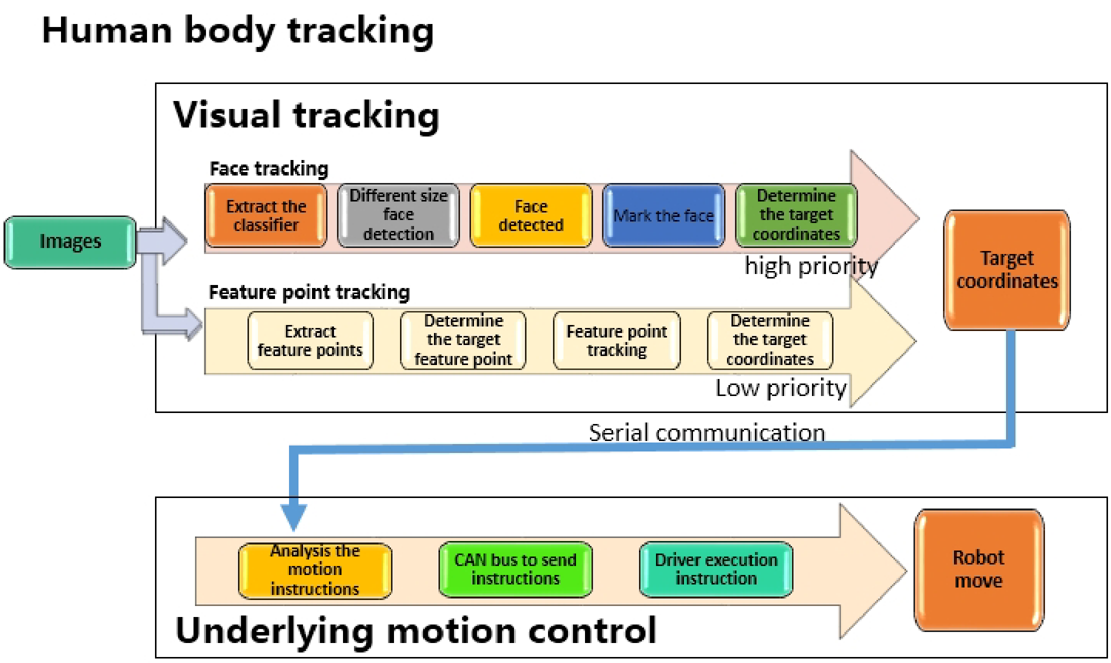


Fig. 8. Human tracking process diagram

The first is to train the classifier. Using the sample harr feature classifier training, to get a class classifier. The classifier can be applied to the detection of the region of interest of the input image after detecting the target area (face), the output of the classifier is 1, otherwise the output is 0. In order to adapt to different sizes of face search, classification needs to change the size of information, with different sizes of the search window to scan the picture several times, and ultimately determine the face area. Since some open source library libraries such as Opencv already contain many well-trained classifiers, we use the trained classifier directly. For face cascade classifier trained to find a rectangular region including the target object in the image, and these regions as a rectangular frame sequence returns to the scanning window of a different size ratio of the image after scanning several times, these regions combined, and returns the average of a sufficiently large number of combinations, face recognition algorithms employed herein can be achieved from the face detection range [-60,60], the front face detection algorithm reaches 200fps, you can achieve more Simultaneous detection of personal faces, computing speed shown in Fig. 9, to meet real-time requirements.

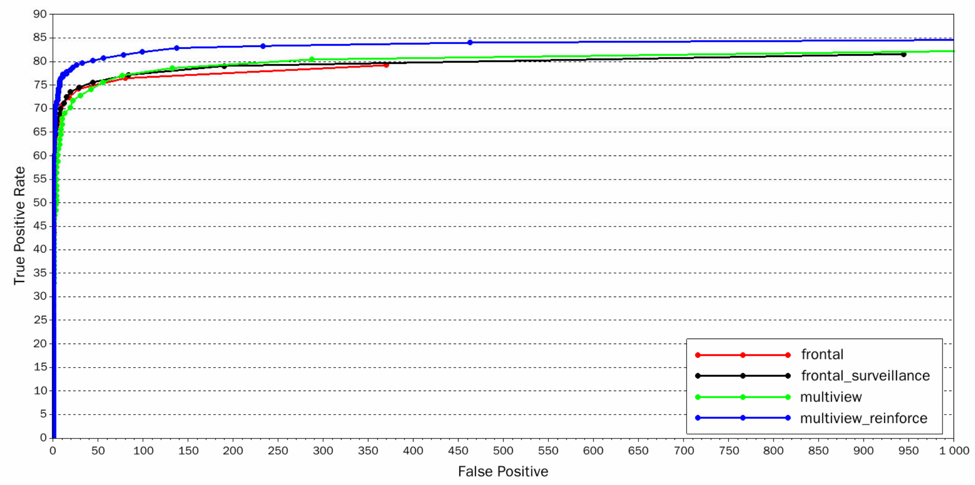


Fig. 9. Face recognition accuracy

Fig. 10 is a face detection renderings, visual acquisition program can detect and identify the face, and can identify the location of the face, identify the output results shown in Fig 11, The first two values in face_rect are the pixel values of the vertices of the rectangle that identify the face, the last are the width and height of the rectangle, respectively. Angle for the human face deflection angle, 0 degrees is facing the camera.

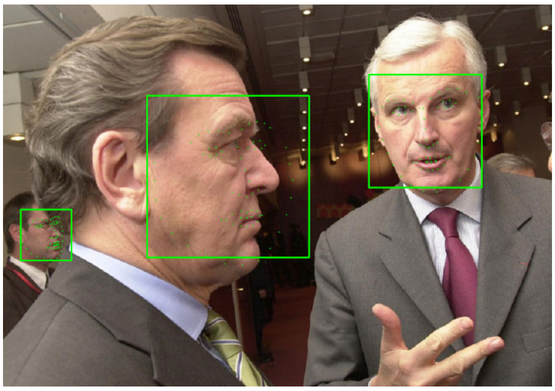


Fig. 10. Face detection renderings

```
3 faces detected.
face_rect=[35, 365, 91, 91], angle=86
face_rect=[652, 126, 201, 201], angle=-3
face_rect=[259, 163, 288, 288], angle=87
```

Fig. 11. Face detection results

In the actual operation, because the user can not face the camera in real time, and sometimes even back to the robot, this time is the blind spot face tracking. In order to ensure the integrity of tracking and ensure that the tracking goal is not lost, this paper uses feature point tracking to assist tracking. As shown in Fig. 8. During human body tracking, when the image information collected by the camera is processed, feature point tracking and face tracking are performed simultaneously, and the corresponding tracking results are obtained respectively, that is, the coordinates of the target. This paper takes the result of face tracking as a high priority and the result of feature tracking as a low priority. When data is sent, the result of the high-priority face tracking will be sent, while the result of the low-priority feature point tracking arriving at the same time will be discarded. When the angle between the user and the camera exceeds the recognition range of the face recognition algorithm [-60,60], the face tracking has no result output, and the feature point tracking will be added to ensure the real-time tracking of the target. In order to ensure that the system occurs misjudgment, when the face tracking has no output result for 300ms, the result of feature point tracking is sent downward. When face tracking has the result output, the result of face tracking is restored.

2.4 Visual Processing and Underlying Motion Control Programs

As the visual acquisition of 25 frames per second to capture, the visual capture needs to detect frame-by-frame images, although the algorithm has been optimized, but the processing of image information is relatively large, in order to ensure the rapidity of the system, the visual tracking and the underlying motion control are separated from each other and cooperate with each other through communication. In this way, even if the visual tracking fails or delays, the underlying motion control can independently perform simple obstacle avoidance to keep the robot safe.

Fig. 12 shows the robot visual information collection interface. The information collected by the camera is displayed in real time on the right window. Users can click on any area of the target to be tracked on the right interface. The video acquisition program will search for the best feature point of the target in the area of 15 × 15 pixels for tracking. The left side of the operating status interface, when the program initialization will detect a variety of connection status, including the camera is open, the communication is normal, tracking the target's real-time display of feature points.

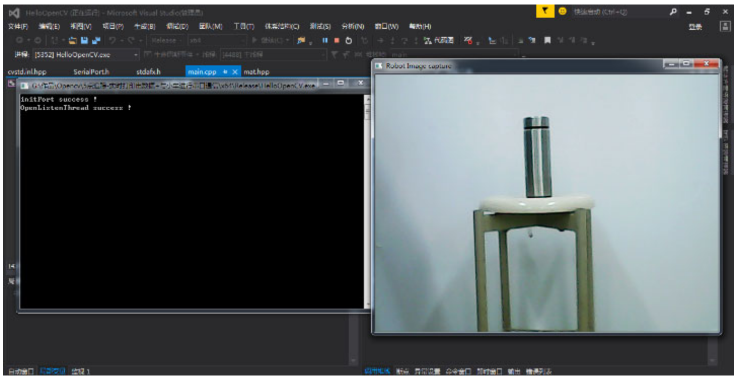


Fig. 12. Visual acquisition program interface

Fig. 13 shows the robot motion control interface. The control center located on the second floor of the robot is via the CAN communication module send commands to the underlying driver module using the CAN bus. As shown in Fig. 14.

Fig. 13. The underlying control program interface

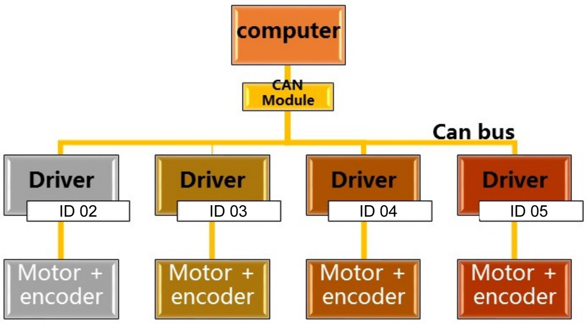


Fig. 14. Robot motion control

Each drive individually controls a motor corresponding to a different ID value, respectively, 02-05, so the drive is connected to the CAN bus. This text adopts the standard CAN2.0 standard communication protocol, the communication speed is 500kbps. CAN instruction code is set to 8, the format is:

[LEN]+[ID]+[FUNC]+[DATA]

The device ID corresponds to each drive ID, and the drive continuously listens to the CAN bus. When intercepting the command corresponding to ID, read the command FUNC, and follow the corresponding data DATA to operate.

In this paper, the motor is a DC servo motor, motor rotor is relatively slender, small moment of inertia, start, brake, speed performance is very good, can achieve frequent positive and negative, more suitable for flexible robot movement requirements. And the mathematical model is simple and easy to calculate, torque, speed and other parameters are linear. This makes the overall control less difficult, while the motor model RM35 motor models, the motor comes with encoder. The encoder is connected to the drive and feeds back the actual speed of the motor, as shown in Fig. 15 for the motor and drive. For the drive motor speed control using speed mode.

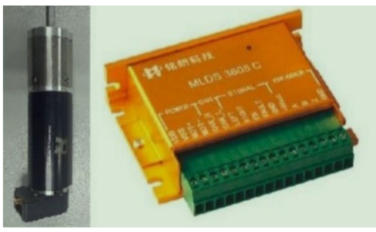


Fig. 15. Motor and drive physical map

The project visual processing program and the underlying control program running in real time. If you use two separate implementation of the computer, you can meet the requirements, but this computer multithreading capabilities will be greatly wasted, the cost of the robot will be higher, is not conducive to the promotion and application.

Serial Communication, refers to the peripherals and computers, through the data signal lines, ground, control lines, etc, according a bit of data transmission of a communication. Serial communication is generally used in the communication between two devices, but through the serial port virtualization, you can make a laptop with multiple serial ports, you can take full advantage of the multi-threaded notebook capabilities.

In this paper, the data transmission between two programs running at the same time is only the int variable of the robot's motion state, and the transmission data is not big, and the real-time requirements can be satisfied by the serial communication.

Most notebooks do not have a serial port or only one serial port. In this paper, in order to achieve the communication between the two programs, two COM7 and COM8 serial ports are virtualized by software, and the two are virtually connected. The two serial communication parameters conFigd for the same, this time, the communication between the two programs to complete the configuration, as shown in Fig. 16, and the Communication parameters as shown in Table 1.

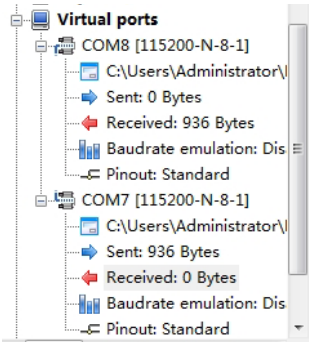


Fig. 16. Serial communication

Table 1. Communication parameters

Serial port number	Baud rate	Data bit	Stop bit	Check Digit	Flow control
COM7	115200	8	1	None	None
COM8	115200	8	1	None	None

3 Experiments

3.1 Motor Speed

As can be seen from the2.2 SPORTS MODEL, the motor speed directly determines the robot's speed. In order to obtain the actual characteristics of the motor output, we record the actual output characteristics of the motor at different input speeds. As shown in Fig. 17. Experimental results show that the motor output characteristics in line with the linear relationship, and with the theoretical curve of the basic coincidence, indicating that the motor speed control accuracy is relatively high.

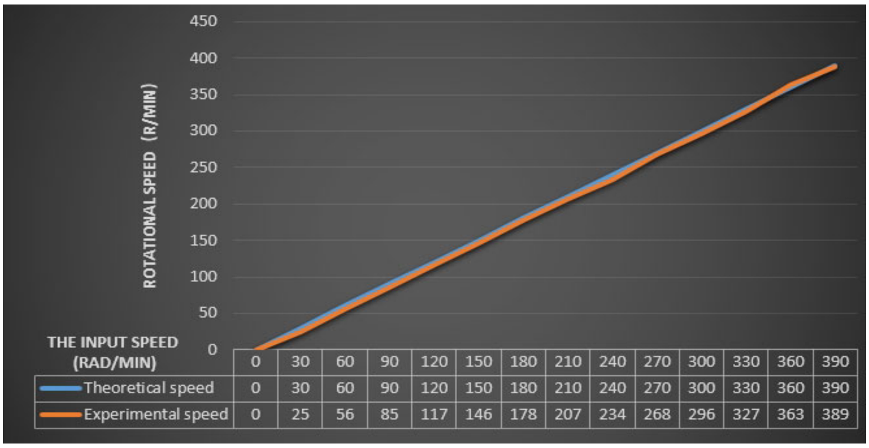


Fig. 15. Motor speed calibration chart

Knowing the speed of the motor and the speed of the robot are crucial to the control. In 2.2SPORTS MODEL, we get the relationship between motor speed and robot speed under ideal conditions. However, due to the friction in the environment, the uneven floor, load and other conditions led to the actual and the theory is not exactly the same, so we experiment to see whether the error is within the allowable range.

As shown in Fig. 18, the robot's actual speed is less than the theoretical value, and the speed curve and the theoretical speed curve are basically the same, the error is within the acceptable range.

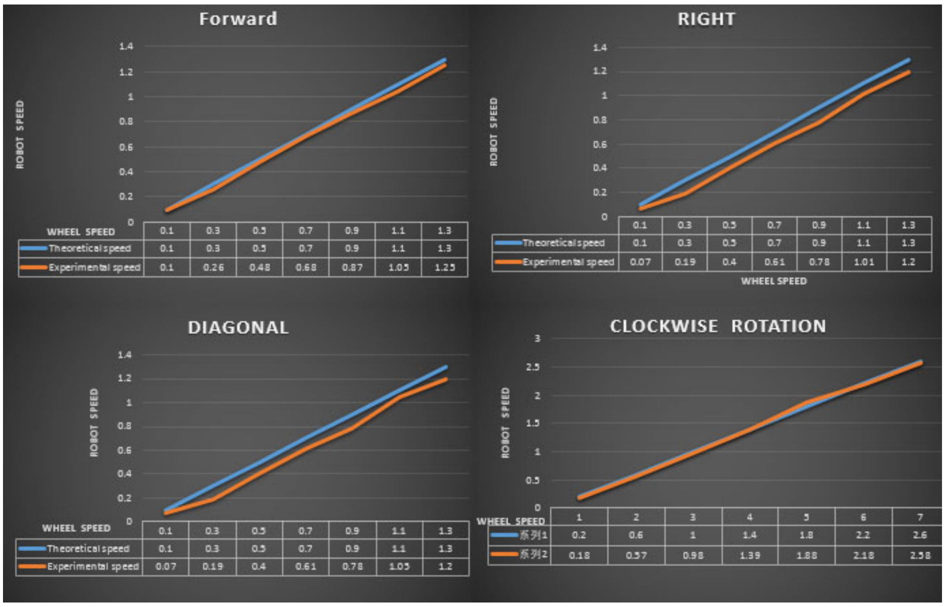


Fig. 16. Relationship between robot speed and motor speed

3.2 Feature Point Detection

In order to verify the tracing effect of the feature points, the following experiments were carried out to visualize the same object, change the threshold value of the search, observe the number of feature points detected and find suitable thresholds that can reflect the features of the object.

As shown in Fig 19, the cup on the stool is tested and the detection threshold is changed to change the number of detectable features. In the Fig, the color is the actual detected feature point. As the threshold decreases, the actual detected number of feature points will also gradually increase. The shape of the cup is detected and its features are more and more complete. The cup can be distinguished from the environment. Continue to decrease the threshold, at which point it can be seen that more features are detected in the reaction, as shown in Fig 19 (6-10). At this time, too many feature points are detected and the target recognition has been interfered. Continue to reduce the threshold, the actual detection of the number of feature points will not change significantly. Finally, after many experiments, we finally determine the threshold as 3X3, at this time can better distinguish the object from the environment, without introducing excessive interference points in the environment.

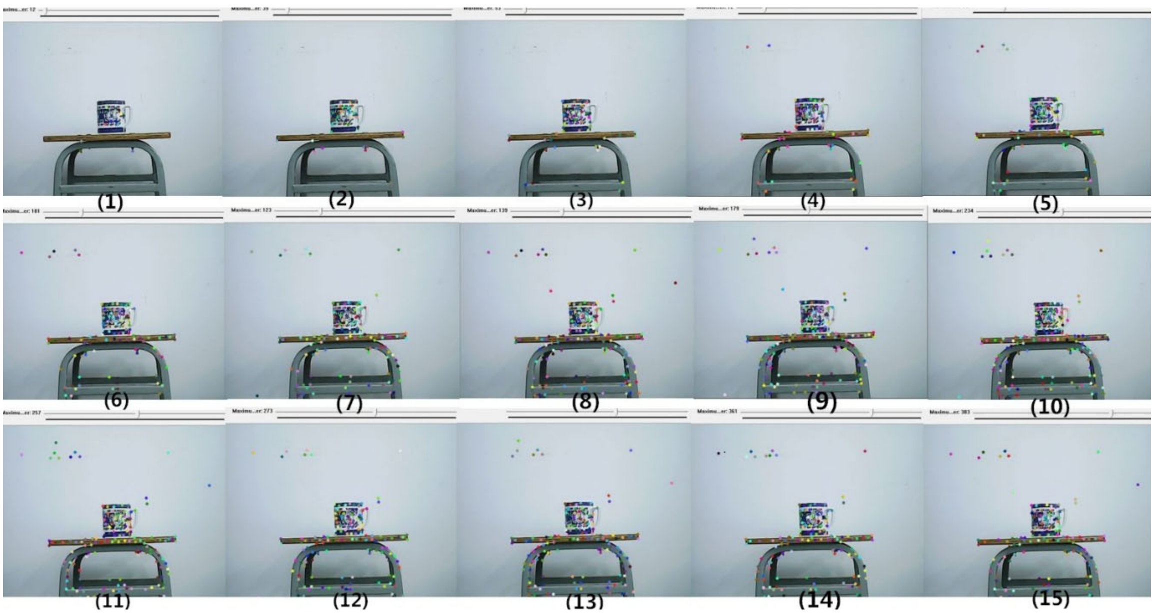


Fig. 17. Feature point renderings

3.3 Face Recognition and Mobile Body Tracking

In order to verify the feasibility of face detection algorithm. We used a visual capture program to identify randomly images from 100 face databases, some of which are shown in Fig. 20. In the experimental results, we can see that the visual detection algorithm can simultaneously identify multiple faces in a picture, even in the case of the side face, can also be identified to meet the actual requirements.

Fig. 18. Part of the face recognition results

In order to verify the tracking effect of the moving target, this paper has carried on the experiment of tracking the moving human body. Select the tracking target for human face detection and feature tracking, face and feature point coordinates and print out. As shown in Fig. 21, the robot is facing the target and human faces and feature points can be detected. Face tracking has a higher priority than feature tracking. Therefore, the robot performs face tracking. At this moment, the robot is sending a forward command to the target.

When the target suddenly moves, the target may be side facing or even back facing the robot. Due to the limited range of face recognition angle (-60°, 60°), The blind spot appears in the face tracking as shown in Fig. 21, therefore Low-priority feature point tracking results control the robot movement. When the robot is turning right, the face is detected again, as shown in Fig. 22. Face detected, use face tracking strategy, and the face tracking is performed. Finally, the robot is the target, stop spinning, to the goal.

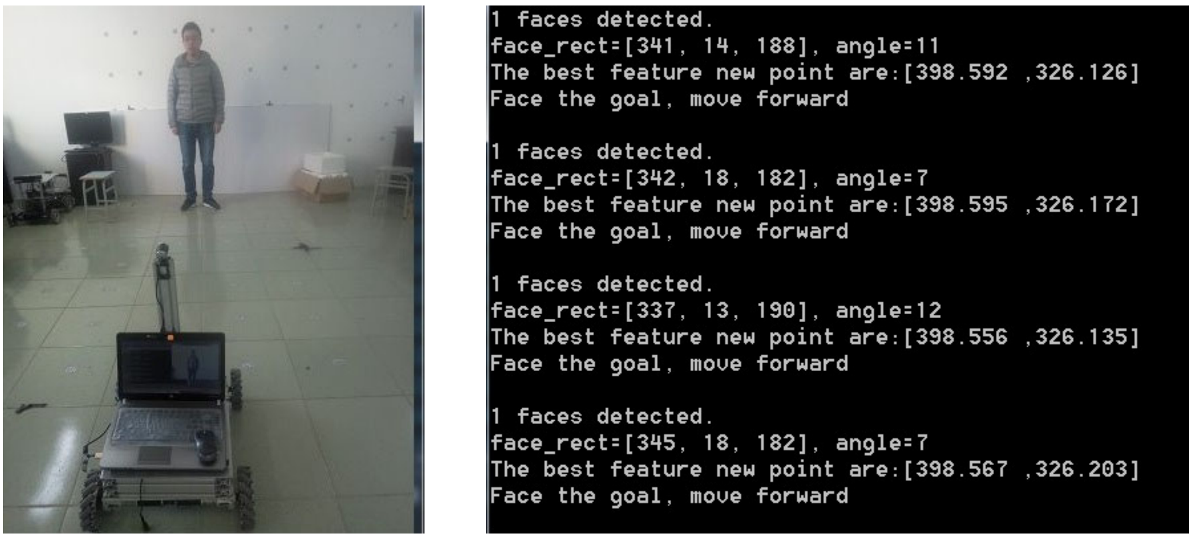
Experiment specific process as follows. The human body is selected as the tracking target in the experiment. As shown in Fig. 23(a), the position of the human face is detected. The result is shown in the Fig. 23(b). The target is in the central position of the robot video and the robot sends forward instructions to move toward the target. Suddenly target move to the right, this time will inevitably enter the blind area of face detection, as shown in Fig. 21, so apply the feature point tracking strategy to detect the target key feature points, detect the target at the right of the video window, issue a right turn command. Rotation until the target is located in the middle of the image acquisition window, and then determine whether to reach the specified distance, if not, still sent forward instructions, to the target movement, shown in Fig. 22. Finally, the robot reaches the target a predetermined distance which is Laser range finder measured , the robot stops automatically.

(a) (b)

Fig. 21. The target suddenly moved to the right, face detection blind spot, adopt the feature point tracking strategy

(a) (b)

Fig. 22. Face detected, use face tracking strategy



(a) (b)

Fig. 23. Tracking people, the goal is ahead to robot

In Fig. 20, the reliability of the visual detection algorithm has been verified. Since the robot detects and tracks the target during the motion, in order to judge the influence of the vibration caused by the robot motion toward the visual detection, we compare recognition success rate of the robot at different speeds. The robot identified the same moving target at different speeds, and the experiment was conducted 50 times. The result was shown in Fig. 24. As can be seen visible robot speed faster or slower, the recognition rate is not ideal, the main reason is that when the target moves, the robot speed too fast or too slow will lead to the target from the tracking range, when the recognition fails. Therefore, the robot's speed should be appropriate, this paper will be set 1m/s as the robot's operating speed.

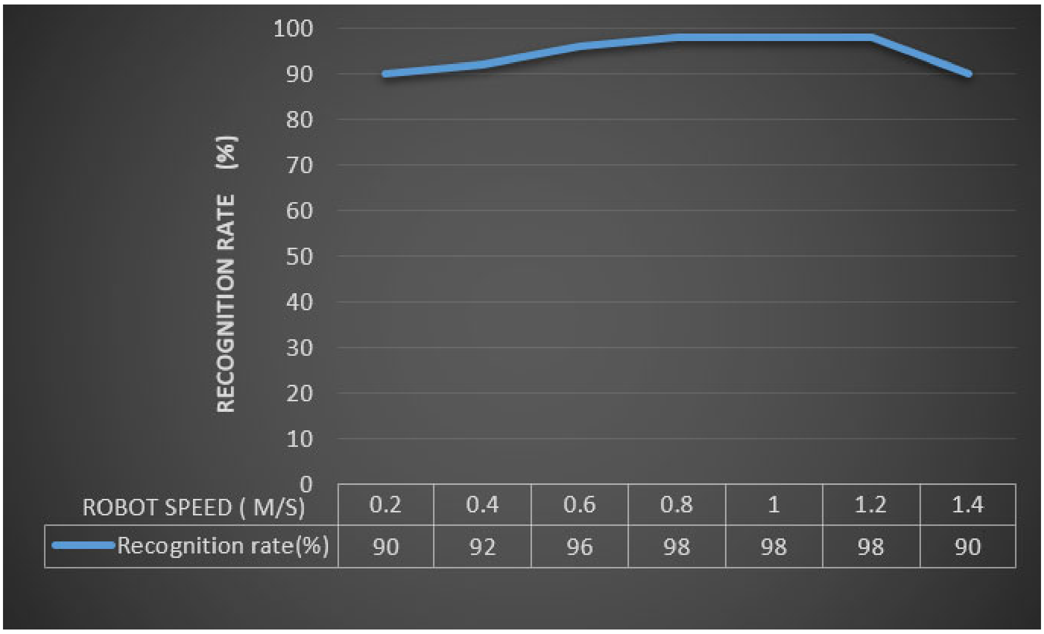


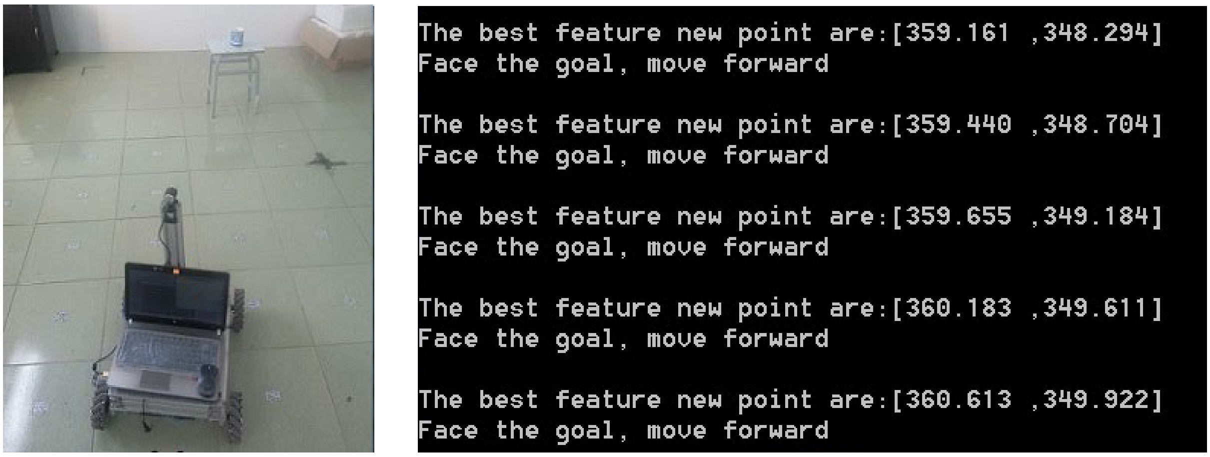
Fig. 19. Relationship between robot speed and recognition rate

3.4 Fixed Object Tracking

As shown in Fig. 25(a), select the cup placed on the stool as the tracking target, (b) is the result of tracking the best feature points in real time. In the initial, the cup is located on the right side of the robot view window. After determining the coordinates of the feature point, the target is determined to be located in the right area, and then the robot executes the right turn instruction and refreshes the position of the cup in real time. Until the face the target, execute the forward instruction, as shown in Fig. 26. After the laser range finder measured the distance to the target preset distance, the robot will stop automatically.

(a) (b)

Fig. 20. Feature point tracking



(a) (b)

Fig. 21. The robot tracks the status of the target in operation

4 Conclusion

In this paper, according the indoor omni-directional mobile robots that can be followed independently are designed for indoor service robots to track a single target and use a dedicated visual sensor to cause a high cost. By using a common camera provided on a robot and using different tracking methods according to different targets Strategy, you can achieve any goal of tracking under any state. Tracking strategy can be divided into two categories, one is tracking the human body. The face tracking and feature tracking, which are based on the classifier, are combined with face tracking as the high priority of tracking. When face blind spots appear, feature point tracking is used to supplement and ensure the integrity of tracking. One is the tracking of objects in any state. In this case, the feature points are used to track the target. Combined with Shi-Tomasi algorithm and Lucas-Kanade algorithm, the two-dimensional coordinates of target sub-pixel level accuracy are obtained. Combined with laser range finder, the three-dimensional coordinates Positioning. In this paper, a series of experiments are carried out. Finally, the feasibility of the system is verified through experiments. The success rate of tracking the target is over 90%, which has high reliability.

Acknowledgement

This research was supported by the National Natural Science Foundation of China (Grant No. 61473027), and Beijing Key Laboratory of Robot Bionics and Function Research (Grant No.BZ0337), and Supported by The Fundamental Research Funds for Beijing Universities, and Beijing Advanced Innovation Center for Intelligent Robots and Systems, and Beijing Advanced Innovation Center for Future Visual Entertainment.

References

[1] V. Alvarez-Santos, X.M. Pardo, R. Iglesias, Feature analysis for human recognition and discrimination: application to a person-following behaviour in a mobile robot, Robotics & Autonomous Systems 60(8)(2012) 21-36.

[2] H. Zender, P. Jensfelt, G.M. Kruijff, Human- and situation-aware people following, in: Proc. IEEE Ro-Man 2007, IEEE International Symposium on Robot & Human Interactive Communication, 2007.

[3] R. Gockley, J. Forlizzi, R. Simmons, Natural person-following behavior for social robots, in: Proc. ACM/IEEE International Conference on Human-Robot Interaction, 2012.

[4] W. Ye, Z. Li, C. Yang, Vision-based human tracking control of a wheeled inverted pendulum robot, IEEE Transactions on

Cybernetics 46(11)(2016) 23-34.

[5] W. Chung, H. Kim, Y. Yoo, The detection and following of human legs through inductive approaches for a mobile robot with a single laser range finder, IEEE Transactions on Industrial Electronics 59(8)(2012) 56-66.

[6] M. C. Hu, C.W. Chen, W.H. Cheng, Real-time human movement retrieval and assessment with Kinect sensor, IEEE Trans Cybern 45(4)(2015) 42-53.

[7] H. Xiao, Z. Li, C. Yang, RGB-D sensor-based visual target detection and tracking for an intelligent wheelchair robot in indoors environments, International Journal of Control Automation & Systems 13(3)(2015) 21-29.

[8] P. Sardain, G. Bessonnet, Forces acting on a biped robot, Center of pressure-zero moment point, IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans 34(5)(2004) 30-37.

[9] K. Erbatur, O. Kurt, Natural ZMP trajectories for biped robot reference generation, IEEE Transactions on Industrial Electronics 56(3)(2009) 35-45.

[10] Q. Huang, K. Kaneko, K. Yokoi, Balance control of a piped robot combining off-line pattern with real-time modification, in: Proc. 2000 Proceedings ICRA'00 IEEE International Conference on Robotics and Automation, 2000.

[11] Y. Yoshida, K. Takeuchi, Y. Miyamoto, Postural balance strategies in response to disturbances in the frontal plane and their implementation with a humanoid robot, IEEE Transactions on Systems, Man, and Cybernetics: Systems 44(6)(2014) 692-704.

[12] P. Sardain, M. Rostami, G. Bessonnet, An anthropomorphic biped robot: dynamic concepts and technological design, IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans 28(6)(1998) 23-38.

[13] H. Minakata, H. Seki, S. Tadakuma, A study of energy-saving shoes for robot considering lateral plane motion, IEEE Transactions on Industrial Electronics 55(3)(2008) 1-6.

[14] K. Harada, S. Kajita, F. Kanehiro, Real-time planning of humanoid robot's gait for force-controlled manipulation, IEEE/ASME Transactions on Mechatronics 12(1)(2007) 53-62.

[15] F. Asano, M. Yamakita, N. Kamamichi, A novel gait generation for biped walking robots based on mechanical energy constraint, IEEE Transactions on Robotics and Automation 20(3)(2004) 65-73.

[16] C. Yang, Z. Li, R. Cui, Neural network-based motion control of an underactuated wheeled inverted pendulum model, IEEE Transactions on Neural Networks & Learning Systems 25(11)(2014) 2004.

[17] Kerstindautenhahn, The art of designing socially intelligent agents: science, fiction, and the human in the loop, Applied Artificial Intelligence 12(7-8)(1998) 573-617.

[18] H.S. Shanee, K. Dror, O.G. Tal, The influence of following angle on performance metrics of a human-following robot, in: Proc. IEEE International Symposium on Robot and Human Interactive Communication, 2016.

[19] S. Karakaya, G. Küçükyıldız, C. Toprak, Development of a human tracking indoor mobile robot platform, in: Proc. International Conference on Mechatronics - Mechatronika, 2015.

[20] E.J. Jung, J.H. Lee, B.J. Yi, Development of a laser-range-finder-based human tracking and control algorithm for a marathoner service robot, IEEE/ASME Transactions on Mechatronics 19(6)(2014) 63-76.

[21] M. Mehdi, P. Niriaska, G. Simon, The walking behaviour of pedestrian social groups and its impact on crowd dynamics, Plos One 5(4)(2010) e10047.

[22] M.L. Walters, K. Dautenhahn, S.N. Woods, Exploratory studies on social spaces between humans and a mechanical-looking robot, Connection Science 18(4)(2006) 29-39.

[23] J.E. Young, Y. Kamiyama, J. Reichenbach, How to walk a robot: a dog-leash human-robot interface, in: Proc. Ro-Man,

2011.

[24] W. Obaid, T. Rabie, M. Baziyad, Real-time color object recognition and navigation for QUARC QBOT2, in: Proc. International Conference on Computer and Applications, 2017.