Design of multi-robot system based on target detection

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Abstract. Traditional target-following robots are not only easy to lose targets, but also unable to solve all kinds of unexpected situations in time. Based on the above problems, this paper designs a multi-robot following system based on target recognition. The system can complete the task of target following through image recognition and processing and PID algorithm control. While completing target following, it can also complete the cooperative control of multi-robots by constructing local networks among robot systems, which makes the system have better processing ability for various situations. After experimental tests, the robot system has higher following robustness and practical value.

Keywords: Robot following system, PID algorithm, network construction, information processing.

1. Introduction
With the rapid development of network communication technology and artificial intelligence technology, robot technology is becoming more and more mature, and the robot following technology is getting more and more attention because of its wide application. There are many kinds of robot following technologies, among which the most common and effective one is to identify the target by the robot's visual signal and follow the specified target.

In recent years, there are more and more enterprises developing robot positioning and following technology in China, with image processing as the core and the technology of coordinating positioning system with sensors has been relatively mature. Robots using this technology can independently sense the external environment, identify and judge, avoid obstacles and follow the path planning, and help solve the problem of autonomous movement and complete complex tasks. In the process of robot development, facing the needs of society and people's growing demand, multi-robot system has gradually entered the market. Multi-robot systems can accomplish many tasks that a single robot system cannot through mutual coordination, and tasks that a single robot can do can also be accomplished with higher efficiency. When the multi-robot system is combined with the following system, it can not only effectively reduce the interference of other moving signals when the target follows, but also have higher stability and accuracy, and can better deal with unexpected situations. The research on the combination of these two technologies is of great value not only for these two fields, but also for the future development of robots.
2. Overall System Design
The design of the following robot system is divided into main controller system, motor drive system, information acquisition system, communication system and power supply system. Among them, the controller selects STM32F103 single chip microcomputer to control the movement and information interaction of the robot; The information collection system uses kinect camera to identify images and collect information. The communication system uses ESP8266 Wi-Fi module with stable performance and low power consumption to transmit information; In the power supply part, 12V lithium battery is used as the energy supply of the robot, and each system cooperates with each other to ensure the robot to complete the task of following the target.

The main controller takes the STM32F103ZET6 chip as the minimum system, reads the information obtained by the camera, analyzes and processes the effective information, outputs the corresponding PWM wave to control the motor speed, obtains the robot speed through the encoder, and uses PID algorithm to accurately control the movement of the robot. While completing the task, the communication system can also be used to complete the communication network construction and collaborative control between robots, so as to avoid the loss of robots when a robot loses control or has an unexpected situation, and to inform the controller in time when the power of the robot is too low or fails, thus effectively enhancing the robustness of the overall system. The overall system architecture diagram is shown in Figure 1.

![Fig. 1 Overall System Frame Diagram](image)

3. System Motion Model
The motion model of the system mainly relies on PID algorithm, which means "proportional, integral and differential", that is, the proportion (p), integral (I) and differential (d) of the deviation between the given value r(t) and the actual output value c(t) are combined linearly to form a control quantity to control the controlled object. The proportional link can reflect the deviation signal e(t) of the control system in proportion immediately. Once the deviation is generated, the regulator immediately produces control action to reduce the deviation. The integral link is mainly used to eliminate static error and improve the system's non-error. The strength of integration depends on the integration time constant TI. The larger TI is, the weaker the integration is, and the stronger it is. The differential link can reflect the change trend (change rate) of the deviation signal and introduce an effective early correction signal into the system before the value of the deviation signal becomes too large, thus speeding up the action speed of the system and reducing the adjustment time. Its control block diagram is shown in Figure 2.

![Fig. 2 PID Control Block Diagram](image)
Since the target is movable, it is impossible to keep in the center of the camera all the time, so it is the best choice to constantly adjust the position of the following robot. During the following process, the orientation of the robot head can be constantly adjusted according to the current position of the target to ensure that the target is always in the center of the camera. In order to maximize the flexibility of the following robot, universal wheels or McNamur wheels are usually selected, but universal wheels require a series of angles between hub shafts, which is troublesome to manufacture, so McNamur wheels are used as the wheeled structure of the robot in this system.

Mecanum wheel as an omni-directional movement equipment, can realize forward movement, transverse movement, oblique movement, rotation and their combination, which is very suitable for following robots. McNamur wheels are generally used in groups of four, two left-handed wheels and two right-handed wheels. The left-hand wheels and the right-hand wheels are chirally symmetrical, and there are many mounting methods. Here, the O-rectangle mounting method is selected, and the rotation of the wheel can generate Z-axis rotation moment, and the force arm of the rotation moment is also relatively long. Firstly, the relevant motion model is constructed.

The chassis equipped with Mecanum wheels can be decomposed into the moving speed of X axis and Y axis and the angular speed of rotation.
Fig. 4 Analysis of Roller Speed of Single Mecanum wheel

$\vec{r}$ is the vector whose geometric center points to the axis;

$\vec{V}$ is the velocity vector of axial movement;

$\vec{V}_{r}$ is the velocity component of the axis in the direction perpendicular to the tangent line; With $\vec{V} = \vec{V}_{r} + \omega \times \vec{r}$, the axial velocity can be easily obtained by calculating the components of x and y axes respectively.

According to the axis speed, the speed $\vec{V}_{i}$ along the direction and the speed $\vec{V}_{\perp}$ perpendicular to the roller direction can be decomposed, where $\hat{u}$ is the unit vector along the roller direction, and the following formula can be obtained:

$$\vec{V}_{i} = \vec{V} \cdot \hat{u} = \left( V_{i} \hat{i} + V_{j} \hat{j} \right) \cdot \left( -\frac{1}{\sqrt{2}} \hat{i} + \frac{1}{\sqrt{2}} \hat{j} \right) = -\frac{1}{\sqrt{2}} V_{i} + \frac{1}{\sqrt{2}} V_{j}$$

From the roller speed, the rotational speed of the wheel can be calculated:

$$\vec{V}_{r} = \vec{V} \cdot \hat{u} = \left( V_{i} \hat{i} + V_{j} \hat{j} \right) \cdot \left( -\frac{1}{\sqrt{2}} \hat{i} + \frac{1}{\sqrt{2}} \hat{j} \right) = -\frac{1}{\sqrt{2}} V_{i} + \frac{1}{\sqrt{2}} V_{j}$$

According to the definitions of and shown in figure 5, there are

$$\begin{cases} V_{x} = V_{xx} + \omega b \\ V_{y} = V_{yy} - \omega a \end{cases}$$

To sum up, the rotational speed of four wheels can be calculated

$$\begin{cases} V_{\omega 1} = V_{y} - V_{xx} + \omega (a + b) \\ V_{\omega 2} = V_{y} + V_{xx} - \omega (a + b) \\ V_{\omega 3} = V_{y} - V_{xx} - \omega (a + b) \\ V_{\omega 4} = V_{y} + V_{xx} + \omega (a + b) \end{cases}$$
Mark $\theta$ as the deflection angle of the robot, the target position is $[X_T \ Y_T \ \theta_T]^T$, and the robot position is $[X_F \ Y_F \ \theta_F]^T$, so the relative error $[e_x \ e_y \ e_\theta]^T$ is:

$$
\begin{bmatrix}
e_x \\
e_y \\
e_\theta
\end{bmatrix}
= \begin{bmatrix}
\cos \theta & \sin \theta & 0 \\
-sin \theta & \cos \theta & 0 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
X_T - X_F \\
Y_T - Y_F \\
\theta_T - \theta_F
\end{bmatrix}
$$

In the following process, the speed of the robot is obtained by PID algorithm, the distance and direction deviation from the target are calculated, the speed of each wheel is calculated by substituting the formula, and the rotating speed of the robot motor is accurately controlled by proportional, integral and differential calculation, so as to achieve accurate control and target following. The PID calculation formula is as follows.

$$
u(t) = kp \left( err(t) + \frac{1}{T_i} \int err(t) dt + \frac{T_d \ddot{err}(t)}{dt} \right)$$

4. Target Recognition
The most important way to identify the target is to obtain the required information through Kinect camera. Kinect camera uses optical coding technology, that is, light source illumination is used to code the space to be measured, and CMOS photosensitive chip is used instead of special photosensitive chip, which greatly reduces the cost. Kinect projects the dot matrix through IR head, and then captures the dot matrix with CMOS sensor to obtain depth information. The whole Kinect is equivalent to a bat, and the infrared projector continuously emits infrared structured light, which is equivalent to the sound waves emitted by bats. The intensity of infrared structured light will be different at different distances, just as sound waves will be attenuated. Infrared sensors, which are equivalent to bat ears, are used to receive feedback messages. Different intensities of structured light can produce different intensities of induction on infrared sensors, so Kinect can know the depth information of objects in front of it and distinguish objects with different depths.
After the camera reads the image, it searches the pixels of the target object line by line. After identifying the target, adjust the front of the car so that the target is always in the center of the camera. In fig. 6, point a is the front position, point o corresponds to the center position of the camera, and O' is the center position corresponding to the target. The distance can be calculated relatively by the number of pixels in the recognition area of the camera. AO is the distance between the front and the target, noted as d, and O'O is the distance between the target center and the camera center, noted as x, so the relative distance y between the car and the target in the front direction is as follows:

$$y = \sqrt{d^2 - x^2}$$

And that offset angle $\theta$ between the vehicle and the target is:

$$\theta = \arcsin \frac{x}{d}$$

With this data, the robot can follow the target with higher accuracy.

5. Network Construction

Bluetooth connection or Wi-Fi connection is generally used in network construction, but Bluetooth connection is relatively more limited, because Bluetooth connection is generally one-to-one, which cannot achieve one-to-many information transmission effect like Wi-Fi. Therefore, Wi-Fi connection is more reasonable and effective in the network construction of multi-robot system, which will not make the following task difficult to complete due to the loss of targets, occlusion of visual field, etc., and the collaboration of robot system will be stronger, and the robustness of the following system will be stronger.

ESP8266 is used in the communication module mentioned above, which has low energy consumption and high stability, and it supports not only UDP but also TCP or SSL. Here, UDP is selected to build the broadcast network, and the coexistence mode of AP and station of ESP8266 module is used. In the broadcast network, each independent robot is an IP address, which is used for identification. Each ESP8266 module can generate an AP in the process of network construction, and at the same time, it can also be used as a station to send and receive data. The module can communicate with other modules or other devices connected to the AP generated by the module to build a small local area network. Here, the first robot in the robot group is set as the wireless access point, which makes it the center of the whole robot local area network, and the rest robots are wireless network stations. When the first robot is used as an access point, it can complete two-way information exchange and data transmission with any other robot to maximize efficiency. When there is a problem with any access point, it can report the abnormality to the first robot, and give instructions for processing after system judgment. At the same time, transparent data transmission is adopted in order to minimize the complexity of transmitting data and executing commands.
6. Experiment
For the robot platform constructed above, MATLAB is used for data simulation experiment. The following system is composed of the first robot and its following robot. Using the navigation and target following functions of the first robot, the absolute error of the multi-robot following system is tested.

The first robot collects information and follows the target according to the established procedure, while the communication network constructed by the whole system provides follow-up information for the following robots, and at the same time collects necessary information for this experiment, and draws a line chart of the relationship between error and time variation between robot and target. The following figure shows the absolute error of the first robot following the target and the relative error of the second position following it.

![Fig. 7 Following error curve of the first robot](image)

![Fig. 8 Following error curve of robot No.2](image)

It is not difficult to see from the error diagram drawn that after the robot system starts to move, after a period of fluctuation, the relative error gradually tends to zero, and the polyline is in a convergent state. Therefore, the following system designed in this paper has good performance, is not easy to lose the target, and has timeliness.

7. Conclusion
In this paper, a multi-robot following system based on target recognition is designed. The target is identified and located by the robot camera, and the robot motion is precisely controlled by the set motion model and PID algorithm. Wi-Fi connection is used between robots to enhance the robustness of the multi-robot following system, and at the same time, the synergy of the robot system can be improved. The system is not easy to lose the target in the process of following the target, and can solve the problem efficiently in case of possible emergencies. It has strong adaptability to various environments, and has great practical application value and room for improvement.
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