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Design of Target Tracking System Based on Apriltag

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Abstract. In the research and development of target tracking, vision-based target tracking technology still has the problems of low accuracy and high cost. This paper designs a tracking system that uses a four-wheel differential mobile chassis as a carrier and uses the 36H11 series tags in Apriltag as a moving target. STM32F103 single-chip microcomputer is used as the core of motion control, and the classic PID control algorithm is used to adjust the wheel speed to achieve target tracking. STM32F765 single-chip microcomputer is used as the image processor of the OV7725 camera to solve the label information. The experimental results show that the Apriltag tag target can be better tracked when the PID parameters are adjusted properly. It can achieve near real-time tracking effect when the tag moving speed is slow, and it can move to the specified position quickly when it is far away from the target.

Keywords. Apriltag; Target tracking; PID algorithm;STM32 microcontroller

1. Introduction

The continuous development of target tracking technology has made it widely used in various fields. In the research of target tracking technology, vision-based target tracking technology has always been a popular research topics. Shafique used the point target tracking method and proposed a multi-frame method to maintain the current consistency of speed and position[1]. Omaniciu uses a target tracking method based on the idea of image segmentation, and proposes a mean-shift method to find clusters in the space where space intersects with color[2]. In order to improve the robustness of target detection and reduce the consumption of computing resources in 2011, the University of Michigan proposed a new visual benchmark system for 2D bar graphs, which combined with the fast edge detection system to form a more superior digital encoding system[3]. Based on previous research, this paper combines vision and mobile chassis to realize a target tracking system based on Apriltag. Through PID control algorithm, adjust the parameters to make it achieve the best tracking effect.

2. Experimental system construction

The experimental system adopts a four-wheel differential mobile chassis as the carrier,

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STM32F103ZET6 as the chassis control core, OV7725 camera as the vision sensor, and STM32F765VIT6 as the visual information processing chip. The TB6612FNG motor drive chip adjusts the speed of the motor. Powers the system with a 1500MAH, Li-Po battery. The block diagram of the target tracking system is shown in Figure 1. The physical map of the experimental system is shown in Figure 2. In Figure 2, a: visual image processing module; b: STM32F103 motion control core; c: motor drive module; d: power supply; e: wireless transmission module.

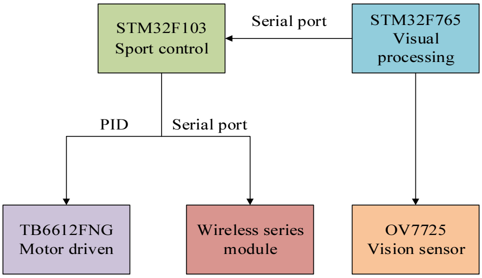

Figure 1. Block diagram of target tracking system.

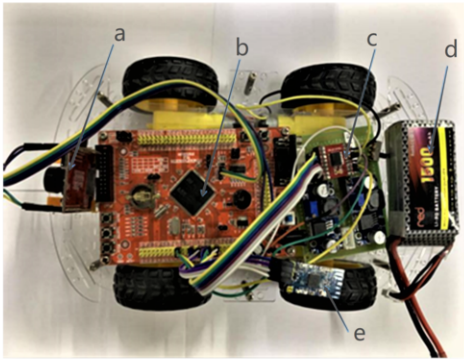

Figure 2. Physical map of the experimental system.

2.1. The working principle of the experimental system

The label is randomly placed on the ground, the camera on the car is used to find the label, and then the car is controlled to reach the specified position, and the relationship between the data obtained and the actual value is observed. Then move the tag in real time and experiment with the tracking function to see if it can track in real time. After the camera recognizes the label, the visual processing chip calculates the position of the label relative to the camera. At this time, the origin of the coordinate system is centered on the camera. Since the experimental platform uses a mobile chassis, it is only necessary to obtain the position information in Z and X directions, and the position information of the tag is sent to the motion control chip through the vision processing chip. The motion control algorithm of the mobile chassis uses the classic PID control algorithm. According to the actual debugging situation of the system, it is found that only PI control is needed to achieve a better control effect. The flow chart of the working principle of the experimental system is shown in Figure 3.

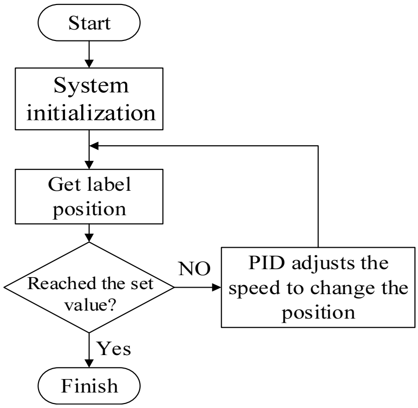

Figure 3. Working principle diagram of the experimental system.

3. Apriltag tag recognition

Label recognition is mainly divided into two steps of detection and decoding. The detection process is mainly divided into three parts (1) identifying line segments, (2) identifying quadrilaterals, (3) homography and external estimation. The decoding of tags is by calculating the relative coordinates of the tags of each bit field, using homography to convert them into image coordinates, and then thresholding the resulting pixels. In order to reduce the influence of light on the recognition effect, the intensity "black" pixel of the spatial variation model and the intensity "white" model of the second model were established in Apriltag [4]. The expression is shown in formula (1).

$$I(x,y) = Ax + Bxy + Cy + D \tag{1}$$

The parameters of the model can be solved through least square regression analysis, and the black and white models are calculated separately and the average value is used as the predicted intensity value. There are currently multiple families of Apriltag tags. The 36H11 family was selected for the experimental system, which has 586 family members, that is, 586 different tags. The larger the number after H, the more family members and the greater the density of the color block of the label. The larger the color block of the same size, the longer the detection distance, and the easier it is to lose the label information. The No. 1 label of the 36H11 family is shown in Figure 4.

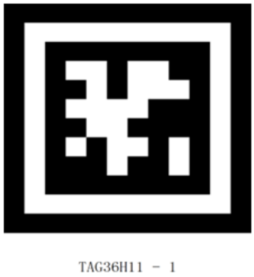

Figure 4. 36H11 family label No. 1.

In this article, Apriltag's recognition method is to import the library file in micopython into the STM32 microcontroller and directly call it to improve the real-time performance of recognition. The Apriltag image taken by the camera is shown in Figure 5.

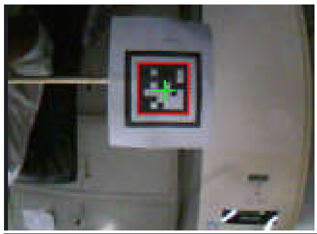

Figure 5. Apriltag image taken by the camera.

3.1. Camera coordinate system transformation

The coordinate origin of the identified position information is the camera, if the position information of the image coordinate system needs to be multiplied by the rotation matrix R. Optionally set a point t in the image to correspond to the camera down vector and the image coordinate system down vector (t1,t2,t3), (t_1', t_2', t_3')T respectively.

The transformation relationship:

$$\begin{pmatrix} t_1' \\ t_2' \\ t_3' \end{pmatrix} = R \begin{pmatrix} t_1 \\ t_2 \\ t_3 \end{pmatrix} + P \tag{2}$$

Where P is the translation amount of coordinate transformation.

4. Application of PID Control Algorithm in Target Tracking System

The PID control algorithm is a classic control algorithm. Although there are many new optimized control algorithms, its essence is the adjustment of proportional or integral derivative. There are two types of PID control algorithms: positional and incremental. Position control will produce a large cumulative error in the control of the motor. In this experimental system, an incremental PI controller is used, making it only related to the errors of the last three times. The PI control model block diagram is shown in Figure 5.

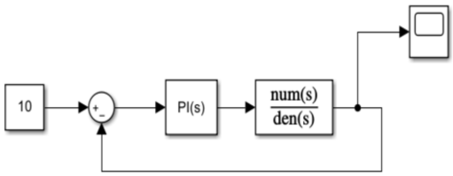

Figure 6. Block diagram of PI control model.

4.1. Mathematical Model of PID Control Algorithm for DC Motor

According to the principle of automatic control and the parameters of the motor, the transfer function of the DC motor can be calculated to establish the mathematical model of PID control through the matlab simulink module. 130 DC motor parameters are shown in Table 1. The speed transfer function of the DC motor is shown in equation (3).

Table 1. 130 DC motor parameters

The main parameters	Value
Rated torque	6.31g·cm
Rated power	0.75W
Rated voltage	3V
Rated speed	8530r/min
Reduction ratio	48:1
Armature inductance	4.9mH
Armature resistance	1.1Ω

Find the transfer function when the motor is running as:

$$G(s) = \frac{K_T}{L_\alpha J s^2 + (L_\alpha B + R_e J)s + K_e K_T + R_\alpha B} \tag{3}$$

Where *KT*: Torque constant; *Lα*: Armature inductance; *J*: Moment of inertia; *Rα*: Armature resistance: *Ke*: Back EMF coefficient; *B*: Viscous damping coefficient.

By calculation:

$$G(s) = \frac{0.05}{3.16 \times 10^{-9} s^2 + 7.25 \times 10^{-6} s + 2.8 \times 10^{-3}} \tag{4}$$

Substitute the obtained transfer function results into the Simulink simulation model, and adjust the PI parameters to obtain the control effect as shown in Figure 6.

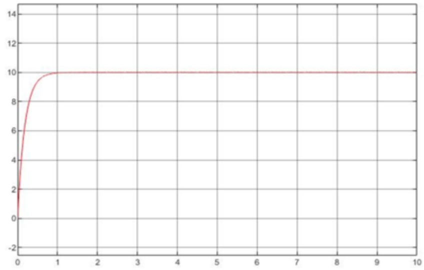

Figure 7. PI control effect diagram.

5. Analysis of results

5.1. Distance calibration error analysis

The calculated position information data is not the real distance. If the real position information is obtained, it needs to be calibrated. Place the labels at different distances to obtain multiple sets of measured values at different distances, average the measured values at different distances, and finally perform curve fitting to obtain the fitting curve between the true value and the measured value as shown in Figure 7. It can be seen from the curve that there is a linear relationship between the real value and the measured value and the fitting effect is better. The fitting equation is shown in equation (5).

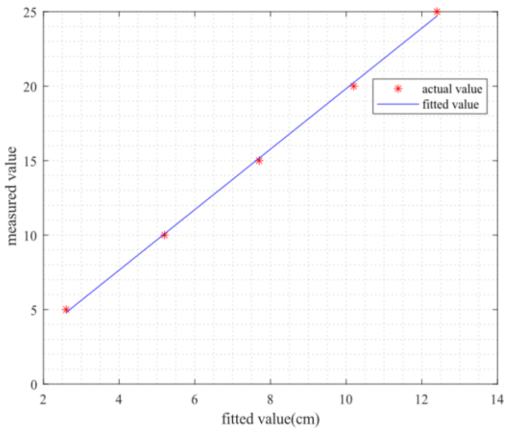

Figure 8. Fitting curve of z-axis true value and measured value.

$$y = 2.031x - 0.475 \tag{5}$$

5.2. Dynamic tracking experiment analysis

The experiment process is divided into three stages. The label is quickly moved to a position about 10 cm away from the lens, then slowly moved for 5 seconds, and finally moved quickly for a certain distance and then stopped. Figure 8 shows the tracking curve of the mobile platform dynamically tracking Apriltag tags. The time period of 0-3 seconds is the fast moving stage, and 3-8 seconds is the uniform moving stage. The label stops moving at 11 seconds. The last point and the first point in the figure are basically in a straight line, that is, the distance between the label and the camera. The distance is the same. The fitting curve expression is shown in formula (6).

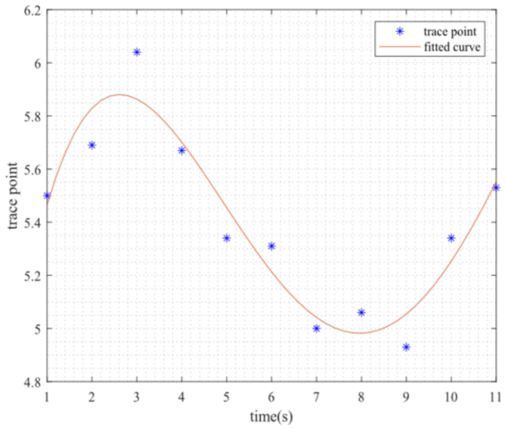

Figure 9. Dynamic tracking curve.

$$y = -0.001x^4 + 0.032x^3 - 0.335x^2 + 1.160x + 4.608 \tag{6}$$

The camera distance tag measurement value set in the experiment program is 5.5, and the measurement value in the dynamic tracking process is subtracted from 5.5 to get the dynamic tracking error. The error value recorded in Table 2 at 10 seconds from the initial state of 0 to the final state error back to 0.03, it can be seen that the dynamic response of moving the site in the process of fast moving the tag is better. The tracking stability is better at a constant speed.

Table 2. Dynamic error value

Time	1	2	3	4	5	6	7	8	9	10
Error	0	0.19	0.54	0.17	-0.16	-0.19	-0.5	-0.44	-0.16	0.03

6. Summary and outlook

This article mainly uses Apriltag visual positioning and tracking algorithm to realize the tracking of tags, and uses the mobile chassis as the carrier to realize the function of target tracking. The mathematical model of the PID transfer function of the experimental platform is established, which is convenient to quickly adjust the PID parameters. The experimental results show that the use of Apriltag algorithm for target tracking has the advantages of strong robustness and good dynamic response, and has wide applicability in the future of moving target tracking. There are many tags in the Apriltag family, which can be used in robot formations, which not only reduces the hardware pressure of mutual communication, but also greatly improves the anti-interference ability. Of course, if you are in an environment with poor visibility or foggy weather, it will affect the accuracy of tag identification.

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