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Realization of the Airborne System for Moving Target Detection and Tracking Based on Quadrotor

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Abstract. In this paper, taking quadrotor as the research object, a kind of airborne vision system is presented to detect and track the moving target. Lower cost and better performance are the remarkable characteristics of the system. Firstly, the overall scheme of the detection and tracking system is designed. Secondly, a new image detection algorithm based on HSV color model and template matching is proposed, then according to image principle, the relative distance from quadrotor to target is calculated. In order to solve the time delay caused by image processing, the target position prediction is made by adding Kalman filter. Then, according to the position information of quadrotor and target, a segmented PID controller is designed to improve the tracking effect. Finally, the algorithm is applied to the actual flight of the quadrotor to verify its feasibility.

1. Introduction (Heading 1)

Moving target detection is to extract the specific moving target from the video sequences. Moving target tracking is a continuous tracking of moving target under the premise of detecting the target. And then we can describe the characteristics of its motion trajectory, position, speed and so on. The moving target detection algorithm mainly includes optical flow method, frame difference method and background subtraction method. Optical flow method is the most complex algorithm and has longer operation time. In practical application, because of the complexity of the scene, the optical flow is not accurate and not suitable for real-time processing. The frame difference method can only represent the relative position change of moving objects in two adjacent frames, cannot obtain the exact shape and is insensitive to the slowly moving objects. Background subtraction method is very dependent on the modeling of the background image, but the modeling is often complex [1-3]. The detection and tracking of moving target is studied by literature [4] and [5]. However, it is still in the simulation phase and is not implemented in the project. Therefore, it is significant to design a set of efficient and stable system, which is easily applied to engineering.

In this paper, taking quadrotor as the research object, a set of airborne system for moving target detection and tracking based on vision is designed. All the processing is done on the quadrotor, which can effectively avoid the interference and time delay of information transmission. Finally, through flight experiments, it is proved that the system has good real-time performance and stability. And that, this system has good practicability.

2. Overall design

Figure 1 shows the working principle diagram of the visual system. This system mainly consists of two parts. One part is the detection and tracking system based on vision. The video image is collected by the camera, and then the image is processed by the industrial control board. The other part is the quadrotor attitude control. The quadrotor patrols in the field looking for the moving object at a certain height. After detecting the target through image processing, the relative distance of the center of the target and quadrotor is calculated by industrial control board. Location information is sent to the flight control system through serial port. And then, the flight attitudes are controlled through a segmented PID controller, so as to keep the quadrotor right above the moving target to realize stable tracking. Through the wireless data transmission, the flight attitudes and tracking effect of the quadrotor can be observed in real time on the mission planner.

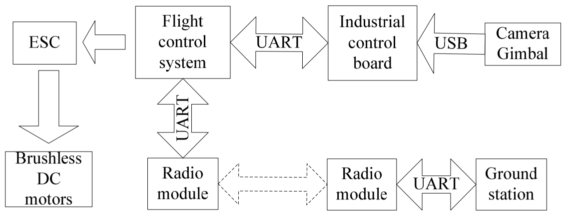

Fig. 1 Hardware structure

3. Target detection

3.1. HSV model

RGB (red, green, blue) model is a spatial model based on the color of human eye identification. In this model, hue, brightness and saturation are put together and it is difficult to carry out digital adjustment. HSV model is described by color, depth and light. H refers to the hue, which ranges from 0° to 360°. It starts from the red color by the counter clockwise direction. 0° represents red, 120° represents green and 240° represents blue. S is the saturation. The value ranges from 0.0 to 1.0, and the value is bigger, the color is deeper. V means value, representing the brightness of the color, ranging from 0 (black) to 255 (white) [6], as shown in figure 2. HSV model has less influence by light and is more stable.

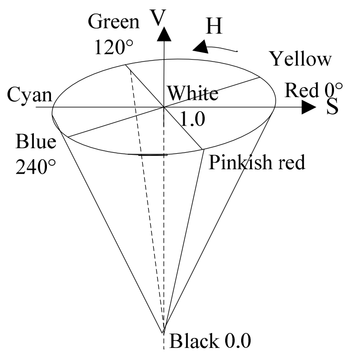

Fig. 2 HSV model

Assume that r,g,b is the RGB coordinates of a color, max=max{r,g,b}, min=min{r,g,b}. The conversion formulas are described as

$$h = \begin{cases} 0^\circ, & \max = \min \\ 60^\circ \times \dfrac{g-b}{\max - \min} + 0^\circ, & \max = r \; and \; g \geq b \\ 60^\circ \times \dfrac{g-b}{\max - \min} + 360^\circ, & \max = r \; and \; g < b \\ 60^\circ \times \dfrac{b-r}{\max - \min} + 120^\circ, & \max = g \\ 60^\circ \times \dfrac{r-g}{\max - \min} + 240^\circ, & \max = b \end{cases} \tag{1}$$

$$s = \begin{cases} 0, & \max = 0 \\ \dfrac{\max - \min}{\max}, & otherwise \end{cases} \tag{2}$$

$$v = \max \tag{3}$$

3.2. Detection algorithm
In this paper, the moving object is shown in figure 3. The characteristic pattern is red convex type.

Fig. 3 FiMoving target

The video images captured by the camera are in the RGB color space. Direct color separation can achieve the purpose of identification of moving objects, but the illumination condition has a great impact on the detection results and the robustness is poor. Therefore, a color feature extraction based on HSV color space is proposed, which has stronger stability.

First of all, because of the wide-angle camera, the video image is distorted, so the video image should be corrected. Secondly, the video image should do model transformation. RGB images are converted to HSV space, using h, s, and v to describe the image. Then, the value of h, s components are limitted according to the target color. Because the target color and background color have great difference, for better recognition of the target, the selected range is wide by threshold adjustment, $h \in (0,40), s \in (0.6,1)$. Finally, through the Hu moment matching [7], the pattern of the target is detected. The criteria is shown in the following formula [8]

$$I(A,B) = \sum_{i=1}^{7} \left| m_i^A - m_i^B \right| \tag{4}$$

Where, A and B are the two contours needed to be matched. m_i^A And m_i^B are defined as

$$m_i^A = sign(h_i^A \cdot \log\left|h_i^A\right|) \tag{5}$$

$$m_i^B = sign(h_i^B \cdot \log\left|h_i^B\right|) \tag{6}$$

h_i^A And h_i^B respectively represent the Hu matrix of A and B.

Fig. 4 640*480 resolution

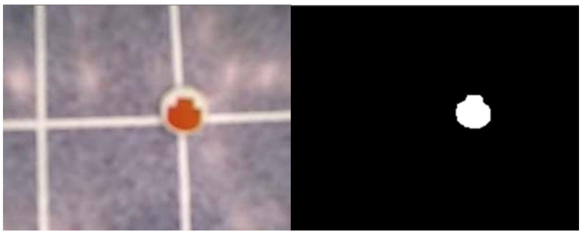

Fig. 5 320*240 resolution

Processing results are shown in figure 4 and figure 5. The two figures are performed under different fields, light and resolutions. The resolution in figure 4 is 640*480, the image is clear and the reflection is weak. The image quality is obviously better. And the resolution of figure 5 is 320*240, the image is blur and reflection phenomenon is serious. However, the processing results of the images are not affected by the quality of the images. Processing results are equally outstanding. Moreover, even if in the higher resolution the processing time of each frame is also under 30ms, the real-time performance is guaranteed.

From this, it is proved that the algorithm of target detection has strong stability.

3.3. Target location

After target detection, the relative distance from target to quadrotor should be calculated to control the quadrotor tracking the target.

In order to ensure the video images collected by the camera are not affected by the quadrotor flight attitude, the camera is indirectly connected with the quadrotor, using a cradle head with two axes. When quadrotor does rolling and pitching motion, the camera does not change orientation with the quadrotor attitude change. That means the camera always faces to the ground. Once the target is detected, the accurate target location is calculated according to the image information and other external information [9] after the camera calibration, the coverage of camera at a fixed height is measured. The image proportion in x_b direction of body axis system is $\tan\alpha$ and in y_b direction is $\tan\beta$, shown as figure 6. When the distance from camera to ground is h, the size of picture captured by camera is:

$$\begin{aligned} x_b &= 2h \cdot \tan\alpha \\ y_b &= 2h \cdot \tan\beta \end{aligned} \tag{7}$$

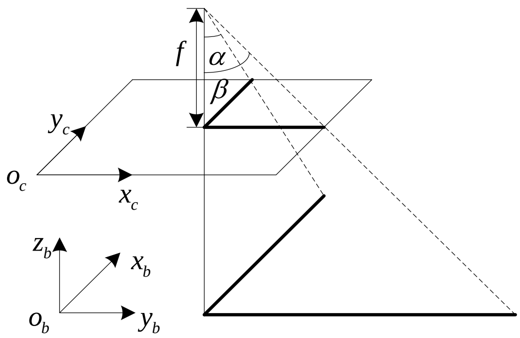

Fig. 6 Position calculation

It is assumed that the center coordinates of target is (x_c, y_c).The size of the image is 640*480, so the actual relative distance from target to camera in body axis system is shown as following formulas:

$$\begin{aligned} d_x &= x_b \cdot \frac{y_c - 240}{480} \\ d_y &= y_b \cdot \frac{x_c - 320}{640} \end{aligned} \tag{8}$$

Because there is a certain delay in image acquisition and processing, the output is lagging behind the actual position. Therefore, the prediction of the target must be carried out [10].

3.4. *Kalman filter prediction*

In this paper, the Kalman filter algorithm is used to smooth and predict the position of the target for better tracking performance. Kalman filter is a recursive process with the advantage of short execution time, so it can meet the requirements of real-time tracking.

The target does uniform rectilinear motion, so the system can be described by a linear stochastic difference equation [9, 10]:

$$X(t) = AX(t-1) + BU(t) + W(t) \tag{9}$$

The measured value of the system is expressed as

$$Z(t) = HX(t) + V(t) \tag{10}$$

Where, A and B represent system parameters. H means measurement parameter of the system. $W(t)$ Represents the process noise with covariance matrix Q, and $V(t)$ represents the measurement noise with covariance matrix R. They are both assumed to be the Gauss white noise.

The calculation procedure of Kalman filter is shown as the following description.

Use the process model of system to predict the next state of the system:

$$X(t\,|\,t-1) = AX(t-1\,|\,t-1) + BU(t) \tag{11}$$

Update the covariance of the predicted value $X(t\,|\,t-1)$:

$$P(t\,|\,t-1) = AP(t-1\,|\,t-1)A^T + Q \tag{12}$$

Calculate the optimal estimate value $X(t \mid t)$ of the t moment:

$$X(t|t) = X(t|t-1) + K(t)(Z(t) - HX(t|t-1)) \tag{13}$$

Calculate Kalman gain:

$$K(t) = P(t|t-1)H^T / (HP(t|t-1)H^T + R) \tag{14}$$

Update the covariance of the optimal estimate value $X(t \mid t)$ of the t moment:

$$P(t|t) = (I - K(t)H)P(t|t-1) \tag{15}$$

The state vector and the measurement vector in this paper are respectively expressed as $X = [x \ y \ \dot{x} \ \dot{y}]^T$ and $Z = [x \ y]^T$, and the state transition matrix and measurement matrix are respectively expressed as:

$$A = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \ H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{16}$$

There is no control variables, so matrix B is not taken into consideration.

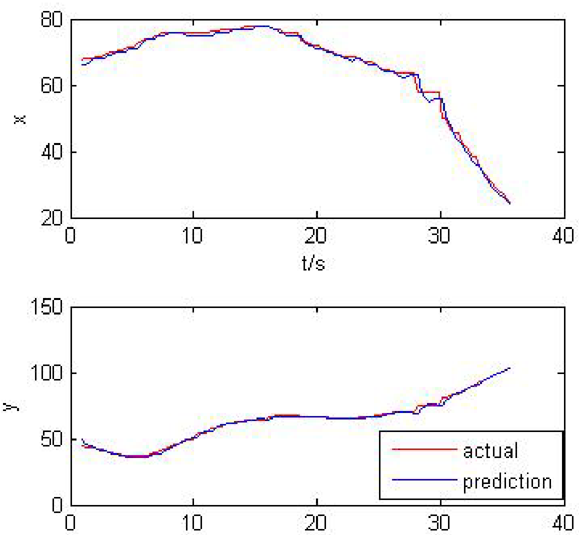

Fig. 7 Predicted and actual curve

According to the above formulas, the initial parameter values and the target position information extracted from each frame, the position of the target can be predicted. The predicted target motion curve is compared with the actual target motion curve as shown in figure 7. From the graph, we can see that the curves are basically anastomotic. The predicted position is well to meet the real-time requirnment.

4. Attitude controller

The position information of target and quadrotor are obtained, then quadrotor can be controlled to tracking the target.

In the process of moving target tracking of quadrotor, PID controller is adequate for this specific attitude control. When the target is not detected, the quadrotor flies in a certain height and looks for the target. The control law of altitude hold is designed as

$$\Delta\delta_h = k_{hp}\Delta e_h + k_{hi}\int \Delta e_h + k_{hd}\Delta e_{\dot{h}} \tag{17}$$

Where, $\Delta\delta_h$ is the controlled variable of altitude. Δe_h And $\Delta e_{\dot{h}}$ are the altitude error and the error of the change rate of altitude. k_{hp} , k_{hi} and k_{hd} are the control parameters.

When the moving target is detected, the quadrotor should keep flying right above the target through PID control. The tracking error can get from the relative position information of quadrotor and target. In this paper, the control law design in x direction is taken as an example to describe in detail, the control in y direction is basically the same.

The tracking control law in x direction is shown as the following:

$$\begin{cases} \Delta\delta_\theta = \\ k_{xp}\Delta e_x + k_{xi}\int \Delta e_x + k_{xd}\Delta e'_x + k'_{xp}u, & |\Delta e_x| \le 50cm \\ \Delta\delta_\theta = k_{xp}\Delta e_x + k_{xd}\Delta e'_x + k'_{xp}u, & |\Delta e_x| > 50cm \end{cases} \tag{18}$$

Where, Δe_x is the difference value between desirable and actual relative position in x direction. $\Delta\delta_\theta$ Is the controlled variable in x direction. $\Delta e'_x$ Is the change rate of Δe_x . k_{xp}, k_{xi} , k_{xd} and k'_{xp} are the control parameters. U is the velocity in x direction.

The control structure in x direction is shown in figure 8. Quadrotor constantly adjusts attitudes to reduce the position error, so as to achieve the tracking of moving targets.

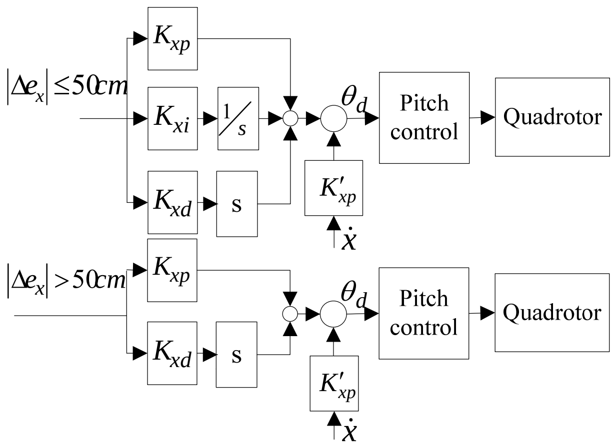

Fig. 8 Control structure of quadrotor in x direction

If the Δe_x meets the condition $|\Delta e_x \le 50cm|$, PID controller is used to improve tracking accuracy. If $|\Delta e_x|$ is more than 50cm, PD controller is used to reduce overshoot and adjustment time, so that tracking error can be reduced quickly. Target tracking of quadrotor is more accurate and stable.

5. Experiment and analysis

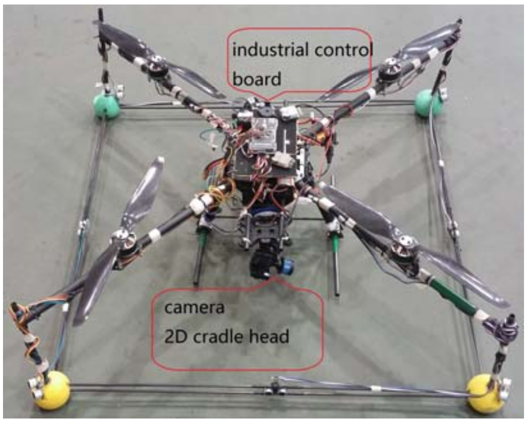

Fig. 9 The quadrotor

The quadrotor in figure 9 is the quadrotor used in actual flight. Image processor has 2.5 inch industrial motherboard, with the type 2I268HW, CPU using Intel Cedar view-M N2600. The gimbal that we choose is a two-axis cradle head of TAROT. 120° wide-angle camera is used to capture image, the maximum resolution of which is 1280*720. An open source flight control board pixhawk [13] is select as the flight control system. The total price of the quadrotor is no more than 7000 RMB.

Figure 10 shows the distance between the quadrotor and the moving target in the X axis direction and figure 11 shows the distance in the Y axis direction. The response time is about 5s. After tracking stability, the error is about 30cm. We can see that the quadrotor has been flying above the moving target and tracking effect is good. So it can be concluded that the algorithm is feasible.

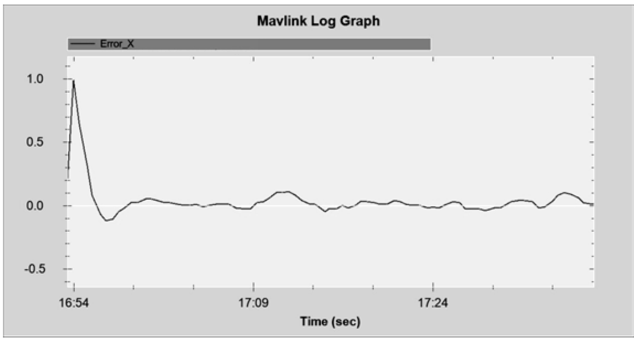

Fig. 10 Distance error in X axis

Fig. 1.

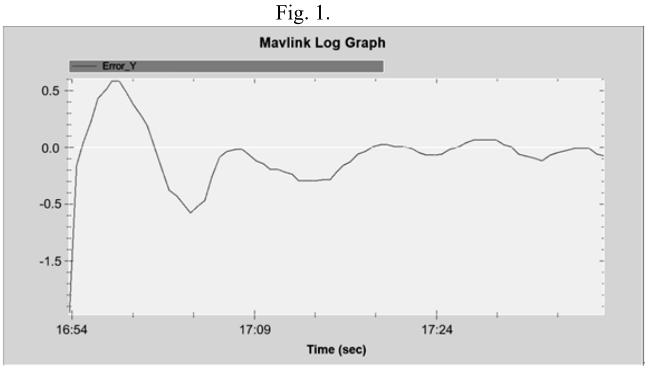

Fig. 11 Distance error in Y axis

6. Conclusion

In this paper, a new image processing algorithm based on color identification and template matching combining with Kalman filter prediction is presented. The algorithm has the advantages of quick detection and high accuracy. The segmented PID controller is designed to improve the tracking accuracy. Finally, through experimental verification, the feasibility of the scheme is proved. All the data processing is completed on the airborne equipment, which can solve the problems caused by data transmission such as unstable communication signals and time delay. Meanwhile, the low cost, fast processing speed and good performance are the great features of this system. The biggest advantage of the airborne system in this paper is that it has a strong engineering practicability.

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