Research on spherical localization and prediction based on real-time vision

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Abstract: In order to meet the real-time and precision requirements of visual feedback in robot control system, a real-time target tracking method based on Kalman filter prediction was proposed.This method uses the binocular vision system fixing the ball. , this method can predict the position of the moving target, define target search scope, and decrease the output noise, so as to improve the tracking speed and accuracy.The experimental results show that compared with particle filter and the original Kalman filter, this method is basically meet the real-time and accuracy requirements of visual control by using predicted value and close-loop control.

Keywords: real-time visual positioning, Extended Kalman filter, Track prediction

1. Introduction

In recent years, moving target tracking and recognition has been widely used in its branch fields. Especially in the case of high-speed movement of the target, how to achieve tracking and trajectory prediction of the moving target [1] has become an important research topic.

Due to strong recovery and low cost of Ping-pong Sports, the research results are representative and can be migrated to other fields.Reliable tracking and positioning, trajectory prediction and other problems of fast sport table tennis have covered visual perception and intelligent control, which is not only a key problem in the field of robot research, but also an urgent problem to be solved in the military and industrial fields. In the military aspect, because of the characteristics of concealment, accuracy and anti-interference required by precision attack weapons, the current video tracking technology has been widely used in infrared, television, monitoring and other tracking systems[2]. In medicine, video tracking technology is applied in automatic analysis of ultrasonic and nuclear magnetic sequence images, providing accurate diagnostic information for doctors through real-time dynamic analysis[3]. The vision tracking localization and trajectory prediction of high-speed moving objects have broad application prospects and great significance.

At present, there are many methods based on motion position prediction for real-time tracking of table tennis trajectory, such as least square fitting[4],particle filter[5] and α-β filtering[6], which can predict the motion trend of the target object by using its past motion state to achieve advance control[7].Some of these methods are difficult to meet the real-time requirements due to the large amount of computation, and some can meet the real-time requirements by reducing the calculation time, but their average prediction error still needs to be improved.

Kalman trajectory tracking algorithm based on adaptive measurement covariance is presented in this paper. Introducing the idea of dynamic adjustment parameters, the method use extend Kalman filter to predict trend of small ball movement, then predicted position of moving object can be obtained. Combined with historical accuracy, the search scope of the target can be restricted to reduce the image search area, extract the moving object's actual location information rapidly and accurately, basically meet the real-time demand of motion control system with higher precision.

2. Target positioning and prediction algorithms

According to the different cameras used, the Ping Pong tracking system can be roughly divided into several types: monocular, binocular, and multi-purpose vision systems.Because the positioning of monocular vision is easily interfered by the element of "table tennis shadow", it is difficult to overcome

by algorithms, and the positioning accuracy and stability of the vision system cannot always be guaranteed during the continuous hitting process.

Therefore, we intend to explore the precise positioning of the target through the binocular vision system, and use the Kalman filter derivative formula to accurately extract the position information of the ball motion trajectory, so as to achieve high precision, relatively good stability, and strong real-time target trajectory prediction.

2.1. The principle of binocular vision

"Binocular vision" applied to ball positioning uses two digital cameras, left and right, to shoot the flying ball target at the same time, and calculates the three-dimensional coordinates in the world coordinate system according to the two-dimensional information of the ping-pong ball imaging in the left view and the right view[8]. Since binocular vision does not need to rely on the element of table tennis's shadow, the requirements of the scene tend to be more loose, and the applicable scope wider. In binocular vision system, two cameras are arranged symmetrically to look down on the target, but the intersection of optical axes of the two cameras is not required.
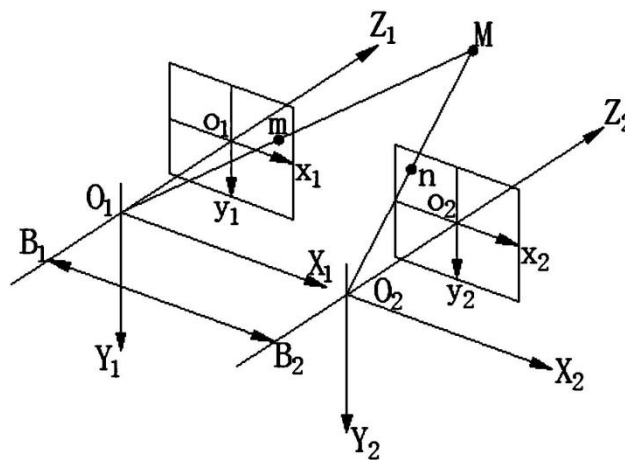

Figure 1: Schematic representation of binocular vision

The step of binocular visual positioning of table tennis is roughly divided into the following steps[9]:

1) Binocular visual calibration: the left and right two cameras are calibration respectively

2) 2D target identification: In the images of left and right cameras, the target identifications of "table tennis area" are conducted to obtain the 2D target position under the left and right image coordinates, recorded as $pl(u_1, v_1)$, $p2(u_2, w_2)$ respectively

3) 3D target positioning: According to triangulation and positioning theory, the coordinate $P(x_w, y_w, z_w)$ of table tennis in the 3D world coordinate system can be calculated by p1 and p2 to complete the positioning of binocular vision on the spatial location of table tennis.

Therefore, this paper will first introduce the method of binocular vision calibration, then describe the method of two-dimensional image collection and table tennis target recognition, and finally analyze the positioning method and trajectory prediction method of three-dimensional information calculated from two-dimensional information.

2.2. Expand the principle of Kalman filter tracking small ball

The Kalman filtering algorithm belongs to the state space-like recursive method[10], which has two types of models: One is observation model, which reflects the relationship between state variables and the actual observation quantity; the other is update model, presenting the change law[11] of the system state with the equation of state.The optimal estimation of the system is finally achieved through these two major models.The following formulations present the working principle[12] of Kalman filtering:

Predictive equations for state vectors:

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

The state vector covariance prediction matrix:

$$P(k|k-1) = AP(k-1|k-1)A + Q \tag{2}$$

The state vector update equation:

$$X(k|k) = X(k|k-1) + Kg(k)(Z(k) - HX(k|k-1)) \tag{3}$$

The Kalman filter gain function:

$$Kg(k) = P(k|k-1)H'/(HP(k|k-1)H' + R) \tag{4}$$

Covariance of the state vector update equation:

$$P(k|k) = (I - Kg(k)H)P(k|k-1) \tag{5}$$

Based on the kinetic modeling of the small ball, the x,y,z-axis equations of motion can be expressed as following:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix}a_x \tag{6}$$

$$\begin{bmatrix} \dot{y}_1 \\ \dot{y}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix}a_y \tag{7}$$

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} - \begin{bmatrix} 0 \\ g \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix}a_z \tag{8}$$

The image coordinates can be changed into 3D spatial coordinates through the state transfer matrix

$$\Phi(t,\tau) = e^{\Delta t} = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} \tag{9}$$

Since the measured covariance has an important influence on the final output of the filter, the larger the measured covariance is, the more unreliable the measured value is, and the output of the filter is more dependent on the state equation of the system itself. Otherwise, the smaller the measured covariance is, the more dependent the output of the filter is on the actual measured result. Therefore, the covariance formula of dynamic correction variable is introduced:

$$R_k = f(d_k) \tag{10}$$

d_k represents the distance between table tennis and binocular cameras in 3D at moment k, as defined as follows:

$$d_k = \sqrt{(x_k - x_c)^2 + (y_k - y_c)^2 + (z_k - z_c)^2} \tag{11}$$

x_k,y_k,z_k represents the coordinate measurements of the 3D coordinate system, and x_c,y_c,z_c represents the midpoint position of the two center connections between the left and right cameras. The value range and increasing process of the function are determined from the actual camera calibration results. Generally, in the tracking initial stage, a smaller R_k value is set to increase fast following performance. Then the fan size is gradually increased to improve the stationarity of the Kalman filter output.

3. Experimentation

3.1. The working process of Kalman filter

The extended Kalman filter algorithm is introduced to track and locate the small ball in real time, and the flow is shown in Figure 2.
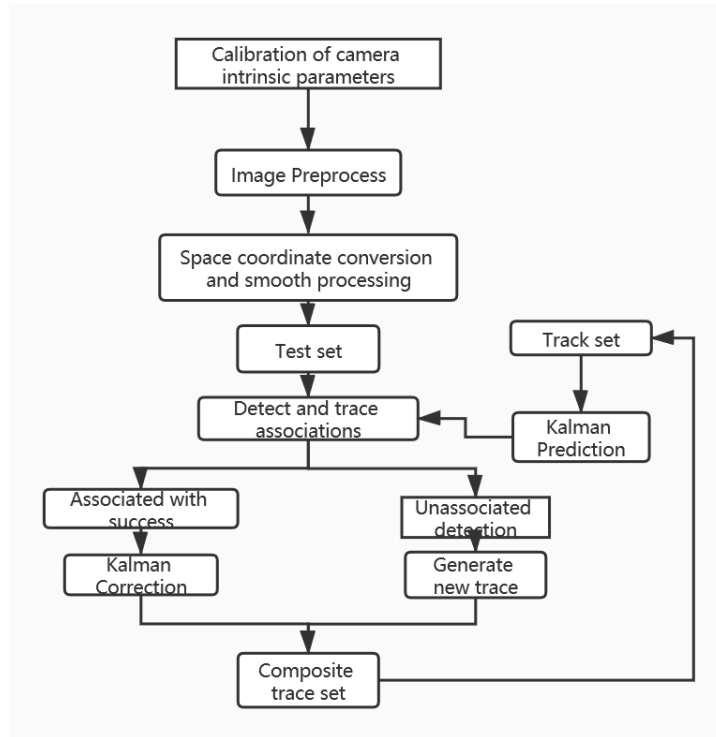
Figure 2: Flow chart of the Extended Kalman filter algorithm

Figure 3 shows the tracking results of the speed of table tennis movement in the x-axis and z-axis of the three-dimensional world coordinate system, in which the solid line represents the output result of the filter, and the circle represents the speed result after differential directly according to the position information obtained from sampling
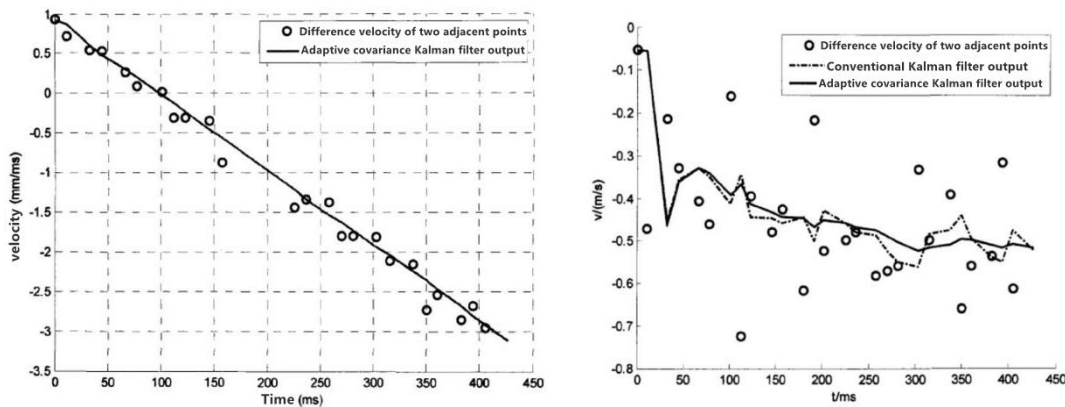

Figure 3: x,z-axis direction speed tracking results

The initial tracking stage of the filter solid line and the dotted line of the conventional filter are set with relatively small measurement covariance, so there is almost no significant difference in the output of the filter However, with the passage of time, the measurement covariance of the adaptive covariance filter gradually increases, and its tracking results tend to be stable, while the output noise of the general Kalman filter is always large and does not converge.

3.2. Interpretation of result

Figure 4 shows the target images of frames 1,22,48 and 72, respectively. The black point is the predicted position of the corresponding moment, and the black circle is the search area, the region of interest. It is seen from the Figure that after the prediction calculation, the search area is reduced to only a small area containing the target, up to 1 / 5 of the full motion area, thus ensuring the speed of the target location information extraction.

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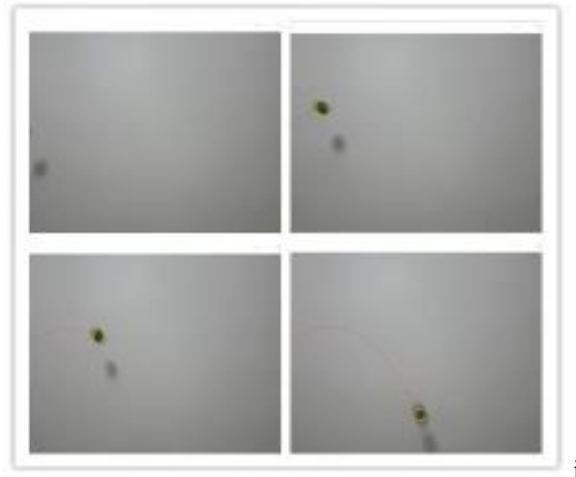
Figure 4: The target image under the prediction-based tracking method

The Gaussian filter and small ball position extraction time is less than 10 ms, prediction algorithm calculation time is 7 ms,so the image processing speed can reach 50 frames / s. Under the guarantee of the image acquisition speed of 50 frames/SEC of the high-speed image acquisition card, the motion control system controls the Angle of the platform at a rate of 50 Hz to eliminate the influence of mechanical clearance ball sliding and external interference and make the ball locate at the target position, enabling the small ball positioning at the target position. Compared with the full-motion region target search method, the predictive target tracking method can improve the real-time performance of visual feedback, and make the ball reach a stable state in about 3 seconds, and the ball can quickly return to the desired position under the condition of artificial interference in 5 seconds.

Table 1: Comparison of the performance of the prediction algorithms

	Particle filtering	Kalman filtering	Expand the Kalman filtering
Mean calculation time/ms	131.996	38.127	39.146
Average prediction error / pixel	4.132	6.564	4.538

It can be concluded from the experiment that when the movement area of the tracked object is large, the prediction operation time is far less than the saved image processing and search time. In this case, the advantages of fast target tracking method based on extended Kalman filter are particularly prominent. Kalman filter and particle filter can also track the target object well, but the above two algorithms have obvious defects. When the frame frequency is 50 Hz, frame loss will inevitably occur. While the extended Kalman filter can better eliminate the noise, make up for the lost key frames and ensure that the calculation time of predictive control is less than the image acquisition period through adaptive smoothing processing. Therefore, the whole motion control system is basically in real-time closed-loop control.

4. Conclusion

In this paper, a real-time tracking and prediction algorithm based on Kalman filter is proposed to extract the position information of moving target quickly and accurately by reducing the search space in the image of the whole moving region. Experimental results show that compared with the existing regional target search method, this method not only meets the accuracy requirement of fast visual feedback of motion control system, but also can basically meet the real-time requirement of target tracking.

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