Acta Technica *62* No. 3A/2017, 173–180

Research on the trajectory tracking technique of table tennis servo machine

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Abstract. At present, the robot visual trajectory tracking algorithm can be divided into two categories: One is based on the template matching algorithm, such as histogram matching and background Gaussian estimation; the other is based on the kinematics model trajectory tracking method, such as particle filter, Kalman filter algorithm and so on. However, there are still many difficulties in the actual real-time trajectory tracking, such as the high speed of the table tennis to make the image blurred, the ball in the flight itself by the air resistance, and camera imaging distortion and other factors. It directly leads to the measurement results deviate from the real motion trajectory. On this basis, this paper presents a discrete Kalman filter estimation algorithm for adaptive measurement of covariance. In the different stages of trajectory tracking, the size of the covariance is dynamically adjusted, which not only ensures the fastness and convergence of the initial phase tracking, but also realizes the real-time and stability requirements. Finally, we carry out the experimental test, and the experimental results verify that the tracking algorithm has a good tracking effect.

Key words. Table tennis dispenser, regression tracking, Kalman filter, measurement covariance.

1. Introduction

In recent years, a novel ping pong robot has gradually become one of the research hot spots by reason of its difficulty and challenge in both real-time and intelligent design [1]. Therefore, for the robots, a high efficient vision system with real-time and adaptability for the environment is the base of the whole robot system. Visual tracking is one of the most important topics in computer vision and artificial intelligence [2]. In the target tracking system, the integration of airborne visual system and navigation is used to locate the moving target in real time [3]. Particle filter can model accurately in non-linear non-Gaussian system, and be widely used in object

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tracking [4]. Along with rapid descending of computation cost, particle filter algorithm gradually becomes the mainstream [5]. At present, the robot visual trajectory tracking algorithm can be divided into two categories: One is based on the template matching algorithm, such as histogram matching, background Gaussian estimation and so on; the other is based on the kinematics model trajectory tracking method, such as particle filter, Kalman filter algorithm and so on. However, there are still many difficulties in the actual real-time trajectory tracking, such as the high speed of the table tennis to make the image blurred, the ball in the flight itself by the air resistance, and camera imaging distortion and other factors, which directly leads to the measurement results deviate from the real motion trajectory [6]. On this basis, this paper presents a discrete Kalman filter estimation algorithm for adaptive measurement of covariance. In the different stages of trajectory tracking, the size of the covariance is dynamically adjusted, which not only ensures the fastness and convergence of the initial phase tracking, but also realizes the real-time and stability requirements. Finally, we carry out the experimental test, and the experimental results verify that the tracking algorithm has a good tracking effect.

2. Methods

2.1. Modeling and discretization of table tennis movement

In the study of statistics and modern target tracking theory, based on time series analysis, people have proposed hidden Markov model. In this section, we introduce the basic principle of the hidden Markov model and the Kalman filtering method.

The object of this paper is the flight trajectory of table tennis in the air. In theory, the flight trajectory of table tennis is the continuous motion equation of time and space coordinates. That is

$$\begin{aligned} x &= x(t), \\ y &= y(t), \\ z &= z(t). \end{aligned} \tag{1}$$

After tracking the position and velocity of the moving object, the literature [7] gives an algorithm to predict the placement and bounce trajectory of table tennis. Take the x-axis direction as an example, as shown in Fig. 1, the definition of two-dimensional vector is $\boldsymbol{x} = [x, \dot{x}]^{\mathrm{T}}$, respectively, on behalf of the table tennis on the x-axis position and speed.

The continuous state equation of table tennis is described as (note that subscripts are different variables here, not time series labels)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} \cdot a_x . \tag{2}$$

When ignoring the ideal situation of interference, table tennis in the x-axis direction to do uniform motion, obviously deterministic input $u = 0$.

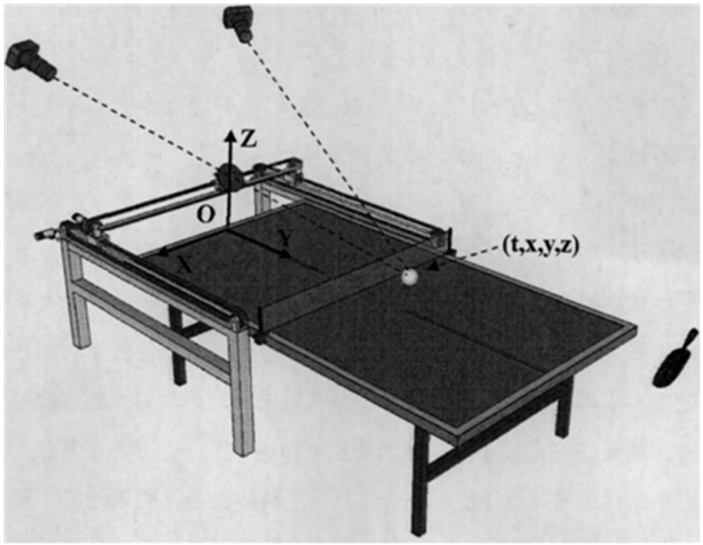

Fig. 1. A three - dimensional coordinate system of table tennis servo machine

2.2. Trajectory tracking algorithm for adaptive measurement covariance

For the elimination of noise in high-speed motion tracking, there are a lot of filtering algorithms. However, a considerable number of algorithms are using frequency domain feature filtering method. From the time domain to the frequency domain, it needs a large amount of computation and it is difficult to guarantee the real-time performance. Therefore, this paper uses a direct time domain filtering method, namely, the discrete Kalman filter.

The algorithm introduces a dynamically modified measurement covariance formula $R_k = f(d_k)$. Here, d_k represents the k-th moment, that is the distance between table tennis and binocular cameras in three-dimensional space. It is defined as follows:

$$d_k = \sqrt{(x_k - x_c)^2 + (y_k - y_c)^2 + (z_k - z_c)^2}\,. \tag{3}$$

In the above formula, x_k, y_k, z_k represent the coordinates of the three-dimensional world coordinate system of the ball, x_c, y_c, z_c represents the coordinates of the midpoint of two optical centers of the left and right cameras. In the binocular vision system used in this paper, the two cameras are placed symmetrically, so this also reflects the depth of binocular vision of table tennis.

3. Experiments and results analysis

The physical device used in this experiment is shown in Fig. 1. In the figure, we define the table tennis robot "visual world coordinate system", the z axis is vertical up, and the xy plane is the table surface. The visual system of the table tennis

robot gives the discrete (t, x, y, z) sequence by locating the spatial position of the table tennis in real time. In this experiment, the robot that we used is the second generation of binocular vision based on the development of the horizontal guide table tennis robot. Consider that the acceleration of gravity is $g = 9.8\,\mathrm{m/s^2}$, so we can set the perturbation acceleration to be $a = 0.1g$. According to the results of camera calibration, the measurement covariance R_k is usually set to the maximum error of measurement. In this experiment, the initial value of R_k is set to 10 mm, and with the decrease of d_k the value of R_k increases gradually to 40 mm.

3.1. Tracking results and contrast experiments

Figure 2 shows the results of the tracking of the axial velocity in the three-dimensional world coordinate system, where the solid line represents the output of the filter and the circle represents the result of the velocity difference directly based on the position information obtained by sampling.

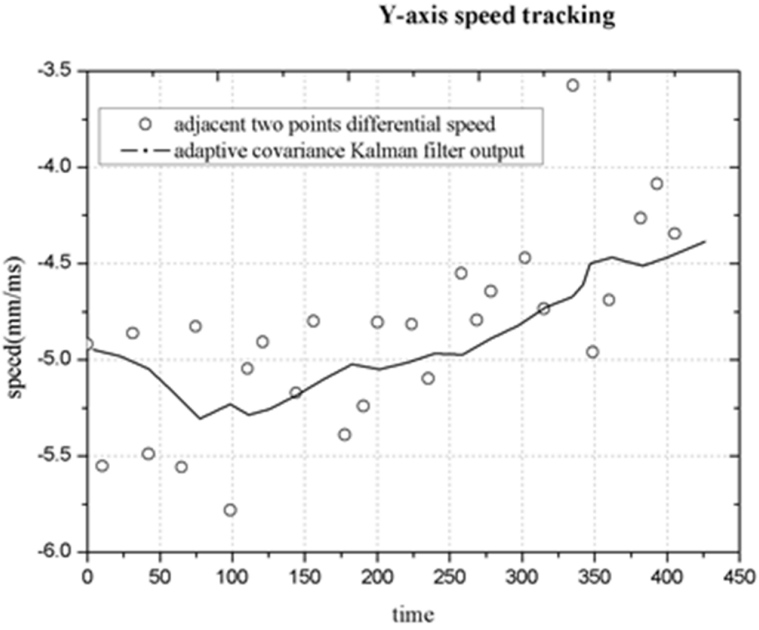

Fig. 2. Table tennis track tracking results indicate–y-axis speed tracking

3.2. Error and correction test

As shown in Figure 3, the anti-jamming performance of the filter is an important measure of real-time visual tracking. In this paper, we introduce a sliding window filtering algorithm (a dashed line) with a smaller computational algorithm, which is often used in the field of digital filtering.

The figure describes the velocity tracking curve in the case of noise interference in

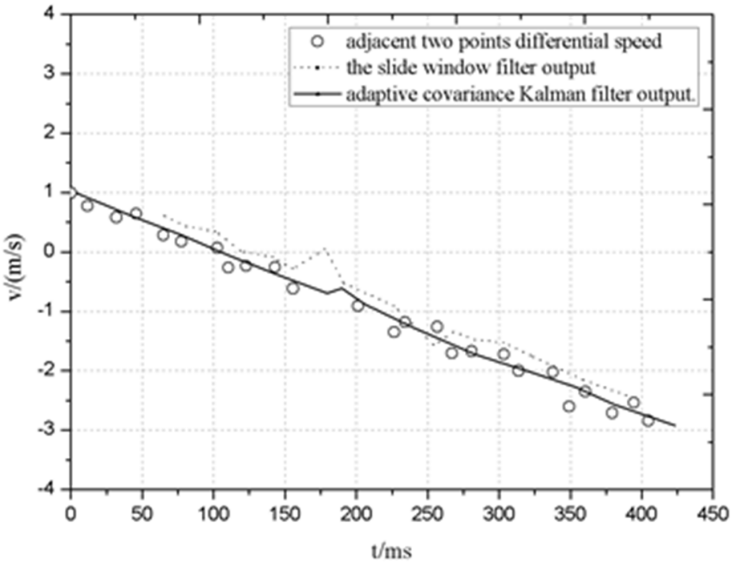

Fig. 3. Tracking results after adding noise to the measured data of z-axis

the z-axis measurement signal. As shown in the figure, a measurement noise signal is introduced near the time of 200 ms, and the measurement result deviates from the actual trajectory. The difference velocity is expressed as a large disturbance (as shown by a circle point in the figure). From the output data curve analysis of the filter, the adaptive measurement of the covariance Kalman filter (solid line) can more effectively suppress the impact of noise on the output, resulting in smaller fluctuations, and it has a large effect on the sliding window filter algorithm output (dotted line).

Due to image processing, light or occlusion and other reasons, it cannot measure the accurate information of table tennis, which means that there may be data loss situation. In this paper, we analyze and simulate the problem of data loss. Figure 4 shows the trajectory tracking results in the case of loss of trajectory measurement data on the z-axis during table tennis. In the case where the Kalman filter in the z-axis direction is between 150 ms and 210 ms and there is no measurement signal input, the track tracking result is shown in Fig. 6. From the velocity tracking curve (solid line in the figure), the adaptive measurement covariance Kalman filter algorithm (solid line) has better adaptability for the loss of data, and the output is smoother, while the sliding window filter algorithm (shown in the dotted line) output has a greater jitter.

4. Discussion of the results

The experimental results show that the initial value of the filtering algorithm has a great influence on the convergence speed. If the initial value is set to a fixed value

of $[0, 0]^{\mathrm{T}}$, and set a relatively large value P of the state covariance at the same time, the resulting tracking process will be a big fluctuation in the first 100 ms and the results of the tracking can be closed to the true value after 100 ms. Therefore, in this experiment, the actual observations are taken as the initial a priori estimates. Since it requires the initial value of the velocity, the difference in the previous two measurements of the position is taken as a priori estimate of the initial velocity. It is proved that the initial value of the measured initial value or multiple measurements is taken as the initial state estimation, so that the follow-up tracking has a better convergence effect. The effective tracking accuracy to ensure that the table tennis drop prediction accuracy is less than 8 cm, and they are all falling within the racket range. At present, the table tennis robot using this method has been able to complete more than 10 rounds of continuous hit.

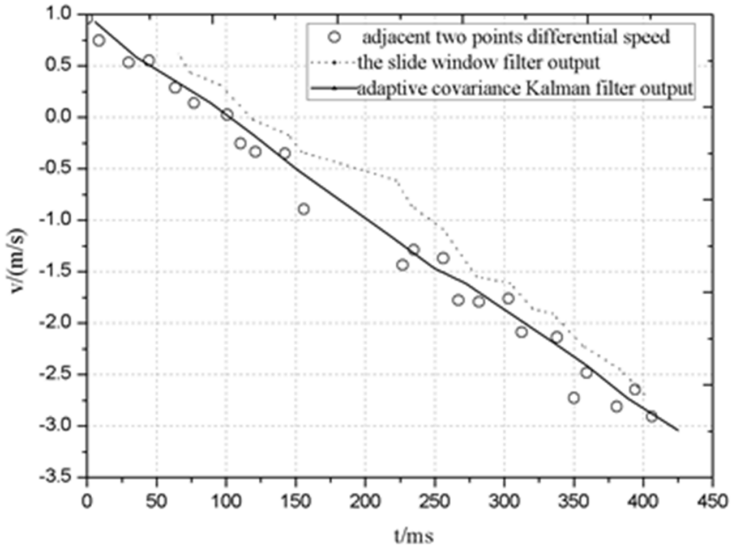

Fig. 4. Analysis of data loss occurs during the z-axis tracking process

5. Conclusion

In this paper, we use the table tennis robot as the research object, and the high-speed flight (5 m/s or more) table tennis as the tracking target, to build a self-adaptive covariance Kalman filter tracking algorithm. The experimental results show that the algorithm has good accuracy and convergence speed, and it can be applied to real-time image tracking and video processing. In real life, a large number of meaningful visual information is included in the movement, such as robot walking positioning and traffic flow detection and so on. Therefore, the real-time motion tracking method has a wider application prospect.

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Received May 7, 2017