JJMIE

Volume 16, Number 1, January. 2022
ISSN 1995-6665
Pages 79 - 86

Jordan Journal of Mechanical and Industrial Engineering

Parallel Computing-Based Dynamics Model for Tracking Moving Targets

Yugang Cui*

Department of Architectural Engineering, Zhengzhou Technical College, Zhengzhou 450121, China

Received 14 July 2021 *Accepted 25 December 2021*

Abstract

In order to solve the problem of low tracking accuracy of tennis ball trajectory caused by noise processing in the past methods based on mean shift algorithm and infrared spectrometer, a dynamic model of tennis ball moving target tracking based on parallel computing is proposed. Based on the analysis of tennis ball movement mechanics, a tennis ball movement image segmentation method based on image segmentation and distortion dynamic information is proposed. Based on image segmentation, the data is denoised. According to the tracking process of parallel computing, the gravity, visual and aerodynamic models are established to track the movement trend of tennis ball after hitting, and the strong tracking filter is used to compensate and correct the mutation points in different directions in the process of tennis ball movement. The experimental results show that the coordinates of the highest point of the tennis ball trajectory in the three-dimensional coordinate system are (-200, 150, 140), which is consistent with the coordinates of the highest point of the actual motion path, and has high robustness to external disturbances.

Keywords: corn; orientation device; physical parameters; the primary belt speed;

1. Introduction

With the rapid development of China's domestic tennis ball and the world's second-largest professional tennis ball players, it has achieved brilliant results in the world [1]. With the development of computer software and hardware technology, the use of computer technology to analyze tennis ball has attracted the active participation of many domestic scientific research workers [2, 3]. Among them, how to track and locate the moving tennis ball target is one of the difficulties to be solved. An improved BTV target tracking technology is proposed in Reference [4]. In order to track the ball, a logical operation is applied between the created background and the image difference, and then the candidate ball is detected by applying threshold and magnification, which can finally lead to the ball tracking. Player detection is performed by finding the largest spot and filling the entire detection object by removing small spots, and the player is tracked according to the contour. Experimental results show that this method achieves high accuracy in target recognition and tracking. Ball tracking has high hit rate and low failure rate, while player tracking hit rate is measured by multi-target tracking accuracy (motp). A tennis target tracking method based on infrared spectrometer is proposed in Reference [5]. The interferogram of moving target is collected by infrared spectrometer, the spectrum is restored, and its phase difference is compared with the actual spectrum. The moving target is marked by local background weighting to track the moving target. Due to the phase difference between the reconstructed spectrum and the actual spectrum and the influence of external dynamic background, the tennis moving target tracking effect is poor. Aiming at solving the problems and shortcomings in target tracking, a tennis target tracking dynamic model based on parallel computing is proposed in this paper. According to the excellent localization characteristics of parallel computing in both time and spatial domain, the adjacent video images are differentiated to extract the feature information reflecting the foreground moving target, so as to overcome the adverse factors of illumination change and the continuous change of moving target scale at any time. At the same time, based on the structural characteristics of the tennis ball court, the adverse interference factors outside the court are excluded.

2. Tennis Ball Moving Object Segmentation

Tennis ball is affected by gravity and air resistance in flight. After the ball is released, it will encounter certain air resistance in flight, which will increase the pressure resistance. The vibration caused by the impact of the ball will produce simple harmonic vibration to the air [6-8]. When the rotating sphere moves forward, the interaction between circulation and air flow changes the streamline distribution and forms a certain pressure difference [9].

The difference between topspin and flat shot is that there is upward and forward pulling action when hitting the ball, so the ball has upward rotation around itself in the first flight. Because the ball has upward rotation trend, the air pressure above the ball is greater than the pressure below.

* Corresponding author e-mail: cuiyugang@163.com.

Therefore, when the ball drifts in the first flight, the ball tends to fall, so the ball falls quickly after passing the net, and it is not easy to hit the bottom line [10-12]. Forehand topspin is faster than flat shot in rotation speed, so under the same conditions, the topspin is faster than flat shot in the second flight. The pressure difference between the upper and lower air flow of the tennis ball will also further expand, resulting in a synchronous increase in the falling trend of the ball [13, 14].

In the instant of hitting, a positive main hitting force $p1$ is applied to the ball to realize the charge of the ball, and a vertical and positive upward movement is added to the racket to make the racket grip the tennis ball and twist it from the back, so that the ball can obtain an additional upward rotation force T. Under the action of this T force, the ball rotates around its center axis OY according to the corresponding speed n (which is usually expressed as several revolutions per minute) [15]. The batter looks up in the direction of the ball. If the additional rotation force T is greater, the rotation speed n of the ball is greater.

At the moment of hitting, a rotating force T is added to the ball, that is to say, friction is applied to the ball to rub and rotate the ball. Therefore, the time for the ball to stay on the chord plane of the racket is much longer than the time for flat hitting, and its contact with the racket, that is, the impact point, is not a fixed point, but a moving line segment [16, 17].

According to the principle of mechanics, a rotating ball must have a moment (M). The moment is equal to the product of the force (F) acting on the sphere and the vertical distance (L) from the force to the center of the sphere. If $L = 0$, the force is passing through the center of the ball, the ball does not produce any rotation, but the ball flies the fastest forward; If F is constant, l increases, M also increases, and the ball rotates faster; If F is constant, the greater the forward force of $F1$ is, the smaller the upward force of $F2$ is, and the faster the ball flies; The greater the $F2$ is, the smaller the $F1$ is, and the faster the ball rotates [18, 19]. It is not difficult to see from the above, the topspin ball must be in the forward force at the same time, but also upward force to rub the ball. The forward force gives positive pressure to the ball and makes the ball fly forward through the center of the ball; The upward force comes from the friction between the racket and the ball, so that the force line on the ball does not pass through the center of the ball and has a vertical distance with the center of the ball, causing the ball to rotate. In this way, the ball can not only move forward, but also rotate to form a topspin ball [20, 21].

Combined with the motion mechanics of tennis ball, the image segmentation process is designed, as shown in Figure 1.

As can be seen from Figure 1, the normal mode of image segmentation is combined with the dynamic information of segmentation distortion, which is used to segment different sub images of tennis ball motion image. Color and texture features are combined, and the hidden layer is processed according to the feature fusion principle to extract color and texture features [22]. In order to realize the target segmentation, the image is segmented by thresholding combined with gray and gradient information.

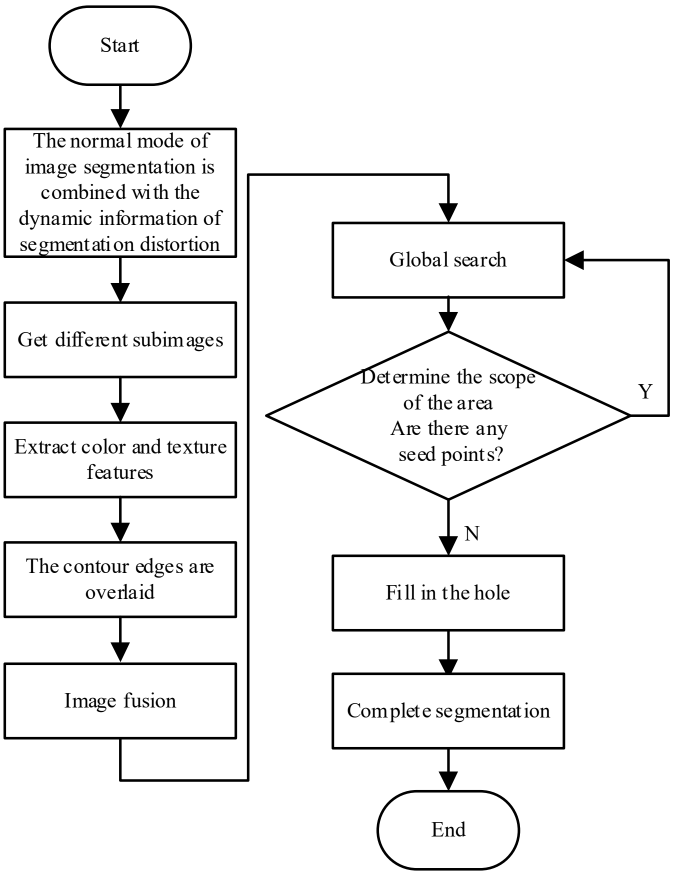


Figure 1. Image segmentation process

The details are as follows:

Step 1: Overlay the edge of the image contour to be segmented;

Step 2: The region growing method is used to superimpose the edge of the contour, and the maximum contour method is used for fusion;

Step 3: Take the upper left corner of the image as the starting point, and use it as the seed point of the search area to search globally, and get the first non-zero gray value pixel. The global search rule takes the seed point as the starting point, and starts the search from top to bottom. After setting the search compensation threshold, it finds the next non-zero pixel. When it finds the region that meets the condition, it determines whether there are seed points in the region [23]. If there are seed points in the area, continue to search until no more seed points appear;

Step 4: Fill in the empty target to make the target have a complete target control;

Step 5: The whole target contour is etched to process the edge redundant information, and the contour is inflated by combining with morphological filtering to get the complete segmentation image.

3. Noise Reduction Algorithm Based on Parallel Computing

In order to track and locate the tennis ball moving target, based on the above-mentioned segmentation method of tennis ball trajectory image, the position of tennis ball is obtained and used as the initial observation value to train and predict the tennis ball moving position based on the Haar like features of tennis ball.

Because the video scene is always affected by noise and tennis ball non-uniform motion, it is easy to lead to its movement often accompanied by multiple or even dozens of pixel size jumps between adjacent two frames, as well as the inevitable occlusion effect in the process of movement, resulting in tennis ball moving target loss [24-26]. In order to overcome the above adverse factors, the following optimization is done in the process of tennis ball target tracking.

If the current tennis ball moving target detection fails, it indicates that the position jump of the front and back of it is larger, or its moving target is temporarily separated from the video image area. In view of the above situation, expand the region of interest of tennis ball target detection, expand the length M and width N of the region of interest correspondingly (in the experiment, $M = N = 25$), and find the target in the expanded region of interest [27, 28]. If the tennis ball target can not be detected after the above processing, it indicates that the tennis ball has been occluded or separated from the video image area, then the lost target is marked accordingly, and the noise reduction algorithm based on parallel computing is used to detect the tennis ball target in the next image.

The data collected under the support of data synchronization protocol has large interference data, so it is necessary to denoise the data. Therefore, the scale transformation method based on parallel computing is designed to process the interference data.

The noise area is assumed to be the (x, y) direction of the ball, and the ball motion path is assumed to be the $x \in [0, W-1], y \in [0, H-1])$ direction of the ball, the background image and foreground image are denoised to get the noise distribution area. Where W is the horizontal displacement and H is the vertical displacement.

The dynamic error of the target image is corrected by using 3D viewpoint switching mode, the expression formula is:

$$\begin{aligned} x &= V\cos\theta\cos\vartheta_1 \\ y &= V\sin\theta \\ z &= -V\cos\theta\sin\vartheta_1 \end{aligned} \tag{1}$$

In Formula (1), x, y, z represents the local information feature points of tennis ball trajectory, and ϑ_1 represents the switching angle of tennis ball trajectory.

If the tennis ball target can not be detected in several consecutive frames, the tracking fails. If the tennis ball target is detected again after the short-term tennis ball target is lost, the tennis ball target tracking training and prediction will be carried out again as the measured value input [29].

4. Dynamic Model Construction of Tennis ball Moving Target Tracking

Parallel computing is one of the most practical algorithms for local optimal solution. It belongs to one of the tracking methods based on the direction information of motion, and can track the target of specific direction of motion. The tracking flow based on parallel computing is shown in Figure 2.

As can be seen from Figure 2, the target location is based on the fact that the real distance of the target is obtained by means of the inverse ratio of parallax and depth. After stereo matching, the parallax map can be calculated to perform 3D ranging operation. The internal and external parameters of the camera are obtained by MATLAB calibration toolbox, and then the reprojection matrix can be obtained by stereo calibration with parallel computing algorithm.

4.1. Dynamic model of target tracking

Assuming that the radar station coordinates are east north one day coordinate system, the aerodynamic model and thrust model are analyzed in half speed, and the gravity and apparent vision model and aerodynamic model are constructed in geocentric inertial coordinate system:

$$v(k) = a_G(k) + a_T(k) + a_A(k) + a_c(k) \tag{2}$$

In Formula (2), $a_T(k)$ and $a_A(k)$ represent thrust and aerodynamic acceleration respectively, $a_G(k)$ represents gravity acceleration vector, and $a_c(k)$ represents visual acceleration.

4.1.1. Gravity and expressive force model

Assuming that the position states of the target in the east north one day coordinate system and the geocentric inertial coordinate system are X_A and X_B respectively, and assuming that the longitude and latitude heights of the radar station are L, B, H, the conversion from the east north one day coordinate system to the geocentric inertial coordinate system is as follows:

$$\mathbf{X}_\mathrm{B} = \mathbf{T}_\mathrm{A}^\mathrm{B}\mathbf{X}_\mathrm{A} - \left[0, 0, R_e + H\right]^\mathrm{T} \tag{3}$$

In Formula (3), R_e is the equivalent radius of the earth.

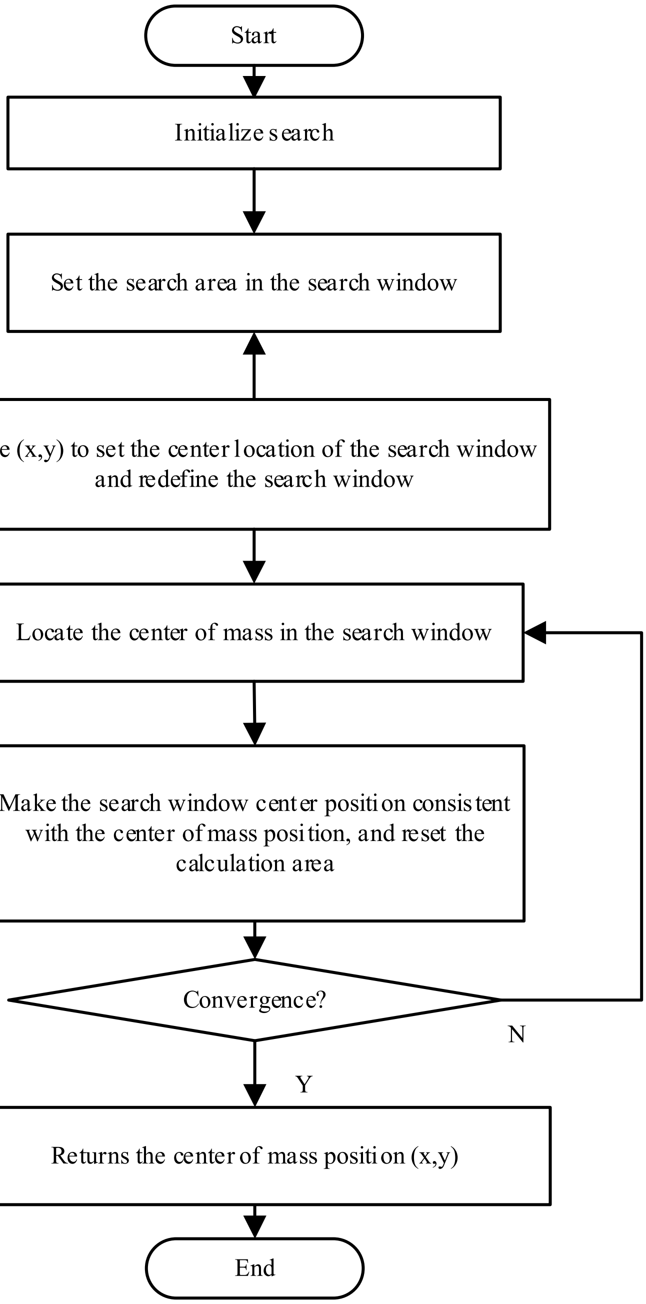


Figure 2. Tracking process based on Parallel Computing

In Formula (3), R_e is the equivalent radius of the earth. The transformation matrix in Formula (3) is as follows:

$$\mathbf{T}_A^B = \begin{bmatrix} -\sin(L+\theta_e t) & \cos(L+\theta_e t) & 0 \\ -\cos(L+\theta_e t)\sin(B) & -\sin(L+\theta_e t)\cos(B) & \cos(B) \\ \cos(L+\theta_e t)\cos(B) & \sin(L+\theta_e t)\cos(B) & \sin(B) \end{bmatrix} \quad (4)$$

In Formula (4), $\theta_e t$ represents the angle between the geocentric inertial coordinate system and the geocentric coordinate system from the reference time to the time t (it is generally assumed that the geocentric coordinate system and the geocentric inertial coordinate system coincide when the radar detects the target). Then the target acceleration in the east north one day coordinate system is:

$$a_A = \mathbf{T}_A^B \ddot{\mathbf{X}}_A + 2\dot{\mathbf{T}}_{ECI}^B \dot{\mathbf{X}}_A + \ddot{\mathbf{T}}_{AI}^B \mathbf{X} \quad (5)$$

One term in Formula (5) is the specific expression of gravity acceleration in the east north one day coordinate system. The acceleration conversion from the geocentric inertial coordinate system to the east north one day coordinate system is based on the target position. The coordinate conversion of acceleration is obtained through the second derivative of time. In this process, the conversion matrix is obtained T_A^B is a function of time, resulting in the conversion of the final gravitational acceleration with two terms.

4.1.2. Aerodynamic model

The acceleration produced by thrust is realized by acting on the air, therefore, the thrust model can be regarded as a special superposed aerodynamic force, it can be expressed as:

$$F(k)=\frac{1}{2}\rho(k)v^2(k)\left[a_v,b_t,c_i\right]\left[-a_d(k),a_t(k),a_b(k)\right]^{\mathrm{T}} \quad (6)$$

In Formula (6): a_v,b_t,c_i represents unit vector of half speed coordinate axis, $\rho(k)$ represents air density, $a_d(k)$ is resistance acceleration, $a_t(k)$ is lateral turning acceleration, and $a_b(k)$ is climbing acceleration. The dynamic model in the half velocity coordinate system has obvious physical significance in expressing the horizontal and vertical plane motion of the target. When the lateral turning acceleration is greater than zero, the tennis ball will fly to the left. When the lateral turning acceleration is less than zero, the tennis ball will fly to the right; The climbing acceleration determines the movement mode of the target in the longitudinal plane; When the climbing acceleration is greater than zero, the tennis ball will fly upward. When the climbing acceleration is less than zero, it falls down.

4.2. Filtering correction of acceleration mutation point

When there is power phase conversion, the tennis ball will produce larger maneuvering acceleration, which will lead to the increase of tracking error. After the initial tracking model is adjusted to match the target motion pattern for a period of time, the tennis ball motion is described more stably, and the predictor is modified by gain. The model needs to ensure the robustness of the tracking algorithm as a whole, and its acceleration will not change abruptly. At the same time, some measurement samples are needed to correct the error of filtering algorithm, so the error of maneuver jump position will increase. To solve this problem, a strong tracking filter is introduced to compensate and correct the maneuvering mutation point. Considering that the power conversion is mainly used to push the tennis ball to pull up from the low point of trajectory, the lift acceleration $a_c(k)$ is selected as the detection parameter of maneuver mutation. Judgment volume:

$$\varepsilon(k)=\lg\frac{a_c(k)-a_c(k-1)}{a_c(k-1)-a_c(k-2)} \quad (7)$$

It can be seen from Formula (7) that when the difference between adjacent accelerations reaches more than two orders of magnitude, that is $\varepsilon(k)\geq 2$, the maneuver mutation is considered to occur, and the strong tracking filter is used to filter and correct the measurement at the current time. The physical picture of the strong tracking filter and the tennis ball track after filtering and correction are shown in Figure 3.

5. Experiment

In order to verify the rationality of the dynamic model of moving target tracking based on parallel computing, tennis ball is taken as the research object to carry out the experimental verification analysis.

5.1. Experimental preparation and segmentation result analysis

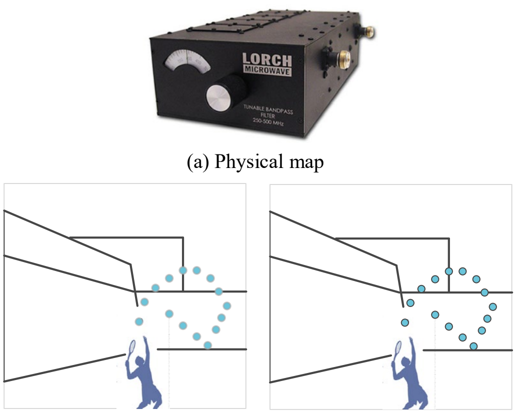
In an 80 m^2 laboratory, tennis ball is used as the experimental object to track its moving target. Set the maximum speed of the tennis ball as 20 m/s and the maximum angular speed as 10 °/s. install the camera above the tennis ball and collect the image every 3 s.

Table 1 shows the number record of tennis ball track images with 30700 filters after segmentation by using the method in this paper, average displacement algorithm and infrared spectrometer method under the conditions of frame 1, 200, 400 and 600.

Table 1. Record of three methods

Number of frames	Paper method	Average displacement algorithm	Infrared spectrometer method
1	194136	165660	153840
200	122856	111004	153803
400	136238	124189	154083
600	193572	173141	154872

Using the sample data segmented by the three methods shown in Table 1, the root mean square errors of the three methods under different segmentation ratios are counted. The results are shown in Figure 4.



(a) Physical map
(b) Before filtering (c) After filtering
Figure 3. Variation of root mean square error of segmentation

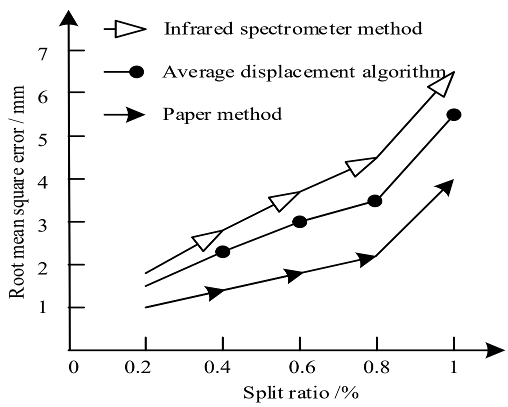


Figure 4. Variation diagram of root mean square error of segmentation

As can be seen from Figure 4, under the same segmentation ratio, the change curve of root means square error of segmentation using the method in this paper is always lower than that of average displacement algorithm and infrared spectrometer method, and the curve is relatively flat. It shows that under the same segmentation ratio, the segmentation error of this method is smaller and more suitable for the actual needs.

5.2. Target setting

Through the image video sequence to obtain 1000 images, the characteristics of the collected image and video are analyzed, and the acquisition process is interfered by external noise. According to the experimental environment, the simulation experiment of tennis ball movement path capture is carried out. First of all, the video sequence of a tennis ball image in the process of throwing is collected to obtain the original image, as shown in Figure 5.

It can be seen from Figure 5 that the camera of IO Industries company is used to take fixed-point pictures of the experimental objects. The camera is placed on the right side of the tennis ball court, 5 m away from the server. The number of the server is recorded through the camera. The characteristics of the best hitting point of the tennis ball server are analyzed by the trajectory of the marker points of the player's arm.

5.3. Experimental results and analysis

Combined with the tennis ball trajectory in Figure 5, the motion path coordinates are analyzed in detail, as shown in Figure 6.

It can be seen from Figure 6 that the coordinates of the highest point of the tennis ball trajectory in the three-dimensional coordinate system are (-200, 150, 140). Under the support of each coordinate point of the actual motion path, the tennis ball trajectory is tracked by using the Mean Shift algorithm, infrared spectrometer and parallel computing methods, as shown in Figure 7.

It can be seen from Figure 7 that the highest point coordinate of the tennis ball trajectory based on Mean Shift algorithm in the three-dimensional coordinate system is (-100, 80, 160), and the tracking points are less, so the tennis ball landing speed is faster; The highest point coordinate of the tennis ball trajectory based on infrared spectrometer in the three-dimensional coordinate system is (-200, 180, 110). Using the parallel computing method, the highest point coordinates of the tennis ball trajectory in the three-dimensional coordinate system are (-200, 150, 140), which are consistent with the highest point coordinates of the actual motion path. Through the above analysis, it can be seen that the tracking result based on the parallel computing method is more accurate.

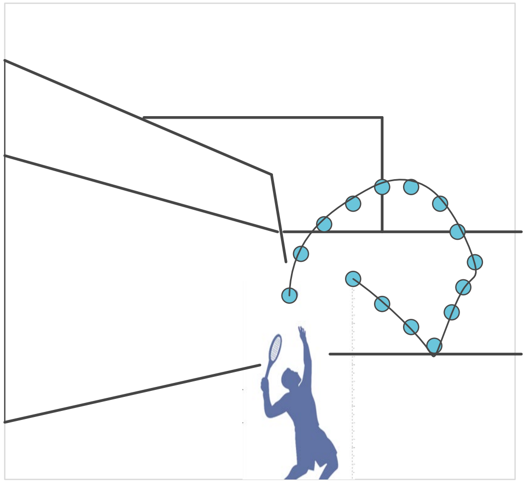


Figure 5. Tennis ball trajectory

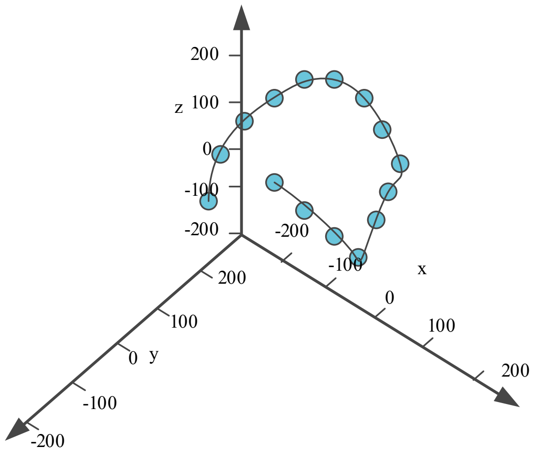


Figure 6. Tennis ball trajectory analysis in 3D coordinated system

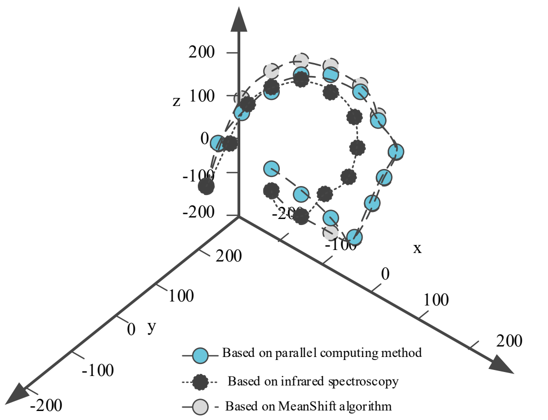


Figure 7. Tennis ball trajectory tracking with different methods

6. Conclusion

The tennis ball moving target tracking dynamic model based on parallel computing can effectively improve the problem of low accuracy of tracking results based on average shift algorithm and infrared spectrometer, which is verified by experiments. The following conclusions are drawn:

1. The accurate prediction of tennis ball moving target tracking trajectory needs high-precision prediction initial value points as the premise. Filtering the tennis ball moving target data can reduce the influence of random error and improve the data accuracy, but it is difficult to meet the requirements of high-precision trajectory prediction of tennis ball moving target. Therefore, starting from the motion characteristics of tennis ball moving target. The dynamic equation of tennis ball moving target is used to constrain the state equation in real time, and the dynamic model of tennis ball moving target tracking based on parallel computing is established. It is modified in real time to improve the target tracking accuracy.
2. The experimental results show that the model in this paper has a high accuracy when tracking the coordinates of the highest point of the trajectory of the tennis ball moving target.

Although this method has accurate capture effect, there are still many problems due to conditions and time constraints, which need to be further improved and studied:

1. During the experiment, when the camera device is used to capture the flight trajectory of the tennis ball flying object, the camera will obtain an image. The exposure time of the camera and the high-speed motion of flying objects blur the image. Therefore, how to eliminate fuzziness and improve the accuracy of positioning results remains to be further studied.
2. It is difficult to keep the background stable when grasping flying objects with the manipulator, so more anti-interference algorithms are needed to extract objects such as regional color segmentation, so as to avoid the interference problem caused by the experimental process.

References

[1] Oshita M, Inao T, Ineno S, et al. Development and evaluation of a self-training system for tennis shots with motion feature assessment and visualization. The Visual Computer, 2019, 35(3): 1-13.

[2] Zhang W, Yang F, Liang Y. A Bayesian framework for joint target tracking, classification and intent inference. IEEE Access, 2019, 7: 66148-66156.

[3] Na W C, Zhang W R, Yan S X, et al. Automated neural-based modeling of microwave devices using parallel computation and interpolation approaches. IEEE Access, 2019, 7: 73929-73937.

[4] Archana M, Kalaisevi Geetha M. Object detection and tracking based on trajectory in broadcast tennis video. Procedia Computer Science, 2015, 58: 225-232.

[5] Matsuoka M., Nakamura T., Osawa T., et al. An evaluation method of reflectance spectra to be obtained by Hayabusa2 Near-Infrared Spectrometer (NIRS3) based on laboratory measurements of carbonaceous chondrites. Earth, Planets and Space, 2017, 69: 120.

[6] Popescu R I, Raison M, Popescu G M, et al. Design and development of a novel type of table tennis aerial robot player with tilting propellers. Mechatronics, 2021, 74(4): 102483.

[7] Bańkosz Z, Winiarski S. Statistical parametric mapping in table tennis topspin backhand shot – Inter-individual differences in angular movement. Gait and Posture, 2020, 81(3): 26-27.

[8] Drees C, Knieb M, Fechner A, et al. Detection of illegal treatment of table tennis rackets using gas chromatography coupled to ion mobility spectrometry – A feasibility study. Analytica Chimica Acta, 2021, 1154(2): 338227.

[9] Bo R, Ming M, Guangguo L. et al. Action recognition model of athletes at the scene of the game based on SVM and multitarget tracking algorithm. Journal of Intelligent and Fuzzy Systems, 2020, 38(6SI): 7303-7314.

[10] Grüschow S, Sadler J C, Sharratt P J, et al. Phenylalanine meta-Hydroxylase: A single residue mediates mechanistic control of aromatic amino acid hydroxylation. Chembiochem, 2020, 21(3): 417-422.

[11] Hu Y, Huang P, Meng Z, et al. Optimal control of approaching target for tethered space robot based on non-singular terminal sliding mode method. Advances in Space Research, 2019, 63(12): 3848-3862.

[12] Zhao Z, Li M, Wang C, et al. Dynamic modeling of brake in power-split DHT and pressure tracking control with sliding mode variable structure method. International Journal of Automotive Technology, 2019, 20(3): 521-530.

[13] Tang F, Lu X, Zhang X, et al. Deep feature tracking based on interactive multiple model. Neurocomputing, 2019, 333: 29-40.

[14] Zhang C, Guan Y. Research on related technologies of vision target tracking based on discrete differential algorithm for deep learning. Journal of Intelligent and Fuzzy Systems, 2019, 37(3): 3267-3274.

[15] Liu S, Wang Y, Dai F, et al. Simultaneous 3D motion detection, long-term tracking and model reconstruction for multi-objects. International Journal of Humanoid Robotics, 2019, 16(4): 2255-2262.

[16] Liu J, Jiang X, Tian X, et al. Hybrid particle filter based dynamic compressed sensing for signal-level multitarget tracking. IEEE Access, 2020, 8: 17134-17148.

[17] Prakash R, Behera L, Mohan S, et al. Dynamic trajectory generation and a robust controller to intercept a moving ball in a game setting. IEEE Transactions on Control Systems Technology, 2020, 28(4): 1418-1432.

[18] Yao G, Saltus R, Dani A. Image moment-based extended object tracking for complex motions. IEEE Sensors Journal, 2020, 20(12): 6560-6572.

[19] Dao D, Guo L. New hybrid SPEA/R-deep learning to predict optimization parameters of cascade FOPID controller according engine speed in powertrain mount system control of half-car dynamic model. Journal of Intelligent and Fuzzy Systems, 2020, 39(1): 53-68.

[20] Lu Y, Yang T, Hatfield B D, et al. Influence of cognitive-motor expertise on brain dynamics of anticipatory-based outcome processing. Psychophysiology, 2020, 57(2): e13477.

[21] Liu W, Zhu L Y, Jin B B, et al. Dynamic modeling of parallel mechanism based on particle system. Journal of Mechanical Engineering Research and Developments, 2016, 39(2): 483-491.

[22] Tang X, Li M, Tharmarasa R, et al. Seamless tracking of apparent point and extended targets using gaussian process PMHT. IEEE Transactions on Signal Processing, 2019, 67(18): 4825-4838.

[23] Muynck G D, Soenens B, Delrue J, et al. Strengthening the assessment of self-talk in sports through a multi-method approach. Scandinavian Journal of Medicine and Science in Sports, 2020, 30(3): 602-614.

[24] Zhu Y Y, Guo N. Unmanned vehicle route tracking method based on video image processing. Jordan Journal of Mechanical and Industrial Engineering, 2020, 14(1): 139-147.
[25] Han B, Huang H, Lei L, et al. An improved IMM algorithm based on STSRCKF for maneuvering target tracking. IEEE Access, 2019, 7: 57795-57804.
[26] Zheng Y J, Feng Y, Joshi S. Construction and study of multi-DOF automobile dynamic model. Journal of Mechanical Engineering Research and Developments, 2016, 39(1): 187-196.
[27] Kachapi, Hashemi S H. Nonlinear vibration and frequency analysis of functionally graded- piezoelectric cylindrical nano-shell with surface elasticity. Jordan Journal of Mechanical and Industrial Engineering, 2018, 12(4): 293-312.
[28] Sidney M, Machar R, Anne-Marie M, et al. Do magnetic resonance imaging abnormalities of the non-dominant wrist correlate with ulnar-sided wrist pain in elite tennis players? Skeletal Radiology, 2020, 49(3): 407-415.
[29] Zhang X Y. Optimized design of adhesive formations for tennis ball. Journal of Mechanical Engineering Research and Developments, 2016, 39(1): 217-225.