Analysis of table tennis rotation trajectory based on depth learning

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Abstract: In order to save training costs and improve the training efficiency and sports competitive ability of table tennis players, this paper aims to conduct a comprehensive analysis of the rotation trajectory of table tennis based on depth learning. Firstly, SURF algorithm is used to divide the table tennis rotation trajectory image into foreground spots and background points. The affine transformation matrix is calculated by background points to complete background motion compensation and eliminate the influence of background motion on the detection of table tennis rotation moving targets. The compensated image is processed by frame difference method and morphological operation, and the table tennis rotating moving target is merged by color, displacement and position information. The LSTM trajectory prediction network is used to predict the rotation trajectory of the table tennis ball. Through the flight trajectory of the table tennis ball, the rotation type of the table tennis ball is inversely deduced. The table tennis ball rotation is decomposed into three coordinate directions. Using the obtained coordinate information of the first five moments of the table tennis ball, the velocity of the table tennis ball is calculated to complete the analysis of the rotation trajectory of the table tennis ball. Through the experimental verification, the motion trajectory prediction accuracy and trajectory prediction efficiency of the proposed method are high, which can effectively improve the efficiency and competitive ability of table tennis training.

Key words: Deep learning; Table Tennis; Rotating motion track; LSTM prediction network;

1.Introduction

The object detection and trajectory prediction for rotating objects have great practicability and importance in many fields. For example, in the military field, it can prevent in advance by accurately positioning local moving targets. In sports, forecasting the trajectory of ball games can help athletes and coaches carry out scientific analysis and judgment, so as to improve sports competitive ability. The results of application in related fields can also be applied to aerospace and industrial production to complete dynamic interaction [1].

Table tennis is a highly competitive, ornamental and interesting sport, which is very popular in all countries of the world. At the same time, it also has a very strong audience base and enthusiasm in China. In international table tennis competitions, Chinese table tennis players often achieve excellent results. The analysis of table tennis rotation trajectory can help athletes practice in daily table tennis training, save training costs, and improve the efficiency of athletes' training. In the research field of table tennis rotation trajectory, it involves many aspects of knowledge learning, such as depth learning and robot kinematics, which has high research value and significance [2]. Table tennis has the characteristics of high-speed rotation, fast movement speed and small volume and mass, which improves the difficulty of research and analysis of table tennis.

Most of the traditional research methods are based on the color and contour of the table tennis ball for target detection. However, in the actual scene, the surrounding environment will cause many problems, such as low accuracy of motion trajectory prediction. Therefore, this paper uses the depth learning method to analyze the rotation trajectory of table tennis in detail.

The innovations of this paper are as follows: (1) By SURF algorithm, the table tennis rotation trajectory image is divided into foreground spots and background points, and the affine transformation matrix is calculated through the background points to complete the background motion compensation. The compensated image is merged with frame difference method and morphological operation. Through color, displacement and position information, the table tennis rotating moving target is merged. The LSTM trajectory prediction network is used to predict the rotation trajectory of the table tennis ball. The rotation type of the table tennis ball is inversely deduced from the flight trajectory of the table tennis ball. Using the obtained coordinate information of the first five moments of the table tennis ball, the velocity of the table tennis ball is calculated to complete the analysis of the rotation trajectory of the table tennis ball. (2) Compared with other methods for predicting the rotation trajectory of table tennis, the method proposed in this paper can effectively save the economic cost of athletes' training and improve their sports competitive ability.

2. Related work

At present, the analysis of table tennis rotating motion track contains a lot of research content, and related experts have carried out in-depth research on it, in order to improve the competitive ability of table tennis players. Sun L S et al. For some table tennis players, the batting level is low, and some problems such as some fast balls and balls with large rotation can not get a good return. Based on Newton's law of motion, the force exerted on table tennis in the air is analyzed in detail, and the flight model and collision model of table tennis are built. Through simulation experiments, the rationality of the model is proved, and then the movement track of table tennis is is analyzed and predicted, the optimal hitting point is defined with the restrictions of the athletes themselves, and the trajectory of table tennis return is planned according to the principle of peace. By combining the position of the hitting point of table tennis with the initial speed and the collision model of table tennis, the speed and posture of the players are calculated. Using simulation experiments, it is proved that the planned speed and posture of table tennis can reach the expected hitting point, but this method does not improve the athlete's competitive ability [3]. In order to improve the competitive ability of table tennis players, Ke L must carry out prediction and feature extraction of table tennis rotating motion track. A method of extracting table tennis rotating motion track based on region growth algorithm is proposed. The video sensor image tracking method is used to collect table tennis rotating motion track images, and edge contour feature extraction is carried out on the collected table tennis motion track images. The fusion model of table tennis motion track image is constructed, and the feature extraction and corner calibration of table tennis rotation motion track image are carried out with the region linear growth method. Based on the distribution of corner points in the image of table tennis track and the distribution of edge outline, the features of table tennis rotating track are extracted to improve the prediction accuracy and control ability of table tennis track. The simulation results show that this method has higher accuracy in predicting table tennis rotating motion track, improves the accuracy of extracting table tennis motion track, and enhances the ability of table tennis players to control and improve their motion. However, this method has the drawbacks of complex calculation process, resulting in lower practical value [4]. Wang K et al. In the process of tracking the table tennis sports target, the accuracy of tracking the pixel points of the sports target image is low, and the problem of image distortion of the table tennis sports target is serious. Therefore, a table tennis rotating sports target track tracking system based on laser scattering is proposed. Because particles and molecules in the air can diffuse and absorb laser beams, the visibility value of air is measured according to the signal weakness received by the receiver of the air channel, and then the background of the table tennis sports target image is separated by the adaptive threshold method. The characteristics of the separability and stability of the table tennis sports target are extracted by the matrix, and the location information of the table tennis sports target is found in the table tennis sports target image. A target tracking error signal is formed to drive the server to complete the target tracking of table tennis. The experimental results show that this method has a high accuracy in target tracking of table tennis, but it does not improve the training efficiency of table tennis players [5]. Kong X et al. analyzed that in recent years, all kinds of sports events have shown a high-speed growth trend. By using video tracking technology to analyze table tennis games, it is helpful for coaches and athletes to formulate more specific tactical and simulation training directions. In this paper, table tennis rotating motion target detection and track tracking are studied. Two calibrated cameras were used to take pictures of table tennis in rotation, get the related video needed for research and analysis, decompose and process the video frame, detect the table tennis ball that has been deformed by ellipse fitting, and extract the ball center. Based on the combination of stereo correction and Euclidean distance, the center of table tennis on left and right images is matched, and the rotating track of table tennis is is tracked by using color features and large-scale optical flow. The three-dimensional spatial coordinates of table tennis are obtained by using triangulation method to complete the reconstruction of table tennis track, but the process is more complex [6].

3. Table tennis rotating target detection method based on SURF

3.1 Background compensation

（1）Background motion model

Camera motion is rotated, shifted and scaled. Therefore, the camera motion is simulated by using the transformation matrix of affine parameters. The background compensation of table tennis rotating target image is completed by solving the matrix of affine transformation. The matrix representation of the affine transformation is:

$$\begin{bmatrix} x_i^t \\ y_i^t \end{bmatrix} = \begin{bmatrix} a_1 x_i^{t-1} + a_2 y_i^{t-1} + t_1 \\ a_3 x_i^{t-1} + a_4 y_i^{t-1} + t_2 \end{bmatrix} \quad (1)$$

In formula (1), a_1、a_2、a_3、a_4 represent camera rotation and scaling motion, t_1 and t_2 represent translation motion, (x_i^{t-1}, y_i^{t-1}) and (x_i^t, y_i^t) represent coordinates of matching feature points (p_i, q_i) in frames $t-1$ and t. Let $A_i = \begin{bmatrix} x_i^{t-1} & y_i^{t-1} & 0 & 0 & 1 & 0 \\ 0 & 0 & x_i^{t-1} & y_i^{t-1} & 0 & 1 \end{bmatrix}$, the matrix of affine transformation $T = [a_1, a_2, a_3, a_4, t_1, t_2]^T$.

By solving the affine transformation matrix, the rotating background of the table tennis ball can be compensated, and the influence of the background on the detection of the rotating moving target of the table tennis ball can be eliminated [7-8].

（2） Background compensation of table tennis rotation based on feature point separation

In order to accurately calculate the matrix of affine transformation and compensate the rotating background of table tennis, the feature points are divided into two parts: the front spot and the background point.

According to formula (2), the distance difference of each characteristic point $d_i(i=1,2,\cdots,N)$, where N is the number of characteristic point pairs, expressed as:

$$d_i=\left\|q_i^T-A_iT^*\right\| \quad (2)$$

d_i expansion is quantified and divided into m groups for statistics. Assuming that the quantified value is k and the logarithm of characteristic points is n_k, $k\in[0,m]$, it has $N=n_0+n_1+\cdots+n_k+\cdots+n_m$. The probability that the quantified value of the feature points in the table tennis rotating motion image is k is expressed as:

$$p_k=\frac{n_k}{N} \quad (3)$$

The mean value and variance of the feature points in the rotation motion image of table tennis can be calculated as:

$$\mu=\sum_{k=0}^{m}kp_k \quad (4)$$

$$\sigma^2=\frac{\sum_{k=0}^{m}(d_i-\mu)^2}{N} \quad (5)$$

Separation of foreground and background points. Find the cause from $0\sim m$ σ^2 Maximum quantification, which is recorded as T_0 as the threshold value. For the background point of table tennis rotating motion image, the background itself will not move except for table tennis. Therefore, the $d_i\prec T_0$ image feature point is judged as the background point, and the opposite is the target point [9-10]. The affine transformation matrix is derived from the calculation of background points.

Background compensation for each image $I_{t-1}(x,y)$ of $t-1$ is performed by an affine transformation matrix, which is expressed as:

$$I'_{t-1}(x,y)=T\cdot I_{t-1}(x,y) \quad (6)$$

The table tennis rotation motion image $I'_{t-1}(x,y)$ after background compensation can be regarded as a static table tennis rotation motion image.

3.2 Detection of Rotating Moving Objects in Table Tennis

After the background compensation, the table tennis rotation image can be roughly detected by combining the frame difference method with morphological operation. However, the target detected by frame difference method will have area dispersion, which is more obvious after morphological operation. For this reason, this paper combines the discrete target regions obtained by the combination of frame difference method and morphological operation through color information, position and displacement information to obtain the completed table tennis rotating target. The detailed steps are as follows:

（1）Because the color information of the rotating table tennis target is approximately the same, when the target is discrete, the discrete target can be merged by the color information in the image. In this paper, HSI color information is used to merge the discrete areas of the table tennis rotation motion image [11-12]. First, find out the rectangles surrounding each discrete area and record their centroids, calculate the component mean and variance of HSI color of pixels in the table tennis rotating motion image area, and make statistics on the distance of color features of adjacent areas, which is expressed as:

$$d_1 = \sqrt{\sum_{\lambda=1}^{3}\left[(\mu_{i\lambda}-\mu_{j\lambda})^2+(\sigma_{i\lambda}-\sigma_{j\lambda})^2\right]} \quad (7)$$

In formula (7), i、j represent two adjacent discrete regions, $\mu_{i\lambda}$ and $\mu_{j\lambda}$ represents the mean, $\sigma_{i\lambda}$ and $\sigma_{j\lambda}$ Represents variance, $\lambda = 1.2.3$ are the corresponding H, S, I components. Set the threshold to T_1 and merge areas if $d_1 \prec T_1$.

Table tennis rotating target movement will generate position and displacement information. In the adjacent two frames, the position and displacement information of the table tennis rotating target will not change significantly. Therefore, this paper uses position and displacement information to merge discrete areas [13-14]. $S_{t-1}^1 = \{x_{t-1}^1, y_{t-1}^1\}$ and $S_{t-1}^2 = \{x_{t-1}^2, y_{t-1}^2\}$ respectively represent the centroids of the two discrete areas in the $t-1$ frame, and $S_t^1 = \{x_t^1, y_t^1\}$ and $S_t^2 = \{x_t^2, y_t^2\}$ respectively represent the centroids of the two discrete areas in the t frame, so the table tennis rotary motion position information d_2 can be expressed as:

$$d_2 = \left\|S_{t-1}^2 - S_{t-1}^1\right\| \quad (8)$$

Set the threshold T_2, and if $d_2 \prec T_2$, the displacement information is calculated. The displacement information d_3 is represented as:

$$d_3 = \left\| (S_t^1 - S_{t-1}^1) - (S_t^2 - S_{t-1}^2) \right\| \quad (9)$$

Set the threshold value T_3. If $d_3 \prec T_3$, expand and merge two discrete areas in the image.

Through the merging of color, displacement and position information, the final table tennis rotating moving target is detected. Figure 1 shows the detection process of table tennis rotating moving objects.

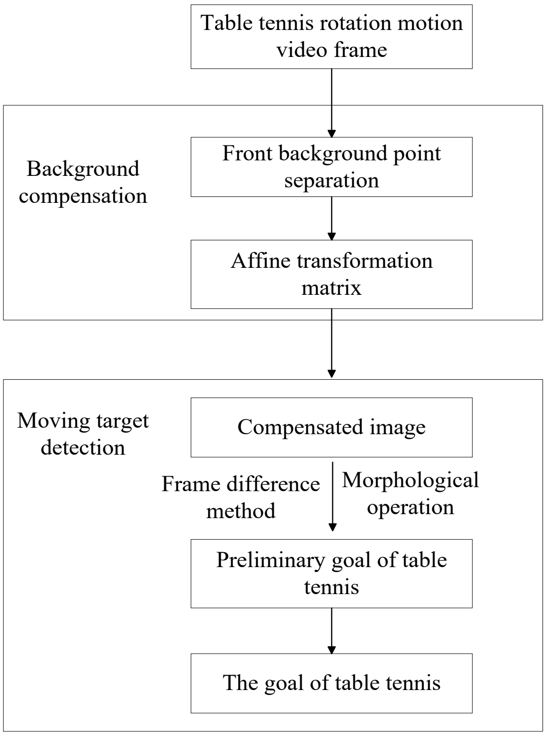

Figure 1 Table tennis rotating moving object detection process

4. Prediction Method of Table Tennis Rotation Trajectory Based on LSTM

Combined with the above detection results of table tennis rotating moving objects, the LSTM based method is used to predict the table tennis rotating motion trajectory [15-16].

LSTM is a special recurrent neural network, which can well solve the long-term dependency problem. The overall structure of LSTM is shown in Figure 2.

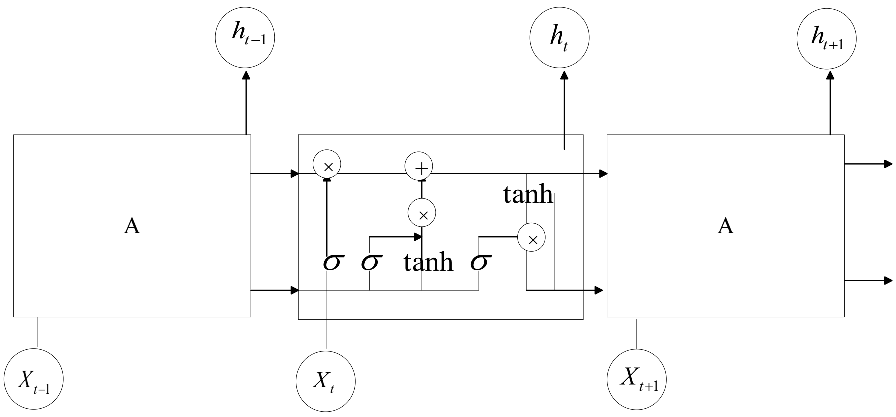

Figure 2 LSTM structure

LSTM adds or deletes information in hidden layer state cells through gating unit. By using the gating method, invalid information can be selectively filtered and effective information can be retained, which can make information transmission more efficient. The basic unit is shown in Figure 3. Consists of sigmoid function and a multiplication operation.

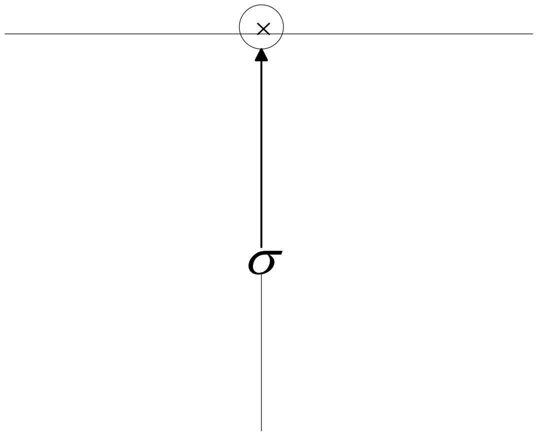

Figure 3 Cell layer structure

The sigmoid function in the forgetting door controls the information of the last moment through the hidden layer unit, and the output of the current moment is affected by the output of the last moment h_{t-1} and the input x_t of the current moment. After passing through the sigmoid layer, the output is between 0 and 1, representing the proportion of some information that passes through.

The output f_t of amnesia gate consists of the output h_{t-1} and offset b_f from the last moment. The three items are weighted and summed. The final output formula of amnesia gate is expressed as:

$$f_t = \sigma\left(W_f \cdot [h_{t-1}, x_t] + b_f\right) \quad (10)$$

Then there is the input gate, which can decide how much information to input into the cell state, so as to generate updated new content. This operation specifically includes two parts. One is the output gate, which transfers the table tennis rotation state information of the previous layer and the current time input to the sigmoid function to determine which information needs to be updated, and multiplies the output and the tanh output. The sigmoid output can determine which information in the tanh output value needs to be retained [17-18].

The input of the input gate is to output h_{t-1} and x_t at the last time and input x_t at the current time. The weighted sum of the two and the bias term is carried out, and the output of the input gate is obtained through the nonlinear activation of sigmoid. At the input layer, candidate vectors $\widetilde{C}_t$ are generated according to h_{t-1} and x_t, which are expressed by formula (11):

$$i_t = \sigma\left(W_i \cdot [h_{t-1}, x_t] + b_i\right)$$
$$\widetilde{C}_t = \tanh\left(W_i \cdot [h_{t-1}, x_t] + b_c\right) \quad (11)$$

On the basis of the above structure, the update of cell status can be completed, and the C_t in the current state can be updated. As can be seen from formula (12), the old state C_t is multiplied by the forgotten layer output f_t, some useless information is filtered, the input layer is multiplied by the candidate value, and the last two are added together to generate the current state C_t.

$$C_t = f_t^* C_{t-1} + i_t * \widetilde{C}_t \quad (12)$$

The final output is obtained by multiplying the tanh output with the sigmoid output.

There are two hidden states h_t and C^t in LSTM. For two δ Define as:

$$\delta_h^\tau = \frac{\partial L}{\partial H^t} \quad (13)$$

$$\delta_C^\tau = \frac{\partial L}{\partial C^t} \quad (14)$$

For the convenience of derivation, the loss function $L(t)$ is divided into two parts, one is the loss of $l(t)$ at the t position at the moment of table tennis rotation, the other is the loss of $L(t+1)$ after the time of table tennis rotation, expressed as: t

$$L(t) = \begin{cases} l(t) + L(t+1) if t \prec \tau \\ l(t) if t = \tau \end{cases} \quad (15)$$

At the index position of the last sequence τ and δ_h^τ and δ_C^τ is expressed as:

$$\delta_h^\tau = \left(\frac{\partial o^\tau}{\partial h^\tau}\right)^T \frac{\partial L(\tau)}{\partial o^\tau} = V^T(\widetilde{y}^\tau - y^\tau)$$
$$\delta_C^\tau = \left(\frac{\partial h^\tau}{\partial C^\tau}\right)^T \frac{\partial L^\tau}{\partial h^\tau} = \delta_h^\tau \cdot o^\tau \cdot (1 - \tanh^2(C^\tau)) \quad (16)$$

δ_h^τ The gradient of is determined by the gradient error output at time t of the layer and by two parts greater than the error at time t, expressed as:

$$\delta_h^t=\frac{\partial L}{\partial h^t}=\frac{\partial l(t)}{\partial h(t)}+\left(\frac{\partial h^{t+1}}{\partial h^t}\right)^T\frac{\partial L(t+1)}{\partial h^{t+1}}=V^T(\widetilde{y}^t-y^t)+\left(\frac{\partial h^{t+1}}{\partial h^t}\right)^T\delta_h^{t+1} \quad (17)$$

The difficulty in reverse propagation of the overall LSTM is the calculation of $\frac{\partial h^{t+1}}{\partial h^t}$. Because $h^t=o^t\cdot\tanh(C^t)$, the recursive relationship of h is specifically contained in o^t, and C^t in tanh can also be expressed as:

$$C^t=C^{t-1}\cdot f^t+i^t\cdot a^t \quad (18)$$

δ_C^τ the error of the reverse gradient is composed of two parts, which are expressed by Formula (19), $\delta_C^{\tau+1}$ represents the gradient error of the previous layer, and h_t represents the gradient error transferred from this layer.

$$\begin{aligned}\delta_C^\tau&=\left(\frac{\partial C^{t+1}}{C^t}\right)^T\frac{\partial L}{\partial C^{t+1}}+\left(\frac{\partial h^t}{\partial C^{t+1}}\right)^T\frac{\partial L}{\partial h^t}\\&=\left(\frac{\partial C^{t+1}}{\partial C^t}\right)^T\partial_C^{t+1}+\delta_C^t\cdot o^t\cdot(1-\tanh^2(C^t)) \quad (19)\\&=\delta_C^{t+1}\cdot f^{t+1}+\delta_h^t\cdot o^t\cdot(1-\tanh^2(C^t))\end{aligned}$$

Adopt δ_h^t and δ_C^t, it can calculate the gradient of prediction parameters of table tennis rotation track in LSTM, for example, the process of calculating W_f gradient is represented as:

$$\frac{\partial L}{\partial W_f}=\sum_{y=1}^{\tau}\left[\delta_C^t\cdot C^{t-1}\cdot f^t\cdot(1-f^t)\right](h^{t-1})T \quad (20)$$

The prediction network of table tennis rotation track receives the position information of table tennis at the current moment, outputs the coordinates of table tennis at the next moment, and the LSTM network structure is shown in Figure 4 [19-20].

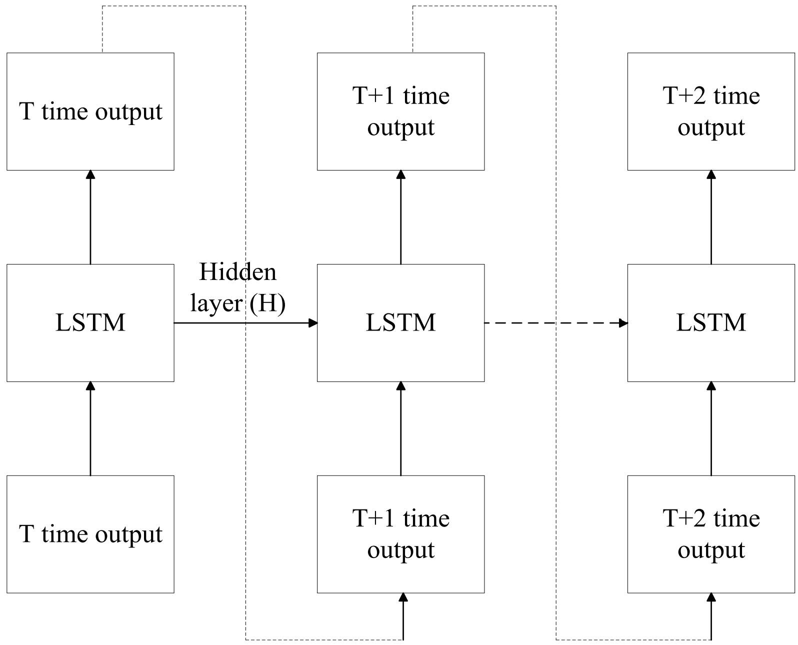

Figure 4 Overall network structure of LSTM

During network training, the network evaluates and optimizes the output predicted value based on the information of the known table tennis rotating motion track. The average spatial distance between the predicted value $P(x_p, y_p, z_p)$ and the actual value $R(x_r, y_r, z_r)$ is calculated by the accuracy of the predicted coordinates, which is expressed as:

$$D = \sqrt{(x_r + x_p)^2 + (y_r + y_p)^2 + (z_r + z_p)^2} \quad (21)$$

The analysis of table tennis rotation track based on deep learning is completed by the above steps.

5. Experimental result

In order to verify the validity of the table tennis rotating motion track analysis based on deep learning proposed in this paper, simulation experiments are carried out. Table 1 represents the experimental platform data.

Table 1 Experimental platform data

Experimental platform	data
operating system	win7
processor	Intel i7
Running memory	6GB
simulation environment	VS2010

This paper conducts hit experiments for different types of rotating table tennis. The ball speed is divided into two types: slow ball (4m/s) and fast ball (6m/s). The feasibility of the methods presented in this paper in the analysis of table tennis rotating motion track is verified, which is indicated by Table 2.

Table 2 Results of rotary table tennis hitting test

	changeup					fire ball				
Rotation type	0	1	2	3	4	0	1	2	3	4

Number of experiments	200	50	50	50	50	200	50	50	50	50
A number of successes	97	-	-	-	-	68	-	-	-	-
A success rate /%	48.5	-	-	-	-	34.4	-	-	-	-
B number of successes	158	36	34	37	29	137	25	22	25	21
B success rate /%	79	72	68	74	58	68.4	49	43	48	40

In Table 2, A stands for comparison test, 0 for no spin ball, 1 for top spin ball, 2 for left spin ball, 3 for down spin ball, and 4 for right spin ball. Under the condition of fastball, the hit success rate of 68.4% can be achieved for the ball without rotation. For table tennis with rotation, the relative success rate can be guaranteed in the process of slow-ball hitting. This shows that the method proposed in this paper can take into account the characteristics of table tennis rotation, and provide guarantee for the players'choice of hitting posture. Fig. 5 shows the accuracy comparison of table tennis rotating target detection using the methods presented in this paper with those in literature [3] and [4].

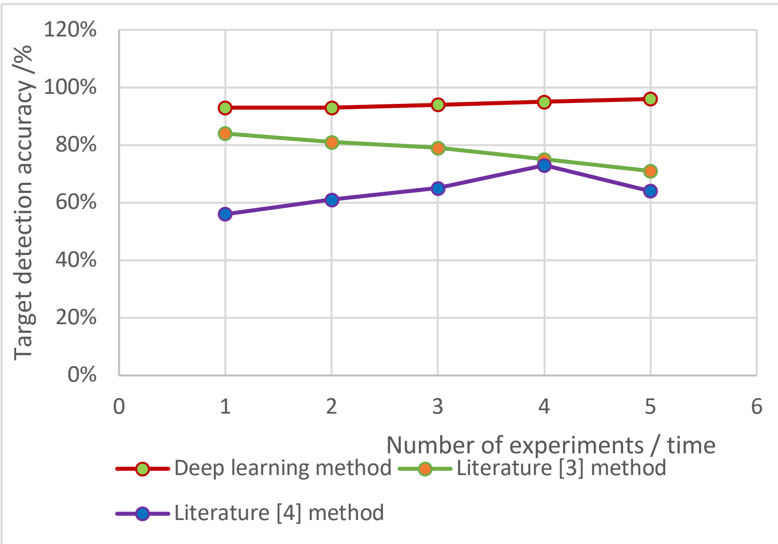

Figure 5 Comparison of accuracy of table tennis rotating moving object detection by different methods

By analyzing Fig. 5, it can be seen that the accuracy of target detection in table tennis rotating motion using the methods mentioned in the literature [3] is higher in five experiments. Although the accuracy of target detection in the first experiment is higher, the overall trend is gradually decreasing. The accuracy of target detection in table tennis rotating motion using the methods mentioned in [3] has been maintained between 60% and 80% in five experiments, although it shows an upward trend. When using the methods mentioned in this paper, the accuracy of detection of rotating table tennis targets has been stable. From the above data, it is shown that the two literature methods are not suitable for the detection of table tennis rotating sports target, but the methods mentioned in this paper can ensure the accuracy of the detection of table tennis rotating sports target. Figures 6 and 7 show the comparison of prediction accuracy between the proposed method and ODE-based method for table tennis rotation track prediction.

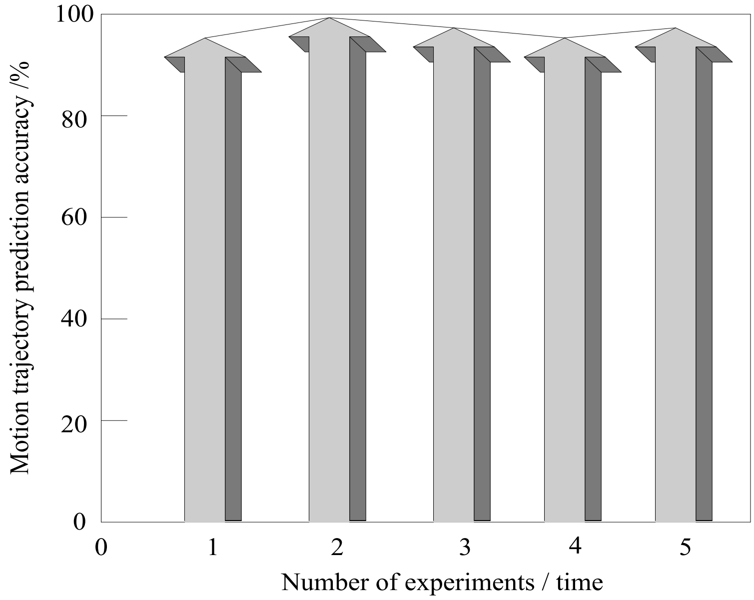

Figure 6 Prediction accuracy of table tennis rotation trajectory of the method proposed in this paper

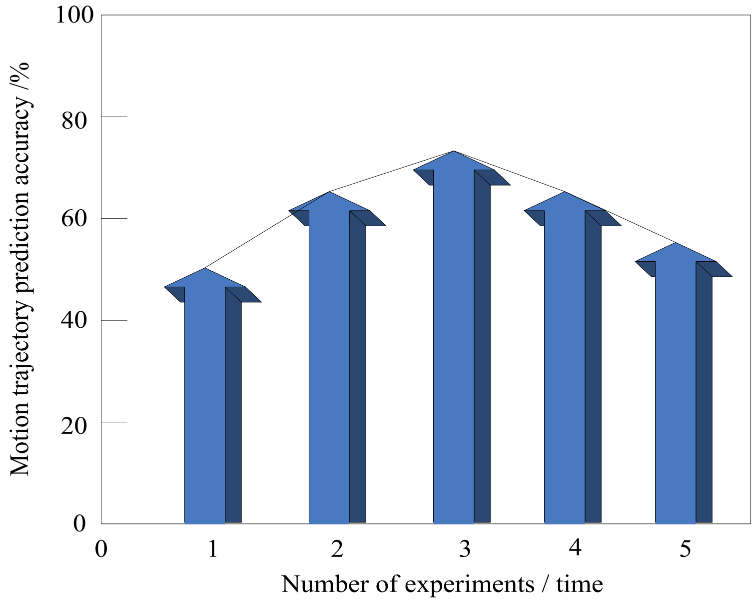

Figure 7 Prediction accuracy of table tennis rotation trajectory based on Ode

From Figure 6 and Figure 7, it can be seen that there are some differences in the prediction accuracy of five times using ODE-based table tennis rotating motion track prediction method. The third experiment has the highest prediction accuracy, but it does not reach 80%. The prediction accuracy of table tennis rotating motion track prediction method based on deep learning proposed in this paper has been stable, and can reach more than 90% in all five experiments. Therefore, the track prediction method based on deep learning can effectively improve the accuracy of table tennis rotating motion track prediction, and thus improve the efficiency of athletes training. Table

3 shows the comparison of the predicted speed of table tennis rotating track between the methods presented in this paper and those in references [5] and [6].

Table 3 Comparison of prediction speed of table tennis rotation trajectory by different methods

different methods	Trajectory prediction speed / s
Methods in this paper	15
Literature [5] method	26
Literature [6] method	34

It can be seen from Table 3 that the speed of prediction of table tennis rotation trajectory using the method proposed in literature [5] is 26 seconds, the speed of prediction of table tennis rotation trajectory using the method proposed in literature [6] is 34 seconds, and the speed of prediction of table tennis rotation trajectory using the method proposed in this paper is 15 seconds, which is obviously superior to the other two literature methods, Moreover, the speed predicted by the method proposed in literature [6] is more than twice the speed predicted by the method proposed in this paper. This shows that the method proposed in this paper can effectively improve the speed of trajectory prediction, improve the efficiency of athletes' training, and save the economic cost of training when applied to the prediction of the rotation trajectory of table tennis.

6.Conclusions

In the visual system, how to detect and predict the moving trajectory of a rotating spherical object has important research significance and application value. The rotating trajectory of table tennis attracts a large number of researchers to conduct in-depth research. Therefore, this paper uses the depth based learning method to predict the rotation trajectory of the table tennis ball. First, it detects the rotation target of the table tennis ball. On the basis of the detection results, it uses LSTM prediction network to predict the rotation trajectory of the table tennis ball. The effectiveness of the proposed method is verified by experiments, which can effectively improve the accuracy of the prediction of the rotation trajectory of the table tennis ball, thus improving the training efficiency of table tennis players, Improve sports competitive ability.

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