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Research Article

Analysis on the Application of Region-growing Algorithm in Table Tennis Trajectory Simulation

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Abstract: Table tennis robot is an important assistant in table tennis players' trainings. During partner trainings, table tennis robot is designed to simulate the motion trail of table tennis by tracking its trajectory after players' batting. As for this, it is consequently of great importance for the robot to real-timely adjust its hitting position and force. In this study, the trajectory of table tennis is divided into two categories: trail tracking and trail prediction, so as to construct the region-growing tracking model and perfection model for table tennis trajectory. On this basis, by drawing support from region-growing algorithm, we are to analyze the motion trail of table tennis captured by video equipments, to simulate its trajectory and to compute the motion speed and other importance information of table tennis in different direction and time. Then, the information acquired will be taken as conductions and input into trail prediction model, so as to precisely simulate the trajectory of table tennis.

Keywords: Region-growing algorithm, simulation, table tennis trajectory

INTRODUCTION

In the 2012 London Olympic Games, China's players again won 4 gold medals in Men's Single, Women's Single, Men's Team and Women's Team, ending the games with 4 gold metal and 2 silver metals. This was the fourth time that China's players won all gold medals in table tennis. As China's national game, table tennis has wide and solid foundation among the Chinese people. China's table tennis team has strong competence (Pei-Yan and Tian-Sheng, 2007). This can never go without long term accumulation, as well as industrious and efficient training. Table tennis is a high aggressive sport event. In daily trainings, every excellent player needs a partner training teams as a support. The performance of the partner training team inevitably affects the improvement of the player's skill (Jian-Dong *et al*., 2011). Owning to large volumes of partner trainers, on the one hand, players' competence is different because of their different level; on the other hand, the expenditure for cultivating players is also increased. As for this, it has become a troublesome problem in high antagonistic sports for us to find high efficient partner trainers of one-off investment and long term use.

With the development of intelligence technology, robot technology and computer technology, man-machine confrontation has gradually become a first choice for players' routine trainings. Table tennis robot is also referred to in increasingly more researches, with the aim to replace the role of partner training team. However, present table tennis robot has not yet been used in real trainings, or has unsatisfied performance in real trainings (Ait-El-Fquih and Desbouvries, 2011). On the one hand, it is restrained by computer hardware and software. On the other hand, precise simulation and prediction of table tennis motion trail is also an important technical bottle neck. China's related scholars have conducted effective explorations on table tennis trajectory simulation (Chengjiang *et al*., 2011). By researching the motion features of table tennis after hitting the board, Yang and Guan (2011) had figured out the mathematical and difference equation in mechanics during the collision process between tennis and table. On this basis, the rebounding speed and time of table tennis in the whole process had been simulated and the changing rule of rebounding frequency and rebounding height along with time had been disclosed (Lionel *et al*., 2012a). Based on numerical theory, Yang and Guan (2011) had constructed the dynamic model of table tennis by applying the knowledge from aerodynamics. They had designed and realized the ODE-based interactive and visual simulation environment. Moreover, the motion trail of table tennis under different spinning situation was also simulated, with very good effect achieved. With regard to the errors resulted by blurring image, air drag, camera imaging distortion and other factors in the high speed motion of table tennis, Zhang *et al*. (2009) proposed a self-adaptive and discrete Kalman trajectory computation method to measure the covariance. This method can accurately track the motion trail of the

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target object. These researches have to some extent provided reference for researches related with table tennis trajectory simulation. Even so, pure mathematic computation is far from enough to consistently and completely describe the process. What's more, the above theories are only applicable to low speed (around 5 m/s) situations. Thirdly, simulations based on third-party software cannot fully solve the problem of real-timely simulating table tennis trajectory on the training site (Lionel *et al*., 2012b).

Based on aerodynamic theories, the study has applied region-growing algorithm in image segmentation and has successfully constructed the model to simulate table tennis motion trail. This model is designed to real-timely capture the video data after players' hit the ball and then to segment and process the data, so as to simulate the motion trail of table tennis before it falls onto the ground. On this basis, numeral model will be utilized in the computation, to analyze and predict the drop point and rebounding path and to provide numeral reference for robots to choose the correct batting position, as well as to use the proper batting force (Jean-Philippe *et al*., 1997).

REGION-GROWING ALGORITHM

When being applied in image segmentation, region-growing algorithm is often designed to segment and identify captured image, so as to acquire the motion information of target object in the video material (Revol-Muller *et al*., 2002).

Image segmentation: Image segmentation is designed to differentiate irrelevant regions with special meanings from each other, so as to extract from the image the parts that users are interested in. Image segmentation is an important constituent part in image processing technology, which takes an important position in image engineering (Andrew and Paul, 1997). Image segmentation technology is mainly comprised by the following procedures: outlining of the image target, figuring out the threshold value of the image for subsequent detection, identification and tracking. Through segmentation-based image information description, extraction and measurement, it is able to convert target elements in the image into information required by users, so as to realize multi-target image processing (Chantal and Michel, 1997).

Concerning image segmentation, researchers have conducted explorations from many aspects and have presented different explanations and descriptions. Among all these research theories, the simplest and most scientific one is to analyze image segmentation by applying the concept of set. It is defined as follows: assuming that Set R stands for the whole image, while R is comprised by non-void subsets of R_1, R_2, R_3…R_N (with the total amount of N), while these subsets comply with the following conditions:

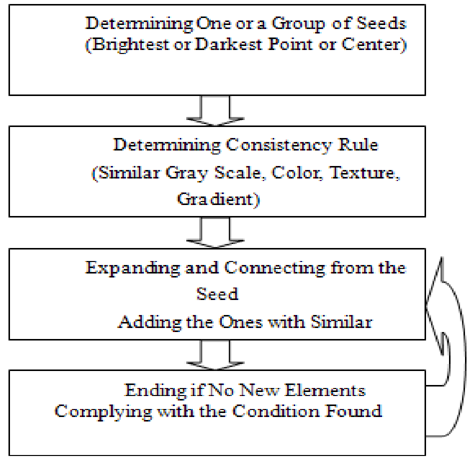


Fig. 1: Procedures of region-growing algorithm

- In segmentation results of each region, the same region has identical pixel
- In segmentation results of each region, different regions have different pixels, i.e., they are mutually different from each other
- By combining all segmented sub-regions, we may obtain a complete image that originally needs to be segmented
- Regions of all subsets are inter-connected

There are many image segmentation methods, such as threshold segmentation, border segmentation, region extraction, etc. Among all these method, the most frequently used methods in region extraction are region-growing, as well as split and mergence.

Region-growing algorithm: Region-growing algorithm is also referred to as region growing (Khalid and Majida, 2009). It is a process that aggregate pixels or sub-regions into larger regions according to pre-defined rules. This algorithm mainly takes into consideration pixels and their spatial and adjacent relations. The basic ideology of region-growing is to gradually grow towards the borders of the region via seed pixel and with the seed pixel as the center. On this basis, according to a certain query rule, the maximum region complying with the consistency condition can be figured out (Anna, 2009). Here, the query rule is just the consistency condition, which includes having the same intensity, gray scale, texture color with the seed pixel. By merging these pixels with their adjacent pixels that have the consistent property, we will be able to get a merged region with the seed pixel as the center. This process will be repeated, until all pixels in the image have been processed. The major ideology of image-growing algorithm is to determine the seed region according to a certain measurement method and then the seed region will be taken as a consistency standard for growing (Chien-Yuan *et al*., 2005). The procedures of region-growing algorithm are shown in Fig. 1:

The complete process of region-growing algorithm is to conduct pre-and-post processing over the information. Pre-processing of region-growing is to extract the target information, while processing after growing is designed to merge split information, so as to get complete information material.

Processing before region-growing: If describing with the term of set, region-growing and splitting process shall be: assuming that Set R represents the whole region of image, dividing R into N parts, so that, in region-growing algorithm, non-void subsets complying with the following 5 conditions are considered to be regions that can be merged:

- $\bigcup_{i=1}^{N} R_i = R$
- For all i and j, i is unequal to j, then $R_i \bigcap R_j \neq \phi$
- For i = 1, 2…N, then PR_i = True
- For i = unequal to j, then $P(R_i \bigcup R_j) = False$
- For i = 1, 2…N, R_i is the connected region

PR_i = the logic predicate to all elements in Set R_i, while ∅ stands for null set.

Processing after region-growing: In region-growing process, nonparametric configuration method is often adopted, which may lead to insufficient growing or excessive growing of the region. As for this, we need to process the image after region-growing and splitting, so as to optimize the problems of insufficient growing or excessive growing. Post-processing can be conducted by integrating the splitting information. The normally adopted method is to apply the initial uniformity standard and corresponding rules to process minimum regions that that cannot be combined with pixels in its adjacent regions in the split image, so as to reduce the number of these regions.

Region-growing splits a single large region, which may creates many small regions. For this reason, smaller regions need to be merged according to their similarity, to make smaller regions more intensified. Region mergence often follows the below procedures:

Step 1: Dividing the image into regions of R_1, R_2, R_3…R_m according to the method of threshold set.

Step 2: Generating adjacent region mergence image according to the region description in region splitting.

Step 3: Ensuring that in RAG, for all R_j, i = 1, 2…m and all R_j, j ≠ i, then R_j and R_j adjoin.

Step 4: For all i and j, computing the appropriate similarity degree S_{ij} between R_j and R_j.

Step 5: If S_{ij}>T, then merge R_j with R_j.

Step 6: Repeating Step 3-5 according to splitting similarity description standard, until no regions need to be merged.

TABLE TENNIS TRAJECTORY NUMERIC MODEL

Force model: Table tennis motion trail does not take into consideration players' batting process. The only course considered is its free motion in space at a certain time point. According to First Law of Newton, table tennis is mainly affected by three forces: Gravity-G, Air Drag-F_a, Magnus Force-F_m. The balance model of the three forces is:

Assuming that the weight of the table tennis is m, speed is v, flying vector speed $\vec{v}$, angular speed $\vec{w}$, air density ρ, drag coefficient of table tennis C_d, Magnus lift coefficient C_m and face area A, we may figure out the force bearing situation of table tennis as described below:

$$G + F_m + F_a = 0$$
$$G = mg$$
$$F_a = \frac{1}{2} C_d \rho A v^2$$
$$F_m = \frac{1}{2} C_m \rho A \left|\vec{v}\right|^2 \frac{\vec{w}}{\left|\vec{w}\right|} \times \frac{\vec{v}}{\left|\vec{v}\right|}$$

Drag C_d and Magnus lift coefficient C_m is measured via experiment according to the conditions on site.

By decomposing the forces, we may get the force bearing information of table tennis, as is shown in the Fig. 2.

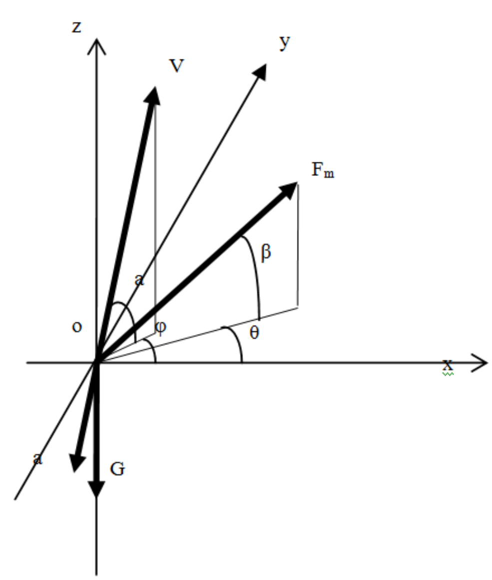


Fig. 2: Table tennis force bearing information

In the diagram, α is the intersection angle between translation speed v and Plane XOY; φ is the intersection angle between the projection of translation speed vector on Plane XOY and Axis x; β is the intersection angle between Magnus force and Plane XOY; θ is the intersection angle between the projection of Magnus force on Plane XOY and Axis x; while T refers to time. On this basis, we may construct the force bearing model of table tennis trajectory as follows:

$$m\left[\frac{dv_x}{dt},\frac{dv_y}{dt},\frac{dv_z}{dt}\right]^T=\begin{bmatrix}\cos\partial\cos\varphi & \cos\beta\cos\theta & 0\\ \cos\partial\sin\varphi & \cos\beta\sin\theta & 0\\ \sin\partial & \sin\beta & 1\end{bmatrix}\begin{bmatrix}F_a\\ F_m\\ G\end{bmatrix}$$

Trajectory prediction model: Based on the force-bearing model, we shall then analyze forces born on different directions, so as to separately predict the motion trail of table tennis along each coordinate axis. Assuming that the initial speed of table tennis at a certain position are separately V_{x0}, V_{y0}, , V_{z0}, , then the speed of table tennis along Axis x, y and z shall be*:*

$$V_x(t)=V_{x0}e^{-kt}$$
$$V_y(t)=V_{y0}e^{-kt}$$
$$V_z(t)=V_{z0}-(V_{z0}+\frac{g}{k})(1-e^{-kt})$$

By calculus the above formula, we may figure out that the position of table tennis at Time t shall be:

$$S_x(t)=S_{x0}+\frac{V_{x0}}{k}(1-e^{-kt})$$
$$S_y(t)=S_{y0}+\frac{V_{y0}}{k}(1-e^{-kt})$$
$$S_z(t)=S_{z0}+(\frac{V_{z0}}{k}+\frac{g}{k^2})(1-e^{-kt})-\frac{g}{k}t$$

TABLE TENNIS TRAJECTORY SIMULATION ANALYSIS

Analysis process: By constructing the region-growing model and motion trail model of table tennis, we will be able to simulate the trajectory of table tennis (Fig. 3). This process is comprised by four steps, as well as two sections: trail tracking and trail prediction, as is shown in Fig. 3:

- **In step 1 and step 2:** By continually captured the video information of players' batting, we will be able to get the video and image of table tennis motion trail. On this basis, motion trail of table tennis can be predicted with region-growing algorithm, so as to deduce reversely the force bearing area of table tennis, as well as the intersection angle between its gravity, moving direction and all coordinates. The information acquired can provide corresponding data for us to simulate the drop point, force and rebounding height of table tennis in subsequent steps.
- Step 3 inputs the information acquired via region-growing algorithm into trajectory numeric mode, so as to figure out the position, speed and rotating direction of table tennis in each time point and to provide data for robot's batting position, force and direction in the 4th step.

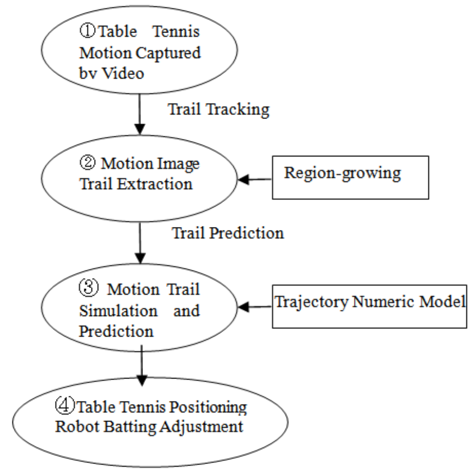


Fig. 3: Table tennis trajectory analysis process

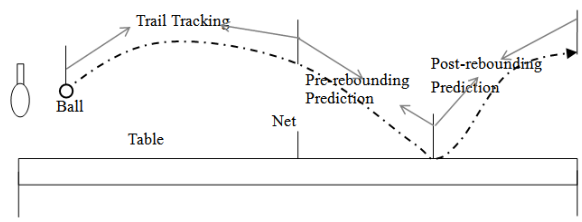


Fig. 4: Table tennis motion trail tracking and prediction

The time period for trail tracking is from the player's batting to the ball's flying above the net, which is executed by applying region-growing algorithm in video monitoring. Trail prediction is comprised by two sections: pre-rebounding and post-rebounding. In pre-rebounding prediction, the trail of ball before hitting the table will be calculated with numeric model, according to initial speed, initial position and other related information obtained in trail tracking. In post-rebounding prediction, the trail of table tennis after it hits the table will be predicted. Table tennis trajectory tracking and prediction is shown in Fig. 4. The focus of this study is to apply region-growing analysis method to analyze table tennis trail tracking, so as to provide data information for simulation in prediction phase.

Table tennis trajectory region-growing analysis:

Image pre-processing: The image source is motion of table tennis captured by single-lens video camera, which has been pre-processed via median filtering and gray scale processing.

Median filtering smoothing: Smoothing for table tennis video has applied median filtering. Median filtering is a sort of nonlinear filtering. As it does not require the statistical features of image in practical computation process, so that it is a quite convenient technology. Median filtering was initially applied in one-dimensional signal processing. Later on, it was also adopted by two-dimensional image signal processing. Under certain conditions, this technology can solve the problem of blurring image resulted by linear filter. Moreover, it is also quite effective in removing impulse interference and image scanning noise. Median filtering is designed to remove noise on the premise of protecting image borders.

Median filtering is comprised by two situations: one-dimension and two-dimension. One-dimensional filtering can be regarded as a window with 2n+1 pixel. Through median filtering processing, the mean value of pixels' gray scale in the window will be used to replace the gray scale of the central pixel in the window. This process is defined as follows: assuming that there is a dimension series f_1, f_2… f_n, setting the length of the window to be an odd number m, so that the process to process the series with median filtering is to continually extract m numbers from the input series, $f_{i-v}…f_i…f_{i+v}$, in which the central value of window shall be v = (m-1) /2. On this basis, sequence the values of the m points in descending order and output the central value of the series as the filtering. The expression of median filtering is:

$$F_i = Med\left\{f_{i-v},\cdots,f_i,\cdots,f_{i+v}\right\}$$

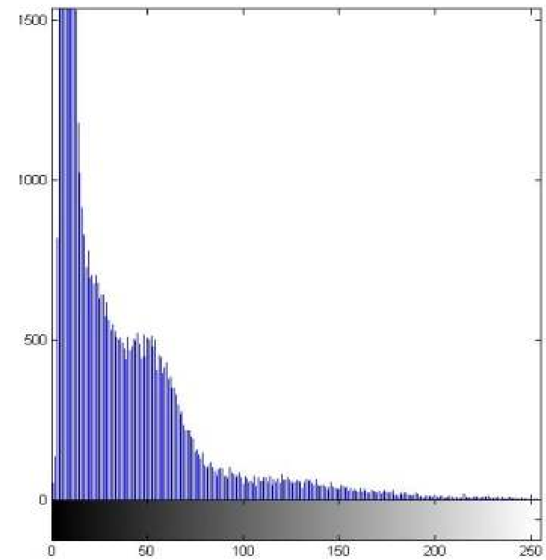
For median filtering of two-dimensional series $\{X_{i,j}\}$, the filtering window is also two-dimensional. However, such two-dimensional window can take on different shapes: line, square, round, cross, ring, etc. Two-dimensional median filtering can be described as follows:

$$F_{i,j} = \underset{A}{Med}\left\{x_{i,j}\right\}$$

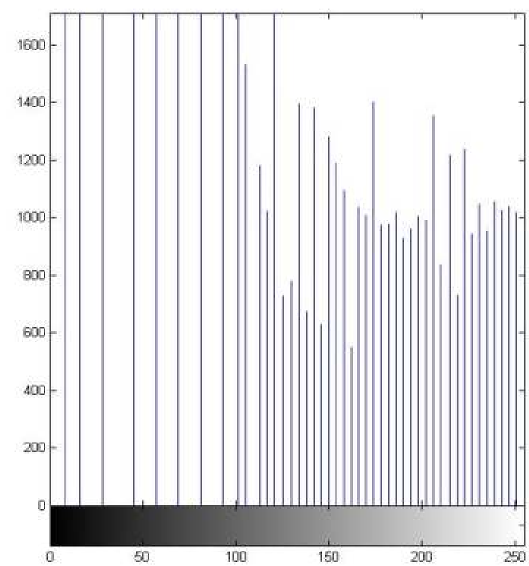
where, A is Filtering window

In practices, the window size shall firstly adopt 3×3, then 5×5, to grow gradually, until reach to the satisfying filtering effect.

Gray scale adjustment: Gray adjustment is an important measure in image process. By expanding the contrast ratio of image, the image can become clearer, with more obvious details. Normally, gray adjustment plays an important role motion image processing. Owning to insufficient exposure or excessive exposure, gray scale of images is often within a small range, so that images are blurring, with no obvious gradation. Normally, linear gray scale adjustment is often adopted to linearly stretch each pixel in each frame of image, which may greatly improve the visual effect of image, making the image clearer, with more details. In image pre-processing, this study also conducted gray scale processing over the video image of table tennis. The finial adjusted image effect is demonstrated in Fig. 5.



(a) Original histogram



(b) Adjusted histogram

Fig. 5: Histograms before and after gray scale adjustment

It can be seen from Fig. 2 to 4 that, the visual effect of (b) is much better than that of (a). Seeing from the histogram before and after the adjustment, Histogram (d) has remove noise in Original Histogram (c). After gray scale adjustment, the image becomes clearer.

Region-growing analysis: In table tennis trainings, table tennis often modes at a high speed. This feature is quite advantageous when determining region-growing rule with gray scale. Thus, we may consider taking gray scale different as the region-growing rule. Assuming that there is an image area R, with N pixel, while the mean value of gray scale is:

$$m = \frac{1}{N} \sum_{R} f(x, y)$$

Comparison to pixel is:

$$\max_{R} | f(x, y) - m | < T$$

in which, T is the threshold value.

Region segmentation over table tennis trajectory image is mainly implemented via the following procedures:

- Firstly, segmenting frame by frame the motion video of table tennis captured by the single-lens camera into N images.
- Progressively scanning the N images acquired and find out the pixels (normally the brightest region) with the same gray scale with the seed pixel from the analyzed image.
- With table tennis gray scale seed pixel as the center, we will then check its adjacent pixels, as well as compare the gray scale of all pixels in the region. If the gray scale is higher or equal to the seed pixel point, they shall be merged.
- With the merged pixel as the center, repeat Step 2, until this region cannot be expanded any more. Storing the position information of this region as Pm, the area of the region obtained as Am; here, m refers to the mth image; storing the videoing time of the mth image as T_m; the intersection angle between motion direction and x, y, z as V_{xm}, V_{ym}, V_{zm}; keeping the values of all variables.
- Repeat Step 2 and 3, until all image regions have been analyzed. On this basis, record the positions of all regions as P_1, P_2…P_n.
- Establish a new coordinate system; draw the positions of P_1-P_n in the system; the continual line obtained is just the tracked motion trail of the table tennis.

Table tennis motion trail simulation result: The positions of N points, the speed at the time of T, the

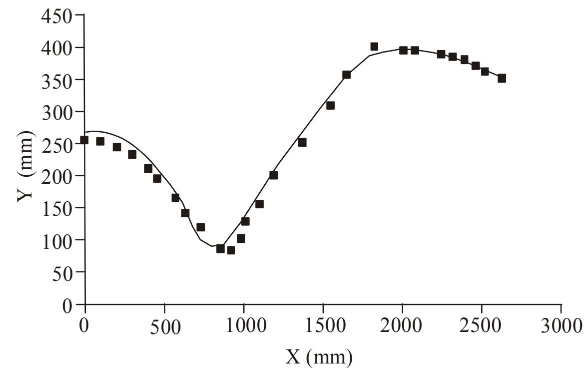


Fig. 6: Prediction result and trail measurement

speed in three directions, surface area and other values obtained in the 4th Step of region-growing analysis will Be taken as the initial value and input into table tennis motion trail simulation model. As for this, we will be able to get the motion path of table tennis. Based on the aforementioned procedures, the study has drawn the measurement trajectory and prediction trajectory in Fig. 6. The diameter of the table tennis is 40 mm, weight 2.7 g, initial height 1.3 m and speed 6.8 m/s. It can be seen from the diagram that, this prediction result prefect matches with the measurement result.

CONCLUSION

Table tennis trajectory simulation is of great importance to table tennis training. On the basis of summarizing predecessors' research achievements in table tennis trajectory simulation, the study further analyzed region-growing algorithm with gray scale as the growing principle. On this basis and by integrating sports mechanics, table tennis trajectory simulation model was constructed. By dividing table tennis motion trail into trail tracking and trail prediction, table tennis image information captured by video equipment was then segmented with region-growing algorithm, for subsequent trail tracking, so as to get the real-time trail information of table tennis. By inputting the information into trail prediction model, we will be able to precisely simulate and predict the motion trail of table tennis. Shown by the research results in this study, by organically combining computer video technology with numeric simulation technology, we will be able to perfectly solve simulation and prediction problems in objects' motion.

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