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Intelligent Data Analysis Model in Tennis Intelligent Training Simulation Design

Xiazhong Chen*

Hunan University of Science and Technology, Xiangtan, Hunan 411201, China

**corresponding author*

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Abstract: With the increasing attention and love of tennis, much tennis-related auxiliary equipment emerges as the times require. A large number of companies specializing in tennis-assisted teaching have emerged in China and internationally, and have achieved some achievements. The main purpose of this paper is to discuss how to use the method of intelligent data analysis to carry out the simulation design of tennis intelligence training. This paper introduced an auxiliary tennis intelligent training simulation system designed by using image processing technology. The auxiliary sports training system used the method of human posture estimation to quantitatively analyze and compare the postures of athletes and coaches, so as to provide coaches with more intuitive exercise analysis and guidance. The experimental results of this paper showed that the highest recognition rate was 100%, and the lowest was 98.0%; the highest accuracy rate was 98.0%, and the lowest was 96.4%. It can be seen that the simulation system had a high recognition rate of actions in tennis training. It is very meaningful to apply the intelligent data analysis model to the simulation design of tennis intelligent training. The system can not only correctly identify the movements of athletes, but also can compare their movements with those of the coaches, so as to correct wrong movements and improve the efficiency of training.

1. Introduction

According to reports, tens of millions of Chinese citizens like to play tennis. Tennis has developed rapidly among the sports that young people like at present, especially in recent years. Tennis players use intelligent assisted simulation training to identify the technical movements they frequently perform in sports and improve their athletic ability. For those who love tennis, these stats are crucial. Now the development trend of intelligent assisted training is that people would start to pay more attention to the performance of intelligent sports equipment. In the next few years, the smart sports equipment product and application market would mature rapidly. In order to better meet the needs of users and achieve better interpretation and analysis of sports information, it is inevitable to develop new smart devices, such as tennis training systems.

International tennis has recently entered a phase of tremendous development. Tennis has grown to become the second largest sport in the world due to a dramatic increase in spectator and commercialization. China's women's tennis has entered a new era, especially in recent years, due to the outstanding performance of outstanding women's tennis players on the international stage, Chinese women's tennis has made remarkable progress in quality. However, compared with the outstanding female tennis players in China, youth tennis training started late, which deserves full attention. Whether it is technical or physical, athletes still have room for improvement. Tennis professionals need to carefully consider key factors in fitness level. The innovation of this paper is that it proposed a human pose estimation algorithm based on an intelligent data analysis model, and designed a tennis intelligent training simulation system. The system recognized the movements of athletes and coaches, which can improve their training efficiency and accuracy.

2. Related Work

As tennis is more and more respected by the public, tennis-specific auxiliary training equipment begins to appear. According to Baiget E, the proper design of training programs depends on the control and quantification of internal and external training loads. Technical proficiency and endurance training, as well as mental and tactical abilities, are critical to tennis performance. Therefore, it can be beneficial to use test and training loads and to consider physiological and technical aspects [1]. In order to model service velocity and location, Anbarci N used a semi-parametric additive mixture model including smooth 1D, 2D, and 3D interactions. The results of the study showed that players who were behind in scoring would make more effort [2]. Cohen-Zada D argued that the sequence of events in tennis matches may have various psychological consequences that alter the probability of a player winning. Furthermore, it is theoretically possible to end any advantage any player has in consecutive matches [3]. According to Kovalchik S A, regulators have recently been implementing new tournament formats to shorten playing times, which has been a general concern in professional tennis [4]. The aim of the Subijana C study was to analyze whether there are gender differences in the level of play and to describe the dual careers of tennis players in the region. It was found that these athletes lacked both a plan for the future of sports and a plan for their personal life [5]. Scholars have found that tennis is becoming more and more popular, so tennis training is essential.

With the advancement of information technology, the introduction of computers with increasingly powerful processors and precise sensors has encouraged human progress. Many fields are rapidly adopting new technical terms, such as cloud computing, big data, Internet of Things, artificial intelligence, etc., and every subject area of the industry has changed. Haridas A V found that researchers interested in artificial intelligence and information processing have long been interested in the recognition of human actions. In recent years, academia has carried out some research in this field [6]. Bo found that timely walking rehabilitation training is particularly important for people who have temporarily lost their ability to walk due to a car accident or fall. Researchers have created an intelligent walking training robot and tested it clinically to demonstrate its efficacy. Users rely on this robot to walk along a series of pre-planned paths for training [7]. Song T believed that without a formal training program, it was difficult for most people to understand the meaning of different gestures. In order to understand complex human gestures, he proposed a new framework for human-computer interaction. This framework has the ability of mass perception and uses multi-view feature learning algorithm as its core technology [8]. According to Gieczyk A, fingerprint and facial recognition are now commonplace in contemporary life. Biometrics has recently gained popularity as an intelligent and secure authentication mechanism.

He proposed a palmprint-based user authentication method, which is suitable for mobile devices and is time-efficient in terms of computation [9]. The popularity of tennis has also led to the development of various complex training aids. Intelligent simulation training can not only recognize the posture of athletes, but also correct their posture.

3. Human Pose Estimation Algorithm Based on Intelligent Data Analysis Model

The majority of traditional sports training techniques rely on eye watching. Athletes' actions are now being recorded and studied using cameras thanks to advancements in computer vision technology [10]. The sports improvement plan is then provided in accordance with the applicable human physiology and physics principles after the sports characteristics of athletes are properly quantified and compared. The technical proficiency and performance of athletes are thereby improved scientifically, which transcends the conventional sports training method that exclusively depends on experience [11].

With people's attention to physical health, the application of intelligent sports equipment is also increasing. Sports watches, sports shoes and other sports equipment featuring smart wear, sports data collection, and high-definition display, as well as smart fitness equipment and other new smart sports equipment have entered people's attention [12]. Smart tennis is shown in Figure 1.

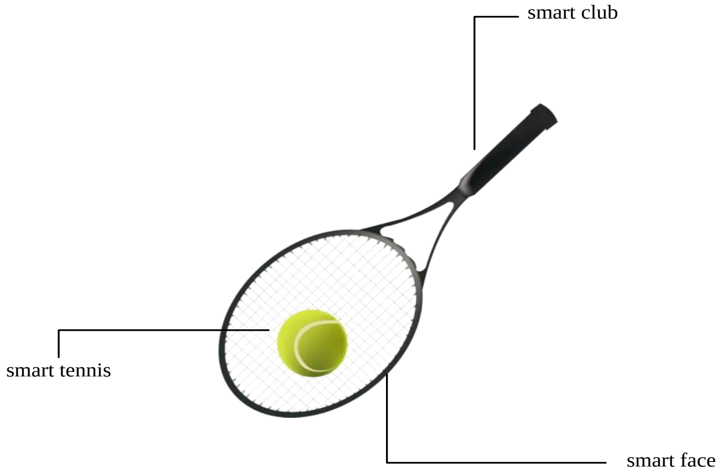


Figure 1. Smart tennis racket

A famous tennis racket manufacturer has released a smart tennis racket as shown in Figure 1. The tennis racket has a built-in sensor, which can track the user's swing strength, hitting speed, hitting point and other information during the swing process, and upload the collected data to the corresponding application for the user's reference [13]. The research results have shown that the combination of somatosensory technology and motion recognition algorithm can provide more scientific and comprehensive healthy exercise for the public, especially for students who need to strengthen physical exercise.

The focus of research workers and research units has shifted to people-oriented technology research and development and product design, and the use of computer vision technology in physical education is also starting to take shape [14]. In order to analyze movement posture and offer training recommendations, this article would use computer vision technologies to follow and detect the moving human body, so that the sports training can be transformed from the traditional experiential training to the movement analysis mode based on computer vision. Through the analysis of the above research results, it can be found that intelligent sports training simulation has great application potential in theory, science and engineering.

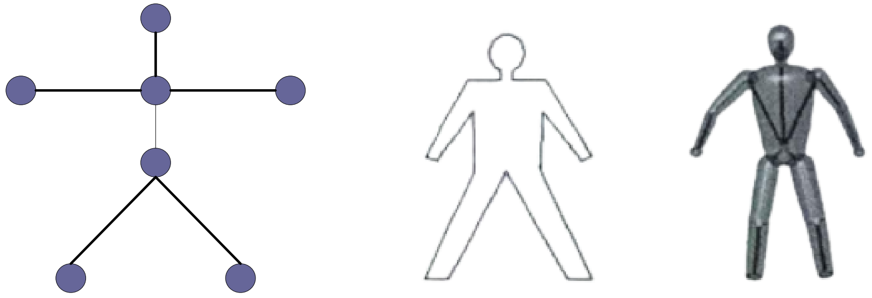
3.1. Human Pose Estimation Algorithm

(1) 3D modeling

With the use of high-tech tools like human-computer interaction technology, the Internet of Things, cloud computing, big data, etc., sports equipment can be made digital, networked, intelligent, and entertaining. It overcomes time and space constraints, enabling people to engage in scientific physical activity more readily and intelligently. Smart sports bring a brand new opportunity for national fitness [15].

The estimation of human body pose is mainly to obtain information such as the position and angle of the human body in 2D and 3D space. By using the method of human posture estimation, the postures of athletes and coaches can be quantitatively analyzed and compared, so as to provide trainers with more intuitive motion analysis and guidance [16]. Therefore, it focuses on the research of human pose data in video and image sequences.

The development of the human body model is based on modeling, and the feature variable space is effectively constrained by the knowledge base to speed up algorithm execution and narrow the matching search space. One-dimensional, 2D, and 3D human body models can be categorized, with the most popular types being bone models, silhouette models, and 3D bone models. The skeleton model includes points and lines, which represent joints and bones, respectively. The specific structure is shown in Figure 2.



Skeleton model

silhouette model

3D bone model

Figure 2. Human body structure model diagram

Figure 2 illustrates how the major body of the skeleton model is made up of points and lines, and how the image is efficiently denoised using the Gaussian filter. There are 2 ways: one is to use a one-dimensional Gaussian kernel to perform secondary weighting respectively; the other is to use a convolution method, which is completed at the core of a 2D Gaussian [17]. The kernel function of the 2D Gaussian is:

$$K = \frac{1}{\sqrt{2\pi\sigma * \sigma}} e^{\frac{a*a+b*b}{2\sigma*\sigma}} \tag{1}$$

The determination of parameter σ can obtain a 2D kernel vector.

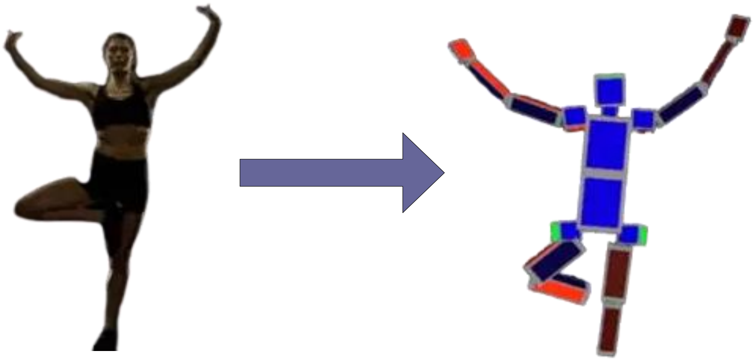
The finite difference method of the first-order partial derivative can be used to obtain two partial derivative matrices in the a and b directions, and the gray gradient of the image is approximated by the first-order difference method [18]. The expression of the gray value gradient is as follows:

$$\theta_{\varphi} = \tan^{-1}\frac{\varphi_2(m,n)}{\varphi_1(m,n)} \tag{2}$$

φ_2 and φ_1 represent the magnitude and direction of the edge gradient, respectively.

(2) Kinect bone recognition algorithm

Kinect's bone tracking and recognition technology is a key step. Once the depth image is removed from the foreground and background, 25 basic bones are identified using a depth feature-based bone joint classifier, and 25 joint points are computed and detected [19]. The specific identification is shown in Figure 3.



Bone Recognition Process

Figure 3. Bone recognition process diagram

In Figure 3, the separation of foreground and background in Kinect uses a separation strategy to separate the human body from the complex depth image. Image segmentation techniques are used to remove background images and output only human images, which reduces the amount of computation required in the subsequent processing flow. Microsoft has created a project example (model) artificial intelligence system for Kinect to identify different body components in depth maps [20].

The depth camera receives and reflects the high frequency modulated wired light pulses transmitted by the Kinect through the infrared transmitter. The process of accurately measuring depth information by directly measuring small changes in time-of-flight is a challenge, because it is very close to the speed of light. For example, within the scope of the Kinect's use, the hardware requirements are hardly too high. The time-of-flight technology photosensitive chip in the depth camera records the precise phase difference $\Delta\varphi$ between the round-trip camera and the object emitted by each pixel. After that, the phase difference is extracted by the data processing unit according to the brightness change rule, and the time-of-flight difference is collected and measured to calculate the depth information $Depth$:

$$Depth = \frac{c}{2}\frac{\Delta\varphi}{2\pi f} \tag{3}$$

The system uses weighted Euclidean distance calculations in the process. Skeletal nodes that have a stronger influence on motion are weighted when matching skeletal features and using the algorithm to calculate the reference template and the user's test template. The standard skeleton feature sequence in the motion template and the user's real-time skeleton feature sequence are the reference template and the test template in the algorithm, respectively. Therefore, Formula (4) represents the test template:

$$T = \{T(1),...,T(m),...,T(M)\} \tag{4}$$

The reference template is as Formula (5):

$$R = \{R(1),...,T(n),...,T(N)\} \tag{5}$$

The specific composition of the feature vector $T(m)$ at time m in the feature time series T is composed of multiple sets of spatial feature pairs between multiple joint points.

Formula (6) illustrates the mapping between the reference skeleton sequence and the feature skeleton sequence:

$$R = \{R(1),...,T(n),...,T(N)\} \tag{6}$$

The skeleton space feature uses the space vector method to extract the relative angles of multiple joint positions in space, so that it can effectively identify the criteria for each decomposition action in motion. It also avoids distractions from the user's unique body shape, resulting in better control.

(3) Background modeling algorithm based on mixture Gaussian model

The primary objective of background subtraction is backdrop modeling. There are a variety of often employed modeling approaches, such as mean or median filtering techniques, nonparametric techniques, single Gaussian background modeling, and mixture Gaussian background modeling, the latter of which has been more successfully applied.

Background modeling is achieved by using the arithmetic mean or median of pixels with the same coordinates in successive image frames as the pixel value of the background:

$$B_t(a,b) = \frac{1}{k}\sum_{i=1}^{k} I_{t=i}(a,b) \tag{7}$$

Among them, $I_{t=i}(a,b)$ represents the video frame at time t, and $B_t(a,b)$ represents the updated background model at time t. However, it can be seen from Formula (7) that k frames of images must be cached when updating the background model. Therefore, the background model parameters are usually updated using Formula (8) to save memory and reduce computation:

$$B_t(a,b) = \lambda I_{t=i}(a,b) + (1-\lambda)B_t(a,b) \tag{8}$$

The update rate λ of the background model is one of them. It is controlled by the update rate, and it is experimentally verified that this value is usually small, usually 0.05, which can reduce the impact of foreground changes on the model.

The single Gaussian model assumes that the background points of the static scene in the image have stable pixel values, and the distribution of their pixel values follows the Gaussian distribution. It is possible to distinguish the model from the current frame to detect moving objects, but the model has difficulty dealing with complex and rapidly changing pixels in real-world scenes.

Each pixel is represented by K single Gaussian distribution states, and these models are sequentially matched during detection. Mixture Gaussian models are allowed to process multiple background changes simultaneously. The weighted sum of the probability density functions (where A_t is the pixel value at time t) is given by Formula (9):

$$P(A_t)=\sum_{i=1}^{k} w_{i,t}\times\eta\left(A_t,u_{i,t},\sum\nolimits_{i,t}\right) \tag{9}$$

Among them, $w_{i,t}$, $u_{i,t}$ and $\sum_{i,t}$ represent the weight, mean and covariance matrix of the i-th model at time t, respectively. $\eta\left(A_t,u_{i,t},\sum_{i,t}\right)$ represents the probability density function of the i-th single Gaussian model of the pixel at time t, which can be expressed as Formula (10):

$$\eta\left(A_t,u_{i,t},\sum\nolimits_{i,t}\right)=\frac{1}{(2\pi)^{\frac{n}{2}}\left|\sum_{i,t}\right|^{\frac{1}{2}}} \tag{10}$$

Each time a new frame of the video image is presented, K Gaussian models created for each individual pixel $I_t(a,b)$ are sequentially matched and tested:

$$\left|I_t(a,b)-u_{i,t-1}\right| \pi\ D\times\sigma_{i,t-1} \tag{11}$$

D represents the confidence parameter in it. When one model cannot match all other models, the least matching model is eliminated and a new Gaussian model is established. A new model is selected based on its smaller weights, higher variance, and pixel values. The model with the largest weight can be considered as the best descriptive model, because the background has been in the image longer than the foreground and has more weight.

Gaussian models are usually sorted in descending order according to parameter values, and the following Formula (12) is used to denote B as the best description model:

$$B=\arg\min_b\left(\sum_{k=1}^{b} w_k\ \phi\ T\right) \tag{12}$$

Background threshold or T is one of them. If the current frame $I(a,b)$ and any one of model B match well, the pixel is regarded as a background point; otherwise, it is judged as a foreground point, which is a moving target.

3.2. Simulation Design of Tennis Intelligent Training

A clever piece of sporting equipment is the tennis training system. It transmits motion data to the tennis racket APP using the wireless transmission feature of the motion sensor module, which is mounted at the base of the tennis racket handle. Through the APP, the type, quantity, percentage and maximum hitting speed of the tennis player's technical movements can be analyzed and calculated in real time. The system constructed in this paper is shown in Figure 4.

It can be seen from Figure 4 that the auxiliary training system is based on the sports images of athletes and coaches. By comparing the differences in the trajectories of the five joint angles of the coach as an additional training index, and correcting the athlete's movements through the coach's movements, the movement posture can be analyzed and training suggestions can be provided.

The tennis swing can be divided into four stages: backswing, downswing, hitting the ball, and following the swing. Swing videos of players and coaches are collected, which arecaptured by Kinect and videotaped by tennis instruction. Some representative images are selected, which show the coach's swing and the athlete's swing respectively. The specific screen is shown in Figure 5.

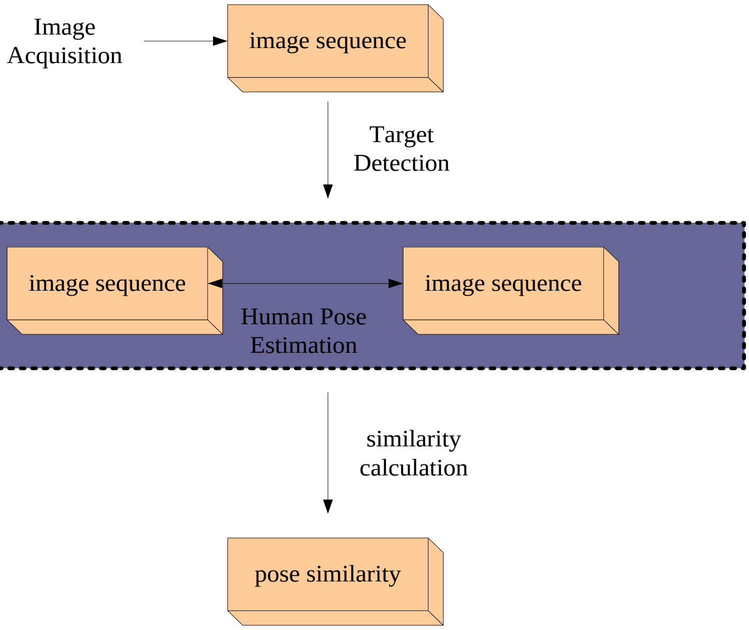


Figure 4. Architecture diagram of auxiliary sports training

Figure 5. Tennis swing

In Figure 5, trainers with different positions and heights would generate different keypoint data. The joint angle composed of 5 key points and the joint angle composed of 15 key points are used for auxiliary analysis.

The 2D joint point coordinates in the continuous image can be obtained by the above method, and a new joint point is obtained by using the principle of known three-point coordinates and the cosine theorem:

$$|AB| = \left((a_2 - a_1)^2 + (b_2 - b_1)^2\right)^{\frac{1}{2}} \tag{13}$$

According to Formula (13), the data of 5 joint angles can be obtained.

The distance between each sample is compared by computing a similarity measure between samples. The most commonly used method is Euclidean distance, as shown in Formula (14):

$$d(a,b) = \left(\sum_{i=1}^{n} (a_i - b_i)^2\right)^{\frac{1}{2}} \tag{14}$$

At the same time, the establishment of eigenvectors is also particularly important. An eigenvector is a vector in an n-dimensional space, which is composed of n features. Usually, a sample is a eigenvector.

The metric function used to determine how similar two poses are is the Euclidean distance. In order to represent the pose of the human body, five joint angles are selected as the set of feature vectors. The eigenvector of the trainer is $(H_1, H_2, H_3, H_4, H_5)$, and the eigenvector of the trainer is $(J_1, J_2, J_3, J_4, J_5)$. Their Euclidean distance is Formula (15):

$$D = \left((J_1 - H_1)^2 + (J_2 - H_2)^2 + (J_3 - H_3)^2 + (J_4 - H_4)^2 + (J_5 - H_5)^2\right)^{\frac{1}{2}} \tag{15}$$

Among them, H represents the joint angle of the trainer, and J represents the joint angle of the coach; the smaller the D value, the more similar the two movements are.

3.3. System Components

When recognizing objects, effective extraction of objects is a necessary link. When the pixel change cannot be determined, the random update method is used to simulate the uncertainty of the pixel.

One of the crucial connections in auxiliary training is human pose estimate. It can take a photograph and extract the human body's stance information. The corresponding attitude assistance index is created by summarizing and analyzing it. The supplementary training methods for human pose estimation can also process contour data of the human body, First, the Canny edge detection algorithm is used to determine the shape of the human body. Figure 6 depicts the specific procedure.

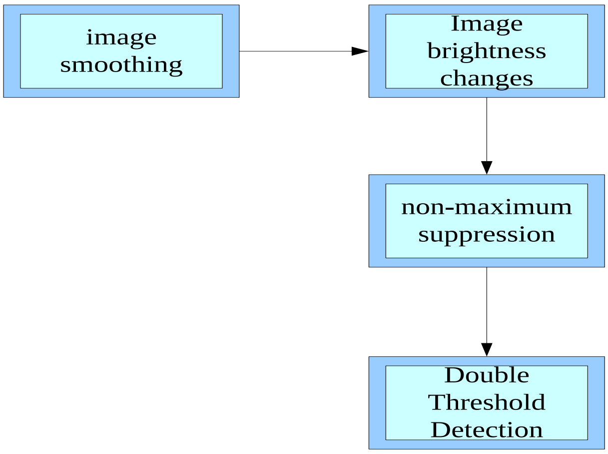


Figure 6. Canny edge detection algorithm

From Figure 6, it can be seen that the Canny edge detection method uses a Gaussian filter to smooth the image, and uses the first-order partial differential method to obtain the magnitude and direction of the gradient. It suppresses the non-maximum value of the gradient magnitude and adopts the double-threshold method for boundary extraction and splicing.

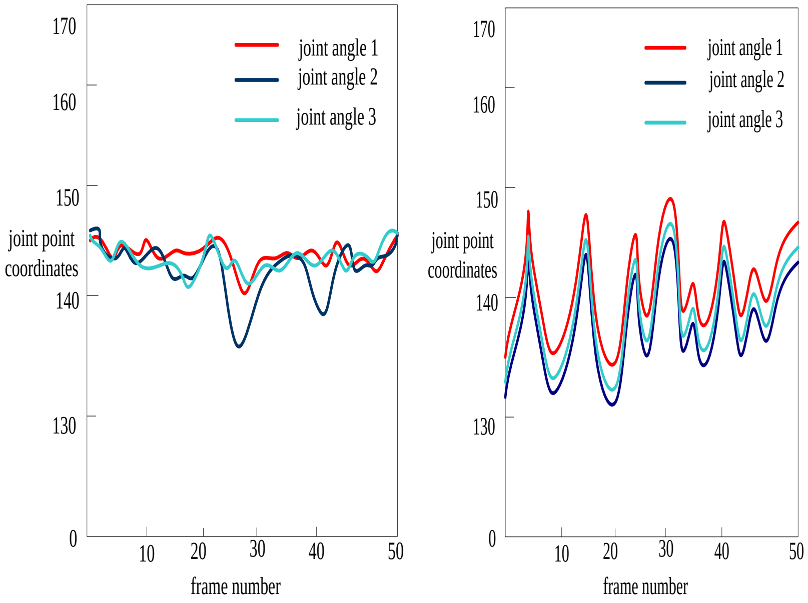
4. Intelligent Training Simulation Results and Discussion

The majority of traditional sports training is based on human experience, and it is challenging to accurately analyze essential motions numerically. In this study, a set of auxiliary training systems based on players' and coaches' swing photographs were developed, mostly for tennis. Auxiliary training indicators included a comparison chart and the similarity of five joint angle trajectories. Experiments showed that the system can provide standardized analysis and quantitative guidance for sports training.

The project used Win7*86+VS2008+OpenCV2.4+ MATLAB as the foundation, and write the relevant functions of each module of the auxiliary training system on this platform to complete the various functions of the system. The specific implementation process of the auxiliary training system is as follows: the auxiliary training system used images captured by the Kinect sensor or other training images as its input; through target recognition, human position estimation based on human silhouette and image processing, the swinging postures of athletes and coaches were obtained.

4.1. Bone Recognition Experiment of Kinect Sensor

This study evaluated the motion trajectories of joint angles and the similarity of each image in 50 frames of moving images. The supplemental training based on joint angle motion is shown in Figure 7.

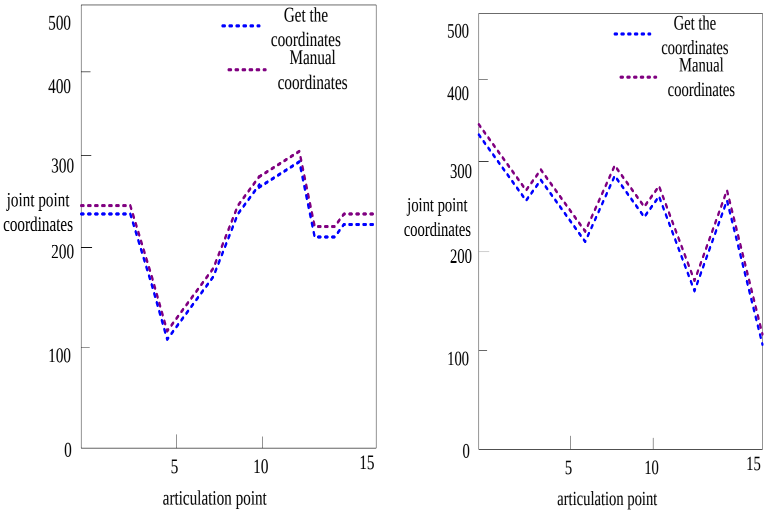


(a) The joint angle trajectory of the coach *(b) The joint angle trajectory of the athlete*

Figure 7. Joint angle trajectories of coaches and athletes

From Figure 7(a), it can be seen that the angles of joint 1 and joint 3 of the coaches changed in a small range, while the angle of joint 3 changed greatly, which indicated that the action of joint 3 is dominant in the entire tennis. It can be seen from Figure 7(b) that the joint angle trajectory of the athlete has changed a lot, so it is possible to adjust their movements by comparing different joint angles.

With the improvement of economic conditions, people have higher and higher requirements on the body, and physical exercise has become an indispensable part of people's lives. In order to make their sports more professional, people not only pay a lot of money to hire personal trainers, but are also interested in smart sports equipment. The X and Y coordinates of the joint points extracted by the auxiliary system are shown in Figure 8.



(a) Comparison diagram of X coordinate of joint point

(b) Comparison diagram of Y coordinate of joint point

Figure 8. Joint point X and Y coordinates

It can be seen from Figure 8(a) that the errors of the X-coordinate joints obtained by the Kinect sensor and the artificial markers were small. From Figure 8(b), it can be seen that the Y-coordinate node position obtained by the Kinect 3D sensor was very close to the manually marked position, which can be used to establish an algorithm verification system for human pose estimation.

On this basis, the photos of the Kinect sensor were used as the input to assist the training system. After target detection, pose estimation based on human silhouette and image processing, the motion states of athletes and coaches were obtained. The 5 joint motion trajectories and pose similarity were used for analysis and guidance.

4.2. Real-time Tennis Technique Action Recognition Test

In the system test, a large number of human motion recognition experiments were carried out. 15 boys and 5 girls each took the test once a day for 5 days. 200 test data were obtained, and the recognition rate of action was analyzed. The identification ability of the system can be tested through the identification test of tennis technical movements. According to the sports characteristics of the players, the technical action can be accurately identified, and the recognition rate and accuracy of the technical action can be determined. The specific results are shown in Table 1 and Table 2.

Table 1. Recognition rate and correct rate of tennis technical movements

Action	Exercise times	Number of recognitions	Recognition rate
Backhand	200	197	98.5%
Forehand	200	198	99.0%
Volley	200	196	98.0%
Serve	200	199	99.5%
High pressure ball	200	200	100%

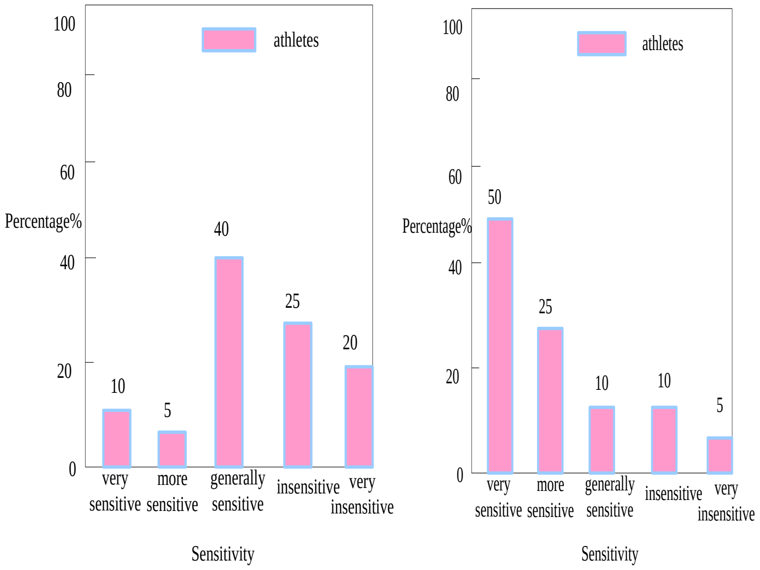
Table 2. Correct rate of technical tennis moves

Action	Number of recognitions	Number of correct identifications	Recognition rate
Backhand	197	190	96.4%
Forehand	198	192	96.9%
Volley	196	189	96.4%
Serve	199	195	98.0%
High pressure ball	200	191	95.5%

It can be obtained from Table 1 and Table 2 that the recognition rates of backhand, forehand, volley, serve and high-pressure ball were 98.5%, 99.0%, 98.0%, 99.5%, and 100%, respectively; the recognition rates of backhand, forehand, volley, serve and high pressure ball were 96.4%, 96.9%, 96.4%, 98.0% and 95.5% respectively. Therefore, the simulation training designed in this paper had a very high recognition rate and correct rate of tennis movements. Experiments showed that the system had a high motion recognition rate and a good motion recognition ability.

4.3. Experience Effect of Simulation Training System

Agility training for female tennis players can ensure that players can improve their flexibility while maximizing speed, control, and reducing physical exertion and redundant movements. It also avoids unnecessary injuries and stimulates muscle fibers effectively. The simulation training system was used to analyze the agility of 60 tennis players, and the results are shown in Figure 9.



(a) The agility of the athlete before the smart training simulation

(b) The agility of the athlete after the smart training simulation

Figure 9. Analysis of the movement agility of tennis players before and after the intelligent training simulation

From Figure 9(a), it can be found that the agility of the athletes before the intelligent training simulation was not high; only 10% were very agile, and 5% were more agile; the proportion of general agility was at most 40%, and the proportion of very inflexible was 20%. From Figure 9(b), it can be found that the agility of athletes had been improved after the intelligent training simulation;

very agile accounted for 50%, and relatively agile was 25%; the average agile ratio was 10%, and the very inflexible was only 5%. It can be found that the intelligent simulation training improved the agility of the athlete's movements.

5. Conclusion

Since computer technology has advanced so quickly nowadays, people have coupled it with physical education to create scientific physical education, which does away with the state of conventional physical training that solely relies on experience. The human pose estimation algorithm used in this paper was based on an intelligent analysis model. The goal of accurately evaluating the movements of coaches and athletes was accomplished by creating a mapping relationship between human features and human posture in the image and using human posture estimation to determine the position and angle of each part of the human body in the 2D plane or 3D space. In order to achieve the shift from the human motion analysis method based on experience to the computer vision-based method, this paper applied the intelligent analysis model to tennis sports training. In this paper, a tennis auxiliary training system was also established, and the effectiveness of the method was verified by experiments. However, the fly in the ointment is that the realism of the results may be reduced due to the lack of actual operation of the system in the experiments. Therefore, the authenticity and scientificity of the experiments should be improved in future work.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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