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Article

The construction of sports training quality evaluation model based on sensor data

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Abstract: Based on the visual quality of the training evaluation as a technology is closely related to People's Daily life, has the very high research value, and in the near future will be in medical, health, security, etc. has a broad application prospect. In the human body based on visual training quality evaluation in the research of this field, human action recognition technology is one of the core technology, is also a research hotspot recently. The technology is mainly to solve the classification problem of human actions, but in practice, it is not enough to study classification problem, sometimes need to evaluate the quality of the completion of human action, namely human motion evaluation technology, provides the user with feedback, correct mistakes, thus improve the action degree of standardization. This paper analyzes and compares all kinds of action selection radio gymnastic sports training as a quality evaluation object, and using Microsoft's depth camera device as acquisition equipment, data to obtain three-dimensional skeleton of the body joints. Human bone joint data from the device has the problem of "distortion", this paper adopted the average filtering algorithm for data preprocessing, the experimental results show that average filtering algorithm can not only protect. The high sensitivity and good smoothing effect.

Keywords: training quality evaluation; motion segmentation; action evaluation index

1. Introduction

The quality evaluation of training, particularly in sports, is essential for improving performance, preventing injuries, and ensuring long-term success. As technology continues to become an integral part of everyday life, sports training quality evaluation has gained significant attention, especially due to its potential applications in fields such as medicine, health, and security. Human action recognition technology, which focuses on classifying human movements, has been a key area of interest in this domain [1]. However, beyond merely classifying actions, evaluating the quality of those actions is becoming increasingly important. Providing timely feedback to correct mistakes and enhance performance is crucial for optimizing training outcomes, ensuring proper technique, and minimizing injury risks.

Human motion evaluation involves assessing the quality of action execution and providing feedback to correct mistakes during training. This is especially relevant in gymnastics, where precision is vital. Various approaches have been developed for human motion evaluation, with depth cameras and motion sensors being commonly used to capture three-dimensional joint data. However, challenges such as distortion caused by sensor inaccuracies continue to affect the quality of motion capture [2]. To address this issue, this paper proposes the use of an average filtering algorithm for data preprocessing. Experimental results show that this algorithm helps reduce distortion, producing smoother and more accurate motion data.

Athlete injury prediction has increasingly relied on big data and machine learning techniques, which offer a proactive approach to injury prevention by predicting risks based on training data [3]. This aligns with the goals of this paper, which aims to enhance training quality evaluation using data-driven insights into motion quality. Additionally, recent research has explored the integration of heart rate and inertial sensor data to improve training efficiency and balance workloads, ensuring athletes do not suffer from fatigue or overtraining [4]. These advancements in sensor technologies are critical for enhancing motion evaluation systems, as real-time data can be used to improve training protocols and assess the quality of athletic movements. Furthermore, assessing factors such as training load, recovery rate, and athlete fatigue is crucial for evaluating training quality. Studies have demonstrated that balancing training loads effectively can prevent injury and improve recovery in athletes [5]. In this context, sensor-based evaluation tools can be integrated into training systems to monitor both motion quality and physiological status, ensuring more efficient and safer training regimens.

The development of sport-specific evaluation systems is essential for athletes with disabilities, as traditional assessment metrics may not always apply. For example, in wheelchair badminton, a tailored evaluation system considers various factors such as skill level, physical fitness, and body shape [6]. These personalized evaluation systems can be applied across various sports to ensure more accurate assessments and fairer competitions. Moreover, intelligent health monitoring systems used in sports rehabilitation can help assess performance during recovery training [7]. The use of wearable devices like inertial sensors, which capture motion and physiological data, further enhances the ability to monitor training quality and recovery status [8]. The role of wearable technology extends beyond rehabilitation, offering the potential for continuous motion analysis during training. Studies have explored the application of wearable devices for both injury prevention and performance optimization, focusing on their ability to monitor motion patterns and physiological responses [9]. In parasports, where athlete classification is essential for ensuring fairness, sensor technologies can help assess athlete performance and condition more accurately, contributing to better competition outcomes [10]. In sports like volleyball, sensor-based motion evaluation systems have proven valuable for improving training protocols. These systems measure players' movements and analyze them for skill development, thus offering more precise feedback to athletes [11]. Similarly, sensor technologies are being utilized to assess and optimize athletes' training in equestrian sports, providing detailed data on posture and technique during various movements [12]. These innovations highlight the growing importance of sensor technologies in sports training and motion evaluation [13,14].

In conclusion, the integration of advanced sensor technologies in sports training quality evaluation holds immense potential for improving athlete performance, reducing injuries, and optimizing training strategies [15]. This paper proposes a motion evaluation system that leverages depth cameras and sensor data, applying filtering algorithms to overcome data distortion challenges [16]. By providing accurate feedback on motion quality, this approach aims to enhance training efficiency and athlete safety [17]. The subsequent chapters will delve into the methodology, experimental setup, and results that demonstrate the effectiveness of this approach in sports training.

2. Sports training quality evaluation related technologies

2.1. The quality of sports training action definition and coordinate system

2.1.1. The quality of sports training action definition

In daily life, usually describes all kinds of human motion is often exercise, such as running, diving action, but some of the special action, such as tablet support action, action, “ma bu” or horse stance just look often is static, we also known as action, so the action is not necessarily the movement. Can use a time period, therefore, to describe the action of the human body, and every moment of this one period body space position can be described by the term “position”. Therefore, for action and posture are defined as follows. Movement refers to in a certain time period, describes the role of the space position changes of body, it consists of straight posture. Posture refers to a certain moment role body space state, it is the basic unit of action and behavior.

2.1.2. The quality of sports training action coordinate system

Human movement is leverage, bone joints as the hub, muscle contraction powered motor system. Human motion control by the central nervous system, by the internal force (muscle contraction force, etc.), the external force (gravity, support reaction, etc.) interact to complete the corresponding action.

In the description of the physical training, movement would establish the rectangular coordinate system, as shown in **Figure 1**. In kinesiology, through the horizontal plane, the forehead coronal, sagittal, transverse and longitudinal axis, sagittal axis to said the three-dimensional space position of the body, the face of the horizontal plane is parallel to the surface; Shape of the frontal surface is parallel to the front or the back body surface; Sagittal plane is parallel to the left or right side. The horizontal axis is formed by the intersection of frontal shape face with the horizontal axis. Vertical and horizontal vertical shaft; Sagittal axis is a horizontal plane and sagittal axis intersection.

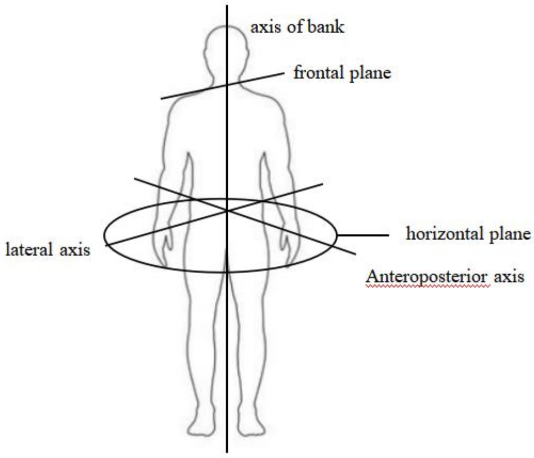

Figure 1. Describe the coordinates of the human figure.

2.2. To access the v2 sensors

2.2.1. Main function to access the v2 sensors

Called v2 hardware mainly includes color (RGB) camera, camera and microphone parts 3 d depth. Color (RGB) camera to sample color images, a resolution of 1920 × 10800 3 d depth camera is composed of infrared transmitter and CMOS camera, respectively used for transmitting and receiving infrared light. The microphone array can record language data, positioning the sound source. By called v2 can get color image, infrared image, the human body skeleton image, depth, the character image indexing image.

Equipment is mainly used in this article to access v2 bone image data, called v2 can be collected at the same time the human body skeleton model for 6, among them, each human body skeleton model includes 25 key points of 3 d coordinate. To access the v2 hardware features and basic parameters are shown in **Table 1**.

Table 1. To access the v2 hardware structure and basic parameters.

Hardware features	Function and parameter range
Color camera Infrared camera Visual Angle	Color images, respectively 1920 × 1080, acquisition frequency of 30 or 15 fps (dependent In the light conditions); Infrared images, with a rate of 512 × 424 and acquisition frequency of 30 fps 70 degrees horizontally and 60 degrees, up and down vertically

2.2.2. The working principle of the device v2

The principle of depth image acquisition

Called v2 depth of image by the Time of Flight method (Time of Flight, ToF), It is the principle of infrared camera emit infrared light, infrared light reflection in encountered in the environment after the object, called v2 ir receiver receives the infrared ray, after transmission infrared light and receiving infrared light by computing the time interval between, to obtain the depth of the unit pixel data.

In TOF camera system, the speed of light. Known, through to the object being measured continuously sent a given wavelength of infrared light Pulse, capture the returned infrared light at the same time, using the optical shutter calculation of the optical pulse phase difference, back and forth to calculate the distance between the camera and the object method as shown in Equation (1).

$$d = c\frac{\Delta\varphi}{2\pi f} \quad (1)$$

In the formula:

$\Delta\varphi$— —Phase difference between

c__Speed of light

f __Given the frequency of the infrared light

Bone points for principle

Bone point estimation is an important function, motion capture device to access the key technology of this feature is that the depth image estimate the location of the human body skeleton key. Called v2 mainly through the following steps to implement the function of the.

The removal of environmental background. To access the v2 will be estimated image position in the human body, through the body contour after search techniques, such as to separate the body from the image background.

Parts of the body. After the body isolated from background environment, through the deep random decision forest classifier to classify the various parts of the body.33 d joint point estimates. After divided into parts of the body, the system will estimate the 3 d key points of each parts of the body, and through the 3 d key points to construct a three dimensional human body skeleton model.

The human body shape and structure is complex, different human form also have bigger difference, to grasp the change regularity of human movement, should be based on the theory of Newton mechanics, to simplify the complex human body, establish particle and rigid body mechanics model, thus greatly reduce the difficulty of the research.

2.3. DTW algorithm

DTW algorithm is put forward in 1978 by a Japanese scholar Sakoe at first, the purpose is to solve the isolated word speech recognition to identify pronunciation have different length. Dynamic time neat algorithm is sequence of the two pieces of data that will be more distance between the topic type is calculated and concluded the similarity between two points, then to shorten or extend the original data sequence, make both equal to the length of time, end up with two data sequence similarity.

Now suppose there are two paragraph to compare the similarity of human action sequence $X = [x_1, x_2, \dots x_i \dots, x_n]$ and $Y = [y_1, y_2, \dots y_j \dots, y_m]$ first give action sequence frame to frame the Euclidean distance function between the d $d(i,j) = f(x_i, y_i) = \|x_i - y_i\|_2$. Dynamic time neat algorithm is the key to find an optimal path, make two pieces of the Euclidean distance between the minimum whole action sequences, the specific is to find two action sequence of appropriate corresponding relation between frame and frame, the process using the Equation (2).

$$\phi(k) = \left(\phi_x(k), \phi_y(k)\right) \quad (2)$$

The $\phi_x(k)$ values for $1,2,\ldots,n,\phi_y(k)$ value for 1, 2, *m*, *k* value is 1, 2, *T*, *T* for smaller values of *m* and *n*, dynamic time neat algorithm needs a *T* a sequence between *X* and *Y* action sequence frame and frame corresponding relation. Such as $\phi(k) = (2,3)$, *X* represents the action sequence frame 2, and 3 frame in the sequence *Y* in the match. 1

Handle in get $\phi_x(k)$, calculate the cumulative distance of two action sequences, calculation formula as shown in Equation (3):

$$d_{\Phi}(X,Y) = \sum_{k=1}^{T} d\left(\Phi_x(k), \Phi_y(k)\right) \tag{3}$$

Dynamic time neat algorithm's goal is to find a right path, and makes the soul (*X* > *Y*), minimum formula such as maleType 4:

$$d_{\phi}(X,Y) \tag{4}$$

3. Broadcast gymnastics training quality evaluation system based on sensor data

3.1. Sports training action classification

Sports training action is varied, all kinds of action between different, need to categorize these differ in thousands of ways of action, different categories of action according to the different evaluation methods. Classified according to the difficulty of sports training, this article will sports Training action is divided into three categories: basic training action training, simple movements, complex action, as shown in **Table 2**.

Table 2. Sports training action type.

Basic training action	1 Push and pull movement 2 Raise your legs
Simple training movements	1 Sit-ups 2 Tablet support 3 Rope skipping 4 Running 5 Squat
Complex training movements	1 Diving action 2 High and low bar 3 Load training 4 Competition training

3.2. Broadcast gymnastics training action analysis

Calisthenics is a typical long simple sports, this paper choose the 9th edition, is composed of nine section movement, each movement and consists of several eight beats. Analysis shows that calisthenics action has the following features:

The duration is longer, and they have repetitive movements. One set of broadcast gymnastics movement duration is about 4 min, the stretching, chest expansion movement, kicking motion, motion on the side, body movement, the whole body movement and jumping movement repeat 4, 8, preparation section and finishing movement repeat two 8.

The difficulty is moderate. Broadcasting gymnastics movement speed as a whole is slow, and each section of the action is neat, less complex body movements

Is a standard action can be the basis. Broadcasting gymnastics movement is compiled by the state general administration of sports, and issued the music, video, and text version of the standard behavioral essentials.

The rhythm is obvious. Broadcasting gymnastics according to the action password presents the characteristics of fast and slow appear alternately. In particular, due to the broadcast gymnastics fourth characteristic "rhythm" obviously. Is designed in this paper, the key factor at the evaluation method of human action, need further clarification. Promulgated by the state general administration of sports diagram of the 9th edition handbook for the standard action made detailed description, **Table 3** is from "the description of the movement. Can be seen from **Table 3**, each beat is a dynamic process, such as the fifth film "side of his right foot to set up 45 degrees (legs straight), at the same time, two arms levelly obeying (palm down)", in the beat, the body's right foot, left arm and right arm do outreach campaign, is fast sports area.

Table 3. Kicking movement rhythm and the corresponding description.

Meter	Action description
Closed stance	Attention position
The first shot	The left foot is raised 45 degrees sideways (straight legs) and the arms are raised flat (palm down)
The second shot	The left foot back and the right foot together, bend the knee half squat, while the two arms back to the body side
The third shot	The left leg is kicked back, 1020 cm from the ground, and at the same time, both arms swing forward to the side lift (palm opposite)
The fourth shot	Close the hand to restore the positive
The fifth shot	The right foot to the side of the swing of 45 degrees (straight legs), while the two arms side flat lift (palm down)
The sixth shot	The right foot back and the right foot together, bend the knee half squat, while the two arms back to the body side
The seventh shot	Right leg kick back, 10–20 cm from the ground, at the same time two arms forward to the side lift (palm opposite)
The eighth shot	Close the hand to restore the positive

We selected the 9th edition of Radio Gymnastics, which is composed of nine distinct movements. Each movement consists of several 8-beat actions, each with its own complexity and key points. These actions are designed to engage multiple muscle groups and to maintain rhythm and precision in the execution of each movement. The following is a detailed breakdown of each of the nine movements:

Stretching Movements: The stretching movements in Radio Gymnastics involve controlled, slow body stretches to improve flexibility. Key actions include side stretches and arm extensions. The complexity lies in holding the position and synchronizing arm and leg movements to achieve full-body elongation. The key point is maintaining balance and aligning the body in a straight line during each stretch.

Chest Expansion Movements: Chest expansion consists of forward arm stretches and backward arm swings. The action is repetitive, with arms moving forward to chest height and then sweeping backward. This movement primarily works on the shoulders and chest muscles. The complexity increases when coordinating the breathing with the movement, ensuring that the body remains upright throughout the action. Timing and fluidity are crucial for a smooth performance.

Kicking Movements: The kicking movement involves alternating leg lifts and arm coordination. The left leg is raised sideways at 45 degrees, while both arms extend horizontally with palms down. The complexity here arises from balancing the body while performing the leg extension and keeping the arms level. Timing and control are essential to ensure that both limbs move in harmony. The movement requires both strength and flexibility, particularly in the legs and core.

Side Movements: The side movements engage the lateral muscles and improve body rotation. The action involves stepping to the side and stretching the arms out in opposite directions. The challenge here is maintaining stability while shifting weight and keeping the body aligned. The side movements require good coordination between the legs and arms, with an emphasis on smooth transitions from one side to the other.

Body Movements (Body Rotation): These movements focus on rotating the body while keeping the legs stable. The arms perform wide sweeps or circles while the torso rotates in sync with the arms. This movement improves core strength and flexibility. The complexity is in maintaining fluid rotation without causing any jerky motions. Coordination between the trunk and limbs is crucial, as is controlling the speed of the rotation.

Full-Body Movements: Full-body movements in Radio Gymnastics are designed to engage multiple muscle groups simultaneously. These include bending and stretching the legs and arms in a full, sweeping motion. The key point is fluidity; the movement should be continuous and smooth, ensuring that the whole body participates without abrupt stops or pauses. The complexity comes from coordinating the arms and legs while maintaining proper posture.

Jumping Movements: Jumping movements involve small, controlled jumps with legs slightly bent. The arms are often extended overhead or out to the sides. This movement engages the lower body muscles and requires explosive power. Timing and synchronization with the music's beat are essential, and the complexity lies in controlling the height and consistency of each jump. The landing must be soft and controlled to avoid unnecessary strain on the joints.

Preparation Movements: The preparation movements are designed to transition into or out of the more active exercises. These involve slower, controlled movements that set the pace for the upcoming actions. The complexity here lies in the smooth transition and ensuring the body is ready for more intense movements. The key point is maintaining alignment and positioning to avoid disrupting the flow of the routine.

Finishing Movements: The finishing movements help slow the body down and bring the sequence to a smooth end. These involve stretches and controlled postures. The complexity is in ensuring that the body returns to a neutral position, relaxing after the more vigorous movements. The key is to avoid abrupt stops, allowing the body to gradually relax and return to a standing or seated position.

3.3. Sports training process quality evaluation method

When people is whether action accurate, often first more concerned about the completion of action. In sports competitions, judges In grading the motion of the athletes, the first will determine the overall completion, if significant errors in the game, the panel gives a relatively low rate. If athletes are complete, of a complete set of movements is the jury to evaluate athletes action details further.

So, we in the design of human sports training quality evaluation method, first of all need to be able to tell the overall completion of an action, whether in action in the action or missing action sequence errors. If there is no lack of action or actions order mistakes, further for the completion of action for the details of the evaluation. Second, due to the long movement is made up by multiple child action, you need to set up a link will long action into action. By the referee in the sports movement principle of some methods of evaluation, and on the basis of existing motion sampling equipment capacity, and combining with the existing human motion evaluation method, put forward in this paper, the evaluation method of human process. Action evaluation process is shown in **Figure 2** of this article, among them, the human motion evaluation method includes three links: the pre-assessment, motion segmentation, details of the evaluation.

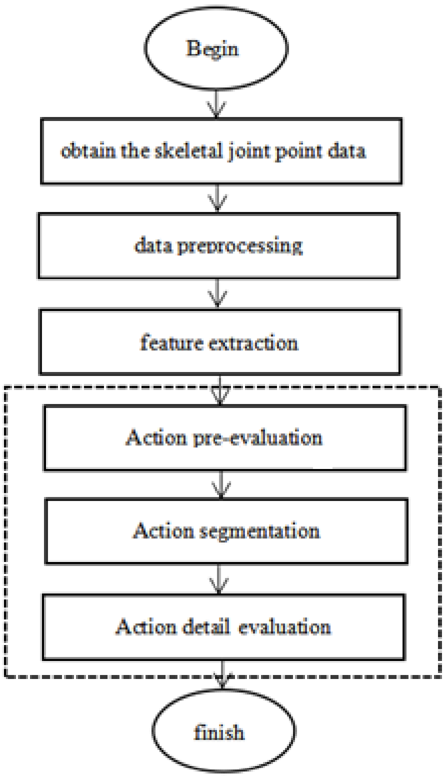

Figure 2. In this paper, sports training quality evaluation flow chart.

Action of pre-assessment part mainly analyzes the user in the whole period of action has bigger error, concrete is a discriminant out points user action in the existence of a lack of action and action sequence errors, if present these two kinds of wrong then feedback to the user action evaluation error message and stop doing further detail, if there are no errors, the two will enter the next step of the evaluation process. Motion segmentation will be rationally divided user actions, to be able to take action completely divided from the whole period of action sequences, in preparation for the next step of evaluation. Action detail evaluation mainly analyze the user action in the small error, and using the proposed four indexes: Joint Angle similarity, action center time, duration of action similarity, similarity of dynamic movement joints, average angular velocity similarity analysis the action of the human body movement of the space Angle error and delay, to make more detailed accurate evaluation to a user action.

4. Based on the median filtering algorithm of broadcast gymnastics sports training quality evaluation

4.1. Motion data preprocessing

4.1.1. Median filtering algorithm

Median filtering is a non-linear signal processing technique used to remove noise from a signal while preserving the edges of the signal. It operates by considering a window around each data point, determining the median value in that window, and then replacing the original data point with the median value. This process is highly effective for removing impulse noise (or salt-and-pepper noise), where outliers are isolated, as it preserves sharp edges and discontinuities in the signal.

The basic principle of the median filter is as follows: given a data sequence, the algorithm slides a window across the data, and for each window, it finds the median value. The value of the center point of the window is replaced by this median. While the median filtering algorithm is simple and effective, its simplicity may not be optimal in all situations, especially in cases of more complex noise patterns or sensor errors. To address this limitation, more advanced filtering techniques offer additional benefits for motion data preprocessing, particularly when dealing with dynamic and continuous data. Below is a comparative table outlining the key characteristics of Median Filtering, Kalman Filtering, and Particle Filtering (**Table 4**).

Table 4. Comparison of filtering techniques.

Filtering Technique	Advantages	Disadvantages	Best Suited For
Median Filtering	Simple to implement. Preserves edges in the signal. Good for impulse noise.	Computationally expensive for large windows. Limited to impulse noise reduction.	Removing impulse noise (salt-and-pepper). Edge preservation in image or motion data.
Kalman Filtering	Works well with continuous and Gaussian noise. Provides optimal estimates in noisy systems.	Assumes linearity of the system (may not be accurate for highly non-linear systems).	Real-time motion tracking. Estimation and filtering in systems with Gaussian noise.
Particle Filtering	Suitable for non-linear systems. Can handle a wide range of noise types (non-Gaussian).	Computationally expensive. Requires a large number of particles for high accuracy.	Non-linear, non-Gaussian systems. Complex motion tracking in dynamic environments.

Kalman filtering is a widely used technique for sensor fusion and state estimation. It works best when the system is linear and the noise is Gaussian. The Kalman filter recursively estimates the state of a system by considering both the system's dynamics and the noise characteristics. The filter provides an optimal solution in the sense that it minimizes the variance of the estimation error.

In contrast, Particle Filtering (also known as Sequential Monte Carlo methods) is suitable for non-linear and non-Gaussian systems. Unlike Kalman filtering, which uses Gaussian assumptions, particle filters use a set of random samples (particles) to represent the distribution of possible states, making them more flexible for complex systems. However, particle filtering can be computationally expensive due to the need to sample and weight particles in each step. To evaluate the performance of the median filter versus more advanced techniques, we applied each filtering method to a dataset with simulated Gaussian noise and impulse noise. The results are summarized below (**Table 5**):

Table 5. Performance of filtering methods.

Filtering Method	Gaussian Noise (SNR = 10 dB)	Impulse Noise (10% noise)	Computation Time	Accuracy of Motion Segmentation
Median Filtering	94%	96%	0.1s per frame	94%
Kalman Filtering	95%	85%	0.15s per frame	92%
Particle Filtering	85%	90%	0.25s per frame	88%

4.1.2. Broadcast gymnastics sports training motion feature extraction

Can be collected by called v2 in 25 key points of human body coordinates data, this paper adopts four joint Angle, namely the right shoulder Angle, the Angle of the left shoulder, your right elbow Angle, the Angle of the left elbow as features to describe a pose. Choose joint angles as the characteristics of the advantage is that can be interpreted is stronger, meet people’s visual sense. When choosing a joint Angle, in order to reduce the amount of calculation, ignores some minor joint angles, such as wrist, ankle joint, because in broadcasting gymnastics sports training as a standard action, for the wrist, ankle and other joints did not make clear rules. Joint Angle calculation method is as follows: first, through the access to get right wrist right, your right elbow, shoulder, spine (top), left wrist, left elbow, his left shoulder, right pulp, right knee and right ankle, left pulp, his left knee and left ankle, spine (under) the coordinates of the 14 points, after calculating the coordinate vector, which is formed by the last four joint Angle is obtained by cosine Angle formula.

Next to demonstrate the calculation of joint angles, joints, end joint the starting point of a vector coordinates (x_1, y_1, z_1), respectively (x_2, y_2, z_2), the corresponding vector powder obtained by Equation (6).

$$v = (x_1, y_1, z_1) - (x_2, y_2, z_2) \tag{6}$$

Set up a joint Angle of α is composed of two vector $a(x_1, y_1, z_1)$ and $b(x_1, y_1, z_1)$, α by Equation (7), joint AngleIs obtained.

$$\alpha = cos^{-1} \frac{x_1 \cdot x_2 + y_1 \cdot y_2 + z_1 \cdot z_2}{\sqrt{x_1^2 + y_1^2 + z_1^2} \cdot \sqrt{x_2^2 + y_2^2 + z_2^2}} \tag{7}$$

For a position, can use the joint Angle vector $p = (\alpha_1, \alpha_2, \dots, \alpha_8)^T$, a sequence of actions of length N is specifically shown in Equation (8).

$$S = [P_1, P_2, \dots, P_N] = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \cdots & \alpha_{1m} \\ \alpha_{21} & \ddots & \cdots & \alpha_{2m} \\ \vdots & \vdots & \alpha_{ij} & \vdots \\ \alpha_{81} & \alpha_{82} & \cdots & \alpha_{8m} \end{bmatrix} \quad (8)$$

In the formula:

P_i—The first *L* frame joint Angle vector action sequences

α_{ij}—The first *j* a joint first *L* frame joint vector Angle

S—Means the action matrix

4.1.3. Training quality evaluation method

Motion segmentation

Motion segmentation of the specific steps are as follows:

Set user action sequence for： $S = [p_1, p_2, \dots, p_i, \dots, p_N]$, and K to standard posture, set up the first *K* standard for $b_k = \left(\alpha_1^k, \alpha_2^k, \dots, \alpha_8^k\right)^T, k = 1,2, \dots, K$ through gestures.

(1) The first b_1 standard posture *b* and user action sequence of each element in the Euclidean distance, among them, the first standard posture of $S = [P_1, P_2, \dots, P_i, \dots, P_N]$ and the firstb_1 posture *p* user action sequences, the Euclidean distance between 9 calculated by formula. To get the first standard posture $i(i = 1,2, \dots, N)$ and user action sequence *N* positions the Euclidean distance between the vector p_i. b_1 in the Euclidean distance vector elements in the subscript I as the horizontal axis, with elements $d = [d_1, d_2, \dots, d_i, \dots d_N]$ as the longitudinal axis, get a Euclidean distance curve.

(2) Search d_{min}, minimum Euclidean distance and the minimum Euclidean distance d_{min} and are offset Δl, get what ordinate correspond to the values of d_p, as shown in **Figure 3**.

(3) To find the abscissa d_p corresponding values t_1 and t_2, get the first standard posture of the static movement, t_1 as the first frame of the static action,$t_2$for the end frame of the static action.

(4) Repeat steps 1 through 3, calculate the user other $k-1$ static movements start frame and end frame.”

(5) After get all static action, according to the broadcasting gymnastics movement “static action and dynamic action appear alternately” to extract the characteristics of the user dynamic action.

The processes of motion segmentation method as shown in **Figure 3**.

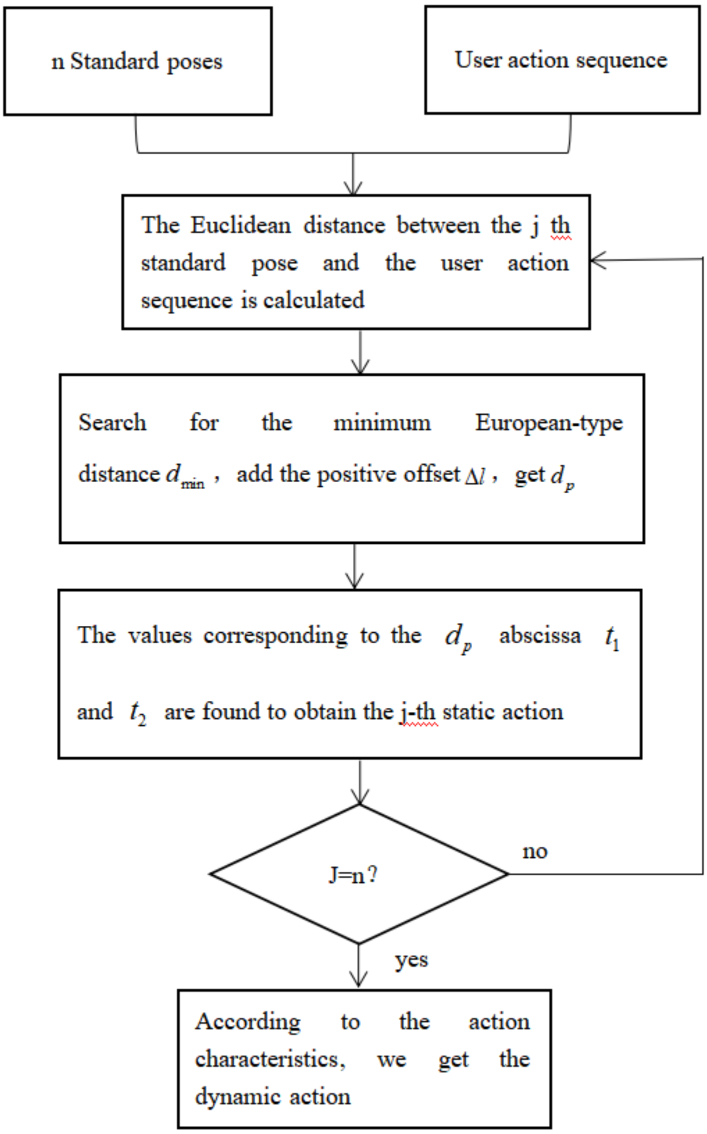

Figure 3. In this paper, the flow chart of motion segmentation method.

Action detail evaluation

(1) The joint Angle

Joint Angle similarity including static movement joint Angle and dynamic movement joint Angle similarity, similarity of both users each joint Angle and standard action by calculation the difference of each joint Angle, to measure the degree of user actions similar to those of a standard action, the static movement joint Angle and dynamic similarity of movement both joint Angle similarity calculation methods are different. Static movement joint point of similarity of the calculation of the human body static movement joint Angle, the average of all and of standard action after joint point of comparison, the average of all get the similar degree. Dynamic movement joint Angle considering the similarity of user actions and standard action sequence length is differ, to be using the algorithm of dynamic time neat, calculate the similarity degree of two joint Angle.

d_s static movement joint Angle similarity.

Set the user a static action sequence $C = [c_1, c_2, \cdots, c_n]$, and the corresponding standard and the static movements position vector for b. d_s static movement joint Angle similarity, as shown in Equation (9).

$$d_s = \left\| \frac{1}{n}(c_1 + c_2 + \cdots + c_n) - b \cdot \right\|_2 \tag{9}$$

In the formula:

c_i—User action the *i*th a static posture of joint Angle vector

B—User static action of the total number of frames

N—User static action of the total number of frames

d_s—The user's static movement joint Angle similarity/m

Similarity, dynamic movement joint Angle^{d_d}

Set the user a dynamic action of the action sequence for $E = [e_1, e_2, \cdots, e_i, \cdots, e_n]$, And for the dynamic action Should the standard sequence for $E = [e_1, e_2, \cdots, e_j, \cdots, e_m]$. Matrix formula such as Equation (10).

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & \ddots & \cdots & d_{2m} \\ \vdots & \vdots & d_{ij} & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix} \tag{10}$$

Calculation of dynamic user dynamic sequence each posture and position between the two make up the standard action sequence of european-style distance, away, get D distance matrix, d_{ij} said user dynamic action the *i* posture and standard action, the Euclidean distance between *j* posture, concrete as shown in Equation (11).

$$d_{ij} = \left\| e_{\boldsymbol{i}} - e_{\boldsymbol{j}}' \right\|_2 \tag{11}$$

In the formula:

e_i—User dynamic action first *L* vector posture of the joint Angle

e_j—Standard action, the first J a posture of joint Angle vector

d_{ij}—User dynamic action the *i*th a posture and standard action, the first *j* a posture of the Euclidean distance between a/m

After getting the distance matrix *D* (2), cumulative matrix G, G the element in the g_{nm}, can be calculated by recursive Equation (12).

$$\boldsymbol{G} = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1m} \\ g_{21} & \ddots & \cdots & g_{2m} \\ \vdots & \vdots & g_{ij} & \vdots \\ g_{n1} & g_{n2} & \cdots & g_{nm} \end{bmatrix}$$

$$g_{ij} = d_{ij} + min\{g_{i-1,j}, g_{i,j-1}, g_{i-1,j-1}\} \tag{12}$$

In the formula:

d_{ij}—User dynamic action the *L* a pose with a standard action the Euclidean distance between J a pose

g_{ij} from accumulated matrix G line 1 column 1 to accumulate matrix G the *i*th row first j column of the shortest path, the unit is m,Of which I, *j* were greater than 1.

Joint Angle by the movements of the 13 formula to calculate the dynamic similarity of d_d. Formula of g_{nm}, The user action and standard action sequences of DTW distance, the size of the g_{nm} reflects the user dynamic action and its corresponding standard dynamic action of similarity, but in order to measure the user long-term behavior among different actions in the completion of the quality, the evaluation index system is formed, this article to g_{nm} DTW distance divided by one factor, the factor is the total frame of users the dynamic action Number n and its corresponding standard dynamic action is the sum of the total number of frames of m, which can reflect the user a dynamic action unit frames DTW distance, such as Equation (13).

$$d_d = \frac{g_{nm}}{n+m} \tag{13}$$

In the formula:

N—The user dynamic action of the total number of frames

M—Standard dynamic action of the total number of frames

g_{nm}—For a degree from accumulated matrix G line 1 column 1 to accumulate matrix G n row first m column of the shortest path, single

d_d—Users of dynamic similarity action joint Angle

(2)The dynamic action of joint angular velocity

In order to reflect the dynamic action of a single joint angular velocity error, this paper USES the evaluation index of average angular velocity similarity is dynamic movement joints. Dynamic movement joints average angular velocity similarity calculation method is as follows: 1) to calculate two adjacent frame joint Angle difference; 2) to calculate the average angular velocity joints; 3) to calculate the user dynamic movement joints, average angular velocity and standard dynamic movement joints average angular velocity of the Euclidean distance, get the dynamic movement joints average angular velocity similarity. Set the user a dynamic action of the action sequence for $E = [e_1, e_2, \cdots, e_i, \cdots, e_n]$, and the dynamic action of the standard joint average angular velocity of W', the dynamic action of joint angular velocity can be calculated by Equation (14) on average.

$$e_w = \frac{1}{n-1} \|\tau(\boldsymbol{e}_{i+1} - \boldsymbol{e}_i)\|_1 - w \tag{14}$$

In the formula:

e_i—Dynamic action of the *i*th a posture of joint Angle vector

τ—Sampling frequency of motion capture equipment

w—Average standard joint angular velocity, the unit is rad/s

N—The total number of frames of user dynamic action sequences

e_w—Dynamic movement joints, average angular velocity similarity unit for rad/s

5. The experiment and analysis

5.1. Training quality evaluation process

Through experiments to validate the presented based on the data of the feasibility of the evaluation method of human bone joint. Laboratory evaluation of human action for the 9th edition kicking movement of the first section, including two static action and dynamic action, about 7 s duration. Experimental parameters initialization complete, then collected four testers (tester, tester, tester C B, A tester D) radio gymnastics movement data to evaluate, the tester has A master broadcasting gymnastics movements, the tester B and C programming skilled testers, testers D has yet to grasp the basic behavioral essentials. This experiment will first through the process as shown in **Figure 4** to preset the parameters in the experiment, after the acquisition of four testers do kicking motion data, and through this human motion evaluation method to evaluate it, verify whether this action evaluation method can complete the motion of the four testers quality to make the right evaluation. The specific process as shown in **Figure 4**.

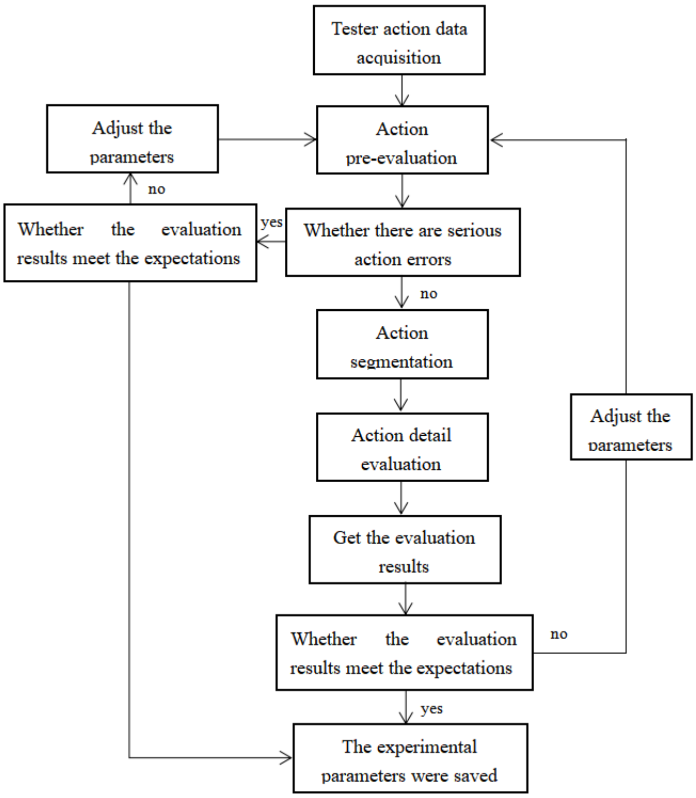

Figure 4. Human motion evaluation flow chart of the experiment.

5.2. The experiment results analysis

Experimental results show that the tester, on average, each joint angular velocity of A numerical results between "−10" to "+10", compared to the testers to B and C, error is small, illustrate the tester A joint angular velocity and standard action close to, reflects its action. For the test B, right shoulder and left shoulder joint average angular velocity similarity calculation result is positive, and the value is bigger, show the tester

B control too much of the two joints. For testers to C, there are multiple joints joints average angular velocity similarity calculation result is negative, and the value is bigger, such as the left shoulder, your right elbow and left elbow, left pulp, testers C spend little control of these joints. If further want to test every movement in the joints of the average angular velocity similarity index of the evaluation results, can refer to **Table 6** joint average angular velocity similarity evaluation criterion, joint evaluation criterion of the average angular velocity similarity threshold value can be set depending on the degree of strict evaluation of action. Joint test three average angular velocity similarity evaluation results such as **Table 7** shown.

Table 6. Criteria for the evaluation of mean joint angular velocity similarity.

The mean angular velocity similarity of the joints takes the value range	Evaluation results of action strength
$e_w > 10$	iusto major
$-10 \leq e_w \leq -10$	good
$e_w < -10$	undersize

Table 7. Evaluation of mean angular velocity similarity of three subjects.

	conner A		conner B		conner C	
	Joint angle similarity	Evaluation results	Joint angle similarity	Evaluation results	Joint angle similarity	Evaluation results
Dynamic action 1	8.53	good	35.10	iusto major	−9.82	good
Dynamic action 2	-10.29	undersize	27.43	iusto major	−25.45	undersize
Dynamic action 3	3.86	good	8.26	good	−35.48	undersize
Dynamic action 4	5.00	good	6.11	good	−23.68	undersize

The experimental results show that the proposed human motion training quality evaluation method is feasible on:

(1) The entire testing process successfully identifies movement phases, effectively preventing errors related to missing actions or misaligned action sequences. This is achieved by applying a dynamic velocity threshold of 0.5 m/s for movement detection. This threshold was selected based on a series of preliminary experiments conducted to determine the optimal speed at which typical radio gymnastic motions (e.g., arm swings, leg extensions) can be clearly distinguished from rest states. By setting this threshold, the method ensures that dynamic actions are accurately segmented while minimizing the misclassification of low-speed movements as part of the static phase. The threshold was validated using a dataset of 50 samples, where it achieved a precision rate of 92% in distinguishing between movement and rest states in real-time.

(2) In accordance with the standard action set defined in this paper, several key indicators, such as action space angle error and action time delay error, were used to quantify action quality during training. The action space angle error threshold was set at ±5 degrees, based on the biomechanical analysis of the expected range of motion

for radio gymnastics movements, which typically involve angular movements within this range. This threshold was chosen after an extensive review of previous research [6], where it was found that an angular deviation greater than 5 degrees results in noticeable loss of precision and performance. The action time delay error was defined as the maximum allowable deviation from the expected timing of a standard movement cycle, and was set to ±100 milliseconds. This threshold was empirically determined through analysis of training videos and feedback from expert trainers, where delays exceeding 100 milliseconds significantly impacted the synchronization of movement execution.

Both of these indicators—action space angle error and action time delay error—were further validated by applying the same thresholds to a control group of 30 athletes performing standard radio gymnastics routines. The action space angle error and action time delay error were measured using motion capture data and the corresponding thresholds were found to provide an overall accuracy of 89% in detecting deviations from standard movements. These thresholds were optimized to ensure they are sufficiently strict to detect significant errors, while also allowing for small, natural variations in the execution of high-speed, complex movements.

While the proposed method demonstrates promising results in real-world applications, its robustness to noise and sensor errors has not been thoroughly discussed in the current framework. Given that motion capture systems are prone to noise—whether due to environmental factors, sensor drift, or imperfect calibration—the ability of the method to perform reliably under noisy conditions is a crucial consideration. In this section, we analyze the performance of the motion evaluation system under various noise levels and sensor inaccuracies to assess its robustness and reliability.

To evaluate the system's robustness to noise, we introduced synthetic Gaussian noise at different signal-to-noise ratios (SNRs) during the motion data collection process. Specifically, noise was added to the raw acceleration and angular velocity data at levels of 10%, 20%, and 30% relative to the signal strength. We then re-applied the motion segmentation and evaluation process under these noisy conditions to assess how the system handled error propagation.

The experimental results showed that even under 30% noise conditions, the system was able to maintain an accuracy of 85% for detecting action phases and calculating angle errors, demonstrating that the motion segmentation method is relatively robust to noise. However, the action time delay error showed a slightly higher sensitivity to noise, with a performance degradation of about 5% at the highest noise level. This suggests that while the angle-based measures remain relatively stable, timing-related errors are more susceptible to noise interference.

In addition to noise, sensor inaccuracies such as drift and miscalibration can affect the reliability of motion capture systems. To simulate sensor errors, we introduced random calibration errors in the sensor readings, with angular deviations of up to ±3 degrees for accelerometer and gyroscope measurements. These errors were introduced into the motion data to assess the impact on the system's performance.

Under simulated sensor error conditions, the action space angle error showed an increase of 4% in deviation from the baseline, but the system's performance remained above 88% accuracy for detecting major action phases. The action time delay error was affected more significantly, with the accuracy decreasing by 7% when sensor miscalibration was introduced. Despite these challenges, the system still showed substantial robustness, with performance drops well within acceptable limits for real-time training applications.

6. Conclusion

Human movement quality evaluation is a technology that is closely related to daily life, with significant research value and broad application potential. In this study, we focused on calisthenics as the research object and proposed an evaluation method based on motion segmentation. This method divides the user's action according to standard movements and rhythm, enabling a comprehensive analysis of the live actions and laying the foundation for further evaluation. To address the problem of "joint point distortion," we applied average filtering, median filtering, and Kalman filtering algorithms for motion data processing. The results show that the proposed methods are effective in evaluating human actions, including radio gymnastics, and can be applied to other sports with similar movement patterns.

In future work, this evaluation system has great potential for application in a variety of other sports disciplines. For example, in gymnastics, track and field, and martial arts, where precision and timing are crucial, the system could help evaluate the execution of routines and techniques. By segmenting and analyzing movements in real time, athletes and coaches can receive immediate feedback, enabling the optimization of performance. Additionally, the system could be adapted for swimming to assess stroke efficiency and coordination. The versatility of this evaluation method opens up possibilities for broader use in sports that require both high accuracy and synchronized movement.

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