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Article

Limb motion mechanics analysis of Taijiquan trainees combined with APAS image analysis system

Jimeng Yan*, **Zhihang Sun**

Zhengzhou Yellow River Nursing Vocational College, Zhengzhou 450066, China
*** Corresponding author:** Jimeng Yan, yjm19882024@163.com

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Abstract: Analyzing the motion mechanics of Taijiquan trainees' limbs can help trainees better understand the mechanics of Taijiquan movement and improve their training speed. However, all the current motion mechanics analysis models still have the disadvantage of poor motion mechanics analysis due to inaccurate motion image feature extraction. Therefore, this study utilizes the Ariel performance analysis system and temporal-difference to construct a motion mechanics analysis model to extract motion image features of Taijiquan and analyze its motion mechanics. analysis. The study first experimented with this analysis model. The outcomes indicated that the model achieved 100% accuracy in the extraction of image feature information and 100% accuracy in the analysis of motion mechanics, which was much higher than the comparative analysis model. The model was then used to analyze the motion mechanics of Taijiquan trainees during bending and squatting posture. The results revealed that the larger the knee fixation angle was, the shorter the completion time of the movement was. When the knee fixation angle was 150°, the time taken to complete the starting, fixing and finishing phases of the movement was 11.21 s, 61.21 s and 12.32 s respectively. Moreover, when the trainees performed the movement, the angle of the trainee's right knee changed gently in the starting phase, while the angle of the trainee's left knee changed more drastically. In summary, the motion mechanics analysis model proposed in the study is able to accurately analyze the limb motion mechanics of Taijiquan trainees as a means of avoiding various injuries during training.

Keywords: Taijiquan; ariel performance analysis system; motion mechanics; analytical modeling; temporal-difference

1. Introduction

In light of the enhancement of contemporary living standards, a growing number of individuals are directing a heightened level of attention towards the condition of human health. Moreover, Taijiquan, as a kind of sport that can help people improve cardiorespiratory function, improve body flexibility, and promote blood circulation, is also more familiar to more people [1,2]. More and more people choose to do Taijiquan training in order to improve their physical fitness. Human body motion mechanics refers to a science that uses the principles of mechanics to study and master the balance of the body and how the body is coordinated when it changes from one posture to another [3]. The analysis of motion mechanics, such as the fixed angle of Taijiquan trainee's limbs and the time of movement completion, can provide an in-depth understanding of the mechanics of Taijiquan, which can improve the effectiveness of Taijiquan practice and the technical ability [4,5]. There are many scholars who have studied the mechanical analysis model. For example, Raj et al. analyzed the motion mechanics of ankle braces by a universal testing machine in order to improve the mechanical strength of ankle braces. The results indicated that the accuracy of the universal testing machine was 79.8% when performing the mechanical analysis [6]. In addition, in order to analyze the various properties of 3D printed materials, Bandinelli et al. designed a mechanical analysis model based on finite element analysis, which was used for comparison with a conventional mechanical analysis model. The results showed a 12.4% increase in the analytical accuracy of the model [7]. To address the problem of unclear analysis of the interaction between the filler particles of the filled polymer and the polymer matrix, Bashir et al. proposed a mechanical analysis model based on dynamic mechanics, which was used to test the model in real situations. The outcomes indicated that the model was able to analyze the forces between filler particles and polymer matrix with an accuracy of 85.8% [8]. However, the above mentioned motion mechanics analysis model also suffers from poor motion mechanics analysis of objects due to inaccurate extraction as well as analysis of motion image features [9]. Accordingly, there is a necessity to optimize the motion mechanics analysis model with the objective of enhancing the precision of the model for the extraction of motion image features.

Ariel performance analysis system (APAS) is a suite of biomechanical analysis system for fine 3D motor action analysis [10]. The system is used in various fields due to its high accuracy and reliability, versatility, and ease of data collection and analysis [11]. For example, Miranda-Oliveira et al. proposed a position detection method based on the APAS system in order to detect the reasonableness of the athlete's position when a soccer player performed a hard kicking maneuver, which was used in a real situation for comparison. The findings demonstrated that the methodology exhibited an enhanced capacity for accurate detection, reaching a detection accuracy of 92.4% [12]. The APAS system, however, when processing image data, there will be a variety of image errors due to the differences in the shooting equipment. Therefore, to address the inherent inaccuracies, it is essential to employ the nearest neighbor interpolation method [13]. While in this study, the motion images of Taijiquan trainees need to be captured and analyzed for feature extraction, and the analysis algorithms in the APAS system need to be selected according to the actual situation. Temporal-difference (TD) is able to analyze the motion trajectory of dynamic images [14]. Therefore, the APAS system in this study utilizes the TD algorithm to analyze the extracted motion images of the Taijiquan trainees in an attempt to improve the accuracy of the system in analyzing the dynamic images.

In summary, although there are many motion mechanics analysis models and methods, these analysis methods and models have inaccurate feature extraction and poor mechanics analysis of motion images, and optimization of the models is needed. Therefore, this research utilizes the APAS image analysis system to analyze and extract the motion mechanics features of images in an attempt to enhance the accuracy of motion mechanics analysis. The innovation of the study is that this study utilizes TD algorithm and nearest neighbor interpolation to analyze the error processing and feature extraction of Taijiquan trainee's body movement images to reduce the analysis error of APAS system.

2. Methods and materials

2.1. Motion mechanics analysis model based on APAS image analysis system

Motion mechanics is the science of studying the laws of motion of objects, which has applications in many fields. For example, in biomechanics, by analyzing the motion mechanics of the human body, it is possible to study the laws of motion of the human body in sports and improve the athletes' performance. In engineering applications, it can be used to analyze and optimize the motion state of objects to ensure the stability and efficiency of design [15]. When analyzing the motion mechanics of the human body in sports, the motion mechanics are generally analyzed through motion images [16]. However, many of the current image and image analysis models still have the problems of low analysis accuracy and insufficient image data, and they need to be optimized. APSA is an instrumentation device for image testing, image processing and analysis. The equipment is capable of analyzing data errors that occur during the motion process through the use of 3D motion analysis. This enables researchers to reduce the occurrence of such errors and thereby improve the accuracy of image analysis. **Figure 1** depicts the basic structure of APAS.

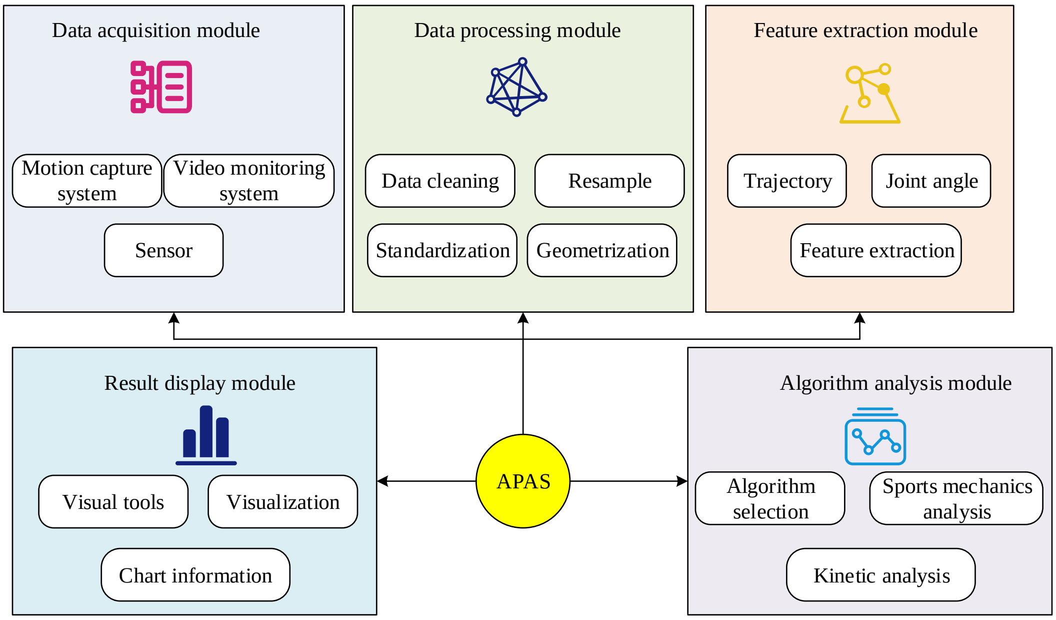

Figure 1. Basic structure of APAS system.

In **Figure 1**, APAS consists of a data acquisition module, a data processing module (DPM), a feature extraction module (FEM), an algorithm analysis module, and a result display module. In the data acquisition module, the raw data are collected by various sensors such as motion capture system and video surveillance system. The collected raw data are then subjected to preprocessing operations such as data cleaning, resampling, normalization, standardization, and geometric correction to ensure the accuracy and reliability of the data. Then the preprocessed data are subjected to feature extraction to extract useful feature information such as human joint angles and motion trajectories. After that, various algorithms are applied to analyze the extracted features, including motion mechanics analysis, dynamics analysis and so on. This part is the core of the APAS system, which determines the analysis capability and accuracy of the system. Finally, the analysis results are transformed into user-understandable graphs and tables through visualization tools and report generation tools. The specific steps when performing data preprocessing operations in the APAS system are shown in **Figure 2**.

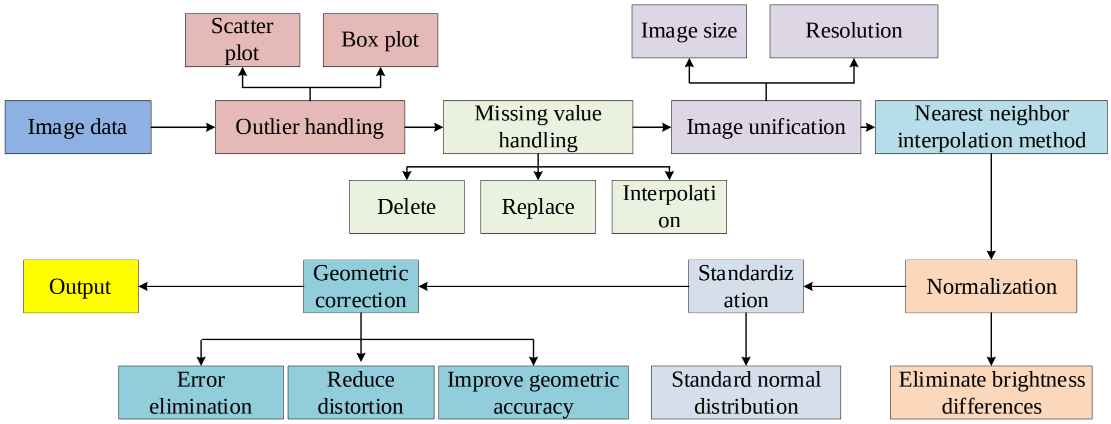

Figure 2. APAS system data preprocessing operation process.

In **Figure 2**, the APAS system first needs to clean the collected data, and this step includes the processing of data missing values and outliers. Missing data can be processed by deleting, replacing or interpolating them. Outliers can be identified by univariate scatter plots or box plots and processed by deleting or correcting them. Data resampling, on the other hand, is designed to unify images of different resolutions and sizes to provide a basis for subsequent data analysis and processing. Resampling is generally performed using the nearest neighbor interpolation method. After resampling, the data also needs to be normalized and normalization process. The image data normalization process is done to eliminate the brightness difference of the image by scaling the pixel values between [0,1]. Whereas normalization is done to make the data conform to a standard normal distribution. Finally, geometric correction is performed on the image data in order to eliminate errors in image shape, size, orientation, and other features of the image produced by the photographic equipment during imaging. The geometric correction also reduces the image distortion and improves the geometric accuracy of the image. The formula of the nearest neighbor interpolation method is shown in Equation (1).

$$\begin{cases} SX = DX \times (\frac{Sw}{Dw}) \\ SY = DY \times (\frac{Sh}{Dh}) \end{cases} \quad (1)$$

In Equation (1), SX and SY are the horizontal and vertical coordinates of the corresponding target image pixels in the source image. DX and DY are the horizontal and vertical coordinates of the target image pixels. Sw and Sh denote the source image width and height. Dw and Dh denote the target image width and height. In Equation (2), the data normalization is calculated.

$$X' = (X - min(X))/(max(X) - min(X)) \quad (2)$$

In Equation (2), X represents the original data. $max(X)$ and $min(X)$ represent the highest and lowest value of the original data. X' is the normalized data. The formula for data normalization is shown in Equation (3).

$$X'' = \frac{X' - \mu}{\sigma} \quad (3)$$

In Equation (3), X'' is standardized data. μ denotes the mean value. σ is the standard deviation. The calculation of image geometric correction is shown in Equation (4).

$$\begin{cases} x' = SX + dSX \\ y' = SY + DSY \end{cases} \quad (4)$$

In Equation (4), dSX and dSY denote the offsets in the translation transformation. The collected data are subjected to preprocessing operations through the above calculations to obtain the final dataset. The FEM of the APAS system often utilizes the mean filtering method to process the feature information of the image data. Equation (5) expresses the calculation method.

$$g(x,y) = 1/M * \sum f(x,y) \quad (5)$$

In Equation (5), $f(x,y)$ and $g(x,y)$ represents the gray value of the original image and processed image at position (x,y). M represents the total number of pixels in the template. The feature data of the image is obtained by the above calculation, and the data is input into the algorithmic analysis of APAS. The extracted feature data are analyzed by selecting the appropriate feature analysis algorithm according to the actual solution problem. The dynamics and motion mechanics transformations are verified based on the analysis results. The basic flow of motion mechanics analysis model based on APAS system is shown in **Figure 3**.

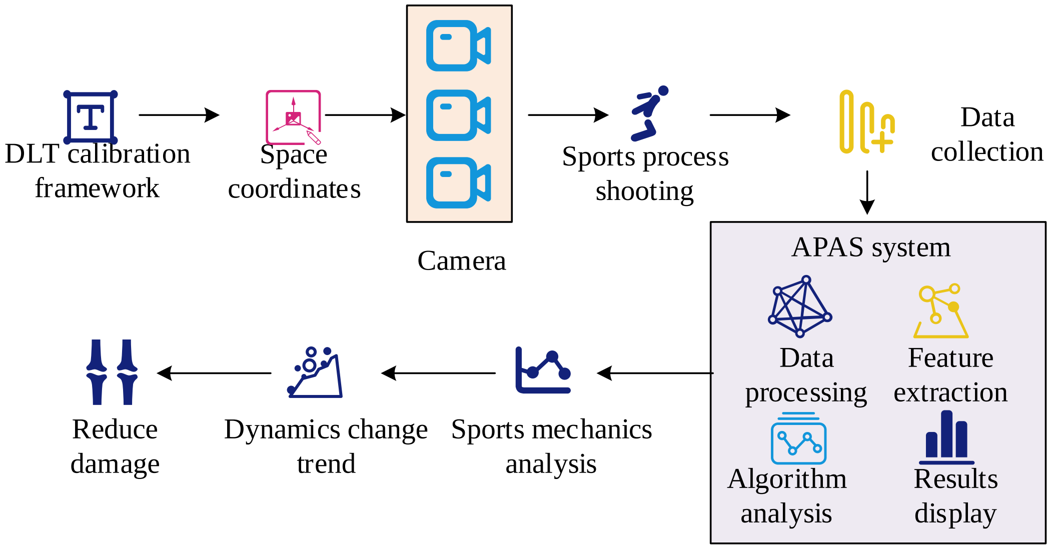

Figure 3. APAS motion mechanics analysis process.

In **Figure 3**, the APAS-based motion mechanics analysis model first establishes a spatial coordinate system using a 3D DLT calibration framework. Multiple cameras are then used to capture the motion process from different angles, which is used as the motion mechanics analysis data. The data is then transferred to the APAS system, where the captured images are processed and analyzed by the DPM, FEM and algorithm analysis module. The system then visualizes the results of the analysis, and analyzes the changes in the motion mechanics of the human body or the object through the visualized images and tables. This can get the trend of the dynamics of the human body or the object when doing a certain action, optimize the performance of the object movement or the human body movement, and reduce the injuries in the process of movement.

2.2. APAS-based limb motion mechanic analysis for Taijiquan trainees

The current motion mechanics analysis model also suffers from inaccurate motion mechanics analysis and poor image feature extraction [17]. To solve this problem, this study analyzes the limb motion mechanic of Taijiquan trainees using the APAS motion mechanics analysis model improved in the previous section, with a view to improving the efficiency of motion mechanics analysis by this system. The basic framework of limb motion mechanic analysis of Taijiquan trainees based on APAS model is shown in **Figure 4**.

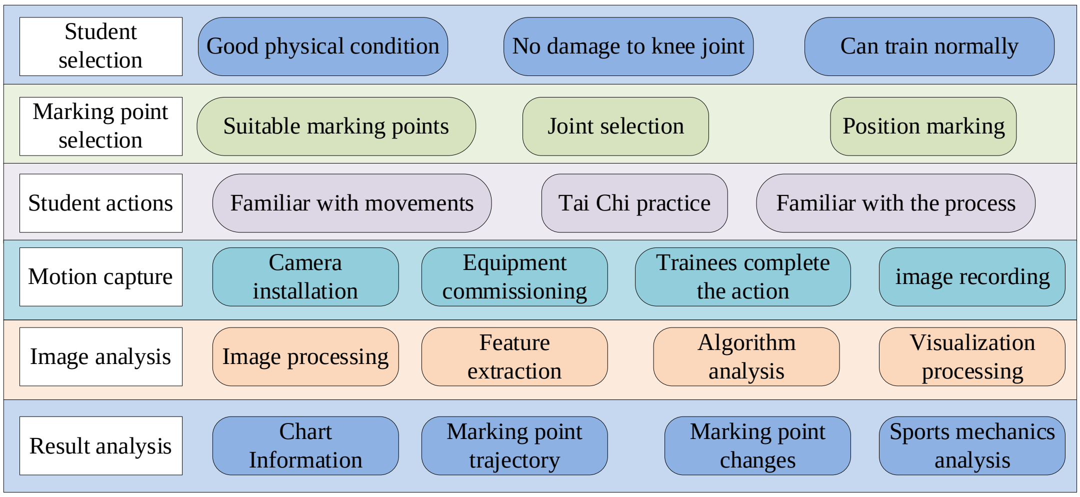

Figure 4. Basic framework of APAS Taijiquan limb motion mechanics analysis.

In **Figure 4**, when conducting motion mechanics analysis on the limb movements of Taijiquan trainees, firstly, it is necessary to select the subjects who have good motor status, good flexibility, coordination, and balance bar, with a willingness to learn Tai Chi, have no damage to the knee joints (KJs) and are able to perform normal movement training, this ensures the quality of data collection. Then the appropriate marker point for analysis should be selected on the subject and the position should be labeled. Afterwards, the subject should be familiarized with the Taijiquan test movements and procedures, and be ready to prepare for the test. After the staff installs and debugs the video camera and other image capturing instruments, the staff issues instructions. The subject makes various Taijiquan movements according to the instruction, and the instrument starts to record all the movement images of the subject's movement. Various noise information may appear in image information recording, and it is necessary to use the total variation denoising method for denoising processing. The core idea of this method is to optimize a total variation energy function, which consists of a data fidelity term and a regularization term. By continuously optimizing the function, the data fidelity term ensures that the denoised image is as close to the original image as possible, while the regularization term smooths the image by minimizing the total variation of the image, preserving the edge details of the image as much as possible, and achieving the removal of noise in the image. And if image blurring occurs during the recording process, the blurred image is first transformed from the spatial frequency domain to the temporal frequency domain through Fourier transform. The grayscale values in the spatial domain are converted to their amplitude and phase in the frequency domain. Then, the inverse filtering frequency is calculated through deconvolution in the inverse filtering algorithm and used for the frequency response of the blurred image to obtain the frequency response of the deconvolved image. Finally, the deconvolved frequency response is transformed back to the spatial domain through Fourier transform to obtain the restored clear image. Then transfer the deblurred image information into the APAS system. The recorded images are analyzed by the DPM, FEM and algorithm analysis module in the system, and the image analysis results are obtained. The analysis results are then visualized for easy understanding and use by the user. Finally, Taijiquan trainees' limb motion mechanic is analyzed by the trajectories and changes of the marker points recorded in the results. The distribution of marker points of the subjects is shown in **Figure 5**.

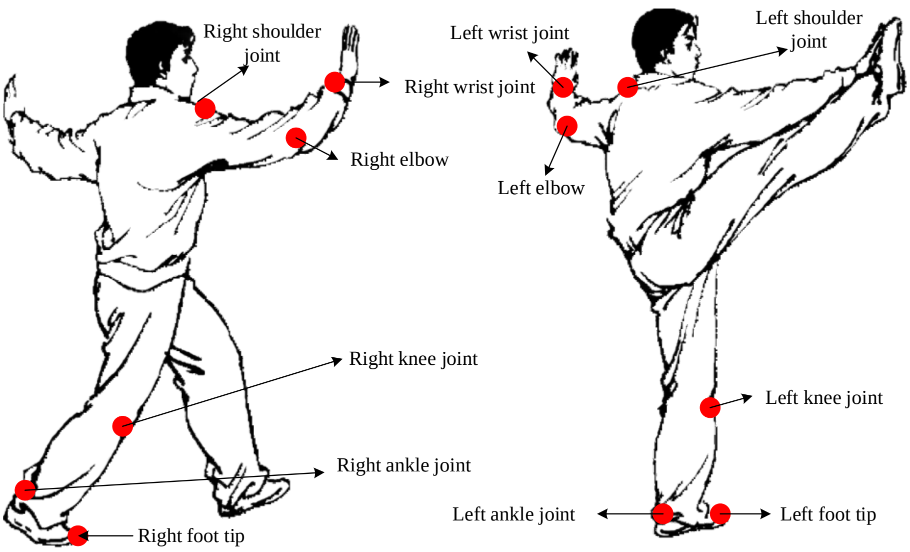

Figure 5. Distribution of marker points among subjects.

In **Figure 5**, most of the places where the subjects are labeled are joint locations, including 12 labeled points such as wrist, ankle, shoulder, knee, and elbow joints. After marking the above joints, the APAS system is used to analyze the changes of the marked points when the subject performs the Taijiquan movement as a way to analyze the limb motion mechanic of the Taijiquan participant. The motion mechanics analysis of the limb contains the analysis of the kinetic energy and impulse of the limb. The limb kinetic energy formula is shown in Equation (6).

$$FS = 1/2mv^2 \tag{6}$$

In Equation (6), F denotes muscle force. S, m, and v denote the distance traveled, mass, and speed of motion of the object, respectively. The impulse is calculated as shown in Equation (7).

$$mv = F_1T \tag{7}$$

In Equation (7), F_1 is the force of the blow and T is the contact time of the blow. This research is about the analysis of the human body motion mechanics, which requires the detection of dynamic images. Therefore, the TD that can detect the changes in human motion is selected to analyze the images in this study [18]. The flow of TD algorithm to analyze the image of Taijiquan trainee during motion is shown in **Figure 6**.

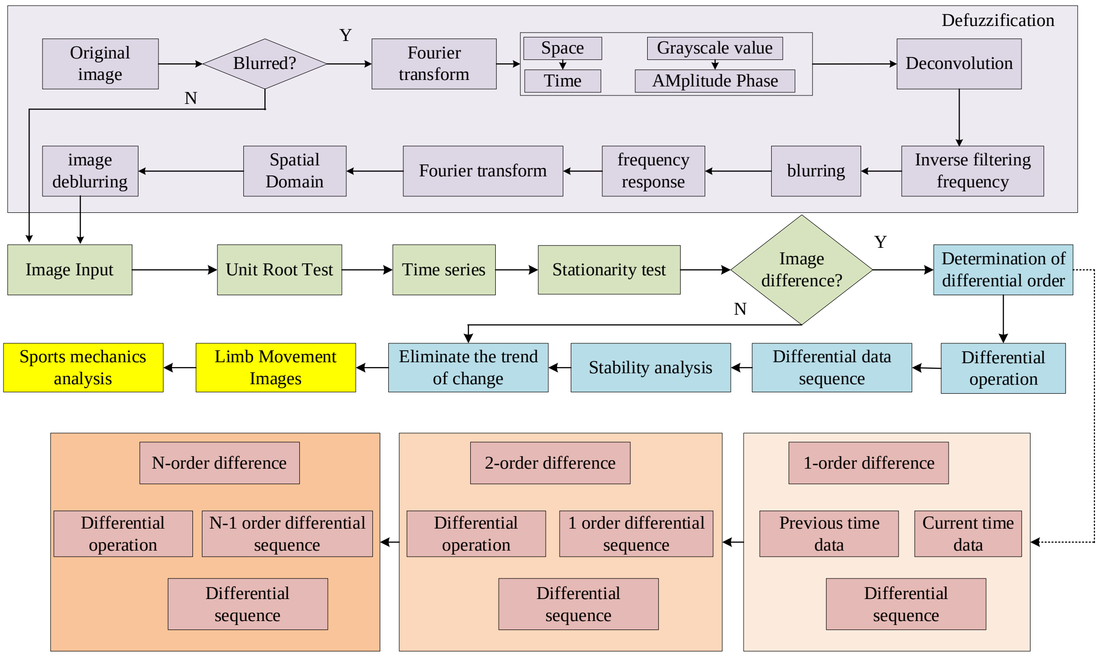

Figure 6. TD algorithm analysis process.

In **Figure 6**, the TD algorithm requires deblurring of the image before analyzing it, and then the TD algorithm first tests the smoothness of the input Taijiquan trainee limb image time series using the unit root test. After that, it determines whether image differencing is needed based on the observed original images. If it is needed then the difference order is determined according to the time series and the difference operation is performed on the image. First-order differencing means subtracting the data of the previous moment from the data of the current moment. Second-order differencing is performed on the sequence after first-order differencing again, and so on, to obtain a sequence of differenced data. That is, the image information of the current moment in the Taijiquan movement is subtracted from the image information of the previous moment to determine the trend of the image. After the difference is completed, the difference sequence should be analyzed for smoothness to ensure that the difference operation has eliminated the trend of the original sequence. Finally, the obtained differential sequence data is used to analyze the limb motion mechanic of the Taijiquan trainees while they are learning. In the TD algorithm, it is necessary to approximate the optimal policy step by step by using the value estimates of the current state and the next state. The calculation is shown in Equation (8).

$$V(S_t) \leftarrow \alpha[R_{t+1} + \gamma V(S_{t+1})] \quad (8)$$

In Equation (8), $V(S_t)$ denotes the value function at state (S_t). $R(S_{t+1})$ denotes the immediate reward obtained after taking action in state (S_t). γ denotes the discount factor. $V(S_{t+1})$ denotes the value function estimate at state (S_{t+1}). α denotes the learning rate. The formula for the difference is shown in Equation (9).

$$\Delta Y(t) = Y(t) - Y(t-1) \quad (9)$$

In Equation (9), $Y(t-1)$ and $Y(t)$ denote the observed value of the matrix at the previous and current moment. $\Delta Y(t)$ denotes the difference of the matrix in time t. In this study, the TD algorithm is used to analyze the changes in the motion trajectories of the marked points in the image, in order to obtain the changes in the motion mechanics of the marked points. The objective is to enhance the efficiency of the training process by modifying the body movements of Taijiquan trainees. This approach aims to augment the training speed while concurrently reducing the overall training time.

3. Results

3.1. Performance analysis of APAS motion mechanics model

To verify the analytical performance of the proposed APAS motion mechanism analysis model, this study compares the data analysis model based on BP network in traditional motion analysis methods, and currently, and compare the image analysis models based on Scale invariant feature transform (SIFT) algorithm and the total variation Field of Experts (TV-FOE) analysis models based on total variation and Markov random fields, which are currently widely used. **Table 1** displays the environmental configuration during the experiment.

Table 1. Experimental environment configuration.

Environment	Index	Type
Hardware environment	OS	Windows10
	Processing element	Intel Core i5-8400 CPU @ 2.80GHz
	Camera	Hikvision DS-2AM1-642X
Data analysis software	SPSS version	SPSS 19.0
	Stata version	Stata 18
	Python version	Python3.6

The images of trainees' Taijiquan records in a certain Taijiquan training center are selected as the experimental dataset for the experiment. The analysis effects of the four analysis models are compared by the above datasets and experimental environment configurations. The analysis accuracy of the four models is shown in **Figure 7**.

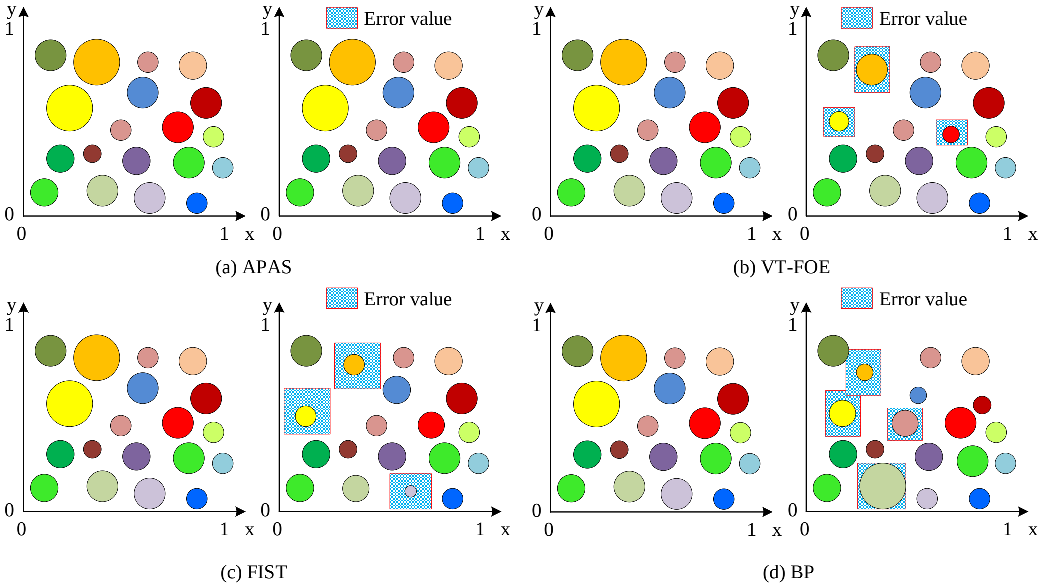

Figure 7. Model analysis accuracy.

Figure 7 shows the individual circles indicating the results of the data analysis. Boxes circled indicate data that are different from the actual analysis results. In **Figure 7a**, the APAS analysis model has the best analysis accuracy. The results of the data analyzed by this model are all the same as the actual results, and the analysis accuracy reaches 100%. In **Figure 7b**, the VT-FOE model has some analysis errors when analyzing the image data. In **Figure 7c**,**d**, the FIST analysis model as well as the BP analysis model analyze the image with a large error, and the gap with the actual results is large. Whereas, the reliability of the motion mechanics analysis is related to the accuracy of the analysis model in extracting the feature information of the motion image. Therefore, this study compares the extraction effect and denoising effect of the feature information of the image when motion mechanics analysis is performed by the four models. The results are shown in **Figure 8**.

In **Figure 8a**, the accuracy of feature information extraction as well as denoising accuracy of APAS analysis model reaches 100%. In **Figure 8b**, the VT-FOE analysis model is able to remove most of the noise information when analyzing the image data. However, there is still some noise information in the retained image and a small portion of feature information is missed. In **Figure 8c**,**d**, there is still a lot of noise and most of the feature information is missed after the image feature information is extracted by the FIST analysis model and the BP analysis model. The findings of this experiment illustrate that the APAS analysis model proposed in the study is capable of enhancing the precision of the subsequent motion mechanics analysis by accurately extracting image data.

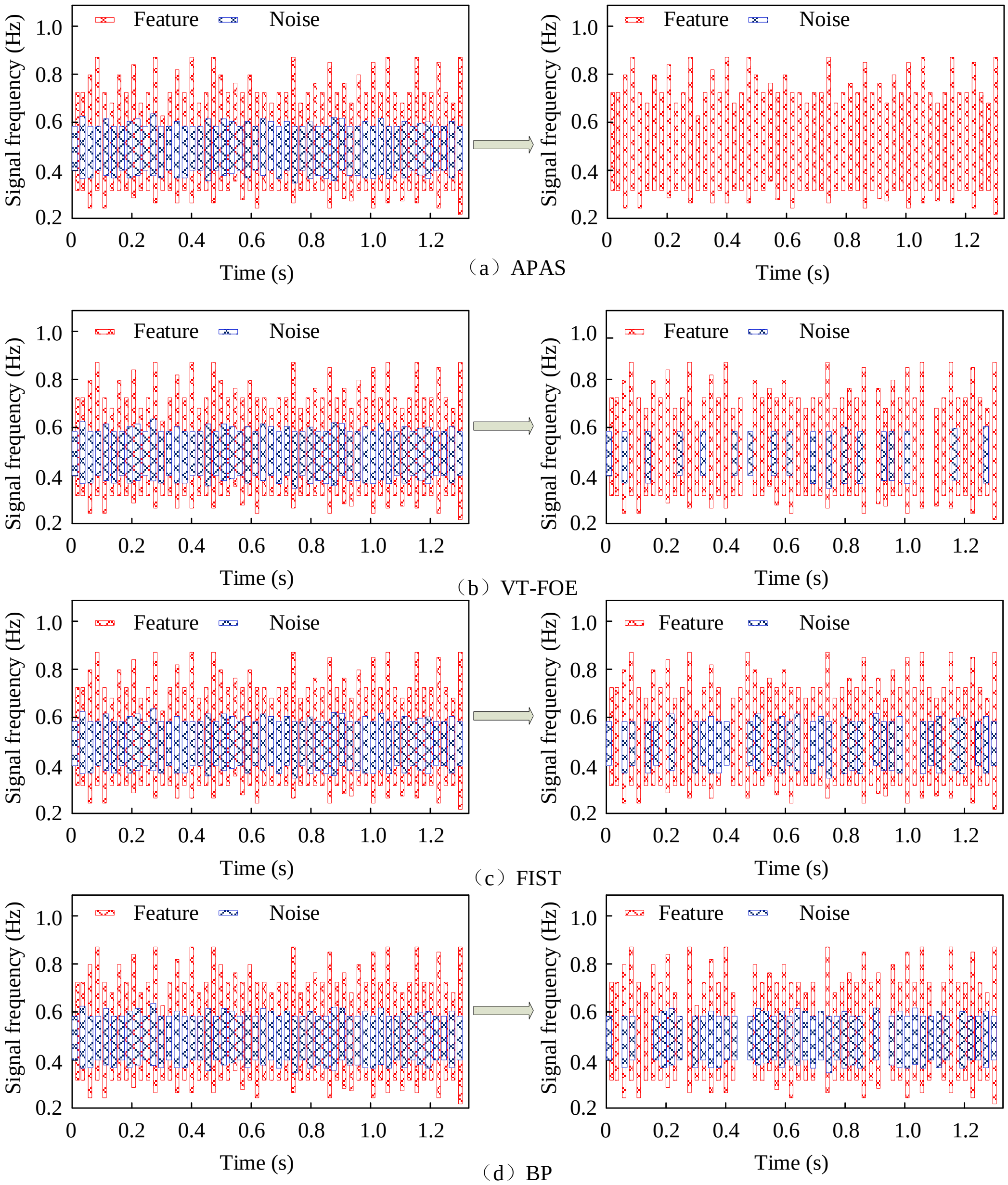

Figure 8. Model feature signal extraction effect.

3.2. Taijiquan trainees' limb motion mechanic analysis

After validating the analytical effect of the APAS model, the model is used to analyze the changes in the limb motion mechanic of Taijiquan trainees. Fifty trainees from a particular Taijiquan training camp are selected as subjects for the experiment. The time taken to complete a movement and other changes in motion mechanics are analyzed by recording various images of the 50 participants during Taijiquan training. Choose to analyze the sports mechanics of Tai Chi related movements for students in winter. The indoor temperature during athlete training is maintained at 17–23 ℃, and in order to capture clear images, the indoor care conditions need to be set to around 300 Lux and kept constant. And during the experiment, the APAS system was first tested by analyzing the motion mechanics of 50 students during warm-up exercises, correcting the image extraction accuracy and motion mechanics analysis accuracy of the APAS system until the system met the expected requirements. Then, the system was used to analyze the motion mechanics of students' Tai Chi movements. And set the sampling rate of the APAS image analysis system to 120 Hz, and the time resolution of motion analysis to 1/120 s. When the sampling rate is 120 Hz, it means that the device can capture 120 images per second. In racing or sports events, this sampling rate can maintain smooth images without dragging or distortion, which is sufficient for capturing slow motion sports training such as Tai Chi. During the experiment, markers should be placed on the left and right knee joints and ankle joints of Tai Chi students. The markers should be directly attached to the skin surface to ensure close contact with the skin and avoid sliding caused by exercise. And when attaching the marked points, adhesive elastic bandages, nylon buckles, tape or other fixing materials should be used to attach the marked points to the designated location of the students. The color of the marked points should be selected as red to contrast with the students' skin color for subsequent data analysis. When performing the squat routine, the standard for completing the movements is that the movements should be natural flow, the center of gravity of the body should be stable, and all movements from squatting to rising should be completed. Firstly, quantitative analysis of joint angles is conducted by selecting different joint angles and testing the changes in students' electromyographic values, in order to select the appropriate joint angle for motion mechanics analysis. The results are shown in **Table 2**.

Table 2. Changes of student joints from different angles.

Angle	**90°**	**100°**	**110°**	**120°**	**130°**	**140°**	**150°**
EMG value	The increase is larger	The increase is larger	The increase is larger	The growth rate decreased	The growth rate decreased	The growth rate decreased	The growth rate decreased
Fatigue performance	Increase	Increase	Increase	Highest	Reduce	Reduce	Reduce
Pressure load	Increase	Increase	Increase	Highest	Reduce	Reduce	Reduce

According to **Table 2**, when the joint angle of the students changes, the various properties of the students' joints and muscles near the joints also change. At 120°, the joint performance of the students reached the extreme value. Therefore, in order to accurately analyze the joint kinematics of the students, the changes in kinematics after the extreme value were significant. Choosing the angle after the extreme value change for analysis can clearly obtain the joint kinematics changes and ensure the accuracy of the results. First, the movement completion of the trainees is analyzed when they perform bending and squatting posture with different angles of the KJ set. The results are shown in **Figure 9**.

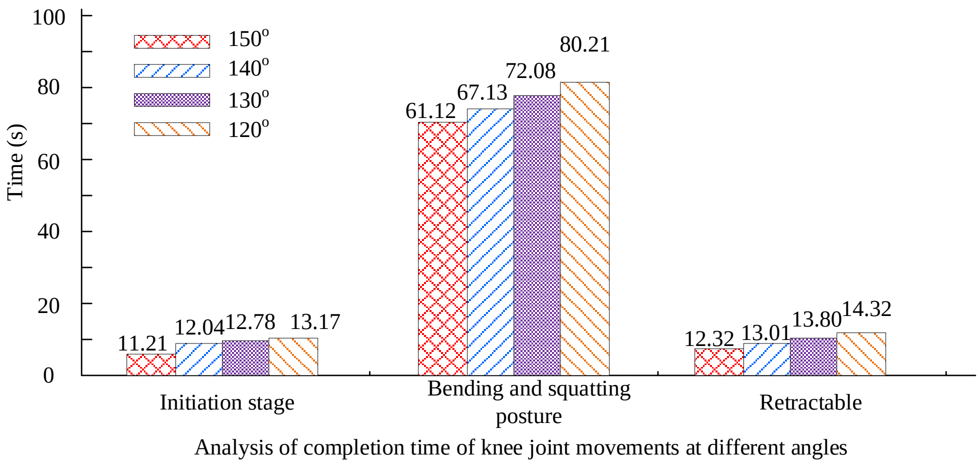

Figure 9. Comparison of action completion time from different perspectives.

In **Figure 9**, in the bending and squatting posture in Taijiquan, the longest time taken to complete the movement is in the middle bending and squatting stage, while the time taken in the rising and closing phases of the movement is shorter. Moreover, when the angle of the posture is larger, the time taken to complete the movement is shorter. Among them, when the fixation angle is 150°, the average time consumed by the trainees in the starting phase is 11.21 s, the average time consumed in the bending and squatting stage is 61.12 s, and the average time consumed by the trainees in the closing phase is 12.32 s. The changes of the knee and ankle joints (AJs) in the limbs of the trainees when they complete the movement under different fixation angles are also analyzed. The results are shown in **Figure 10**.

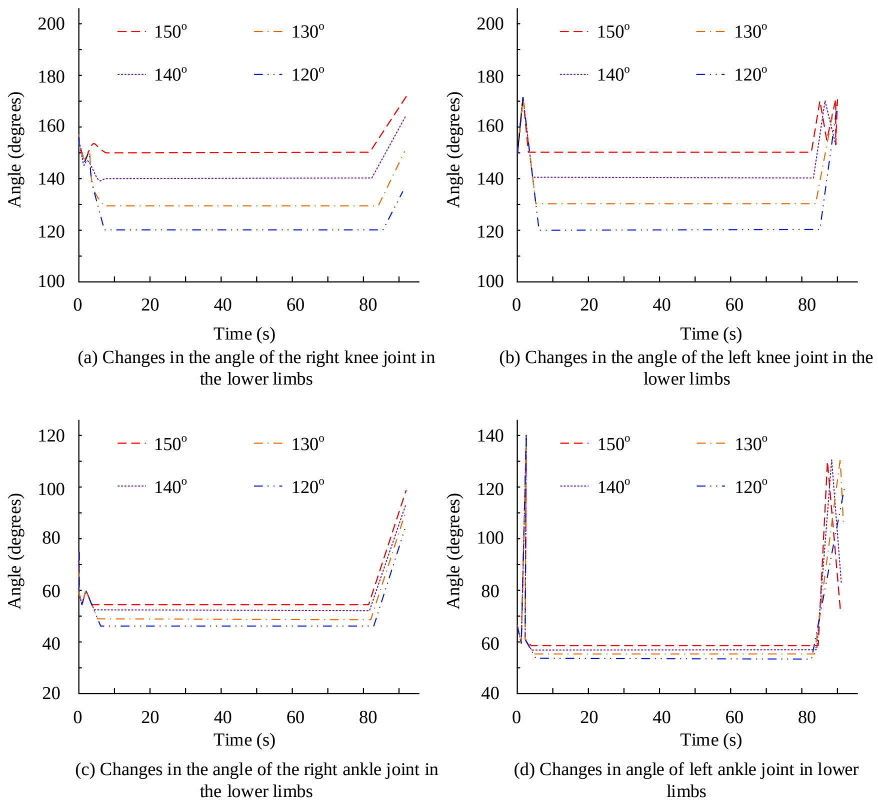

Figure 10. Changes in knee and ankle joint angles of students at different angles.

In **Figure 10a**, when completing the bending and squatting posture in Taijiquan, the first 5 s of the movement is the starting phase of the movement. At this time, the trainee's right KJ angle of the lower limb changes more gently, and the trainee's right KJ angle shows a decreasing trend in 5~10 s. In the middle stage of the movement, the angle of the trainee's KJ remains unchanged. Moreover, when the angle of the stance is smaller, the angle of the trainee's right KJ is smaller. In **Figure 10b**, the angular changes in the left KJ of the participant's lower limb are more dramatic in the early period as well as in the later period. The other time periods show the same trend of changes in the angle of the right KJ. In **Figure 10c**,**d**, during the bending and squatting posture, the participant's right AJ angle changes (ACs) in the pre-phase are more gentle. On the other hand, the participant's left AJ has a very large ups and downs in the AC, whose difference reaches 80°. Furthermore, in the later stages of the movement, the AC of the right AJ is an upward trend, while the change of the left AJ is larger and has no specific pattern. Then the ACs of the knee and AJs of the trainees' limbs in the ascending and descending phases of the bending and squatting stages of the Taijiquan line are compared at the completion of the movement. The KJ angles and changes over time are shown in **Table 3**.

In **Table 3**, when Taijiquan trainees performed bending and squatting exercises, the time difference between the completion times of the left and right KJs of the trainees' lower limbs is small when the trainees performed squatting maneuvers and pullback maneuvers. The maximum time difference is only 0.04 s. The completion time increases slightly with the decrease of the fixation angle in the bending and squatting preparation, but the increase is within 1 s. During the squat phase, the movement change profile of the trainee's right and left KJs is low. However, during the recovery stage, the AC profile of both the right and left KJs of the trainees is higher. In particular, the maximum value of the AC in the right knee is 11.1°, while the maximum value of the AC in the left knee reaches 42.2°, and the AC of the right and left knee increases significantly when the fixation angle decreases. This result indicated that when performing Taijiquan bending and squatting training, it is necessary to pay attention to the change of the center of gravity in the left KJ to avoid knee injuries.

Table 3. Changes in knee joint angle over time.

Stage	Fixed angle	Lower limb right knee joint		Left knee joint of lower limb	
		Time (s)	Angle (°)	Time (s)	Angle (°)
Squatting stage	150°	2.12~2.46	154.3~150.1	2.11~2.42	156.3~150.2
	140°	2.23~2.57	149.6~143.4	2.21~2.53	151.6~143.5
	130°	2.38~3.17	142.5~140.8	2.39~3.19	147.5~141.7
	120°	3.02~3.98	141.4~139.7	3.00~3.97	144.4~140.4
Recovery stage	150°	69.76~71.23	152.3~152.4	69.75~71.23	152.1~154.9
	140°	73.76~73.42	143.4~148.7	73.76~73.42	143.4~157.7
	130°	74.78~74.23	135.2~140.1	74.78~74.23	135.2~162.1
	120°	78.76~76.52	128.3~139.4	78.76~76.52	128.2~168.4

4. Discussion and conclusion

To increase the accuracy of the current motion mechanics analysis model and the efficiency of motion image feature extraction, this study organically combined the APAS image analysis system with TD. The combined APAS system was used to construct a Taijiquan motion mechanics analysis model. The model was then used to analyze the motion mechanics of Taijiquan trainees' body movements. For verifying the performance of this analysis model, the study conducted a comparison test between the APAS analysis model and the VT-FOE analysis model, and the FIST analysis mode. The experimental results indicated that among the three analysis models, the feature extraction accuracy and denoising accuracy of APAS analysis model for motion images reached 100%. VT-FOE analysis model and FIST analysis model also had feature information omission and low noise removal rate when performing image feature extraction and image noise extraction. Moreover, when using the three models for motion mechanics analysis, only the APAS analytical model achieved 100% accuracy in the analysis of motion mechanics, while the analysis of the other analytical models had varying degrees of error. The result was similar to that of Mastalerz. At the same time, the motion dynamics analysis model based on APAS image analysis system proposed in the study has higher accuracy in motion image extraction, denoising, and motion dynamics analysis than traditional motion analysis methods based on BP algorithm. The reason for this result may be that the nearest neighbor interpolation was used in the APAS motion mechanics analysis model. This reduced the errors in image size, shape, etc. caused when motion images were taken, thus improving the image feature extraction's as well as the accuracy of the motion mechanics analysis [19].

The study was conducted to analyze the motion mechanics of Taijiquan trainees while performing bending and squatting posture using APAS analytical model. The results showed that the completion time of bending and squatting posture was highly related to the changes in knee and AJ angles and the size of the stance angle. The larger the stance angle of the trainees, the shorter the completion time of the movement. Moreover, the larger the stance angle, the lower the AC of the left and right KJs and the left and right AJs of the trainees. While performing the completion of the movement, the participants' left knee and left AJs had more intense angular changes, while the right ankle and right KJs had more moderate angular changes. During the squat phase of the movement, the trainee's right and left KJs showed lower changes in motion. In contrast, during the recovery stage, the participant's right and left KJs had more dramatic changes in motion. This result coincided with Eckhaus's result, which indicated that the trainees should pay attention to the control of the setting angle when performing the Taijiquan bending and squatting posture. In case of trainees with poor knee and AJs, the maneuver should be completed with a large setting angle to protect the joints by reducing the elapsed time to completion [20]. And in order to better protect the ankle and knee joints of Tai Chi students, teachers should instruct them to avoid bending their knee joints too much when squatting during training. They should increase the fixed angle, reduce the angle changes of the knee and ankle joints, and avoid excessive joint damage; In order to prevent significant changes in the kinematics of the left and right knee and ankle joints during the recovery phase, students should move slowly and steadily to reduce the impact on their joints. In addition, during the flexion and squatting posture, pay attention to the stability of the knees and ankles. The knees should be kept slightly bent to avoid complete extension and reduce joint pressure. Ankles should be kept relaxed to avoid excessive tension causing ankle joint injuries.

In conclusion, the APAS motion mechanics analysis model, as proposed in the study, is capable of accurately analyzing the motion mechanics of Taijiquan trainees, thereby ensuring the safety of trainee training. Moreover, the skill levels of the 50 Tai Chi students selected in this study varied, but the proposed system was able to accurately analyze their motor mechanics, indicating that the system is also applicable to students with different skill levels. However, the APAS image analysis system in the APAS motion mechanics analysis model also exhibits image blurring when capturing the trainee's motion images, which can have a detrimental impact on the resulting data. This issue can be addressed in the future by either denoise the images or utilizing high-quality imaging equipment.

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