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Aerobics Movement Visualisation Analysis Based on 3D Motion Capture System

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Abstract: *With the continuous development of 3D motion capture technology, its application in the field of sports is increasingly widespread. In this paper, based on the 3D motion capture system, the visual analysis method of aerobics movements is studied. The basic principles of 3D motion capture technology and its application in aerobics training are introduced. This paper discusses in detail the acquisition and processing flow of aerobics movement data, including data preprocessing, noise removal and extraction of key features. A three-dimensional model-based aerobics movement visualisation and analysis system is designed and implemented, which is able to display the quality of athletes' movements in real time and assist coaches and athletes in movement evaluation and improvement. This paper analyses the potential applications of this technology in aerobics and other sports fields, and proposes future research directions. The results show that visual analysis based on 3D motion capture technology not only improves the accuracy of movement assessment, but also provides athletes with more intuitive and actionable training feedback.*

Keywords: *3D motion capture; aerobics; movement analysis; visualisation; movement assessment*

1. Introduction

With the continuous progress of science and technology, the technical means in the training and competition of athletes are constantly updated, especially with the widespread adoption of advanced technologies such as 3D motion capture in various sports disciplines[1]. This technology provides an innovative approach to enhancing athletic performance by capturing and analyzing detailed movement data. Aerobics, being a rhythmic and technically demanding sport, requires not only precision but also a high level of fluidity in its movements[2]. The accuracy and smoothness of an athlete's actions directly influence both the outcome of competitions and the effectiveness of their training regimen. Proper assessment and optimization of these movements have become crucial for improving performance and reducing the risk of injury. In this context, 3D motion capture technology offers a powerful tool for analyzing each movement with great precision, helping coaches and athletes fine-tune their techniques and ensure that every motion is executed with optimal form. This advancement in technology presents new opportunities for athletes to enhance their training processes, making it easier to detect flaws, track progress, and ultimately achieve better results in competition.

Three-dimensional motion capture technology uses multiple sensors to track athletes' movement trajectories in real time, and transforms the movements into digital data through computer algorithms, which provides a more accurate and intuitive way for movement analysis[3]. More and more research has begun to focus on how to apply 3D motion capture technology to aerobics and other competitive sports to improve the accuracy of movement analysis and training efficiency[4].

Despite the remarkable progress of 3D motion capture technology in sports training, combining it with aerobics movement analysis still faces many challenges. Aerobics, with its dynamic and complex movements, presents a unique challenge in accurately capturing and analyzing motion data[5]. Issues such as how to efficiently capture high-speed, fluid motions, how to process and model intricate movement patterns, and how to transform these vast amounts of raw data into intuitive and easy-to-understand visualizations remain significant hurdles[6]. Furthermore, ensuring that the captured data reflects real-world performance under different conditions, such as varying speeds or fatigue levels, requires advanced calibration and adjustment. Another challenge lies in the integration of real-time feedback into training processes, allowing athletes and coaches to make on-the-spot corrections. As the

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technology continues to evolve, further in-depth research is needed to overcome these technical obstacles and enhance the practicality and applicability of 3D motion capture for aerobics training. With continued development, these systems could offer unparalleled insights into athletes' biomechanics, providing a new era of precision in sport performance analysis.

The aim of this paper is to explore the visualisation and analysis of aerobics movements based on a 3D motion capture system. The basic principles of 3D motion capture technology and its application scenarios in aerobics are introduced. The process of motion data acquisition, processing and analysis is discussed in detail. A visual analysis system of aerobics movements is designed and implemented, and its application value and development prospect in actual training are discussed.

2. Application of 3D Motion Capture Technology in Aerobics

3D Motion Capture (3D Motion Capture) has been widely used in sports training and sports analysis in recent years, especially in sports that require high accuracy, such as gymnastics, dance and aerobics. Traditional aerobics training usually relies on coaches‘ visual observation and experience to assess the quality of athletes’ movements, but this approach is highly subjective and difficult to capture subtle movement differences[7]. Three-dimensional motion capture technology can provide more objective and scientific analysis results by accurately recording the real-time position of each joint of the athlete's body, which has become an important tool to improve the effectiveness of aerobics training[8].

In aerobics training, the 3D motion capture system can capture every detail of the athlete's movements with high precision, offering a level of analysis that was previously unattainable. This technology enables coaches and athletes to gain an intuitive understanding of the normality, smoothness, and fluidity of the movements, which are crucial in a sport that demands rhythmic consistency and technical accuracy. Using motion capture devices such as reflective markers or sensors placed on key body joints, the system tracks every movement trajectory of the athlete in three-dimensional space, converting these physical movements into digital data[9]. This data not only demonstrates the temporal and spatial distribution of the movement, but also provides a deeper understanding by quantifying parameters such as joint angles, velocity, acceleration, and the forces applied during each motion[10]. Furthermore, it can analyze the coordination between different body parts, which is essential in a highly synchronized sport like aerobics. Through comprehensive movement assessment, this system allows for a detailed breakdown of the athlete's performance, highlighting areas for improvement and offering data-driven insights for technique optimization. Euclidean Distance for Joint Displacement:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (1)$$

The application of 3D motion capture technology in aerobics provides an essential foundation for movement optimization and personalized training. In aerobics, even when different athletes perform the same movement, the execution may vary significantly due to differences in physical condition, movement habits, or training levels. These discrepancies can affect the overall quality and precision of the movements, impacting performance outcomes[11]. By utilizing the 3D motion capture system, coaches can gather individualized movement data for each athlete, allowing for a detailed analysis of their techniques. This system helps identify specific issues such as incorrect posture or improper alignment during complex movements like kicks or turns, where athletes may unknowingly adopt irregular positions[12]. By accurately capturing these movements in 3D space, the system provides a clear and objective view of the athlete’s form, revealing subtle flaws that could go unnoticed in traditional training methods. With this data, coaches can design tailored adjustment plans to correct these issues, providing athletes with targeted feedback and enhancing their training efficiency. The ability to track improvements over time further empowers athletes to refine their techniques, ultimately leading to better performance and reduced injury risk,showed in Figure 1.

Although the application of 3D motion capture technology in aerobics has many advantages, its practical application still faces some challenges. Capture systems are costly and have demanding environmental requirements, such as the need for relatively wide space and high-quality lighting conditions. Captured data requires complex processing and analysis, which puts higher demands on the level of technology. With the continuous progress of technology and the gradual popularisation of equipment, the application prospect of 3D motion capture technology is still broad in aerobics and other sports, and is expected to become a necessary tool in standardised training in the future.

ISSN 2618-1576 Vol. 7, Issue 2: 68-75, DOI: 10.25236/FSR.2025.070211

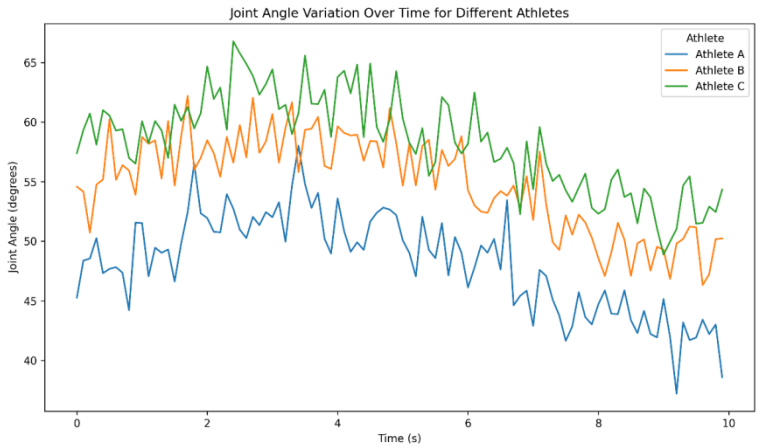

Figure 1 Joint Angle Variation Over Time for Different Athletes

3. Aerobics action data acquisition and processing

Aerobics action data acquisition and processing is the fundamental step in applying 3D motion capture technology to aerobics analysis. To ensure high accuracy and efficiency in capturing movement data, it is crucial to begin with precise data acquisition using suitable equipment, followed by effective data pre-processing to eliminate noise and errors. The final step involves in-depth analysis and optimization of the collected data to guarantee that the outcomes are both accurate and actionable. This process typically involves three key steps: data acquisition and equipment selection, data pre-processing and noise removal, and data analysis and action recognition. During the data acquisition phase, careful attention must be given to selecting the right sensors or reflective markers, ensuring they are placed correctly to capture every relevant detail of the athlete's movements. Once the data is gathered, pre-processing techniques such as filtering and smoothing are applied to clean the data and remove any irrelevant or noisy signals caused by environmental factors or system limitations. The subsequent analysis phase focuses on interpreting the clean data, identifying key movement patterns, and recognizing specific actions or flaws in technique. By carefully designing and implementing these steps, a robust, high-quality dataset is generated, providing valuable support for more advanced movement analysis, performance optimization, and visual representation of the athlete's actions. This ensures that the entire process is both reliable and practical for training and competition scenarios.

3.1. Data Acquisition Process and Equipment Selection

Data acquisition is the basic link in the application of 3D motion capture technology in aerobics, and accurate data acquisition determines the accuracy of subsequent analysis and visualisation. In aerobics training and competitions, the execution of movements is often very fast and complex, how to accurately capture the movements of athletes in these dynamic environments is the key to the realisation of the technology. 3D motion capture systems record the movement trajectories of individual joints and body parts by wearing reflective markers or using sensors on the athlete's body. These data are captured by high-speed cameras or sensors, converted into digital signals, and transmitted to a computer for further processing.

There are several factors to consider when selecting a motion capture device. The accuracy of the capture device is crucial because aerobics movements require extremely high movement specifications, and any slight error may affect the final evaluation results. Commonly used devices on the market are divided into two main categories: optical capture systems and inertial sensor systems. Optical capture systems use multiple high-speed cameras and reflective markers, and the position information of the reflective markers is captured by the cameras to calculate the 3D position of the joints. The advantage of this type of system is that it is more accurate, but it is more demanding on the environment, requiring sufficient light and a large enough operating space. Inertial sensor systems, on the other hand, capture motion data through accelerometers, gyroscopes and other sensors worn on the athlete's body, which have higher convenience and applicability and are suitable for narrow spaces or outdoor scenarios, but their accuracy may be slightly inferior to optical systems. Joint Angle Calculation Using the Dot Product:

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$$\theta = \arccos\left(\frac{\vec{A}\cdot\vec{B}}{|\vec{A}||\vec{B}|}\right) \quad (2)$$

During data capture, athletes need to wear a specific set of markers or sensors. For optical capture systems, reflective markers need to be fixed on various parts of the athlete's body (e.g., head, shoulders, elbows, knees, feet, etc.) so that the camera can accurately track the movement of the markers. During this process, the capture device records the athlete's movement trajectory in real time and converts it into digitised 3D data. In order to ensure efficient and accurate data acquisition, multiple cameras are used to capture the athlete's movements from different angles simultaneously, ensuring that every detail is captured. Inertial sensor systems, on the other hand, directly capture the athlete's movement data by installing sensors on the athlete's body, avoiding the environmental and spatial limitations of optical systems and enabling more flexible application in various training scenarios,showed in Figure 2 :

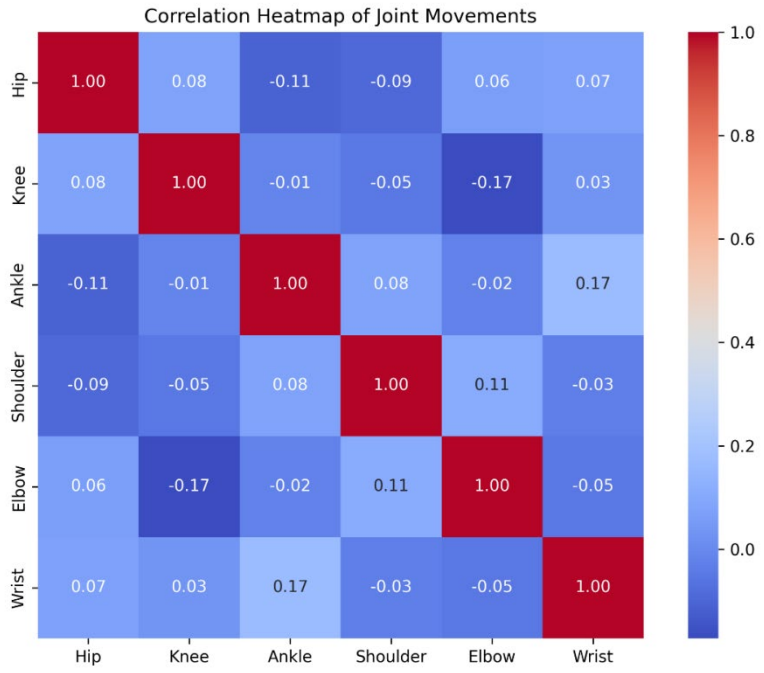

Figure 2 Correlation Heatmap of Joint Movements

Choosing the right equipment does not only depend on its hardware performance, how to choose the right equipment according to the characteristics and goals of aerobics training is also very important. Aerobics as a kind of rhythmic, coherent movement, often requires the capture system can quickly respond and provide real-time feedback. The response speed and data processing capability of the equipment is an aspect that needs special attention when choosing equipment. Optical systems have the advantage of high precision and detailed movement analysis, and are suitable for occasions requiring high movement specification; while inertial sensor systems are suitable for training or competition environments requiring a large amount of moving space due to their convenience and flexibility. The choice of equipment will be based on a combination of training needs, space conditions and budget.

3.2. Data Preprocessing and Noise Removal

Data acquisition is the foundational link in the application of 3D motion capture technology in aerobics, and the accuracy of this data is crucial for ensuring the precision of subsequent analysis and visualization. In aerobics training and competitions, the execution of movements is often rapid, dynamic, and involves complex coordination between different body parts. Capturing these movements accurately in such fast-paced, high-intensity environments poses a significant challenge. 3D motion capture systems address this challenge by recording the movement trajectories of individual joints and body parts using reflective markers or sensors attached to the athlete's body. These markers reflect infrared light emitted by high-speed cameras, allowing precise tracking of the athlete’s movements in real time. The captured data is then converted into digital signals, which are sent to a computer for further processing. This process allows the system to generate detailed, high-resolution motion data, enabling coaches and athletes to assess movement quality with a high degree of accuracy. The system's ability to capture fine-grained details of motion is essential for identifying even subtle flaws or inefficiencies in technique,

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which can significantly impact performance.

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3.3. Key Feature Extraction and Motion Recognition

In the application of 3D motion capture technology, key feature extraction and action recognition are the core links to achieve accurate analysis and action evaluation. In the movement analysis of aerobics, all parts of the athlete's body will perform complex movements at different speeds and angles, and the extraction of key features is the first step in identifying and analysing the movements. The key features usually include the angle changes of the athlete's joints, the rotation amplitude of the limbs, and the changes in body posture. These features can reflect the precision and smoothness of the movement, which is an important basis for movement recognition and movement quality assessment.

In order to extract the key features in aerobics movements, it is first necessary to identify the important joint points from the 3D motion data. These joint points usually include the head, shoulders, elbows, knees and ankles, and the 3D coordinate changes of these parts are recorded by a motion capture system. Based on these key points, the angle changes between different joints can be calculated, and then the key features of each movement can be extracted. In order to improve the accuracy of action recognition, it is often necessary to combine with time series analysis to take into account the temporal dimension of the action and the changes in the motion trajectory. These features provide an important basis for subsequent action classification and quality evaluation.

After the key features have been extracted, the task of action recognition is to determine which type of aerobics movement the athlete is performing based on these features. Action recognition usually relies on machine learning and pattern recognition algorithms, especially deep learning-based methods, which can better handle complex action data. By training a dataset containing a variety of aerobics movements, machine learning models are able to learn the different features between the movements and accurately classify them based on the new data input. Commonly used models include Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), which can efficiently process dynamic and time-series data, identifying the type of movement and the quality of execution.

In addition to basic action classification, action recognition in aerobics also needs to consider the

ISSN 2618-1576 Vol. 7, Issue 2: 68-75, DOI: 10.25236/FSR.2025.070211

normality and execution quality of actions. This requires movement recognition systems that can not only distinguish between different movement categories, but also assess whether the movements are standardised or not. The system can analyse whether the athlete's posture is standard, and whether the fluidity and rhythm of the movement meets the requirements. This process involves the precise quantification of every detail in the movement, including the amplitude of movement of the joints, the rate of change of angles, etc. These factors will affect the athlete's movement scores, providing valuable feedback and improvement suggestions for coaches and athletes.

4. Motion Visualisation and Analysis System Design

The core of the design of the movement visualisation and analysis system is to transform the 3D motion capture data into an intuitive and easy-to-understand visual form to provide movement analysis and feedback for athletes and coaches. The main task of the system is to construct a 3D model by capturing each movement of the athlete in real time and displaying the athlete's movement trajectory and body posture on the screen. Through this visual display, the athlete can see more clearly the details of his/her execution of the movement, which helps to discover and improve the deficiencies in the movement, thus improving the training effect.

In the process of implementing the system, it is firstly necessary to process the huge amount of data from the 3D motion capture equipment effectively. These data usually include the 3D coordinate information of each joint of the athlete. By calculating and analysing these coordinates, the system can accurately reconstruct the movement process of the athlete and display it in the virtual space. The system must have efficient rendering capabilities to ensure that the details of the movements are smoothly presented, and at the same time respond quickly to data updates to ensure that the athlete's movements can be displayed in real time.

The accuracy and clarity of the visualisation is key to the design of the system. In order to realistically present the athlete's movements, the system uses 3D modelling and skeletal animation techniques to transform the athlete's movements into a virtual character representation. The dynamic changes of each joint and body posture adjustment can be accurately simulated. In order to make the analysis more intuitive, the system can also highlight certain important movement details through different colours, trajectory markers, etc., helping the user to focus on the core issues of the athlete's movements.

The system also integrates a movement quality assessment function, which is capable of scoring the athlete's movements according to a predefined standard model. By analysing joint angles, fluidity and rhythm, the system can provide feedback on movement problems and help athletes make adjustments accordingly. Based on the analysis results, coaches can formulate personalised training plans for athletes to gradually improve their movement accuracy and performance.

5. Conclusion

Aerobics movement visualisation and analysis based on 3D motion capture system provides athletes with a new way of training and evaluation. Through accurate motion data capture and efficient visualisation technology, the system is able to present athletes' movement trajectories and postures in real time, helping athletes and coaches to better understand and improve their movement performance. The visualisation not only improves the accuracy of movement analysis, but also enables athletes to get instant feedback during the training process, so that they can adjust their movements in time and avoid wrong training habits.

By extracting and analyzing key features of the movement, the system is able to quantify the quality of each movement and identify potential flaws that may hinder performance. This detailed analysis provides valuable data that can be used to design personalized training programs tailored to the specific needs of each athlete. Athletes can use the system's feedback to focus on areas such as improving movement precision, fluidity, and synchronization, ultimately enhancing their overall performance. The application of this system in aerobics training not only strengthens the effectiveness of technical training but also offers a scientific and objective basis for optimizing movements. This approach ensures that training is no longer based on subjective observation alone, but is supported by accurate, data-driven insights. As a result, athletes can make more targeted improvements, refine their techniques, and reduce the risk of injury. By offering clear, actionable feedback, the system makes training more precise, focused, and efficient, leading to better long-term outcomes in competition performance.

ISSN 2618-1576 Vol. 7, Issue 2: 68-75, DOI: 10.25236/FSR.2025.070211

With the continuous progress of motion capture technology and artificial intelligence algorithms, the movement analysis and visualisation system based on 3D motion capture system is expected to further enhance its performance and application scope. The system will not only be limited to the field of aerobics, but more sports can also benefit from this technology. The further development of advanced technologies such as integrated virtual reality and augmented reality is expected to provide athletes with a more immersive training experience, opening up new directions for intelligent and personalised sports training.

The aerobics movement visualization and analysis system based on 3D motion capture technology holds immense potential for enhancing athlete training and optimizing movement performance. By providing real-time, detailed insights into every aspect of an athlete's movements, this system offers a unique opportunity to improve technique, reduce errors, and enhance overall performance. As the technology continues to evolve and improve, it is expected to become even more accurate, efficient, and user-friendly, allowing for broader application across a variety of sports disciplines. This will enable coaches and athletes to leverage data-driven insights for more precise training adjustments and personalized strategies. In the future, the system is likely to play a pivotal role in the development of more intelligent and refined training programs, empowering athletes to achieve peak performance. By integrating advanced technologies such as artificial intelligence and machine learning, the system could not only analyze movements but also predict potential weaknesses and suggest corrective actions, leading to more effective and adaptive training methods across sports.

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