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Construction Strategies and Experimental Design of the Action Recognition and Optimization System for Gymnasts

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Abstract: *This research is dedicated to designing a detailed construction plan for an action recognition and optimization system for gymnasts and making a detailed plan for its subsequent experimental procedures. When the system construction and experiments are still in the preliminary theoretical exploration and preparation stage, through in-depth analysis of aspects such as the establishment of deep learning models, the layout of the interactive interface, and the collaborative architecture of cloud and edge computing, as well as a comprehensive conception of the experimental design. It lays a solid theoretical foundation for the subsequent actual implementation of relevant work, provides a detailed planning blueprint, helps transform this system from a theoretical concept into practical application step by step, and promotes the intelligent transformation in the field of gymnastics training.*

Keywords: *Movement Recognition; Deep Learning; Collaborative Computing; Interactive Interface; Gymnastics Training*

1. Introduction

In the realm of gymnastics training, the traditional model has long been the cornerstone. It predominantly relies on the experience-based judgment of coaches, who, armed with years of expertise, observe athletes' movements and offer guidance. However, this conventional approach, while valuable, is not without its limitations. It lacks precise quantitative analysis of athletes' movements. In modern competitive sports, where the demand for refined and scientific training is ever-increasing, this shortfall becomes particularly evident. The need for a more precise and data-driven method has become imperative[1].

Fortuitously, the rapid development of artificial intelligence technology has ushered in a new era. Deep learning, a subset of artificial intelligence, has emerged as a powerful tool. It has the potential to revolutionize the recognition and optimization of gymnastic movements. By leveraging advanced algorithms and vast amounts of data, deep learning can provide a level of precision and insight that was previously unattainable.

This study, recognizing the transformative potential of deep learning, sets out with a clear and ambitious goal. It aims to comprehensively and deeply explore the theoretical foundation of system construction. This involves delving into the underlying principles, examining the various components, and understanding how they interact to form a cohesive and effective system. Additionally, the study focuses on the ideas of experimental design. It seeks to develop innovative and rigorous methodologies that can effectively test and validate the theoretical concepts.

By achieving these objectives, the study provides a sufficient theoretical basis for the subsequent actual construction of the system. This theoretical groundwork is crucial. It ensures that the system, when built, will be robust, reliable, and capable of meeting the demands of modern gymnastics training.Moreover, the study's findings have the potential to promote the advancement of gymnastics training towards the direction of intelligence. It paves the way for a future where training is not only based on experience but also enhanced by the power of artificial intelligence, leading to improved performance and greater achievements in the world of gymnastics.

2. Multi-source data collection and processing of the system

In the system to be constructed, multi-source data collection is a crucial initial step. The data sources are planned to be mainly from two channels: videos and sensors[1]. We have deeply cooperated with professional gymnastics training institutions and extensively collected the training and competition data of 258 gymnasts of different ages, covering amateur athletes, teenagers, and professional athletes. A variety of advanced devices are used for data collection, including high-definition training videos, high-precision acceleration sensors, gyroscope sensors, and motion capture cameras, etc. Precisely install the sensors at the key joint parts of the athletes (see Figure 1), such as the wrists, ankles, knee joints, hip joints, etc., to ensure that subtle movement changes and motion trajectories can be captured[2].

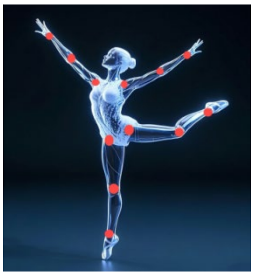

Figure 1 Schematic Diagram of Identifying Key Marking Points

For the video data, it is expected that the OpenCV library will be used for frame-by-frame extraction[2].Additionally, image processing techniques such as histogram equalization and Gaussian filtering will be applied for image enhancement, so as to improve the clarity and contrast of the images and enhance the effect of feature extraction. For the sensor data, it is expected that a Butterworth low-pass filter will be used for filtering and denoising[3] to remove high-frequency noise interference and ensure the accuracy and reliability of the data[3].

3. Ideas for the Construction and Optimization of the Deep Learning Model

3.1 The Parts of CNN and RNN in the Model Architecture

A hybrid model combining a Convolutional Neural Network(CNN) and a Recurrent Neural Network(RNN) is selected. On this basis, it is planned to introduce the Attention Mechanism to enhance the model's ability to understand and recognize complex action sequences. CNN can effectively extract the spatial features of images and recognize the spatial information of gymnastic movement postures. On the other hand, RNN is good at processing time series data and can track the dynamic changes of gymnastic movements in the time dimension[4-5].

To address the issues of gradient vanishing or gradient explosion that may occur during the training process of the traditional Convolutional Neural Network(CNN) model, Residual Connection is introduced. It is represented by (Formula1):

$$y = F_{(x)} + x \tag{1}$$

Among them, x is the input, y is the output, and $F_{(x)}$ is the residual function. This structure enables the model to learn more complex feature representations and accelerates the training convergence process[6].

The Long Short-Term Memory network (LSTM) is adopted as a variant of the Recurrent Neural Network(RNN)[4]. LSTM can effectively deal with the problem of long-term dependencies in time series data[5], which is crucial for analyzing the dynamic changes of gymnastic movements in the time dimension. Its core structure includes the input gate i_t, the forget gate f_t, the output gate o_t and the memory cell C_t. The calculation formulas (2-6) are as follows:

$$i_t = \sigma(W_{ii}x_t + b_{tt} + W_{hi}h_{t-1} + b_{hi}) \tag{2}$$

$$f_t = \sigma(W_{if} x_t + b_{if} + W_{hf} h_{t-1} + b_{hf}) \tag{3}$$

$$o_t = \sigma(W_{io} x_t + b_{io} + W_{ho} h_{t-1} + b_{ho}) \tag{4}$$

$$C_t = f_t \cdot C_{t-1} + i_t \cdot \tanh(W_{ic} x_t - b_{ic} + W_{hc} h_{t-1} + b_{hc}) \tag{5}$$

$$h_t = o_t \cdot \tanh(C_t) \tag{6}$$

Among them, X_t is the input at the current moment, h_{t-1} is the hidden state at the previous moment, W and b are the weight matrix and the bias vector respectively, and σ is the sigmoid activation function.I have completed the in-depth study of the principles of LSTM and the derivation and verification of the relevant formulas. Subsequently,I will build the model and debug the parameters[7].

3.2 The Part of the Attention Mechanism in the Model Architecture

The attention mechanism[6] is adopted. According to the attention allocation theory, different weights are assigned to different movement postures, enabling the model to focus on the key movement postures, thus improving the recognition accuracy and robustness. The calculation formula (7) of the attention mechanism is as follows:

$$Attention(Q, K, V) = soft\max\left(\frac{QK^T}{\sqrt{d_k}}\right)V \tag{7}$$

Among them, Q、K、V are the query vector, key vector, and value vector respectively, and d_k is the dimension of the key vector.Through the attention mechanism,the model can automatically pay attention to the key parts and key time points in the movement, improving its ability to recognize complex movements.It will be applied and verified in the actual model in the follow-up.

4. Design of the Friendly Interaction Interface

Design the system interaction interface based on the principles of simplicity, ease of use, and efficient interaction[7]. It is envisioned that the interface mainly includes core modules such as video playback, data display, and a window for guidance suggestions.The video playback window should support a variety of playback operations, such as pausing, fast-forwarding, slow-playing, frame-by-frame playback, etc., which is convenient for athletes and coaches to review the training process and analyze the movement details accurately[8-9].

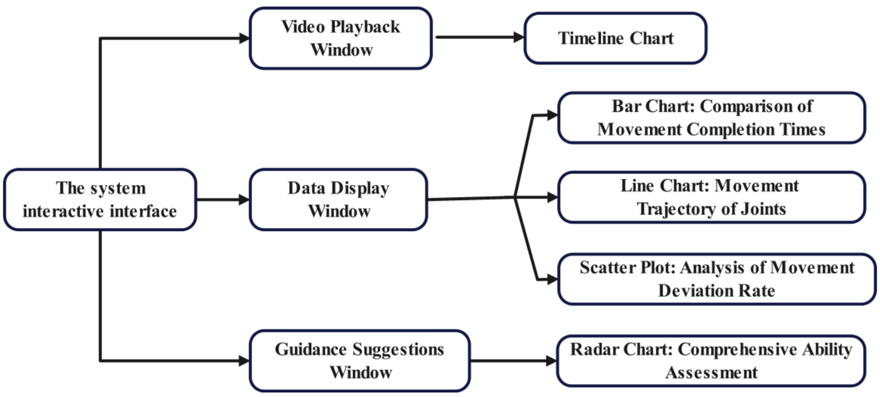

Figure 2 Schematic Diagram of the Contents of the Data Display Window

The data display window can adopt intuitive chart forms, such as bar charts, line charts, scatter plots, etc. (See Figure2 above),to present the statistical analysis results of the recognition data, including the completion time of the movements, the movement deviation rate, the joint movement trajectory, etc. Achieving the above assumptions can make the data information clear at a glance and greatly improve

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the training efficiency[10].

It is expected that the guidance suggestions window should provide athletes with personalized training suggestions from the perspectives of biomechanics and sports training science[8] based on the analysis results of the recognition data. For example, based on the angle of movement deviation and the distribution of force, specific directions for movement improvement and the range of adjustment are provided. Reasonably adjust the training intensity and training plan according to the athletes' physical fitness data and historical data of training intensity. By monitoring the range of motion of athletes' joints and the degree of muscle fatigue, predict the risk of sports injuries and provide corresponding prevention and rehabilitation suggestions. The design of the interface layout should follow the principles of ergonomics. The operation buttons should be simple and clear, with rapid response, making it easy for users to quickly get started and operate efficiently.

5. Collaborative Processing of Cloud Computing and Edge Computing

Considering that the gymnastics training scenario has relatively high requirements for the real-time performance and accuracy of data processing, this study proposes a scheme of collaborative processing between cloud computing and edge computing in this design.

The cloud has powerful computing capabilities and massive storage resources, and it can undertake complex tasks such as large-scale data preprocessing, deep learning model training, and updating. However, cloud computing has the problems of data transmission delay and limited bandwidth, making it difficult to meet the scenarios with high real-time requirements. Edge computing is close to the data source and has the characteristics of low latency, high bandwidth, and high reliability, enabling it to process sensor data in real time. For example, during athletes' training, edge computing devices can analyze sensor data in real time, conduct preliminary recognition and judgment of the movements, promptly detect any deviations in the movements, and provide real-time feedback. However, its computing and storage capabilities are relatively limited, making it difficult to handle large-scale data and complex model training tasks.

In order to integrate the advantages of both, this study plans to establish mechanisms for data synchronization, task allocation, and result feedback. In terms of data synchronization, an efficient transmission protocol will be utilized to ensure that the data between the cloud and the edge side are consistent and real-time. In terms of task allocation, according to the nature of the tasks and the requirements for real-time performance, tasks with strong real-time requirements, such as motion recognition, are assigned to edge computing devices, while tasks of large-scale data processing and model training are the responsibility of the cloud. In terms of result feedback, edge computing devices promptly provide real-time analysis results to athletes and coaches. Meanwhile, the cloud synchronizes the achievements of model training and optimization to the edge computing devices, so as to improve the overall performance of the system.

6. Test Planning

6.1 Test Subjects and Objectives

In order to conduct a comprehensive and thorough evaluation of the action recognition and optimization system for gymnasts constructed based on deep learning technology, a carefully selected group of test subjects has been planned. A total of 50 gymnasts, representing a diverse range of training levels, age groups, and genders, will be included in the study. Specifically, the test subjects will consist of 15 amateur gymnastics enthusiasts who are passionate about the sport but have not undergone extensive professional training. Their inclusion will provide valuable insights into how the system performs with individuals who have a basic understanding of gymnastics but lack the advanced skills and techniques of professional athletes.

In addition to the amateur enthusiasts, 15 adolescent professional gymnasts will also be part of the test group. These young athletes are at a critical stage in their development, where they are honing their skills and building the foundation for future success. Their participation will help assess the system's ability to recognize and optimize movements in a group that is still growing and evolving in their gymnastics abilities.

Furthermore, 20 adult professional gymnasts will be included in the study. These individuals

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represent the pinnacle of gymnastics excellence, with years of rigorous training and competition experience. Their involvement will ensure that the system is tested under the highest standards of performance, providing a comprehensive evaluation of its capabilities in recognizing complex and highly skilled movements.

The selection of test subjects from these different categories is aimed at covering a wide spectrum of skill levels and physical conditions. By including amateur enthusiasts, adolescent professionals, and adult professionals, the study aims to ensure that the test results are widely representative. This comprehensive approach will allow for a thorough assessment of the system's performance across various scenarios and will provide valuable insights into its applicability in different contexts.

The primary objective of this study is to verify the feasibility and effectiveness of the action recognition and optimization system for gymnasts constructed based on deep learning technology in the theoretical assumption. This involves several key aspects that need to be evaluated.

Firstly, the study will focus on evaluating the system's ability to accurately recognize gymnastic movements. This is a crucial component, as the accuracy of movement recognition forms the basis for all subsequent optimization suggestions. The system will be tested to determine how well it can identify a wide range of gymnastic movements, from basic exercises to complex routines. This will involve comparing the system's recognition results with the actual movements performed by the test subjects, ensuring that the system can reliably and accurately detect even the most subtle differences in movement execution.

Secondly, the study will test whether the system can provide scientific and effective movement optimization suggestions based on the recognition results. This will involve examining the system's ability to analyze the biomechanics of the recognized movements and provide actionable recommendations for improvement. The optimization suggestions will be evaluated from the perspectives of biomechanics and sports training, ensuring that they are grounded in scientific principles and are practical for implementation in a training environment.

The ultimate goal of the study is to explore the actual effect of the system on improving the training effectiveness and competitive level of gymnasts. This will involve monitoring the progress of the test subjects over a period of time, observing how the system's suggestions impact their performance. The study will assess whether the system can help gymnasts refine their techniques, enhance their training efficiency, and ultimately lead to improved results in competitions. By examining the practical application of the system in a real-world setting, the study aims to provide concrete evidence of its potential to revolutionize gymnastics training and contribute to the advancement of the sport.

6.2 Test Methods

In terms of the experimental method, it is planned to adopt the methods of comparative and simulation experiments.

Randomly divide the 50 gymnasts into an experimental group of 30 people and a control group of 20 people. During the training, the experimental group uses the action recognition and optimization system. The system monitors and analyzes the actions in real time and provides feedback with suggestions. The control group adopts the traditional coaching mode. After the training cycle is completed, compare the movement quality, training efficiency, and competition results of the athletes in the two groups.

Use computer simulation to generate gymnastics movement data that includes various types of movement deviations and difficulty levels. On the one hand, these data are used to train and optimize the deep learning model, enhancing its ability to recognize and analyze complex movements. On the other hand, input the data into the system to simulate various scenarios, and evaluate the performance indicators of the system, such as the accuracy rate of action recognition and the sensitivity of deviation detection.

6.3 Test Indicators and Statistics

It is planned to take the action recognition accuracy rate, the action deviation detection rate, and the athletes' training effectiveness as the system test indicators[9].

The action recognition accuracy rate needs to be calculated by using manually annotated simulated data and the actually collected action data of athletes as the true labels, comparing them with the

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recognition results of the system, and then determining the recognition accuracy rate of the system for various gymnastic actions(Formula 8).

$$\text{Action recognition accuracy rate} = \left(\frac{\text{The number of actions recognized correctly}}{\text{The total number of actions}} \right) \times 100\% \tag{8}$$

The action deviation detection rate is the ratio of the number of action deviations detected by the system to the actual number of action deviations, which reflects the system's ability to detect action deviations(Formula 9).

$$\text{Action deviation detection rate} = \left(\frac{\text{The number of action deviations detected correctly}}{\text{The actual number of action deviations}} \right) \times 100\% \tag{9}$$

The indicators of athletes' training effectiveness include the quality score of action completion, physical fitness improvement indicators (such as changes in the test data of physical qualities like strength, speed, endurance, etc.), and the improvement of competition results.

6.4 Expected Results and Discussions

It is expected that after the athletes in the experimental group use the action recognition and optimization system for training, their scores for the quality of action completion, indicators of physical fitness improvement, as well as competition results will be better than those of the athletes in the control group. The system is expected to achieve a high level in terms of the action recognition accuracy rate and the action deviation detection rate, with the expected rates reaching above 90% and 85% respectively.

If the test results meet the expectations, it will prove the effectiveness and application value of the system in the training of gymnasts, providing strong support for the intelligent development of gymnastics training. If the results do not conform to the expectations, the reasons will be analyzed in depth, such as defects in the model design, problems with data quality, unreasonable settings of system parameters, etc., so as to carry out targeted optimization and improvement of the system.

6.5 Risk Assessment and Response

During the process of experiment preparation and implementation, it is predicted that there are various potential risks, which need to be properly addressed[10].

In terms of data quality, issues such as incomplete data or data interference may occur, which will undoubtedly have an adverse impact on the system training and the experimental results. Therefore, before data collection, it is essential to strictly calibrate the equipment and formulate detailed specifications. During the data collection process, real-time monitoring should be carried out. In the data processing stage, cleaning and verification technologies should be applied to ensure the reliability of the data.

In terms of system performance, situations such as unstable operation, slow recognition, and deviation in analysis results may occur. During the system construction and testing stage, technologies such as distributed computing should be fully utilized for performance optimization. At the same time, the model should be trained repeatedly and the parameters adjusted to improve the accuracy of the system.

Regarding the problem that athletes may have poor cooperation due to their unfamiliarity with the new system, system usage training should be organized before the experiment, and dedicated personnel should be arranged to provide on-site guidance and answer questions during the experiment, so as to improve the athletes' acceptance and cooperation with the system.

7. Conclusion

In this paper, we have embarked on a comprehensive and thorough exploration of the construction strategies and experimental design for the action recognition and optimization system for gymnasts. This endeavor has been meticulously executed, with each link of the system's architecture and functionality being carefully planned and envisioned. The result is a robust theoretical framework that not only outlines the essential components and processes but also provides a clear roadmap for the practical realization of the system.

The detailed planning and envisioning undertaken in this study have laid a solid theoretical foundation for the subsequent practical construction and experimentation of the system. This foundation is crucial, as it ensures that the system's development is grounded in well-founded principles and methodologies. It provides a clear understanding of the system's objectives, the technologies involved, and the expected outcomes, thereby facilitating a smooth transition from theoretical conception to practical implementation.

While the implementation phase of the system has not yet been initiated, the research achievements of this stage are significant. They provide a clear direction and a detailed blueprint for the future work that lies ahead. This blueprint encompasses the various stages of development, from the initial construction of the system's core components to the rigorous experimental testing required to validate its performance. It also includes the iterative process of refinement, where feedback from experiments will be used to enhance the system's capabilities and address any potential challenges.

In the subsequent research, we will gradually promote the construction and experimental work of the system in accordance with the established plan. This will involve a phased approach, where each stage builds upon the previous one, ensuring that the system's development is systematic and methodical. The initial stages will focus on the development and integration of the core components, followed by extensive testing to evaluate the system's performance in recognizing and optimizing gymnastic movements.

Throughout this process, the design and implementation of the system will be continuously improved. This iterative approach will allow us to refine the system based on real-world data and feedback, ensuring that it meets the highest standards of accuracy and effectiveness. We will also explore the system's potential applications in various contexts, such as training programs for different levels of gymnasts, rehabilitation for injuries, and performance enhancement for competitive athletes.

The ultimate goal of this research is to contribute to the intelligent development of gymnastics training. By leveraging the power of deep learning and advanced technologies, we aim to create a system that can revolutionize the way gymnasts train and compete. This system will not only enhance the precision and efficiency of training but also provide valuable insights into the biomechanics of gymnastic movements, leading to improved performance and reduced risk of injuries.

In conclusion, this paper has laid the groundwork for a significant advancement in the field of gymnastics training. The comprehensive and thorough discussion of the construction strategies and experimental design provides a strong foundation for the future development of the action recognition and optimization system. As we move forward, we are confident that the continuous improvement and refinement of the system will lead to tangible benefits for gymnasts and trainers alike, paving the way for a more intelligent and effective approach to gymnastics training.

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