Digital Technology Empowers the Optimization of Martial Arts Teaching and Training: A Study on Movement Correction and Training Effect Evaluation Based on Motion Capture Technology

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ABSTRACT Traditional martial arts teaching lacks refined diagnosis and quantitative intervention for motor skills, limiting objective movement evaluation and personalized training. This study proposes a quantitative assessment and correction framework for martial arts movements based on inertial motion capture technology, where wireless sensing and multimodal motion perception provide reliable support for high-precision human movement analysis. A data acquisition system employing 17 IMU sensors is established, and a multidimensional evaluation model incorporating posture stability, joint angle, trajectory straightness, and completion rate is developed for typical movements including the bow stance punch and whirlwind kick. Through real-time visual feedback and an 8-week controlled teaching experiment, the proposed system demonstrates effective movement correction and training optimization. Experimental results show that pelvic sway during the bow stance punch is reduced by 35.0%, while the body rotation completion rate during the whirlwind kick reaches 95.6%, indicating significant improvements in movement accuracy and objective training evaluation. The proposed framework provides an effective digital solution for intelligent motion analysis and electromagnetic sensing-enabled sports training applications.

INDEX TERMS motion capture, martial arts instruction, electromagnetic sensing, wireless sensing, technique correction

I. INTRODUCTION

AS a treasure of classical Chinese culture, martial arts is undergoing a modernization shift toward scientific precision. Although recent studies have produced abundant findings in other areas like martial arts teaching philosophy, novel models, and cultural integration, the evaluation and correction of the vessel of all skills teaching the technical movements themselves, remains heavily dependent on the experience, observations, and subjective descriptions of the instructors with no high-precise, quantifiable, and immediate feedback support. This situation complicates the development of increased efficiency in teaching and really individualized training guidance becomes hard to realize.

The present paper logically deploys high-precision motion capture technology in martial arts teaching/training applications, develops and deploys a system comprising of a martial arts motion capture and real-life analysis system using inertial measurement units, boasts of high environmental adaptability, and convenient deployment. In the case of typical martial arts motions, multi-dimensional and quantifiable technical movement evaluation index model is derived which changes subjective movement assessment to objective indicators of data. The paper presents empirical evidence of the promoting role played by this technology in martial arts movement correction and skill acquisition. These results offer a data-driven practical approach to the digital transformation of martial arts teaching.

This paper is structured as follows: it reviews the current research status of the modernization of martial arts teaching and the application of related technologies; it elaborates on the architecture design, evaluation model construction, and experimental methods of the proposed system; it analyzes and discusses the experimental results; and finally, it summarizes the entire paper, pointing out the research value and future directions.

II. RELATED WORK

The modernization and scientific transformation of martial arts teaching is becoming an interdisciplinary and multi-paradigm research field. Nazeer et al. [1] constructed image fuzzy Dombi weighted average and weighted geometric aggregation operators , and used these operators to aggregate the fuzzy evaluation infor mation of multiple evaluators on various skill indicators of martial arts teachers . Huang et al. [2] used literature review, expert interviews and logical analysis to analyze the goal orientation, implementation principles and implementation path of the martial arts teaching model in colleges and universities from the perspective of deep learning. My [3] analyzed the cultural value, educational value and contemporary challenges of tradi tional Vietnamese martial arts. Jia et al. [4] conducted an empirical study on the specific teaching methods, strategies and the concepts and experiences of coaches engaged in martial arts teaching in Europe . As a way of cultivating the mind and body, martial arts has always been considered to have the potential value of cultivating character and tempering will. Liu and Wang [5] explored how to organically combine martial arts teaching with mental health education or psychological development training .

Santos et al. [6] evaluated the effectiveness of online teaching by comparing the differences in test data before and after receiving online Arnis teaching between the experimental group and the control group, and analyzing the changes within the experimental group. Yan et al. [7] reviewed the application of the NSCA-AP system in martial arts teaching, explored its potential value in optimizing teaching quality, and put forward corresponding teaching reform suggestions. Wu and Yao [8] believed that: martial arts teaching in colleges and universities should combine adherence to tradition and innovation, explore the intrinsic value of martial arts, adhere to the core techniques of martial arts, and promote the modernization and innovation of martial arts teaching in colleges and universities. Jia et al. [9] showed that it is feasible and effective to adopt the “online + offline” mixed teaching model for teaching martial arts in colleges and universities. Wibowo et al. [10] explained the basic principles, different types, and workflow of motion capture systems. Existing research has achieved fruitful results in updating the concept of martial arts teaching, reconstructing the model, interpreting culture, and perceiving effects, laying the foundation for deepening the field. However, most studies focus on the teaching framework, cultural value, or the subjective feelings of learners, while lacking high-precision and quantifiable technical support for the refined diagnosis and intervention of the most core and objective movement itself in the process of martial arts skill acquisition. This paper establishes a quantitative evaluation index model using high-precision motion capture technology to achieve accurate monitoring and personalized correction of the training process. This makes up for the shortcomings of existing research in terms of technology implementation and data-driven aspects, and provides an operable practical path for the digital upgrade of martial arts teaching.

III. METHODS

A. SYSTEM ARCHITECTURE DESIGN AND DATA ACQUISITION SCHEME

To achieve accurate capture and analysis of martial arts movements, this study proposes and constructs a quantitative evaluation and correction system for martial arts movements based on multimodal data fusion. The core of this system adopts an inertial measurement unit motion capture system. Its selection is based on the following considerations: compared with optical motion capture systems, inertial systems are less affected by ambient light and spatial obstruction, are more suitable for deployment in conventional teaching venues such as gymnasiums, and have higher accuracy and real-time performance, which can meet the requirements of immediate teaching feedback [11-12] .

The system hardware consists of 17 wireless IMU sensor nodes, fixed to the subject’s head, thoracic spine, lumbar spine, pelvis, both shoulders, upper arm, forearm, palm, thigh, calf, and foot. These sensors synchro nously acquire triaxial accelerometer, triaxial gyroscope, and triaxial magnetometer data at a frequency of 60 Hz. A built-in sensor fusion algorithm calculates and outputs the three-dimensional pose (Eulerian angles or quaternions) of each skeletal segment in the global coordinate system in real time. All data is transmitted wirelessly to the central processing unit (a high-performance laptop). Table 1 lists the system configuration details for the main body parts :

TABLE 1. Configuration Parameters of Key Sensor Nodes

Body parts	Sensor model	Sampling frequency (Hz)	Data output type
head	IMU-H1	60	Quaternion
thoracic	IMU-T2	60	Euler angles
pelvis	IMU-P3	60	Quaternion
thigh	IMU-L4	60	Euler angles
calves	IMU-L5	60	Quaternion
feet	IMU-F6	60	Euler angles
upper arm	IMU-A7	60	Quaternion

The use of a high-density array of 17 sensors across the entire body is based on several key considerations. First, it aims to build a universal and scalable data acquisition platform, reserving the capability for future analysis of more complex martial arts movements (such as aerial kicks and side somersaults, which require precise upper limb and head posture control), preventing system failure due to insufficient sensors in future research. Second, the high-density sensor array can capture subtle coupled movements between different parts of the body. For example, in the bow stance, the stability of the head sensors can indirectly reflect the overall posture control level, while the trajectory data from the hand sensors provides a quantitative basis for analyzing the technical requirement of “force reaching the fist surface,” which is crucial for a comprehensive understanding of the biomechanical characteristics of the movement. Finally, redundant sensor data can be used for cross-validation and improved posture calculation accuracy, ensuring that even if individual sensor signals are briefly disturbed, the system can still reconstruct a reliable whole-body posture through kinematic constraints of adjacent segments, thus guaranteeing the robustness and accuracy of core evaluation indica tors. Therefore, this design represents an optimal trade-off between system versatility, data integrity, and measurement accuracy.

The system software platform is a self-developed martial arts movement analysis module. Its main functions include:

(1) Data reception and parsing: Real-time reception and parsing of raw data streams from all sensors.

(2) Skeletal model reconstruction: Based on sensor posture data, a standardized digital human skeleton model is driven in real time in virtual space to realize synchronous visualization of movements. In this skeletal model, all relevant nodes (including the wrist, shoulder, and ankle joints) are virtual nodes calculated using inverse kinematics algorithms based on data from adjacent IMU sensors, rather than physical markers.

(3) Movement calibration and baseline establishment: Before each data collection, the subjects are required to maintain a standard upright posture (T-Pose) for system calibration to eliminate errors caused by sensor installation positions. To address the inherent sensor drift issue in inertial measurement unit (IMU) systems during long training sessions, a periodic recalibration scheme was implemented. Specifically, during the 90-minute training period, participants in the experimental group underwent a 5-second T-pose calibration at the start of training, and recalibrated after 15 minutes of continuous motion acquisition. Furthermore, the system's sensor fusion algorithm integrated a Zero Velocity Update (ZUPT) heuristic during brief pauses between motion repetitions. This combined approach minimized the accumulated error of gyroscope integration, ensuring that the drift of the skeletal model remained within acceptable limits (joint angles less than 2°) throughout the entire 90 minutes. At the same time, martial arts experts (holding national-level coach certificates) are invited to complete standard movements, and their data is stored in the database as the "gold standard" template as the benchmark for subsequent evaluation.

(4) Quantitative index calculation: Based on the reconstructed skeletal model movement data, the preset evaluation index is calculated in real time.

(5) Feedback report generation: After training, the system automatically generates an analysis report containing data tables, curve comparison charts and three-dimensional animation playback, which intuitively displays movement deviations [13].

B. CONSTRUCTION OF A QUANTITATIVE EVALUATION INDEX MODEL FOR MARTIAL ARTS MOVEMENTS

The construction of the evaluation index model is crucial to this study, because the scientific construction of the evaluation index model can ultimately test the scientific validity of the revision and evaluation. The model construction was guided by the principle of action decomposition-main parameter identification-correlation with sports performance, and the basic evaluation dimensions of the two selected typical actions "Lunge Punch" and "Tornado Kick" were developed.

Lunge Punch emphasizes the stability of the lower limbs and the direction of force of the upper limbs. The specific indicators are as follows:

(1) Arch position stability: measure the amplitude (standard deviation) of the pelvic center point shaking on the horizontal plane during exercise. The smaller the amplitude, the higher the core stability.

(2) Front knee joint angle: The knee joint angle when the front knee joint is flexed to its lowest position in the bow posture. The optimal range is set between $+5^\circ$ and -5°. The calf should be at 90° to the ground to prevent the tip of the knee from being exposed to the toes, and the angle should not be too small.

(3) Straightness of punch trajectory: Measure the root mean square deviation between the motion trajectory of the wrist virtual node and the shoulder virtual node calculated based on the IMU skeleton model and the ideal straight line (horizontal forward) trajectory when punching.

(4) Trunk rotation angle: The rotation angle of the trunk relative to the pelvis when punching (measured by sensors on the thoracic spine), used to evaluate the synchronization of waist and hip strength.

For the "whirlwind kick", the focus is on the height of takeoff, the coordination of body rotation and the stability of landing. Specific indicators include:

(1) Takeoff angle: the angle between the velocity vector of the body's center of gravity and the horizontal plane at the moment the takeoff leg pushes off the ground, which affects the height of takeoff and the timing of rotation.

(2) Maximum height of takeoff: the height of the highest point reached by the body's center of gravity after takeoff relative to the height when standing.

(3) Rotation angle completion: the ratio of the actual rotation angle of the body to the target rotation angle (360°) at the moment of impact.

(4) Landing stability index: The area of the pressure center at the supporting ankle (a virtual node of the ankle joint calculated based on the IMU skeletal model) that swings within 2 seconds after landing. The smaller the area, the better the landing stability [14-15].

C. EXPERIMENTAL DESIGN AND DATA ANALYSIS STRATEGIES

In order to check the efficiency of the system, this research was able to develop a pre- and post-test experi mental control study. A total of 40 university students (22 men and 18 women) enrolled in a course on martial arts as an elective process were recruited as test subjects. Everyone was a martial arts beginner who did not have a long-term experience in a given sport. The experimental group (20 participants) and the control group (20 participants) were randomly made up of the subjects. The two groups were trained by the same senior martial arts instructor and all the trainees had a total of 8 weeks of training, two 90 minutes of classes each week. The training dealt with two maneuvers which were the bow stance punch and the whirlwind kick. This study was approved by the Ethics Committee of Longdong University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form. The control group adopted conventional teaching strategies, which predominately entailed group explanation and demonstration by the coach, group activity by students and coach monitoring and verbal correction. To eliminate the confounding effect of "frequency of individualized attention," the control group received the same number of one-on-one instructional sessions as the experimental group (3–5 times per training session). However, the coach's feedback for the control group was based solely on real-time visual observation and empirical judgment, without any quantitative data support. Besides the ordinary teaching, the experimental group employed motion capture system in this study as a way of assisted training. This particular procedure was in this way: during the particular training period of every lesson the students in the experimental group took turns using the motion capture device to make 3-5 movements. The system gave an immediate evalu ation report, which could be viewed by students and coaches jointly upon completion and could view the 3D animation playback, the overlay analysis between the data curves to the standard template, and the main deviations reported by the system According to the report, the coach gave specific individualized instructions, and the students were engaged in corrective exercises. Thus, both groups received equal frequencies of individualized instruction; the only difference was the feedback modality (quantitative, data-driven feedback from the motion capture system vs. traditional verbal feedback based on subjective observation). Pre-test and post-test Data collection was done prior to the commencement of the experiment (pre-test) and after the conclusion of the eighth week of training (post-test). Each participant was given three lung punches and three whirlwind kicks to perform in a motion capture system and these were the best scores that were analyzed, although the participants were not told what their grouping was about. The analysis of data was done using statistic software. To ascertain that there were no significant differences in the baseline level of the two groups, first, an independent samples t-test was done on the pre-test data of the two groups to make sure that both groups did not have significant differences in their baseline level. After that, with the post-test data, there was mixed-design ANOVA to compare the interaction and main effects of group (experimental group vs. control group) and test time (pre-test vs. post-test) with different quantitative indicators. A simple effects analysis was also done in cases where the indicators exhibited considerable interactions in order to compare the differences in the post-test in the two groups.

IV. RESULTS AND DISCUSSION

A. EXPERIMENTAL SETUP AND DATA ACQUISITION PROCESS

The experiment was conducted strictly according to the predetermined plan in a university gymnasium. To ensure data quality, the motion capture system was calibrated before each data collection session, and participants were guided by designated personnel to correctly wear the sensor suits. The entire experiment proceeded smoothly, with all participants completing all training and testing phases without any withdrawals, and the data collection was complete and valid. The experimental group participants showed high interest and acceptance of the wearable device, and the visual reports from the feedback system were very intuitive, helping them understand any problems with their own movements.

B. ACCURACY ANALYSIS OF TECHNICAL MOVEMENT CORRECTION

By analyzing continuous data collected during the training process of the experimental group, this system demonstrated excellent movement deviation recognition capabilities. Taking the "bow stance punch" movement as an example, the system was able to accurately capture common errors made by beginners. Figure 1 shows the changes in key indicators of the "bow stance punch" movement among the experimental group trainees when they first used the system and after four weeks of corrective training.

In Figure 1 , the student's initial movements exhibited several issues, including core instability (excessive pelvic sway), improper lunge depth (excessive knee flexion), non-straight punch trajectory, and insufficient hip and waist power (insufficient trunk rotation). After four weeks of precise data feedback and targeted practice, all indicators showed significant improvement, particularly pelvic stability and the straightness of the punch trajectory, resulting in a marked improvement in movement quality. This demonstrates that the quantitative feedback provided by the system can effectively replace the coach's experience-based judgment, making corrective guidance more targeted and persuasive, and helping students quickly identify areas for improvement.

C. QUANTITATIVE COMPARISON OF TRAINING EFFECTIVENESS EVALUATION

To comprehensively evaluate the impact of the system on training effectiveness, we conducted statistical analysis on the pre-test and post-test data of the experimental and control groups. As shown in Table 2, the p-values between

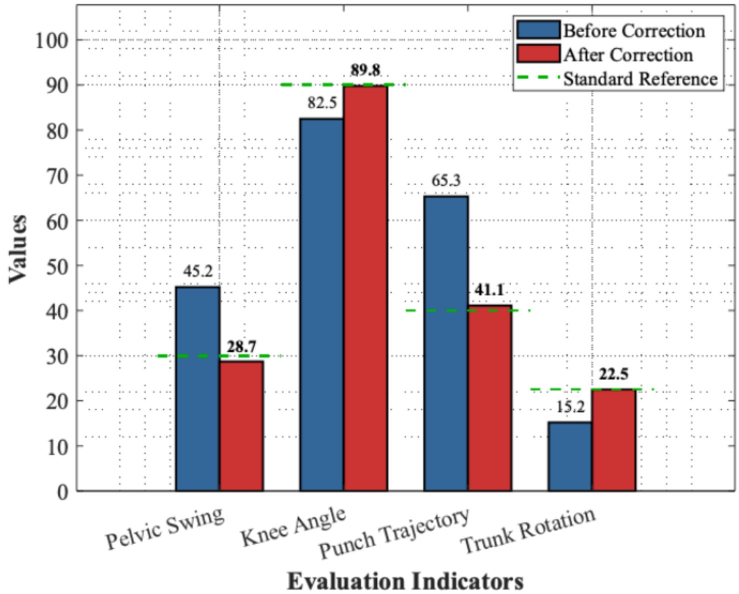

FIGURE 1. Comparison of key indicators before and after correction of the "bow stance punch" movement

the pre-test groups for all indicators were greater than 0.05 (range 0.72-0.89), indicating that the baseline levels of the two groups were balanced before training, meeting the prerequisite for subsequent comparison. Table 2 shows the pre- and post-test mean values and inter-group comparisons for the core indicators of "lunge punch" and "whirlwind kick".

TABLE 2. Comparison of quantitative indicators of training effects between the experimental group and the control group (mean $\pm$ standard deviation)

Action	Evaluation indicators	Group	Pre-test	Pre-test between groups p-value	Post-test	Intra-group progress	Differences between post-test groups (p-value)
Lunge punch	Pelvic sway amplitude (mm)	Experimental group	44.8$\pm$10.2	0.72	29.1$\pm$5.3**	35.04%	< 0.01
		Control group	43.5$\pm$9.8		36.7$\pm$7.1*	15.63%	
	Approximity of front knee angle (%)	Experimental group	70.5$\pm$15.3	0.85	92.8$\pm$4.1**	31.63%	< 0.01
		Control group	71.2$\pm$14.7		81.3$\pm$10.5*	14.19%	
Whirlwind Kick	Rotation angle completion rate (%)	Experimental group	78.3$\pm$12.5	0.89	95.6$\pm$3.5**	22.09%	< 0.01
		Control group	77.8$\pm$11.9		86.4$\pm$8.2*	11.05%	
	Landing stability index (cm^2)	Experimental group	125.6$\pm$35.4	0.82	85.2$\pm$20.1**	32.16%	< 0.05
		Control group	128.3$\pm$33.7		105.8$\pm$25.6*	17.54%	

** indicates $p < 0.05$ for comparison between pre- and post-tests within the group, * indicates $p < 0.01$. Progress = (Pre-test value - Post-test value) / Pre-test value (Sway amplitude and stability index are negative indicators, and the absolute value is used in the calculation).

Table 2 shows that after eight weeks of training, both groups of subjects showed significant improvement in all indicators compared to the pre-test (p<0.05), indicating that the traditional teaching method itself is effective. However, the experimental group, which incorporated the motion capture system, showed a much greater improvement than the control group. For example, in the pelvic stability index of the "bow stance punch," the experimental group improved by 35.04%, while the control group only improved by 15.63%; in the rotation completion rate of the "whirlwind kick," the experimental group achieved a high completion rate of 95.6%, significantly higher than the control group's 86.4%. Statistical analysis showed statistically significant differences between the two groups in all indicators of the post-test (p<0.05 or p<0.01). Because the frequency of one-on-one coaching sessions was strictly equalized between the two groups, the superior performance of the experimental group can be confidently attributed to the motion capture system's quantitative feedback rather than to a mere "Hawthorne effect" or increased attention. This finding strongly demonstrates that motion capture-based quantitative feedback more effectively facilitates martial arts skill acquisition, offering significant advantages in improving movement accuracy, completion quality, and stability.

D. DISCUSSION OF SYSTEM ADVANTAGES AND APPLICATION PROSPECTS

The findings of this research wholly justify the massive application prospect of the suggested motion capture system in the teaching of martial arts. The three principal areas of its benefits include, first, the objectivity and accuracy of assessment. The system changes the vague the movement seems a bit off to the absolute specific of the knee valgus X degrees, and it erases the ambiguity of subjective assessment. Second, immediacy and visualization of the feedback. Once the movement is completed, the trainees are able to instantly visualize their results with 3D animation and data reports in comparison with a generic template. Such visual effect contributes to their solid knowledge of the proper movement pattern significantly, which is consistent with the laws of motor skill formation. Lastly, customization of training. This system has the potential to establish a separate digital profile of every trainee, where long-term progress curve can be followed, allowing the coach to have a more specific training plan according to the trends in the data, resulting in the actual individualized instruction.

Naturally, there are also certain limitations of this research, including a rather small sample size, intermediate experiment, and experiments focusing on novice students. Further studies may broaden the sample and type (e.g., by involving athletes with varying degrees of skills), duration of the intervention to determine the longterm condition, and whether physiological measures incorporating electromyography (EMG) signal could be considered in the models of multimodal assessment to gain a better understanding of the biomechanical character of movement techniques. Moreover, suppression of system expenses and easing of operation processes to allow the use of the systems in the grassroots units of teaching are also important issues that must be tackled in future.

V. CONCLUSION

By offering a quantitative measurement and correction system using inertial motion capture, this paper addresses the problems of subjective movement diagnosis and unclear feedback in martial arts teaching . This integrated approach ensures that the subtle physical nuances of both martial arts are captured and corrected through objective, data-driven feedback. This experi-mental study demonstrates that this system can successfully correct any technical movement in a learner due to the quality and training efficiency of the form of bow stance punch and whirlwind kick through accurate data response in real time and in a graphic representation which is a viable technical solution, in the digital and scientific transformation of martial arts training. Yet, the sample and the period of the experiment used in this study are small, and the research is more participant-oriented at teachers in the first stages. Future studies may include increased sample diversity, a longer intervention duration to examine sustained therapy effects and an attempt to incorporate more biomarkers to better represent a multimodal model, including electromyography and stress.

AUTHOR CONTRIBUTIONS

The author independently completed all the work.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Longdong University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

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