# Rethinking Volleyball Skill Evaluation through Wearable Physical Technologies

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**Abstract.** Volleyball requires complex technical coordination and high physical intensity, and its skill assessment faces ongoing challenges. With the rapid development of wearable sensing technology, the assessment of sports performance is increasingly shifting from traditional experience-based observation to quantifiable physical measurement. This study critically explores the impact of this shift by analyzing two representative cases: an AI-assisted IMU-based jump detection system and a self-powered PVDF sensor for spike monitoring. The results show that wearable devices improve the objectivity, efficiency, and accuracy of sports performance assessment by real-time monitoring of physical indicators such as acceleration and impact force. However, existing technologies are still insufficient in capturing the cognitive, affective, and situational dimensions of sports skills. Therefore, skill judgment based on human perception remains irreplaceable. This paper proposes a complementary integration of data-driven and coach-driven approaches, and wearable technology should be used as a tool to assist rather than replace the judgment of professional sports coaches. The limitations of this study are its focus on specific skill types and the lack of athlete-centered empirical validation. Future research should develop multimodal, context-aware perception systems and explore their integration into a human-centered coaching framework.

**Keywords:** Volleyball skill assessment, wearable technology, IMU, PVDF sensor, datafication.

## 1. Introduction

As a highly competitive team sport, volleyball has significant technical complexity. Athletes need to frequently complete high-intensity and high-coordination actions such as take-off, spiking and fast movement in the game, which not only requires good physical fitness and reaction ability, but also relies on highly sophisticated movement control and tactical coordination [1]. Therefore, accurately evaluating athletes' technical performance has long been a central concern in both volleyball coaching practice and sports science research.

In recent years, with the development of wearable device technology, sports performance evaluation is gradually moving towards dataization and physicalization. Based on the application of inertial measurement units (IMUs), accelerometers, wristband sensors and other devices, coaches and researchers can obtain physical indicators such as acceleration, impact force, displacement speed, etc. of athletes during training or competition in real time. These wearable devices are becoming an important supplement to traditional technical evaluation methods due to their convenience and immediacy of data, and are even used as alternative means in some scenarios [2]. Although existing research focuses on the application effect and accuracy analysis of wearable devices in sports training, there is still a lack of systematic theoretical discussion on the "paradigm shift in skill understanding" implied behind them. Especially in volleyball and other sports that are highly sensitive to timing, rhythm control and body coordination, whether physical evaluation will compress or even distort the original "sensory-experiential" technical cognition is still a research gap.

This study aims to explore the theoretical and practical implications of physicalization of sports skill evaluation. Through a literature review and analysis of technical case studies, this research will explore how wearable devices are reshaping the understanding of "skill" in sports contexts. It further examines whether quantitative indicators such as acceleration and impact force are sufficient to fully represent an athlete's actual performance, and whether such data-driven evaluations can replace the professional judgment of coaches and the embodied perception of athletes in highly physical and experience-based competitive environments.

# 2. Physical Sensing Technologies and Datafication in Sports Assessment

## 2.1 Development and Application of Wearable Physical Devices in Sports

In recent years, with the rapid development of Internet of Things (IoT) technology, micro-nanoelectronics technology and flexible materials science, the application of wearable physical devices in sports training and evaluation has become increasingly popular, and has shown a trend of miniaturization, flexibility and intelligent integration. These devices are primarily designed for high-frequency, low-latency collection and analysis of physiological and motion data during physical activity, making them essential tools for evaluating sports performance. This development is not only due to the improvement of hardware performance, but also benefits from the enhancement of data processing capabilities. For example, the widespread use of embedded edge computing chips allows some signals to be processed locally in real time on the device, thereby reducing dependence on external devices. Additionally, the intelligent configuration of sensor networks and advancements in multimodal data fusion technologies enable the simultaneous collection of multiple data types such as electromyography, heart rate, and acceleration, providing a more comprehensive and dynamic representation of movement states. This trend of evolution from "passive recording" to "active perception" and even "intelligent feedback" makes wearable physical devices no longer just an auxiliary tool for training, but also an important link connecting training, rehabilitation and personalized evaluation.

Commonly used devices in research and practice include inertial measurement units (IMUs), wristband or attached sensors, laser-induced graphene (LIG) flexible pressure sensors, and self-powered systems that have developed rapidly in recent years, such as wearable devices based on piezoelectric materials or triboelectric nanogenerators. These devices are usually integrated into key sports force points such as the wrist, ankle, waist or chest back to achieve a perception capability that is closer to the actual action structure, thereby improving the timeliness and accuracy of the data [3].

Although the devices have different forms, the core physical quantities they collect are highly consistent, mainly including acceleration, angular velocity, impact force, posture angle and motion trajectory. These parameters can not only be used for real-time monitoring and remote transmission, but can also be combined with artificial intelligence algorithms, such as support vector machines (SVM) and long short-term memory networks (LSTM), for motion recognition, skill scoring, fatigue analysis and other fields[4] Researchers generally believe that physical quantities have strong objectivity, repeatability and standardization potential, and are therefore widely used in competitive sports, rehabilitation medicine and public health training.

## 2.2 Trends in Datafication and Standardization in Sports Skill Assessment

Many studies have used wearable devices to conduct quantitative analysis of athletes' skills, promoting sports assessment to develop in the direction of "datafication-standardization". For example, IMU is often used to evaluate the vertical jump height in volleyball, and the athlete's ground-lift time and maximum height are calculated by collecting acceleration data; at the same time, wrist-worn accelerometers are also used to monitor the force rhythm and maximum hitting speed in spiking actions, assisting coaches in identifying action efficiency and physical fitness. In track and field, basketball, gymnastics and other events, similar devices are also used for action symmetry analysis, fatigue status assessment and training plan adjustment. According to recent literature, wearable physical devices have already been adopted by a majority of elite sports teams—serving as essential assets for training monitoring, injury prevention, and performance enhancement[3][5].

This trend is reflected in the fact that sports performance is increasingly transformed into a set of physical data indicators that are traceable, quantifiable and have standardized comparative significance, becoming the core reference for measuring skill levels. Based on these data, coaches can achieve scientific management of training load, movement quality and technical progress, realize real-time feedback and personalized training program design, thereby improving training efficiency and competitive level. At the same time, the standardization and objectivity of data significantly reduce the influence of subjective bias in traditional evaluation, provide a fairer and more transparent basis for athlete selection and performance evaluation, and promote the scientific and digital transformation of competitive sports management.

# 3. Case Analysis: Volleyball and Physical Quantification

## 3.1 Automatic detection and height estimation of volleyball jumps based on waist IMU physical device

Xu et al. proposed an innovative sports skill assessment method, which realizes the automatic recognition of volleyball jumps and accurate estimation of jump height by wearing an inertial measurement unit (IMU) on the athlete's waist and combining it with advanced artificial intelligence algorithms. This study focuses on using multi-stage temporal convolutional networks (MS-TCN) to process high-frequency motion data collected by IMU to solve the shortcomings of traditional jump detection methods in real-time and accuracy [6].

Specifically, the research team first collected a total of 337 jump data from 10 volleyball players in training. The IMU device is installed on the waist and collects core physical quantities such as acceleration and angular velocity to ensure detailed capture of the entire movement process [6]. Subsequently, MS-TCN is used to perform multi-stage decomposition and feature extraction on the time series data, effectively identifying the take-off and landing moments of the jump, and realizing automatic detection of the jump action. In terms of jump height estimation, the model calculates the athlete's ground departure time and the corresponding maximum jump height by analyzing the acceleration changes during the jump. The experimental results show that the evaluation system has significantly better accuracy in jump detection than the existing commercial device VERT, and shows high accuracy and stability in height estimation error. This not only verifies the effectiveness of the waist-based IMU combined with the deep learning model, but also reflects the practical potential of wearable devices in the quantitative evaluation of sports skills [6].

In addition, this system has strong real-time processing capabilities and is suitable for daily training and competition scenarios, providing coaches with instant feedback and data support. The study also pointed out that this lightweight waist-worn method has better user experience and operational convenience than traditional fixed cameras or multi-sensor systems, and reduces the cost and complexity of equipment deployment. However, the device system involves a single type of action, does not cover more complex sports skills, and has a limited scope of application. At the same time, the accuracy of the wearing position has a great impact on the data quality, and improper wearing may reduce the detection effect. Also, the deep learning algorithm has high requirements for computing resources, and the processing power and energy consumption limitations of the device need to be considered in practical applications.

## 3.2 Application of PVDF-Based Self-Powered Wearable Sensors in Monitoring Volleyball Skills

Liu et al. developed a self-powered wearable motion sensor based on piezoelectric film, aiming to achieve real-time monitoring of spiking action and pulse changes in volleyball. The device is designed based on the piezoelectric properties of polyvinylidene fluoride (PVDF) material [7]. PVDF is an excellent piezoelectric polymer material with good flexibility, mechanical strength and electrical response sensitivity. In the sensor, the researchers cut the PVDF film into specific sizes and fit it to the athlete's palm or forearm, so that it can bend and stretch mechanically with skin deformation during spiking action. Its working principle is based on the piezoelectric effect. When the movement causes the membrane to deform, the dipole orientation changes inside the PVDF material, thereby generating a voltage signal between the electrodes. After simple amplification and filtering, the electrical signal can be used to identify the amplitude, frequency and force characteristics of the spiking action, and even monitor the pulse waveform synchronized with the spiking, as an auxiliary evaluation indicator of exercise intensity and physiological state.

In the experimental design, the device showed good motion recognition accuracy and pulse response consistency. For example, in volleyball training, spiking movements of different strengths and angles can generate electrical signal responses of different amplitudes, with high differentiation and stability [7]. In addition, the device does not require battery power and is completely driven by the movement itself, realizing an "energy autonomous closed loop" sensing method, which is particularly useful in continuous, high-frequency motion monitoring. In practical applications, this type of sensor is very suitable for primary training monitoring of young athletes, physical fitness assessment scenarios, and big data collection tasks. The researchers also proposed the design of embedding it into "sportswear" or "wearable gloves" to achieve a more systematic motion monitoring function.

The device features ease of wear, rapid response, and low manufacturing cost, making it well-suited for integration into wearable gloves or athletic apparel. This potential scalability enables the construction of large-scale sports skill databases for performance monitoring and analysis. However, the device still has certain limitations. For example, its sensing accuracy may be limited by fit stability and environmental noise interference in high-speed movements or complex scenes; in addition, data processing still requires external hardware support, making it difficult to achieve complete "independent intelligent" recognition functions.

### 3.3 Comparative Analysis

These two cases represent two typical paths of current wearable physical devices in volleyball skill monitoring, and reflect the differences in application focus and performance characteristics of different technical solutions. The jump detection system based on waist IMU performs well in terms of accuracy of motion recognition and algorithm intelligence. With the combination of high-frequency inertial data and multi-stage temporal convolutional network, it realizes accurate recognition and height estimation of volleyball jump movements, which is particularly suitable for competitive training scenarios that require high-precision analysis. However, the system is sensitive to the position of the device and relies on strong computing resource support, making it difficult to adapt to diverse skill monitoring in complex environments. In contrast, the self-powered sensor based on PVDF piezoelectric film has more advantages in flexible material integration and energy autonomy. The device can generate electrical signals through body movements, and realize synchronous monitoring of spiking movements and pulse changes without the need for external power supply, which is particularly suitable for long-term, low-maintenance basic training and data collection scenarios. Its design is lightweight and low-cost, suitable for embedding in gloves or sportswear, and has good scalability and big data construction potential. However, due to the limitations of sensor fit stability and external environmental interference, its signal accuracy may decrease in high-intensity or complex movements, and it still relies on external hardware for data processing. In general, IMU devices represent a model-driven high-precision monitoring path, while PVDF sensors embody a material-driven energy efficiency priority strategy. The two are complementary in the practice of sports skill quantification, and also reflect the dual needs of "intelligent perception" and "scenario adaptation" in current technological development.

## 4. Discussion

There are significant differences between the traditional coaching perspective and the sports technology perspective in the current way sports technology is embedded in sports skill assessment. With the popularity of wearable devices, the sports technology perspective emphasizes the collection and analysis of objective data, converts skill performance into standardized parameters through indicators such as acceleration, angular velocity, and impact force, and realizes quantitative tracking and algorithm scoring. This trend has significantly improved the repeatability and efficiency of the assessment, and also provided a solid data foundation for training formulation and feedback mechanisms.

While these technological solutions bring clear advantages in data accuracy and efficiency, they also highlight a cognitive gap with traditional coaching perspectives. The coach's judgment often comes from the "perceptual experience" accumulated from long-term observation of athletes, including dimensions that are difficult to quantify, such as movement rhythm, psychological state, and on-the-spot judgment. IMU or PVDF devices collect more physical performances such as "movement trajectory" and "physical load", while the understanding of the skills behind them needs to rely on the coach's interpretation. If technical output is used as the only criterion for skill assessment, people may ignore the more complex "situational factors" behind technical performance, and even mistakenly equate "jumping high" with "good skills". Therefore, technical tools should be regarded as an extension and supplement to the coach's perceptual ability, rather than replacing its judgment system. The ideal path should be "human-machine collaboration". Coaches use the physical information provided by the equipment to verify observational hypotheses or discover problems that were difficult to detect through previous experience, thereby forming a feedback loop between data and experience and improving the overall level of skill understanding and training strategies. This fusion path not only helps avoid excessive reliance on technology, but also meets the essential needs of complex, dynamic and people-oriented sports training.

## 5. Conclusion

This study explores the evolving role of wearable physical sensing technologies in quantifying and assessing volleyball skills, with a particular focus on the shift in sports coaching assessment paradigms from empirical to data-driven. By analyzing an IMU-based jump detection device and a PVDF-based self-powered spike monitoring device, this study illustrates how wearable devices significantly expand the scope, accuracy, and efficiency of skill measurement. The results confirm that physical metrics such as acceleration, impact force, and movement tempo can be effective indicators of certain aspects of technical performance. However, current wearable devices mainly capture mechanical and physiological outputs, but fail to cover the contextual, cognitive, and affective dimensions of skills, while traditional coaching remains crucial in training. Future wearable devices need to improve their technical architecture towards more robust, multimodal, and context-sensitive sensing solutions that can capture richer embodied sports experiences.

However, this study mainly relies on secondary data analysis and case-based technology reviews. While the selected cases represent current technological advances, the scope of the study remains limited to specific skill types and cannot fully reflect the diversity and complexity of volleyball skills, especially those involving tactical interactions, decision-making, and spatial coordination. Second, this evaluation is mainly based on the technical aspects of skill quantification, and there is limited empirical validation from the perspective of athletes or coaches. Future research should adopt a mixed method to expand equipment evaluation for different skills and sports. There is also a need to explore how coaches and athletes can jointly construct the meaning of wearable indicators and whether these data will reshape existing coaching practices or decision-making processes.

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