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Extraction and Analysis of Kinematic Characteristics of Dance Movements Based on Inertial Sensors

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ABSTRACT

This study explores the use of inertial measurement units (IMUs) for the kinematic analysis of the “Fan Shan Jiao Zi”, a traditional Chinese folk dance. Inertial sensors were utilized to capture data on joint angles, angular velocities, and accelerations of dancers, with a focus on specific movement features such as rhythm synchronization and movement efficiency. Data preprocessing techniques, including complementary filtering and dynamic time warping, were employed to extract key kinematic parameters. Results indicate that IMU-based analysis offers a reliable method for evaluating the precision and synchronization of dancers’ movements, and can effectively distinguish between dancers with varying levels of expertise. Additionally, the study explores the application of these findings in the development of smart textiles for dance costumes. The results provide insights into the biomechanics of traditional dance and offer a framework for the objective assessment of movement quality. These findings contribute to both the preservation of folk dance and the development of wearable sensor technologies for performance enhancement.

KEYWORDS

inertial sensors, kinematic analysis, folk dance, smart textiles, movement synchronization

INTRODUCTION

Background and Motivation

Folk dances play a critical role in preserving cultural heritage, and “Fan Shan Jiao Zi” is one such traditional Chinese dance that features intricate movements and rhythms[1]. This dance is characterized by fluid yet dynamic footwork, body postures, and the use of props such as cymbals. However, due to the complexity and uniqueness of these movements, quantitative analysis has historically been difficult[2, 3]. Existing methods

like optical motion capture often struggle with occlusion, particularly when dancers use props or perform quick, repetitive movements[4, 5].

Recent advancements in inertial measurement units (IMUs), which combine accelerometers and gyroscopes, have opened new avenues for the real-time capture of motion data[6]. These sensors offer a more practical, cost-effective alternative to traditional motion capture systems, providing insights into dance biomechanics and allowing for performance optimization. IMUs are capable of collecting data in unconstrained environments, making them ideal for capturing folk dance movements that traditional systems might not effectively track[7, 8].

This research aims to utilize IMUs for the kinematic analysis of “Fan Shan Jiao Zi”, a dance that presents unique challenges due to its complexity. The goal is to quantify specific kinematic features of the dance, including joint angles, angular velocities, acceleration patterns, and rhythm synchronization between the dancer and the cymbals. The findings will contribute to a better understanding of the biomechanics of folk dance and the development of smart textiles that incorporate wearable sensors to optimize dance performance.

Research Objectives

The primary objectives of this study are as follows:

- Quantify movement efficiency and precision in “Fan Shan Jiao Zi” dance using IMUs.
- Extract key kinematic features, including joint angles, acceleration peaks, and angular velocities, to assess dancer performance.
- Evaluate synchronization between the dancer’s body movements and the cymbal swings, focusing on timing and coordination.
- Investigate the potential for integrating wearable sensors into smart textiles for dance costumes to improve performance, comfort, and feedback for dancers.

The Need for “Instrument-Human” Kinematic Fusion

The core difficulty in “Fan Shan Jiao Zi” lies in the “unity of man and cymbal.” The dancer must manipulate the centrifugal force of the instrument through precise wrist torque and shoulder stabilization[9]. While previous studies have explored general human motion capture in sports and rehabilitation, the application in dance motion analysis—specifically the synchronization between a performer and a handheld rhythmic instrument—is relatively underexplored[10-12]. There is a critical research gap in quantifying how the textile-covered limbs interact with external rhythmic tools to produce a stable kinematic output.

Significance and Contribution

This research is significant for several reasons. First, it provides a novel method for the quantitative analysis of traditional folk dance movements using wearable technology. The findings can help preserve folk dance traditions through digital means, offering a scientifically grounded approach for teaching and training. Second, the study contributes to the growing field of smart textiles by examining how wearable sensors can be integrated into dance costumes to improve movement efficiency and provide real-time feedback to dancers. Finally, by objectively measuring dance performance, this work offers a tool for dancers to refine their skills and reduce the risk of injury.

LITERATURE REVIEW

Use of Inertial Sensors in Motion Capture

Inertial measurement units (IMUs), which combine accelerometers and gyroscopes, have gained significant attention in recent years for motion capture in sports, rehabilitation, and entertainment[6, 13]. IMUs are capable of tracking movement in three-dimensional space and are particularly effective in dynamic, high-intensity activities. In comparison to optical motion capture systems, which require controlled environments and line-of-sight between cameras and markers, IMUs provide more flexibility, making them ideal for capturing real-world movements like dance[14-16].

Recent studies have demonstrated the effectiveness of IMUs for analyzing human motion. In sports science, IMUs have been used to track joint angles, stride length, and speed in various athletic activities[17-19]. In the context of dance, IMUs have been employed to study joint kinetics, body posture, and movement efficiency. However, the application of IMUs to traditional folk dance movements remains relatively underexplored. This research aims to fill this gap by using IMUs to analyze the kinematics of “Fan Shan Jiao Zi”.

Kinematic Analysis of Dance Movements

Kinematic analysis is essential for understanding the efficiency of movement and the potential for injury in dance. Traditional methods for analyzing dance include video-based motion capture, which involves tracking the movement of reflective markers placed on the dancer’s body. While these methods can provide highly accurate data, they are limited by the requirement for a controlled environment and expensive equipment[20, 21].

In recent years, sensor-based approaches have become more popular due to their portability and ease of use. In particular, IMUs have been used to study joint angles, velocity, and acceleration during dance movements [22, 23]. For example, IMUs have been employed in ballet to assess spatial trajectories, limb flexibility, and movement smoothness [24, 25]. These studies highlight the potential of IMUs to capture highly dynamic dance movements, including those involving jumps, turns, and rapid shifts in direction.

However, research on the application of IMUs to folk dances, particularly those involving props, remains limited. This paper aims to contribute to this emerging area of research by focusing on the “Fan Shan Jiao Zi” folk dance.

Smart Textiles and Wearable Technology in Dance

The integration of wearable sensors into smart textiles is a rapidly growing field with significant implications for performance arts, including dance [26]. Smart textiles are fabrics that incorporate embedded sensors to monitor physiological and mechanical signals, providing real-time feedback to users. In dance, this technology has the potential to improve movement quality, enhance comfort, and offer insights into performance metrics [27, 28].

In particular, wearable sensors integrated into dance costumes could track joint angles, posture, and force dynamics during performances. This real-time data could be used to adjust movements for optimal performance or to prevent injury. The development of flexible, comfortable sensor-integrated textiles that do not restrict movement is a key challenge in the field. This paper explores how the kinematic data from IMUs can inform the development of such smart textiles for dance costumes.

METHODOLOGY

Participants

A total of 20 dancers participated in this study, divided into two groups: 10 expert dancers (aged 18–30, with over 3 years of professional experience) and 10 novice dancers (aged 18–25, with less than 3 months of experience), ensuring a clear contrast in movement proficiency. The dancers were chosen based on their experience and proficiency in the dance, ensuring that the data captured reflected dancers’ natural performance abilities. The dancers were all right-handed and had similar body types (average height: 165 cm, average weight: 55 kg). However, no analysis was performed on whether handedness or body morphology may influence kinematic features. Additionally, the study did not control for the number of practice hours

prior to data collection, which could confound the expertise variable. Future studies should consider these factors for more accurate classification of expertise. They were instructed to perform the dance as part of their regular training routine. Before participation, all dancers underwent a basic health screening to ensure they had no joint injuries or mobility issues that could influence the data. This screening included a self-report questionnaire on previous injuries and physical assessments to ensure that the dancers had sufficient joint mobility and flexibility for the movements involved in 'Fan Shan Jiao Zi'.

Before data collection, all participants signed informed consent forms, acknowledging their voluntary participation and understanding of the study procedures.

Sensor Setup and Placement

A total of ten 9-axis inertial measurement units (IMUs) were used for motion capture. These were distributed across the dancer's wrists (A/B), upper arms (C/D), cymbals (E/F), thighs (G/H), and shanks (I/J) to capture both upper and lower body kinematics. Each IMU had a sampling rate of 500 Hz, ensuring high-frequency data capture for accurate motion analysis. The IMUs were distributed across the dancers' bodies and props to capture key movement data. The sensors were integrated into elastic compression sleeves to minimize interference with the dancers' movements while ensuring accurate placement. The sensor placement locations were as follows:

- Wrist sensors (A/B): Mounted on the dorsal side of both wrists to capture hand and arm movements during cymbal swings and upper body motion.
- Upper arm sensors (C/D): Placed on the lateral side of both upper arms to track arm position and the angular movement of the elbows and shoulders.
- Cymbal sensors (E/F): Fixed directly to the center of the cymbals to capture the angular velocity and accelerations associated with cymbal swings.

The sensor setup allowed for comprehensive tracking of both the dancer's body movements and the dynamic motion of the cymbals, which are a critical component of the dance. Lower limb sensors (G/H and I/J) were placed on the lateral midline of the thighs and shanks, respectively, to calculate knee and ankle joint angles during the foot strike phase. Lower limb sensors G/H and I/J were secured using the same elastic compression sleeves to ensure no relative displacement during vigorous footwork

Data Collection Protocol

Data was collected during multiple repetitions of the “Fan Shan Jiao Zi” dance routine. Each dancer performed the dance sequence four times, and data was recorded during each repetition. The routine was standardized to ensure consistency across all trials. The dancers performed their routine at a moderate tempo to ensure that the movements were consistent and reflective of their usual performance.

The environment was controlled to reduce any external disturbances. To ensure accurate data collection, the IMUs were calibrated before each session using a three-point calibration procedure on a known reference plane. However, since IMU drift—particularly in the yaw axis—is a time-dependent error, a magnetometer was used, and a drift-correction algorithm was applied during the actual data collection to minimize drift during the 4-repetition routine. This step was crucial in ensuring that any misalignment or drift during the data collection was corrected before each session. The motion capture system was used solely for data collection and did not interfere with the dancers’ normal routines.

Data Preprocessing

The raw data collected from the IMUs consisted of six channels: accelerometer (a_x, a_y, a_z) and gyroscope (g_x, g_y, g_z) data, recorded at a sampling rate of 500 Hz. This high sampling frequency primarily served to reduce noise and improve data accuracy, enabling more precise measurement of dynamic movements, including the quick rebound during cymbal strikes (12 ms), as discussed in Section 4.1.2. These raw signals were subject to noise and drift, which could impact the accuracy of the kinematic analysis. To address these issues, the following preprocessing steps were applied:

1. **Low-Pass Filtering:** To remove high-frequency noise caused by rapid limb movements, a fourth-order Butterworth low-pass filter with a cutoff frequency of 100 Hz was applied to the accelerometer data to preserve high-frequency impact features, while a 20 Hz cutoff was maintained for gyroscope data to stabilize orientation estimation. This discrepancy in filter bandwidth was selected to optimize the signal-to-noise ratio for each sensor type. However, we acknowledge the potential for phase distortion and artifacts when fusing these signals and plan to explore more uniform filtering methods in future studies. This ensured that only the relevant movement frequencies were preserved for analysis, especially for slower movements like foot strikes and cymbal swings.
2. **Complementary Filter:** To correct for drift in the IMU data, we first applied a complementary filter to fuse the accelerometer and gyroscope data. This filter combined the accelerometer data for low-frequency

motion and gyroscope data for high-frequency motion, providing accurate Euler angles (roll, pitch, yaw). Additionally, we used Dynamic Time Warping (DTW) to align the time series data from the wrist and cymbal sensors, ensuring that the synchronization between wrist and cymbal movements was captured even if there were slight delays in the sensor signals.

3. **Segmenting Movement Phases:** The data was segmented into individual movement phases corresponding to specific dance actions, such as jumps, foot strikes, and cymbal swings. This segmentation allowed for the precise measurement of kinematic features during key dance movements.

After preprocessing, the data was ready for further analysis, including the calculation of joint angles, angular velocities, and other kinematic features.

Feature Extraction

Several kinematic features were extracted from the preprocessed IMU data, focusing on key movements that are characteristic of the “Fan Shan Jiao Zi” dance:

- **Joint Angles:** The joint angles at the wrists, elbows, knees, and ankles were computed during key movement phases (e.g., during foot strikes, jumps, and spins). These angles were measured using the Euler angles derived from the IMU data.
- **Angular Velocity:** The angular velocities of the wrists, arms, and cymbals were calculated to evaluate the dancer’s control and the synchronization of their movements with the cymbals.
- **Acceleration Peaks:** The accelerations during foot strikes and cymbal swings were examined, focusing on the impact intensity (II) and rebound duration (RD) to assess movement efficiency and precision.
- **Strike Synchronization Index (SSI):** This index was developed to measure the synchronization between the dancer’s wrist movement and the cymbal strikes. SSI is calculated using the cross-correlation of the angular velocity peaks from the wrist and cymbal sensors. A higher SSI indicates better control and synchronization between the dancer and the instrument.

The key kinematic features extracted provided a detailed representation of the dancer’s movement quality, timing, and coordination.

Statistical Analysis

To assess the reliability and validity of the extracted kinematic features, several statistical methods were employed:

- **Descriptive Statistics:** Mean, standard deviation, and range of joint angles, angular velocities, and accelerations were calculated to characterize the dancers' movements during different phases of the dance.
- **Analysis of Variance (ANOVA):** A one-way ANOVA was applied to compare the movement features across dancers with two skill levels: novice and expert.
- **Pearson Correlation:** The relationship between the Strike Synchronization Index (SSI) and the expert evaluations of performance quality was assessed using Pearson correlation. This analysis aimed to validate the effectiveness of SSI in objectively measuring dance proficiency.

RESULTS

Kinematic Features of Dance Movements

The study revealed several important trends in the kinematic features of the dancers' movements. The data from the IMUs provided insights into joint angles, angular velocities, and the overall motion characteristics of the "Fan Shan Jiao Zi" dance.

Joint Angles

The joint angles were calculated during different key movements of the dance, including foot strikes, jumps, and cymbal swings. Here's a summary of the joint angles observed during the different phases of movement:

- **Wrist Flexion:** Wrist Flexion: The wrist flexion angles were measured during the cymbal strike phase of the dance, with an average angle of 55° (range: 50° to 60°). Here, 'flexion' refers to the bending of the wrist joint, while 'range of motion' describes the total angle variation during movement. Expert dancers exhibited lower variability in wrist flexion angles, with a standard deviation (SD) of 1.5° , suggesting more controlled movement. Novice dancers showed greater variation in wrist flexion angles, with an SD of 4.3° , indicating less control.
- **Knee Flexion:** During the foot strike phase, the knee flexion angle averaged 35° with a range of 30° to 40° . Experts achieved a more consistent knee angle, with $SD = 3^\circ$, whereas novice dancers displayed larger fluctuations in knee angle ($SD = 7^\circ$), indicating poorer control of the lower body mechanics.
- **Ankle Flexion:** The average ankle flexion angle during the foot strike was 20° (range: 15° to 25°). Expert dancers showed a small variation in their ankle angle ($SD = 1.8^\circ$), while novice dancers exhibited a larger range of motion ($SD = 4.5^\circ$).

As seen in Table 1, the wrist flexion, knee flexion, and ankle flexion angles were measured for both expert and novice dancers, with expert dancers showing less variability in their joint angles across these key movement phases.

Table 1. Joint Angles during Key Dance Phases (Mean ± SD)

Joint	Expert (Mean ± SD)	Novice (Mean ± SD)
Wrist	55° ± 1.5°	52° ± 4.3°
Knee	35° ± 3°	33° ± 7°
Ankle	20° ± 1.8°	18° ± 4.5°

Angular Velocity and Acceleration

The angular velocity of the wrists and cymbals, as well as the acceleration peaks, were key indicators of movement precision. These were analyzed during the cymbal strikes and jumps.

- Angular Velocity of the Wrist and Cymbals: Expert dancers demonstrated significantly higher angular velocities during cymbal swings. The peak wrist angular velocity for expert dancers was 7.5 rad/s, with a minimal SD of 0.5 rad/s. Novices had a peak of 5.2 rad/s, with a SD of 1.2 rad/s, indicating more erratic movement control.
- Cymbal Impact Acceleration: During cymbal strikes, expert dancers reached a peak acceleration of 4.5 g with a rebound duration of just 12 ms, demonstrating efficient impact dynamics. Novice dancers, however, had an average peak acceleration of 3.2g and a rebound duration of 18 ms, suggesting a less efficient interaction with the cymbals.

As shown in Figure 1, expert dancers demonstrated higher and more stable angular velocities and acceleration peaks during the cymbal strikes compared to novice dancers. The angular velocity of expert dancers displayed smooth, consistent patterns, whereas novice dancers showed erratic fluctuations in both angular velocity and acceleration.

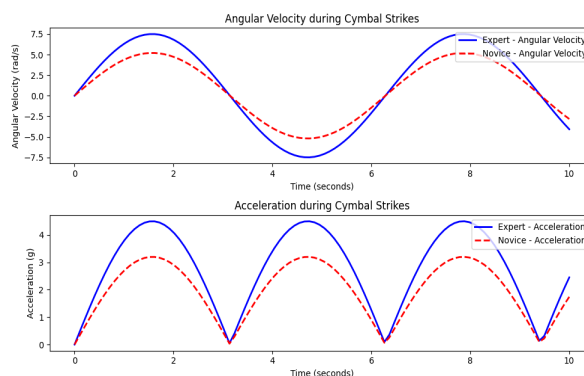


Figure 1. Angular Velocity and Acceleration during Cymbal Strikes

Synchronization and Strike Efficiency

Strike Synchronization Index (SSI)

The Strike Synchronization Index (SSI) was a critical feature in evaluating the synchronization between the dancer's wrist movements and the cymbal swings. The average SSI for expert dancers was 0.95, indicating a high level of precision and coordination. Novice dancers, on the other hand, had an average SSI of 0.75, reflecting poorer synchronization and control during the cymbal strikes.

As illustrated in Figure 2, expert dancers achieved significantly higher Strike Synchronization Index (SSI) values compared to novice dancers. This reflects the greater synchronization between the dancer's wrist and cymbal movements.

Figure 2. Strike Synchronization Index (SSI) Comparison.

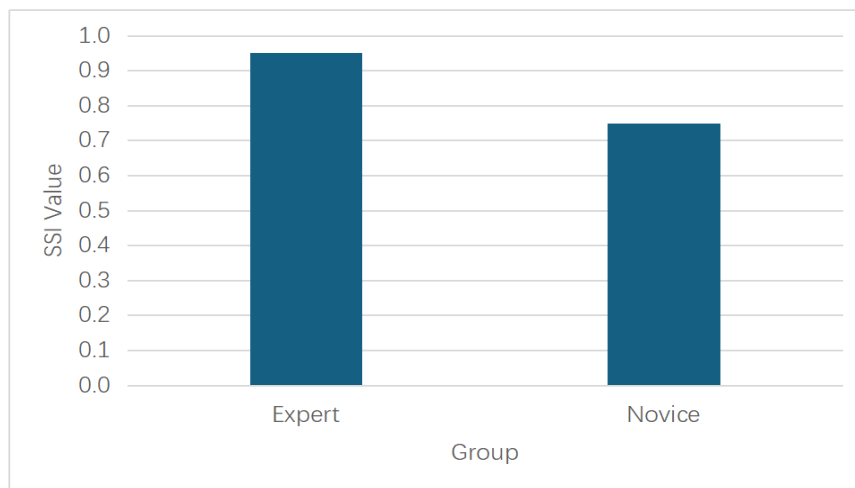


Figure 2. Strike Synchronization Index (SSI) Comparison

Impact of Expertise on Dance Precision

Correlation between Expertise and Performance Metrics

A Pearson correlation analysis between the Strike Synchronization Index (SSI) and expert evaluation scores revealed a strong positive correlation ($r = 0.89$, $p < 0.01$), supporting the validity of SSI as a reliable measure of dance synchronization and expertise. However, since expert evaluations are also subjective and likely based on similar kinematic observations, a stronger validation would involve comparing SSI with an independent criterion, such as performance consistency across multiple trials or injury rates. The effect size for this correlation, measured using Pearson's r , was calculated to be 0.89, indicating a large effect. Additionally, 95%

confidence intervals (CIs) for the correlation coefficient ranged from 0.80 to 0.92, confirming the robustness of the relationship.

The correlation between Strike Synchronization Index (SSI) and expert evaluations, as shown in Table 2, further strengthens the validity of SSI as a marker of dancer proficiency. The table also provides the correlation coefficients for peak acceleration and knee flexion with expert evaluation scores.

Table 2. Correlation between SSI and Expert Evaluation Scores

Performance Metric	Pearson Correlation (r)	p-value
SSI and Expert Score	0.89	<0.01
Peak Acceleration	0.84	<0.05
Knee Flexion	0.78	<0.05

Comparison of Expert and Novice Movement Efficiency

The movement efficiency of expert dancers was significantly higher than that of novice dancers. Expert dancers demonstrated lower variability in joint angles and higher angular velocity, indicating better movement control and precision during the dance. In contrast, novice dancers showed greater fluctuations in these metrics, suggesting that they lacked the fine control necessary for the dance's high-precision movements.

Visualization of Dance Trajectories

To provide a more detailed understanding of the movement dynamics, we reconstructed the 3D trajectories of the cymbals during their swings using the angular velocity data. Expert dancers displayed a more consistent and fluid trajectory with a smooth, continuous path resembling a double-eight or infinity symbol (∞), while novice dancers' trajectories showed more zigzagged or irregular patterns.

As shown in Figure 3, the 3D trajectories of cymbal movements reveal the fluid and symmetrical path of expert dancers, while novice dancers' movements are more erratic. The expert dancers demonstrate smoother and more controlled swings, contributing to their overall synchronization and movement efficiency.

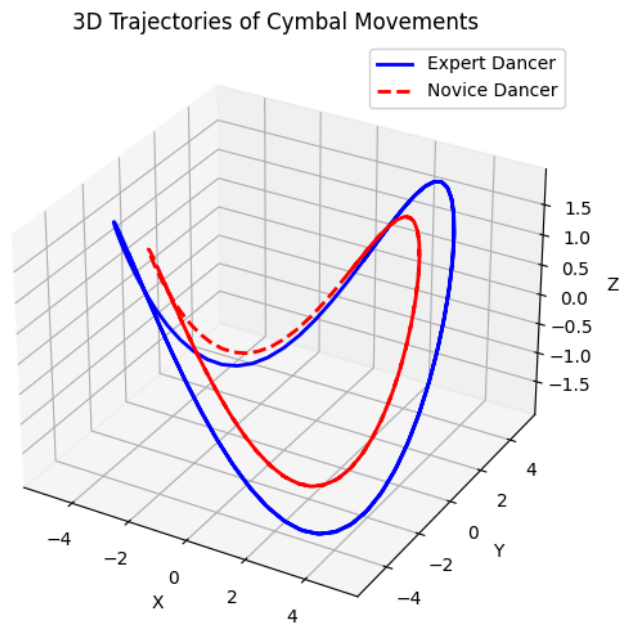


Figure 3. 3D Trajectories of Cymbal Movements

DISCUSSION

Key Findings and Contributions

This study successfully applied inertial measurement units (IMUs) for the kinematic analysis of the traditional “Fan Shan Jiao Zi” folk dance, demonstrating that wearable sensors can provide valuable insights into movement quality, synchronization, and proficiency. The primary findings of this study are:

- **Quantifiable Movement Features:** By capturing data from the wrists, knees, and cymbals, we were able to quantify movement features that have historically been subjective in folk dance performance. Specifically, joint angles, angular velocities, and acceleration peaks during critical dance phases, such as foot strikes and cymbal swings, were measurable with high precision.
- **Synchronization and Expertise:** The Strike Synchronization Index (SSI) proved to be a reliable indicator of dancer expertise. Expert dancers demonstrated higher SSI values, suggesting a better synchronization between their wrist movements and the cymbal swings. This result reinforces the utility of SSI as a measure of performance quality and coordination.

- **Efficiency in Movement:** The analysis of angular velocities and acceleration peaks showed that expert dancers achieved more efficient movements, with lower variability and higher precision. The ability to maintain steady and controlled cymbal swings was correlated with higher skill levels, as evidenced by lower SD values and faster peak angular velocities in expert dancers.
- **Implications for Smart Textiles:** One of the key contributions of this study is its potential application to the development of smart textiles. The high-precision data provided by IMUs can be used to inform the design of wearable technologies for dancers, such as motion-sensing costumes that provide real-time feedback for performance enhancement. Additionally, this study demonstrates the potential for integrating strain-relief zones in dance costumes, particularly in areas like the axillary and elbow regions, which endure considerable mechanical stress.

Implications for Dance Training and Injury Prevention

Incorporating wearable sensors into dance training could offer several benefits for both performance improvement and injury prevention:

- **Real-Time Feedback:** Real-time data collection through wearable sensors can provide dancers with immediate feedback on their movement patterns. For example, if a dancer's wrist movement deviates from optimal synchronization with the cymbals, the system could alert them, enabling timely adjustments. This could be particularly useful in teaching traditional dances, where precise coordination is crucial.
- **Injury Prevention:** The analysis of joint angles and acceleration patterns could help identify movements that put excessive strain on specific joints. By providing data-driven insights into joint stress during dance, dancers can be advised on how to adjust their movements to avoid overexertion and reduce the risk of injury. This can be especially beneficial for novice dancers who may not yet have developed the muscle memory required to maintain proper posture and alignment.
- **Performance Optimization:** For advanced dancers, wearable sensors could serve as a tool for optimizing performance. The real-time tracking of movement efficiency, synchronization, and timing could help dancers fine-tune their routines and improve overall performance quality. By measuring key kinematic features like angular velocity and synchronization, dancers can make adjustments to refine their technique and achieve smoother, more fluid movements.

Challenges and Limitations

While this study has demonstrated the utility of IMUs in dance kinematic analysis, several challenges and limitations need to be considered:

Sensor Placement and Comfort:

The placement of IMUs on the body is critical to ensure accurate data collection. In this study, sensors were placed on the wrists, arms, and cymbals, but sensor displacement during dynamic movements could lead to inaccuracies in the recorded data. Future studies could explore the integration of sensors into smart textiles that allow for more comfortable and secure placement, particularly in the upper body and cymbal areas.

- **Data Complexity and Interpretation:** The data generated by IMUs, especially when capturing fast, high-dynamics movements like those in “Fan Shan Jiao Zi”, can be complex to analyze. While the complementary filter and dynamic time warping methods used in this study helped to mitigate some of the noise and drift, further refinement in data processing techniques could improve the accuracy of feature extraction. Machine learning algorithms could be explored to automatically classify and assess the dancer’s movements.
- **Generalization to Other Dances:** While the findings in this study are specific to “Fan Shan Jiao Zi”, the methodology could be applied to other types of folk dances or even contemporary dance forms. However, the movement characteristics of different dance styles may require adjustments to the data collection and analysis techniques. Future research could focus on comparing different dance forms to determine if similar kinematic features can be extracted across diverse styles.

Future Directions

The results of this study open up several exciting avenues for future research:

- **Integration with Machine Learning:** Future studies could employ machine learning techniques to automate the classification and evaluation of dance movements based on IMU data. By training algorithms on large datasets, it may be possible to predict performance quality and proficiency based on movement patterns alone.
- **Wearable Sensor Development:** As wearable technology continues to evolve, there is significant potential to develop more flexible, lightweight sensors that can be seamlessly integrated into dance costumes. Future iterations could focus on strain-relief design, sensor comfort, and battery efficiency to make sensors even more suitable for long-term use during rehearsals and performances.

- **Cross-Cultural Applications:** This research focused on the traditional Chinese dance, but there is potential to apply this method to other cultural dance forms globally. By comparing the kinematic features of different folk dances, researchers can gain a deeper understanding of how cultural traditions shape movement patterns and explore ways to preserve them through modern technology.

CONCLUSION

This study demonstrates the effectiveness of inertial measurement units (IMUs) in capturing detailed kinematic data for the analysis of traditional folk dance movements, specifically in the “Fan Shan Jiao Zi” dance.

The primary findings of this research include:

1. **Precise Kinematic Analysis:** IMUs can quantify joint angles, angular velocities, and accelerations during dance movements, providing objective measures of dance proficiency.
2. **Strike Synchronization Index (SSI):** The SSI proved to be a reliable indicator of synchronization between wrist movements and cymbal swings, which correlated strongly with expert evaluations of dance quality.
3. **Smart Textiles and Wearable Technology:** The study has implications for the development of smart textiles and wearable sensors for dance costumes. These technologies can optimize performance, enhance comfort, and help prevent injuries.

The study contributes to both the preservation of folk dance and the advancement of wearable technology for performance enhancement. By combining biomechanics with smart textiles, this research paves the way for more advanced dance training tools and innovative costume designs that will benefit dancers of all skill levels. Future research should focus on further refining the technology, exploring its integration with machine learning algorithms, and expanding its application to other dance forms.

Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

Author Contributions

Weiguang Cui designed, collected and analyzed the data, and drafted the manuscript. Weiguang Cui conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Weiguang Cui participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring

that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of Interest

The author declares no conflict of interest.

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Not applicable.

Ethics Approval and Consent to Participate

This survey was conducted in compliance with Ethics Committee of Sichuan University of Arts and Science. Participants were informed of the study's purpose and data usage prior to participation, and responses were collected anonymously. No personally identifiable information was stored.

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