Harmonizing Movement and Technology: An Advanced Analysis of Dance Through Artificial Intelligence- Based Pose Estimation and Classification

Amy Grech

December 2024

1 Introduction

Recent advancements in artificial intelligence (AI) have opened new avenues for the performing arts, particularly in the field of dance. Researchers such as Wang and Ngoi [14] have shown that AI-based pose estimation tools can provide real-time, quantitative feedback for dancers, while Grammalidis et al. [4] have underscored the importance of such technology in preserving folk and traditional dances. In parallel, Mu [7] and Hu and Ahuja [5] have demonstrated how computer vision and machine learning can assist in capturing, analyzing, and classifying complex dance movements.

Spanish dance, with its rich tapestry of footwork, body movements, and intricate arm positions, demands an exceptional level of technical precision from dancers. Evaluating this technical skill is a critical element in both training and performance assessments, as any imprecision can compromise the stylistic fidelity and overall quality of a performance. Traditionally, the assessment of dance technique relies on the expert eye of instructors or judges, a method that can be subjective and susceptible to human error. Instructors often face particular difficulty when observing multiple dancers in ensemble settings or focusing on subtle aspects of technique in a single dancer. This challenge motivates the development of technological tools that can augment the existing approach to dance technique assessment.

1.1 Motivation

From a practical standpoint, dance instructors and adjudicators frequently encounter the challenge of evaluating precise technique in Spanish dance forms. Factors such as time constraints, the need to observe multiple students simultaneously, and the highly detailed nature of Spanish dance movements complicate the assessment process. This difficulty drives research efforts to create

computational aids that offer objective, data-driven methods for analyzing and scoring technique. Specifically, an AI-driven pose estimation and classification tool can help streamline assessments, reduce human error, and facilitate the teaching–learning dynamic by providing immediate feedback. By leveraging cutting-edge computer vision and machine learning algorithms, these systems have the potential to bolster both individual and group training sessions in Spanish dance, thereby enhancing educational outcomes and artistic excellence.

1.2 Aims and Objectives

This study aims to develop a pose estimation and classification tool specifically tailored to Spanish dance, with a focus on the intricacies of dance interpretation and footwork. By integrating pose estimation algorithms with dance-specific classification methods, the proposed system aspires to enrich the technological analysis of Spanish dance performances. The central goals include:

- Designing and validating a framework for AI-based pose estimation in Spanish dance.
- Incorporating classification models that capture both arm positions and precise footwork patterns.
- Evaluating the performance of this system against traditional, manually driven assessment methods to gauge its accuracy and applicability.

1.3 Hypothesis

This study proposes the hypothesis that implementing an AI-based pose estimation and classification tool for basic arm positions in Spanish dance can significantly improve the precision of performance assessments.

1.4 Research Questions

To explore this hypothesis, three key questions guide the research:

1. How accurately can the AI-based pose estimation tool identify and classify movements in Spanish dance when compared to traditional manual assessment methods?
2. How accurately can the AI-based pose estimation tool identify and classify footwork in Spanish dance when compared to traditional manual assessment methods?
3. What impact does the implementation of an AI-based pose estimation tool have on performance assessment of Spanish dancers?

By addressing these questions, the study seeks to bridge the gap between subjective, human-based evaluations and emerging AI technologies. Its findings

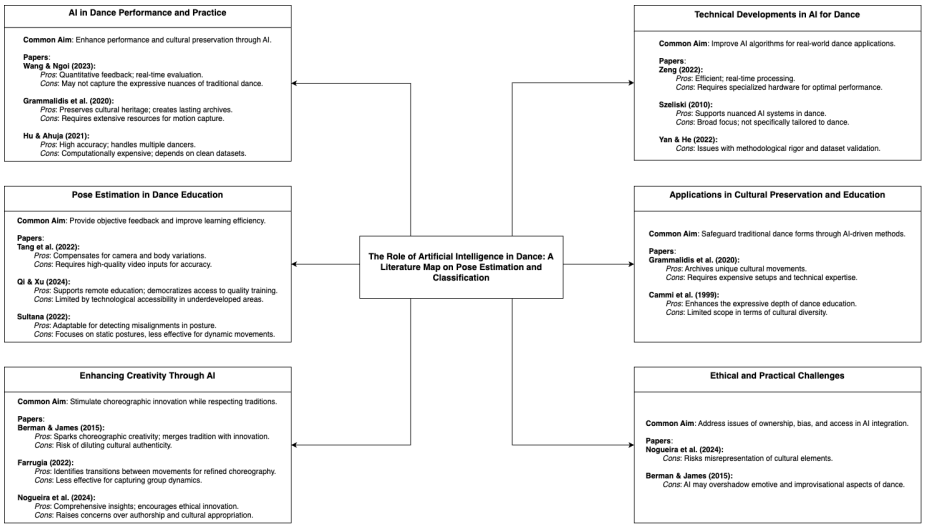

Figure 1: Literature Map

will inform educators, choreographers, and dancers on how to integrate objective, data-driven methods into established teaching and performance practices, ultimately enhancing the artistry and precision that define Spanish dance.

2 Literature Review

2.1 Introduction

The fusion of artificial intelligence (AI) and dance is revolutionizing the performing arts, creating novel tools for choreography, dance education, and cultural preservation. Through advanced computational methods that capture, analyze, and classify human movement, AI-driven systems can offer objective, data-based insights into dance performance, traditionally reliant on subjective evaluation. In Spanish dance—famed for its intricate footwork, precise arm placements, and rhythmic complexity—accurate evaluation of technical skill can be difficult to achieve consistently through human judgment alone. AI-based solutions aimed at pose estimation and movement classification promise to address this challenge, providing educators, dancers, and choreographers with uniform metrics and real-time feedback.

This review examines key developments in AI-driven pose estimation for dance, focusing on how such technologies can enhance the teaching, performance, and preservation of Spanish dance. It explores applications in dance education, creativity, cultural documentation, and offers insights into the ethical and practical considerations that accompany the integration of AI in traditional dance forms.

2.2 AI in Dance Performance and Practice

AI's role in analyzing and enhancing dance performance has grown significantly, leveraging computer vision and machine learning to elevate both educational and creative processes. Wang and Ngoi [14] propose a real-time dance analysis system using pose estimation to provide consistent, quantitative feedback. By detecting skeletal points and evaluating movement accuracy, the approach enables data-driven decisions for refining performance. This is especially crucial in Spanish dance, where a small misstep in foot placement or imprecise arm extension can undermine stylistic clarity.

Beyond performance optimization, AI holds promise for cultural preservation. Grammalidis et al. [4] document regional Greek dance forms through motion capture, demonstrating how folk dances can be archived before they vanish. A similar methodology would benefit Spanish dance genres, which are numerous and regionally distinct. Capturing postural data and footwork patterns preserves not only visual records but also quantifiable datasets for future study, ensuring heritage dances remain accessible to upcoming generations of dancers and scholars.

Mu [7] leverages convolutional neural networks (CNNs) to synchronize musical elements—such as tempo and rhythm—with choreographic sequences. In Spanish dance, complex rhythmic structures (e.g., the *palos* in flamenco) require intricate interplay between the music and dancer. Mapping music features to movement not only creates more effective training tools but also expands creative horizons, helping choreographers merge traditional Spanish dance with contemporary or fusion styles.

Further advancement in dance recognition is evident in work by Hu and Ahuja [5], who propose an unsupervised 3D pose estimation framework. By integrating low-level 2D pose data with higher-level semantic information, their hierarchical model accurately recognizes complex choreographies involving multiple dancers. Spanish dance ensembles often include group performances with interwoven lines and transitions, making multi-dancer analysis techniques extremely valuable for assessing spatial and temporal relationships.

Meanwhile, Wallace et al. [13] highlight how AI can serve as a creative partner rather than just a computational tool. In their interactive workshops, dancers employ AI to generate new choreographic ideas. Spanish dance, with its deeply rooted traditions, can benefit from these generative systems by expanding stylistic boundaries—introducing, for instance, novel footwork or inventive rhythms that respect traditional foundations but also invite innovation.

2.3 Pose Estimation in Dance Education

Pose estimation technologies have opened new avenues for dance education by offering tools that assess both quantitative and qualitative aspects of movement. Tang et al. [12] present a deep learning system that compensates for variations in camera angles, dancers' body types, and performance timing. Through video frame alignment and feature plane similarity, movement quality can be evaluated

with accuracy. In Spanish dance education, correct alignment of the torso, angle of the wrists, or spacing of footwork is paramount, and small deviations can greatly affect performance authenticity.

Qi and Xu [9] identify three key ways AI can reshape dance education: (1) bolstering teaching tools, (2) enabling autonomous learning, and (3) embedding objective criteria into assessments. Automation of minor error detection—such as incorrect weight distribution or misaligned elbows—helps dancers correct mistakes more efficiently. Autonomous learning platforms also democratize dance education, giving students lacking proximity to expert instructors the chance to receive high-quality training. This can be game-changing for mastering techniques like *zapateado* (footwork) or *braceo* (armwork), which demand intense precision.

Although Sultana's [10] research on standing desk posture classification may seem distant from the dance sphere, its technical underpinnings apply. Using keypoint extraction and classification methods like Support Vector Machines (SVM) and Multilayer Perceptrons (MLPs), posture analysis can be automated and adapted for dance. Such methods could track upper-body fluidity or the clarity of footwork in flamenco or bolero, helping instructors offer more consistent feedback without being physically present.

2.4 Enhancing Creativity Through AI

Beyond analyzing performance, AI has emerged as a powerful catalyst for creativity in choreographic processes. Berman and James [1] explore AI-driven virtual avatars that generate new dance sequences, effectively stimulating choreographic ideas. Spanish dance is steeped in tradition, and incorporating AI-generated variations—such as inventive *palmas* (hand-clapping) patterns—allows choreographers to remain faithful to cultural roots while experimenting with fresh stylistic twists.

Nogueira et al. [8] offer a systematic review of machine learning applications that support dance creativity, from generating new movement patterns to analyzing existing ones. This prompts conversations about ownership of AI-generated choreography. In traditional dances, questions arise over whether data-driven innovations might dilute or misrepresent cherished cultural components. Establishing guidelines around cultural sensitivity is essential: choreographic inspiration from algorithms must still respect the historical and emotional significance of Spanish dance.

Similarly, Farrugia's [3] work on behavior detection—though originally devised for identifying violent movements—demonstrates how segmenting and analyzing body motions can reveal transitions between movements. In choreographic terms, such a framework can aid Spanish dancers and choreographers in understanding the flow from the forceful stomp of a heel to the fluid arcs of the arms. With granular data insights, creators can push boundaries without undermining traditional artistry.

2.5 Technical Developments in AI for Dance

Recent improvements in AI-based pose estimation now make it feasible for real-world dance applications. Zeng [16] presents a multimodal recognition system using CNNs and image processing, demonstrating notable efficiency gains. For Spanish dance studios, optimized runtime and lower memory costs mean easier adoption of AI-driven feedback in real-time sessions, helping dancers refine footwork or posture swiftly.

Although later retracted, Yan and He's [15] study initially underscored the importance of methodological rigor in deep learning for dance. Its retraction highlights the need for high-quality datasets, thorough validation, and transparent reporting—crucial when dealing with complex performing arts data.

Hu and Ahuja's [5] hierarchical framework is especially pertinent in multi-dancer scenarios that typify Spanish group performances. When dancers partially occlude each other—common in a *tablao* or *peña* setting—robust AI systems can still track individual poses, enabling the evaluation of synchronization and spatial formation.

Szeliski's foundational work on computer vision [11] provides a broader backdrop, highlighting essential algorithms for motion detection and pose estimation. As these core methods inform specialized dance AI systems, a deeper grasp of computer vision allows developers and practitioners to more effectively harness AI in nuanced areas like capturing subtle torso shifts in flamenco or tracking the rhythmic interplay between dancers and live musicians.

2.6 Applications in Cultural Preservation and Education

One of AI's most significant contributions is the preservation of dance traditions. Grammalidis et al. [4] demonstrate how motion capture archives can keep folk dances from fading into obscurity. Spanish dance encompasses numerous regional variations, from *sevillanas* to *fandangos*, each with unique stylistic elements. Digitally capturing posture data and footwork patterns makes it possible to pass on these traditions more faithfully, even if local experts become scarce.

AI-driven posture classification systems, like the one by Sultana [10], can be adapted for Spanish dance instruction to guide students in real time. For instance, an algorithm might alert a beginner when their arms fail to match the elegant extensions required for flamenco or correct the angle of a *bate* (the sweeping motion of a skirt). Such feedback is especially useful for those studying remotely.

Cammi et al. [2] explore the link between physical gestures and emotional expressions, drawing on Rudolf Laban's Theory of Effort. Since Spanish dance is renowned for its emotional intensity—from the lightheartedness of *sevillanas* to the passionate sorrow of *soleá*—integrating emotion-sensing AI could deepen audience understanding and offer dancers a clearer sense of how their expressions register visually. This kind of cross-pollination between expressive theory and computational analysis opens novel pathways to interpret and teach the

emotional layers of Spanish dance.

Finally, Jordan and Mitchell [6] note how supervised and unsupervised models can enhance decision-making across fields. In dance, these models can identify errors in alignment or footwork by comparing movement data against benchmark standards. Over time, refined algorithms may offer immediate corrections, significantly expediting skill acquisition in demanding dance styles.

2.7 AI-Driven Dance Evaluation and Feedback

Central to AI's growing influence is its ability to deliver rapid, detailed evaluations of dance performance. Tang et al. [12] use a 3D pose estimation system that aligns student performances with reference videos. Subtle deviations in timing or alignment are flagged, helping dancers make immediate corrections. In Spanish dance, where the tempo-driven footwork and rhythmic accents must be precisely executed, such real-time feedback can greatly speed up technical mastery.

Qi and Xu [9] underscore the long-term impact of AI systems, as they store historical data and identify trends in a dancer's progress. Consistent errors—like a perpetually misaligned upper body or habitual under-extension of the arms—can be tracked, prompting tailored exercises or drills. This data-driven approach empowers instructors to customize their teaching strategies for each student's strengths and weaknesses. It also preserves the artistic spirit of Spanish dance, as the system focuses on improving technical underpinnings while leaving expressive choices to individual dancers.

2.8 Ethical and Practical Challenges in AI and Dance

Despite its benefits, AI integration in dance entails ethical and operational complications. One chief concern is intellectual property: Nogueira et al. [8] note that AI-generated choreography raises questions about authorship. Traditional forms like Spanish dance rely heavily on inherited steps and gestures. When algorithms rearrange these elements, to whom does the resulting sequence belong? Cultural custodians may worry that computerized remixing of historic movements diminishes their authenticity or disrespects lineage.

Berman and James [1] further question whether dependence on AI might erode the vital human component of dance. Spanish dance, particularly flamenco, is celebrated for its emotive power and improvisational character, where a dancer's personal interpretation is central to the performance. Overemphasis on automated precision risks sidelining spontaneity and passion.

Practical constraints also arise. AI systems hinge on high-quality video inputs—optimal lighting, camera angles, and minimal visual obstruction. For smaller studios or cultural venues, meeting these requirements may be difficult, potentially compromising system accuracy. Likewise, dancers who train outdoors or in traditional courtyard spaces, especially common in flamenco culture, may lack the controlled conditions needed to capture reliable motion data.

2.9 Broader Implications and Future Directions

The merging of AI and dance indicates broader ramifications across other fields—physical therapy, sports analytics, and beyond. For Spanish dance in particular, the specificity of pose estimation can serve as a template for other culturally rich dance forms that also feature complex footwork and emotive expression.

A pressing issue is accessibility. Currently, advanced AI solutions can be expensive and require technical expertise to implement. As the field matures, more affordable, user-friendly platforms must be developed so smaller dance schools and community groups can benefit. Researchers must also prioritize ethical clarity around data ownership, consent, and the diversity of training datasets, ensuring that certain dance styles are neither underrepresented nor misrepresented.

Real-time feedback is another area ripe for exploration. Sensor-based wearables, when paired with refined computer vision methods, could offer unprecedented accuracy in tracking movement angles and weight distribution. Tailored machine learning models might adapt to each dancer's progression, offering more personalized training regimens. In Spanish dance, which thrives on disciplined repetition, such ongoing, precise coaching can accelerate students' acquisition of technique while preserving the form's artistic richness.

Moreover, future research could delve into capturing the emotional and improvisational elements central to flamenco. Algorithms that integrate pose estimation with sentiment analysis or acoustic feature extraction from guitar strumming or singing might measure not only technical correctness but also the often elusive "duende"—the spirit or soul of flamenco. Such developments offer the potential to enhance performance feedback in ways that honor both technical and expressive dimensions.

2.10 Conclusion

AI-driven pose estimation and classification are reshaping how dance is analyzed, taught, and preserved. For Spanish dance—which demands both technical precision and strong emotional resonance—AI systems can provide standardized, data-rich evaluations that support learning and performance. Automated assessments help dancers refine footwork and posture more efficiently, while large-scale motion capture archives have the potential to safeguard a heritage deeply rooted in regional identities.

Nonetheless, such integration comes with critical considerations. Maintaining the soul of Spanish dance—the improvisational spark and emotional intensity—must coexist with the objective rigor of AI. Ethical questions around data ownership, potential biases in algorithmic design, and the creative role of AI-generated choreography remain crucial. Moreover, the technology's practical viability depends on balancing hardware requirements, environmental conditions, and budgetary constraints.

Moving forward, AI's influence on dance will likely expand, opening new horizons in real-time personalized feedback and emotional analysis. Spanish

dance practitioners, educators, and researchers have the opportunity to leverage AI responsibly, ensuring it not only enhances technique but also honors the essence of this culturally rich art form. By weaving together tradition and technological innovation, AI can become a powerful ally in preserving heritage and nurturing future generations of dancers.

References

[1] A. Berman and V. James. Kinetic imaginations: Exploring the possibilities of combining ai and dance. In *IJCAI Proceedings*, pages 2430–2435, 2015.

[2] A. Cammi, S. Hashimoto, K. Suzuki, and R. Trocca. Kansei analysis of dance performance. In *IEEE International Conference on Systems, Man, and Cybernetics*, pages 327–331, 1999.

[3] S. Farrugia. Violent behaviour detection using time-sequence pose estimation data, 2022.

[4] N. Grammalidis, I. Kico, and F. Liarokapis. Analysis of human motion based on ai technologies: Applications for safeguarding folk dance performances. In *Strategic Innovative Marketing and Tourism*, pages 321–330. Springer, 2020.

[5] X. Hu and N. Ahuja. Unsupervised 3d pose estimation for hierarchical dance video recognition. In *International Conference on Computer Vision (ICCV)*, pages 1–12, 2021.

[6] Michael I Jordan and Tom M Mitchell. Machine learning: Trends, perspectives, and prospects. *Science*, 349(6245):255–260, 2015.

[7] J. Mu. Pose estimation-assisted dance tracking system based on convolutional neural network. *Computational Intelligence and Neuroscience*, 2022:1–10, 2022.

[8] M. R. Nogueira, P. Menezes, and J. Maçãs de Carvalho. Exploring the impact of machine learning on dance performance: A systematic review. *International Journal of Performance Arts and Digital Media*, pages 1–50, 2024.

[9] T. Qi and B. Xu. Research on the status and development pathways of artificial intelligence technology in dance education. *Region-Educational Research and Reviews*, 6(9):28–32, 2024.

[10] N. Sultana. Classifying healthy standing desk posture using machine learning, 2022.

[11] Richard Szeliski. *Computer Vision: Algorithms and Applications*. Springer, 2010.

[12] H. Tang, Y. Luo, and J. Yang. Research on dance movement evaluation method based on deep learning posture estimation. *IEEE Conf. Big Data Engineering and Education*, pages 172–177, 2022.

[13] Isabel Wallace, Amanda Smith, and Oliver Jones. Interactive ai for creative dance workshops: Embracing serendipity and non-human artifacts. In *Proceedings of the ACM SIGCHI Conference on Creativity and Cognition*, pages 512–521. ACM, 2023.

[14] Z. Wang and M. Ngoi. A real-time dance analysis program to assist in dance practice using pose estimation. In *Proc. CSIT Conf.*, pages 69–78, 2023.

[15] M. Yan and Z. He. Dance action recognition model using deep learning network in streaming media environment. *Journal of Environmental and Public Health*, 2022:1–10, 2022. Retracted.

[16] Z. Zeng. Research on multimodal dance movement recognition based on artificial intelligence image technology. *Computational Intelligence and Neuroscience*, 2022:1–8, 2022.