HeyDancing: An AR/VR-Based Dancing Coach

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***Abstract*—Virtual reality (VR) and augmented reality (AR) have paved the way for numerous innovative and impactful applications. This work presents HeyDancing, a novel immersive dance training platform leveraging virtual reality and augmented reality (VR/AR) to enhance user engagement and improve learning outcomes in dance education. Unlike traditional methods, which often lack personalized feedback and real-time correction, HeyDancing incorporates motion capture, real-time correction, and customizable learning modules to offer an interactive, iterative, and adaptable training experience. Users can control the pace of their learning by adjusting the speed of the music and focusing on specific segments, ensuring a personalized approach. With support for both VR and AR modes, the platform allows learners to switch between fully immersive and augmented environments based on their preference. By addressing key limitations of existing VR/AR dance platforms, HeyDancing aims to improve both engagement and skill acquisition efficiency, offering new insights into the application of extended reality (XR) technologies in performance arts training.**

***Index Terms*—Virtual reality, Augmented Reality, Motion Capture, Human Animation, Virtual Character, Dance Training.**

I. Introduction

Dance is a vital component of human culture, serving as a powerful medium of expression, physical fitness, and creative exploration [1]. As both an art form and a means of communication, dance plays a crucial role in preserving traditional intangible heritage [2] and fostering social connections through structured activities such as leader dance [3]. However, learning to dance independently remains a significant challenge due to the lack of direct instruction, real-time feedback, and performance evaluation.

While several dance training applications have been developed, most are limited to two-dimensional (2D) formats that lack the realism and interactivity necessary for effective skill acquisition. The recent advances in virtual reality (VR) and augmented reality (AR) technologies offer promising avenues to overcome these limitations by enabling fully immersive and interactive training environments. VR/AR-based dance training systems can not only enhance engagement but also provide real-time feedback to facilitate more efficient learning.

Motivated by the potential of immersive technologies, we introduce **HeyDancing**, a next-generation dance coaching application that leverages VR/AR to redefine dance education. The system aims to address the key limitations of traditional methods and existing digital solutions by offering real-time motion capture, interactive visualization, and continuous feedback in an immersive environment. The overarching goal of **HeyDancing** is to make dance training both engaging and effective, thereby improving user experience and learning outcomes.

To develop an effective VR/AR-based dance training platform, several core functionalities were prioritized:

- **Real-Time Motion Capture**: A system capable of capturing real-time human body poses is essential. While numerous advanced algorithms exist for both 2D and 3D pose estimation, **HeyDancing** focuses on 3D pose capture for a more realistic and engaging experience.
- **Real-Time Rendering**: A dynamic rendering system visualizes both the user's avatar and the virtual coach in real time. This enables users to see their movements in a virtual environment and interact with the virtual coach as if they were physically present.
- **Real-Time Feedback**: Providing immediate feedback on user performance is critical for skill development. **HeyDancing** offers detailed feedback on the accuracy of specific body parts during movements, such as arms and legs, to guide users in refining their technique.
- **Combination of VR and AR Modes**: **HeyDancing** integrates both VR and AR modes into a single application, allowing users to select their preferred mode based on their environment and training needs. The VR mode offers a fully immersive experience, while the AR mode allows users to practice in a real-world setting with virtual guidance.

Building upon these key functionalities, we implemented **HeyDancing** using a fixed multi-camera setup to capture real-time user movements and map them onto a 3D avatar. The system integrates music and motion data from the AIST++ dataset [4] to animate the virtual coach, ensuring a diverse and dynamic training experience.

By combining virtual reality (VR) and augmented reality (AR) technologies with real-time motion tracking, **HeyDancing** offers a novel approach to dance training. Users wearing a head-mounted display (HMD) interact with a virtual coach while their movements are captured by the multi-camera system. This setup provides real-time corrections and guidance, transforming the learning process into an engaging and immersive experience. Ultimately, **HeyDancing** aims to advance research in XR applications for performance arts by demonstrating the potential of immersive technologies in education and skill acquisition.

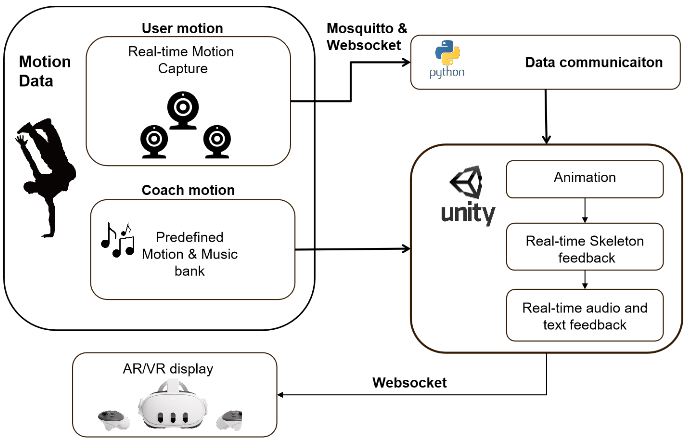

Fig. 1. Overall system design of the HeyDancing application

II. Related Work

This section reviews recent work on dance training systems using virtual reality (VR) and augmented reality (AR) technologies, focusing on publications between 2019 and 2024. We first examine VR-based systems, followed by AR-based approaches.

A. VR-based dancing training work

A comprehensive literature search was conducted to identify related works on VR-based dance training systems published between 2019 and 2024. Advanced search techniques were utilized with the query: `(TI("dancing" OR "dance") OR AB("dancing" OR "dance")) AND (TI("Virtual reality" OR "VR") OR AB("Virtual reality" OR "VR")) AND (TI("Train" OR "Training" OR "teach" OR "learn" OR "fitness") OR AB("Train" OR "Training" OR "teach" OR "learn" OR "fitness"))`. The search results were refined to include only peer-reviewed papers. Following a manual selection process, four relevant works were identified. These papers are introduced in chronological order to illustrate the progression of research in this domain.

Simon Senecal et al. (2020) proposed a salsa VR dance training system that allowed users to learn salsa dancing with a virtual partner, focusing on a leader-follower dance setting [5]. The system evaluated training performance using MMF and LMA features before and after training, but it lacked real-time feedback. In 2022, A. Roumana et al. developed a system for recording choreographies and replaying them in a VR environment [6]. This system utilized Microsoft Kinect for motion capture and 3D models from the Mixamo website for visualization but did not implement specific teaching methods. Around the same time, Kazuhiro Esaki et al. introduced a hip-hop dance training system that employed an image-based motion capture system and an automatic evaluation module based on contrastive learning and classification models [7]. While this system provided overall scores in a radar chart format, it also lacked real-time feedback. Building on these foundations, Yiqi Xiu et al. (2024) introduced a cave-based rhythm training system designed to improve rhythm synchronization. Kazuhiro Esaki et al. further refined their system by incorporating an advanced evaluation model capable of providing detailed feedback [8]. This improved system utilized a motion-feedback dataset with 33 joints instead of 17, applying contrastive learning-based expression learning and a reference-guided model for feature extraction and scoring. This work provided valuable insights for our research.

B. AR-based dancing training work

Following a similar approach to the previous search strategy, the query used here was: `(TI("dancing" OR "dance") OR AB("dancing" OR "dance")) AND (TI("Augmented reality" OR "AR") OR AB("Augmented reality" OR "AR")) AND (TI("Train" OR "Training" OR "teach" OR "learn" OR "fitness") OR AB("Train" OR "Training" OR "teach" OR "learn" OR "fitness"))`. After a manual selection process, four relevant works were identified. These studies are introduced in chronological order to illustrate the development of research in AR-based dance training systems.

Javid Iqbal et al. (2019) provided a taxonomic overview of AR-based Dance Training Systems (ARDTS) and conducted a pilot experiment focusing on posture matching and motor skill development [9]. Their approach relied on a pose matching model and evaluated performance using the Technology Acceptance Model (TAM). Manjit Singh Sidhu et al. (2022) proposed an AR-based training method offering real-time feedback in a 2D format and incorporating three training modes: novice, intermediate, and expert [10]. Iris Kico et al. (2024) developed an AR-based dance training system leveraging ARCore platform, complemented by non-invasive brain stimulation to accelerate the learning process [11]. Cai-Ling Wu (2024) introduced an AR dance training system designed for university dance courses. This system utilized card scanning and demonstrated that AR-based learning methods could enhance student engagement and improve their learning outcomes [12].

C. Contribution of Our Work

Although significant progress has been made in both VR- and AR-based dance training systems, our approach differs in several key aspects. For VR-based methods, we provide real-time skeleton feedback with visual cues highlighting specific body parts, as well as real-time text and audio feedback to enhance the user experience during training intervals. Unlike existing AR-based methods, our system offers a fully 3D platform for motion illustration and feedback. Moreover, to the best of our knowledge, this is the first system to integrate both VR and AR modes into a single application, allowing users to switch between immersive and augmented environments according to their preferences and needs. This dual-mode capability offers greater flexibility and personalization in dance training, setting our work apart from prior research.

III. Methodology

A. Overview

Building upon previous research, we introduce our VR/AR-based dance training system, **HeyDancing**. As shown in Figure 1, the system comprises four primary modules: the motion capture module, data communication module, animation and feedback calculation module (developed in Unity3D), and the VR/AR display module. Each module plays a crucial role in providing an immersive, real-time dance training experience. The following subsections provide detailed descriptions of these components.

B. Motion Collection Module

To create an effective dance training system, it is essential to capture the motions of both the user and the virtual coach. Real-time motion capture is employed for users, while high-quality, pre-recorded motion sequences are used for the coach.

User Motion Capture: We adopt a marker-less motion capture approach using ceiling-mounted cameras. These cameras track user movements with high precision by applying a 2D keypoint detection algorithm to identify joint positions in 2D images captured from multiple angles. The 3D positions of the body joints are calculated using camera parameters and the detected 2D joint locations through a triangulation method. In total, 14 joints are tracked in real time, with a frame rate of approximately 25 frames per second (fps). This system supports multi-user detection, enhancing flexibility for group training scenarios.

Coach Motion Data: For the coach's motion, we utilize the GDance dataset [13], which contains synchronized motion and music data across seven dance styles and 16 music genres. Each dance motion is represented by 3D joint positions for 24 joints. For this study, we manually selected three hip-hop dance routines from the dataset to serve as the virtual coach's choreography.

C. Data Communication

Since the motion capture system operates on an Ubuntu platform while the Unity development environment runs on Windows, efficient data communication is critical for seamless real-time performance. Initially, Mosquitto is employed to transfer motion data from the motion capture system to the Windows PC. Subsequently, WebSockets are used to transmit motion data between the Unity application and the VR headset. This setup ensures minimal latency, allowing for real-time animation of the user's avatar within the VR environment.

D. Animation and Feedback Calculation Module

The animation module visualizes motion data by animating 3D humanoid characters representing the user and the coach. The characters are sourced from Mixamo, a free resource providing customizable 3D models and animations. Forward kinematics is applied to compute joint rotations, with the 'HIP' joint serving as the root.

Feedback Mechanisms: Two types of feedback mechanisms are incorporated:

- **Real-Time Audio and Text Feedback**: Using the Dynamic Time Warping (DTW) algorithm [14], the system synchronizes motion sequences of the user and the coach. The Euclidean distance between corresponding frames is calculated within a sliding window of 30 frames, updated once per second. The system classifies performance intervals into three categories: "perfect" (distance < 10), "good" ($10 \leq$ distance < 20), and "missed" (distance ≥ 20).
- **Real-Time Skeleton Feedback**: To provide localized feedback on specific body parts, a skeleton-based visual feedback system is implemented. The Euclidean distance between corresponding bones of the user and the coach is calculated, and the skeleton color is adjusted accordingly: green for "perfect" (distance < 10 units), white for "good" ($10 \leq$ distance < 20 units), and red for "missed" (distance ≥ 20 units). This color-coded feedback offers users an intuitive understanding of their performance and areas for improvement.

As shown in Figure 2, the skeleton feedback is displayed on the left, while the 3D avatar appears on the right. For example, when the leg position matches the coach's movement, it is shown in green, while errors in arm movement are highlighted in red.

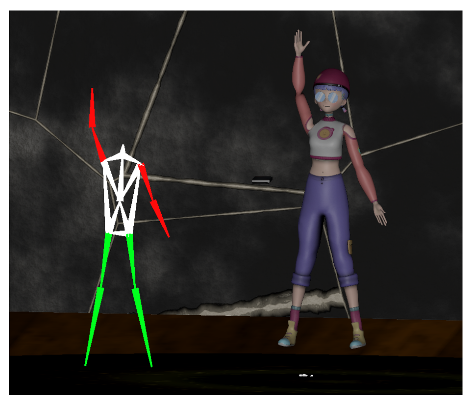

Fig. 2. Skeleton Feedback

E. User Interaction Design

The user interface is designed for simplicity and flexibility, allowing users to select dance routines, adjust difficulty levels, and monitor their progress through voice commands or gesture controls. Two types of interfaces are provided: interactable and non-interactable interfaces.

Interactable Interfaces. The interactable interfaces are designed to enable users to select dance routines and customize their learning experience according to personal preferences. Two menus have been developed to support this functionality: the dancing library panel and the palm menu.

The dancing library panel allows users to browse a collection of dance routines, select songs, and preview dance movements before initiating a training session. Additionally, users can switch between VR and AR modes using this panel, offering flexibility in choosing the desired mode of interaction. The dancing library panel is illustrated in Figure 3.

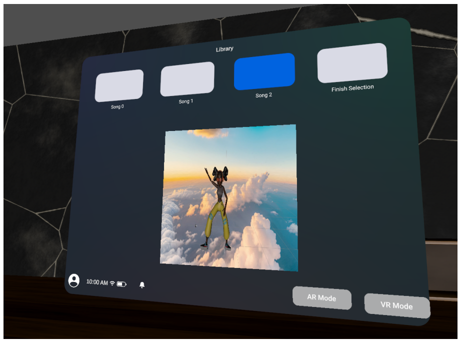

Fig. 3. Dancing library panel

Once a routine is selected, users can access the palm menu, which provides controls for adjusting the motion speed and navigating the routine by moving forward or backward. This design promotes a flexible, user-centered learning experience by enabling real-time adjustments during training. The palm menu is illustrated in Figure 4.

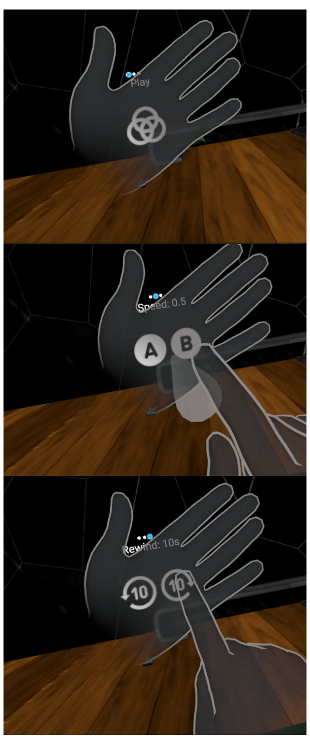

Fig. 4. Palm menu

Non-Interactable Interfaces. The non-interactable interfaces serve two main purposes. First, they function as a user guide, providing essential information about the system and explaining the roles of various components to assist users in navigating and operating the environment. Second, they deliver performance feedback, offering users valuable insights into their dancing performance to facilitate skill improvement.

As illustrated in Figures 5 and 6, these interfaces introduce the use of the palm menu and skeleton feedback, helping users become familiar with the system's core functionalities. Figure 7 shows text labels for the coach character and real-time text feedback provided during training sessions, ensuring that users receive continuous guidance throughout the learning process.

Fig. 5. Palme Menu Guide

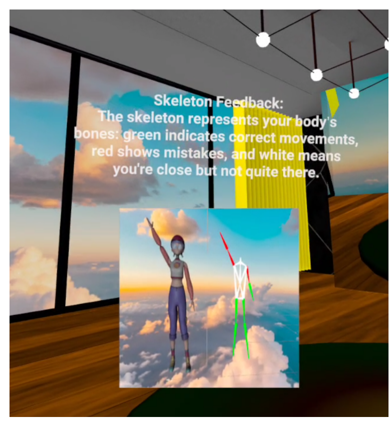

Fig. 6. Skeleton Feedback Guide

F. VR/AR display

Our system supports two distinct modes: virtual reality (VR) mode and augmented reality (AR) mode, both optimized for use with the Meta Quest 3 headset.

In VR mode, users train in a fully virtual environment designed as a dance hall, with a mirror positioned on the front wall to allow real-time visualization of their avatar and interactions within the virtual space. This immersive environment enhances user engagement and helps them focus entirely on their training. The virtual environment was obtained from a

Fig. 7. Text Guide

publicly available Unity asset [1]. Figure 8 illustrates the VR environment.

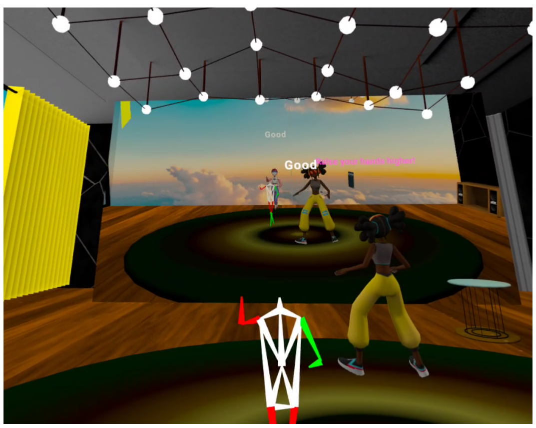

Fig. 8. VR Mode

The AR mode seamlessly integrates virtual coaching with real-world interactions. Users begin by scanning their physical environment using the Meta Quest 3 headset. Once AR mode is activated, the system detects primary vertical surfaces and anchors the virtual mirror to one of them. Other virtual elements, including the coach and interactive menus, are positioned relative to the identified surfaces. This mode allows users to view their real surroundings alongside the virtual coach, who provides step-by-step guidance throughout the training session. Visual feedback, such as posture corrections and directional cues, is overlaid directly onto the user's field of view, ensuring an engaging and intuitive training experience. Figure 9 illustrates the AR environment.

[1]https://assetstore.unity.com/packages/3d/props/interior/hotel-room-collection-214335

Fig. 9. AR Mode

G. *User Research Method*

The primary objective of the user research was to assess the usability of the HeyDancing application and to gain a detailed understanding of target users' needs, behaviors, and expectations for an AR/VR-based dance learning system. These insights were essential for refining HeyDancing's features and enhancing the overall user experience. To achieve this, we adopted a mixed-method approach, combining quantitative and qualitative techniques to collect comprehensive feedback from participants:

1) **Survey:** A Google Form was distributed to gather quantitative data on participants' dance experience, familiarity with AR/VR devices, and initial impressions of the system.
2) **Interviews:** Semi-structured interviews were conducted following the testing sessions to collect in-depth qualitative feedback regarding participants' experiences, preferences, and any challenges they faced while using the application.
3) **Observation:** Real-time observations were carried out during user testing to monitor participants' interactions with the system. This method allowed us to identify usability issues and areas where additional guidance or improvements were needed.

IV. Results

A. *Hardware and Software Implementation*

The system was tested on the Meta Quest 3 headset. Motion capture was performed using a multi-camera setup provided by Sony, with the capture system running on a PC with Ubuntu OS. The VR and AR interfaces were developed using Unity on a Windows-based PC.

B. *User Testing and Feedback*

*1) **Participant Demographics**:* We gathered feedback from 11 participants with diverse backgrounds. The age distribution of participants was as follows: 27.3% were between 18 and 25 years old, 63.6% were between 26 and 35 years old, and

9.1% were between 36 and 45 years old. In terms of gender, 63.6% of participants were male, while 36.4% were female. Regarding occupation, the majority of participants (72.7%) were students, followed by 18.2% who were technology professionals, including VR developers, engineers, and designers. Additionally, 9.1% of participants were dance professionals.

Although participants represented a range of occupations, the majority were students or staff members from an academic setting. This relatively homogeneous sample may limit the generalizability of the findings to other user groups, such as professional dancers or casual learners outside the university environment.

*2) **Quantitative Analysis**:* The user research provided valuable insights into participants' backgrounds and their experiences in developing dancing skills. Most participants were either beginners (54.5%) or had intermediate dance skills (36.4%). Regarding AR/VR familiarity, 45.5% of participants reported being highly familiar with the technology, while the rest exhibited varying degrees of familiarity.

Table I summarizes the questionnaire items related to system performance along with the average score for each. The majority of users found the system easy to use, with 63.7% giving high usability scores (4 or 5 out of 5). As shown in Figure 10, most participants rated the interface as intuitive and easy to navigate, with 54.5% assigning high ratings for ease of use.

With respect to the virtual avatar, most participants were satisfied with the synchronization between their real movements and the avatar's actions (Figure 11). However, two participants noted a noticeable motion delay when performing rapid movements, indicating a potential area for further optimization.

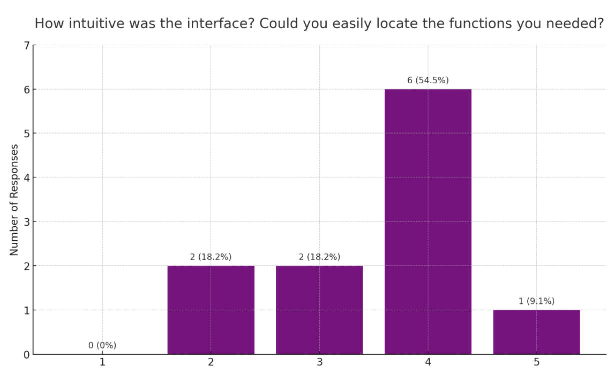

Fig. 10. Feedback on Interface Accessibility

User satisfaction was high, with an average rating of 4.6 out of 5. The VR mode received 72.7% high ratings, while the AR mode received 50% high ratings. These insights will guide future iterations to ensure that HeyDancing continues to meet user expectations.

*3) **Qualitative Analysis**:* Participants provided valuable suggestions for improving the *HeyDancing* system through interviews and on-site observations.

Regarding real-time feedback, participants appreciated the virtual coach's responses, noting that encouraging feedback messages, such as *"Good"* and *"Great"*, motivated them to continue improving their performance. It is worth noting that the scoring system was intentionally adjusted during testing to provide more positive feedback in the early stages. This approach was designed to prevent user demotivation, particularly since most participants were unfamiliar with the system at the start.

Question	Average Point
Q6. How easy was it for you to learn how to use the system? (1: Very difficult, 5: Very easy)	3.82/5
Q7. How intuitive was the interface? Could you easily locate the functions you needed? (1: Very difficult, 5: Very easy)	4.18/5
Q8. Was the virtual coach's guidance clear and easy to follow? (1: Not accurate at all, 5: Very accurate)	4.45/5
Q9. To what extent did the user avatar closely follow your body movements in real time? (1: Not at all, 5: Perfectly)	4.55/5
Q10. How satisfied are you with the overall experience of using VR-Based Dancing Coach? (1: Very dissatisfied, 5: Very satisfied)	4.45/5
Q11. How satisfied are you with the overall experience of using AR-Based Dancing Coach? (1: Very dissatisfied, 5: Very satisfied)	4.20/5

TABLE I
SUMMARY OF QUESTIONNAIRE AND ITS RESULTS

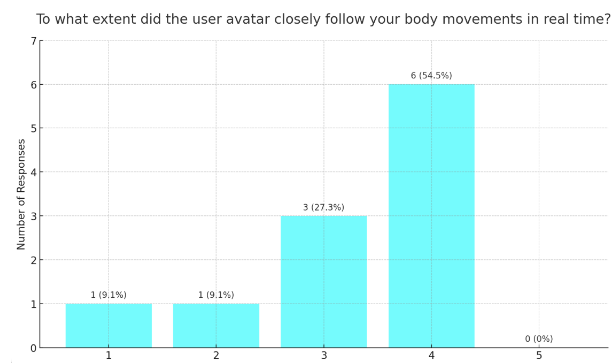

Fig. 11. Feedback on 3D Avatar Performance

Several participants praised the current lenient scoring system for encouraging beginners, although some advanced users felt it lacked precision. To address this, we plan to introduce different scoring modes, including a "Beginner Mode" with lenient feedback and an "Advanced Mode" offering more detailed and precise evaluation.

Another common suggestion was to improve the clarity of visual cues. Participants mentioned that clearer visual guidance would help them better follow the virtual coach's movements, thereby enhancing their accuracy. This enhancement will be prioritized in future updates.

Additionally, many participants requested a step-by-step learning mode that would allow them to practice individual dance moves before advancing to more complex sequences. Such a feature would provide a more gradual learning curve, particularly benefiting novice users.

Lastly, a few participants pointed out that certain button labels were difficult to read due to low contrast or small font size. Improving the contrast and increasing the font size will enhance the interface's readability and usability.

V. Limitations

This study has several limitations. First, the participants were primarily students and technical professionals aged between 18 and 35, resulting in a relatively homogeneous group. This may limit the applicability of the findings to a broader audience, such as professional dancers or older users. Second, the scoring system used during testing was intentionally lenient to encourage beginners. While this approach helped maintain user motivation, it may have reduced the accuracy of performance evaluations, especially for more advanced users seeking detailed feedback. Finally, due to time and resource constraints, the sample size was small, with only 11 participants. A larger and more diverse sample would be needed for more generalizable results.

VI. Future Work

Future work will focus on involving more diverse users, improving the scoring system, and expanding system features. To gather broader feedback, we plan to include participants of different ages and dance experience levels, especially advanced dancers and older users. We will refine the scoring system by adding modes for different skill levels. A "Beginner Mode" will offer supportive feedback, while an "Advanced Mode" will provide detailed and precise evaluations to help experienced users improve. Expanding the range of dance styles and difficulty levels will make the system more versatile. Supporting various genres and complexity levels ensures users get a personalized learning experience. The feedback system will be enhanced with advanced analytics to give personalized tips based on users' movements, making the learning process more effective. Finally, long-term studies will track user progress over time, helping us evaluate how well the system improves dance skills and guiding future improvements.

Acknowledgment

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