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A Digital Intelligence Framework for Multi-modal Recording and Instruction of Kunqu Opera Body Movements Using Labanotation

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SUMMARY: *In response to the contemporary demands of digitally recording and instructing Kunqu Opera body movements, this paper proposes a digital intelligence framework that integrates Laban Movement Theory with multi-modal data acquisition technologies. Centered on the basic skills techniques of Kunqu opera body movements, the study develops a digital Labanotation generation method, supported by multi-modal data collection and symbolic mapping, to accurately extract and standardize key features of stylized body patterns. Further, the generated labanotations are integrated into an interactively designed visual learning platform that combines 3D virtual characters with structured symbolic representation, offering learners a multi-modal instructional environment that merges analytical rigor with intuitive perception.Together, these components constitute a unified framework that advances the scientific documentation and teaching of Kunqu Opera movements, while providing a scalable solution for the intelligent preservation and dissemination of intangible cultural heritage in the digital era.*

KEYWORDS: *Labanotation; Kunqu opera body movements; Multi-modal technology; Basic skills techniques; Digital intelligence inheritance*

1 Introduction

1.1 The Inheritance of Kunqu opera Body Movements and the Challenge of recording and instructing

As a Masterpieces of the Oral and Intangible Heritage of Humanity, Kunqu opera is unique in the history of world drama with its unique performance form of the integration of culture, music, appearance and dance. Throughout the development history of Kunqu opera performance, it becomes evident that its evolution is fundamentally rooted in the development, formalization, and standardization of stylized movements in Chinese opera performance. Chinese opera theorist Qi Rushan pointed out, “The opera circles have named it ‘Body Movements,’ which is the principle of dance.” By avoiding the direct representation of life forms, Kunqu opera refines, abstracts, and standardizes the techniques of objective movements, forming a highly stylized and dance-oriented performance form. It thus constructs a unique system for the inheritance of traditional Chinese opera performance and

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classical formula standards. In particular, the establishment of the basic training system of four skills and five means is the core of stylized performance of Kunqu opera. Among the four skills, *singing, recitation, acting and acrobatics*, *acting and acrobatics* account for half. Among the five methods, *Wushu techniques of hands, eyes, body and legs* is almost built around the body movements**.** Through strict and standardized body training, no matter what gender, age actors can accurately convey the emotions and intentions of the role. Solid basic skills play an extremely important role in the success of an actor's performance**.** These frameworks of body movements, refined and explored over generations by artists, are not only the core foundation for the inheritance of Kunqu opera skills but also the key elements in expressing its performance aesthetics and artistic imagery.

Traditionally, the inheritance of Kunqu opera mainly relies on the Oral Imparting with Physical Instruction between teachers and students. Although this method can effectively retain the tacit knowledge of Kunqu opera performance, and realize the transmission of performance skills from generation to generation. However, this kind of inheritance highly depends on the individual experience and interpretation of actors, and the movement is inevitably distorted and distorted in the process of inheritance, especially the limitations in analysis and communication are increasingly apparent. With the development of recording technology, the recording of opera movements has undergone the evolution from traditional text recording to modern combination of graphic and text, and then to today's digital video recording, and people's understanding of Kunqu opera body movements has gradually moved from perceptual inheritance to rational analysis. Especially in recent years, the application of 3D motion capture technology in intangible performing arts such as Kunqu opera has not only broken the situation that Kunqu opera body movements are difficult to reproduce through digital restoration, but also promoted the multi-dimensional three-dimensional reproduction of Kunqu opera performances in the digital space with the blessing of digital technologies such as virtual reality and human-computer interaction. The introduction of digital technology has provided a new possibility for the recording and restoration of Kunqu opera, but the existing recording mode still mainly stays in the *image-centered* external action form reproduction, and has not really got rid of the *oral and physical instruction* visual experience orientation. This recording method, which focuses on intuitive feelings, lacks systematic analysis and description methods based on scientific framework, thus limiting its value in practical applications such as teaching and criticism. On the one hand, teaching practice is insufficient in tools. The current recording method fails to provide systematic action analysis tools and can not effectively decompose the standardized elements of body movements. As a result, in the traditional teaching process, students usually rely solely on their vision and lack an understanding of the regularity of movement structure and internal logic, which can easily result in the phenomenon of *blind imitation* or *copying without understanding*. On the other hand, the scientific nature of commentary and analysis is lacking. When judging and classifying performance styles, they are used to literary and sentimental descriptions such as *heroic*, *gentle* and *elegant*, which makes it difficult to form a unified and clear scientific analysis framework. Moreover, the movement analysis is sketchy, which mainly focuses on summarizing the overall morphological characteristics through the significant changes of a single limb, ignoring the scientific expression of the deep structure and connotation of the movement, which is difficult to provide a solid basis for the study of performance style. These limitations not only restrict the scientific protection of classical skills of body movements, but also limit the ability of modern opera workers to obtain theoretical support in the process of figure arrangement and innovation.

Therefore, at present when Kunqu opera performances are facing continuous development in modernization and scientification, it is urgent to use the combination of digital technology

and scientific theoretical framework to build a systematic recording method for the body movements in Kunqu opera, so as to preserve, reproduce and analyze the structure, form and characteristics of Kunqu opera body movements. It is not only an urgent need to protect the essence of Kunqu opera performance, but also a key path to promote the inheritance and innovation of Kunqu opera.

1.2 The Necessity of the Introduction of Labanotation

Based on the need of scientific recording and analysis in the study of Kunqu opera body movements, this paper introduces the movement recording and analysis system in modern dance research, Labanotation[1]. As a highly abstract and standardized symbol system, Labanotation can summarize movement rules through symbolic means, not only covering the posture performance of human body in three-dimensional space, but also highlighting the structural characteristics of movements while recording dynamic information. This approach ensures that the recording focuses on the essential characteristics of the action, rather than being limited to the individual performance of a particular actor. Applying the scientific observation method of Labanotation and standardized symbol system to the study of Kunqu opera body movements can, in addition to effectively decomposing and extracting the movement trajectory and dynamic characteristics of different opera role types and roles in three-dimensional space and time, form standardized records and deepen the rational understanding of the core characteristics of Kunqu opera body movements. It also provides a scientific and analyzable theoretical framework for the inheritance of Kunqu opera skills.

At the same time, with the rapid development of sensor and digital interaction technology, the automatic generation technology of Labanotation based on computer breaks through the limitation of traditional Labanotation recording mainly relying on manual observation and manual recording by Certified Laban Movement Analysts (CMAs) with its objectivity and efficiency, and provides a new digital path for the mapping between motion data of Kunqu opera body movements and Labanotation symbols. Based on this, the paper constructs a digital Labanotation system for recording Kunqu opera body movements by integrating Labanotation and multi-modal data acquisition technology, and proposes an efficient method for digital Labanotation. Through the multi-modal data collection of the performance inherited by professional Kunqu opera actors, the typical characteristics of the Kunqu opera body movements are extracted and standardized, so as to make up for the shortcomings of the traditional body record in symbolic representation and rational analysis. Furthermore, by integrating 3D virtual character dynamics with symbolic representation, a visual interactive system for body movement appreciation based on Kunqu opera Labanotation has been developed. This system enables learners to gain a more comprehensive understanding of the essence of Kunqu opera performance in a digital environment. It improves the dissemination and practicability of the results of the digital Labanotation, and provides scientific and technical support for the inheritance, innovation and teaching of Kunqu opera performance in the digital era.

2 The Course and Challenge of Body Form Recording in Kunqu opera

Western dramatists believe that performance cannot be preserved, the reason is that Western drama performance pays more attention to personalized representation and subjective psychological experience. Influenced by Eastern aesthetics, Kunqu opera built a set of rules-based performance systems through stylized movements, transforming artistic

summaries of objective movements into standardized, choreographed physical techniques independent of the actors. This stylized feature is not only the core of Kunqu opera, but also forms the basis of the unique skill inheritance of traditional opera. However, as long as there are no two identical people, there is no such thing as a completely unaltered body heritage. For the scientific research and inheritance of Kunqu opera body movements, only by relying on scientific and effective recording and reproduction methods can we truly master the stylized movements and provide support for the protection, teaching and research of Kunqu opera body movements. From the initial recording of Kunqu opera in the form of writing in the Qing Dynasty, to the exploration of performance science in the early modern period, and then to the application of contemporary video technology, the recording of Kunqu opera has always faced multiple challenges of consciousness transformation, technical conditions and form transformation. By combing through the development path of Kunqu opera's body movements record, it not only helps to reveal the value and limitations of traditional recording methods, but also provides important enlightenment for the modern inheritance and innovation of Kunqu opera in the digital era.

2.1 The Evolution of Traditional Body Records

2.1.1 Performance Records of the Qing Dynasty Kunqu opera

Beginning with the Kunqu opera Sifan (Yearning for the Mundane Life), transcribed in the ninth year of Emperor Kangxi's reign (1670), stage body techniques—originally passed down orally between masters and apprentices—began to be systematically documented in written form. This transition is reflected in works such as *Shenyin Jiangu Lu* (Selected Kunqu Plays for Stage Performance), *Kunyi Shen Duan Pu* (Notation of Body Movements for Kunqu and Yiyang Operas), and performance manuscripts compiled by actors such as Cao Wenlan and Cao Chunshan.

Building upon the *kejie* (stage directions) found in traditional chuanqi opera scripts, Kunqu practitioners developed annotation systems such as the yizhuxiang (incense-time style), yuzhu (jade-column style), and interlinear notations to describe body movements alongside the textual content. These methods integrated physical performance with the lyrical structure of the opera, thereby preserving the terminology and stylistic features of stage movement choreography.Although these materials provide valuable historical basis for the origin, development and technical system of Kunqu opera body pieces, due to the particularity of the opera industry at that time, the Notation of Body Movements as treasure of the operatic circle tend to be personal notes, so the recording standards are different, and the contents are mostly simple movement terms, lacking the description of the specific body movement structure. Moreover, it is impossible to talk about the specific details such as the rhythm and amplitude of the movements, which also makes it difficult to be directly applied as the basis for the body line in the teaching of modern Kunqu opera.

2.1.2 The Exploration of Body Shape Records in the Early Modern Period

Opera theorist Qi Rushan emphasized that while artistic forms must evolve over time, such evolution must remain grounded in fundamental principles. He argued that without systematic and scientific documentation of both the formal structure and underlying meaning of stylized movements, these performance elements cannot be widely understood, analyzed, or transmitted. Consequently, the development of opera performance as an academic discipline would be significantly hindered. In 1932, in response to the absence of any comprehensive study on physical movements in traditional Chinese operas, Qi Rushan compiled *Guoju Shenduan Pu* (Notation of Body Movements of Chinese Operas), the first systematic work

dedicated to the interpretation and codification of stylized performance techniques in opera. Drawing on extensive practical experience in Kunqu opera performance, the book also incorporates techniques from related genres such as Bangzi and Huidian. It systematically records 256 routine basic skill techniques for body movements commonly used in traditional opera. Qi Rushan further provides detailed analyses of movement postures, highlighting stylistic characteristics across different role types—offering valuable insight into performance methodology.

Although the classification and recording method in *Notation of Body Movements of Chinese Operas* provided an important reference for the follow-up research on body movements, due to the limitations of folk recording techniques and conditions at that time, its colloquial records had relatively large errors in the restoration process. Take *Yunshou* (Cloud Hand) as an example (refer to Table 1): due to the general description of the action, coupled with the lack of specific positioning or a reference system for the route and direction of the upper limb in the movement space, it is difficult to clarify the nature of this interaction.

Table 1: Yunshou from Notation of Body Movements of Chinese Operas

Name	Yunshou
Posture	The actor begins with the left hand underneath, palm facing upward to the right, and the right hand above, palm facing downward to the left. The two hands move toward each other in a crossing motion, then both are withdrawn. The positions reverse—left hand on top, right hand underneath—and cross again. The left hand is then drawn to the left, followed by the right hand to the right. The actor's gaze follows the left hand first, then shifts to the right hand, and finally returns to the front after the movement ends.
Role Types	Jing: The actor makes a wide circular motion with the arms, sometimes stepping forward before pulling back. Sheng: The arms move in a tighter circle with a slight shoulder pullback. Xiao Sheng: The circles are smaller, with the shoulders pulling back as much as possible. … (Additional variations across roles omitted for brevity).

2.1.3 The Perfection of the Body Movement Record after the Founding of the People's Republic

After the establishment of the People's Republic of China, the professionalization and modernization of opera performance as an academic discipline led to increasingly systematic and precise documentation of body movements. This development facilitated the transmission and exchange of Kunqu movement techniques across different regions and practitioner communities, allowing professionals to refine their performance through more standardized references. From the 1950s onward, with the oral support of veteran performers, a number of classical body patterns—previously preserved only through oral and physical transmission—were collected and recorded. Works such as *Records of Qian Baosen's Peking Opera Performance*, *Memories of My Life as a Clown in the Kunqu Opera by Hua Chuanhao*, and *Learning and Performing in Chinese Opera by Hou Xiru*i made efforts to use tools like anatomical terminology, photographs, and diagrams to document these movements more scientifically. These efforts laid the groundwork for the inclusion of body movement notation in opera textbooks.

Taking Wan Fengshu's participation in the compilation of the official textbook of the National Academy of Chinese Theatre Arts, *Textbook on Basic Skills of Body Movements for Traditional Chinese Opera Performance*, as an example, the textbook draws on the

experience of earlier generations and adopts a rigorous written style, avoiding the literary and colloquial expressions typical of oral transmission.The movements are systematically deconstructed into fundamental elements using a step-by-step approach consistent with traditional opera pedagogy. Core technical points are emphasized to support effective learning. The curriculum follows a progressive structure: foundational stylized techniques—such as Shanbang (single shoulder raise), An Zhang (pressing palm), and Ta Bu (Dan role footwork)—are introduced early, enabling direct reference in subsequent teaching of complex movements (see Table 2). This hierarchical design improves the efficiency of documentation and ensures terminological consistency.To enhance visual comprehension, the textbook integrates posture sketches alongside the breakdown of each movement (see Figure 1). These sketches provide a concrete formal language to clarify textual descriptions and minimize ambiguity. The use of stylized drawings also avoids distortion caused by performer-specific body variations, increasing both the accuracy and generalizability of the visual record.

Although static decomposition improves structural clarity, it fails to capture the timing, dynamics, and rhythmic flow of movement. Moreover, variations in professional background, performance experience, and opera interpretation lead to inconsistencies in selecting actions, identifying technical points, and creating instructional imagery. These gaps affect the objectivity and standardization of movement documentation. Therefore, a key challenge in Kunqu opera studies remains: how to leverage modern technology to create clearer, more concise, and standardized records that faithfully reflect the interpretive logic of Chinese opera performance.

Table 2: Yunshou for Male Actor form Textbook on Basic Skills of Body Movements for Traditional Chinese Opera Performance

Yunshou Ready Position: The actor’s hands are on his hips, and the mlae actor is standing in steps, with looking straight ahead.
1 Place the left palm on the chest, while raising the right arm to the right side at shoulder level, with a small circle of arms, looking at the right palm.
2 Knead the right palm into the bosom, and put it slightly forward with the left palm.
3 The left palm is tilted to the upper left, while the right palm is lifted above the right forehead.
4 Lift his left palm above his head; Right palm slightly sit wrist two palms outward, look at the right palm.
5 Slow arms out to the right and look at the right palm
6 Both arms move slowly across the chest to the left. The left arm lifts to shoulder height in a fist; the gaze follows the left fist. At the same time, the right arm draws to the chest in a pressing palm.
7 The left fist stays still. The eyes follow the right palm as it circles outward to the right. The wrist turns downward, palm facing right. Then, the performer shakes the head, changes expression, and faces forward with a fixed gaze.

Figure 1: The sketch of Yunshou body posture in the Textbook on Basic Skills of Body Movements for Traditional Chinese Opera Performance

2.2 The Application of Digital Image Recording Means

2.2.1 The Popularity of Dynamic Video Shooting

In the 21st century, video technology has become an essential tool for recording and studying traditional Chinese opera performances, including Kunqu. With the widespread adoption of digital recording and playback devices, dynamic videos comprehensively capture the positions, gestures, and rhythmic nuances of Kunqu body movements. These recordings not only preserve the classic performances of renowned artists but also effectively compensate for the limitations of traditional static documentation by offering observers a vivid and intuitive experience. Moreover, supported by streaming media platforms, video-based records have expanded beyond academic contexts into public dissemination, contributing to the broader visibility and appreciation of Kunqu and other operatic forms.

Various institutions and cultural organizations have produced digital video content to support the documentation and teaching of traditional opera movements. As shown in Table 3, these recordings differ significantly in performer attire, camera setup, video type, and content focus. For instance, short-form videos on platforms like TikTok typically feature complete sequences performed in full costume, emphasizing visual appeal and performance continuity. In contrast, long-form instructional videos on MOOC platforms adopt multi-camera setups and practice attire to highlight key technical details and enhance instructional clarity.

These diverse practices also underscore the limitations of current video-based technologies in conveying the spatial structure and internal logic of movement. Specifically, due to constraints in device performance, frame rates, and platform formats, video recordings often rely on fixed angles or fragmented perspectives. Additionally, recordings produced for aesthetic purposes may further obscure subtle motion details due to costume interference or selective framing. These issues result in inconsistencies and omissions in the visual data, reducing the precision of documentation and limiting its value in pedagogical applications, structural analysis, and scholarly interpretation.

Table 3: Characteristics of Streaming Media-Based Recordings of Body Movements

Record Source	Platform	Viedo Type	Performer Attire	Camera Setup	Content Focus
Zhengzhou dramatists Association (Opera Class)	Tik Tok	Short video	Opera costume	Fixed position, medium shot	Continuous movement demonstration
Shanghai Theatre Academy (The Basic Skills of Traditional Chinese Opera)	China University MOOC	Long video	Practice attire	Multi-camera, various shot scales	Online course explanations with full-body view and embedded close-ups of upper limbs
Ministry of Culture and Tourism (Yue Opera Verse)	muliple platforms	Long video	Practice attire	Fixed station, medium shot	Breakdown and continuous demonstration of actions

2.2.2 Exploration of Motion Capture Technology

In recent years, with the rapid development of digital recording technologies such as motion capture, three-dimensional modeling, and interactive visualization, the documentation of

traditional Chinese opera movements has expanded from two-dimensional representation to multidimensional spatial and temporal reconstruction. These technologies enable detailed tracking of performers' limb and joint trajectories, allowing digital models to simulate complex stylized actions with high fidelity. As a result, digital recording has not only preserved the dynamic, rhythmic, and technical characteristics of traditional movement patterns, but also created a new data foundation for systematic analysis and teaching.

Emerging research has applied these methods in various contexts. Studies [2-4]have employed interactive digital media platforms to create immersive experiences, demonstrating the potential of digital technologies to enhance the accessibility and communicative power of traditional Chinese opera, particularly among younger audiences.

Despite this progress, 3D motion capture technology still faces critical challenges in achieving a systematic and scientific framework for body movement documentation and analysis. First, motion capture demands a high degree of precision in data acquisition and integration. Factors such as equipment calibration, the performer's movement quality, and the scientific rigor of post-processing workflows directly affect the fidelity and usability of the resulting data. Second, although 3D visualization enables flexible and interactive display formats, this very flexibility may dilute the centrality of body movement in Kunqu performance, making it harder for viewers to focus on the narrative and expressive core of the performance. Furthermore, existing motion capture-based recording methods often emphasize external stylistic replication while overlooking the internal structure and underlying logic of traditional movement patterns. As a result, the transition from oral-based instruction to a truly scientific, digitally intelligent framework for recording and instructing body movements still requires further integration of multi-disciplinary technologies and theoretical refinement.

2.3 Summary and Reflection

The documentation of Kunqu Opera has evolved from traditional written records to modern digital imagery, reflecting both the diversified needs of heritage transmission and a shift from perceptual inheritance to analytical research. However, the academic community still lacks systematic standards for recording body movements. Many traditional practitioners emphasize oral and physical instruction as the only legitimate method of transmission, often overlooking the value of scientific documentation. This mindset restricts deeper exploration into standardized recording methods.

Although text, video, and digital tools each offer benefits, they primarily focus on the visual restoration of surface-level movements and lack structural analysis and scientific rigor, which limits their applicability in advanced teaching and research (see Table 4). In contrast to the well-developed notation systems for Kunqu music—such as gongche, simplified, and staff notation—body movement documentation remains underdeveloped in terms of rational structure and analytical depth.

From preserving classical movement techniques to designing new choreographies and analyzing performers' unique styles, scientific and standardized recording of body movements is essential. A modern recording system that decomposes and codifies core elements—similar to how music scores function—can provide a unified and accessible framework for teaching, analysis, and innovation. Developing such a system is key to advancing the modernization and sustainable development of Kunqu Opera culture.

Table 4: Comparison of Recording Modalities for Kunqu Opera Body Movements

Dimension	Text	Sketch	Video	3D Motion Capture
Media Type	Static	Static	Dynamic	Dynamic
Transmission Flexibility	High	High	Medium	Low (requires post-processing)
Perspective	First-person	Third-person	Third-person	Third-person
Presentation Effect	Abstract	Intuitive but fragmented	Intuitive and continuous	Intuitive and continuous
Accuracy Factors	Highly subjective[1]	Semi-subjective[2]	Context-sensitive[3]	Setup-sensitive[4]
Replay/Reduction	Needs expert interpretation	Partial visualization	Replayable but fixed-view	Replayable and multi-angle analyzable
Reading/Viewing Mode	Adaptively adjustable (omission, skimming, re-reading) with controllable sensory load		Fragmented reading is informative. The display content is presented linearly	

Notes:
[1] Influenced by observer's understanding, linguistic ability, and notation conventions.
[2] Dependent on structural accuracy, drawing skill, and perspective selection.
[3] Affected by performer state, costume, environment, camera setup.
[4]Limited by capture resolution, spatial range, and rendering method.

3 Application potential and digital exploration of Labanotation

To meet the modern demand for systematic documentation and teaching of Kunqu Opera body movements, this paper introduces Labanotation—a mature system widely adopted in contemporary dance research. As one of the three major systems for recording human movement worldwide, Labanotation provides a scientific method for motion analysis and acts as a bridge for cross-cultural exchange in the performing arts.Unlike traditional text- or video-based methods, Labanotation—like musical notation—uses standardized symbols to represent spatial, temporal, and qualitative features of movement. This structured representation captures the internal logic and dynamics of physical actions, offering a robust foundation for analyzing and digitally preserving Kunqu's movement vocabulary.

3.1 Structure and Scientific Basis of Labanotation

Developed by Rudolf Laban, Labanotation is a core component of his movement theory. It employs a staff and symbolic system to document movement across four dimensions: body, space, time, and effort. This allows for precise descriptions of body part coordination and highlights key technical features of movement, supporting both teaching and academic research with systematic accuracy.

The structure of staff mimics the physiological characteristics of the human body, based on three vertical lines. The center line marks the movement rhythm and symbolizes the spine dividing the right and left of the body, with each column corresponding to a part of the body (as shown in Figure 2), which can be subdivided into 4 to 11 columns to accommodate different movement characteristics. The Labanotation system includes 27 core direction

symbols (as shown in Figure 3), along with supplementary symbols used to describe movement nuances—such as foot contact symbols (see Figure 4) that specify heel or toe support and enhance the depiction of footwork dynamics. Each direction symbol represents a specific element action. The shape, length and position of the symbol indicate the direction path of the action, the movement time and the cooperative relationship between body parts, while modification symbols further refine the expression of the action. By marking symbols in the corresponding column, the movements of various parts of the human body can be accurately recorded. The entire Labanotation system is highly adaptable and operational, allowing for flexible adjustments to the staff structure as well as the type and number of symbols based on the key features of different performance forms, providing powerful tool support for the scientific study of complex body movements. Specific standards are referenced[1].

Another notable feature of Labanotation is its multi-level first-person movement recording/interpretation method: bottom-up vertical reading can grasp the overall spatio-temporal changes of movements; A single section of horizontal reading can analyze the trajectory and cooperation of each part of the body. This combination of macro and micro recording methods, through the integration of symbolic thinking and body movement thinking, establishes a new kind of action-language cognition.

It effectively helps learners coordinate and integrate the functions of different body parts, stimulates their subjective initiative, and avoids the passive imitation often driven solely by intuition. In the field of traditional Chinese folk dance—whose body movement logic shares structural similarities with that of Kunqu opera—Labanotation has been successfully used to document the typical form characteristics of various ethnic dances, such as the Tibetan folk dances and Yi folk dances[5]. These practical examples provide useful references for symbolically representing body movements in Kunqu opera.

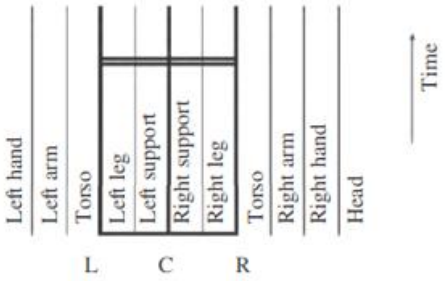


Figure 2: Structure of Staff

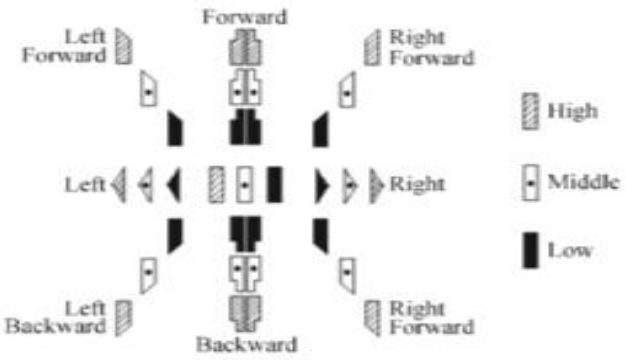


Figure 3: Direction Symbols

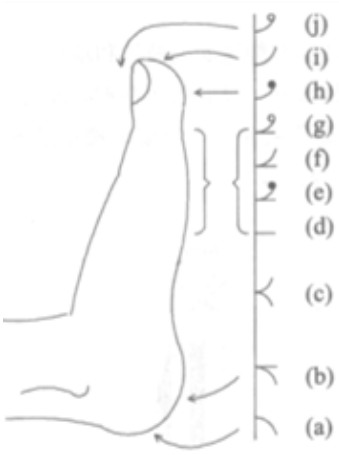


Figure 4: supporting part of the footSymbols

3.2 Exploration of digital Labanotation

With the rapid development of digital technology, Labanotation has not been eliminated, but by virtue of its highly systematic symbol system and scientific representation dimension, it has shown great potential to combine with modern technology. As Feng Shuangbai, secretary of the China Dance Association, said, “In today’s highly developed electronic imaging, Labanotation, as a way of recording dance, no longer has an absolute advantage, but its promotion is carried out to a greater extent as a way of analyzing and thinking about dance art, and the scientific nature contained in this way of analyzing and thinking can not be replaced by electronic imaging technology”. However, the manual drawing process of traditional Labanotation is complicated and inefficient, and the professional requirements of the recorder are high, which becomes the main bottleneck of its widespread popularization. In order to solve this problem, researchers in the fields of computer science, kinematics and dance theory have launched interdisciplinary cooperation to explore the new possibilities of Labanotation through digital technology. This transformation and exploration mainly focus on the following three directions: The first way is to develop software tools to assist the drawing and management of Labanotation. One of the most widely used software is Laban Writer[6], promoted by the International Laban Council for Dynamic Drawing (ICKL). In addition, there are other tools, such as Labanatory[7], Calaban[8] and LED & LINTEL[9], which have greatly improved the convenience and efficiency of recording, making Labanotation more suitable for dissemination in the digital age. However, these tools still require significant time investment from professionals and have limited ability to improve the efficiency and objectivity of Labanotation recording.

The second way is to use labanotation to drive the mannequin to generate animation. For example, tools such as Laban Editor[10]and Laban Dancer[11]are able to transform Labanotation into dynamic 3D human movements. Y. Tongpaeng[12, 13] et al. tried to use XML to digitally transcribe existing Labanotation. Thai dance is preserved, taught and disseminated with the visual aid of 3D animation by converting the data recorded for CMA into accurate machine-readable information. Although these tools play a crucial role in displaying and facilitating the learning of Labanotation, and more effectively support the protection and preservation of intangible cultural heritage, their core value is to provide a visual display of movement for Labanotation, and the recording of Labanotation still relies on manual labor.

With the continuous innovation of sensors and digital interaction technology, the computer-based automatic generation method of Labanotation, with its excellent objective

data processing and analysis capabilities, has built a bridge for the automatic conversion between the performance of human movements and the recording of Labanotation symbols, and has become the third most important way in the digital exploration Labanotation. Hachimura and Nakamura [14] took the lead in proposing a method to generate Labanotation using motion capture data based on Laban spatial analysis. Jiaji Wang et al. [15]further combined 3D human motion capture data, rule matching, deep learning and other methods to improve and improve the accuracy of automatic recognition of Labanotation symbols. Xingquan Cai[16]tried to generate Labanotation symbols directly from video footage. Although these studies are still in the stage of interdisciplinary exploration, they have initially demonstrated the potential of recording and disseminating traditional dance movements in an efficient and standardized way. This technological progress not only provides an important reference for the scientific record of Kunqu opera, but also opens up a new path for the digital protection and modern inheritance of intangible cultural heritage.

4 The Digital Research Method of Kunqu opera Labanotation

Although Labanotation has advanced in digital applications and supports the structured reproduction of diverse dance movements, its adaptation to the stylistically nuanced and role-specific body movements of Kunqu opera remains a significant challenge. The generation of Kunqu opera Labanotation not only needs to continue the technical accumulation of the existing automatic exploration, but also needs to optimize the unique characteristics and aesthetic connotation of the stylized movements of Kunqu opera, and build a scientific recording system in line with the laws of Kunqu opera body. Therefore, this paper combines the characteristics of Kunqu opera, analyzes the shortcomings of the existing generation methods, and puts forward the following core problems:

Firstly, there is insufficient connection between movement acquisition data and the observation of Labanotation. The key to generating Kunqu opera Labanotation lies in the feature analysis of movement data. However, existing methods primarily focus on the accuracy of data acquisition technology during the collection stage, without considering an observational perspective based on the needs of Labanotation. They don't define clear acquisition targets from the perspective of movement feature extraction and classification, nor have they established targeted methods for movement acquisition and analysis. As a result, the deep impact of motion capture data on the methodology and accuracy of Labanotation generation is not fully realized. Although Kunqu opera movements are stylized, the opera encompasses multiple role types and character, and even basic skills of movements can vary in performance due to differences in genre and the individual style of actors. How to integrate the movement differences of different actors in the collection stage and achieve the balance of standardization and individuation when extracting the basic characteristics of routine movements is the key to promote the generation of Kunqu opera Labanotation.

Secondly, existing Labanotation generation methods remain inadequate in adapting to the distinctive body movement features of Kunqu Opera. Most of the existing Labanotation generation methods are based on general algorithms, which have a clear performance when recording simple and clear movement features, but still face the adaptation challenge when characterizing specific performance forms. The uniqueness of Kunqu opera is not only reflected in its highly stylized movements but also in its aesthetic features of *roundness* and *curvature* — smooth, symmetrical actions and seamless transitions. This contrasts sharply with existing algorithms, which typically focus on identifying clear changes in movement by

analyzing turning points, pauses, and other external features. Since the characteristic of roundness is essentially a continuous, dynamic flow without obvious interruptions, it is difficult to accurately capture the core features of Kunqu opera without carefully observing, segmenting, and symbolically interpreting these characteristics. Therefore, it is necessary to design more targeted action feature extraction algorithms and symbolic judgment methods to adapt to the unique dynamic aesthetics of Kunqu opera and show the unique rhythm and cultural connotation of its movements in the round flow.

Finally, the existing Labanotation generation methods are limited by the number of Laban symbols available. Current studies primarily use 27 core basic Labanotation direction symbols to construct generation methods. While these symbols cover most of the basic movements, they fall short in representing subtle differences in movement details. This limitation restricts the ability of the notation to convey the intricacies and artistic depth of the movements, and the subtle variations in movement still require additional specific movement symbols for more accurate representation. Therefore, a key challenge remains: how to expand the number of symbols used in Labanotation generation in a way that balances the readability of the notation with its artistic quality, without increasing the cognitive load for readers.

To address these challenges, this paper starts with the core basic techniques of Kunqu opera body movements and proposes a standardized multimodal framework for movement feature acquisition and processing. The discussion is structured around the following three aspects:

(1) Study on the Alignment Between Labanotation Symbol System and Kunqu opera Body Movements. From the perspective of Laban Movement Analysis (LMA), we collaborated with experienced CMAs and Kunqu opera performance instructors to establish a standardized framework for collecting and processing Kunqu opera body movements characteristics. Additionally, with the technical support of the Motion Capture Laboratory at Dalian University, a set of standardized data acquisition protocols and procedures was designed to achieve comprehensive multimodal acquisition of Kunqu opera body features, incorporating key modified symbols and multi-sensor motion capture technologies.

(2) Research on the Generation Method of Kunqu opera Labanotation. Based on the collected body feature data of Kunqu opera, this paper explores and develops methods for segmenting and extracting elemental movements in Kunqu opera performances. It optimizes the mapping relationship between the Labanotation symbol system and the characteristic movements of Kunqu opera programs, improving the accuracy of Labanotation symbols in representing complex movement features.

(3) Application of Digital Kunqu opera Labanotation and Development of Interactive Software.By integrating scientific Labanotation with the demonstration of three-dimensional virtual characters, this research develops a visual interactive learning system for Kunqu opera Labanotation. Through rational analysis of cooperative symbols and dynamic visual perception, the system enhances the popularity of Kunqu opera Labanotation and its practical application in teaching and communication.

5 Design and Implementation of Digital Kunqu opera Labanotation

5.1 Digital Collection and Analysis of Kunqu opera Body Movements Characteristics

The basic skills of body movements is the core of Kunqu opera performance, and its characteristic analysis and standardized collection directly determine the accuracy and

adaptability of Labanotation generation. These basic body skills are characterized by relatively standardized postures, forming the normative foundation for performance training among both male and female Kunqu actors.This consistency aligns well with the core symbolic nature of Labanotation, which focuses on essential movement features, and enhances its generalizability in both performer selection and pedagogical applications. Combined with the theoretical method of Laban Movement Analysis, this paper extracts the movement characteristics from the three dimensions of spatial structure, rhythm relationship and detail expression, and plans the corresponding digital collection methods and technical implementation.

5.1.1 Spatial Structure Feature

The spatial structure of the movement is the foundation of Kunqu opera body performance. The stylized performance of Kunqu opera requires that each movement strictly follow the norms in terms of path, posture and power. In order to capture the normative characteristics of movements in spatial dimension, this paper made reference to professional materials such as Kunqu opera Performance [6], and combined with actual performance experience, carried out a detailed decomposition of the representative body movements of the Sheng Role (male role) and the Dan Role (female role), and extracted key spatial characteristics. For example, the *Yunshou* movement is detailed in eight core steps, such as standing, raising hands, drawing circles, and stretching, and the spatial starting point and end point of each step are defined.

A uniform posture is adopted as the standard starting point for all body segment data collection: the actor stands in a Ziwu bu, with the left foot forward, the right foot back, and the arms hanging naturally. The movement specifications for each step are jointly confirmed by Kunqu opera professionals and participating actors, ensuring that the performance meets artistic standards in terms of precise step counts, accurate measurements, and standardized positioning. The collection norm established on the basis of consensus helps to unify the spatial performance differences among different actors, improve the consistency and accuracy of movement collection, and provide a solid foundation for the mapping of subsequent Labanotation symbols.

5.1.2 Rhythm Relation Feature

Movement rhythm endows Kunqu opera’s bodily performance with vitality and serves as a core expression of its dynamic aesthetics. Unlike stage performances, where rhythm is guided by musical melodies, the basic skills of bodily movements in Kunqu opera are typically practiced without musical accompaniment, placing greater emphasis on movement coordination—specifically, technical training for such coordination. The movements should be in harmony with each other, unified into a single "Jintou" (referring to variations in force, speed, and intensity in performance), which facilitates the organic, sequential movement of different body parts and forms a coherent action sequence. This coordination enhances bodily awareness and control, resulting in a harmonious, smooth, and rounded visual beauty.

In order to show this coordination of the body through recording rhythm, this paper adopts uniform rhythm and speed as the time reference to provide a stable rhythm framework for the orderly series of decomposition movements. The constant tempo allows the actor to focus more on the flow of the movement and avoid the influence of personal rhythm deviation on the continuity of the movement. Relevant studies have shown that the repetition of the same sequence of movements at a constant tempo is conducive to the learning and perception of movements[17]. Under this framework, this paper sets different Beats Per Minute (BPM) according to the characteristics of different bodies: for example, *Slow Steps of the Guimendan Role* uses 50 BPM to show poise, and *Steps of the Huadan Role* uses 60 BPM to show agility.

With the metronome providing a standardized reference, actors can more clearly show the dynamics and textures of different bodies. It also provides a clear time scale for the rhythm division of Kunqu opera Labanotation, enhancing the operability and guidance of the generated Labanotation in teaching.

By integrating the analysis of the core features of the basic skills of Kunqu opera in the two dimensions of *structure* and *rhythm*, this paper has developed a digital collection scheme. Table 5 shows the decomposition steps of some typical body movements and their corresponding rhythm characteristics. This norm not only reduces the impact of individual differences of actors, but also better meets the requirements of normativity and repeatability of Kunqu opera Labanotation generation.

Table 5: Decomposition Step Data and Rhythm Matching Scale of Typical Basic Skills

	Basic Skills (Part)	Structure: Number of decomposition steps	Number of beats(BPM)
Male	Slow Steps of the Jingsheng Role (Footwork)	4	50
	Shanbang (body postures and movementst)	6	55
	Yunshou (Hand Movement)	8	50
Female	Slow Steps of the Guimendan Role(Footwork)	4	50
	Squatting and Turning Over (body postures and movements)	6	60
	Following-the-Wind Flag Posture (Hand Movement)	5	50

5.1.3 Focus on Detail

Kunqu opera body movements performance training is often called *TaXi*, in which *Ta* is the movement of footwork, reflecting the core role of feet in body training. Foot movements not only directly affect the movement of the body's center of gravity, but also maintain the balance and coordination of the body by guiding the center of gravity transfer. On the contrary, the change of the center of gravity promotes the adjustment of the pace, so as to achieve the fluency and stability of the movement, and reflects the style characteristics of different role types. Even in a standing position, differences in posture—whether standing on two feet, one foot, or shifting weight between feet—can reveal unique limb dynamics through changes in gravity distribution and muscle tension. For this reason, in the Kunqu opera tradition, "footwork" is almost synonymous with an actor's comprehensive skill, encompassing body movement, performance expression, and stylized forms.

To capture these subtleties, this study supplements Labanotation's basic spatial symbols with two additional notations based on CMA recommendations: the Support (Place) Symbol 𝅘𝅥(a small solid dot with a vertical stem) indicates the stationary support position and gait direction; the Foot Contact Symbols (see Figure 4) represent toe and heel contact with the ground, reflecting changes in support and gravity distribution. This paper primarily uses the Heel and Toe symbols. These notations help reveal fine-grained aspects of footwork often obscured in video recordings due to costume occlusion or camera limitations.

5.1.4 Technology Matching of Feature Acquisition

In order to fully capture the space, rhythm and footwork characteristics of Kunqu opera, the 3D Vicon Motion Capture system (Mocap) and the Flexiforce flexible pressure sensor are used in this paper. The combination of the two techniques forms a multi-modal data set through synchronous acquisition, which provides a solid data foundation for the digital

Labanotation recording of Kunqu opera.

The 3D Vicon mocap is used to record the three-dimensional movement path and pose changes in the performance, especially the center of gravity and step direction indicated by the Support (Place) Symbol. The system uses 12 5-megapixel infrared cameras to capture actors' fine movements at a high sampling rate of 100 frames per second, and outputs the data to TRC and C3D formats via Vicon Nexus 2.10 software. The TRC format records the three-dimensional coordinates of markers (X, Y, Z), which serves as the basis for Labanotation symbol mapping. Compared with the traditional BVH format (based on Euler angles), it significantly reduces the complexity of data processing. The C3D format improves the precision and detail performance of action animation. Combined with the actual demand of Kunqu opera performance, through the experimental test, 36 light-emitting marks were finally configured on the motion capture suit to ensure the integrity and accuracy of the motion capture.

The flexible pressure sensor focuses on capturing the shift of the center of gravity of the foot and ground contact details by detecting the force point of the foot, as well as the support position and its influence on the center of gravity movement. It also supports the change of the center of gravity of the support foot and the description of the supporting part of the footSymbols for judging and describing the change of the support position. This method can avoid issues such as foot data drift or foot occlusion caused by squatting movements during the data capture process of 3D motion capture, thereby improving the accuracy of determining the changes in the supporting foot’s center of gravity. Considering that the Kunqu opera movement rarely involves ballet-like toe support, the sensor is placed on the sole and heel of the actor’s foot. The sensor performs data recording at 20hz, and the data is stored in CSV format.

5.2 Methods for Generating Kunqu opera Labanotation

Based on the four column standard records of Labanotation (support, leg, body, arm), this paper constructs a systematic Labanotation generation process according to the characteristic requirements of Kunqu opera body routine movements (as shown in Figure 5).

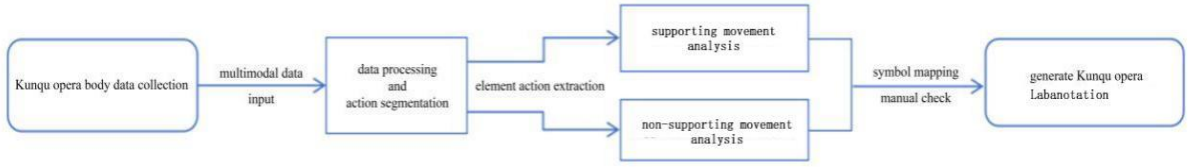


Figure 5: The Kunqu opera Labanotation generation flow chart of our method

5.2.1 Data Processing and Motion Segmentation

Based on the analysis of the structure and rhythm characteristics of Kunqu opera body movements, this paper normalized the collected data, extracted key movements and their time and space information, segmented and analyzed according to the needs of the generation of labanotation symbols, and decomposed the complex Kunqu opera stylized body movements into symbolic basic movement elements.

(1)Data processing: Kalman filter is used to process the collected pressure sensor data, adjust the threshold value according to the physiological characteristics of different actors, and convert the analog data of the footwork into the switching quantity (contact =1, no contact =0). Considering that the duration of a single element’s action is usually not less than 0.1 seconds, in order to improve computational efficiency, the 3D motion data is

downsampled to 20 frames, and it is aligned with the pressure sensing data to ensure data synchronization and timing consistency.

(2)Action paragraph segmentation and rhythm alignment: According to the rhythm scale set by different body movements, the continuous movement data is segmented into action paragraphs consistent with the segmentation time of Labanotation. Through the comparison of three-dimensional space coordinates and beat characteristics, the paragraph division of movements is completed to ensure that the data after segmentation can meet the rhythm requirements of the Labanotation, and support the refinement of subsequent movement elements.

(3)Segmentation of body movements: According to the Labanotation standards for recording uniform movements and smooth trajectories (as shown in Figure 6), the three key postures (beginning, middle, and end) of each movement segment are extracted by calculating equal time intervals. Each movement per beat is subdivided into two elemental movements, and the corresponding spatial symbols are mapped to two small sections of the Labanotation staff. Considering the variation in limb lengths among performers of different heights, this study adopts an angular velocity–based segmentation method derived from empirical data in [15]. Specifically, if the angular velocity of a body part remains below 0.18 rad/s for five consecutive frames within a subsection, the movement is identified as entering a standstill state. If no significant displacement of the body posture occurs after this pause, the system discards the corresponding symbolic notations for that motion segment. This procedure not only complies with the standards of Labanotation but also enhances the simplicity and clarity of the symbolic recording process.

Figure 6: Circle Track Symbol Record in Labanotation

(4) Center of gravity action segmentation: Taking the rigid center of the pelvis as the benchmark of center of gravity movement, combined with the Laban direction specification, the gentle change of center of gravity is segmented and symbolized. The difference between adjacent frames is used to calculate the motion vector and quantify the direction of the center of gravity. The direction judgment is made between every two frames, the center of gravity action is divided into the element action in a single beat according to the change of the Laban direction, and the start and end point of the change of direction are clearly recorded in the symbol.

5.2.2 Recognition and Mapping of Labanotation Symbols

Based on the distinct characteristics of movement recording for non-supporting movements (limb movements such as leg postures and arm movements) and supporting movements (such as the center of gravity), this paper employs corresponding analysis methods to identify and

map the Labanotation symbols for Kunqu opera body movements. The coordinate system for generating Labanotation is established with the front of the performer's body as the reference point. By quantifying the body posture and center of gravity movement characteristics, the Labanotation symbols are systematically generated.

(1)Non-Supporting Column Movement Analysis

Non-supporting movement is the core of the performance of Kunqu opera. The Labanotation clarifies the spatial relationship between the root joint (attachment point) and the free end (end) of the limb (as shown in Figure 7). Based on the final pose of each section of the limb after segmentation, the pose vector of the action was calculated by the coordinate difference between the end and root joints in the pose, and its changes in the horizontal and vertical directions were quantified, and the action was mapped to 27 basic direction symbols (as shown in Figure 3).

In the horizontal directions, by calculating the Angle between the projection of the pose vector on the X-Z plane and the positive direction of the Z axis, the body movements are mapped to the subspaces of the Labanotation corresponding spatial partition (as shown in Figure 8). Where, the in-situ action is determined according to the Angle between the vector and the coordinate axis Y-axis, and the threshold is [0,π]. If the human body remains in place, just judge the change in the vertical direction; In the vertical directions, by calculating the Angle between the pose vector and the positive direction of the Y axis, the body movements are divided into three levels: high, middle and low in the Laban direction (as shown in Figure 8). For example, if the horizontal Angle of the left arm is 20° and the vertical Angle is 160°, the *forward low* symbol▙ is recorded in the left arm bar of the Labanotation. In order to avoid symbolic redundancy, only the movement of elements that change direction is recorded for body movements. If the symbols are consistent between sections, they are merged by adjusting the symbol length.

Finally, the three-dimensional coordinates of skeletal model joints are used as the input features for each motion recognition method. In addition, the *joint normalization vectors* proposed in[15] are incorporated to enhance the accuracy and robustness of the generated Labanotation symbols.

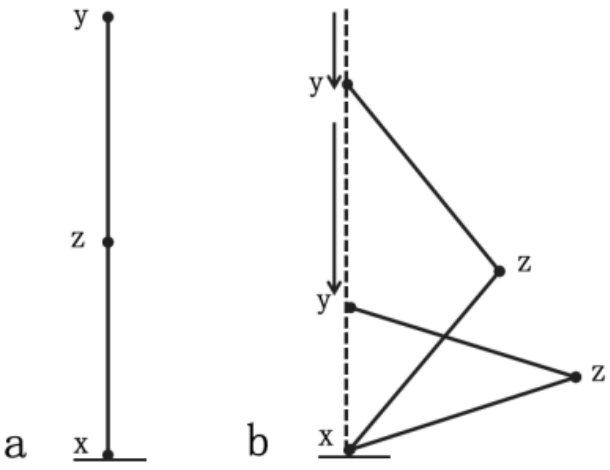


Figure 7: Analysis Method of Limb Movements

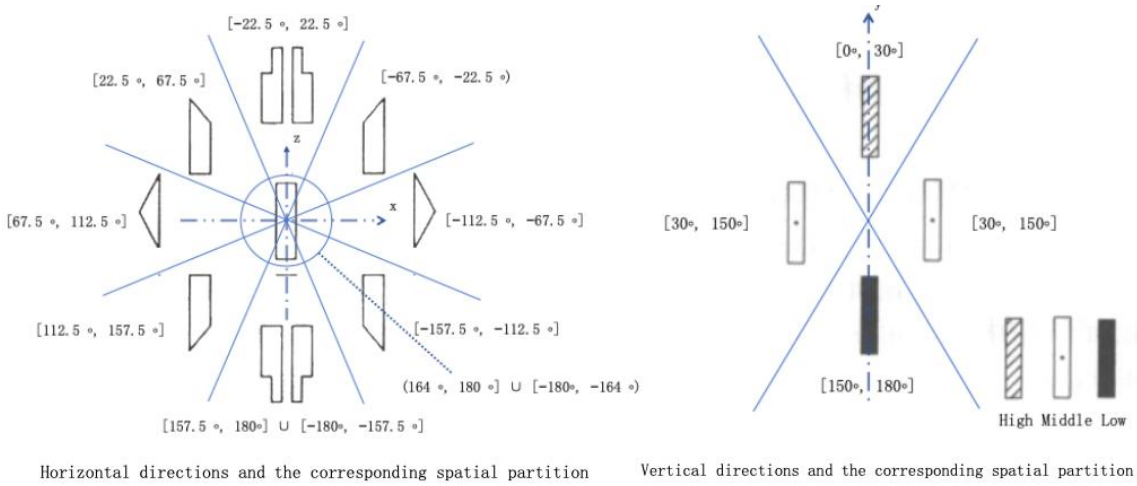


Figure 8: Laban Direction Symbols and the Corresponding Spatial Partition

(2) Supporting Column Movement Analysis

The symbol description of the supporting column action involves the direction of the center of gravity movement, the support state, and the change of the center of gravity caused by the support movement, and needs to be marked according to the specific support position.

In the analysis of Laban direction symbols, the processing method of the horizontal direction is the same as that of the body movement.The vertical direction is divided into three states based on changes in the center of gravity height: low (squatting), middle (standing), and high (tiptoe). For instance, when the difference between the vertical height during the movement and the initial height falls within the range of [-3, 5] cm, it is classified as the middle state; when the difference is lower than -3 cm, it is classified as the low state; and when the difference is higher than 5 cm, it is classified as the high state.

Based on the characteristics of foot support in Kunqu opera basic skills, this paper divides the description of the center of gravity in the supporting column into three types: Bounce (no support), Support-Type Movemen(support movement), and Center of Gravity Control (center of gravity unchanged), and classifies and labels the support state by combining foot pressure sensing data (1 or 0).

① Bounce: Defined as a temporary suspension of both feet in the air (e.g., a leap or jump). This can be detected via pressure sensors when both feet register zero, indicating no ground contact. Although the body appears elevated, Labanotation does not explicitly mark vertical displacement during flight. Instead, the airborne phase is represented as a notation gap on the staff, symbolizing the absence of support.

The notation for such actions includes:

(1) The initial in-place preparation (e.g., standing → squatting);

(2) A blank section representing the airborne trajectory;

(3) The landing phase, where horizontal direction (e.g., forward) and post-landing vertical attitude (e.g., middle) are recorded.

Sensor data prior to takeoff is used to annotate the support source—1/1 indicating double-foot support, 1/0 single-foot.

②Support-Type Movement: Transitions are divided into in-situ support and non-in-situ support, based on whether the body's center of gravity (CoG) shifts horizontally.

(1) In-situ support keeps the center of gravity (CoG) vertically aligned. It is recognized via pressure data: bilateral support (1/1) or unilateral (1/0). A particularly valuable case is the virtual step, where one leg bears the full weight and the other merely touches the ground without load-bearing. This condition is difficult to identify through 3D motion capture alone,

as spatial data does not reflect support status. If the touching foot shows 0 on both heel and toe sensors, it confirms non-support. This distinction enables precise analysis of subtle movement qualities, especially in traditional stylized performances that rely on intricate weight distribution.

(2)Non-in-situ support involves horizontal CoG shift. One leg initiates motion while the opposite foot lifts progressively from heel to toe. At the moment the supporting leg reads 0, and the opposite foot shows heel=0 and toe=1, the CoG direction aligns with the final posture of the power leg, confirming it as the active support limb.

③ Center of Gravity Control: In Labanotation, when no movement or jump symbol is recorded in the support column, a place-in-position symbol ○ (small circle) must be used. This indicates that the foot remains stationary while bearing weight, ensuring the center of gravity remains grounded. Including this symbol avoids ambiguity in movement segmentation and preserves notational completeness.

(3) Manual Correction of Labanotation

In order to further improve the representation accuracy of Kunqu opera Labanotation, this paper adds manual correction link on the basis of digital generation. The CMAs awere invited to review and revise the Kunqu opera Labanotation generated through the proposed method, ensuring that each notation accurately conveys the performance characteristics specific to Kunqu opera. The manual correction not only improves the representation accuracy of Labanotation, but also establishes the standard for the digital Kunqu opera Labanotation. This process has accumulated experience and standardized data of movement calibration, provided a key reference for the optimization of automatic Labanotation symbol generation method, and promoted the accuracy and practicality of Kunqu opera Labanotation in the application process, laying a solid foundation for subsequent teaching, dissemination and research.

3. Verification and Analysis of Kunqu opera Labanotation

To evaluate the effectiveness of Kunqu Opera Labanotation in accurately representing the foundational characteristics of body movement, the classical sequence Slow Steps from the Guimendan Role was selected for analysis. A detailed symbolic transcription was conducted (as shown in Table 6), and its features were compared with descriptions from the Dictionary of the Stagecraft of Traditional Chinese Drama (see Table 7). The results show that, aside from minor differences in the initial stance, the Labanotation offers a precise and systematic representation of the movement. Furthermore, its standardized symbolic language reduces ambiguity, making it particularly advantageous for international dissemination and academic communication.

Table 6: Analysis of Labanotation of Guimendan role walking

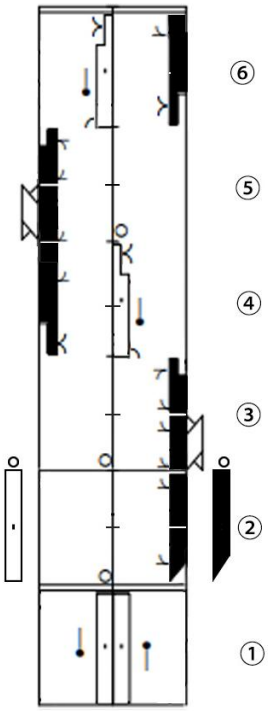
Labanotation	Analysis of formula
	①Initial posture: The gait starts with the classical Ziwu bu, where the center of gravity is evenly distributed. An in-situ support is shown with place support symbols in both supporting columns, and the solid dot direction of supporting column indicates that the feet are in the state of the left foot in forward and the right foot in back. The legs are in position and naturally twist due to the difference in foot position. ②Dan' posture: Keep the center of gravity of the left foot in place, release the support of the right foot and lift, and move the right leg to the left in a low direction to close the support leg. Left arm in position, right arm down left. ③ Kicking Step: With the left foot maintaining support, the right leg lowers to its previous position before extending forward in a low direction, forming a stylized forward kick initiated from the support base. ④stepping down:The right foot transitions into support by landing gradually from heel to full foot. The center of gravity shifts to a forward-mid position, maintaining a linear trajectory with short and stable step amplitude. The right leg rotates outward to the right-forward direction, with foot alignment consistent with the leg orientation. Simultaneously, the left leg performs a light dragging motion toward the rear-left of the body, following the grounding of the right foot. ⑤Repeat start and kick: The right foot takes over as the supporting limb while the left leg repeats the starting kick motion in a mirrored direction. ⑥Repeat: The left foot lands and supports from heel to full foot, and the right foot repeats the start and kick step.

Table 7: Slow Steps of the Guimendan Role

Figure chart	Program parsing
	①Begin in the Right Tabu(foot step) stance. Both water sleeves hang from the wrists. The left arm bends with the hand placed near the right chest; the right hand rests slightly forward of the right waist. The chest is slightly concave, head upright, eyes looking straight ahead. ②Lift the right foot, flexing the ankle with the instep forward. Just before landing, slightly turn the toe outward to form a "八"-shaped angle, stepping forward with control. ③Place the heel down first, then press the full foot flat to the ground, achieving stable support. ④Step forward with the left foot in the same manner. Continue this slow, alternating gait until reaching the designated stage position as required by the scene.

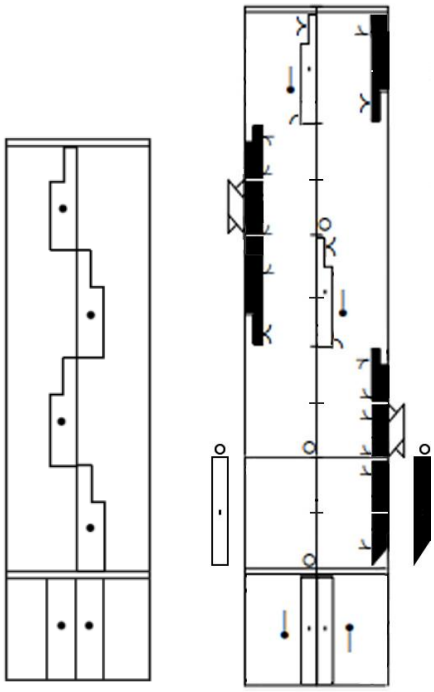


Figure 9: Normal forward gait [18] and the Guimendan role slow walk in clinical analysis of human gait

In order to further explore the application value of Labanotation in Kunqu opera research, this paper compared the normal forward gait in clinical analysis of gait, that is, the natural gait and the highly stylized *Slow Steps of the Guimendan Role*, and analyzed the similarities and differences between the two in attitude control and center of gravity transfer through symbolic features (as shown in Figure 9). To reveal how Kunqu opera body movements through the refinement of life action and artistic treatment to shape the role image. Labanotation describes the step of daily walking as the process of "completely shifting the weight of the body from one foot to the other"[18], and the main function of the foot alternations is to achieve the forward shift of the weight. On this basis, Slow Steps of the Guimendan Role shows the unique artistic characteristics of female limbs and gaits through fine movement design. Through the alternations of the supporting foot and the postural foot and the ground motions, the slow and delicate characteristics of the pace of ancient women are amplified. The alternating movement between the supporting and posture legs, along with the grounded steps, accentuates the slow and delicate characteristics of ancient women's footwork. The leg movements follow an outward and forward arc, accompanied by the natural twisting of the body. This not only maintains the stability of the overall center of gravity while moving in a straight line but also fully showcases the smooth, rounded beauty of the body, conveying the dignified, subtle, and charming essence of the Guimendan Role (i.e. the miss boudoir). By translating this traditional physical knowledge into Labanotation for structural analysis and comparative study, this paper validates the effectiveness of digitally generated Labanotation in capturing procedural movement features, and introduces a comprehensive body-space-image framework for analyzing Kunqu opera movement aesthetics.

6 Development of visual interaction system

Although generated Kunqu opera Labanotation for basic skills allows for precise and structured analysis of body movements, its highly abstract symbolic system often poses difficulties for beginners in associating symbols with physical performance, thereby limiting its broader application in instructional settings.

To improve accessibility and instructional effectiveness, this study develops an interactive visual learning system based on Unity3D, utilizing the same multimodal actor data sources. Recent studies have demonstrated that virtual characters can significantly enhance learner engagement, improve the understanding of complex movement patterns, and increase perceived presence in digital learning environments [19, 20]. As a practical implementation of the proposed digital intelligence framework, the system integrates symbolic representation with the characteristics and advantages of 3D virtual character visualization (see Table 8), establishing a multi-modal instructional environment that effectively bridges analytical

Table 8: Comparison Between Labanotation and 3D Virtual Character Visualization in Kunqu Opera Training

	Labanotation	3D Virtual Character Visualization
perspective	First-person	Third-person
Core of Representation	Essential movement characteristics	Outward physical appearance
Performance Characteristics	Representation of symbols	Simulated Realistic Image
Cognitive Mode	Rational, analytical thinking	Visual-intuitive, image-based thinking
Information Processing Method	Active interpretation (logical analysis)	Intuitive learning (immersion awareness)

6.1 System Objectives and Core Functions

Focusing on the teaching and communication needs of Kunqu opera Labanotation, this system aims to achieve the following three goals through the precise characterization of core features of movements by Labanotation symbols, combined with dynamic demonstration and interactive functions:

(1) Enhancing learning accuracy and efficiency. concurrently presenting dynamic movements and symbolic notations, learners can perceive action features from multiple dimensions and establish the correlation between symbols and actual movements. Interactive visualization lowers the learning barrier and compensates for the inadequacy of basic Laban symbols in depicting complex motions such as rotations and oscillations, effectively alleviating the cognitive load resulting from over-extending specific movement symbols.

(2) Facilitating Movement Perception and Analysis. The system provides two learning modes. one can sense the coherent manifestation of movements and understand how Labanotation portrays the structure and rhythm of movements. In the analysis mode, by sliding through the Labanotation frame by frame, one can compare and observe the spatio-temporal correspondence between the virtual character's dynamic actions and the symbolic records, thereby deeply analyzing the dynamic performance and logical implications of the character.

(3)Strengthening Inheritance and Dissemination. Through a scientific and intuitive learning experience, the gap between Kunqu Opera and contemporary users is bridged,

integrating Kunqu Opera performances into the digital communication ecosystem. The system not only extends the teaching and application scenarios of Kunqu Opera's stylized movements but also furnishes an innovative interactive platform to draw the attention of the younger generation to Kunqu Opera culture, thereby propelling the inheritance and development of Kunqu Opera in the new era.

6.2 The Design of Virtual Characters

This paper presents the dynamic changes in the internal and external structure of Kunqu opera in multiple dimensions, and highlights the application value of the system in the teaching and communication of visual assisted Labanotation. This paper designs and realizes two types of virtual characters - the skeleton character and the simulated digital human character. The design combines the aesthetic characteristics of Kunqu opera with the digital expression form, and lays a foundation for the subsequent animation production in the 3D character animation software MotionBuilder 2022.

(1)Skeleton Characters Design

The skeleton characters are mainly simplified appearance, aiming to highlight the movement structure and logical relationship. This paper uses Adobe Mixamo’s default Bot model (Xbot and Ybot, representing female and male, respectively). Each character is colored with #f2f2e8 and #ebede8, indicating the skeleton and joint areas respectively. The design reduces visual interference by eliminating redundancy, so that learners can focus on the movement characteristics of Kunqu opera body movements and the corresponding relationship with Labanotation symbols.

(2)Simulation Digital Human characters Design

Recent costume research shows that integrating traditional opera patterns and color schemes into modern design significantly enhances visual engagement and cultural resonance in digital and fashion contexts[21, 22]. Thus, the simulative digital characters restore the traditional aesthetic style of Kunqu opera performance through high-fidelity modeling and vivid visual presentation. The overall color scheme draws inspiration from blue-and-green landscape painting, blending with iconic costume elements from Kunqu opera. Using detailed embroidery effects—such as colorful threads and gold-hook patterns—the characters visually embody both elegance and delicacy, enhancing their aesthetic appeal on digital platforms.

The male digital human model is based on the XiaoSheng Role as the prototype, designed with a youthful image featuring a burly build, broad shoulders, and a narrow waist. The cuff is integrated into the sleeve design, with shoulder and back adorned in a shoulder-style overlay; the decorations throughout feature "hui" patterns and ball cloud motifs. The hem and cuffs are designed with layered "mountain-water-cloud" patterns in a seascape style, emphasizing a sense of depth. The color of the inner lining is unified with the outer robe, and the white stand collar simulates the effect of Kunqu opera water sleeves.

The female digital human model portrays the XiaoDan Role, highlighting soft and elegant characteristics. The dress integrates the traditional cloud shoulder with a modern off-the-shoulder style, emphasizing the expressiveness of shoulder movements. The outer garment is crafted from polarized crepe satin, decorated with blue-to-white gradient broken-branch patterns to simulate the visual effect of Kunqu opera water sleeves. The lower garment is a modified long skirt, with twist-pattern trims along the hem—both fitting modern aesthetics and facilitating movement demonstration.

(3)Dynamic Adjustment of the Virtual Character Model

1) Skeletal Structure and Skinning Optimization

The character skeleton is built in accordance with MotionBuilder’s bipedal standards to ensure compatibility with motion capture retargeting. Given the large amplitude and

complexity of Kunqu Opera body movements, weight painting and skinning were carefully adjusted. Frame-by-frame corrections were applied to eliminate distortions and misalignments between the model and skeleton. Rigorous testing of high-difficulty actions was conducted to ensure smoothness, anatomical coherence, and accurate response to motion input.

2) Clothing Pattern Design and Fabric Simulation

Clothing patterns were created in Marvelous Designer, with texture mapping refined in Photoshop. To simulate realistic dynamic behavior of traditional Kunqu garments (e.g., sleeves, skirts), the fabric's physical parameters—such as tensile strength and bending stiffness—were tuned using the Marvelous simulation engine. Particular attention was given to enhancing the natural flow and drape of garments under large-scale opera movements, ensuring both aesthetic fidelity and physical realism.

(4)Advantages and Purposes of Multi-character

The purpose of multi-character design is to help users understand the correlation between movement features and Labanotation recording from different levels through the role switching function. Skeleton characters focus on the structural features of the action, providing clear symbols and action reference; Simulative digital human characters restore the performance situation through realistic performance, enhance the expressive force and artistic beauty of the action, and attract young users' interest in learning Kunqu opera body movements.

With the support of animation, users can freely switch roles, compare the performance differences between the same body movement and the skeleton and the digital person, and further understand the diversity of Labanotation details and movement features. Meanwhile, the cross-gender role-switching function offers users a unique cross-gender performance experience in Chinese opera — presenting male actions through female characters or the other way around, enabling them to perceive the stability of the stylized body movements of Kunqu Opera within different role types. With high-quality animation and smooth switching mechanism, it strengthens users' comprehensive understanding of the core features of Labanotation, while satisfying diversified learning needs.

6.3 Motion Capture Data Optimization and Character Animation Production

To ensure the fidelity and fluidity of virtual character performance, this study utilizes C3D-format motion capture data, which is imported into MotionBuilder 2022 for processing. In the initial stage, the BaseAnimation layer is employed to smooth motion curves, remove noise and artifacts, and correct anomalies in the movement trajectories, enhancing coherence and skeletal adaptability.

During retargeting, skeletal mapping techniques are used to align motion data with the virtual model, correcting positional offsets and ensuring natural joint articulation. Frame-by-frame adjustments are applied to eliminate mesh penetration, jitter, and deformation issues, thereby ensuring visual consistency and anatomical accuracy.

The finalized animation is exported in FBX format and integrated into the system to support real-time demonstration and interactive teaching. Through this process (as shown in Figure 10), the system successfully realized the accurate reproduction of Kun opera movement rhythm and details (as shown in Figure 11 and Figure 12). Prefabricated high-quality animation not only improves the application effect of three-dimensional dynamic representation technology, but also simplifies the management and standardized application of action data, which better meets the needs of Kun opera teaching and digital communication.

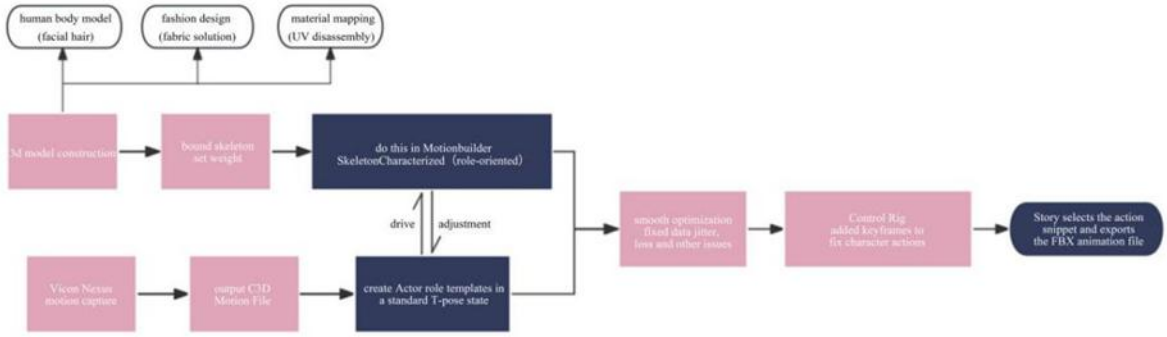


Figure 10: The Process of Forming an Animation File with Motion Capture Data

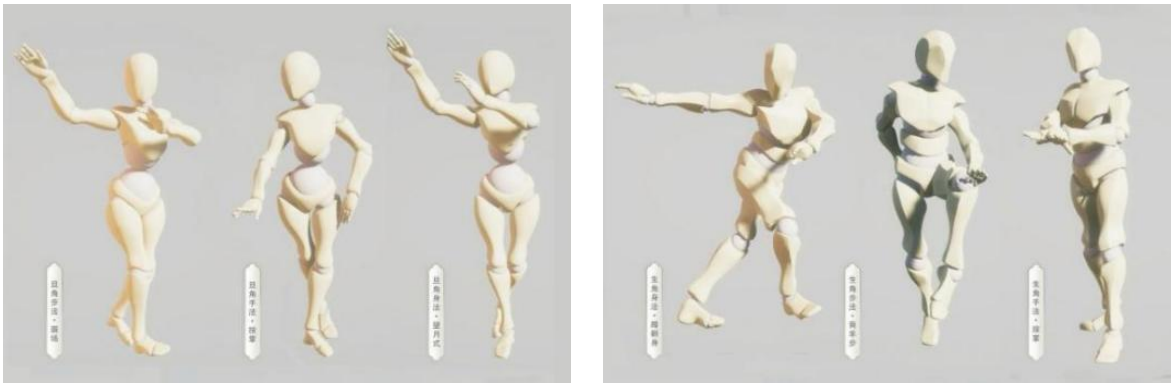


Figure 11: Posture of Skeleton Characters

Figure 12: Posture of Simulation Digital Human Characters

6.4 Comprehensive Design of Interactive Applications

(1)Platform Development

The interactive platform is developed based on the Unity3D engine, leveraging its flexibility in rendering, hardware compatibility, and interactive design. Virtual character models, animations, and materials are imported and optimized for real-time rendering, ensuring smooth visual performance across medium- and low-spec devices.

To achieve precise synchronization between the animation and Labanotation display, the system utilizes Unity's Timeline and Playable Director components. Through scripting control, the Labanotation scroll is tightly aligned with animation playback, supporting real-time speed adjustment and pause for frame-by-frame analysis, thereby facilitating intuitive understanding of the symbolic-motion relationship.

In addition, the system architecture reserves scalability for mobile and AR/VR devices, offering cross-platform compatibility and laying the technical foundation for diversified applications in Kunqu Opera teaching and digital dissemination.

(2)Interface Design and Function Layout

The system's UI design draws inspiration from the aesthetic elements of Kunqu Opera—such as dressing boxes, headdresses, and traditional motifs (see Figure 13). The interface adopts a clean and intuitive layout, divided into three functional sections: left, center, and right (see Figure 14).

The left panel organizes movement segments based on the standard sequence of Kunqu performance techniques—technique, posture, footwork, and their combinations. A hierarchical menu (Body Movement → Role Type → Specific Action) enables users to efficiently locate desired segments. A drop-down bar at the top further assists in navigation.

The center panel serves as the playback area for virtual character animations, offering controls for play, pause, and speed adjustment. Users can rotate the model 360° and zoom in/out to observe movement details from multiple angles, enhancing immersion and spatial understanding.

The right panel presents the corresponding Labanotation, with synchronized playback and frame-by-frame sliding. This allows users to compare movement sequences and symbolic representations in real time. Role-switching options at the bottom-right enable users to explore interpretive differences across character types.

By integrating the traditional aesthetics of Kunqu Opera with modern interactive design, the system has built a digital platform that supports intuitive learning, rational comparison, analysis, and multi-perspective exploration of Kunqu Opera body movements.

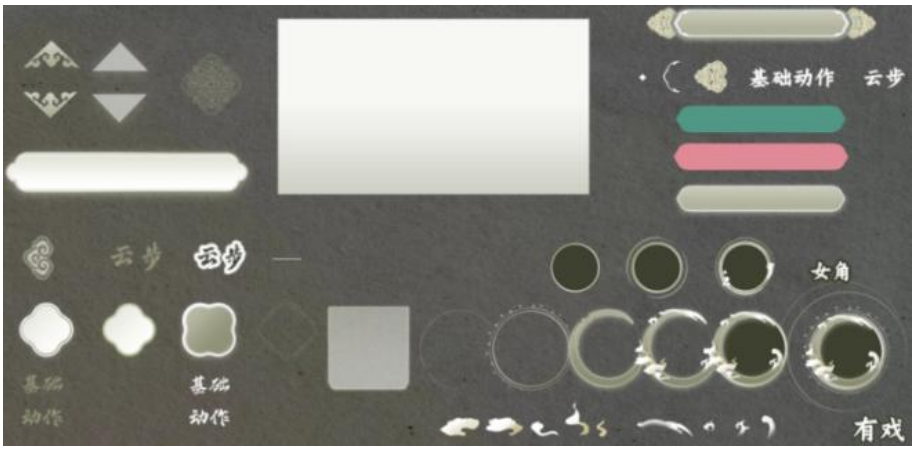


Figure 13: Interface UI Components (part)

Figure 14: Software Interface

6.5 Evaluation of Applications

To evaluate the practical effectiveness of the system in Kunqu Opera instruction, a teaching test was conducted with 15 undergraduate students from Beijing Technology and Business University, including one non-Chinese participant. The participants, aged between 18 and 21, all had some background in modern dance but were relatively unfamiliar with Kunqu performance and Labanotation.

The test results show that the students can basically restore the core points of the four body movements, and most students can clearly describe the characteristics of the movements and their internal logical relations. Students generally gave positive feedback, believing that the interactive design and visual presentation of the system significantly enhanced their understanding of Labanotation symbols, helped them more intuitively perceive the external performance and internal fluidity of movements, and significantly improved the learning efficiency. Especially when studying role-specific movements, such as Yunshou , students gained a deeper understanding of the subtle differences in limb shapes and textures between the Sheng and Dan roles through the dynamic demonstrations of virtual characters. This process also enhanced their awareness of how Labanotation's symbolic instructions generate movements that are fundamentally the same in essence, yet differ in form and expressiveness.

In general, the test results verify the effectiveness and potential of this system in Kunqu opera teaching. Students have systematically enhanced their ability to master the movement characteristics of Kunqu opera and deepened their understanding of Kunqu opera Labanotation. At the same time, in the post-study survey, most students suggested that the system should add personalized learning suggestions and marking functions in the future, so as to facilitate review and further deepening of learning. These feedbacks also provide a clear direction for the optimization, upgrading and function expansion of the system.

7 Conclusion

The proposed digital intelligence framework, grounded in Laban's movement theory, integrates multi-modal data collection, symbolic feature extraction, and visual interactive instruction. Within this framework, a visual learning system—anchored in Labanotation and supported by 3D motion visualization—bridges rational symbolic analysis with intuitive perceptual understanding, particularly for the teaching and comprehension of Kunqu opera's core basic skills. This interdisciplinary exploration provides innovative ideas for the modern protection, inheritance and scientific development of Kunqu opera performance.

7.1 Enhancing Scientific Recording of Kunqu Opera through Digital Intelligence

The Labanotation-based recording method proposed in this study does not aim to replace traditional oral transmission, but rather to enhance it through scientific digital encoding. By integrating Labanotation with motion capture, symbolic mapping, and multimodal data analysis, the proposed digital intelligence framework enables objective, standardized, and research-oriented documentation of Kunqu body movements. Through symbolic representation, the essential characteristics of procedural movements are extracted and stored systematically, ensuring consistency across different learners. This approach significantly reduces interpretive errors caused by memory deviations and provides a data-driven foundation for both performance preservation and future choreography.

7.2 Bridging Theory and Practice in Kunqu Body Movement Research

While traditional research methods such as textual analysis and historical documentation remain indispensable, modern body movement research must evolve in line with digital and pedagogical developments. By using data captured through digital systems and encoded with Labanotation, practitioners can construct a digital movement vocabulary, enabling systematic interpretation and creative extension. For instance, through the visualized analysis of classical movement patterns, performers can design new gestures within the digital platform that remain grounded in tradition. This fusion of data and creativity supports the sustainable evolution of Kunqu Opera's expressive system within a technologically enriched context.

7.3 Supporting Pedagogical Innovation in Kunqu Opera Training

Labanotation is not a rigid system of rules but a dynamic framework for integrating kinesthetic awareness with cognitive structure. The interactive learning system developed in this study, which incorporates 3D virtual character demonstration and real-time symbolic feedback, allows students to intuitively explore the spatial logic and expressive nuances of Kunqu movements. Through visualized feedback, motion tracking, and symbolic alignment, learners strengthen both their action thinking and structural understanding. This integrated teaching approach promotes student-centered, scalable, and intelligent training, encouraging the development of personalized movement expression within a traditional artform.

7.4 Fostering Cross-Cultural and Interdisciplinary Communication

As a universal symbolic system, Labanotation transcends linguistic and cultural barriers, offering a shared interface for studying and appreciating Kunqu Opera across different cultures and disciplines. The digitally visualized notation system proposed in this study facilitates communication for international audiences unfamiliar with Kunqu by providing

clear, visual movement representations. Moreover, the system's modular structure and visual-symbolic mapping open up possibilities for interdisciplinary application in dance, theater, animation, and digital heritage. This approach expands Kunqu's global visibility and supports its sustainable development in the digital era.

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