ROBOTIC ARTISTRY: ASSESSING NAO ROBOT'S POTENTIAL IN MIMICKING WUXI OPERA MOVEMENTS*

Ding Weihao[1] and Gomesh Karnchanapayap[2]

[1-2]**Faculty of Decorative Arts, Silpakorn University, Bangkok, Thailand**

[1]**School of Art and Design, Zhenjiang College, Zhenjiang, Jiangsu, China**

Corresponding Author's Email: karnchanapayap_g@silpakorn.edu

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Abstract

This study explores the integration of traditional Wuxi opera with modern technology by employing a humanoid robot (NAO) to mimic the movements of Wuxi opera performers. With the growing interest in using technology to preserve and teach traditional performing arts, the research analyzes the movement characteristics of Wuxi opera and assesses the NAO robot's capabilities and limitations in imitating these actions. Adopting a qualitative approach, the study involved a comprehensive review of existing literature on Wuxi opera movements and an analysis of the robot's functional performance. Findings reveal that Wuxi opera movements, rich in cultural meaning, can be divided into static poses and continuing movements. The NAO robot successfully replicated many basic motions but struggled with complex actions such as jumping, rolling, kicking, and waist-turning due to mechanical constraints. Although it cannot fully reproduce the subtle nuances and complexity of human performance, the NAO robot shows potential as an innovative supplemental tool. Human instructors can leverage its capabilities

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to assist in demonstrating fundamental movements, enhancing student engagement and fostering cultural appreciation in Wuxi opera education.

Keywords: Wuxi Opera, NAO Robot, Movement Imitation, Performance Arts Education

Introduction

Wuxi opera is an invaluable intangible cultural heritage of China. It is a renowned form of traditional theater from Jiangsu province celebrated for its distinctive performance techniques and rich aesthetic value (Shenchao, 2020). In 2008, it was officially designated as a National Intangible Cultural Heritage of the People's Republic of China (Shi, 2023). Over the years, Wuxi opera has captivated audiences with its expressive portrayal of emotions, intricate movements, and compelling storytelling (Ruru, 2012).The knowledge of the opera is diminishing, and interventions are required to preserve the heritage. Despite its cultural and historical significance, the opera faces significant challenges, particularly the decline in the number of inheritors. With the declining number of skilled performers and educators, there is an urgent need for innovative solutions to ensure the preservation and continuity of this valuable art form (Qing, 2021). This pressing situation provides the basis for exploring modern approaches to preserving and promoting Wuxi opera.

Robotic technology holds a potential solution to the survival of Wuxi opera. The rapid development of robotics and digital technologies has introduced new opportunities for the modernization and preservation of traditional performing arts, including Wuxi opera (Kayani & Haddad, 2019). Humanoid robots, such as the NAO robot, can be visually programmed to execute a range of actions and interactive functions, presenting a novel means of bridging the gap between tradition and modernity (Greer et al., 2019). These technological advancements not only enable the imitating of the movements

of opera performers but also can be used to train students interested in the traditional performance arts. By integrating such technologies, we can modernize the dissemination of Wuxi opera, making it more accessible to younger generations and enhancing its educational impact.

This study looked at how NAO robots can imitate the movements of Wuxi opera by performing a systematic analysis. The researchers studied the movements of Wuxi opera, checked how well the NAO robot can replicate them, and critique the issues that prevent it from fully mimicking human performances.

Objectives

1. To systematically analyze the Wuxi Opera performance movements.

2. To study the limitations of NAO robotics in replicating Wuxi opera performance movements.

Literature Review

1. The Wuxi Opera Status Quo

Wuxi Opera is a valuable Chinese regional cultural performance art. It's a major form of traditional opera in Jiangsu and has a history spanning over two centuries. In 2008, it received the designation of national intangible cultural heritage (Jing, 2018; Shen, 2023). This type of opera originated from Tanhuang folk traditions and was later influenced by the locals from Suzhou Pingtan and Xuanjuan areas, making the opera style unique to the region (Qing, 2021).

Outdated methods of passing on the practice and the absence of inheritors cause Wuxi Opera difficulties in its preservation and adoption (Shenchao, 2020). Presently, one can learn about Wuxi Opera by watching live performances, visiting cultural museum exhibitions, and getting training from

specialized Wuxi opera institutions (Qing, 2021). Furthermore, Ding (2024) reports a decline in interest among younger audiences, with university students making up only 1.5% of the surveyed population. Museums primarily rely on static displays with minimal interaction, while professional training programs predominantly cater to adolescents and retirees, leaving young adults underserved. The use of digital technology in teaching Wuxi Opera remains limited, and empirical studies on its effectiveness in education and public engagement are scarce. While Peking Opera, another traditional Chinese opera, has successfully integrated AR and VR technologies to enhance audience interaction and immersion, there has been no integration of such technologies into Wuxi opera (Shi, 2023).

To tackle these challenges, researchers suggest combining different fields. Some ideas include adding Wuxi Opera to college courses on aesthetics, creating interactive digital tools, and using film and social media to reach more people (Ding, 2024). These approaches aim to modernize Wuxi Opera while ensuring its long-term sustainability.

The authors propose a possible approach to modernizing the education of Wuxi Opera is to incorporate robots as Wuxi Opera movement instructors. While there are many makes and brands of humanoid robots available in the market, the NAO robot is an affordable humanoid robot that can mimic human movement. At the time of this study, the NAO robot was available for purchase at US$18,990, which is within a consumer-level price range. Additionally, the robot's ranges of motion allow it to imitate human movements. Therefore, we selected the NAO robot for this study.

2. The NAO Robot

The NAO robot, developed by Aldebaran Robotics (now SoftBank Robotics), is a widely used humanoid platform in education, research, and service industries. Since its 2006 launch, NAO has been recognized for its

flexible programming, user-friendly design, and advanced sensor suite, making it a key tool in global robotics research (Gouaillier et al., 2009).

The robot's hardware includes high-definition cameras, multiple microphones, pressure sensors, and 25 degrees of freedom, enabling complex movements and interactions. The NAO's development has undergone significant advancements; each iteration made it more advanced. The first production model, Nao RoboCup (2008), became the standard platform in the RoboCup competition, accelerating research in robotic mobility and perception. The NAO Next Gen (2011) has better eyesight, is more durable, and has a system to avoid collisions, making it more reliable. The NAO Evolution (2014) added multilingual speech synthesis and advanced facial recognition, improving user interaction. The latest NAO V6 (2018) has improved voice features, can recognize gestures, and supports programming in Python. This makes it very useful for educational purposes.

The NAO V6 robot has many movable parts and a precise control system, making it a viable option for mimicking the movements in Wuxi Opera performances. Its highly flexible joints and motion synchronization capabilities allow it to imitate complex gestures, dance steps, and expressive movements essential to opera performances (Gouaillier et al., 2009; Sahu et al., 2021). Additionally, programming languages like Python, C++, and Java can be used to improve NAO's ability. This allows for personalized dance routines and coordinated actions on stage. The graphical programming user interface simplifies motion design, making it accessible even to users with limited coding experience (Podpečan, 2014).

While existing research on the application of NAO robots in Wuxi opera performance or education is limited, there are studies on the effectiveness of using NAO robots in artistic and educational settings. There is a study that utilized NAO robots in participatory Shakespearean performances, enhancing

social interaction among elderly participants and reducing depressive symptoms (Greer et al., 2019).

Huang (2020) explored NAO's application in robotic calligraphy, showing its ability to replicate traditional brushstrokes. These studies highlight NAO's potential in creative fields, suggesting that its integration into Wuxi opera aesthetic education could offer students a novel and immersive approach to learning traditional opera.

Research on robotics in the performing arts underscores the potential of humanoid robots in educational applications and interactive learning. However, a significant knowledge gap remains regarding the comprehensive integration of robotics—particularly NAO robots—into Wuxi Opera education and training.

Mothodology

This study used qualitative methods to analyze Wuxi Opera movements and assess the NAO V6 robot's limitations in mimicking them. The researchers analyzed Wuxi opera movements from video resources, studied the NAO robot from the technical manual, and compared its feasibility with actual performance moves. The study underwent ethical review and was approved by the Silpakorn University Institutional Review Board. Approval was granted under reference number REC 68.0205-023-1049, ensuring that the research adhered to ethical guidelines and safeguarded the rights and well-being of participants involved in the study.

1. Movement Analysis

The researchers used high-quality Wuxi Opera performance footage as the primary source to classify and document key movements. This study

focuses on joint-based body movements, incorporating insights from existing research on opera performance to explore their aesthetic and cultural significance.

2. Experimentation with NAO Robot

We used Choregraphe software and Python programming to design and program the NAO robot to mimic Wuxi Opera movements. We conducted experiments to evaluate the robot's performance in executing these movements, emphasizing precision, coordination, and fluidity.

3. Actual Movements and Robot Movements Comparative Analysis

We compared how well the NAO V6 can mimic Wuxi Opera movements and looked at its technical limitations. The analysis specifically examines the robot's restricted range of motion and its limited capacity for expressive gestures. Additionally, the study explored potential optimization strategies to enhance the robot's ability to replicate the Wuxi opera performance moves.

4. Research Framework

This study explored the physical movements of Wuxi opera and the use of the NAO robot to imitate the movements. Figure 1 depicts the study's conceptual framework which the researchers first analyzed the Wuxi opera movements both static and continuing movements, then we created joint diagrams for the NAO robot, and compare the actual performer's poses to the simulated NAO poses to see the possibility of mimicking Wuxi opera's movements using NAO robot.

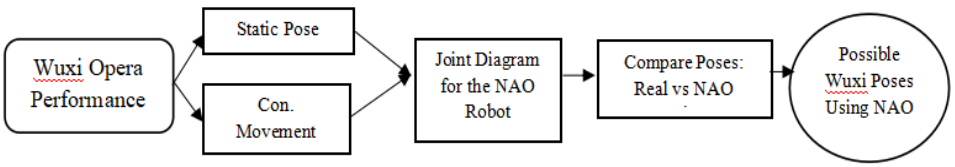
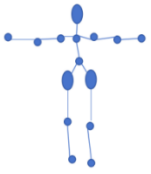


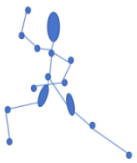
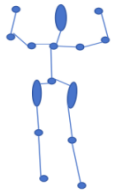
Figure 1 Conceptual framework (Constructed by the researchers)

Results

Objective 1. The research findings indicate that Wuxi opera performances feature remarkably diverse and highly artistic movements. The movements of a Wuxi opera performer are inherently symbolic and highly stylized to convey complex emotions and display visual narratives (Zheng, 2023). The researchers first analyzed the Wuxi opera moves, then illustrated the poses for clarity, and created respective joint diagrams according to the robot's rotation points. The performance movements can be categorized into two categories: static poses and continuing movements. Tables 1 shows detailed analysis of Wuxi opera's static poses.

Table 1 Analysis of Wuxi Opera's Static Poses

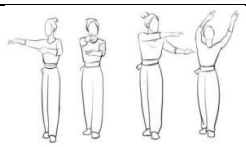
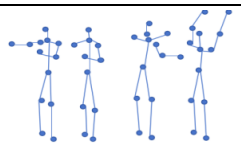
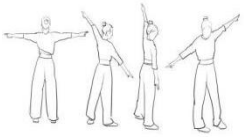
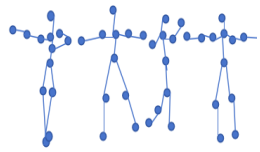
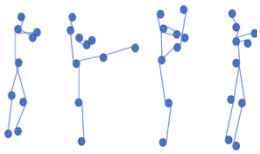
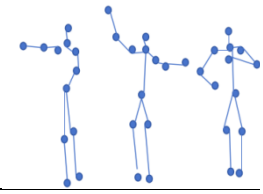
Pose	Photo	Illustration	Joint Diagram
1. 拉三膀 (Pulling Three Arms)			
2. 拖掌 (Dragging Palm)			
3. 按掌 (Pressing Palm)			
4. 顺风旗 (Wind-Following Flag)			

5.下拉按掌豹头 (Downward Pull–Press Palm)			
6. 冲拳 (Thrust Punch)			
7. 虎豹头 (Tiger–Leopard Head)			
8.下拉按掌 (Downward Pull Pressing Palm)			

Continuing movements in Wuxi opera are more complex as they consist of fluid sequences of body motion. Tables 2 below shows detailed analysis of Wuxi opera's continuing poses.

Table 2 Analysis of Wuxi Opera's Continuing Movements

Movement	Photo	Illustration	Joint Diagram
1. 腰功 (Waist Techniques)			
2. 跳卧鱼 (Jumping Lying Fish)			

3. 云手 (Cloud Hands)			
4. 串翻身 (Sequence Body Flip)			
5. 滚背 (Rolling the Back)			
6. 平转 (Horizontal Turn)			
7. 踢正腿 (Straight Leg Kick)			
8. 圆场 (Circular Movement)			

Detailed study of the movement in Wuxi opera helped us better understand how metaphor and visual signs work together in Chinese performing arts (Shin, 2010). This study not only enhances students' comprehension of Wuxi opera's aesthetics and performance meanings but also serves as a valuable scholarly resource for educators in the fields of visual aesthetics, semiotics, and Chinese opera literature.

Objective 2. The results show that although the NAO robot can imitate many poses and movements, it has difficulty imitating certain movements because of its innate limitations. Despite possessing 25 degrees of freedom,

the robot struggles with certain movements that require wide arcs, such as jumping, rolling, kicking, and waist-turning.

Table 3 presents a comparative analysis of Wuxi Opera poses simulated using the NAO robot's Choregraphe software to those performed by a real opera performer.

Table 3 Static Pose Comparison Between the Actual Wuxi Opera Performer Pose and the NAO Robot Simulation Pose

Pose	Actual Performer	NAO Robot	Replicability
1. 拉三膀 (Pulling Three Arms)			Yes
2. 拖掌 (Dragging Palm)			Yes
3. 按掌 (Pressing Palm)			Yes
4. 顺风旗 (Wind-Following Flag)			Yes
5. 滚背 (Rolling the Back)			Yes
6. 冲拳 (Thrust Punch)			Yes

7. 虎豹头 (Tiger–Leopard Head)			Yes
8. 下拉按掌 (Downward Pull Pressing Palm)			Yes

Table 4 shows the analysis of Wuxi opera's continuing movements which for some parts of a movement, the NAO robot cannot replicate. Those unable to be replicated movements are marked with an "X" symbol.

Table 4 Continuing Movement Comparison Between the Actual Wuxi Opera Performer Pose and the NAO Robot Simulation Pose

Movement	Performer	NAO Robot	Replicability
1. 腰功 (Waist Techniques)			No. The lack of sufficient degrees of freedom in the waist prevents imitation.
2. 跳卧鱼 (Jumping Lying Fish)			Partial. The jumping movements and leg-bending actions cannot be imitated.
3. 云手 (Cloud Hands)			Yes

4. 串翻身 (Sequence Body Flip)			Yes
5. 滚背 (Rolling the Back)			Partial. The rolling movements cannot be imitated.
6. 平转 (Horizontal Turn)			Yes
7. 踢正腿 (Straight Leg Kick)			Yes
8. 圆场 (Circular Movement)			Partial. Insufficient degrees of freedom in the legs area.

The NAO robot's limitations in imitating Chinese opera movements are primarily related to the legs and waist. For example, certain opera techniques necessitate dramatic backward bending or arching of the waist ("body performance"), but the NAO's "waist joint" lacks the range of motion required for such pronounced trunk flexion. Furthermore, the jumping and high leg-lift actions in opera, such as kicking the leg over the head, frequently require leg joints to be nearly 180° flexible, sometimes exceeding normal human capabilities. NAO's hip joints (HipPitch, HipRoll) and knee joints (KneePitch) are incapable of achieving such extreme extensions or elevated leg lifts, let alone maintaining them for extended periods.

Discussion

The findings of this study highlight both the potential and limitations of the NAO V6 robot in mimicking Wuxi Opera performance movements. The results confirm that while the NAO robot can successfully replicate static poses and some continuous movements, it struggles with highly dynamic actions that require extensive flexibility, high degrees of freedom, and precise balance control. This discussion examines the implications of these findings in two main areas: technological capabilities and educational applications.

1. Technological Capabilities and Constraints

Our analysis demonstrates that NAO's 25 degrees of freedom allow it to replicate a wide range of symbolic and stylized gestures that define Wuxi Opera. The robot can perform movements such as "Pulling Three Arms," "Wind-Following Flag," and "Thrust Punch" with reasonable accuracy. These gestures, which rely on arm and hand coordination rather than complex lower-body mechanics, align well with NAO's structural design and joint configurations.

However, the robot's limitations become evident when imitating movements requiring greater flexibility and fluidity, particularly those involving the waist and legs. Movements such as "Jumping Lying Fish," "Rolling the Back," and "Straight Leg Kick" were either partially replicated or impossible to execute due to NAO's restricted range of motion in the waist and hip joints. The absence of sufficient articulation in these areas prevented the robot from achieving the expressive dynamism characteristic of Wuxi Opera's aesthetic. This finding aligns with previous studies on humanoid robots in performing arts, which also reported difficulties in replicating high-amplitude and acrobatic actions (Greer et al., 2019; Huang, 2020).

2. Implications for Educational Applications

Despite its limitations, the NAO robot presents a valuable tool for Wuxi Opera education, particularly for beginners and students learning fundamental movements. Its ability to accurately demonstrate basic static poses and controlled gestures makes it an effective aid for teaching symbolic movements and the semiotics of traditional opera performance. By integrating robotic assistance in Wuxi Opera training, educators can enhance student engagement and provide an interactive learning experience.

Moreover, NAO's programmable nature allows instructors to design customized choreography sequences, ensuring that students can visualize movement patterns from multiple perspectives. The graphical user interface of the Choregraphe software simplifies this process, making it accessible to users without extensive programming experience. The potential of humanoid robots in performing arts education has been noted in other creative disciplines, such as robotic calligraphy and participatory theatre performances (Greer et al., 2019; Podpečan, 2014). These studies suggest that robotic integration can enrich traditional art education by fostering interactivity and offering new modes of engagement.

3. Originality and body of knowledge

This study contributes to the growing body of research on robotics in performing arts education, demonstrating the NAO V6 robot's capacity to imitate select Wuxi Opera movements while highlighting its technical constraints. While the robot effectively replicates static poses and some continuous gestures, its inability to execute high-amplitude movements limits its role in advanced opera training. Nevertheless, its potential as an educational tool for foundational learning is significant. Future advancements in robotics and AI-driven motion adaptation may bridge the gap between human performance and robotic mimicry, offering new possibilities for integrating humanoid robots into traditional performing arts education.

Recommendation

Given the study's findings, further research is necessary to explore ways of enhancing humanoid robot capabilities for performing arts applications. Several potential research directions emerge from this study:

1. Hardware Modifications: Future iterations of humanoid robots designed for performance applications should feature improved waist and leg articulation to better simulate acrobatic and dynamic movements. Increased degrees of freedom, particularly in the spine and hip joints, would allow for more expressive.

2. Hybrid Training Approaches: Combining robotic assistance with traditional teaching methods may optimize the educational experience. For example, students could observe NAO's movements for fundamental gesture recognition while simultaneously working with instructors to master complex physical techniques.

3. Customized NAO Robot Design: In Wuxi Opera, costumes, makeup, props, and stage coordination highlight character identity, personality, and dramatic context, producing a strong visual impact. However, the NAO robot's standard form has limited aesthetic expression. Thus, future research can focus on adding visual design elements to the NAO robot to reflect the identity of Wuxi opera better.

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