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Optimization of retargeting motion capture for Remo dance using fuzzy logic

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Abstract
Retargeting motion capture for traditional dance animation faces challenges in maintaining biomechanical accuracy while preserving cultural expressiveness, especially when human motion data are transferred to character models with different skeletal structures. This research aims to optimize the retargeting of East Java Remo dance through an adaptive artificial intelligence-based evaluation approach. The Remo dance movement was recorded using a multi-camera optical motion capture system and retargeted to two types of 3D characters: realistic and stylized. The evaluation was conducted using quantitative metrics (Mean Squared Error, Structural Similarity Index, Dynamic Time Warping, and Kalman Filtering), as well as a qualitative approach through Laban Movement Analysis. Subsequently, Mamdani fuzzy logic was integrated to synthesize all these parameters into the Fuzzy Retargeting Quality Score (FRQS). The results showed that the realistic character had higher movement accuracy (MSE = 0.0032; SSI = 0.89; DTW = 0.92) and obtained an FRQS value of 86.4 (very optimal category), whereas the stylized character obtained an FRQS of 71.2 (moderately optimal), reflecting a compromise between movement precision and visual appeal. The integration of fuzzy logic allows for more contextual and human-centric retargeting evaluation, as well as strengthening the dual-model approach to preserving and educating about traditional dance through digital animation.

1. Introduction

Remo dance is an important representation of Indonesia's intangible cultural heritage, originating from East Java. Its energetic, dynamic, and expressive characteristics make this dance both an artistic performance and a symbol of Javanese men's heroism and agility [1]. Technology-based preservation approaches are now a global concern, especially as they enable the translation of cultural expressiveness into digital forms that can be distributed across media [2]. However, preserving the authentic movement of Remo Dance amid the challenges of cultural digitalization and the shifting tastes of younger generations demands a new approach that combines traditional heritage with visual technological innovation. Motion capture (MoCap) technology has become one of the most promising methods for the documentation and preservation of traditional dance due to its ability to precisely record three-dimensional movement data [3]. In recent years, motion capture systems have also been widely used in digital cultural heritage research, not only for documentation but also for performance analysis and movement learning using artificial intelligence [4]. Its application has been successfully used in the digitization of the Serampang Laut dance [5] and Dunhuang dance [6], demonstrating the effectiveness of this method in capturing the essence of complex body movements.

However, significant challenges arise in the retargeting process when transferring motion capture data to characters with different skeletal structures. These challenges can be categorized into two key problems. First, the technical problem involves the loss of biomechanical accuracy, spatial distortion, and temporal misalignment during motion transfer, which often results in artifacts such as joint instability and inconsistent motion phases [7]. Second, the conceptual problem is the absence of culturally sensitive and human-centric evaluation metrics [8], [9]. Existing approaches mainly rely on numerical accuracy and visual similarity, which are insufficient to represent the expressive and symbolic dimensions of traditional dance [10]. These limitations highlight the need for an evaluation framework that integrates computational precision with cultural interpretation.

Artificial intelligence-based approaches such as Dynamic Time Warping (DTW) and extended Kalman Filtering are also key in aligning and validating animation results against original motion data [11]. Furthermore, evaluation based on Laban Movement Analysis (LMA) becomes an important tool for measuring aspects of cultural expressiveness in digital dance movements [12]. Previous studies on motion retargeting have predominantly focused on improving numerical accuracy, spatial alignment, or visual realism using techniques such as inverse kinematics, smoothing filters, and temporal synchronization algorithms [8], [9], [10], [11]. While these approaches are effective in enhancing technical performance, they lack integrated decision-making mechanisms that incorporate both quantitative metrics and

expressive evaluation. In the context of cultural dance preservation, this creates a critical gap, as movement quality cannot be fully represented by numerical indicators alone. This research addresses this gap by introducing a fuzzy logic-based framework that functions as a bridging mechanism between computational precision and cultural interpretation. The novelty of this approach lies not merely in the use of fuzzy logic, but in its role in synthesizing objective metrics and subjective expert knowledge into a unified evaluation system.

This research offers a dual-model approach by comparing the performance of stylized and realistic 3D characters in representing Remo dance movements through quantitative and qualitative evaluation parameters. Realistic models focus on biomechanical precision, whereas stylized models aim to appeal to a young audience [13]. The integration of these two approaches aligns with the trend of human-centered AI-based cultural animation design, which emphasizes a balance between biomechanical accuracy and user aesthetic perception [14], [15]. Fuzzy-based approaches are also used for procedural movement in animation, such as camera movement [16], character interaction, and other environmental assets, which expands the scope of artificial intelligence in optimizing animation production [17].

This combination of strategies becomes the meeting point between cultural preservation and educational animation design. Thus, this research encourages the strengthening of cultural digitalization while also filling a research gap in the optimization of data-driven retargeting for local dance movements. The results of this study are expected to be an important reference in the development of other cultural dance animations while also supporting the creation of an automated evaluation system that is more sensitive to the aesthetic complexity and meaning of movement in Indonesian culture. This study is positioned at the intersection of motion capture technology, artificial intelligence, and digital cultural heritage. Unlike conventional retargeting optimization approaches that primarily emphasize numerical accuracy or visual realism, this research embeds cultural expressiveness as a core component of algorithmic evaluation. By integrating computational metrics with human-centered interpretative frameworks, the proposed method advances retargeting evaluation from a purely technical process into a culturally aware decision-making system. This interdisciplinary positioning strengthens the relevance of this work for both intelligent systems research and digital heritage preservation domains. The main contributions of this research can be summarized as follows:

- Development of a dual-model retargeting evaluation framework comparing realistic and stylized characters.
- Introduction of the Fuzzy Retargeting Quality Score (FRQS) as a composite and human-centric evaluation metric.
- Integration of quantitative methods (MSE, SSI, DTW, Kalman Filtering) with qualitative evaluation using Laban Movement Analysis (LMA).
- Implementation of fuzzy inference as a decision-making mechanism bridging numerical accuracy and cultural expressiveness.
- Contribution to digital preservation methodologies for Indonesian traditional dance through AI-based motion evaluation.

To address these challenges, this study proposes an integrated evaluation framework that combines motion capture technology, artificial intelligence, and cultural movement analysis. The proposed approach introduces a dual-model retargeting evaluation (realistic and stylized characters) and a Fuzzy Retargeting Quality Score (FRQS) that synthesizes quantitative metrics and qualitative expert knowledge. The novelty of this work lies in the use of fuzzy logic as a bridging mechanism between computational accuracy and cultural expressiveness, enabling a more human-centric and context-aware evaluation of traditional dance animation.

2. Research Method

This research uses a quantitative-computational approach to evaluate and optimize the retargeting values of Remo dance movements recorded using motion capture technology. This approach aligns with current research directions in the field of human motion analysis, which combine statistical models and fuzzy-based intelligent systems to assess movement quality multidimensionally [18], [19]. The main goal is to analyze animation models that visually and structurally closely resemble the original movements of human dancers, considering biomechanical accuracy parameters as well as the audience's aesthetic perception. The initial step was to record the movements of the Remo dance using a multi-camera optical motion capture system. This system has been proven to accurately record three-dimensional movements in ethnic dances and other traditional cultural performances [20]. The MoCap data obtained were then processed through Blender software to be retargeted to two 3D character types: realistic and stylized, as shown in Figure 1. This retargeting process becomes a crucial stage because it involves the transformation of movement between different bone structures [21], which can lead to spatial errors, especially in extremities such as hands and feet [22]. Pose- and shape-aware retargeting approaches have proven effective in reducing spatial errors through adaptive interskeleton mapping, as introduced in the latest generation cross-frame models [7], [10].

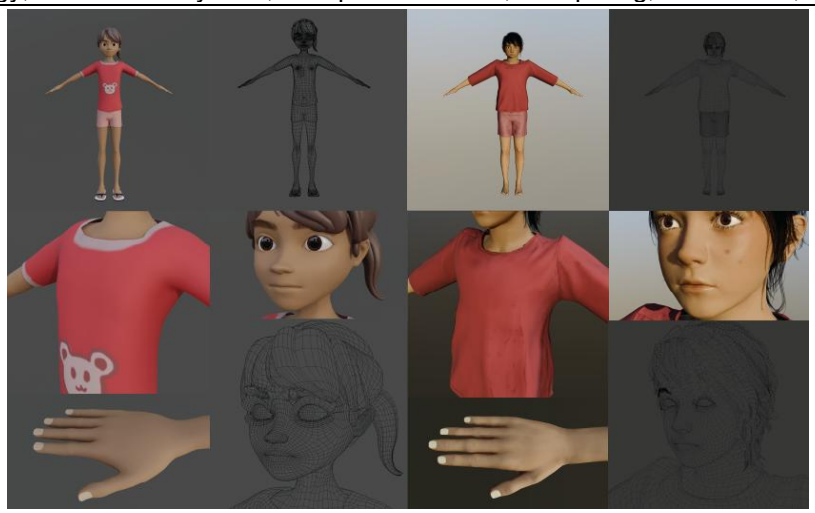

Figure 1. Stylized and Realistic Character Models used in this Study to Compare Retargeting Performance, Representing Two Different Approaches to Balancing Biomechanical Accuracy and Visual Appeal

To optimize retargeting results, segmentation and keyframe mapping based on motion phases were performed, supplemented by spatial and temporal interpolation to maintain movement continuity. Initial evaluation used joint position error and pose similarity index as quantitative indicators [23]. Meanwhile, retargeting errors were minimized through adaptive inverse kinematics techniques and the incorporation of elastic deformation to address character geometry differences [9]. As part of the validation, an artificial intelligence-based motion evaluation system was used to compare the animation results with the original motion template. The Dynamic Time Warping (DTW) algorithm was employed for temporal alignment due to its effectiveness in measuring sequence similarity in motion data, as demonstrated in prior motion analysis studies [11]. The combination of these two algorithms has also been adopted in human movement performance evaluation research because it can simultaneously identify temporal and spatial deviations [23]. This approach is adapted from previous research on optimizing various dance movements using motion capture and real-time motion tracking systems [24], [25].

Laban Movement Analysis (LMA) is incorporated as a qualitative framework to evaluate movement expressiveness, extending its application from motion retrieval studies to culturally grounded animation assessment [12]. This is important because the movements in Remo dance are not just spatial positions but also contain narrative meaning and a spirit of resistance that must be preserved in the retargeted animation. The results of the subsequent movement evaluation were interpreted using a combination of metrics: Mean Squared Error (MSE) for joint position, Structural Similarity Index (SSI) for movement images, and subjective scoring from dance experts and cultural animators [26]. With these data, a multivariate regression-based predictive model was built to identify the technical parameters that most influence the suitability of retargeting results compared with the original motion.

To accommodate the multidimensional and ambiguous nature of dance movement quality, this study integrates the Mamdani fuzzy logic system as a decision optimization layer. The Mamdani inference system was chosen for its ability to combine quantitative and qualitative parameters in a linguistic form, which closely resembles how humans evaluate movement performance [18], [27]. Quantitative parameters (MSE, SSI, DTW) and qualitative parameters (LMA score) were mapped into linguistic sets. The fuzzy inference system was used to generate a retargeting quality score (Fuzzy Retargeting Quality Score/FRQS) that represents the balance between biomechanical accuracy and cultural expressiveness. This methodological approach yielded visually realistic dance animations and facilitated the creation of an AI-driven automated rating system for traditional cultural dances. This methodological design extends prior work in cultural heritage digitization [6] by operationalizing both computational and interpretative evaluation into a unified system.

3. Results and Discussion

As shown in Table 1, the realistic character consistently outperforms the stylized model across both MSE and SSI metrics. This indicates that the realistic model is more capable of preserving both biomechanical accuracy and visual similarity to the original motion. More importantly, this performance difference suggests that structural similarity alone is not sufficient without maintaining joint-level precision, which is critical in representing culturally meaningful dance movements. In addition to these technical metrics, a subjective assessment was conducted by dance experts and cultural animators to evaluate the aesthetic aspects, fluidity, and cultural authenticity of the animated movements. In this scoring, although realistic characters were rated higher in terms of movement authenticity and cultural expression, stylized characters received high scores for visual appeal, particularly for young audiences. This indicates that lower

MSE and higher SSI values are not only indicators of numerical accuracy but also reflect the system's ability to preserve movement authenticity. In the context of traditional dance, this is particularly important, as accurate motion reproduction directly influences cultural interpretation and learning effectiveness.

Table 1. MSE-SSI Evaluation and Expert Subjective Scoring

Character Type	Mean Squared Error (MSE)	Structural Similarity Index (SSI)	Expert Subjective Scoring
Realistic	0.0032	0.89	8.7
Stylized	0.0068	0.76	7.2

Table 2. Analysis of Laban Movement Analysis (LMA) on the Remo Dance Animation

LMA aspect	Realistic character	Stylized character	Interpretation Explanation
Body	9.0	7.5	Realistic characters show high precision in articulating body joints, whereas stylized characters are less accurate, especially in the lower extremities.
Effort	8.8	7.8	Realistic characters replicate the dynamics and energy of the original movement, whereas stylized characters lose some of the dynamic energy of the movement.
Space	8.7	7.3	Realistic animation effectively utilizes movement space, maintaining depth, range, and spatial patterns that closely resemble the original, unlike stylized animation, which is more limited.
Shape	8.9	8.0	Realistic characters consistently maintain their body shape and smoother movement transitions, whereas stylized characters tend to experience some form of distortion.

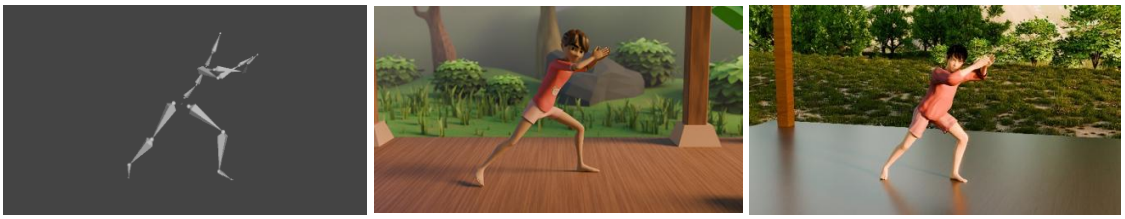

Figure 2. Details of Motion Capture Movements Translated onto an Animated Character

The experimental results in this study show that the motion capture data retargeting process for the Remo dance produces significantly different animation qualities between the two-character model types: stylized and realistic. The realistic model demonstrates higher movement accuracy, requires less adjustment to the graphical data, and can maintain the authenticity of the Remo dance movements more precisely, as shown in Figure 2. Analysis of Laban Movement Analysis of the Remo dance animation, as shown in Table 2, reveals that realistic characters can represent movements with high expressiveness across various key aspects evaluated. In terms of the body, realistic animation shows joint articulation that is very close to the dancer's original movements, reflecting high technical skill in motion retargeting through motion capture technology. Conversely, stylized characters exhibit a lack of precision in the lower extremities, affecting the overall biomechanical alignment of movements. In terms of effort, the realistic animation successfully captures the energy, tempo, and intensity of the Remo dance's movements, showcasing dynamics that reflect the courage and agility characteristic of the dance. Although stylized characters remain visually appealing, they are less capable of reproducing the dynamics equivalent to those of realistic models, resulting in weaker movement energy.

From a spatial perspective, realistic animation is effective in using three-dimensional space, showcasing depth, range, and movement patterns similar to the original dancers' movements. This animation more accurately preserves the characteristic patterns of Remo dance, such as hand gestures, dynamic forward steps, and foot stomps. On the other hand, stylized characters face limitations in exploring movement space, making some key elements of the spatial pattern less clear. Recent studies show that the representation of dance movements in three-dimensional space can be improved through a spatial-temporal graph neural network system, which allows for more accurate trajectory prediction for stylized visual styles [28]. In terms of shape, the realistic characters show very smooth and consistently

maintained transitions between poses, making the aesthetics of movement closer to the appearance of real dancers. The stylized character, although visually expressive, exhibits some form of distortion that reduces the overall aesthetic quality of the movement, especially during rapid changes in pose or direction of movement. Nevertheless, the LMA analysis simulation confirms that the realistic character is superior to the stylized character in maintaining the expressiveness and accuracy of Remo dance movements.

Table 3. Evaluation of Movement using DTW and Extended Kalman Filtering

Evaluation Method	Character Type	Alignment Value	Motion Average Deviation	Interpretation Explanation
DTW	Realistic	0.92	2.8	The temporal alignment of the realistic animation's movements is very high, indicating that this animation is almost perfectly synchronized with the original movement phases.
DTW	Stylized	0.80	5.3	Stylized animation has lower temporal phase alignment of movement with higher spatial deviation, indicating imperfections in synchronizing complex movements, such as foot stomps and hand gestures.
Kalman Filter	Realistic	0.94	2.4	The Extended Kalman Filter shows that realistic animation can dynamically maintain the original motion prediction with a very low error rate.
Kalman Filter	Stylized	0.77	6.0	Stylized animation shows less stable motion prediction results, indicating the need for additional interpolation and optimization in motion retargeting to make it more realistic.

As presented in Table 3, the realistic model demonstrates significantly better temporal alignment and lower motion deviation compared with the stylized model. This indicates that the realistic model is more effective in preserving the temporal structure and synchronization of movement. In contrast, the stylized model shows noticeable inconsistencies in timing and spatial accuracy, particularly in complex motion segments, which affects the overall coherence of the animation. These findings indicate that the stylized model struggles to preserve fine-grained motion details, particularly in complex movement segments involving extremities such as hands and feet. The use of Extended Kalman Filtering for further evaluation highlights the performance differences between the two animation types. For realistic characters, the Kalman filtering results further confirm stable motion prediction and dynamic consistency. This stability is essential for ensuring smooth transitions and continuity in dance movements. On the other hand, the stylized model exhibits less stable predictions, indicating the need for additional optimization to achieve comparable motion fidelity. The high DTW alignment observed in the realistic model suggests strong temporal consistency with the original motion, which is essential in preserving rhythmic structure in traditional dance. Compared to prior studies that primarily focus on spatial accuracy [11], this result highlights the importance of integrating temporal evaluation for culturally meaningful motion representation.

These results show that stylized characters face challenges in accurately predicting movements, especially in segments requiring rapid and high-intensity changes, necessitating additional adjustments or the use of more advanced spatial and temporal interpolation techniques. Overall, this simulation clarifies that realistic animated characters offer better accuracy and stability in digitally replicating the cultural movements of the Remo dance. However, stylized characters remain relevant, particularly for educational or entertainment media that emphasize visual appeal over precise movement. Table 4 shows the definition of the membership functions used in the fuzzy system. The value range is determined based on the empirical distribution of the MSE, SSI, DTW, and LMA scores. This approach allows the fuzzy system to capture the gradual transitions between movement quality conditions, which cannot be represented in binary form by conventional evaluation methods. Compared with previous motion retargeting approaches that rely on single-metric evaluation or focus mainly on visual realism [8]–[11], the proposed method provides a more comprehensive assessment by integrating multiple quantitative and qualitative parameters. This enables a more robust evaluation of movement quality, particularly in cultural contexts where expressiveness and meaning play a critical role. Unlike prior approaches that primarily rely on single-metric evaluation, this study demonstrates that combining multiple metrics with fuzzy inference provides a more robust and context-aware assessment.

Table 4. Membership Functions used in the Fuzzy Inference System, Illustrating How Quantitative Metrics are Transformed into Linguistic Variables to Model Expert-based Evaluation of Movement Quality

Variable	Linguistic Set	Value Range
MSE	Low	0 – 0.004

	Medium	0.003 – 0.007
	High	> 0.006
SSI	Low	< 0.75
	Medium	0.70 – 0.85
	High	> 0.80
DTW	Bad	< 0.80
	Good	0.78 – 0.90
	Excellent	> 0.88
Score LMA	Weak	< 7.5
	Moderate	7.0 – 8.5
	Strong	> 8.0

Table 5. Fuzzy Inference Rules Representing Expert Knowledge in Evaluating Movement Quality, Demonstrating How Biomechanical Accuracy and Expressive Parameters are Integrated into Decision-making Logic

No	Rule
R1	IF MSE low AND SSI high AND DTW excellent AND LMA strong THEN FRQS very optimal
R2	IF MSE low AND SSI medium AND DTW good AND LMA strong THEN FRQS optimal
R3	IF MSE medium AND SSI medium AND DTW good AND LMA moderate THEN FRQS fairly optimal
R4	IF MSE high AND SSI low AND DTW bad THEN FRQS unoptimal
R5	IF SSI high AND LMA strong BUT MSE medium THEN FRQS optimal

Fuzzy inference rules, as shown in Table 5, represent how animation and dance experts intuitively evaluate the quality of movement. The combination of biomechanical parameters and cultural expressiveness allows the system to provide more adaptive decisions than a single numerical threshold-based approach. The defuzzification results in Table 6 show that the realistic character obtained an FRQS value of 86.4 and was categorized as “Very Optimal”. This reflects a high degree of consistency between biomechanical accuracy, temporal alignment, and cultural expressiveness. Conversely, the stylized character scored 71.2 on the FRQS and fell into the “Fairly Optimal” category, indicating a compromise between visual appeal and movement precision. The integration of fuzzy logic allows retargeting evaluation systems to move from a descriptive approach toward an intelligent decision-making approach. Unlike a single, standalone metric, fuzzy logic combines various dimensions of movement quality into a single interpretive score that is more aligned with human perception. In the context of traditional dance, this approach is important because the quality of movement cannot be reduced solely to spatial accuracy but must also consider cultural meaning, energy dynamics, and expressive continuity.

Table 6. Defuzzification Results of Fuzzy Retargeting Quality Score (FRQS)

Character Type	Quality Score	Fuzzy Category
Realistic	86.4	Very Optimal
Stylized	71.2	Fairly Optimal

The retargeting results on the realistic model show that only a little additional animation is needed for the face and fingers, whereas the stylized model requires frame-by-frame animation for the legs. This finding reinforces that character bone structure and rigging significantly influence the efficiency and suitability of retargeting results, consistent with the findings of [7]. Visually, the animation on the realistic model provides a more defined and expressive sense of movement. This is important because Remo dance is known for its agile and powerful movements, which, if translated incorrectly, can lose the cultural meaning of its movements [1]. Therefore, a higher smoothing frequency is needed to maintain the details of the movement dynamics. However, from a visual appeal perspective for children, the stylized model is considered more adaptable because its cartoonish and expressive forms are more easily accepted by the target audience, as demonstrated in a study [13] that observed that animated characters with disproportionate character proportions are more effective in attracting children's attention. Despite their lower FRQS scores, stylized characters remain highly relevant in practical applications. Their visual abstraction and exaggerated proportions make them more engaging for younger audiences and suitable for educational media, where accessibility and attractiveness may take precedence over strict biomechanical fidelity. This reinforces the importance of the dual-model approach as a balance between accuracy and audience engagement. The fuzzy results reinforce the validity of the dual-model approach, demonstrating that realistic models are more suitable for precision-based cultural preservation, while stylized models

remain effective for educational and entertainment purposes. This confirms the importance of balancing movement accuracy and visual appeal based on application context. These results demonstrate that the proposed framework offers a significant contribution beyond conventional retargeting evaluation methods. By incorporating both computational and cultural dimensions, this approach provides a meaningful advancement toward intelligent and human-centered evaluation systems for digital cultural heritage.

4. Conclusion

This research proposes an interdisciplinary framework that integrates motion capture technology, artificial intelligence, and digital cultural heritage for optimizing Remo dance retargeting. By combining computational accuracy with cultural expressiveness, this study moves beyond conventional animation optimization approaches that focus solely on numerical precision. The proposed framework demonstrates how algorithmic evaluation can incorporate human-centered and culturally sensitive criteria, positioning this work as a bridge between technical animation systems and digital heritage preservation. The integration of Mamdani fuzzy logic in this research makes a significant contribution to bridging the quantitative and qualitative evaluation of the traditional dance motion capture retargeting process. By mapping numerical metrics (MSE, SSI, and DTW) and expressiveness parameters based on Laban Movement Analysis into a fuzzy inference system, this study successfully generated the Fuzzy Retargeting Quality Score (FRQS) as a comprehensive indicator of movement quality. This score allows for a more adaptive assessment of animation quality, approaching the way human experts evaluate dance movement, which cannot be fully represented by a single numerical threshold. The defuzzification results show that the realistic character model consistently falls into the “Very Optimal” category, whereas the stylized model falls into the “Fairly Optimal” category. These findings confirm that fuzzy logic is capable of revealing the inherent compromise between biomechanical accuracy and visual appeal, while also strengthening the validity of the proposed dual-model approach. Thus, a fuzzy system can serve as an evaluation tool and decision-making mechanism in determining retargeting strategies that align with cultural preservation goals or audience needs.

From a state-of-the-art perspective, this research utilizes a combination of the latest techniques in motion capture-based animation optimization, such as the use of Butterworth smoothing filters, an inverse kinematics-based adaptive rigging system, and analysis based on DTW and Kalman Filtering algorithms. The results show that this method can improve the stability of animated motion and reduce spatial deviation to a score of less than 3 in the realistic model, making it one of the best performances in the application of Nusantara cultural dance retargeting. This research successfully fills the research gap that has previously existed between the need for precise cultural movement preservation and educational character designs that align with the interests of the younger generation. Most previous studies have focused on technically documenting movement or animation systems [7], [20], while this research integrates an evaluation of cultural performative aspects and audience visual preferences. This research also contributes a methodological foundation that can be adapted for other dances through a data-driven parameterization-based retargeting approach.

Conceptually, the fuzzy logic-based approach developed in this research contributes to the development of a more contextual, interpretive, and culturally sensitive dance animation evaluation system. This framework can be further developed as an automated or semi-automated evaluation system for other traditional dance retargeting, including the integration of machine learning for dynamic fuzzy rule adaptation. Thus, this research can enrich the field of motion capture-based animation and open up new opportunities for the preservation of intangible cultural heritage through a human-centric artificial intelligence approach. Further research indicates that the integration of AI into the animation pipeline can be developed from various aspects, including integration with CAD [29]. The findings of this research can serve as an initial model for wider application in other Indonesian dance preservation contexts and as an important reference in the development of a culture-based automatic movement evaluation system. Looking ahead, expanding the study toward multiple characters and exploring facial expressions and dance emotions through machine learning will further refine the digital animation-based cultural documentation and education system.

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