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The Use of Motion Capture Technology in 3D Animation

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Abstract: This research explores the application of Motion Capture (MoCap) technology in 3D animation, discussing the potential of algorithms in understanding human motion and enhancing motion capture technology. Through a comprehensive review, the study identifies the strengths and limitations of motion capture systems, emphasizing the importance of maintaining a balance between accessibility and quality in the process. The research utilizes a literature review and comprehensive analysis of motion capture technology in the context of 3D animation as its methodology. Literature sources were acquired from online journal databases such as IEEE, Google Scholar, and ScienceDirect. The literature analysis involves four phases of approach, including data extraction and systematic evaluation of the content of each source. The study reveals several challenges, including the complexity of synchronizing motion data with 3D models, understanding algorithms for human motion, and improving motion capture technology. Additionally, the research highlights the potential of machine learning algorithms to enhance the accuracy and efficiency of motion capture data processing. The research findings emphasize the importance of maintaining a balance between accessibility and quality when selecting motion capture systems for 3D animation production. Furthermore, machine learning algorithms are detected to improve the accuracy and efficiency of motion capture data processing. Identified challenges include integrating motion capture into 3D animation production, considering costs, and resource requirements, and integration with animation software. The potential use of motion capture in film production, video games, and other applications provides insights into the significant impact of this technology on the visual experience for audiences. In summary, this study offers an extensive examination of the motion capture procedure, as well as its potential and obstacles within the domain of 3D animation.

Keywords: Motion Capture, 3D-Model, 3D-Animation

1. INTRODUCTION

In the current digital era, three-dimensional (3D) animation has become an integral element in the entertainment industry and information technology-based applications [1], [2]. The success of 3D animation lies not only in its ability to produce stunning visuals but also in its ability to represent motion with high accuracy and realism [3], [4]. In this context, motion capture technology emerges as a critical element that transforms the paradigm of 3D animation production [5]. The foundation of using 3D modeling in IT-based applications creates a strong basis for understanding the advantages of 3D animation. With its reusability, detailed breakdown, and ability to depict depth, 3D animation has become the preferred choice for creating deep and immersive visual experiences. One recent significant evolution is the integration of motion capture in 3D animation production [6], [7], [8].

For instance, films such as Ready Player One (2018) [9] and Avengers: Endgame (2019) [10] highlight the use of motion capture to create digital characters with incredibly realistic movements, delivering a captivating cinematic experience for the audience. In the realm of cutting-edge technology, the latest installment in the Avatar series, Avatar: The Way of Water (2022) produced by 20th Century Studios [11], takes motion capture to new heights. The film employs state-of-the-art motion capture techniques, seamlessly integrating them with 3D animation. This not only enhances interactivity, realism, and automation but also poses unique challenges in synchronizing motion data with 3D models, understanding human motion algorithms, and staying ahead of advancements in motion capture technology itself. Despite these complexities, the result is a mesmerizing fusion of technology and storytelling that pushes the boundaries of cinematic innovation.

This research aims to bridge the knowledge gap in understanding the utilization of motion capture in the context of 3D animation. Focusing on the relationship between accessibility, simplicity, and data quality, the study seeks to provide a thorough overview of the process and development possibilities of motion capture (MoCap). Through

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a comprehensive review, the study not only identifies the strengths and weaknesses of motion capture systems but also emphasizes the importance of balancing accessibility and data quality throughout the process. By considering these concepts, the research aims to contribute to a practical understanding of how motion capture can be effectively integrated into 3D animation production. The study also explores the potential of algorithms in understanding human motion and enhancing motion capture technology, paving the way for further development. Overall, this research is an in-depth literature review aiming to identify challenges and opportunities related to the use of motion capture in the context of 3D animation. Therefore, it predicted that this research can provide a solid knowledge foundation for practitioners and researchers interested in incorporating motion capture technology into 3D animation production. Some contributions of this research include:

1) Comprehensive motion capture overview: this research provides a thorough review and analysis of the use of motion capture technology in the context of 3D animation, identifying strengths and weaknesses of the systems and emphasizing the importance of maintaining a balance between accessibility and data quality.
2) Exploration of algorithm potential: the focus is on exploring the potential of algorithms in understanding human motion and enhancing motion capture technology, with an emphasis on the significance of machine learning algorithms to improve accuracy and data processing in motion capture.
3) Challenges and opportunities in integration: the study offers insights into the challenges and opportunities of integrating motion capture into 3D animation production, including identifying issues such as costs, resource requirements, and integration with animation software

2. LITERATURE REVIEW

A. Evolution of 3D Animation and the Role of Motion Capture

The evolution of 3D animation has undergone significant development alongside advances in computer technology. From its humble beginnings to achieving astonishing levels of realism, 3D animation has become one of the most prominent forms of digital art. According to [12], [13], advancements in hardware and software technology have greatly contributed to the ability of 3D animation to reproduce human movement and expressions more accurately. Software updates, increased computing speed, and algorithm evolution have transformed 3D animation from mere visual representation into a deep immersive experience [14], [15], [16]. One of the most significant breakthroughs in the evolution of 3D animation is the use of motion capture technology. Motion capture allows animators to record real movements from human actors or physical objects and then apply that data to animated characters. This method has shifted the paradigm of animation, providing a level of realism never seen before.

For instance, [17], [18]demonstrate that motion capture can enhance the quality of human character animation by producing more natural and compelling movements. Motion capture is not limited to creating human characters but is also applied to animals, objects, and other virtual entities. With the advancement of motion capture technology, its use has become broader and more sophisticated. For example, in recent Hollywood films, motion capture technology has been used to create lifelike and expressive fantasy animal characters, delivering a deep visual experience for the audience [19], [20]. [21] also emphasizes that 3D animation technology is not just a visual tool but has become a medium capable of creating strong emotional engagement for the audience.

Success in reproducing a realistic virtual environment has opened the door to a deeper and more impactful cinematic experience. With this enhancement, 3D animation has transformed into an art form that not only visualizes stories but also emanates emotions and builds a connection between the audience and the work. With the evolution of 3D animation and the role of motion capture, entertainment industries such as film, video games, and animation have become more dynamic and captivating. Animators now have more powerful tools to create visually pleasing digital artworks. With the relentless progress of technology, it is an undeniable fact that 3D animation and motion capture will play a pivotal role in pushing the boundaries of the digital entertainment industry in the years to come. Motion capture (MoCap) is not just an additional element but also a key component in enhancing the level of realism in the world of 3D animation. As outlined by [5], this method involves the use of sensors that recognize and record physical movements from objects or individuals in the real world, and then transfer them into a virtual environment. This process allows animators not only to reproduce movements but also to capture human expressions and characteristics of motion, creating a result that appears natural and realistically responds to the virtual environment.

In this context, MoCap serves not only to visualize digital characters with incredible realism but also provides flexibility to animators to capture complex and detailed movements. The use of MoCap in films like Avengers: Endgame (2019) adds a new dimension to digital characters, bringing them to life with authentic movements and realistic responses. On the other hand, in the film Avatar: The Way of Water (2022) MoCap is expected to deliver a mesmerizing visual experience, elevating digital characters to a high level of realism, and enabling animators to capture nuances of movements that are subtler and detailed. The integration of MoCap in the evolution of 3D animation not only enhances visual quality but also opens the door to creating more dynamic and impressive digital artwork. By incorporating the uniqueness of human movement into digital characters, MoCap creates a cinematic experience that is deeper and more convincing for the audience. This innovation not only changes the way we perceive 3D animation but also expands the possibilities for creating richer and more engaging visual narratives.

B. *Current State of Motion Capture (MoCap) in 3D Animation*

Motion capture is a technology that enables the capturing of movements from objects or humans into a digital model, such as a 3D animated character. The development of motion capture in 3D animation has undergone significant evolution over time, driven by advancements in sensor technology that provide higher motion accuracy, allowing the creation of animations with a higher level of detail and the development of more realistic characters [22]. This opens new opportunities and enhances the quality of animation production. Innovation in facial capture has expanded, enabling animators to capture facial expressions and mouth movements with precision, providing animated characters with a richer emotional nuance. Another breakthrough involves combining mocap with traditional animation techniques. In certain 3D animation projects, this method allows animators to integrate human skills with traditional creativity, resulting in more dynamic and expressive animations. The use of motion capture is no longer limited to the body alone but also includes capturing facial expression movements, creating more lifelike characters. The current motion capture 3D animation can seen in figure 1.

The utilization of motion capture is becoming more prevalent, especially within the gaming sector. This technology plays a crucial role in creating lifelike and responsive characters, ultimately elevating the overall gaming immersion. The incorporation of artificial intelligence in mocap processing also contributes significantly by improving data quality and optimizing animation outcomes [23], [24]. It is important to note the development of real-time motion capture, allowing animators to see mocap results directly during the shooting process, speeding up and simplifying animation development. Furthermore, lighter and more portable motion capture equipment enables shooting in different locations, providing flexibility in production. In a broader industry context, the integration of motion capture with virtual reality (VR) and augmented reality (AR) technologies is on the rise [25], [26], [27]. For example, [26], attempted to propose a method to create an experimental environment using motion-capture-based avatars to enhance the immersive environment, resulting in quite positive and interesting feedback. All these developments collectively reflect the continuous evolution in the field of motion capture, reinforcing its role in modern 3D animation production.

C. *Method and Technology in Motion Capture*

There are various methods to construct and represent 3D models, but here some models are the most widely used currently

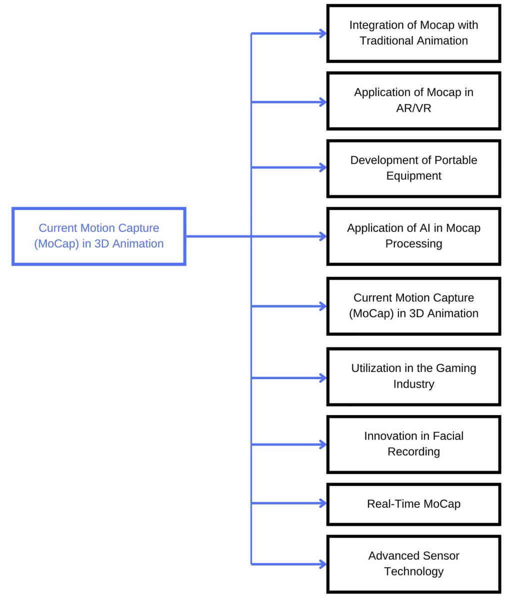

Figure 1. Current MoCap in 3D animation

1) *Passive Optical System*

In the context of motion capture, passive optical systems emerge as the primary solution for recording and replicating the movements of objects or bodies in 3D animation. The strategic placement of passive optical systems on objects or bodies to be monitored is a key element in the functionality of this system. In the operation of passive optical systems, passive markers take center stage. These small objects or spheres do not emit light themselves and are typically made of materials responsive to infrared light. Several infrared cameras are placed around the monitoring area to capture the movements of passive markers. The data captured by the cameras is then processed by motion capture software. This process involves analysis to measure the position and orientation of markers in each frame of the recording, followed by the reconstruction of movements in 3D space. The advantages of passive optical systems include high accuracy, especially when lighting conditions are well-controlled. Additionally, the stability of passive markers makes them less susceptible to disturbances that could affect motion measurements. For instance, the Vicon motion capture system has emerged as one of the leading systems [28]. This system utilizes passive markers and infrared cameras to capture movements. Vicon has made significant contributions across various industries, including animation, sports, and scientific research, reinforcing the crucial role of this technology in realizing 3D animation and other applications

2) *Active Optical Systems*

Active optical systems have become an effective solution in the world of motion capture, utilizing active markers that emit infrared light to record and replicate the movements of objects or bodies in 3D animation. In contrast to passive optical systems, active markers are equipped with a light source, such as LEDs, emitting infrared light detectable by infrared cameras. In the operation of active optical systems, infrared cameras placed around the monitoring area capture the movements of active markers. The data received by the cameras is then processed by motion capture software, which analyzes and measures the position and orientation of active markers in each frame of the recording. The result of this process is the reconstruction of movements in three-dimensional space, providing information that can be used to control 3D characters or objects in a virtual environment. The advantages of active optical systems include high accuracy, especially as active markers are easily identifiable, and flexibility in various lighting conditions. For example, motion analysiscorporation's Raptor series utilizes this technology by using active markers and infrared cameras [29]. The Raptor series is frequently used in various applications such as sports, simulation, and animation, highlighting its significant role in the motion capture industry.

3) Inertial Motion Capture

Inertial motion capture is a technology that utilizes inertia sensors to record and replicate the movements of objects or bodies in 3D animation. In this system, inertia sensors are placed on parts of the body to be monitored, such as wrists, arms, or the entire body. Unlike optical systems, inertial motion capture does not require cameras or physical markers, providing freedom of movement unrestricted by specific infrastructure or lighting. The operation of inertial motion capture begins with the use of inertia sensors that measure changes in acceleration and orientation. This data is then collected and used to replicate movements in a virtual environment. The primary advantage of this technology is its ability to provide a portable and wireless solution, making it a suitable choice for applications outside studios or in the field. A widely known example of inertial motion Capture is the Xsens MVN system [30]. Xsens MVN utilizes a set of inertia sensors attached to a costume worn by the user. This system has been used in various fields, including the entertainment industry, sports, and research.

Several other studies supporting the success of inertial motion capture, such as [31], [32] describe the implementation of inertia sensors in recording human motion with a satisfactory level of accuracy. [32] proposes a method for accurate orientation estimation and joint angle calibration, the findings suggest that their newly suggested system enhances the accuracy of joint measurements when compared to current inertia sensor-based systems. Nevertheless, the system's frequent requirement for both initial and in-process calibration, essential for achieving sensor-to-segment (StoS) calibration consistently during the entire process, implies the need for regular calibration efforts. Despite the need for substantial enhancements, inertial motion capture remains an attractive option in the realm of 3D animation and motion-based applications, providing a viable alternative, particularly in settings that demand increased mobility and flexibility of movement.

4) Markerless Motion Capture

Markerless motion capture is a technology that enables the recording and reconstruction of movements of objects or bodies in 3D animation without using physical markers placed on the surface of the object or body. This system differs from the traditional approach that relies on physical markers to record movements. The operation of Markerless motion capture begins with the use of a camera or a series of cameras placed around the monitoring area. These cameras record the movements of objects or bodies, and the resulting video data is processed using specialized software. Image processing algorithms and artificial intelligence are employed to identify and track unique features on objects or bodies, such as shape, color, or texture. One of the primary advantages of markerless motion capture is its ability to record movements naturally without the need for marker placement on subjects. This provides greater flexibility and allows the application of motion capture in situations where the use of physical markers is impractical.

As an example, the latest utilization of the Markerless Motion Capture system was carried out by [33]. [33] employed dynamic Gaussian splatting from the Markerless Motion Capture System to reconstruct infants' movements. The results demonstrated a significant improvement in scene initialization and infant motion tracking; however, artifacts were still noticeable in the reconstruction, partly due to imperfect segmentation masks. In contrast to [33], [34] analyzed crucial movements to assess in-vivo human biomechanics using the Markerless motion capture system assisted by Microsoft Kinect. In this system, the camera has depth and infrared sensors to track body movements without the need for physical markers. The results show positive developments in accuracy and reliability, while specific challenges remain the focus of research to improve the performance and applicability of this system. With technological advancements and improvements in image processing algorithms, Markerless motion capture continues to be an active research area, offering the potential to transform how movements are recorded and utilized across various industries

5) Surface Electromyography

Surface electromyography is a technology used to record and analyze the electrical activity in muscles during contraction or relaxation. This system employs surface electrodes placed on the skin to detect the electrical signals generated by muscle activity. This technology provides valuable information about muscle contraction patterns, strength, and muscle coordination and is commonly used in various applications, including the medical field, sports, and rehabilitation. The operation of surface electromyography begins with the placement of electrodes on the skin above the muscle to be monitored. The electrodes measure the electrical potential produced by muscle cells during contraction or relaxation. The surface electromyography signals are then converted into graphical or numerical data through signal processing software.

The main advantage of surface electromyography is its ability to provide direct information about muscle activity, including contraction patterns and strength. This makes it highly valuable for understanding human movement, evaluating rehabilitation, or optimizing sports performance. An example of surface electromyography application is in the field of medical rehabilitation, where surface electromyography can be used to monitor and measure muscle activity during physiotherapy sessions [35]. In sports, surface electromyography can be utilized to analyze sports techniques or detect muscle imbalances that may lead to injuries. Research by [36] discusses the application of surface electromyography in understanding muscle activity during human movement. This study highlights the importance of this technology in supporting medical diagnoses and improving human-machine interface designs. While surface electromyography has advantages in measuring direct muscle activity, it is important to note that its signals can be influenced by external factors, such as electrode placement and the thickness of the fat layer beneath the skin. Therefore, proper care and calibration are necessary to ensure accurate results. With the ongoing development of technology and research in this field, surface electromyography remains a valuable tool for understanding the dynamics of human muscles and supporting various applications, including in the fields of health and sports.

Motion capture technology holds a pivotal role in various applications within the digital industries, highlighting its significance in the development of creative content, simulations, motion analysis, and human-machine interactions. Film as a showcase of the excellence of motion capture can create realistic digital characters and provide an immersive experience. The film Avatar: The Way of Water (2022) [11] (figure 2) demonstrates the key role of MoCap in bringing the wonders of animation technology to the big screen. In this context, the film directed by Cameron in 2022 becomes a stunning showcase to illustrate the advanced capabilities of MoCap. The use of MoCap in the film allows the creation of digital characters that not only appear realistic in terms of movement but also capture facial expressions with a high level of accuracy. Actors wearing MoCap sensors can record their movements and facial expressions into digital characters, producing responses that appear natural and profound. This creates an immersive experience for the audience, where digital characters not only become visual entities but also radiate authentic emotions and personalities. MoCap enables filmmakers to create a virtual world inhabited by digital characters with movements and behaviors that seem real. Audiences can feel tension, joy, and other emotions through digital characters generated by MoCap technology. This not only highlights the advancements in animation technology but also proves that MoCap can create a more profound and engaging cinematic experience, impacting the entertainment industry.

Figure 2. Motion capture in Avatar: the way of water (Source: [11])

MoCap is extensively utilized in the animation and film production sectors. Its ability to record authentic movements from actors or objects facilitates the creation of realistic and natural animated characters, contributing significantly to the visual appeal of films and animated content. In the realm of game development, motion capture plays a crucial role in creating lifelike character animations. This enhances the gaming experience by providing characters with realistic movements, thereby increasing the overall interactivity and immersion for players. In the context of film production, motion capture is key to improving efficiency by directly recording the movements of actors, reducing the need for time-consuming traditional frame-by-frame animation. This technology is also widely integrated with computer-computer-generated imagery (CGI) to create characters or creatures that may be challenging to realize with practical effects, as seen in games like Avengers: endgame and Avatar: the way of water.

The use of MoCap in the film industry presents digital characters with highly convincing movements that align with human motions with high precision. By recording actor movements into digital models, MoCap creates realistic responses to the virtual environment. This not only enhances visual appeal but also eliminates the robotic impression often associated with traditional computer animation. MoCap not only observes body movements but also recognizes facial expressions and emotional nuances. This creates more realistic responses to the virtual environment. For example, a digital character can naturally respond to specific situations, such as laughing, crying, or showing surprise. Through MoCap, digital characters become not only static representations but living entities with natural movements. This creates visually appealing images and makes the audience feel involved in the unfolding story This aligns with [37], who states that MoCap can overcome the issue of robotic effects by presenting natural movements, eliminating stiffness that can reduce the visual appeal and the authenticity of the cinematic experience. By leveraging MoCap technology, the film industry has been able to create digital characters that not only look like real humans but also express emotions and interact with their virtual environment in a highly convincing manner.

D. Medical Simulation and Rehabilitation

Motion capture finds application in medical simulations where it aids in recording and analyzing human body movements. This is particularly valuable for training medical professionals, analyzing patient movements, and developing tailored medical treatment solutions. The technology is employed in medical rehabilitation programs to monitor and analyze patient movements. This assists healthcare professionals in designing personalized recovery programs tailored to individual needs, contributing to the rehabilitation process. The use of motion monitoring in rehabilitation by [33], developed using semantic segmentation masks to focus on infants, significantly improves scene initialization and demonstrates potential in creating new scene displays and tracking infant movements. This aligns with the findings of [38], who detected kinematic abnormalities in Individuals with knee osteoarthritis using Markerless motion capture during functional movement screens and daily activities. The result indicates that the functional movement screen has higher sensitivity than daily activities in identifying kinematic abnormalities in individuals with knee osteoarthritis, with knee flexion, trunk sagittal angle, and trunk frontal angle during in-line lunge as the most responsive indicators.

3. METHOD AND DATA

A. Method

This research employs the methodology of literature review and comprehensive analysis of motion capture technology in the context of 3D animation as a framework to gather relevant information. A thorough review is conducted on various aspects, including an evaluation of the strengths and weaknesses of motion capture systems, as well as an exploration of their potential development. This methodology specifically aims to identify challenges faced in using MoCap for 3D animation and pinpoint potential opportunities, such as advancements in technology or possible expansions in applications.

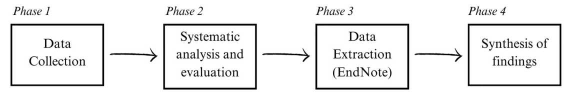

Figure 3. Conceptual approach

B. Data and Approach

The research literature sources are obtained through three online journal databases: IEEE, Google Scholar, and ScienceDirect. Literature sources include journal articles, books, and published conference proceedings. The literature analysis conducted in this study goes through four phases of approach. The flow of the approach is shown in figure 3. The obtained data amount to 300, consisting of scientific journals, proceedings, and theses. The data were analyzed in-depth and evaluated, leading to the identification of the final set of data used in the research, which comprised 25 entries. Subsequently, these data were extracted and synthesized at the end of the phase.

1) Phase 1: Data Collection

Identification and implementation of data collection methods aligned with the research objectives. This approach includes the selection of data collection instruments (interviews, surveys, observations), experimental design, and/or the use of secondary data. The focus is on aligning methods with research questions and objectives.

2) Phase 2: Systematic Analysis and Evaluation

Selection of an analytical approach appropriate for the type of data collected. For example, if the data is qualitative, researchers may apply thematic analysis or content analysis. If the data is quantitative, statistical analysis may be applied. The basic concept here is to maintain consistency and precision in conducting the analysis to gain a profound understanding.

3) Phase 3: Data Extraction using EndNote

EndNote is a reference management tool used to organize and compile references. The conceptual approach here involves a good understanding of how to use EndNote to manage literature, extract data from relevant sources, and ensure the accuracy of citations and efficient reference management.

4) Phase 4: Synthesis of Findings

At this stage, the conceptual approach involves integrating research findings, interpreting data, and forming a cohesive conclusion. Researchers must ensure that the

TABLE I. The challenge of MoCap in 3D animation

No	*Main Content*	*Point of challenges*	Author
1	The complexity of synchronizing motion data with a 3D model	Coordinate systems, data resolution, and motion complexity. Time and synchronicity, latency, and interpolation and processing techniques. Motion recognition and correction, and the use of markers and annotation modeling	[39], [40], [41] [42], [43], [44]
2	Algorithm in human motion	Motion segmentation, feature extraction, and context understanding. Machine learning for motion classification and sensor correlation analysis.	[45], [46], [47] [48], [49], [50] [44]
3	Advancements in motion capture technology	Advanced sensors. Use of inertial technology and visual monitoring. Real-time data processing. Implementation of deep learning. Contextual understanding. Miniaturization and portability.	[51], [52], [39] [53], [54], [45] [46], [48], [49] [40], [55], [56] [50], [57], [58] [42], [59], [60] [61], [43]

synthesis of findings is based on the conceptual framework developed earlier and is relevant to the research questions. Combining findings with existing literature and identifying practical implications and future research directions are also part of the conceptual approach at this stage. By adopting a conceptual approach in each phase, the research establishes a strong theoretical and methodological foundation.

4. RESULT

A. Challenges of Motion Capture in 3D Animation

Although MoCap is becoming more popular with its benefits, integrating it into 3D animation is not a simple task. This process involves several challenges, including the complexity of synchronizing motion data with the 3D model, understanding algorithms for human motion, and improving the motion capture technology itself. From various collected literature, a thorough analysis was conducted. Some of the most common and relevant challenges found in motion capture for 3D animation in this study are shown in Table I.

1) The Complexity of Synchronizing Motion Data with the 3D Model

One of the main challenges in integrating MoCap with 3D animation is the complexity of synchronizing motion data with the 3D model. This process involves harmonizing the motion data obtained from MoCap sensors with the digital character model existing in the virtual environment. As mentioned by [32], [42], this challenge arises due to differences in coordinate systems, data resolution, and the complexity of movements that must be accurately mapped into the 3D model. Motion data from MoCap sensors is generally measured in a global coordinate system, which may differ from the local coordinate system used in the 3D model. Synchronization requires transforming motion data

TABLE II. Main findings

No	*Indicator (finding)*	*Implication/solution*
1	Accessibility of motion capture technology	Motion capture technology is becoming more accessible to various groups, including independent content creators and and small developers. The decrease in the price of motion capture devices and the availability of more affordable software solutions have increased its accessibility.
2	Ease of use	Modern motion capture solutions increasingly integrate user-friendly interfaces, simplifying the usage process even for users with limited technical backgrounds. Online tutorials and guides have contributed to the ease of use, reducing barriers for those who want to use motion capture technology.
3	Data quality in 3D animation	Innovations in motion capture sensors and software have improved the accuracy and quality of the generated data. The increase in sensor resolution and data processing algorithms has brought significant improvements in replicating movements with a higher level of detail.
4	Challenges still faced	Despite the improved accessibility, some challenges persist, such as resource availability and operational costs. Adaptability to various types of projects and specific needs remains a focus of development.
5	Implications for the industry	The results of this research provide valuable insights for the 3D animation industry, particularly in selecting motion capture solutions that align with needs and budgets. The development of more affordable motion capture technology can open doors to more creative and innovative projects.

to match the coordinate system of the 3D model. Additionally, MoCap sensors may produce data with different resolutions, while the 3D model may have a higher resolution. The synchronization process requires interpolation or data processing to ensure resolution compatibility between motion data and the 3D model.

Not all recorded movements can be easily mapped directly to the 3D model. Some movements may be more complex or simpler than what can be represented by a digital character model. This necessitates sophisticated interpolation or approximation techniques to address differences in movement complexity [39]. It is crucial to ensure that motion data and the 3D model are in precise temporal synchronization. Small errors in timing can result in animations that appear unnatural or strange. Moreover, MoCap sensors may have latency that needs to be balanced to make the movements appear responsive and in line with the virtual environment's dynamics. According to [53], [46], [40], interpolation techniques such as splines or complex mathematical algorithms can be applied to smooth out movements and fill in data gaps. Additionally, applying filters or signal processing techniques can clean motion data from noise or jitter that may occur during the data capture process and identify significant movement differences from unwanted noise or motion. There are other complexities in motion capture data synchronization, such as correcting movements that do not match the 3D model's characteristics by ensuring that markers on the body or objects used in MoCap align with the 3D model. In this case, animators can use annotation models to provide additional information about movements to aid in more accurate mapping. Handling these complexities requires a combination of skills in mathematics, programming, and a deep understanding of both MoCap systems and 3D models. State-of-the-art technologies like deep learning and machine learning are also employed to enhance accuracy and automation in the synchronization process [46], [47], [44].

2) *Algorithm for Human Motion*

The next challenge is understanding algorithms for human motion. Although MoCap sensors can record motion data, sophisticated algorithms are needed to interpret and transfer this data into natural-looking digital character movements. As mentioned by [45], ineffective algorithm understanding can result in movements that appear unrealistic or deviate from the actor's original intention. By identifying the strengths and weaknesses of the MoCap system, it is hoped that a solution can be found to achieve an optimal balance between accessibility and data quality. Algorithms can assist in breaking down complex movements into smaller segments that can be analyzed. This allows for a better understanding of how the body moves in the context of specific activities. Furthermore, algorithms can be used to extract important features from motion data, such as body pose, speed, and acceleration. This aids in identifying distinctive movement patterns and key characteristics. According to [45], [48], [49], data processing algorithms can help understand the context surrounding movements. For example, they can identify whether someone is walking, running, or performing other specific actions. In terms of technology, machine learning approaches can be used to classify types of movements based on MoCap data, enabling the development of models that can automatically recognize and categorize human movements. Therefore, algorithms can further be employed to analyze correlations among MoCap sensors [46], [47], [50], [44]. This, in turn, will help rectify inaccuracies or time differences among the sensors used.

3) *Advancements in Motion Capture Technology*

The development of motion capture technology continues, yet challenges arise when hardware and software struggle to effectively capture highly complex or subtle movements. Errors in measurement or resolution limitations can lead to inaccuracies in reproducing movements in 3D animation. Research by [51], [54], [45], [48], [49], [50], [42], [44] suggests that the advancement of more sophisticated MoCap sensors with higher accuracy can enhance the quality of obtained data. Sensors capable of high-precision measurements and capturing movements with better resolution will yield more accurate data [53], [55], [56], [57], [60]. The combination of inertial and visual monitoring technologies can provide greater advantages, helping overcome the limitations of a single sensor type and offering more information about movements. Improvements in real-time data processing capabilities allow for quick responses to changes in motion, crucial for applications requiring direct and real-time interaction.

The application of deep learning algorithms can assist in analyzing complex movement patterns. Deep learning models can learn from large datasets and produce better representations of human motion [53], [49], [50], [58] . Integrating technology that understands context can enhance the system's ability to recognize movements in different situations, whether in a virtual environment or the real world. The development of smaller, lighter, and portable MoCap sensors can improve accessibility and enable their use in various contexts and locations[51], [52], [53], [54], [46], [40], [59], [61]. These challenges, along with other issues such as the need for accurate calibration and noise mitigation in data, create complexity in developing an effective and accurate MoCap system for 3D animation. The integration of motion capture with 3D animation requires careful approaches and innovative solutions to address these challenges and ensure the results meet expectations in creating digital characters with realistic and natural movements.

B. *Accessibility, Simplicity, and Data Quality in the Motion Capture Process*

The main findings related to accessibility, simplicity, and data quality in the motion capture process are shown in Table II where there are several indicators and implications. The motion capture process begins with placing markers on the object or human body to be recorded. Sensor systems and cameras then capture the movement of markers in real time or during specific recording sessions. The generated data is then processed to create a 3D motion model. Accessibility, in the context of motion capture technology, involves ease of use and the availability of devices. In the world of 3D animation development, optimal accessibility not only simplifies the implementation of motion capture technology but also plays a crucial role in opening broader opportunities for various studios and creative individuals. When motion capture systems become more affordable and easily accessible, the doors of innovation swing wide open, providing opportunities for animation industry professionals from all walks of life to adopt and leverage this technology. Consequently, increased accessibility not only creates a more inclusive environment but also stimulates industry growth by enriching the diversity of ideas and creativity applied in the world of 3D animation.

Simplicity in the motion capture process is significantly relevant to the level of operational ease of a system without sacrificing data quality. When a system can be operated easily without requiring deep technical expertise, it opens the door to a diverse range of users, including those who may not have a strong technical background. The advantage of simplicity lies not only in the aspect of easier use but also in the improvement of workflow efficiency. A simple system can expedite the motion capture process, enabling users to achieve satisfying results quickly and effectively. The speed in task execution not only means more efficient use of time but also provides greater flexibility for users to focus on the creative aspects of their work without being hindered by simplicity in the process also has a positive impact on financial aspects. An easily operable system not only reduces the burden of initial implementation costs but also offers potential long-term maintenance cost reductions. In other words, simplicity not only enhances the initial affordability of a system but also adds value through reduced operational costs over time. Therefore, simplicity is not only a determining factor in ease of use but also plays a key role in supporting the sustainability and competitiveness of a motion capture solution.

The quality of motion capture data is a central point that underlies the creation of 3D animations that appear realistic and natural. To achieve optimal data quality, a high level of accuracy is required in recording every movement. This involves efforts to reduce noise that can blur details and address potential issues such as the emergence of double silhouettes, which can diminish the authenticity of the recorded movements. In this context, achieving good data quality is not merely a matter of accuracy but also involves finding a balance between accuracy and data acquisition speed. Technology that can present a harmony between high accuracy and efficiency in the data acquisition process plays a crucial role in producing impressive 3D animations. An effective motion capture system is not only capable of recording movements with high precision but also can do so without sacrificing the speed of data acquisition. Thus, such technology not only supports the creation of more realistic animations but also ensures that the animation production workflow can proceed efficiently and effectively. To meet market expectations for increasingly realistic 3D animations, attention to motion capture data quality as a key element becomes increasingly important. Therefore, the continuous development of motion capture technology improving data quality, minimizing noise, and addressing issues such as double silhouettes become a fundamental foundation to propel the animation industry to higher levels.

C. Discussion

The findings and implications of this research depict a complex and diverse landscape in the use of motion capture for 3D animation. Firstly, the aspects of quality and real-time efficiency emphasize the importance of selecting a motion capture method that is not only efficient but also accurate to ensure high-quality 3D animation results. The balance between processing speed and motion precision is key to achieving this goal. When looking at the spectrum of motion capture usage, the research highlights that this technology is not limited to high-budget film industries but also extends to consumer applications. The variation in needs between large-budget projects and projects with limited budgets highlights the flexibility of motion capture in various contexts. The by excessive technical complexity. Furthermore, the importance of balancing accessibility and quality is that in choosing a motion capture system, it is necessary to consider how far the technology can provide adequate data quality without significantly increasing costs. The availability of affordable yet accurate solutions pose a challenge that needs to be dealt with. The spotlight on the role of machine learning algorithms suggests that motion capture technology can be further enhanced with artificial intelligence integration. Machine learning algorithms can help improve accuracy and data processing, unlocking new potentials for the development of this technology. The emphasis on Balance, as recognized in this research, underscores that achieving success in motion capture use requires alignment between accessibility, data quality, and real-time efficiency. This necessitates careful attention to each of these key elements during the implementation process. Finally, the potential and challenges in the development of motion capture technology highlight that while this technology has great potential in creating realistic 3D animations, challenges such as costs, resource needs, and integration with animation software remain a focus of concern.

Implications in the practice of the 3D animation industry: the research findings provide deep insights into the challenges and advantages of integrating motion capture technology in 3D animation production. By understanding the complexity of this process, the animation industry can identify areas where motion capture can provide significant added value, such as creating more realistic and expressive characters. However, challenges like the complexity of synchronizing motion data with the 3D model also need to be considered to ensure the successful implementation of motion capture.

Future development of motion capture technology: the research findings highlight the potential use of machine learning algorithms to improve the accuracy and efficiency of motion capture data processing. This provides an in-depth view of the direction of future development in motion capture technology, where integration with machine learning technology can bring significant improvements in the quality and speed of the motion capture process.

Contribution to the development of the 3D animation industry: by understanding the challenges and potential of motion capture, this research contributes to the overall development of the 3D animation industry. The implications of the research findings include the potential use of motion capture in film production, video games, and other applications, providing insights into how this technology can bring significant changes to the visual experience for audiences.

D. Limitations

In outlining the limitations of the conducted research, excluding in-depth case studies or field research. This approach was chosen to investigate and extract relevant information from existing textual sources. Additionally, the data and literature utilized in this research were confined to sources accessible through specific online databases. In other words, the sources accessed for literary analysis were restricted by their availability and accessibility through the designated database platform. However, it should be noted that these limitations resulted in the inability to comprehensively explore certain aspects of motion capture and 3D animation that may exist beyond the scope of these literary sources. Therefore, the outcomes of this research do not encompass all dimensions or nuances that may exist in the broader context of motion capture and 3D animation.

E. Considerations for future research

The case study of motion capture implementation provides concrete insights into the application of this technology in 3D animation production, whether in the film industry, video games, or other applications. In future research, the focus can be placed on exploring the practical challenges and advantages encountered during the implementation of motion capture. Through case studies, this research is expected to offer a deep understanding that is valuable for optimizing the use of motion capture in the context of 3D animation production. Furthermore, future research can delve into the development of machine learning algorithms specifically designed to enhance the accuracy and efficiency of motion capture data processing. The presence of more advanced algorithms can bring significant improvements to motion capture technology, creating a stronger foundation for the development of more sophisticated applications. By concentrating on this aspect, future research will make a significant contribution to the advancement of more effective and advanced motion capture technology. By combining both research directions, the study can holistically enrich our understanding of the integration of motion capture in 3D animation and drive further progress in this field.

5. CONCLUSION

The findings of this study reveal that the selection of motion capture methods should consider real-time quality and efficiency to achieve high-quality 3D animation. Motion capture technology demonstrates its flexibility from film production to consumer use, adapting to projects of various scales. Moreover, the balance between accessibility and quality in choosing a motion capture system is a pressing need, requiring an affordable solution that still provides adequate data. This research also identifies the role of machine learning algorithms as a crucial aspect in enhancing the accuracy and processing of motion capture data. Finally, an analysis of the potential of this study specifically focused on literary analysis, and obstacles of motion capture, including costs of animation software integration, provides a comprehensive overview of the complexity and potential of motion capture in 3D animation. For future research, it is recommended to further optimize the real-time quality and efficiency of motion capture. The balance between accessibility and the quality of motion capture results could be explored in greater depth. Additionally, future research could focus more on the role of machine learning algorithms in improving motion recognition accuracy and data processing efficiency. Lastly, the research could be expanded to various other aspects, such as psychological and interaction aspects of motion capture for business model development in the industrial sector

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