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Analysis of Motion Capture Technology Research and Typical Applications

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Abstract: Motion capture technology is one of the key topics of current research, with researchers exploring its applications in fields such as sports, entertainment, and video games. However, there is a research gap in current mainstream motion capture analysis based on different sensors. This study analyzes motion capture systems using contact and non-contact sensors, discussing their respective advantages, disadvantages, and solutions, particularly in terms of their performance in various industries, as well as issues such as data drift, accuracy, and cost. The research methods involve multiple capturing techniques included in both contact and non-contact motion capture. The results indicate that future motion capture technology will focus on cost optimization, device miniaturization, and markerless technology development. Additionally, motion capture has potential applications in psychology, with a hypothesis proposed for the development of emotion-responsive motion capture through in-depth integration with AI, which could be a major breakthrough. This evolution of motion capture technology aims to foster innovation across more application fields.

Keywords: Motion Capture Technology, Sensors, Markerless Motion Capture, Artificial Intelligence, Deep Learning.

1. Introduction

Since the 1990s, Motion Capture technology has developed rapidly and is now found in many applications, including film and television production, game development, sports analysis, medical rehabilitation, virtual reality, and augmented reality. The core principle involves digitally capturing the trajectories of moving objects or the human body to accurately reproduce dynamic behaviors. This technology further enhances the realism of virtual character animation while providing valuable data for rehabilitation therapy and behavioral analysis research in medicine, psychology, and sports science [1-4]. The further development of this technology has opened up new avenues for interdisciplinary applications, significantly advancing creativity in the entertainment industry and providing robust technical support for sports optimization and rehabilitation medicine [3,4]. In the entertainment sector, MoCap technology improves the authenticity of virtual characters; in the medical field, it is applied to optimize patient rehabilitation assessments and treatment plans [1,4]. This paper will focus on motion capture technology and its typical methods, highlighting the advantages and challenges encountered in various applications. Markerless motion capture, based on deep learning and computer vision, enables motion capture without physical markers, enhancing the technology's flexibility and intelligence [5,6]. With the integration of AI and deep learning, Motion Capture is becoming increasingly intelligent, with broad prospects in fields such as machine learning and autonomous driving. This review particularly covers both contact-based and non-contact Motion Capture technologies, including inertial, mechanical, electromagnetic, optical, depth cameras, and LiDAR technologies. The development of Motion Capture technology is not limited to traditional entertainment and medical fields but is continuously expanding into emerging areas. With advancements in AI and deep learning, motion capture technology has become more intelligent and automated. In the future, MoCap will be more widely applied in high-tech fields such as autonomous driving, intelligent robotics, and virtual reality, providing foundational support for innovation in these industries. Additionally, with the widespread adoption of markerless technology, Motion Capture systems will become more flexible and user-friendly [5], further reducing equipment costs, enabling entry into more everyday application scenarios. Overall, Motion Capture technology is expected to achieve broader interdisciplinary integration in the future, driving technological progress and innovation across industries.

This paper aims to systematically review the implementation of modern motion capture technology and analyze adaptation methods while discussing its current applications and technical challenges in various industries. It evaluates the strengths and weaknesses of existing technologies and suggests potential future development directions, such as the popularization of markerless Motion Capture technology and its integration with artificial intelligence, which may promote widespread application in the Motion Capture field. Based on a literature review and analysis of existing technologies, this study delves into motion capture technology. It first introduces contact-based Motion Capture technologies, including inertial sensors, mechanical, and electromagnetic methods. Most of these rely on sensors and exoskeletons to capture motion by measuring the rotation angles of human joints [7]. The paper then continues with non-contact techniques: optical systems, depth cameras, and LiDAR. A comparative analysis is conducted on the performance of each technology in different application scenarios, considering factors such as cost, accuracy, occlusion handling, and device convenience. Data analysis is based on the results of the literature review and typical application scenarios, focusing on fields such as healthcare, entertainment, and virtual reality.

2. Motion Capture Technology (MoCap)

2.1. Basic Process of Motion Capture

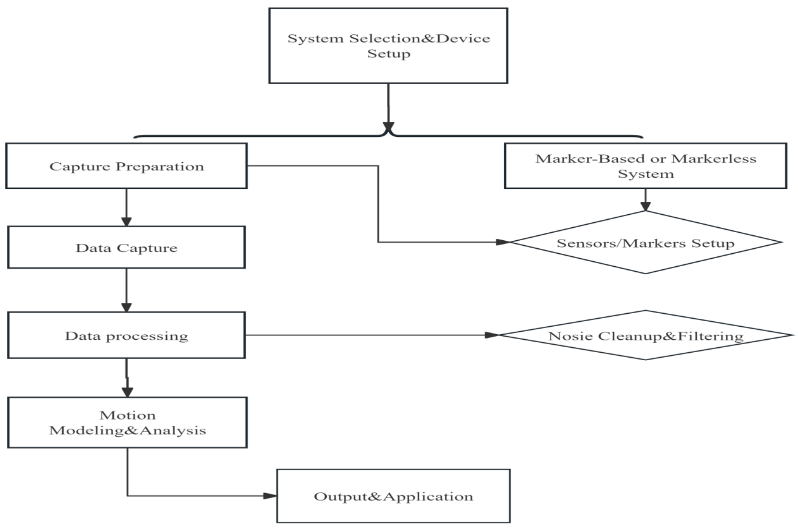

Figure 1: Process of Motion Capture

The diagram as show in Figure 1 outlines the fundamental workflow of a Motion Capture (MoCap) system, detailing the sequence of steps involved in capturing, processing, and analyzing motion data for various applications.

2.2. Motion capture based on sensor classification

The mainstream motion capture technologies in the market, based on sensors, can be categorized into contact-based and non-contact-based systems.

Contact-based Motion Capture: A technique that captures motion by placing sensors or markers at key points on the human body or object.

Non-contact Motion Capture: A technique that captures motion using remote sensors without the need to place any physical devices or markers on the human body.

Six popular motion capture technologies can be derived from contact-based and non-contact-based systems, as demonstrated in Table 1.

Table 1: A Comparative Overview of Motion Capture Technologies.

	Subtype	Advantages	Disadvantages	Applications	Authors
Mechanical Motion Capture	**Contact-based**	Accurate, real-time prediction, complex	Sensor errors, magnetic interference, needs calibration	Real-time motion prediction in healthcare, virtual reality, and sports	Huailiang Xia et. al. [8]
Mechanical Motion Capture	**Contact-based**	High precision, no camera needed, works in obstacles	Bulky, restrictive, expensive setup	Precision joint data in rehabilitation and robotics	Nakashima M et. al. [7]
Electromagnetic Motion Capture	**Contact-based**	Energy-efficient, low-frequency, wearable tech	Sensitive to magnetic fields, environmental interference	Wearable tech, energy harvesting	Ge Shi et. al. [9]
Optical Motion Capture	**Non-contact**	High precision, accurate for full body tracking	Requires multiple cameras, occlusion, lighting issues	Film production, clinical motion analysis	Dasgupta A et. al. [5]
Depth Camera Motion Capture	**Non-contact**	Lighting-independent, 3D data, privacy protection	Expensive, complex tasks affect performance	Surgical skill assessment, hand movement tracking, VR simulations	Zuckerman, I. et. al. [10]
LiDAR Motion Capture	**Non-contact**	Large-scale capture, accurate in outdoor environments	Sparse data, occlusion, complex data fusion	Outdoor multi-person tracking, robotics	Yiming Ren et. al. [11]

3. Challenges and Current Solutions

3.1. Challenges

Contact-based: It relies on multiple sensors, making it prone to interference and slower data transmission, especially in complex environments where it is susceptible to magnetic field disturbances [8].The system's equipment is bulky, affecting the naturalness of movement and making it inconvenient to use in dynamic motion scenarios[7]. Although motion capture technology offers high accuracy, the need for extensive cable connections significantly restricts the range of motion, and interference in magnetic field environments remains a serious challenge[9].

Non-contact: Motion capture systems are prone to occlusion and line-of-sight limitations, particularly in multi-character or complex environments[11].In complex postures or large-scale motion scenarios, point cloud data is prone to distortion, affecting accuracy[10]. Markerless motion capture relies on computer vision, but its accuracy in complex movements still needs improvement, with errors being particularly significant during high-speed motions[6].

3.2. Current Solutions

Occlusion and data loss issues: Deep learning algorithms, such as U-net and LSTM, have been used to restore lost marker data, particularly in cases of prolonged data loss. By combining synchronized data from multiple cameras with adaptive regression models, reconstruction errors can be significantly reduced [12]. Real-time data completion techniques based on deep learning have enabled the rapid reconstruction of occluded motion segments. Additionally, multimodal fusion techniques have been employed to integrate different data sources (e.g., IMU and visual data), reducing the impact of occlusion in virtual environments [13].

Equipment costs and operational complexity: By integrating low-cost, portable sensors such as IMU, UWB, and radar systems with optical systems, it is possible to enhance capture flexibility and accuracy while reducing costs, making it particularly suitable for large-scale dynamic motion scenarios [14].

4. Industry applications of motion capture

4.1. Medical applications

In the field of medical rehabilitation, motion capture technology has been widely used to assess and analyze patient movements without the need for physical markers. This system, known as markerless motion capture (MMC), uses computer vision to record natural human motion, supporting clinical assessments and rehabilitation training. MMC has been applied to evaluate motor functions in conditions such as Parkinson's disease, cerebral palsy, and post-stroke recovery, providing reliable joint movement data, detecting gait abnormalities, and assessing treatment effectiveness. It serves as a non-invasive and efficient tool for tracking rehabilitation progress, playing a vital role in modern medical evaluations [4].

4.2. Film

In film production, motion capture systems have been key tools for creating realistic character animations. Using specially designed suits with marker sensors, high-resolution cameras can accurately capture actors' motion data. This technology allows filmmakers to accurately reproduce complex movements and facial expressions, resulting in lifelike virtual characters. However, a major challenge for this system has been occlusion, particularly when capturing fine movements, such as fingers, or interactions involving multiple actors [15]. Figure 2 shows the application of motion capture in the rising film industry of Planet of the Apes.

Figure 2: Motion Capture in film applications[15]

4.3. Game

In the gaming industry, motion capture has been widely used to create realistic character movements and enhance player immersion. Using specially designed suits equipped with sensors, actors' movements are captured and converted into digital animations. This enables game developers to achieve smooth movements and realistic facial expressions for characters, as seen in games like The Last of Us and Assassin's Creed. However, the technology still faces challenges in capturing complex interactions, such as combat or fine hand movements, primarily due to sensor occlusion and motion blur during fast actions Colour[16]. Figure 3 shows the application of motion capture in the game.

Figure 3: Baby JJ Motion Capture splitscreen.[16]

Table 2: The applications of motion capture

Industry	Application	Specific Cases	Methods	Advantages	Authors
Healthcare	Rehabilitation training, clinical evaluation, AI-based analysis	Stroke recovery evaluation using Kinect, motion analysis for Parkinson's	Markerless motion capture, Microsoft Kinect, AI and deep learning models	Natural, non-invasive, detailed data for individualized rehabilitation	Lam, W.W.T.et . al. [3]

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Table 2: (continued).

Film	Creating virtual characters, facial expression capture, real-time feedback	Avatar, Planet of the Apes – virtual character creation	Marker-based optical capture, facial motion capture, multi-camera systems	Realistic movement, faster animation production, creative flexibility	Retinger, M.et. Al. [14]
Game	Character motion and expression, real-time capture, multiplayer interactions	Tomb Raider: Underworld, Hellblade: Senua's Sacrifice, Assassin's Creed	Optical capture with markers, facial capture, real-time capture for VR	High realism in character actions, immersive experiences, multiplayer control	Lavrador, E.et. Al. [16]

4.4. Applications of Motion Capture in Psychology

Motion capture has been widely used in the fields shown in Table 2 since the 1990s. However, in recent years, a literature review has revealed that motion capture has also been applied in psychology.

Motion capture has proven to be valuable in research on gesture-speech synchronization, emotional expression, and the impact of nonverbal behavior on cognitive processes. By accurately recording human movements and converting them into digital models, researchers have been able to analyze the relationship between actions and psychological states in depth. For example, studies on gesture-speech synchronization have found that temporal coordination of gestures significantly enhances memory for verbal information. Additionally, motion capture technology can precisely capture facial and bodily movements associated with emotional expressions, revealing nonverbal behavior patterns under different emotional states. Experiments conducted in virtual environments have further expanded the application of this technology, allowing researchers to control experimental variables through virtual characters and simulate realistic social interactions to analyze participants' psychological responses. The advantages of this technology include high-precision recording of subtle movements and real-time feedback, greatly enhancing the accuracy and control ability of psychological experiments[2]. Figure 4 shows the appearance and process of the speaker's wearing.

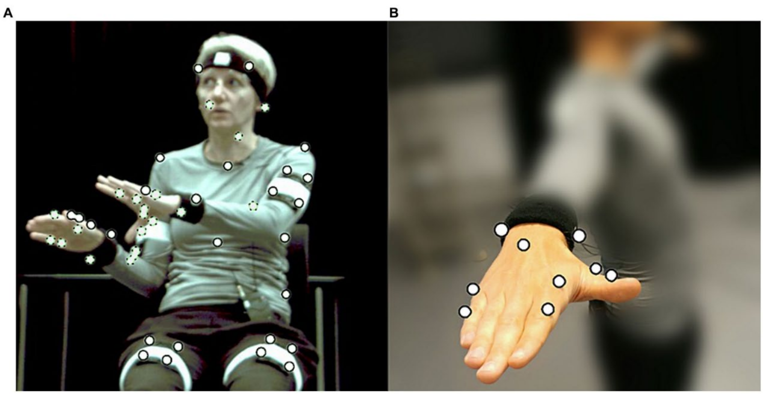

Figure 4: (A) Speaker during MOCAP recording wearing markers (white circles). Dotted outlines indicate markers concealed in the current view. (B) Placement of MOCAP markers on hands and fingers.[2]

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5. Future Prospects of Motion Capture

5.1. The Popularization of Markerless Motion Capture

Markerless motion capture technology relies on computer vision and artificial intelligence, enabling the capture of human dynamic information without the need for physical markers or devices. In the future, markerless motion capture is expected to achieve breakthroughs in accuracy, real-time processing, and naturalness, particularly in fields such as virtual reality, film production, and sports science. The popularization of this technology will reduce costs and simplify operations, making motion capture systems accessible to general users and small enterprises [5,15].

5.2. Deep Integration with Artificial Intelligence (AI)

The rapid advancement of AI and deep learning models has significantly enhanced the intelligent processing capabilities of motion capture, particularly in automated data analysis, motion prediction, and lost data recovery. AI-based motion capture systems are capable of autonomously learning and predicting complex human motion trajectories, handling more intricate multi-subject scenarios, and generating high-precision motion data in real time. Table captions/numbering [1].

5.3. Capture in Multi-Subject Scenarios

The application of motion capture in multi-subject and complex scenarios is expected to become more widespread. With advancements in system processing capabilities and algorithms, future developments will enable more accurate capture of dynamic interactions among multiple subjects, providing precise data support for fields such as sports performance and medical rehabilitation[16].

5.4. Future Research Directions

The development of emotion-responsive motion capture could represent a breakthrough in the field of motion capture. This technology would not only record the subject's physical movements but also adapt flexibly based on emotional states. By integrating real-time emotional feedback—derived from physiological signals such as heart rate, micro-expressions, and voice changes—the system adjusts the way movements are read and represented. The specific process is illustrated in Figure 5.

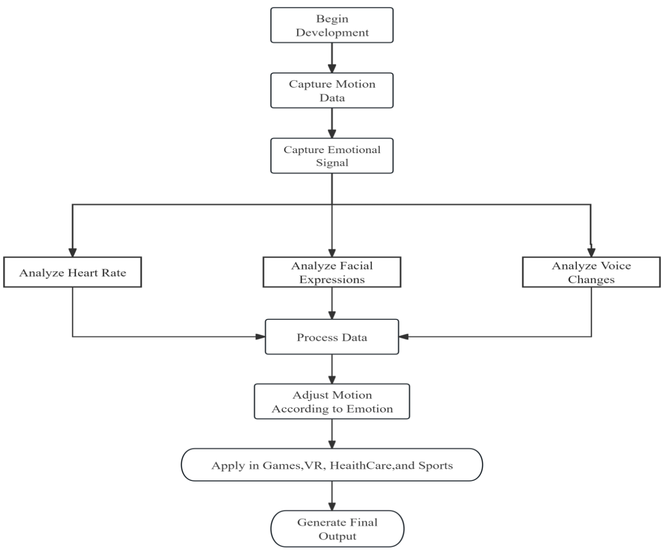

Figure 5: Emotion-Responsive Motion Capture: A New Breakthrough

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6. Conclusion

This paper provides a systematic review of motion capture technology and its applications across various fields, with a focus on analyzing the advantages and disadvantages of contact-based and non-contact-based capture systems, particularly in medical, entertainment, and sports science applications. By examining multiple technologies, such as inertial, mechanical, electromagnetic, optical, depth cameras, and LiDAR, the study explores issues related to accuracy, data processing, and cost. The findings indicate that future developments in motion capture will move toward cost optimization, lightweight equipment, and markerless capture, with further integration with artificial intelligence (AI) driving increased system intelligence and adoption.

In the future, markerless motion capture is expected to be applied in a wider range of fields due to its convenience and low cost, particularly in virtual reality, film production, and sports analysis. With deeper integration of AI and deep learning, motion capture technology will achieve significant improvements in accuracy and real-time performance, enabling more complex and detailed motion prediction and data recovery. This will provide robust technical support for areas such as education, intelligent robotics, and autonomous driving, further advancing the broad adoption and development of motion capture technology.

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