Motion Capture Technology in Animation

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Abstract

Motion capture is a pivotal technology that has revolutionized various industries, from entertainment and sports to healthcare and robotics.
This paper provides a concise overview of motion capture technology, including its methods, applications, and the associated advantages and disadvantages. Motion capture is a versatile tool with applications in fields such as entertainment, healthcare, and robotics. The advantages of precision and efficiency it offers are balanced by challenges related to cost, equipment, and privacy concerns. Understanding these aspects is crucial for harnessing the full potential of motion capture in several trades.

Keywords: - *Motion Capture technology, mocap, CGI in mocap, motion capture sensors, marker-based and markerless mocap*

1. INTRODUCTION

Motion capture is a widely employed technique that involves the meticulous recording of objects or human movements. Its applications span across various domains, such as the military, entertainment, sports, and healthcare, while also playing a crucial role in validating computer vision systems and enhancing robotic performance. [6][7] Particularly in the realms of filmmaking and video game development, motion capture is instrumental in recording the actions of human actors and translating this data into the animation of digital character models, be they 2D or 3D representations. [5] When it extends to capturing subtle facial expressions and intricate finger movements, it's often termed "performance capture." It's worth noting that motion capture is sometimes synonymous with "motion tracking," although, in the context of filmmaking and gaming, the latter term predominantly pertains to match moving.

During motion capture sessions, the movements of one or more actors are meticulously sampled multiple times per second. While earlier techniques relied on imagery from multiple cameras to compute 3D positions, contemporary motion capture primarily focuses on recording actors' movements, separating them from their visual appearances. The recorded animation data is then applied to a 3D model, ensuring that the model mirrors the actions of the actor, marking a departure from the traditional technique of rotoscoping. [8] This process necessitates the estimation of the physical space, encompassing location and direction, and its meticulous documentation through computerized systems.

[9] Figure 1 shows the setup required for motion capture using multiple cameras, sensors, and computerized systems in a spacious environment.

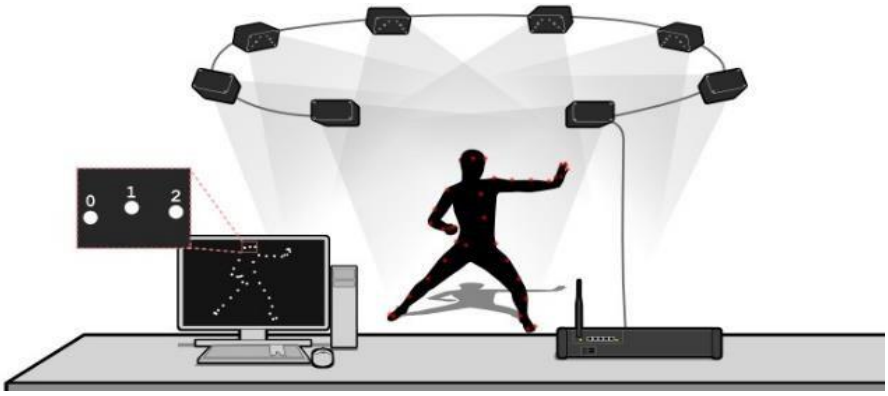


Figure 1. Set up for motion capture using multiple cameras.

2. Literature Review and Evolution

In 1915, Max Fleischer, a pioneering animator, introduced a groundbreaking technique known as rotoscoping. This innovation enabled the creation of lifelike movements for animated characters by superimposing hand-drawn frames onto live-action film footage. Max Fleischer, in a creative endeavor, utilized footage of his brother donned in a clown costume dancing on a rooftop. He painstakingly traced each frame of this live-action footage onto the animation of Koko the Clown, marking the birth of rotoscoping.

The impact of rotoscoping extended beyond the Fleischer studio. It played a pivotal role in some of Disney's most beloved classics, including "Snow White and the Seven Dwarves" and "Alice in Wonderland." This technique brought a level of realism and fluidity to animation that was unprecedented in its time.

In the 1950s, animator Lee Harrison III embarked on a journey to develop the world's inaugural motion capture suit. This innovative suit could capture and instantaneously animate an actor's movements. The bodysuit was equipped with potentiometers that meticulously recorded every motion, translating them into rough animations displayed on a monitor. Over the subsequent two decades, animators made significant strides in improving these suits. They embedded active markers within the suits and employed substantial cameras to track movements, resulting in highly detailed and precise digital animations.

In the early 2000s, motion capture technology continued to evolve, but it was filmmaker James Cameron who sought to push the boundaries even further. Cameron's vision for the film world necessitated a more advanced mocap technology. He patiently waited for the tech to catch up, ultimately pioneering a "virtual camera." With this innovative technology, Cameron could observe the CGI representations of actors in real-time as their performances were being captured. These live streams were projected onto a monitor, immersing him within the digital world of

Pandora. Cameron's contributions propelled motion capture to new heights, transcending traditional suits and sets. His groundbreaking work earned him three prestigious Academy Awards, marking a new era in the world of filmmaking and motion capture technology. [10][11]

3. Motion Capture Methods

Since the remarkable success of "Avatar," motion capture technology has seen continuous advancements. Filmmakers now have an array of motion capture options at their disposal. These include marker-based systems, which rely on tracking physical markers attached to actors, and markerless systems, utilizing software to track actors' movements by identifying distinctive features.

Motion capture has come a long way since it was first created in the 1970s and 1980s as a photogrammetric analysis tool in biomechanics research. As technology has advanced, it has found uses in training, education, sports, and more recently, computer animation for movies, television shows, and video games.

In the earlier days, performers were required to attire markers nearby respectively joint to facilitate motion identification through marker points or angles. Various marker types, including acoustic, inertial, LED, magnetic, and reflective markers, or groupings thereof, have been used. The system's resolution, both spatial and temporal, plays a crucial role, with motion blur posing challenges similar to small resolution.

Novel approaches have evolved with the advent of the 21st century and significant technology breakthroughs. Nowadays, the majority of systems are able to separate the performer's silhouette from the background and use mathematical modeling to calculate the joint angles. For movements not readily visible in silhouette changes, hybrid systems have been introduced, combining marker and silhouette techniques with a reduced marker presence.

Moreover, in the field of robotics, certain motion capture systems utilize simultaneous mapping and localization methods to improve their performance. This ongoing evolution of motion capture technology continues to shape diverse fields, expanding the possibilities for realistic, dynamic movement representation. [12]

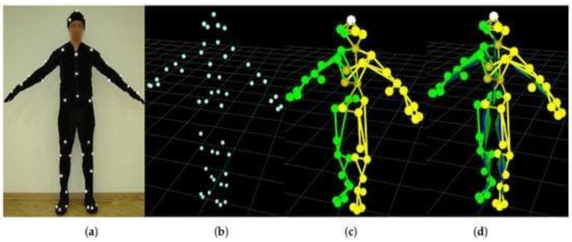
3.1 Optical Capture

Optical motion capture (OMC) systems leverage image sensors to capture data that enables the triangulation of a subject's 3D position. These systems typically involve multiple cameras, strategically calibrated to provide overlapping projections. In the traditional approach, data acquisition relies on special markers affixed to actors, but contemporary systems have evolved to dynamically identify surface features for each unique subject, eliminating the need for markers. More cameras are added to accommodate larger groups of performers or to increase the capturing area. Joint angle calculations are made easier by these systems, which provide three degrees of freedom for every marker. Rotational data is also derived from the relative location of three or more markers, including the wrist, elbow, and shoulder. Lately, hybrid systems have surfaced that combine optical and inertial sensors to reduce occlusion, improve multi-user tracking, and reduce the need for post-capture data cleaning.[5]

Optical motion capture fundamentally operates through the visual chasing and triangulation of markers, be they active or retro-reflective passive markers. This technique adheres to a rigid body model, where the incessant points of these markers, recorded as trajectories, become pivotal in later stages of data processing. The resulting trajectories serve as the driving force behind the creation of an associated skeleton model, which holds great significance in the animation of a diverse array of characters, whether they be human-like or animal, within the realms of animation, gaming, and simulation. [13]

Neural network architectures are used to build a skeleton model with the data acquired. Some methods of doing this are the ‘Optical Motion Capture Pipeline’ as shown in Figure 2, the ‘Functional Body Mesh’ method as shown in Figure 3, and many more.

Figure 2 The motion capture pipeline consists of the following stages: actor (a); registered



markers (b); body mesh (c); mesh matched skeleton (d).

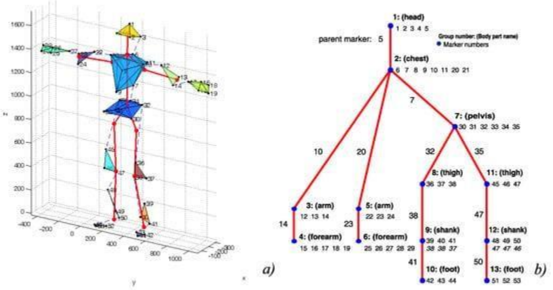


Figure 3. Annotated with parents and siblings, the body model's outline (a) and corresponding parts hierarchy (b) are shown.

3.1.1 With Markers

In this method, specialized markers are strategically placed on the actor's body to precisely track their movements. These markers serve as reference points, enabling the motion capture system to record and replicate the actor's actions with remarkable accuracy. Marker- based mocap is particularly useful in scenarios where precise, detailed motion data is required, such as in the creation of lifelike characters for films, video games, and scientific research.

3.1.1.1 Passive Markers

With order to reflect light that is produced close to the camera's lens, passive optical systems employ markers coated with a retroreflective substance. It is possible to change the camera's threshold such that flesh and fabric are not sampled and only the bright reflecting markers are. The light is reflected by a retroreflector, as seen in Figure 4. [14]

Figure 4. A gold corner cube retroreflector

The cameras are calibrated, their positions are determined, and each camera's lens distortion is measured using an item to which markers have been placed at known points. A three-dimensional fix can be established by observing a marker with two calibrated cameras. These systems usually consist of 2 to 48 cameras, while some large-scale configurations have more than 300 cameras. Their main goal is to reduce marker swapping problems.[15] To mitigate the challenge of marker swapping, vendors have developed constraint software, a critical tool, particularly in passive marker systems when every marker has the same appearance. Passive systems have the advantage of not needing the user to wear cables or electronic equipment, in contrast to active markers and magnetic systems. Rather, they use hundreds of rubber balls that are taped with reflective material; these may need to be changed on a regular basis. These markers are applied to the skin of the subject directly (a common technique in biomechanics investigations) or to a performer wearing a full-body spandex costume that has been painstakingly tailored for motion capture. This setup proves highly efficient, and capable of capturing a substantial number of markers at impressive frame rates, typically ranging from 120 to 160 frames per second. Through adjusting the tenacity and focusing on a lesser state of interest, some systems can even achieve astonishing tracking speeds of up to 10,000 frames per second.[5]

3.1.1.2 Active Markers

Active optical motion capture systems employ a unique approach to triangulate positions by swiftly illuminating individual LEDs or groups of LEDs using specialized software, akin to celestial navigation principles. What sets these systems apart is that instead of relying on external light sources, the markers themselves are motorized to release light. This innovation takes advantage of the inverse square law, where the power of illumination decreases with distance. As a result, active optical systems can effectively expand the capture volume and distances, providing a substantial advantage. This approach also contributes to a extraordinary signal-to-noise ratio, yielding minimal marker jitter and consequently enhancing measurement resolution.[5]

Markers in active systems be able to be powered consecutively in synchronization by the detention scheme, allowing for exclusive ID of apiece marker for a specific frame, albeit at a potential cost to the frame rate. This real-time marker identification proves invaluable in dynamic applications. Alternatively, marker identification can be achieved algorithmically, albeit requiring additional data processing. Furthermore, some systems explore the use of coloured LED markers. Now these setups, apiece colour corresponds to a exact point on the body, adding a layer of versatility and potential applications in motion capture.

3.1.2 Without Markers

Recent advancements in computer vision have ushered in a new era for motion capture with the rapid growth of markerless techniques. Markerless systems, like those created at the Max Planck Institute, Stanford University, University of Maryland, and MIT, eliminate the need for subjects to wear any specialized tracking equipment. Instead, these systems harness the power of specially designed computer algorithms, which enable the analysis of multiple optical input streams. By leveraging these algorithms, the system can effectively identify human forms and disassemble them into their individual components for precise tracking. This innovative approach holds tremendous potential for revolutionizing motion capture by making it more accessible and less intrusive for subjects, facilitating a wide range of applications across various industries.

3.2 Non-Optical Capture

A non-optical motion capture system tracks motion based on the relative positions of various parts, whereas an optical motion capture system uses a camera. [16]

This method offers an alternative approach to capturing movement without relying on cameras and markers. Here, subjects wear suits or units that contain sensors like accelerometers, gyroscopes, etc. These sensors track the orientation and movement of body parts, providing real-time data for animation or analysis. Figure 5 shows a sensor suit in motion capture. [25]

Figure 5. Shows a motion capture sensor system

3.2.1 Inertial Systems

Biomechanical models, complex sensor fusion algorithms, and tiny inertial sensors are the foundation of inertial motion capture technology [17]. With the help of these systems, users can wirelessly record and analyze motion data from inertial sensors on a computer. To measure rotational rates, inertial systems often use inertial measurement units (IMUs), which are made up of a combination of accelerometers, magnetometers, and gyroscopes. These rotational data are then rendered into a minimal representation within the software. Similar to optical marker-based systems, the accuracy and naturalness of the data generated by inertial systems improve with the inclusion of more IMU sensors. Interestingly, inertial motion capture systems do not require external transmitters, cameras, or markers for relative motions; nevertheless, if necessary, these elements can be included to determine the user's absolute position. When combined with a magnetic bearing sensor, these devices can record a human's whole six-degree range of motion in real time. However, the resolution and resistance to electromagnetic interference are reduced, and they are only able to offer limited directional information. [18]

Inertial motion capture systems offer several advantages, including their versatility for use in various environments, including confined spaces, their portability, and the ability to cover extensive capture areas without the need for a cumbersome setup. However, there are some disadvantages to consider, such as potential limitations in positional accuracy and the possibility of positional drift over time, which can impact the overall precision of the motion capture data.

3.2.2 Mechanical Systems

Exoskeleton motion capture systems, also known as mechanical motion capture systems, provide a unique method of monitoring body joint angles. These systems use skeletal-like structures with sensors that are directly affixed to the body. The articulated mechanical components of this exoskeleton move in unison with the performer's bodily movements, allowing for the measurement of the performer's relative movement. Mechanical wave detention systems are characterized by their actual capabilities, affordability, freedom from occlusion issues, and wireless (untethered) functionality, offering an infinite detention capacity. Naturally, these systems consist of rigid structures composed of connected, straight metal or plastic rods interconnected with potentiometers that articulate at the body's joins, providing a reliable and flexible means of capturing human movement.[5]

3.2.3. *Magnetic Systems*

Magnetic motion capture systems operate on the principle of calculating position and orientation through the relative magnetic flux generated by three orthogonal coils found on both the transmitter and each receiver. By carefully assessing the intensity of voltage or current across these three coils, these systems can precisely determine both the range and orientation of tracked objects, thereby mapping out the tracking volume. This magnetic technology yields a 6DOF (six degrees of freedom) sensor output, offering valuable results with significantly fewer markers than optical systems require. In magnetic systems, just a pair of markers, typically placed on the upper and lower arm to monitor elbow position and angle, can effectively capture motion data.[19]

While magnetic systems exhibit advantages like immunity to occlusion by non-metallic objects, they are susceptible to interference from metal objects such as rebar and electrical sources like monitors, lights, cables, and computers in the environment, all of which can distort the magnetic field. The sensor response is notably nonlinear, particularly at the edges of the capture area. The presence of wiring from the sensors can sometimes restrict extreme performance movements. On a positive note, magnetic systems allow real-time monitoring of motion capture sessions. It's worth noting that magnetic systems tend to have substantially smaller capture volumes compared to optical systems.[19]

3.2.4. Stretch Sensors

Stretch sensors, often made from silicone, represent a versatile class of flexible parallel plate capacitors designed to measure various physical parameters such as stretch, bend, shear, or pressure. Their operation hinges on the principle that changes in capacitance occur as the sensor experiences stretching or compression. What sets stretch sensors apart is their capability to transmit this data either through Bluetooth technology or direct input, rendering them particularly adept at detecting even the slightest alterations in bodily movements.

Stretch sensors are immune to magnetic interference, which ensures their reliable functionality without being affected by external factors like magnets. Additionally, these sensors do not suffer from occlusion, meaning that they can perform consistently even when obstructed by other objects or materials.
In contrast to inertial systems, which are susceptible to positional drift, stretch sensors maintain their accuracy thanks to their stretchable nature. This property makes them ideal for applications where precision and reliability are paramount. [5]

However, it's essential to note that stretchable sensors, in line for to the physical characteristics of their substrates then leading resources, may exhibit a moderately great signal-to-noise ratio. As a result, additional processing steps such as filtering or employing machine learning techniques are often necessary to optimize the data collected from these sensors for motion capture applications. While these solutions undoubtedly enhance data quality, they may introduce a slightly higher latency when compared to alternative sensor technologies.

4. Applications of Mocap

Motion capture (mocap) technology has a wide range of applications across various trades. It involves capturing the movements of objects or living beings and translating them into digital data. Here are some common applications of mocap technology:

4.2. Video Games

Mocap is extensively used in the gaming industry to create realistic character movements and animations, enhancing the overall gaming experience.This technology has become an integral part of the video game industry, enabling the lifelike animation of competitors, aggressive artists, and various in-game types.

Motion capture in gaming began as early as 1988, when Magical Company's 2D arcade fighting game, Last Apostle Puppet Show, used motion capture for digital sprites, and Martech's video game Vixen (starring model Corinne Russell) [20] used a more basic form of motion capture to animate the 2D player characters.[21]

The Sega Model arcade games Virtua Fighter (1993) [22][23] in addition to Virtua Fighter 2 (1994), which notably featured 3D character models animated using this technique, marked one of the turning points in the growth of motion capture in video games.

4.3. Robotics

In robotics, mocap is used to program and refine the movements of robots and automated systems, making them more precise and adaptable to different tasks.

Optical motion capture systems have found another valuable application in the realm of indoor positioning. Robotics researchers have embraced these systems for their capability to aid the development and assessment of controller, estimate, and perception procedures and hardware. While the Global Navigation Satellite System (GNSS) in conjunction with Real-Time Kinematics (RTK) can achieve centimeter-level accuracy in outdoor settings, this accuracy is greatly reduced in situations where there is obstruction to the satellites' line of sight, which is frequently the case in indoor settings.

To address this challenge, a majority of commercial optical motion capture system vendors have thoughtfully provided open-source teamsters that seamlessly integrate with the widely used Robotic Operating System (ROS) outline. This integration empowers investigators and inventers to efficiently trial and refine their robotic systems in the controlled environment of indoor spaces, fostering innovation and progress in the field of robotics.[5]

4.4. Movies

Motion capture is a technologically advanced technique used in film and animation that records an actor's movements and physical performance in order to transfer them to a computer-generated image (CGI) figure. Mocap is capable of tracking a wide range of motion, including body motions and face expressions. Though it is most commonly utilised to create CGI characters for live-action movies, mocap can also be employed in animated films..

Figure 6. T.J. Storm with added tail for Godzilla shooting using mocap

Figure 7. Facial mocap technology used to capture facial expressions in 'Avatar'

Figure 7. Facial mocap technology used to capture facial expressions in 'Avatar'

Figure 6 and Figure 7 show the mocap technology in use during the shooting of movies 'Godzilla' and 'Avatar' respectively. [24][2]

Several well-known motion capture characters include:
Avengers: Endgame's Thanos
Smaug — The Hobbit: Smaug's Desolation
[components link] Caesar — Rise of the Planet of the Apes [1]

4.5. VR and AR

Mocap technology enhances the immersion and realism of VR and AR experiences by accurately tracking users' movements and gestures.

Virtual reality (VR) and augmented reality (AR) pioneers like uSens and Gestigon have ushered in a new era of user interaction with digital content, offering the capability to capture and translate hand motions into real-time digital experiences. This technological feat has unlocked a plethora of applications, ranging from immersive training simulations and visual perception assessments to the seamless navigation of 3D virtual environments. Such innovation enables users to embark on virtual walk- throughs and explore digital realms as if they were physically present. [5]

Furthermore, motion capture technology has become an integral component of digital puppetry systems, where it plays a pivotal role in animating computer-generated characters in real-time. This dynamic fusion of motion capture and digital puppetry empowers creators and performers to breathe life into their virtual characters, offering limitless possibilities for real-time, interactive storytelling and entertainment.

5. Components of Motion Capture for Filmmaking

5.2. Mocap Suit

The foundation of any motion imprisonment system is the essential mocap outfit. This specialized garment serves as the linchpin in the process. Typically outfitted with an array of sensors, usually between 15 to 20, the mocap suit is engineered to meticulously track not only the actor's movements but also factors like gravitational pull and rotation, ensuring a comprehensive and accurate representation of their motion. Altogether of the motion information captured is then transferred to the dedicated software to imprisonment the motion in concurrent. [1]

5.3. Head Mounted Camera

A remarkable facet of mocap technology remains its capacity to imprisonment the specifics of an actor's facial expressions. This level of precision extends to capturing the most subtle emotional cues, such as the quiver of a lip or the fleeting shifts in the actor's gaze. These intricate details are then translated into the movements and expressions of computer-generated characters, thereby enhancing the authenticity and emotional depth of the final digital creations.

This breakthrough in facial motion capture has played a pivotal role in the creation of iconic characters in the world of mocap, including the likes of Caesar in "Planet of the Apes" and Thanos in "Avengers: Infinity War" and "Avengers: Endgame." [1]

5.4. Software

Post-filming, the VFX (Visual Effects) team uses the motion imprisonment information derived from an actor's facemask terms and act to breathe life into digital characters by infusing them with intricate details and subtleties, creating a fully realized and emotionally resonant presence on screen. This ambitious endeavour hinges on the adept use of specialized software, often relying on Autodesk's powerful tools, such by way of Autodesk MotionBuilder otherwise 3DS Max.

Motion capture stands as a true game-changer in the realm of filmmaking. It empowers filmmakers to craft characters that transcend the ordinary, bringing them to life with an unparalleled level of detail and authenticity that captivates audiences and fuels the imagination. [1]

6. Motion Capture on Animals

Motion capture technology isn't limited to human applications; it has also found valuable use in capturing the movements of animals. Researchers and filmmakers employ mocap to study and replicate the natural and often complex movements of various species, from birds and mammals to insects and marine life. This technology allows for the creation of realistic animal animations in films, video games, and scientific studies, enhancing our understanding of animal behaviour and contributing to the authenticity of digital and animated portrayals of the animal kingdom.

Vicon, a leading choice in motion capture companies has worked with several animals for uses such as a library of mocap data and scans of dogs, horses, and cats to be integrated into their game engine as full navigation movements. [3]

The DIGIC's struggle while occupied by horses for the first time:

"We had a fabric stitched to improve the markers' stickiness for our second horse shot because we had trouble getting them to stay on the horse during our first one. There were other issues with that as well. For example, the fabric on the horse's legs might tangle and stretch if it became overly sweaty. We were able to extract useful data from the sessions after three or four shots, and that experience served as the basis for the development of the current marker set." [3]

Figure 8. Mocap sensors on a cat to record its movements.

Some highlights from Vicon's MOCAT project:

It wasn't as easy for DIGIC to transfer their experience with horses to cats because of all of their work with horses. Practically speaking, the Mocap Division Lead, Csaba Kovári, states that "We had to do the marker placement differently because we couldn't dress the cats."

Additionally, it was not possible to place markings on the tails since doing so would have prevented natural movement. Then there was the problem of getting the cats to perform as requested.

"Even though the cats were well-trained and had appeared in numerous films, Kovári notes that it was difficult to get them to walk organically around the marks. An extended process of acclimatisation was the solution. Start by applying one or two markers to the cat's body for a short while, then progressively increase the number of markers to the entire set. The usage of sensors on cats for mocap is depicted in Figure 8. [3]
Figure 9 shows the process of animating animals, here a horse, using the data collected through mocap.

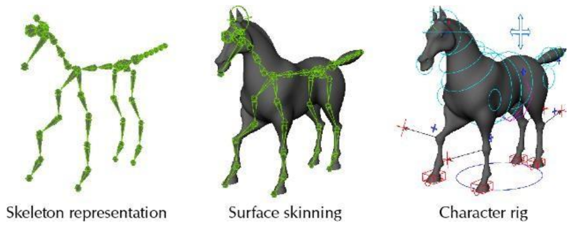


Figure 9. Mocap process to animate a horse

7. Conclusion

The future of motion capture (mocap) holds immense promise, driven by the relentless march of technology and its ever-expanding applications. As we look ahead, we anticipate even more refined and unobtrusive mocap solutions. These systems are likely to incorporate cutting- edge sensor technologies, reducing the need for physical markers and allowing for more natural and immersive motion capture experiences. Furthermore, combining machine learning techniques with artificial intelligence will be crucial, enabling mocap systems to recognize and adapt to a broader range of movements and gestures.

The marriage of mocap with virtual and augmented reality will offer transformative possibilities, revolutionizing not only the entertainment industry but also fields like telemedicine, education, and remote collaboration. The future of mocap is about breaking boundaries and pushing the envelope in how we interact with the digital world, with applications that are limited only by our imagination and technological innovation.

Motion capture technology is an ever-evolving field that will surely serve as the foundation for the metaverse. Rob Löring, senior business director of 3D body motion at Xsens, believes that uploading data to the cloud will be the next significant advancement in mocap.. This would allow data to be processed quickly without having to depend on a single PC with high processing power.

The cloud would also facilitate the collaboration of teams based in different countries. As remote work becomes commonplace, this makes total sense. This would allow multiple users to access data almost immediately. In addition, this would in turn drive mocap setups to become more portable, making the technology more accessible to start-ups and smaller studios. [4]

10. Acknowledgments

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