

Optical Inertial and Markerless Motion Capture in Biomechanical Research and Healthcare

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DESCRIPTION

Biomechanics, the study of the mechanical principles governing human movement, has evolved significantly over the past decades due to technological advancements. Among these, motion capture technology has emerged as a pivotal tool for accurately analyzing human motion in both clinical and research settings. Motion capture systems enable researchers, clinicians and engineers to quantify body movements with precision, providing critical insights into musculoskeletal function, injury mechanisms, rehabilitation outcomes and performance optimization in sports. The integration of biomechanics with advanced motion capture technology has revolutionized the way human motion is studied, allowing for detailed analysis that was previously impossible with traditional observational methods.

Motion capture technology works by tracking the spatial positions of specific points on the body over time, which are then used to reconstruct the movements in three-dimensional space. Modern systems can be broadly categorized into optical, inertial and markerless technologies. Optical systems, often considered the gold standard, use cameras to detect reflective markers placed on the subject's body. These markers reflect infrared light emitted by the cameras, allowing the software to calculate their exact positions and reconstruct joint kinematics and segmental motion. Optical systems provide high accuracy and temporal resolution, making them ideal for detailed biomechanical studies, particularly in gait analysis, sports biomechanics and rehabilitation research.

Inertial motion capture systems, on the other hand, rely on wearable sensors such as accelerometers, gyroscopes and magnetometers to measure linear acceleration, angular velocity and orientation of body segments. These systems are highly portable and do not require a fixed laboratory setup, which makes them suitable for field studies, sports performance evaluation and monitoring patients during daily activities. While inertial systems may have slightly lower accuracy compared to optical systems, recent improvements in sensor fusion algorithms and calibration techniques have enhanced their reliability,

enabling comprehensive biomechanical analysis outside traditional lab environments.

Markerless motion capture is another significant advancement in the field. These systems use computer vision and artificial intelligence algorithms to detect and track body movements directly from video recordings without requiring any markers or wearable sensors. Markerless systems offer the advantage of minimal preparation time and natural movement patterns since subjects are not constrained by markers or suits. With improvements in deep learning algorithms and high-resolution cameras, markerless motion capture is increasingly being adopted in clinical gait analysis, sports performance assessment and ergonomic studies, providing a non-invasive, efficient and scalable solution for biomechanical research.

The applications of motion capture technology in biomechanical analysis are vast. In clinical settings, motion capture allows for the precise assessment of gait abnormalities, joint disorders and rehabilitation progress. For example, patients recovering from stroke, knee replacement, or spinal injuries can be evaluated objectively, enabling clinicians to design personalized therapy programs and track improvements over time. In sports biomechanics, motion capture provides detailed insights into athletes' movements, helping optimize technique, prevent injuries and enhance performance. By analyzing joint angles, muscle activation patterns and force distribution, coaches and sports scientists can make data-driven decisions to improve training outcomes.

Another area where motion capture has had a transformative impact is in ergonomics and workplace safety. By analyzing the biomechanics of repetitive tasks or awkward postures, motion capture systems help identify risk factors for musculoskeletal injuries and guide the design of safer work environments. Similarly, in prosthetics and orthotics, motion capture data is used to evaluate the effectiveness of devices, ensuring optimal fit, comfort and functionality for users. In addition, motion capture technology is increasingly integrated with computational modeling, finite element analysis and musculoskeletal simulations to provide comprehensive insights into forces,

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stresses and muscle activation during complex movements, further advancing biomechanical research.

Despite its numerous benefits, motion capture technology faces challenges such as high costs, complex setup and the need for expert operation. However, ongoing advancements in affordable camera systems, AI-based markerless tracking and wireless wearable sensors are overcoming these limitations, making motion capture more accessible to a wider range of applications. The combination of high-resolution data, real-time feedback and advanced analytical tools continues to push the boundaries of what can be achieved in biomechanics research and clinical practice.

CONCLUSION

In conclusion, advances in biomechanical analysis using motion capture technology have transformed the study and application of human movement. By providing accurate, detailed and quantitative data on motion patterns, these technologies enable better clinical assessments, optimized sports performance, improved rehabilitation strategies and safer workplace practices. As motion capture systems become more sophisticated, accessible and integrated with computational models and AI, the potential for understanding, enhancing and rehabilitating human movement will continue to expand, making it an indispensable tool in modern biomechanics and healthcare.