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Assignment Report
Human Motion Analysis using SIMI Motion Analysis

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Contents

1 Introduction

Human movement analysis is a vital area of biomechanics that integrates anatomy, physiology, physics, and engineering to study how the human body moves and functions. It plays an important role in clinical rehabilitation, sports performance, ergonomics, and biomedical research by capturing, quantifying, and interpreting complex three-dimensional movements. This involves analyzing kinematic parameters such as joint angles, velocities, and accelerations, along with kinetic parameters like forces and moments acting on body segments. In this laboratory session, we used the SIMI Motion Analysis System, an advanced image-based motion capture technology that employs synchronized cameras and marker tracking to provide precise 2D and 3D kinematic data for biomechanical assessment.

2 Experimental Procedure

The experimental procedure for human motion analysis using the SIMI Motion Analysis System involved several critical stages, each requiring precise execution to ensure accurate and reliable data collection.

2.1 System Setup and Calibration

The first stage involved assembling the SIMI motion analysis system according to the standardized configuration. The system consisted of multiple synchronized industrial cameras positioned strategically around the capture volume to ensure optimal marker visibility and tracking accuracy.

The 3D calibration process was performed using specialized calibration tools including the L-frame and T-wand . The L-frame provided a reference coordinate system for the capture volume, while the T-wand was used to define the spatial relationships between cameras and establish the working volume dimensions. This calibration process is crucial for accurate 3D reconstruction of marker positions and subsequent kinematic calculations.

2.2 Marker Placement

Following the calibration, reflective markers were strategically placed on anatomical landmarks according to the standardized protocol outlined in the appendix. The marker set included both compulsory markers (positions 2, 5, 8, 12) and optional markers (positions 1, 6, 9, 10) for inverse dynamics analysis.

Key marker placement locations included:

- Hip markers (left_h, right_h): Positioned on the greater trochanter
- Knee markers (left_k, right_k): Placed on the lateral femoral epicondyle
- Ankle markers (left_a, right_a): Positioned on the lateral malleolus
- Foot markers (left_f, right_f): Placed on the fifth metatarsal head

2.3 Data Acquisition

The data acquisition phase involved recording synchronized video from all cameras while the subject performed predetermined movement tasks. Before the main data collection, a short test acquisition was performed to verify system functionality and marker visibility. Three experimental trials were conducted for each motion to ensure statistical reliability and account for natural movement variability.

The system recorded marker trajectories at 100 Hz, providing high temporal resolution for accurate kinematic analysis. Simultaneously, the cameras captured high-resolution video at matching frame rates to enable synchronized analysis of movement patterns.

2.4 Data Processing and Analysis

Following data acquisition, the recorded marker data was processed using the SIMI Motion software. This involved automatic marker tracking with manual verification and correction where necessary. Joint angles were calculated using the three-dimensional coordinates of relevant markers through inverse kinematic analysis.

The processed data was exported to C3D file format, enabling compatibility with various biomechanical analysis software packages for further investigation and reporting.

3 Results and Analysis

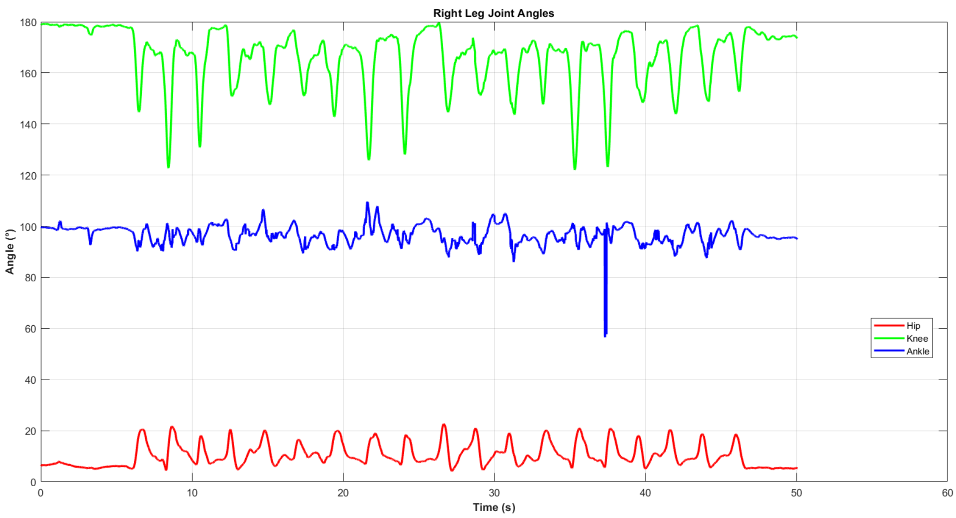

Figure 1: Joint angles of the Right leg (hip, knee, and ankle) over time.

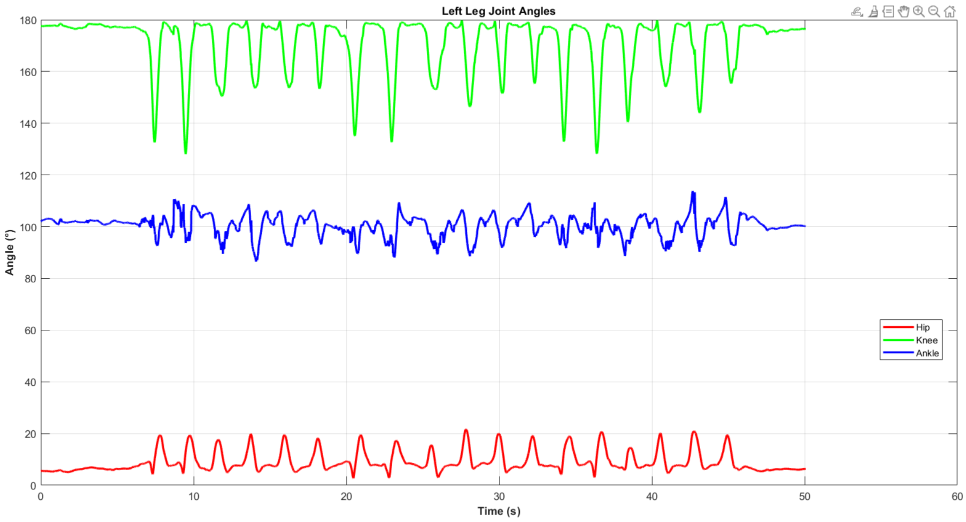

Figure 2: Joint angles of the left leg (hip, knee, and ankle) over time.

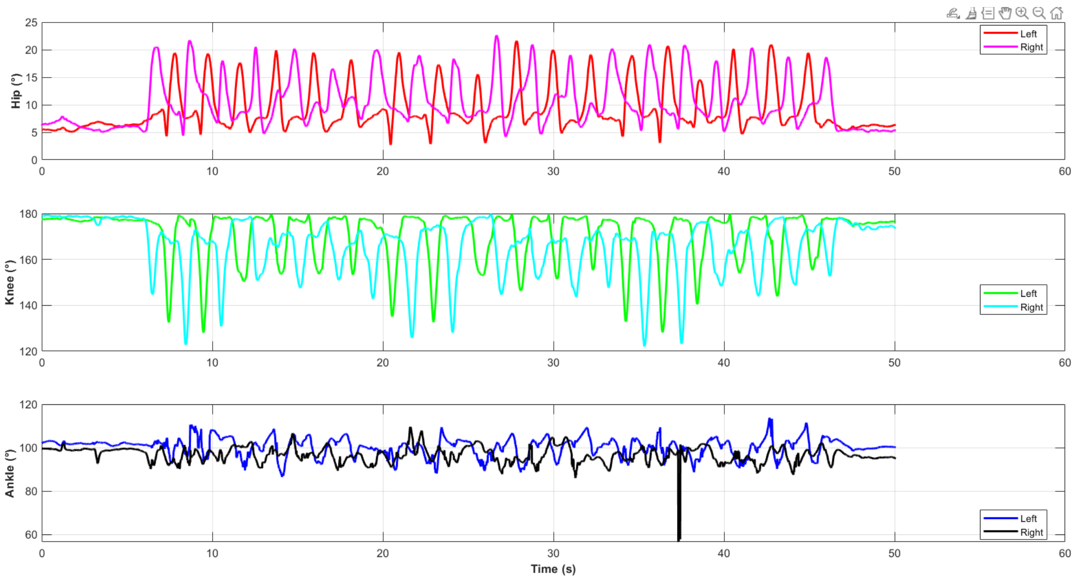

Figure 3: joint angles compared

Hip Joint (Red/Magenta curves)

The hip angle shows small-amplitude oscillations between approximately 5°–20°. These fluctuations correspond to hip flexion and extension during each step. Peaks occur when the leg is brought forward (maximum flexion), while troughs correspond to when the leg is extended backward during push-off. The relatively lower range compared to the knee and ankle indicates stability of hip movement, which mainly acts as the pivot for leg swing.

Knee Joint (Green/Cyan curves)

The knee angle fluctuates strongly between approximately 130°–180°, showing a clear cyclic pattern of flexion–extension. Sharp drops (towards 130°–140°) occur during the swing phase, when the knee flexes to allow the foot to clear the ground. Rises back to near 180° correspond to the stance phase, when the leg is extended to support body weight. The repetitive peaks and valleys show multiple steps taken within the $\sim 50\,\mathrm{s}$ trial, confirming periodic gait cycles.

Ankle Joint (Blue/Black curves)

The ankle angle fluctuates around 90°–100°, with smaller variations compared to the knee. Spikes upward represent plantarflexion (push-off phase) as the foot pushes against the ground. Dips downward reflect dorsiflexion (heel strike/foot clearance). Some irregular spikes (e.g., around 35–40s) may be due to marker noise, foot strike variations, or trial inconsistencies.

Left vs Right Comparison

Both legs show similar periodic patterns, confirming a symmetric gait. Small phase differences between left and right indicate alternating stepping — when the left knee is flexed, the right is extended, which matches the biomechanics of walking/running. Any noticeable asymmetry (slight amplitude difference) might suggest uneven step length or marker placement error.

Summary of Angle Meaning

- **Hip angle:** flexion/extension of the thigh. Larger positive values indicate hip flexion (leg forward), while smaller or negative values indicate extension (leg backward).
- **Knee angle:** bending at the knee. Smaller values mean the knee is nearly straight, while larger values indicate knee flexion (during swing phase).
- **Ankle angle:** dorsiflexion/plantarflexion. Higher values mean dorsiflexion (toes up), while lower values mean plantarflexion (toes down, push-off).

4 Methods of Motion Analysis

This section outlines common methods used in human motion analysis, grouped by measurement modality.

4.1 X-ray methods

Planar X-rays

Capture relative positions of implants and bones. Serial images taken over time are compared to reveal implant misalignment or component wear.

Fluoroscopy

Traces movement of internal structures (e.g., bone segments) using continuous X-ray imaging from a fluoroscope.

Roentgen Stereophotogrammetric Analysis (RSA)

Monitors wear and migration of joint replacements (hip, knee). Two radiographs are acquired simultaneously for 3D tracking.

4.2 Mechanical methods

Goniometer

Measures simple joint angles. The device is aligned with the anatomical joint axis and attached to limb segments.

Instrumented Spatial Linkage

A serial chain with revolute joints and angular displacement transducers. Transformations link measurements from one segment to the next after fixing terminal links to bones.

4.3 Optical methods

Still Photos

Multiple cameras at known coordinates capture frames of body motion; frames are spatially aligned to reconstruct movement.

Video Cameras

The most common approach for marker-based motion capture:

- **Infrared cameras + passive markers:** Multi-camera systems with IR strobes track retroreflective markers.
- **Passive cameras + active markers:** LED markers emit IR light; cameras quantify emitted signals to compute trajectories.

5 Commercial Motion Analysis Systems

The market for motion analysis systems offers various commercial solutions, each with distinct characteristics, advantages, and limitations suited to different applications and user requirements.

System	Key Features	Advantages and Disadvantages
SIMI Motion Analysis System		
Overview	Image-based tracking, 2D/3D analysis, markerless options, integration with external devices, real-time visualization	• **Advantages**: Flexible indoor/outdoor, low infrastructure needs, cost-effective, portable, user-friendly • **Disadvantages**: Lower accuracy, lighting sensitivity, limited scalability for large volumes, manual intervention sometimes needed
Vicon Motion Capture Systems		
Overview	Infrared optical, sub-millimeter accuracy, scalable, real-time processing, extensive software suite	• **Advantages**: Highest accuracy, robust, widely supported, proven research and industrial use • **Disadvantages**: High cost, complex setup, requires controlled environment, limited portability, marker occlusion issues
Qualisys Motion Capture Systems		

System	Key Features	Advantages and Disadvantages
Overview	High-speed hybrid marker/markerless system, advanced analysis modules, real-time streaming	• **Advantages**: Excellent accuracy, versatile, strong research focus, robust quality assurance • **Disadvantages**: Premium pricing, setup complexity, requires specialized knowledge, limited regional availability
OptiTrack Motion Capture Systems		
Overview	Cost-effective, scalable, integrates with force plates/EMG, user-friendly software	• **Advantages**: Good value, straightforward setup, broad application scope, responsive support • **Disadvantages**: Less advanced software ecosystem, fewer high-end features, smaller user community

6 Conclusion

This laboratory session provided hands-on experience with the SIMI Motion Analysis System, demonstrating principles of quantitative human movement analysis through captured kinematic data that revealed complex joint angle patterns and movement strategies. The observed bilateral asymmetries highlighted the importance of comprehensive movement assessment, while the comparison of commercial systems illustrated various technological approaches with distinct trade-offs in accuracy, cost, and complexity. Future developments in markerless and AI-enhanced systems promise expanded applications across healthcare, sports, and ergonomics, with this practical experience providing valuable foundation for biomedical engineering applications.

7 References

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