Engineering an Open-source Motion Capture Platform to Characterize Abnormal Gaits for Resource-limited Environments

Alexander Dyer[1]
[1]Harvard School of Engineering and Applied Sciences

ACRM
AMERICAN CONGRESS OF REHABILITATION MEDICINE

Harvard John A. Paulson School of Engineering and Applied Sciences

Introduction

Falls are a leading cause of death and disability for individuals aged >65 [1]. Many developing communities **lack interpretable and reliable clinical tools** to diagnose and assess gait abnormalities [2-3]. Current tools rely on specialized hardware (IR) or black-box processing, decreasing accessibility [4-5].

Primary Aims

1. Develop **motion capture software** using widely available camera equipment for accurate 3D marker tracking.
2. Deploy the motion capture system **to characterize abnormal gaits** and assess **kinematically relevant features.**
3. Engineer and validate a data pipeline to process motion capture recordings and **predict abnormalities accurately** without significant black-box abstraction.

Design Methodology

Overview: Two Cameras in Stereovision Arrangement to Capture Treadmill Gait.

Pre-Trial Calibration Processing:
- Distortion Correction via Zhang's Method.
- Marker Detection using Calibration Video.

Individual Trial Processing:
- Kalman Filter for Accurate Marker Position.
- Inverse Kinematics to Obtain Joint Angles.
- Low-Pass Filter to Reduce Noise.
- Data Interpolation for Standardization

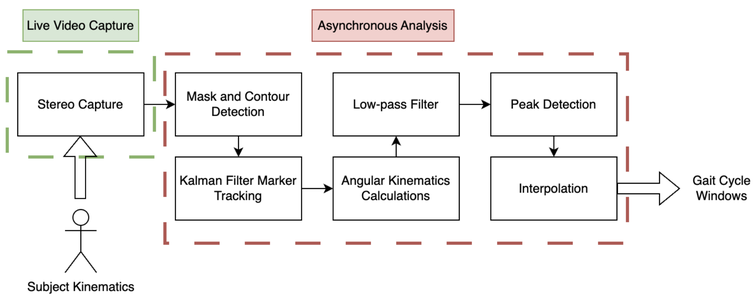


Figure 1. System Diagram of Motion Capture Processing

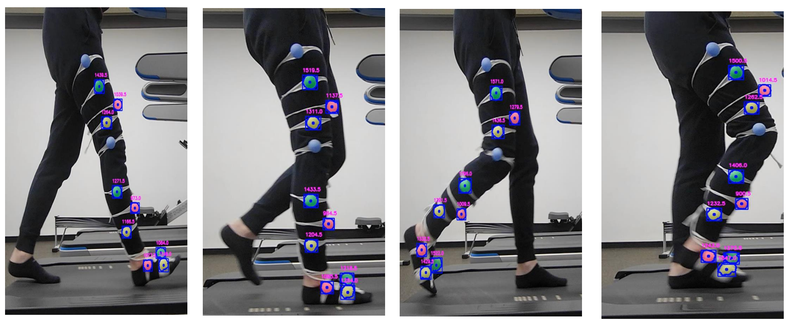


Figure 2. Gait Cycle Video Capture with Marker Detection (Top from Left: Heel Strike, Stance, Toe-off, Swing)

References

[1] M. L. Finlayson and E. W. Peterson, "Falls, Aging, and Disability," Physical Medicine and Rehabilitation Clinics of North America, vol. 21, no. 2, pp. 357–373, May 2010.
[2] L. Alberghina, E. Ochola, C. Turibamwe, V. Omona, S. Stacchiotti, and C. Malloggi, "Delivering physiotherapy services in developing countries for children with cerebral palsy: An example from North Uganda," IJQHC Communications, vol. 2, p. lyac004, Jan. 2022.
[3] R. T. Haimanot, "The Challenges of Physiotherapy in a Developing Country Such as Ethiopia - Short Communication," Journal of Yoga and Physiotherapy, vol. 9, pp. 1–2, Feb. 2022. Publisher: Juniper Publishers.
[4] M. Menolotto, D.-S. Komaris, S. Tedesco, B. O'Flynn, and M. Walsh, "Motion Capture Technology in Industrial Applications: A Systematic Review," Sensors, vol. 20, p. 5687, Jan. 2020. Number: 19 Publisher: Multidisciplinary Digital Publishing Institute.
[5] H. Prasanth, M. Caban, U. Keller, G. Courtine, A. Ijspeert, H. Vallery, and J. von Zitzewitz, "Wearable Sensor-Based Real-Time Gait Detection: A Systematic Review," Sensors, vol. 21, p. 2727, Jan. 2021. Number: 8 Publisher: Multidisciplinary Digital Publishing Institute.

Scan for Abstract and More Information

Gait Characterization Methods & Results

Methodology: One participant was employed for characterization. In each trial, the participant would walk on a treadmill at a constant speed. The participant would walk normally or mimic an abnormal gait: **crouch, spastic, or steppage**.

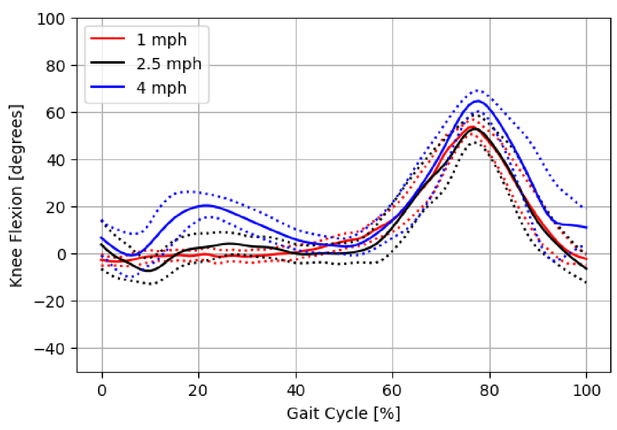


Figure 3. Knee Flexion for Normal Gait across Gait Cycle

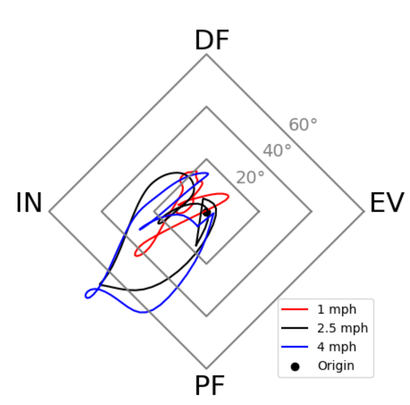


Figure 4. Foot Kinematics for Normal Gait Inversion/Eversion (IV/EV) and Dorsiflexion/Plantarflexion (DF/PF)

Gait Prediction Evaluation Methods & Results

Methodology: Employ linear and non-linear techniques to predict to which abnormality category a gait sequence belongs.
- Linear Discriminant Analysis (LDA)
- Logistic Regression (LOG)
- Simple Vector Machine (SVM)
- K-Nearest Neighbor (KNN)

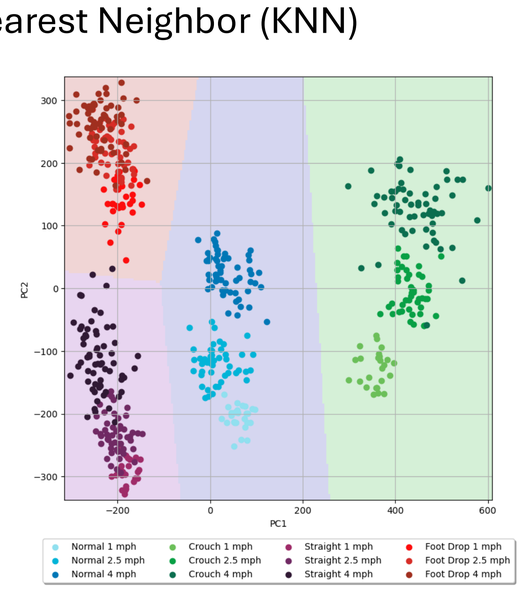


Figure 5. PCA of Gait Signals with LDA Boundaries

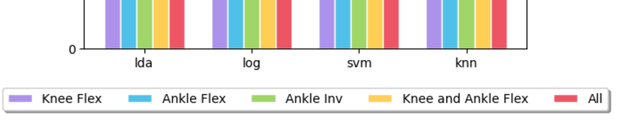


Figure 6. Accuracy of Different Prediction Techniques

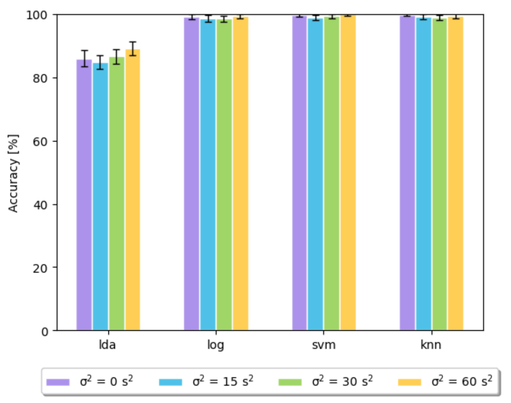


Figure 7. Prediction Accuracy Across Methods for All Kinematic Data with Signal Noise Added

Multi-Subject Validation Methods & Results

Methodology: Use the prediction parameters from **one subject's training to evaluate prediction effectiveness on another subject**. Compare these results to **combined training and testing**. Employ an equal number of gait samples for each speed and abnormality combination.

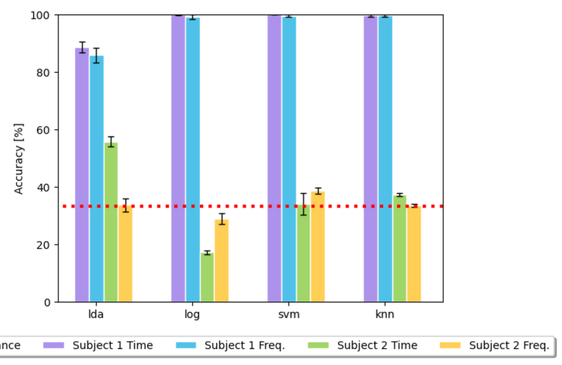


Figure 8. Split Subject Training and Testing in Time and Frequency Domains

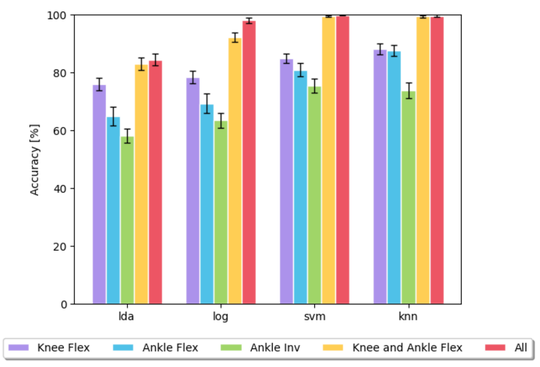


Figure 9. Combined Subject Training and Testing in Time and Frequency Domains

Conclusions

- Successful Deployment on Different Camera Hardware.
- **>95% Accuracy** for Interpretable Methods.
- **Integration of Ankle and Knee Data**.
- **Prediction Robustness** to Signal Noise.

Future Work

- Validation on a **Larger Subject Sample**.
- Employ Subjects with **Clinically Documented Abnormalities**.
- Compare Accuracy to State-of-the-Art **Clinical Motion Capture**.
- **Feedback** from Clinical Providers.