Optimal Control Simulation of a 2D Biomechanical Model for Sensor-Based Gait Analysis

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MACHINE LEARNING & DATA ANALYTICS

Introduction

Gait Analysis

Sports:

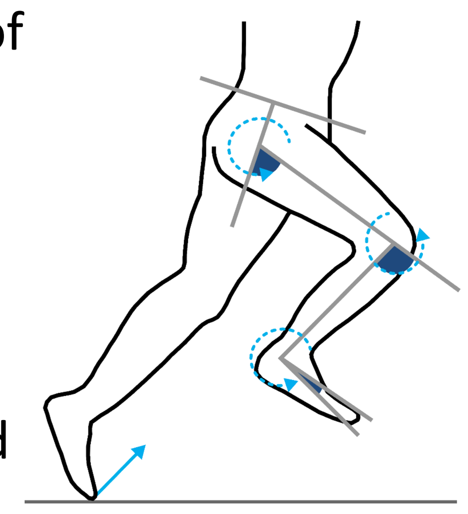
- ➔ Improve performance [1]
- ➔ Prevent injuries [2]

Medicine:

- ➔ Support diagnosis [3]
- ➔ Prediction of prognosis [4]

Challenges

Ambulatory assessment of kinematics and kinetics based on noisy measurement data, sensor drift over time and a limited number of sensing devices.



Our Approach

We propose an inertial motion capture method that simultaneously obtains 2D kinematics and kinetics of the lower body by solving an optimal control problem of a musculoskeletal model using noisy data of seven inertial measurement units.

Methods

Data Collection

Inertial motion capturing:

7 inertial measurement units

Optical motion capturing:

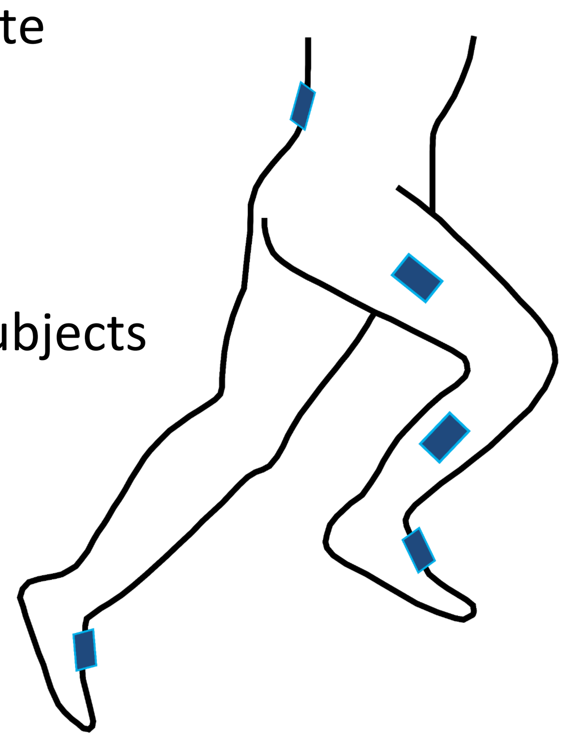
Vicon + Force plate

Study Protocol:

9 male healthy subjects

3 running speeds

10 trials each



Measured Data → **Simulated Data** →

Minimize $\mathcal{F}\{\boldsymbol{x}(t), \boldsymbol{u}(t)\}$

subject to
$$\boldsymbol{f}(\boldsymbol{x}(t), \dot{\boldsymbol{x}}(t), \boldsymbol{u}(t)) = 0$$
$$\boldsymbol{x}_L \leq \boldsymbol{x} \leq \boldsymbol{x}_U$$
$$\boldsymbol{u}_L \leq \boldsymbol{u} \leq \boldsymbol{u}_U$$
$$\boldsymbol{x}(T) = \boldsymbol{x}(0) + v\,T\,\tilde{\boldsymbol{x}}$$

using direct collocation.

↓

$\boldsymbol{x}(t)$ **and** $\boldsymbol{u}(t)$

Musculoskeletal Model [5]

State vector: $\boldsymbol{x}(t)$

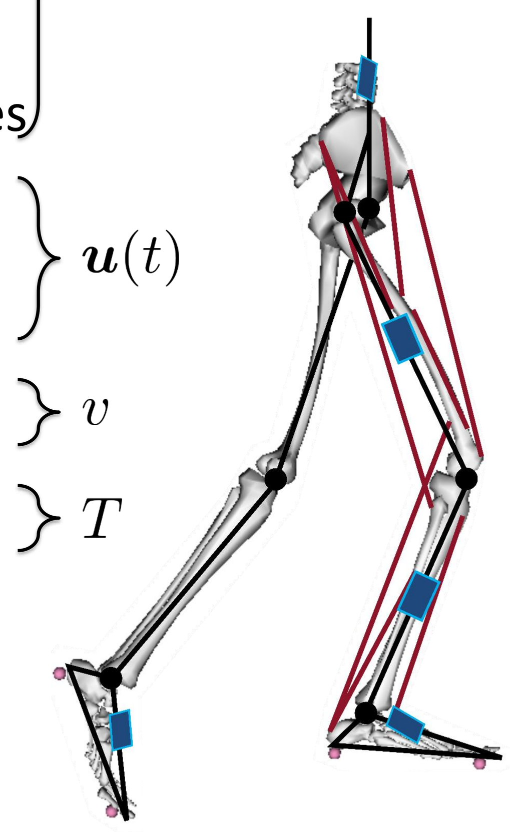
- Kinematic DOFs
- Muscle states
- Ground contact states

Control vector: $\boldsymbol{u}(t)$

- Neural excitation

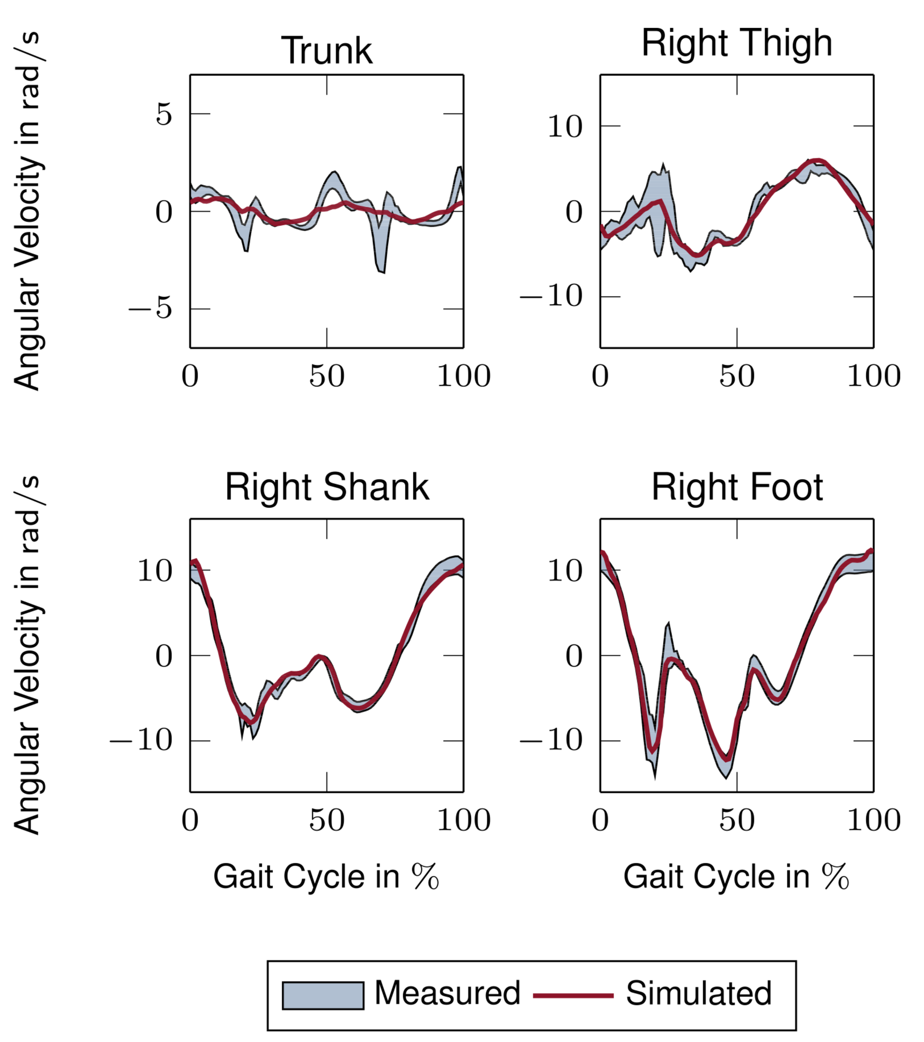
Running speed $\}\ v$

Duration of one cycle $\}\ T$

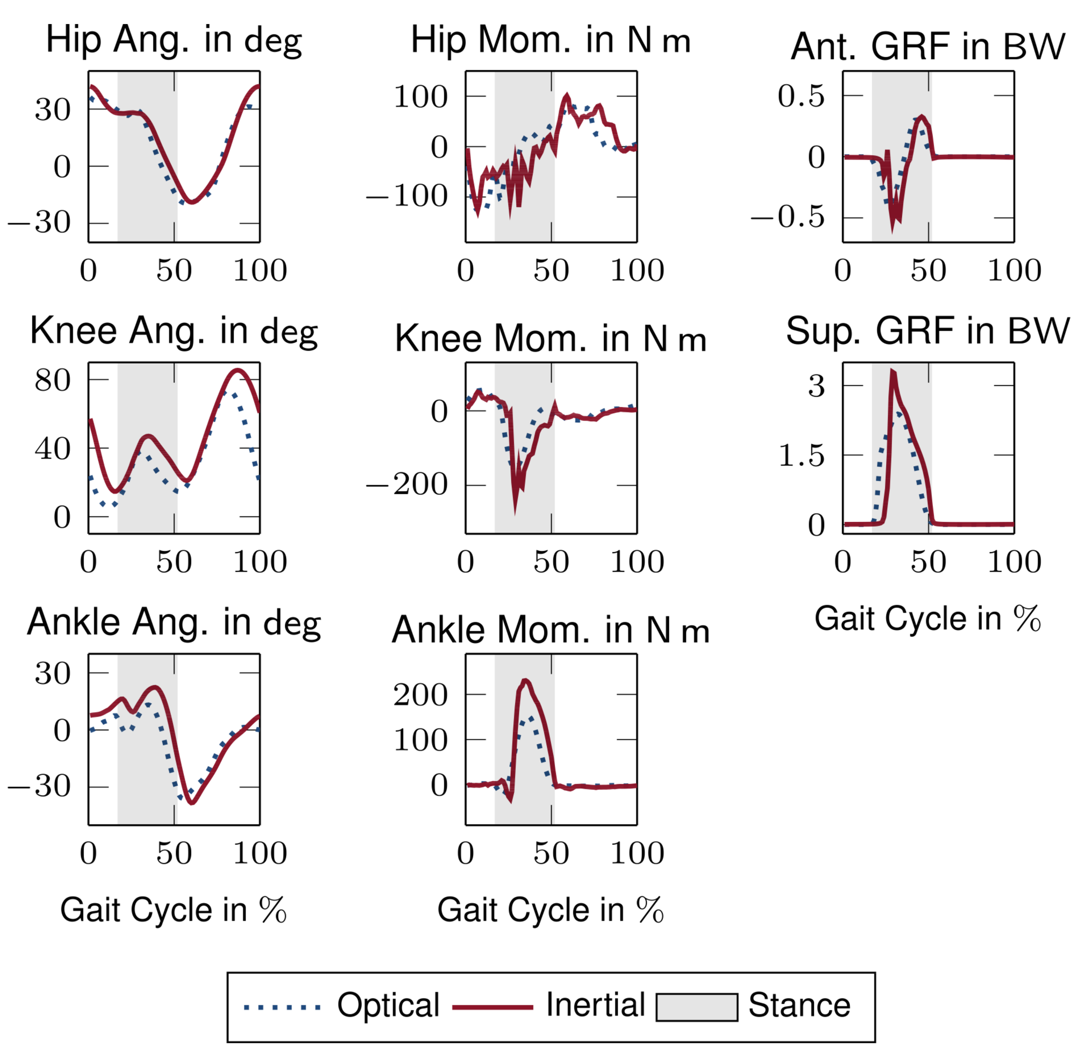


Results

Inertial Data Tracking



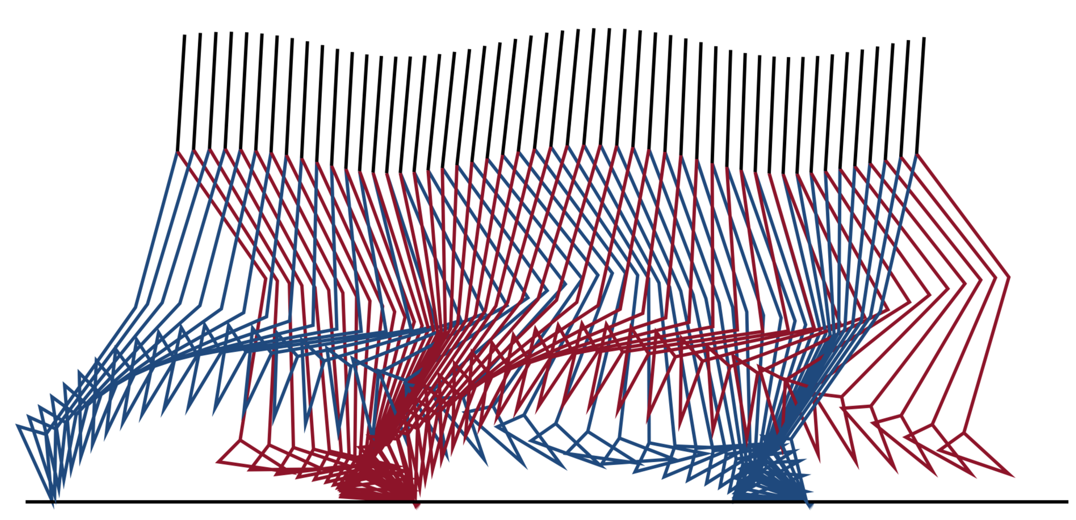
Biomechanical Analysis



Coefficient of Multiple Correlation

Mean coefficients of multiple correlation values over all subjects and all running speeds were between 0.83 and 0.98 for joint angles, joint moments and GRFs.

Stick Figure

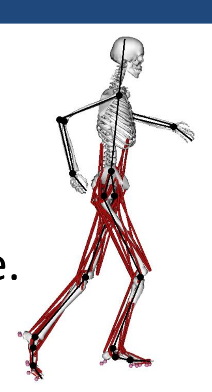


Summary

It could be shown that it is feasible to reconstruct 2D kinematics and kinetics from running movements using inertial data and optimal control simulation.

Outlook

Extension to a 3D full body model to simulate motion outside the sagittal plane.



References

[1] R.G. Lockie et al., J Hum Kinet, 2015.
[2] K. Small et al., Sensors, 2014.
[3] J. Klucken et al., PLoS ONE, 2013.
[4] R. Baker, J Neuroeng Rehabil, 2006.
[5] A. van den Bogert et al., Procedia IUTAM, 2011.