BME 450 Sports Engineering
Fall 2018

Lab 3: Motion Capture for Sports Biomechanics
Due: Friday, November 23, 2018

1. Overview

Motion capture has implications for basic science (e.g., validating model-based theories of human motor control) and applied research (e.g., design optimization of sports equipment). Two mainstream motion capture modalities in sports biomechanics are inertial measurement units (IMUs) and camera-based systems. IMUs contain triaxial accelerometers, rate gyroscopes, and magnetometers. The accelerometers measure accelerations including the gravitational acceleration, the magnetometers measure the geomagnetic field, and the rate gyroscopes measure angular velocities; associated software typically implement a multibody biomechanical model and sensor fusion algorithms to compute the joint angular kinematics. In comparison, optical motion capture systems utilize 2D images from multiple synchronized cameras to triangulate 3D coordinates of specialized markers. The following teaching lab will provide students hands-on experience with inertial and optical motion capture systems, biomechanics signal processing, and multibody kinematic modelling and analyses.

2. Experimental Data Collection

Motion capture experiments will be conducted in the BME biomechanics and biosignals teaching lab (DWE-3506) on Friday, November 2, 2018. Together with assistance from the students, one participant will be instrumented with a 7-IMU sensor system (XSENS Technologies), including one IMU positioned on the lower-back and three on each lower-limb. The system will be tethered to guarantee reliable power and data transmission. Students will implement the IMU system calibration via having the participant perform known standing poses. The IMU global coordinate system includes positive Z upwards and positive X forwards (i.e., from the rear-to-front bicycle wheels). In the standard anatomical position, the local coordinate systems (i.e., origins at proximal joint centers) include positive x forwards and positive y upwards from proximal-to-distal joints. Motion capture data will be collected while the participant pedals on a stationary bicycle. See Appendix for detailed software outputs.

3D marker positions in a global coordinate system will be simultaneously collected using a 10-camera motion capture system (OptiTrack). Using double-sided adhesive tape, students will place 16 passive retroreflective markers on the participant at anatomical locations coinciding with those from a predetermined skeleton model. Students will perform the camera system calibration including 1) masking unwanted reflections, 2) wanding the 3D capture volume, and 3) setting the origin and global coordinate system (i.e., positive Y upwards and positive Z forwards). The OptiTrack skeleton model will be calibrated by having the participant perform known standing poses. See Appendix for detailed software outputs.

Lengths are expressed in meters and orientations expressed using quaternions. Data from the inertial and optical motion capture systems will be preprocessed and uploaded to LEARN. Note that both systems will be sampled at 100 Hz. Relevant data will be highlighted in the Excel spreadsheet.

3. Kinematic Modelling and Analyses

Part I: Calculate the orientation quaternions (i.e., four Euler parameters) for the right and left thigh and shank segments at each time step by numerically integrating the corresponding IMU sensor angular velocities. Each time step is 10 milliseconds. Be mindful about your quaternion initial conditions (hint: use experimental data at time=0). Consider rereading class Lecture 13 on Euler Angles and Quaternions. Remember that quaternion lengths must equal 1. Compare your calculated orientation quaternions with those automatically exported from the IMU software, labelled "sensor orientation quaternions" in the Excel spreadsheet. Comment on the differences.

Part II: Transform the right and left thigh and shank IMU sensor angular velocities from the local coordinate system to the global coordinate system.

Part III: Compute the right and left knee joint angular velocities at each time step using the IMU angular velocities of adjacent body segments (i.e., the sensor angular velocities of the thigh and shank segments). Consider reviewing the double-pendulum example from class Lecture 3. Plot the trajectories for both knee joint angular velocities throughout the collection time. From a multibody kinematics perspective, comment on the potential limitations of expressing these lower-limb joint angular velocities within a single 2D plane. State an alternative method for computing such lower-limb joint angular kinematics from the exported IMU data parameters.

Part IV: Using the sagittal-plane thigh marker positions from the camera-based system (expressed in the global coordinate system) and an inverse pendulum model (see Appendix for schematic), calculate the right and left thigh marker positions relative to the fixed hip joint centers and determine the hip joint angular displacements. Assume rigid body segments and frictionless revolute joints. Consider revisiting class Lecture 2 on Particle Kinematics. Plot the trajectories for the right and left hip joint angular displacements throughout the collection time. Compare your calculated hip joint angles with those automatically exported from the IMU software. Comment on the differences.

4. Final Report

The final report should include: a brief introduction, pertinent (labelled) figures, responses to questions, summary of results with conclusions, and MATLAB code in the Appendix. Reports must be uploaded to the Dropbox on LEARN using **PDF format** before 11:59 PM on Friday, November 23, 2018.

5. Appendix

Inertial Measurement Unit System Output

Segments (Pelvis, and Right and Left Thigh, Shank, and Foot):

- 1x4 quaternion vectors of segment orientations in global coordinate system
- 1x3 position vectors [m] of segment origins in global coordinate system
- 1x3 velocity vectors [m/s] of segment origins in global coordinate system
- 1x3 acceleration vectors [m/s^2] of segment origins in global coordinate system
- 1x3 angular velocity vectors [rad/s] of segment in global coordinate system
- 1x3 angular acceleration vectors [rad/s^2] of segment origins in global coordinate system

Sensors (Pelvis, and Right and Left Thigh, Shank, and Foot):

- 1x3 sensor acceleration vectors [acc/s^2]
- 1x3 sensor angular velocity vectors [rad/s]
- 1x3 sensor magnetic field vectors [au]
- 1x4 quaternions of sensor orientations in global coordinate system

Joints (Right and Left Hip, Knee, Ankle, and Ball-Foot):

- 1x3 Euler joint angle vectors [rad] calculated using ZXY Euler sequence (Z: flexion/extension, X: abduction/adduction, and Y: internal/external rotation)

Optical Motion Capture System Output

- 3D orientation quaternions and center positions for the pelvis, and right and left thigh, shank, and foot segments
- 3D marker positions in the global coordinate system for the right and left anterior superior iliac spines, posterior superior iliac spines, thighs, knees, tibias, ankles, heels, and toes (note that these include quantities for both "raw" and "segment" marker positions).

Schematic for Part IV