Coursework 1 – Human Movement Analysis
Due at 3pm, 11 November 2022

1. Introduction

Gait analysis broadly encompasses the study of locomotion. As movements can occur quickly, data collection is performed with sample rates of at least 60 Hz (and often higher). This generates large quantities of data that are impractical to process by hand. The primary aim of this coursework is to use MATLAB to help post-process some data from your motion capture lab and then to interpret your findings.

While kinematics – joint angles, velocities, and accelerations – can be calculated directly, what cannot be determined from a motion capture lab are the forces generated by the muscles that enable us to move. One of the objectives of this coursework is to calculate some of these forces.

Before you begin, be sure to read this document in full, and don't forget to save your code and results as you progress through the analysis.

Your final submission will consist of **one pdf file** that:

- contains the **calculations** specified in **green** (these may be done by hand or type-written, but must show your steps and should not be coded)
- answers the **questions** written in **blue**
- shows the **figures** described in **purple,** and
- **includes the MATLAB code** you used to perform the necessary calculations, as an appendix.

The MATLAB programming in this project requires that you index an array. For guidance on this, follow this link https://uk.mathworks.com/help/matlab/learn_matlab/array-indexing.html. The syntax for some common MATLAB functions is listed in a separate file within the Coursework 1 folder on Blackboard. This is accompanied by some tips for plotting figures in MATLAB.

2. The obligatory back-story

Over the summer you performed a data collection session in your laboratory and recorded the x, y, and z coordinates of a series of reflective markers that you placed on a volunteer. These coordinates were determined using an optical motion capture system. The collected data are provided in the accompanying spreadsheet: Marker_data_2022.xls.

Coordinates were recorded in the lab coordinate frame. When you open the Marker_data_2022.xlsx file, you will notice that there are data for 30 markers. For each column, the marker location and coordinate (x, y, or z) are included in the first row.

3. Completing the dataset

One disadvantage of optical tracking systems that we mentioned in class is that a 'line-of-sight' is required. This can become a problem at certain instances during the gait cycle. For example, as a participant walks, markers may be obscured from some cameras as the contralateral limb moves between the marker and camera. Markers must be visible to at least two cameras (and often three) for their 3D positions in the capture volume to be reconstructed. When only one camera (or none!) can see the marker, its trajectory is not reconstructed. This creates a gap in the marker trajectory.

During your gait trial, the volunteer's right leg has occluded the marker on the medial side of the left knee for frames 98 through 123.

There are three commonly used approaches to fill in the missing data points:

(i) Linear interpolation – As the name implies, this method involves drawing a straight line from the start to the end of the gap.
Hint: `[F,TF] = fillmissing(A,'linear')`, where A is the array, and the value 1 (true) in entries of TF corresponds to the values of F that are filled.

(ii) Cubic spline filling.
Hint: `[F,TF] = fillmissing(A,'spline')`.

(iii) Redundant marker filling. In the case where there are more than three markers attached to a rigid segment, the visible markers can be used to construct a segment-fixed frame of reference. Since all the markers are attached to the same rigid segment (one of our assumptions), the position of the missing marker in the segment-fixed frame will be constant throughout the motion.

Demonstrate the calculation to create a transformation matrix describing the left thigh using the L.Thigh.Superior, L.Thigh.Inferior, and L.Thigh.Lateral for frame 98.
Use the following guidelines to construct your coordinate frames:

- Origin: L.Thigh.Superior
- Initial vectors using points: (1) L.Thigh.Superior & L.Thigh.Inferior and (2) L.Thigh.Superior & L.Thigh.Lateral
- y-axis pointing superiorly, parallel to a line between markers: L.Thigh.Superior & L.Thigh.Inferior

Now, load the Marker_data_2022.xlsx into MATLAB. Fill the empty cells with 'NaN' (not a number); you may find that in your spreadsheet they have been filled with '0's, so replace these. Fill the gap in L.Knee.Medial using the three approaches.

Plot the three trajectories of L.Knee.Medial obtained using the filling techniques above from 20 frames prior, to 20 frames following the gap. Be sure to include a legend on the graph.

Describe any differences you observe and their implications for subsequent analyses (approximately 100 words suggested).

4. Relating the limb segments to the lab

You would like to calculate the joint angles for the left and right knees. To determine these, you first need to create the transformation matrices that describe the locations and orientations of the limb segments relative to the laboratory coordinate system. The coordinate systems of all limb segments should have axes constructed such that x points to participant's left, y points proximally, and z points anteriorly (due to the right-hand rule).

Use the following guidelines to construct your coordinate frames:

- Thigh:
  - Origin: Patella

  - ✯ Initial vectors using points: (1) Thigh.Superior & Thigh.Inferior and (2) Knee.Lateral & Knee.Medial
  - ✯ x-axis parallel to a line between markers: Knee.Lateral & Knee.Medial
- Shank:
  - ✯ Origin: Shank_Inf
  - ✯ Initial vectors using points: (1) Shank.Superior & Shank.Inferior and (2) Ankle.Lateral & Ankle.Medial
  - ✯ x-axis parallel to a line between markers: Ankle.Lateral & Ankle.Medial

Demonstrate the calculations to create the transformation matrix between the <u>right</u> (1) thigh and lab coordinate systems and (2) shank and lab coordinate systems for frame 105.

Sense-check: You should find that the segment coordinate systems in frame 105 are approximately aligned.

5. Calculating joint angles

Now that you've determined the coordinate transforms of the thigh and shank with respect to the lab, you can calculate the joint angles for the knee. You choose to use an Euler X-Z-Y sequence of rotations to determine the joint angles.

Demonstrate the combination of unit rotations required to obtain the rotation matrix describing an X-Z-Y rotation sequence and state the equations you will use to calculate each joint angle.

For the left and right knees, list the name of the joint motion associated with a positive rotation about each axis and state why these are the same or different, depending on the leg (approximately 60 words suggested).

Joint rotations of the knee can be determined from the transformation matrix that expresses the shank with respect to the thigh.

Demonstrate the calculation of the transformation matrix that describes the right shank with respect to the right thigh for frame 105.
Determine the joint angles of the right knee in frame 105. State them with their associated joint motion.

Sense-check: Since the coordinate systems are approximately aligned, these should have magnitudes of less than 40°.

6. Expanding the calculations to include all frames.

Using the method described above, write a MATLAB script to calculate for all frames of the trial:

- the transformation matrices relating the left and right shanks and thighs with respect to the lab frame;
- the transformation matrices to describe the shank respect to the to the thigh for left and right sides;
- the joint angles for the left and right knees.

Plot the joint angles for the left and right knees for all frames such that flexion, external rotation, and abduction are positive.

Do your joint angles 'make sense'? Why or why not? Discuss the patterns of joint motion to justify your response (approximately 120 words suggested).

7. Determining muscle forces

Four of the major muscles that provide motion at the hip, are the gluteus maximus (G_{MAX}), gluteus medius (G_{MED}), hamstrings (H) and sartorius (S). The moment arms of the muscles relative to each axis of rotation dictate the function(s) of the muscles (Figure 1).

Draw a diagram of the femur and muscles in the transverse view, making the origin of the axes at the hip centre. Show all dimensions.

Write out moment balance equation about all three axes.

You have determined that the joint resultant moments at the hip (acting on the femur) are [M_x, M_y, M_z] = [-5.4, -15, -30.2] Nm, but you do not have enough information to solve for the forces generated by all of the muscles. You decide to eliminate one muscle from the problem.

Write out the system of equations in matrix form, i.e. [3 x 1 moments] = [3x4 coefficients][4x1 muscles].

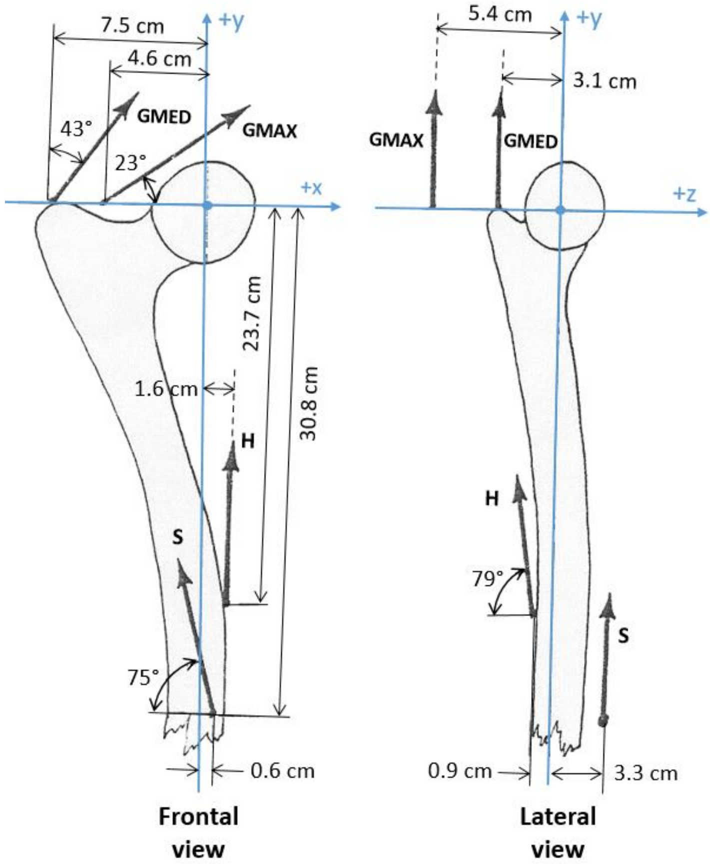

Figure 1. Frontal and lateral views of the right leg including insertions and lines of action for gluteus maximus (GMAX), gluteus medius (GMED), hamstrings (H), and sartorius (S)

Set the force of each muscle to 0 N in turn and **solve for the remaining muscle forces.**

Using your understanding of the mechanics of the system, select which muscle you would eliminate and justify your choice (approximately 30 words suggested).