BIOENG-404 - Homework 2: OpenSim

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1 Overview

No questions in the Overview section

2 Generic Model

1. How many bodies (segments) does model_generic have?

   12

2. How many coordinates (degrees of freedom) does model_generic have?

   19

3. Which two bodies are connected by the hip_r joint?

   `pelvis` and `femur_r`

4. Which coordinate represents right ankle flexion? In this model, is dorsiflexion described as a positive or negative angle?

   `ankle_angle_r` is the right ankle flexion coordinate. Dorsiflexion is associated with a positive increase in the `ankle_angle_r` coordinate.

5. What is the maximum isometric force that the soleus muscle can produce?

   `max_isometric_force`$= 3549.0N$

6. Some muscles in the model are represented by multiple muscle-tendon actuators. For example, the gluteus medius muscle is split into glut_med1, glut_med2, and glut_med3. Which other muscles in the model are divided into multiple compartments? Why do you think these muscles are represented this way?

   The *gluteus medius* muscle is a relatively "wide muscle", it is attached to the ilium along a line and has a much more narrow attachment to the greater trochanter (on the femur). Using a simple "point-to-point" model as is normally the case with OpenSim muscles would therefore yield an inaccurate representation of it's behavior (one would miss moments created by the width of the muscle for example).

   It is not the only muscle represented that way in the simulation, the *gluteus minimus* `glut_min1,2,3_l,r`, the *gluteus maximus* `glut_max1,2,3_l,r`, the *adductor magnus*, `add_mag_1,2,3_l,r` are also represented in that way for the same reasons.

3 Tools for analyzing models and data

7. Are the ankle flexion moment arms of the gastrocnemius and soleus muscles plotted as positive or negative? Given the muscles' geometric paths and the sign convention for the ankle_angle_r coordinate as defined in model_generic, does your answer make sense?

   Both the flexion moment arms are negative. When the body is in a standing pose the moment that the bodies creates on the ankle is in the direction of dorsiflexion (in our model, this corresponds to positive change of ankle angle) to counteract this effect the ankle muscle produces a negative moment.

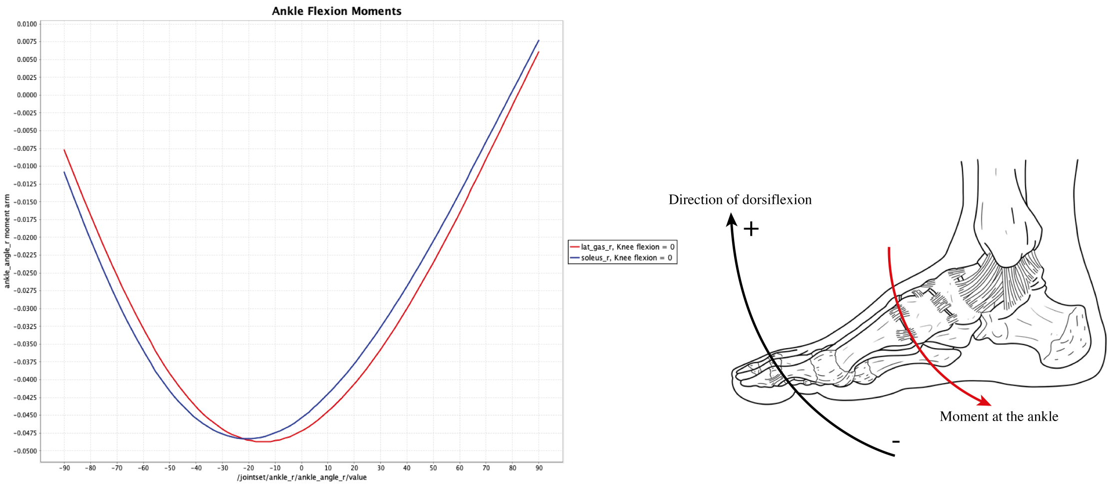


Figure 1: left : moments as plotted in OpenSim (left) and schematic representation of the ankle and moments in the sagittal plane (right)

8. Your plot shows the muscles' moment arms about the ankle with the knee fully extended. Do you think the muscles' moment arms about the ankle will change if the knee is flexed?

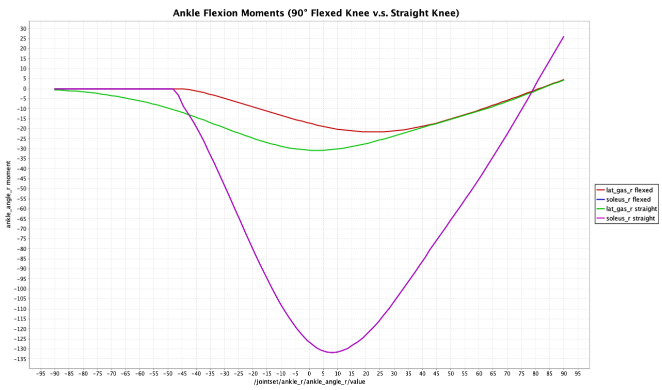


Figure 2: Plot of moments in the ankle for both flexed and straight knee.

   When the knee is flexed, the ankle is subject to much more intense moments than when it is straight as can be show in OpenSim by plotting the straight and flexed (90°) knee moments together.

9. Open the task.c3d file located in tutorial/experimental_data with Mokka.

   (a) Report the subject's height, weight, age, and sex by inspecting the metadata

      The subject is a 15 year old *male*, weighting 41.5kg and of 1610mm height.

(b) How does the coordinate system of the experiment (lab) differ from the coordinate system in OpenSim?

In OpenSim, the up direction corresponds to the y axis, in the experiment, the z axis points up.

(c) Visualize the ground reaction forces (Analog channels, then drag and drop the component into an analog type plot). What do you observe in terms of the quality of the signal?

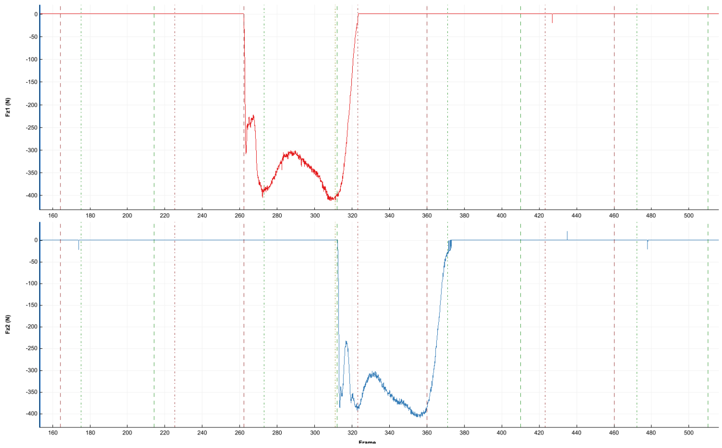


Figure 3: Ground reaction forces, as displayed in Mokka

The signal is somewhat noisy and only shows values when the patient is walking over the pressure plate.

(d) Calculate the linear envelop (Tools -> Analog -> Smooth / Linear Envelope) of the right tibialis anterior's EMG. What is the linear envelop?

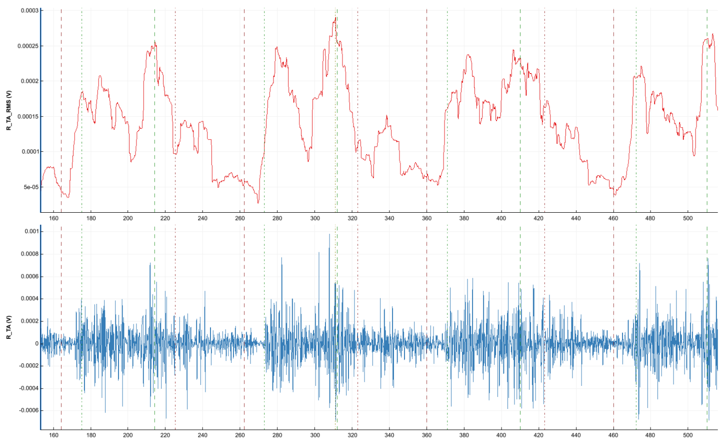


Figure 4: Linear envelope of the tibialis anterior EMG signal (top) and unprocessed tibialis anterior EMG signal (bottom).

The linear envelope of a signal describes the evolution of it's amplitude of oscillation over time. More rigorously it is defined as a combination of a rectification of the signal with some kind of low-pass filter.

10. Preview the markers (task.trc) and ground reaction forces (task_grf.mot) in the OpenSim GUI by synchronizing them. Check if the forces are correctly applied to the foot. Which labels in the ground reaction force data correspond to the left and right leg?

Synchronizing the pressure sensor data with the motion capture shows a good alignment between the left and right leg pressure sensors. The forces on the left and right feet are respectively labeled `left_ground_force_v` and `right_ground_force` in the `task_grf.mot` file.

11. What is the function of the Adjust Model Markers option in the Scaling tool?

    When checked it allows for manual adjustment of the model markers (which can in turn improve the quality of inverse kinematics solutions).

12. What is the scale factor for the left talus, calcaneus, and toes?

    We use the same value for the left talus, calcaneus and the toes :
    `scale factor = 0.990274, 0.990274, 0.990274`

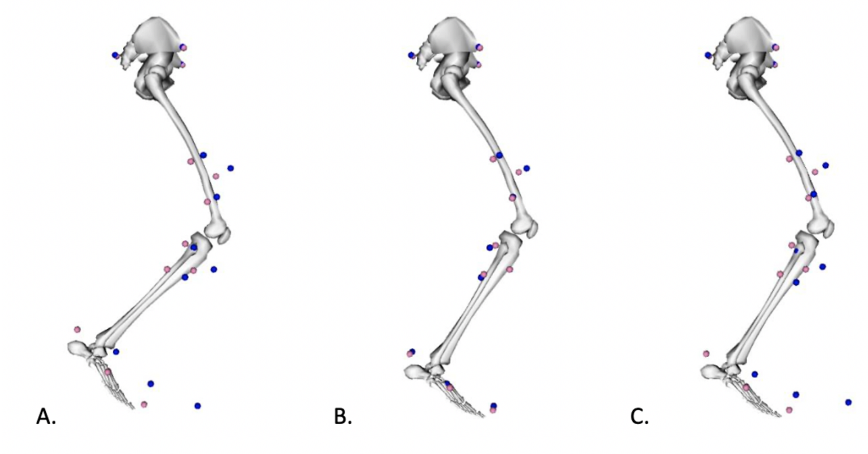
13. In the metadata of the task.c3d file in Mokka (View -> Metadata -> SUBJECTS), there exist direct segment length measurements. Compare the left and right foot length and the one reported by the Scaling tool (check the message window after running the tool, where the length is reported in meters).

    According to the metadata the right foot is 200mm long and the left foot is 220mm long. According to the experimental data (inferred using the scaling tool) the right foot is 201mm long and the left foot is 198mm long. The direct measurement gives a significant size difference between both feet whereas the scaling tool doesn't pick up on it, this may be due to marker placement.

14. For the model shown on the right, which coordinate(s) need to be adjusted to create a model pose that "best matches" the experimental markers shown at the beginning of the swing phase?

    E. Knee and Ankle

15. For the model poses and experimental markers shown below, which combination of pose and markers has the minimum marker errors?



    The *B* pose-marker combination yields the smallest error.

16. In theory, experimental markers on the thigh and shank could have more skin movement artifacts compared with the foot markers; which of the following scenarios would be most appropriate for the weighted least squares minimization solved by the Inverse Kinematics Tool?

    4. All of the above

17. What is the root-mean-squared (RMS) marker error from the last frame of the motion? Does this seem reasonable?

    $\texttt{RMS}(\text{frame} = 363 \ (\textit{last frame})) = 7.84131 * 10^{-3} m$
    This seems reasonably small.

18. Plot the hip flexion-extension, knee flexion-extension, and ankle plantar flexion-dorsiflexion angles of the left leg on a single graph. Search through the internet and compare the shape of these curves for a healthy gait. Do they seem normal?

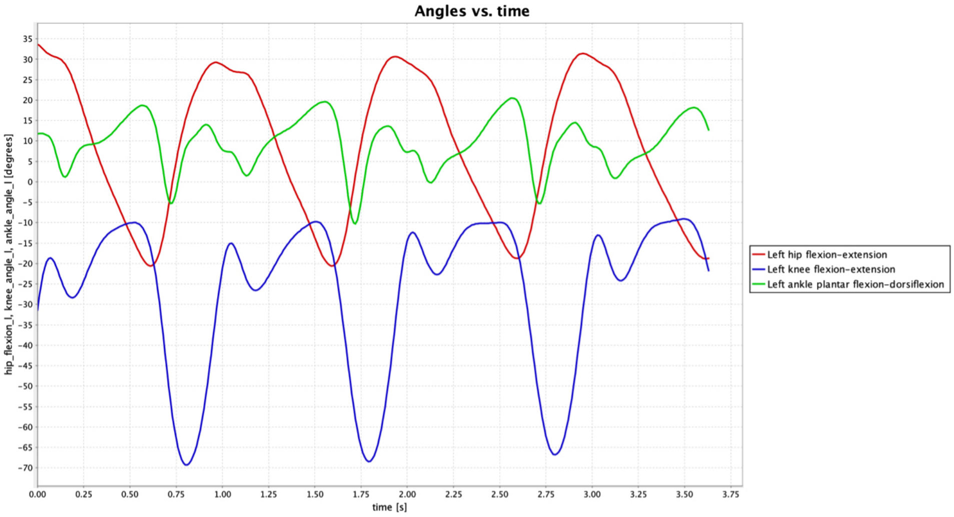


Figure 5: Plots of left hip, knee and ankle flexion-extension over time.

    The curves seem relatively normal in shape, comparing values with Oberg et. al's comparative study [**1**], we observe that the angles reached by the joints at different key points in the gait (mid stande, swing, flexion extension etc.) are within what is considered normal for a healthy patient.

19. For the model shown on the right, what is the value (θ) of the knee coordinate (Note: extension is +)?

    Answer B. $-54.9°$

20. Given that the model shown on the right is at rest, what is the knee's velocity?

    Answer D. $0°/s$

21. For the model poses shown below at rest and with gravity (g) as the only force acting on the model, which pose requires the largest torque at the knee joint?

    When resting the moment is the strongest on the flexed knee, so the correct answer is A.

22. Plot the hip flexion-extension, knee flexion-extension, and ankle plantar flexion-dorsiflexion moments of the left leg on a single graph. Search through the internet and compare the shape of these curves for a healthy gait. Do they seem normal?

    The ankle moment is constantly positive (whereas it should hit 0 during part of the gait) while the knee moment is constantly negative (again it should hit 0 at some point). This seems to indicate that the muscles are contracted during the entire gait. Which may indicate a gait pathology such as crouch gait (as described by Connor et. al [**2**]) which is commonly associated with cerebral palsy in children.

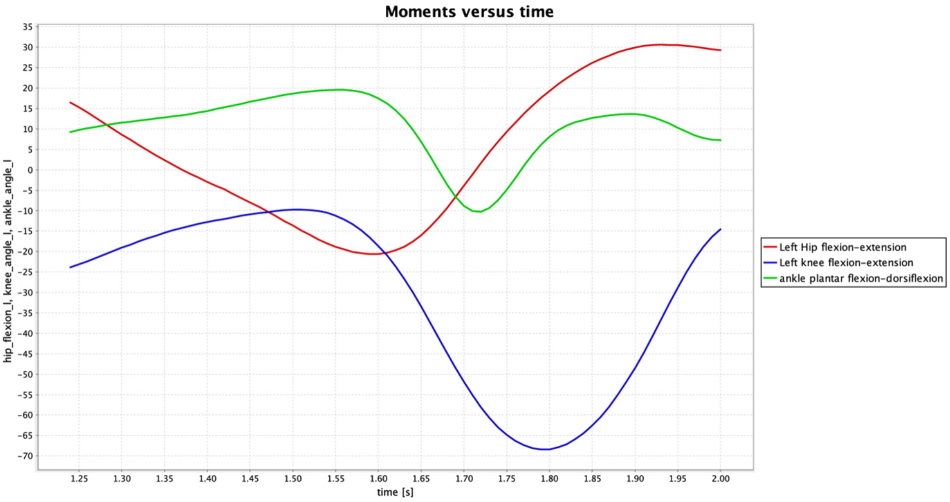


Figure 6: Plots of the hip, knee and ankle flexion-extension (flexion-dorsiflexion for the ankle) moments over time (in $N \cdot m$).

23. Why does the force-length curve of the contractile element of the muscle have a bell shape? Please elaborate.

    The force length relationship is determined by the overlap between actin and myosin filaments and cross-bridge formation in the muscle fibre. The peak of the bell shape is the length at which the overlap is maximal. At short lengths actin filaments slide passed each other which reduces the number of cross-bridges, and therefore the produced force. At longer length the myofilament overlap is lowwer and the cross-bridge formation is also smaller.

24. What is the meaning of the force-velocity shape of the contractile element, and how does it relates to physiology?

    The rate of shortening or lengthening of muscle fibre has an influence on the force that is produced (which is what explains the force-velocity relationship). This effect is mostly governed by probabilistic effects in cross-bridge formation. The higher the velocity, the lower the probability that a cross-bridge forms in a low-strain configuration and therefore, the lower the force.

25. After executing SO, the muscle activations task_StaticOptimization_activation.sto are exported in the static_optimization folder. The EMG envelop emg_env.sto was extracted and saved in the experimental_data folder. Compare the activations predicted by SO with the EMG for the following muscles: lat_gas_l, tib_ant_l, rect_fem_l. Please comment.

26. What is the difference between muscle excitation and activation? What does the EMG measure? How can we compare measured EMG and predicted muscle activity from OpenSim?

    Muscle excitation is ... **FINIR**

27. Is the cost function used in SO appropriate for studying pathological conditions such as Cerebral palsy or Parkinson's disease?

    TODO

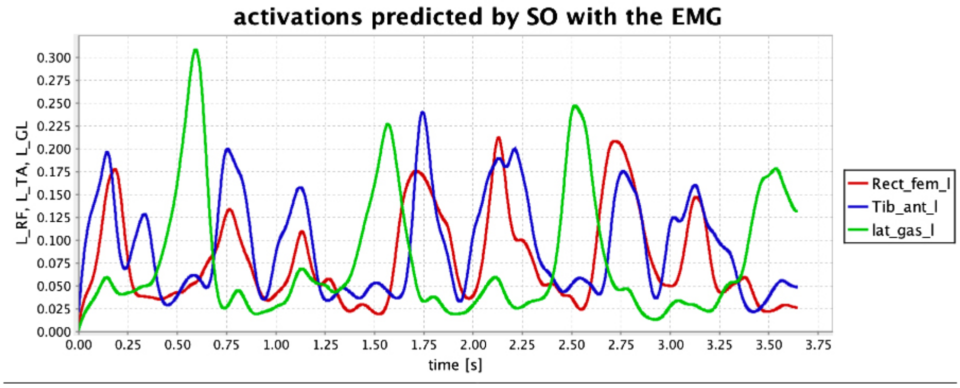


Figure 7: Activation predicted by solving the static optimization problem.

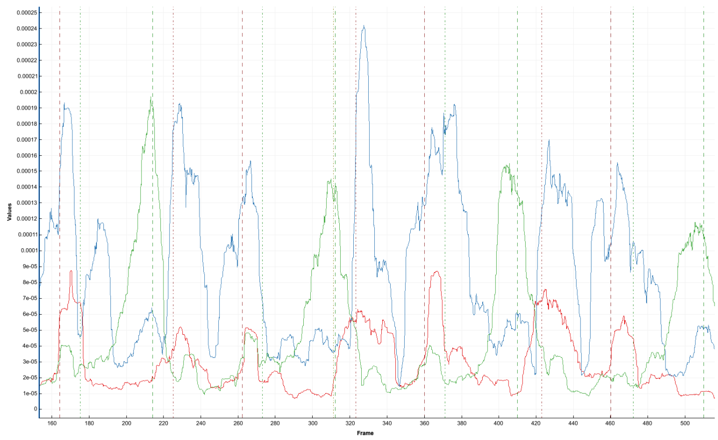


Figure 8: EMG data recorded while performing the experiment.

References

[1] Oberg T, Karsznia A, Oberg K. "*Joint angle parameters in gait: reference data for normal subjects, 10-79 years of age.*" *Journal of Rehabilitation Research and Developpement vol. 31, No. 3*, pp. 199-213, 1994.

[2] Connor J., Cobanoglu M. "*Stance Phase Problems in Cerebral Palsy (Strength).*" *Handbook of Human Motion, Springer*, 2016.