BIOM1010 Engineering in Medicine and Biology

Musculoskeletal Modelling in Physical Rehabilitation

Introduction

This activity will introduce you to the open source software, OpenSim, which is used in modelling and simulation of human movement. In this activity, you will be introduced to the software, its interface and some of its functionalities, as well as have the opportunity to evaluate the risk of injury during landing and to design the optimal ankle brace for prevention of ankle injuries.

You will need a number of files for this activity:

- **afoCuff.STL**: contains the geometry for the upper part of the ankle brace.
- **afoPlate.STL**: contains the geometry for the lower part of the ankle brace.
- **ToyLandingModel.osim**: contains the model of the skeleton without the ankle brace.
- **ToyLandingModel_AFO.osim**: contains the model of the skeleton with a passive (i.e., unpowered) ankle brace.
- **ToyLandingModel_activeAFO.osim**: contains the model of the skeleton with an active (i.e., powered) ankle brace.
- **ActiveAFO_Controls.xml**: contains the control parameters for the active ankle brace.

These files are available via Moodle. Please download these files and save them in one folder. Alternatively, if you are working on your own computer, you can find these files in the ToyDropLanding folder, which is located within where you installed OpenSim (for me, C:\Opensim 3.3\Models\ToyDropLanding). Let's get started!

Part I. Familiarisation and Exploration

I.A. The Model

a. Launch OpenSim.
b. Open the model ToyLandingModel.osim by clicking **File** in the toolbar and then **Open Model…** Double-click ToyLandingModel.osim. The graphical user interface (GUI) should now look something similar to the figure shown on the next page (your background might be black).

   Things to note about the model before continuing include:
   - The skeleton consists of a torso, a pelvis, and two legs with a total of 23 degrees of freedom and 70 muscle-tendon actuators (force generators).
   - The model consists of various elements, which can be viewed from the **Navigator** tab (left hand side). Expand the model by clicking the + icon next to the model's name. You should see groups such as Bodies, Joints, Constraints, etc.

This tutorial is from the introductory example "Simulation-Based Design to Prevent Ankle Injuries", available from the OpenSim documentation.

- In this model, motion between the tibia and foot is described by two joints: ankle_r and subtalar_r. These represent the talocrural (or “true ankle”) joint and the subtalar joint, respectively.
- Contact spheres (shown in blue) are attached to the feet to produce foot-floor contact forces. You can investigate these further via the **Navigator** tab by expanding **Forces** and clicking on **Contact Forces**.

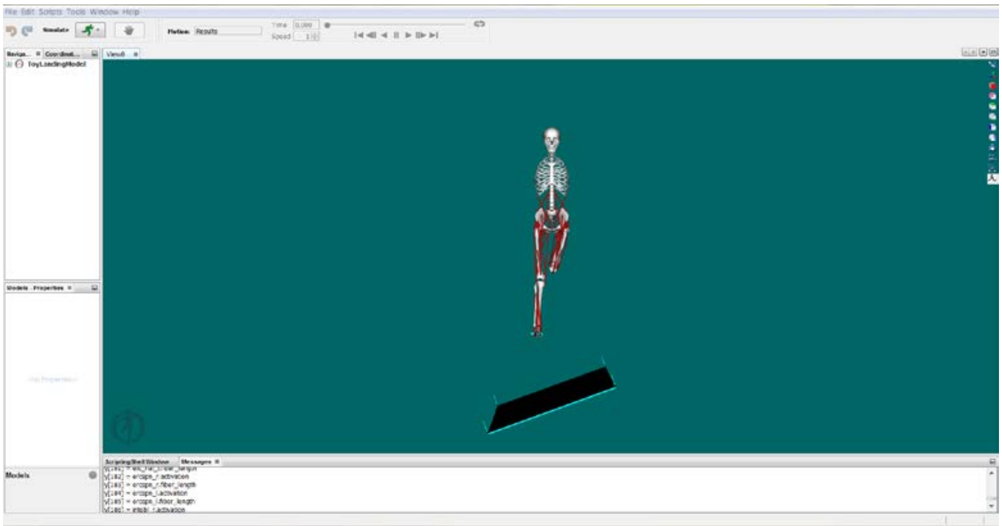

Figure 1 The graphical user interface of OpenSim

I.B. The Model’s Joint Coordinates

The floor is modelled as a contact plane with four degrees of freedom (three rotational and one translational). The model is posed so it will land on its right leg on contact with the platform. The left hip and knee joints are locked to hold the pose and avoid interference from the left leg during landing. You can explore these degrees of freedom using the **Coordinates** panel on the left hand side.

a. Select the **Coordinates** tab.
b. Use the sliders to change the ankle_angle_r and subtalar_angle_r coordinates. Zoom in on the ankle joint. Click and drag with the right mouse button to zoom in and out. Use the middle mouse button to pan and the left mouse button to rotate the view.
c. Unlock the platform_rx coordinate by click the little lock icon.
d. Enter values in the platform_rx text field or move the slider to change the angle of the platform in the frontal plane. You can use the platform_ry and platform_rz coordinates to rotate the platforms around its other two axes.
e. Unlock platform_ty and change its value to move the platform up and down.
f. Return the model to its original pose by clicking **Poses>** and choosing **Default**.
g. **Lock** all the platform coordinates.

Questions

1. Which degrees of freedom enable ankle inversion/eversion?
2. To tilt the platform in the sagittal plane (side view), would you change platform_ry or platform_rz?
3. Why do you think the mtp_angle_r coordinate in the model is locked?

Part II. Evaluation (No Brace)

II.A. Simulate a Drop Landing

a. First check that the model is in its Default pose, with platform_rx set to 20°, platform_ry to 0°, platform_rz to 0° and platform_ty to -0.5m. All four platform coordinates should be locked. This will prevent the platform from falling or rotating on impact.
b. Locate the simulate button (a little green running person) in the OpenSim toolbar.
c. Click the little arrow next to the simulate button and select the **End Time…** drop down item. Set the simulation time to **0.4s** in the pop window. From here on in, OpenSim will remember this choice when you hit the simulate button and run a forward simulation for 0.4s.
d. Click the **simulate** button. OpenSim will use the current pose of the model as the starting state for the simulation. The model will animate during the forward simulation.
e. Once the simulation has completed, you can use the animation controls above the view window to play, pause, and scroll through the resulting motion and muscle activity (no activation (dark blue) to full activation (bright red)). Zoom in on the ankle joint and replay the motion.
f. Click on the **Navigator** panel and find the **Motions** list. The motion **Results** in bold corresponds to the simulation you just generated.
g. Right click the bold **Results** motion and **Rename…** Call this motion **Unassisted**.
h. To save the results, right click the **Unassisted** motion and select **Save As…** Name this file Result_Unassisted. It should have a STO (storage) or MOT (motion) file extension. Either file type is fine.

II.B. Analyse the Results

a. Open a new plot window by selecting **Tools** and **Plot…**
b. Click **Y-Quantity** and select **Unassisted (Deg.)…** near the bottom of the list to select kinematic data from your last simulation. If you saved the motion to a file, you can also use the **Load file…** option and navigate to the desired results file.
c. In the **Filter by pattern** text box, type “sub” to filter the results to just those containing the text string “sub”.
d. Select **subtalar_angle_r** and click **OK**.
e. Select **X-Quantity** and choose **time**.
f. Click **Add** to display the data as a curve.
g. Click on **Figure 1** in the Curves List to highlight it. Click again to rename. Modify the title field (e.g., “Ankle Inversion during Drop Landing”). Alternatively, right click and edit using the **Properties** menu, or click **Properties…**
h. Click on **subtalar_angle_r** to highlight the curve label in the Curves List box and click again to rename. Since this simulation used a model with no assistive devices, change this curve name to **Unassisted**.
i. Answer the questions in the green box below, then **minimise** the plot window. Keep the plot window open so you can use it to compare these results to simulations with an AFO.

Questions

4. What is the maximum subtalar angle during the drop landing?
5. Would an ankle inversion injury have occurred during this landing? According to previous research (Siegler et al., 1990; Lapointe et al., 1997), angles larger than 25 degrees may cause injury.

Part III. Analysis with Passive Brace

You will now repeat Part II using a model with a two-segment passive ankle foot orthosis (AFO):

- The AFO has a footplate that is rigidly attached to the foot and a cuff that is rigidly attached to the tibia.
- The footplate and cuff are connected at two hinge points by six-dimensional springs called bushing. Pink markers identify the connection points. The bushing resist the relative translation and rotation of the footplate and cuff.

III.A. Explore the AFO Model

a. Select **File** and click **Open Model…** Choose **ToyLandingModel_AFO.osim**. Once the model opens you will see a similar drop-landing model, but with an AFO (or brace) attached to the right foot. The model will also appear in the Navigator panel. Its name is in bold, indicating it is the current model.
b. Explore the model using the **Navigator** panel. Which new bodies and joints define the AFO that has been added?
c. Find the **Property Editor** to see more details about these new components. If you don't see the Property Editor in the bottom left corner of your screen select **Properties** from the **Window** menu in the toolbar to display it.

III.B. Simulate and Analyse a "Soft" AFO

a. Repeat the simulation steps from Part II.A. above. The simulation button acts on the current model, shown in bold in the Navigator panel. This should be the ToyLandModel_AFO that you just loaded. Rename the new results as **SoftAFO** this time and save as **Results_SoftAFO**.
b. Repeat the plotting steps from Part II.B. above. This time, instead of opening a new plot window, **maximise** the plot from Part II to add a new curve. Rename the new data curve from subtalar_angle_r to **SoftAFO**, then **minimise** the plot window. (Don't close the plot window! We will add another curve later.)

III.C. Simulate and Analyse a "Stiff" AFO

Now let's make the AFO stiffer. You can edit the properties of the AFO using the OpenSim GUI's Property Editor.

a. In the **Navigator** panel, go to **Forces** and click **Other Forces** to find **AFO_med_bushing**.
b. Highlight the **AFO_med_bushing** by clicking it once. You should now see the properties of the AFO_med_bushing in the Property Editor below.

c. Find the property in the list called **translational_stiffness**. This property controls the stiffness of the bushing that prevents the AFO cuff from translating with respect to the footplate on the medial side of the brace.
d. Make the translational_stiffness 10 times stiffer in each direction, i.e., set the translational_stiffness property to 100000 100000 100000.
e. Repeat steps b – d for **AFO_lat_bushing**.
f. Repeat the simulation steps from Part II.A. one more time. Rename and save the new results as **StiffAFO** this time.
g. Repear the plotting steps from Part II.B. Once again, instead of opening a new plot window, re-open the plot from Part II to add a new curve. Rename the new data curve from subtalar_angle_r to **StiffAFO**.

Questions

6. You have now simulated three different drop-landing conditions: with a brace, with a soft brace, and with a stiffer brace. What differences in peak ankle inversion do you observe between the simulations?
7. Could this brace mitigate ankle inversion injuries?

Part IV. Analysis with Active Brace

Rehabilitation robotics are providing new active devices to help train and optimise movement. Orthotics for ankle injury prevention have traditionally been passive devices, but what if you could create an active mode for landing? We will add a torque motor at the ankle to model an active orthotic. Your challenge will be to optimise the timing and activation level of the active orthotic to prevent ankle inversion injury.

IV.A. Explore the Active AFO Model

a. Select **File** and **Open Model…** to open **ToyLandingModel_activeAFO.osim**.
b. Explore the model using the **Navigator** panel. What new forces have been added?
    i. What degree of freedom does this motor control have?
    ii. What is the optimal force of this motor?

IV.B. Modify the Active AFO Torque Profile

The default setting for the active AFO is ‘off’ and you will need to define when the orthotic is active. To specify the torque produced by the active AFO and run a forward simulation, we will use the **Forward Dynamics** tool, which allows specification of additional settings.

a. Select **Tools** and click **Forward Dynamics…** to launch the Forward Dynamics tool.
b. Under the **Main Settings** tab, find the **Input** subsection.
c. Check the box for **Solve for equilibrium for actuator states**. This will initialise the tendon and muscle fibres before starting the integration.
d. Set the **Time range to process** as **0** to **0.4**.
e. Change the output **Directory** by adding **\ActiveAFO** to the end of the displayed folder name.
f. In the **Input** subsection, select the **folder button** next to Controls. Open the file **ActiveAFO_Controls.xml**.

g. Select the small pencil button next to the Controls box to edit the controls file. Under **Select Excitation**, check the box next to **ActiveAFO** and his **OK**. This will open the Excitation Editor, which shows the excitation of a controller (in our case, the activeAFO) with respect to time.
h. Change the excitation profile by moving the points in the Excitation Editor. To select a point, hold down Ctrl and click on the point (similarly you can select multiple points by holding down Ctrl and dragging the mouse over multiple points). To change the value of the points, you can either drag them on the screen, or enter a value in the **Set selected point to** box. You can also add or remove points. Click the **Help** button for more information.
i. Once you are done editing the excitation profile, select **Save As** to save an XML file called **ActiveAFO_Edited.xml.** Close the Excitation Editor.
j. On the Forward Dynamics setup screen, make sure your edited Controls file is selected by selecting the **folder button** and choosing your new controls file.
k. You can save your setting to reuse later by clicking on the **Save…** button and saving your setting (e.g., setup_forward_activeAFO.xml).
l. Click **Run**. This will use the default options for all other settings. Since you haven't specified an Initial State file, the tool will use the current pose of the model in the GUI as the starting state for the simulation. This is why it is really important to return the model to its default position before running any simulation.
m. The model will animate during the forward simulation. You can **close** the tool after you've click Run.
n. Rename the new motion to **ActiveAFO**. The results will be automatically saved by the Forward Dynamics tool in the directory you specified in step e.

Part V. Brace Optimisation

Challenge

Your challenge is to create the optimal brace for drop landing. Edit the activation of the brace and the stiffness to optimise your design. Criteria to consider include:

- Minimal brace stiffness for maximum comfort and low material costs
- Smallest torque required from the active brace for a small compact motor
- Minimal amount of time the brace is active to maximise battery life
- Prevention of ankle injury, i.e., inversion angle <25°

Interrogate the efficacy of the optimal brace you have designed by exploring other scenarios, such as, but not limited to:

- Adding a backpack to the model (by adding a new body or increasing torso mass)
- Changing the initial pose of the model (e.g., increasing the initial ankle plantarflexion angle)
- Testing different landing scenarios (e.g., platform slope, surface characteristics)