OpenSim Exercise: Evaluate Ankle Inversion Injury Risk During a Drop Landing

Overview

The purpose of this exercise is to demonstrate how to apply OpenSim to evaluate injury risk for soldiers under varying conditions during a drop landing task. The conditions include the effects of a passive ankle-foot orthosis (AFO) and added load due to a 25kg backpack. In a short amount of time, users should be comfortable running forward dynamics simulations with varying conditions and plotting the results to compare their effects.

Note that the model and controller used in this example are for demonstration purposes. The model does not represent a complete set of lower extremity muscles, especially those necessary for controlling the ankle, subtalar, and metatarsophalangeal (MTP) joints. The controller is a simplified version of the mono-synaptic stretch reflex generated by muscle spindles that detect lengthening of muscle fibers. In this case, the reflex is due to whole muscle-tendon lengthening speed and is not isolated to lengthening speed of the muscle fiber. Additionally, there is no transmission delay from stretch detection to eliciting a muscle excitation.

I. Setting up OpenSim and exploring the musculoskeletal model

A. Installing OpenSim and the custom plugin for the model controller

1. Download the installer for OpenSim version 2.4 here. Take note of which version of the installer you download (e.g. VCP9 or VC10E).
    a. There are several versions of OpenSim that were built using different Microsoft Visual C++ compilers, in order to facilitate the development of user programs and OpenSim plugins using the OpenSim application programming interface (API).
    b. If you plan on developing using the OpenSim API, be sure to use a version that matches your version of the Visual C++ compiler (VC8 pro, VC9 pro, or VC10 express).
    c. If you are not planning on using the API, you can download the first link (VC9P).
2. Run the .exe and follow instructions to install OpenSim. Note: Only install OpenSim in folders for which you have read and write privileges. For example, do not install OpenSim in *C:\Program Files*.
3. Take note of where you install OpenSim. We will refer to this location as *[OpenSimRoot]* from now on.
4. Download the **LandingDemoFiles.zip** archive from the OpenSim for Warrior Web Project.
5. Unzip the archive on your Windows Desktop or any preferred working directory.
6. Navigate to your new *LandingDemoFiles* directory and find the library files named **ReflexControllerPlugin_<version>.dll** (<version> refers to the compiler used to build the library).
7. Find the <version> that matches the OpenSim version you downloaded.
8. Open a new Windows Explorer window and navigate to *[OpenSimRoot]* directory.
9. Copy/Paste **ReflexControllerPlugin_<version>.dll** into *[OpenSimRoot]\plugins.* If the *\plugins* directory does not exist, make one and paste the libraries in it.
10. **VC8 Users:** You must copy/paste both library files **ReflexControllerPlugin_<version>.dll** and **ReflexControllerPlugin_<version>.lib**.

B. Launching OpenSim and loading the ReflexControllerPlugin

1. You can launch OpenSim 2.4 from the Windows Start Menu. If you used default installation settings, simply select *Windows>All Programs>OpenSim 2.4>OpenSim.* You will see multiple information panels and an empty main view.
2. To load the ReflexControllerPlugin, select *Tools>User Plugins>ReflexControllerPlugin.dll.* If you cannot load the plug-in, you likely selected the wrong <version>. Repeat steps 6 to 11 above with a different <version> of the plugin.
3. From now on, any model file containing this custom reflex controller can be read, loaded, and run from the

OpenSim Gui.

C. Opening and exploring the drop-landing musculoskeletal model

The Model

1. In the OpenSim GUI, select *File>Open Model****,*** then select **LandingModel_no_AFO.osim**.

The OpenSim GUI will now show a view window containing a model with a skeleton and a platform. The skeleton contains a torso, pelvis, and two legs comprised of 23 degrees of freedom and 54 muscle-tendon actuators. Attached to the feet are contact spheres that produce forces against the floor. The floor is comprised of a contact plane and four degrees of freedom which you can use to rotate and lower the contact plane relative to the skeleton before simulating a drop.

The Ankle Joints

Motion between the tibia and foot is described by two joints. You can explore these joints and the bodies they connect using the Navigator tab in the left panel. Expanding the model will show multiple groups, including Bodies and Joints. Expanding the Joints group will reveal all joints in the model. The joints associated with the ankle of the right leg are **ankle_r** and **subtalar_r**. These represent the talocrural joint, or "true ankle", and the subtalar joint.

Explore the model's joint coordinates

1. Locate the **Coordinates** tab in the left panel.
2. Use the sliders to change the **ankle_angle_r** and **subtalar_angle_r** coordinates
3. Unlock the **platform_rx** coordinate (by clicking on the lock icon).
4. Enter values in the **platform_rx** text field or move the slider to change the angle of the platform in the frontal plane. If you desire, you can use the **platform_ry** and **platform_rz** coordinates to rotate the platform around its remaining orthogonal axes.
5. Unlock **platform_ty** and change its value to move the platform up and down.
6. Select *Coordinates>Poses>Default* from the coordinate panel to return the model to it's original posture.

Questions

1. Which degrees of freedom enable ankle inversion/eversion?
2. In order to tilt the platform in the sagittal plane, would you change **platform_ry** or **platform_rz**?

II. Evaluate ankle inversion injury during a drop landing on a sloped surface

A. Simulate a drop landing

1. Unlock all platform coordinates.
2. Select *Coordinates>Poses>Default*. This returns the model to its default pose.
3. Set **platform_rx** to 20 degrees, **platform_ry** to 0 degrees, **platform_rz** to 0 degrees, and **platform_ty** to -0.5 meters.
4. Lock all 4 coordinates of the platform. This will prevent the platform from falling or rotating on impact.
5. Select *Coordinates>Poses>Set Default* (**not** "*Default*"). This will set the current pose (including any locked coordinates) as the new default position, which the forward simulation will use as its initial conditions.
6. Select *Tools>Forward Dynamics*. This opens the Forward Dynamics tool.
7. Under the *Main Settings* tab, find the *Input* subsection.
8. Check the box for **Solve for equilibrium for actuator states**. This will initialize the tendon and muscle fibers before starting the integration.
9. Select run, using the default options for all other settings. The model will animate during the forward simulation.

10. Once the simulation completes, use the animation controls above the view window to play, pause, and scroll the resulting motion and muscle activity.

B. Plot and analyze simulation results

1. With the model and simulation from Part A still loaded, open a plot by selecting *Tools>Plot...*
2. Click the *Y-Quantity* button to begin selecting data to plot.
3. Select **Results(Deg.)** near the bottom of the list to select kinematic data for your last simulation
4. In the pattern text box, type "sub" to filter all results.
5. Select **subtalar_angle_r** and click **ok**.
6. Select *X-Quantity>Time* to choose time as the independent variable.
7. Click **Add** to display the data as a curve.
8. Select **Properties** to relabel the plot axes and title.
9. Modify the title field to "Ankle Inversion (subtalar angle) during drop-landing"
10. Right click the curve label named "subtalar_angle_r" in the Curves List box and select "rename".
11. Since this simulation used a model with no assistive devices, change this curve name to "unassisted"
12. Keep this plot window open so you may use it to compare these results to simulations in the next exercises.

Questions

1. What is the maximum subtalar angle during the drop landing?
2. Would an ankle inversion injury have occurred during this landing?

III. Analyze the effects of an ankle-foot orthosis (AFO) on ankle inversion during the drop landing

You will now repeat **Part II** using two new models with assistive devices. Select *File>Open Model* and open the file named **LandingModel_soft_AFO.osim**. Once the model loads, you will see a similar drop-landing model, but with an ankle-foot-orthosis (AFO) attached to the right foot. You will also notice that the model is already posed in the initial conditions we used in **Part II**.

1. Explore the model using the **Navigator** panel. Which new bodies and joints define the AFO we added? You can right click new bodies and select Property Viewer to see more details about them.
2. In the navigator panel, select the **Forces** group and then it's subgroup, **Other Forces**.
3. Right click **AFOBushing** and select **Property Viewer** to see details about the force between the AFO foot plate and cuff bodies.
4. Repeat **Part II.A** steps 6 - 9 and **II.B** steps 2 - 7 using the plot window you created earlier. This will allow you to add new data to the previous plot and compare the two simulations.
    a. If you change the pose of the model, you will need to select *Coordinates>Poses>Default* before running the Forward tool to place the model back in its default pose.
5. Rename the new data curve from "subtalar_angle_r" to "soft AFO" (as in step II.B 10).
6. Select *File>Open Model* and open the file named **LandingModel_stiff_AFO.osim**.
7. Repeat the forward simulation process using this model with a stiff AFO. Remember to plot your results to compare all three simulations!

Questions

1. You have now simulated three different drop-landing conditions: without an AFO, with a soft AFO, and with a stiffer AFO. What differences in peak ankle inversion do you observe between the simulations?
2. Could this AFO mitigate ankle inversion injuries?

IV. Analyze the effects of load carriage on the performance of an AFO

Soldiers rarely operate in ideal conditions or without equipment. How would you expect these finding to change for a subject wearing a full combat load? Packaged with this example you will find a drop-landing model that includes the stiff AFO and an additional 25 kg body segment to represent a backpack. Use what you've learned in the earlier parts to simulate the model with a backpack load and to determine whether our assessment of whether or not he AFO could mitigate injury still holds.

Questions

1. Is the AFO able to mitigate ankle inversion injury when the model includes a 25kg backpack load?
2. Why do you think the model collapsed with the added load of the backpack? Are the ankle inversion angles observed still valid? How could you change the model or controller to prevent collapse?

Building your own assistive device

Now that you have learned to load models, perform, simulations, and explore your results in OpenSim, the next step is to represent your own designs in OpenSim. In OpenSim 2.4, you can edit existing models (.osim files) and add your own model components using an xml editor. See the model editing example to learn more about adding model components that OpenSim already provides. You can also define new model components using the OpenSim API (See the Developer's Guide).