Example: RRA and CMC

In this exercise, you will generate a forward simulation of the stance phase of gait. You will use a simplified model (leg6dof9muscles.osim). The model consists of the pelvis, thigh, shank, and foot segments along with the psoas major, gluteus maximus, rectus femoris, vastus intermedius, biceps femoris long head, biceps femoris short head, tibialis anterior, medial gastrocnemius, and soleus muscles. This simple model is not intended for research.

You can find the model and the necessary files for this example in the directory where you installed OpenSim (e.g. C:\OpenSim2.3.2\examples\Leg6Dof9Musc).

If you have questions about the inputs, outputs, or best practices for any of the tools, please refer to the corresponding chapter of your handout.

A. Preliminaries

1. Load the leg6dof9muscles.osim model.
2. Preview the kinematics and ground-reaction forces with the model located in the Leg6Dof9Musc\Stance directory
    a. Load the motion file, leg69_IK_stance.mot, and hit play.
    b. Under File, choose Preview Motion Data and select leg69_stance_grf.mot
    c. Select both motions: hold the control key, right click to sync motions, and hit play.

Questions:

1. What type of data is available?
2. For what time range were GRFs measured for the leg of interest

B. Use Inverse Dynamics to determine the amount of residual force that is required for the model's dynamics to be consistent with applied ground reaction forces:

1. Right click the leg69 model and make it the current model.
2. Launch the Inverse Dynamics tool.
3. Use the loaded motion file that you previewed above. Under Input->Motion->Loaded motion, "ik trial".
4. Check the box to filter coordinates at 6Hz.

5. Specify the time range as 0.5s to 1.5s, the period in which ground reaction forces are defined.
6. Specify an output directory (e.g. Stance\ID_Results)
7. Select the External Loads tab and check the External Loads box.
8. Edit the External Loads settings by clicking the pencil icon.
    a. Select the leg69_stance_grf.mot as the Force data file. This file describes the force applied at the foot's center of pressure described in the lab reference frame.
    b. Select leg69_IK_stance.mot and filter at 6Hz.
    c. Forces listed in the motion file are added as individual forces by hitting the Add button.
        i. Provide a name (e.g. "Right_GRF")
        ii. Applied to body (e.g. calcn_r)
        iii. Check Applies Force and select Point Force
        iv. Force Columns select "ground_force_vx", y & z selected automatically
        v. Point Columns select "ground_force_px"
        vi. The GRF free moment is a torque, so check "Applies Torque"
        vii. Torque Columns, scroll down and select "ground_torque_x"
        viii. Both the GRF and CoP are expressed in the ground (lab) frame
        ix. Click OK
    d. Hit Save and enter a filename for the External Force (e.g. "leg69_right_GRF.xml")
9. Save settings (e.g. "leg69_Setup_ID_stance.xml"), then hit Run.
10. Plot the forces and moment acting on the pelvis and the net joint moments for the hip, knee and ankle.

Questions:

1. Why are the residuals (forces on the pelvis) so large? Hint: what is the model missing when compared to the subject that generated the GRFs in the lab?
2. Why is the vertical force so large (and not the other residuals)?

C. Use the RRA tool to reduce residuals. In other words, adjust the model to compensate for model inconsistency with the applied GRFs.

1. Launch the Reduce Residuals tool.
2. Specify Desired Kinematics: leg69_IK_stance.mot.

3. Check the box to filter kinematics at 6Hz.
4. Specify the tracking tasks for RRA. With an XML editor, edit the swing CMC tasks to include pelvis kinematics in the set of tracking tasks. When you copy and paste to create a new tracking task, you will need to change the CMC_Joint name and coordinate.
    a. If you are not familiar with editing XML files, you can copy the task file provided in Stance/Reference/ leg69_Tracking_Tasks.xml
5. Specify Actuator control constraints. These constraints define the maximum and minimum control limits for all actuators (leg69_residuals_motors_control_limits.xml).
6. Check "Adjust model". Click on the folder icon, make sure you are in the Stance folder, and specify a new model name (e.g. leg69_adjusted_COM_pelvis.osim). Hit Save. The "body" (e.g. pelvis) center-of-mass adjustments will be made to this model.
7. Specify the time range as 0.5s to 1.5s.
8. Specify an output directory (e.g. Stance\RRA)
9. Select the "Actuators" tab and choose "<u>Replace</u> model's force set" to replace the model's muscles with residual and joint motor actuators. Click Edit and then add leg69_RRA_residuals_motors.xml.
10. Check the External Loads box and specify the file you created for Inverse Dynamics (e.g. "leg69_right_GRF.xml")
11. Save your settings to an RRA setup file (e.g. leg69_Setup_RRA_stance.xml).
12. Hit Run. Why does the model "float" down and up?
13. Preview the model motion with the GRF again. To get an estimate for the mass adjustment, what phase of the gait should you restrict your RRA analysis to?
14. Repeat RRA over the new time interval (and save the new settings).
    a. What is the recommended mass adjustment?
    b. Open up the messages window and locate the recommendation from the latest run of RRA, e.g. dmass = 44.037
    c. What is the recommended location change for the center of mass? Is it reasonable?
15. Make the recommended mass adjustments to the pelvis of the com-adjusted model created by RRA.
    a. To edit the model use your favorite XML editor to edit the model file.
    b. You may also want to rename the model in the Navigator window (e.g. leg6dof9musc_adjusted) by right clicking on the current model name and selecting Rename.

16. Re-run RRA with the adjusted model. Can you get the mass adjustments suggested by RRA to be zero?
17. Plot the RRA residual actuator forces (leg6dof9musc_Actuation_Force.sto, MZ, FX, FY) – how do they compare to the forces acting on the pelvis from your ID results?
18. Plot tracking kinematics outputted by RRA (e.g. leg6dof9musc_Kinematics_q.sto) vs. kinematics from IK.
19. Increase the tracking task weights for coordinates that show poor tracking (via File->Edit). Relax tracking weight for coordinates that are within a degree, since the optimizer can use this to reduce residuals. See the handout for more information about getting good results from RRA.
20. Repeat 15 through 19 to converge on a torque driven simulation of single limb stance that has minimum residuals with good tracking. Now you are ready for Computed Muscle Control.

Questions:

1. Why does the model initially "float" up and down?
2. What was the process you used to reduce residuals forces while maintaining good tracking?
3. What coordinates were most difficult to track? Why?
4. How small is small enough for residual forces and tracking errors?

D. Use the Computed Muscle Control (CMC) Tool to determine the muscle excitations, activations and forces that generate a forward dynamics simulation of the stance-phase of gait.

1. Load the final adjusted model from RRA
2. Consider the residual and motor actuators necessary for CMC (e.g. modify leg69_RRA_residuals_motors.xml using Edit->File or an XML editor)
   a. With muscles present, reduce the optimal force of joint motors so that their use during CMC is penalized and the use of muscles to generate joint moments is favored.
   b. Save the edited the actuators as a new file (e.g. leg69_CMC_residuals_motors.xml).

3. Launch the CMC Tool and select the storage file with output states from RRA (e.g. kinematics_q.sto) as the Desired kinematics to track (no filtering is required since the kinematics are result of a simulation).
4. Apply tracking tasks. Use the same tasks file as for RRA.
5. Include limits on muscle actuators by using leg69_muscles_residuals_motor_control_limits.xml as Actuator constraints.
6. Define time range for the stance simulation (same as for RRA).
7. Specify the output directory (e.g. Stance\CMC).
8. Append the Actuator set that you created to the model's force set to include joint motor and residual actuators to the set of existing muscles in the model.
9. Specify the external loads (same as for RRA).
10. Save your settings to a file.
11. Run CMC. If CMC does not execute completely, review the tips and tricks in the handout for help with troubleshooting.
12. How do the kinematics compare to the IK solution for stance?
13. Run a forward simulation with the controls from CMC and initial states from CMC. How do the kinematics compare to the original IK solution? Running FD after CMC is a method of verifying that the controls from CMC do in fact generate a forward simulation consistent with the observed kinematics and applied GRFs.

Questions:

1. What is the difference between the actuator constraints file used in CMC and the file for RRA?
2. Plot the muscle activations, found in the states file. Are the observed activations close to what you expect (e.g. values found in the literature)?
3. How can you assess the quality of your resulting simulation?
4. Are the residuals below 2% of body-weight?
5. Are the motor moments at the hip, knee and ankle significant?