Inverse Dynamics[[1]](#footnote-1)

# I. Objectives

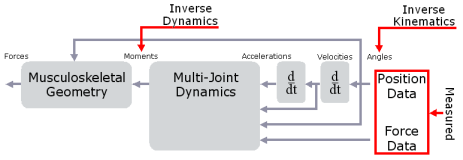
## Purpose

## The purpose of this tutorial is to demonstrate how OpenSim solves an inverse dynamics problem using experimental data. To diagnose movement disorders and study human movement, biomechanists frequently ask human subjects to perform movements in a motion capture laboratory and use computational tools to analyze these movements. A common step in analyzing a movement is to compute the joint angles and joint moments of the subject during movement. OpenSim has tools for computing these quantities:

## *Inverse kinematics* is used to compute joint angles.

## *Inverse dynamics* is used to compute net joint reaction forces and net joint moments.

## *Inverse kinematics* computes the joint angles for a musculoskeletal model that best reproduce the motion of a subject. *Inverse dynamics* then uses joint angles, angular velocities, and angular accelerations of the model, together with the experimental ground reaction forces and moments, to solve for the net reaction forces and net moments at each of the joints. The schematic below shows an overview of the inverse kinematics and inverse dynamics problems.



In this tutorial, you will:

* Become familiar with OpenSim's Inverse Dynamics tools
* Solve an inverse dynamics problem using experimental data
* Interpret the results of the inverse dynamics solution
* Investigate the dynamic inconsistencies that arise during inverse dynamics

## Format

Each section of the tutorial guides you in using certain tools within and asks you to answer a few questions. The menu titles and option names you must select and any commands you must type to run OpenSim will appear in bold face. The questions can be answered based on information from OpenSim and basic knowledge of the human musculoskeletal system. After you complete the tutorial, feel free to explore OpenSim and the other analysis tools further on your own. Depending on the amount of exploration you do, this tutorial should take 1-2 hours to complete.

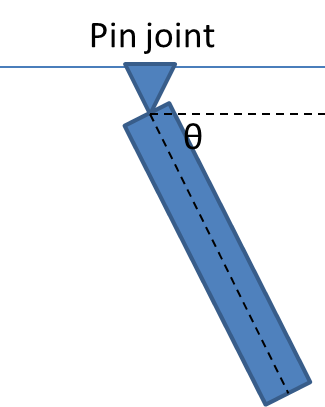
This lab is an extension of the results you obtained from the lab on Scaling and Inverse Kinematics. You will need these files to continue.

# II. Inverse Dynamics

*Dynamics* is the study of motion *and* the forces and moments that produce that motion. Thus, to perform dynamical analyses, such as inverse dynamics, estimation of mass and inertia is required. The purpose of inverse dynamics is to estimate the forces and moments that cause a particular motion, and its results can be used to infer how muscles are utilized for that motion. To determine these forces and moments, equations of motion for the system are solved iteratively [3]. The equations of motion are derived using the kinematic description and mass properties of a musculoskeletal model. Then, using the joint angles from inverse kinematics and experimental ground reaction force data, the net reaction forces and net moments at each of the joints are calculated such that the dynamic equilibrium conditions and boundary conditions are satisfied [3].

*Note: Joint reaction, or inter-segmental, force is the total force acting across a particular joint in a model. This should not be confused with joint bone-on-bone force, which is the actual force seen across the articulating surfaces of the joint and include the effect of muscle activity. For a thorough discussion on this topic see pp 77-79 in [4].*

First, use a simple pendulum model to understand the basics of the inverse dynamics calculations. A pendulum (mass 25kg, moment of inertia 0.625 Nms2, length 0.5m) swings from a frictionless pin joint with θ = sin(2πt). Use a computer programming language (e.g. Matlab, C, C++, etc.) to calculate the required torque that should be applied to the pendulum to achieve the prescribed motion for 2 seconds. Plot the torque as a function of time.



To solve the inverse dynamics problem in OpenSim:

* Click the **Tools** menu and select **Inverse Dynamics**.
* In the *Inverse Dynamics Tool* dialog, click **Load** to load an Inverse Dynamics setup file.
* In the file browser, ensure that you are in the ***Gait2354\_Simbody*** folder, select the file ***subject01\_Setup\_InverseDynamics.xml*** and click **Open**. *Note: If the****Motion From File****textbox appears red, this means the textbox was filled with an inappropriate file name. Make sure the motion file was saved with the correct file name in the Inverse Kinematics section.*
* Note the folder listed in the **Directory** textbox, located in the **Output** section of the dialog. The storage file containing the inverse dynamics results will be saved in this folder: *examples\Gait2354\_Simbody\ResultsInverseDynamics*
* Click **Run** at the bottom of the dialog. Then click **Close**.

When completed, examine the results of the inverse dynamics solution by plotting the net moments at the left and right ankles:

* Click **Tools** and select **Plot**.
* In the *Plotter* window, click the **Y-Quantity** button and select **Load File**.
* In the file browser, go to the *ResultsInverseDynamics* folder, select the file ***inverse\_dynamics.sto***, and click **Open**.
* In the menu, select **ankle\_angle\_r\_moment** and**ankle\_angle\_l\_moment** by clicking the corresponding checkboxes, then click **OK**. *Note*: To quickly find these quantities, type ankle into the pattern text box.
* Click the **X-Quantity** button, select **time**, and click **OK**.
* Back in the *Plotter* window, click **Add** to add the moment curves to the plot.
* Print your plot by **right clicking** on the plot and selecting **Print**. *Note: To export the plot as an image by****right-clicking****the plot and selecting****Export Image****.*
* After printing the plot and answering the following questions, **close** the *Plotter* window.

## Questions

1. On your plot of the ankle moments, identify when heel strike, stance phase, toe off, and swing phase occur for each curve (i.e., left leg and right leg).
2. Based on your plot and the angle convention for the ankle, give an explanation of what is happening at the ankle just before toe-off. Hint: It may be useful to use the Coordinate sliders to understand the angle convention for the ankle.

# References

1. Delp, S.L., Loan, J.P., Hoy, M.G., Zajac, F.E., Topp E.L., Rosen, J.M. An interactive graphics-based model of the lower extremity to study orthopaedic surgical procedures. IEEE Transactions on Biomedical Engineering, vol. 37, pp. 757-767, 1990.
2. Anderson, F.C., Pandy, M.G. A dynamic optimization solution for vertical jumping in three dimensions. Computer Methods in Biomechanical and Biomedical Engineering, vol. 2, pp. 201-231, 1999.
3. Kuo, A.D. A least squares estimation approach to improving the precision of inverse dynamics computations, Journal of Biomechanical Engineering, vol. 120, pp. 148-159, 1998.
4. Winter, D.A. Biomechanics and Motor Control of Human Movement, Wiley and Sons, pp. 77-79, 1990.
5. Thelen, D.G., Anderson, F.C. Using computed muscle control to generate forward dynamic simulations of human walking from experimental data, Journal of Biomechanics, vol. 39, pp. 1107-1115, 2006.
6. John, C.T., Anderson, F.C., Guendelman, E., Arnold, A.S., Delp, S.L. An algorithm for generating muscle-actuated simulations of long-duration movements, Biomedical Computation at Stanford (BCATS) Symposium, Stanford University, 21 October 2006, Poster Presentation.
7. Delp, S.L., Anderson, F.C., Arnold, A.S., Loan, P., Habib, A., John, C.T., Guendelman, E., Thelen, D.G. OpenSim: Open-source software to create and analyze dynamic simulations of movement. IEEE Transactions on Biomedical Engineering, vol. 55, pp. 1940-1950, 2007.

# Deliverables

Answer all questions posed in the tutorial and turn in your report electronically (as a .docx format) using Blackboard. Restate each question, followed by your answer. Be sure to include plots and/or figures to support your answers. For example, if you answer a question with ‘the knee flexion moment arm of the hamstrings decreased with knee flexion angle’, be sure to include a plot to support your statement. The report will be graded as follows:

|  |  |
| --- | --- |
| **Question** | **Points Possible** |
| Copy of code to calculate pendulum torque | 1 |
| torque as a function of time for 2 seconds | 1 |
| 1. On your plot of the ankle moments, identify when heel strike (1pt), stance phase (1pt), toe off (1pt), and swing phase (1pt) occur for each curve (i.e., left leg and right leg). | 4 |
| 2. Based on your plot and the angle convention for the ankle, give an explanation of what is happening at the ankle just before toe-off (1pt). | 1 |
| **Total** | **7** |

1. This lab adapted from <http://simtk-confluence.stanford.edu:8080/display/OpenSim/Tutorial+3+-+Scaling%2C+Inverse+Kinematics%2C+and+Inverse+Dynamics> [↑](#footnote-ref-1)