Introduction to Residuals[[1]](#footnote-1)

# I. Objectives

## Purpose

In solving the inverse dynamics problem, both kinematical data and force plate data were used, making this an over-determined problem. In other words, the problem has more equations than unknowns (i.e., degrees of freedom). Due to errors in the experimental motion data and inaccuracies in the musculoskeletal model, it turns out that Newton’s second law is violated, or http://simtk-confluence.stanford.edu:8080/download/thumbnails/5115855/f%3Dma.png?version=1&modificationDate=1379005366820 [3]. One method to handle this dynamical inconsistency is to compute and apply residual forces and moments to a particular body segment in the model, such that Newton’s second law becomes:

http://simtk-confluence.stanford.edu:8080/download/thumbnails/5115855/f%3Dma2.png?version=1&modificationDate=1379005431464

† An analogous equation relates the ground reaction moment,*http://simtk-confluence.stanford.edu:8080/download/thumbnails/5115855/A1.png?version=1&modificationDate=1379005486412* to the residual moment,*http://simtk-confluence.stanford.edu:8080/download/thumbnails/5115855/A2.png?version=1&modificationDate=1379005537918* .

In this tutorial, you will:

* Become familiar with residuals: what they are and how they arise

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

# II. Residuals

In this musculoskeletal model, the residuals are applied to the pelvis segment. To see the residuals from the inverse dynamics solution:

* 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 **pelvis\_tx\_force**, **pelvis\_ty\_force**, and**pelvis\_tz\_force** by clicking the corresponding **checkboxes**, then click **OK**.
* Click the **X-Quantity** button, select **time**, and click **OK**.
* Click **Add** to add the curves to the plot.

1. What are the maximum magnitudes of the residual forces? Using the mass of the subject from Question 1, what fraction of body weight are the maximum residual forces?
2. Using the residual torque in the z-direction, use Matlab to calculate and plot how much the torso center of mass and flexion-extension angle could be adjusted in the sagittal to remove this residual. Compare these alterations with those proposed by the OpenSim RRA results by using a plot.

While computing and applying residual forces and moments makes the model’s motion dynamically consistent with the external forces http://simtk-confluence.stanford.edu:8080/download/thumbnails/5115855/f%3Dma3.png?version=1&modificationDate=1379005699331, this strategy is undesirable because the residuals can be large. More advanced strategies have been developed to deal with the problem of residuals and dynamic inconsistencies, such as least-squares optimization [3], the Residual Elimination Algorithm (REA) [5], and the Residual Reduction Algorithm (RRA) [6]. Additionally, OpenSim implements a Residual Reduction Algorithm as part of its workflow for generating muscle-actuated simulations [7]. Reference [6] is attached at the end of this tutorial. For additional information on these strategies, please also refer to [3], [5], and [7].

# 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** |
| 1. What are the maximum magnitudes of the residual forces (1pt)? Using the mass of the subject from Question 1 of the ‘Scale and Inverse Kinematics Lab’, what fraction of body weight are the maximum residual forces (1pt)? | 2 |
| 2. Using the residual torque in the z-direction, use Matlab to calculate and plot how much the torso center of mass could be adjusted in the sagittal to remove this residual. Compare these alterations with those proposed by the OpenSim RRA results by using a plot.  1pt for calculation code  1pt for plot of Δtorso center of mass as a function of time  1pt for plot comparing your calculation with OpenSim results | 3 |
| 2. Using the residual torque in the z-direction, use Matlab (1pt for code) to calculate and plot how much the flexion-extension angle could be adjusted in the sagittal to remove this residual. Compare these alterations with those proposed by the OpenSim RRA results by using a plot.  1pt for calculation code  1pt for plot of Δtorso angle as a function of time  1pt for plot comparing your calculation with OpenSim results | 3 |
| **Total** | **8** |

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)