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Short communication

Automated optimization of residual reduction algorithm parameters in OpenSim

Jordan T. Sturdy [a], Anne K. Silverman [a], Nathan T. Pickle [a,b,*]

[a] Colorado School of Mines, Golden, CO
[b] CFD Research Corp., Huntsville, AL

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ABSTRACT

The residual reduction algorithm (RRA) in OpenSim is designed to improve dynamic consistency of kinematics and ground reaction forces in movement simulations of musculoskeletal models. RRA requires the user to select numerous tracking weights for the joint kinematics to reduce residual errors. Selection is often performed manually, which can be time-consuming and is unlikely to yield optimal tracking weights. A multi-heuristic optimization algorithm was used to expedite tracking weight decision making to reduce residual errors. This method produced more rigorous results than manual iterations and although the total computation time was not significantly reduced, this method does not require the user to monitor the algorithm's progress to find a solution, thereby reducing manual tuning. Supporting documentation and code to implement this optimization is freely provided to assist the community with developing movement simulations.

1. Introduction

Musculoskeletal models and simulations have seen significant increase in adoption in recent years, facilitated by software platforms such as OpenSim (Delp et al., 2007, simtk.org). Inverse dynamics calculations are frequently the basis of these simulations. Inverse dynamics uses experimental observations, i.e., ground reaction forces and joint kinematics, to calculate the joint moments required to produce these observed data (Yamaguchi, 2005). This calculation contains multiple sources of error including modeling assumptions (e.g., rigid body assumptions, segment inertial properties), and measurement error (e.g., soft tissue artifact). These sources of error result in dynamic inconsistency (Kingma and Toussaint, 1996; Pearsall and Costigan, 1999; Riemer et al., 2008), meaning additional fictitious forces are required to produce a simulated motion that replicates the experimental data. Several methods have been proposed to reduce errors to improve dynamic consistency (Cahouët et al., 2002; Ganley and Powers, 2004; Kuo, 1998), including OpenSim's residual reduction algorithm (RRA, https://simtk-confluence.stanford.edu/display/OpenSim/Residual+Reduction+Algorithm) that reduces the fictitious, or "residual", forces and moments applied at the pelvis. RRA first computes changes to the total model mass as $\Delta m = F_{y,avg}/g$, where $F_{y,avg}$ is the average vertical residual force across the simulation and g is acceleration due to gravity. RRA also calculates an altered torso center of mass (COM) location to reduce residual moments in the frontal and transverse planes. In addition, RRA can change the model joint accelerations slightly to achieve better dynamic consistency and further reduce residual forces and moments. Thus, there is a tradeoff between the residuals and the kinematic errors, where the tradeoff is governed by user-selected tracking weights. OpenSim's documentation recommends users manually adjust the tracking weights until the residuals are minimized, which is a time-consuming process. In this paper we describe an open-source software tool (provided in Python and MATLAB) for optimization of tracking weights in RRA, which provides biomechanics researchers with an automated method for selecting RRA tracking weights, increasing efficiency in developing high-quality movement simulations.

2. Methods

A Tracking Weight Selection Algorithm (TWSA) was developed to optimize the tracking weight values, which serve as inputs to the optimization algorithm RRA in OpenSim. A modified random hill climbing algorithm was used to explore the search space.

* Corresponding author.
E-mail address: nathantpickle@gmail.com (N.T. Pickle).

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