Simulation Analysis: Estimating Joint Loads

OpenSim Workshop
Investigating a Simulation:

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EMGs → Controls

Musculotendon Dynamics → Musculoskeletal Geometry

Forces → Moments

Multibody Dynamics

Accelerations → Velocities, Angles

Simulated Movement

OpenSim Model

Analysis

Fiber/Tendon Lengths

Moment Arms

Body Kinematics

Joint Reactions

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The Analyze Tool:

Controls
Simulation States

Analyze Tool

Model
Analysis

Results
Example: Quantifying Joint Loads

Design Biomedical Devices

Predict Tissue Stress

Study degradation

Argenson et al, J. Biomech 2005

Besier et al, MED. SCI. SP & EXERCISE, 2006

USC2000, 2009,
http://www.flickr.com/photos/usc2000/3189533413/
Joint Reaction Analysis

Joint reaction forces and moments
- satisfy joint constraints
- represent internal loads carried by the joint structure
- result from all loads acting on the model

Prevent movements that cannot be produced

Available from the Analyze Tool
Cut apart the joint

What loads are transferred across the joint interface?

Joint loads constrain the tibia to move on the ellipse.
Estimating Joint Loads

Know

- Model
- Joint Kinematics
- External Loads
- Muscle Forces

Fit to measurements

Estimate

Calculate

Joint Reaction Forces and Moments
Static Optimization

Input

Model
Joint Kinematics
External Loads

Output

Muscle Forces
Muscle Activations

Complete dynamic description
Joint Reaction analysis calculates joint loads in a post processing step.

This step traverses all joints in the musculoskeletal model.
Joint Reaction analysis calculates joint loads in a post processing step.

This step traverses all joints in the musculoskeletal model.
Joint Reaction analysis calculates joint loads in a post processing step.

This step traverses all joints in the musculoskeletal model.
Calculation of the joint reaction forces on $S_i$
\[ \sum F_{\text{external}} + \sum F_{\text{muscles}} + R_{i+1} + R_i = M_i a_i \]
\[ R_i = M_i a_i - \left( \sum F_{external} + \sum F_{muscles} + R_{i+1} \right) \]
Joint Reaction Analysis: Setting It Up

Inputs from Static Optimization

Model
Kinematics
External Loads data
Residual Actuators

Inputs specific to JointReaction

Muscle force data
Joints of interest
Bodies of interest
Coordinate reference frames

Output

*_JointReaction_ReactionLoads.sto*
Induced acceleration analysis

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Induced Acceleration Analysis

Equations of motion

$$[\mathbf{M}] \ddot{\mathbf{q}} = \mathbf{G}(\mathbf{q}) + \mathbf{V}(\mathbf{q}, \dot{\mathbf{q}}) + \mathbf{S}(\mathbf{q}, \dot{\mathbf{q}}) + [\mathbf{R}] \mathbf{f}$$

- M: Mass matrix
- Q: Generalized coordinates
- G: Gravity
- V: Coriolis and centrifugal effects
- S: Generalized force due to contact elements (msl force)
- F: Generalized force (muscle force)
- R: Force transformation matrix (moment arms)
Induced Acceleration Analysis

- General formulation
  \[ \ddot{q}_i = [M]^{-1} \{F_i\} \]
- Muscle force
  \[ \ddot{q}_m = [M]^{-1} [R] f_m \]
- With contact forces
  \[ \ddot{q}_i = [M]^{-1} \{F_i + S_i\} \]
## Induced Acceleration Analysis

<table>
<thead>
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- Stiff 3D linear and torsional springs approximate a weld constraint
## Induced Acceleration Analysis

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- Replaces the contribution of contact with an appropriate kinematic constraint.
- Kinematic constraint reaction forces are resolved simultaneously with the constrained equations of motion.
## Induced Acceleration Analysis

- **Model Contact**

### Point
- no translations
(Allows relative rotation)

- $\rho_x(q) - \rho_{x,o} = 0$
- $\rho_y(q) = 0$
- $\rho_z(q) - \rho_{z,o} = 0$

### Weld
- no translations
- no rotations

- $\rho_x(q) - \rho_{x,o} = 0$
- $\rho_y(q) = 0$
- $\rho_z(q) - \rho_{z,o} = 0$
- $\theta_x(q) - \theta_{x,o} = 0$
- $\theta_y(q) - \theta_{y,o} = 0$
- $\theta_z(q) - \theta_{z,o} = 0$

### Roll
- non-penetrating
- fore-aft no-slip
- med/lat no-slip
- vertical no-twist

- $\rho_y(q) = 0$
- $\dot{\rho}_x(q, \dot{q}) = 0$
- $\dot{\rho}_z(q, \dot{q}) = 0$
- $\omega_y(q, \dot{q}) = 0$

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Pure rolling

Constraint on a rolling body in contact with a plane defined on another body (Hamner et al., 2010)
Induced Acceleration Analysis

- Muscle Potentials: accounts for a theoretical force increase (1N).
- Muscle IAA: accounts for the instantaneous muscle force (xN)
Induced Acceleration Analysis
• Verify superposition

Contribution to com acceleration (Liu, 2006)

Kinematic or Bodykinematic Analysis
Induced Acceleration Analysis

• How to use IA:
  – COM vs angular kinematics
  – Requires Muscle force distribution (e.g. SO)
  – Does not work in case of missing contact forces (e.g. unilateral forces during double stance)