Simulation Analysis: Estimating Joint Loads

OpenSim Workshop
The Analyze Tool:

- Controls
- Simulation States

Analyse Tool

- Model
- Analysis

Results
Example: Quantifying Joint Loads

Design Biomedical Devices

Argenson et al, J. Biomech 2005

Predict Tissue Stress

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

Study degradation

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

Choose the joint load representation

Available from the Analyze Tool
Joint Reaction Analysis
Two Part discussion

Conceptual Overview:
Estimating joint forces and moments during gait.

Demonstration:
Static Optimization and a Joint Reaction Analyses.
Cut apart the joint
What loads are transferred across the joint interface?
Joint loads constrain the tibia to move on the ellipse.

\[ R \downarrow i \]

\[ F \downarrow \text{external} \]
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 $S_i$
\[ \sum F_{\text{external}} + \sum F_{\text{muscles}} + R_{i+1} + R_i = M_i a_i \]
\[ R_i = M_i a_i - \left( \sum F_{\text{external}} + \sum F_{\text{muscles}} + R_{i+1} \right) \]
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

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

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

<table>
<thead>
<tr>
<th>PERTURBATION</th>
<th>INDUCED ACCELERATION</th>
</tr>
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<tbody>
<tr>
<td>Perturb muscle force (1N) and study effect on COM acceleration</td>
<td></td>
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<tr>
<td>Forward integration over 0.03s</td>
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<td></td>
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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

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<tr>
<th>Point</th>
<th>Weld</th>
<th>Roll</th>
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<tr>
<td>- no translations</td>
<td>- no translations</td>
<td>- non-penetrating</td>
</tr>
<tr>
<td>(Allows relative rotation)</td>
<td>- no rotations</td>
<td>- fore-aft no-slip</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- med/lat no-slip</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- vertical no-twist</td>
</tr>
<tr>
<td>$\rho_x(q) - \rho_{x,o} = 0$</td>
<td>$\rho_y(q) = 0$</td>
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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 analysis 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)
Example of IAA

• Gait2393 model
• Run:
  – Scale
  – IK
  – (RRA)
  – SO
  – Analysis