OpenSim Simulation Pipeline

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Feb, 2013
Pipeline tools: what’s available?

Scale

Inverse Kinematics

Inverse Dynamics

Static Optimization

Induced Acceleration Analysis

Muscle contributions to GRF, joint acceleration

Muscle Forces

Joint Torques

$q_{IK}$

$q_{RRA}, \dot{q}_{RRA}, \ddot{q}_{RRA}, \tau_{RRA}$

$q_{CMC}, \dot{q}_{CMC}, \ddot{q}_{CMC}, F_{CMC}^{M}$

$\tau_{ID}$

$F_{M}^{M}$
Inverse Dynamics

Solved algebraically from the ground up: NO FORWARD INTEGRATION

FREE JOINT... but...

\( f_i, \tau_i \neq 0 \)

Residual Forces / Torques due to overdetermined system

Segment i

Segment i-1

Segment 2

Segment 1

Boundary Conditions

“Residuals” appear because of a mismatch between the model and the experimental data \( (\theta, f_{\text{ground}}, \tau_{\text{ground}}) \).

Solve for distal reactions:

\[
\begin{align*}
\dot{f} - mx &= 0 \\
\tau - I\ddot{\theta} &= 0
\end{align*}
\]
Are “residuals” bad?

**YES:** “Residuals” do not occur in reality: our motion is fully actuated by torques (via muscles) at the joint and NOT by the “hand of god”.

**NO:** We acknowledge that our experimental data contains errors (e.g. noise, skin artifact). We also acknowledge that our models are not perfect. “Residuals”, therefore represent these lumped unmodeled phenomenon / errors. Having zero “residuals” would mean that we are modeling our subject perfectly and with perfect experimental data, which is highly unlikely.
Static Optimization

Solved independently at each time step: NO FORWARD INTEGRATION

solve for: \( \mathbf{a} = \mathbf{a}^M \)

by minimizing: \( J(\mathbf{a}) = \sum_{i=1}^{nm} \left( a_i^M \right)^2 \)

subject to: \( \sum_{j=1}^{nj} \sum_{i=1}^{nm} \left[ a_i^M \cdot F_{o,i}^M \cdot f \left( \tau_i^M, v_i^M \right) + F_{p,i}^M \right] \cdot \text{MomArm}_{i,j} = \tau_j \)

\( 0 < \mathbf{a}^M < 1 \)

More muscles than joints: over-determined problem
Static Optimization

Joint moments are resolved into individual muscular torques

Sprinting (9.0 m/s)
What pipeline is best for me?

- Scale
- Inverse Kinematics
- Inverse Dynamics
- Static Optimization
- Induced Acceleration Analysis

Muscle contributions to GRF, joint acceleration

Joint Torques

Muscle Forces

$q_{IK}$

$\tau_{RRA}$

$\dot{q}_{RRA}$, $\ddot{q}_{RRA}$

$F^M_{CMC}$

$q_{RRA}$, $\dot{q}_{RRA}$, $\ddot{q}_{RRA}$

$q_{CMC}$, $\dot{q}_{CMC}$, $\ddot{q}_{CMC}$
<table>
<thead>
<tr>
<th>Feature</th>
<th>Inverse Dynamics</th>
<th>RRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward integration</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Tracks experimental kinematics</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Activation &amp; contraction dynamics</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Time to execute</td>
<td>~10 sec</td>
<td>~5 mins</td>
</tr>
<tr>
<td>Experimental ground force applied to foot</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Control over “residuals”</td>
<td>NONE</td>
<td>Can reduce residuals at the expense of modifying kinematics</td>
</tr>
<tr>
<td>Feature</td>
<td>Static Optimization</td>
<td>CMC</td>
</tr>
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<tr>
<td>Activation &amp; contraction dynamics</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Time to execute</td>
<td>~2 mins</td>
<td>~30 mins</td>
</tr>
<tr>
<td>Experimental ground force applied to foot</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Time dependant objective function</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Objective function used distribute muscle force</td>
<td>min(a²) across all muscles at each time step</td>
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</tr>
</tbody>
</table>
CMC Versus Static Optimization


1999 ASB Pre-Doctoral Award

Static and dynamic optimization solutions for gait are practically equivalent

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Special Issue Article

Comparison of different methods for estimating muscle forces in human movement

Yi-Chung Lin, Tim W Dorn, Anthony G Schache and Marcus G Pandy