Behind Computed Muscle Control

OpenSim Workshop
1. “static optimization” muscle model differs from dynamical model in forward simulation.

2. Acceleration data is discrete and noisy.

3. A nonlinear dynamical systems can be chaotic.

Solution: Close the loop!
Computed Muscle Control (CMC)

Estimated Control

Musculotendon Dynamics → Musculoskeletal Geometry → Multibody Dynamics → ∫∫

Forces → Moments → Accelerations

Static Optimization+

Accelerations(t+T)

Controls=x(t)

PD Control

Simulated Movement

Observed Movement

Estimated Control

\[
\ddot{q}^* = \hat{q} - k_v (\dot{q} - \hat{q}) - k_p (q - \hat{q})
\]
Computed Muscle Control (CMC)

Musculotendon Dynamics → Musculoskeletal Geometry → Multibody Dynamics → \[ \int \int \] → Simulated Movement

Estimated Control → Musculotendon Dynamics

Controls = \( x(t) \)

Min: \[ J(f(t+T)) \]
Subject to:
\[ f(u_{\min}(t)) < f(t+T) < f(u_{\max}(t)) \]

PD Control

Observed Movement

\[ f(t+T) \rightarrow ^{-1} \text{Musculotendon Dynamics} \rightarrow u(t) \]
Inside the CMC Algorithm

Estimated Control

Simulated Movement

Observed Movement

Static Optimization & Root Solve

PD Control

Controls = u(t)

Accelerations(t+T)

Integrate forwards

Min: $J(f(t+T))$

$u^*$

$u_{\text{max}}$

$u_{\text{min}}$

$f(y,t)$

$f_{\text{max}}(t+T)$

$f_{\text{min}}(t+T)$

Root solve for $u(t)$
Computed Muscle Control Tool:

1. Musculotendon Dynamics
2. Musculoskeletal Geometry
3. Multibody Dynamics
4. ∫∫
5. Simulated Movement
6. Estimated Control
7. Forces
8. Moments
9. Accelerations
10. Velocities, Angles
11. Controls = u(t)
12. Accelerations(t+T)
13. Static Optimization+
14. PD Control
15. Observed Movement
16. CMC Tool
**Computed Muscle Control**

**TIPS & TRICKS**

You can use results from IK or RRA. For best results, track RRA output not IK.

Increase max excitation of reserves if CMC is failing.

Compare to EMG and constrain excitations where there is a mismatch.

Command Line: `cmc -S cmc_setup_file.xml`
Our Experience with Computed Muscle Control

Use CMC to generate inputs for a forward simulation that tracks experimental data.

CMC does not globally optimize cost function.

Solution is sensitive to initial time of simulation.

Wesseling et al., 2014
Demo

C:\OpenSim 3.2\Models\Gait2392_Simbody\n
Evaluating your Results:
• See table.
• Compare simulated activations to experimental EMG data (either recorded from your subject or from the literature)

<table>
<thead>
<tr>
<th>Thresholds</th>
<th>GOOD</th>
<th>OKAY</th>
<th>BAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX Residual Force (N)</td>
<td>0-10 N</td>
<td>10-25 N</td>
<td>&gt; 25 N</td>
</tr>
<tr>
<td>RMS Residual Force (N)</td>
<td>0-10 N</td>
<td>10-25 N</td>
<td>&gt; 25 N</td>
</tr>
<tr>
<td>MAX Residual Moment (Nm)</td>
<td>0-50 Nm</td>
<td>50-75 Nm</td>
<td>&gt; 75 Nm</td>
</tr>
<tr>
<td>RMS Residual Moment (Nm)</td>
<td>0-30 Nm</td>
<td>30-50 Nm</td>
<td>&gt; 50 Nm</td>
</tr>
<tr>
<td>MAX pErr (trans, cm)</td>
<td>0-1 cm</td>
<td>1-2 cm</td>
<td>&gt; 2 cm</td>
</tr>
<tr>
<td>RMS pErr (trans, cm)</td>
<td>0-1 cm</td>
<td>1-2 cm</td>
<td>&gt; 2 cm</td>
</tr>
<tr>
<td>MAX pErr (rot, deg)</td>
<td>0-2 deg</td>
<td>2-5 deg</td>
<td>&gt; 5 deg</td>
</tr>
<tr>
<td>RMS pErr (rot, deg)</td>
<td>0-2 deg</td>
<td>2-5 deg</td>
<td>&gt; 5 deg</td>
</tr>
<tr>
<td>MAX Reserve (Nm)</td>
<td>0-25 Nm</td>
<td>25-50 Nm</td>
<td>&gt; 50 Nm</td>
</tr>
<tr>
<td>RMS Reserve (Nm)</td>
<td>0-10 Nm</td>
<td>10-25 Nm</td>
<td>&gt; 25 Nm</td>
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