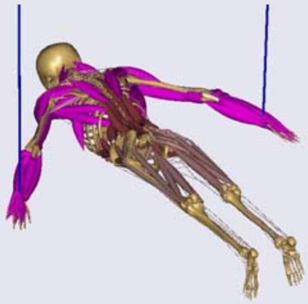
Muscle Recruitment Algorithms

To fit your screen:
Sharing (upper right corner)->
View->Autofit



The web cast will start in a few minutes….

1. The basics (~15 min)
2. AnyBody implementations (~25 min)
3. Conclusions (~5 min)
4. Q&A session (~10 min)

Please follow the instructions to set up the audio:
www.anybodytech.com/fileadmin/downloads/AudioInstructionsWebEx.pdf

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People

John Rasmussen (Presenter)

Casper Gerner Mikkelsen (Host)

Søren Tørholm (Panelist)

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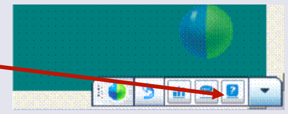
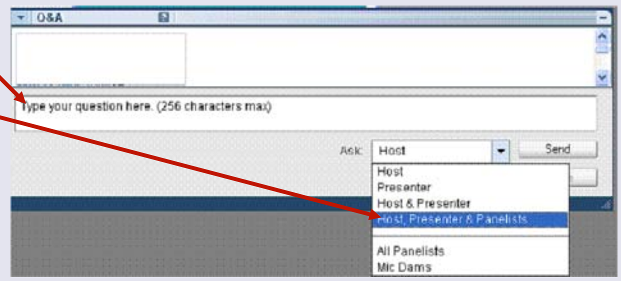
Q&A Panel

- Søren Tørholm
- Launch the Q&A panel here.
- Type your questions in the Q&A panel.
- Send the question to ”Host, Presenter & Panelists”
- Notice the answer displays next to the question in the Q&A box. You may have to scroll up to see it.





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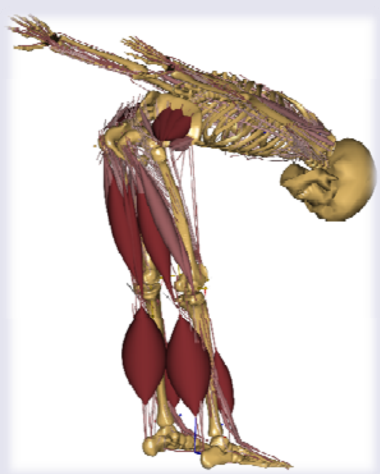
1/3 The Basics



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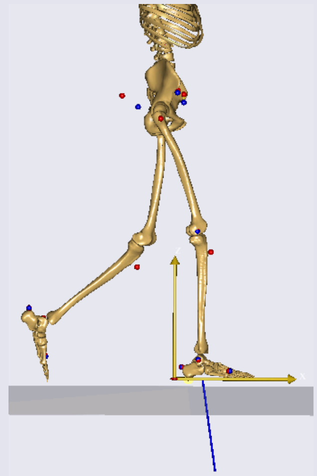
Old-school inverse dynamics is…

- Traditionally originating from gait analysis.
- Computing joint moments from measured GRFs.
- Requires open chain mechanisms.
- Solution of a series of uncoupled simple equations.
- Computes net joint moments but NOT joint forces.
- Often disregards gravity and inertia forces, i.e. quasi-static.



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…not very useful

- Most situations are not “open chain”.
- Adding “environments” tends to create closed chains.
- We do not always have measured interface forces.
- We do not always have experimental data at all.
- Dynamics may be important.
- Joint forces are important.

We need: Closed chains, muscles and dynamics!

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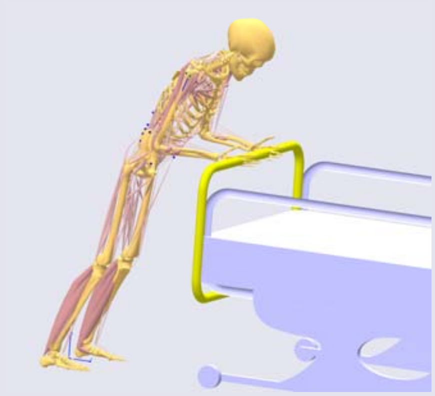
Good news:

- Muscles and closed chains create the same complication:
  - Redundancy
  - Statical indeterminacy
- Redundancy can be resolved by optimization.



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Equilibrium

Internal forces

Applied forces (including inertia forces)

Joint reactions

Muscle forces

$$\mathbf{C}\mathbf{f} = \mathbf{d}, \text{ where } \mathbf{f} = [\mathbf{f}^{(\mathbf{R})}, \mathbf{f}^{(\mathbf{M})}]$$

$$f_i^{(M)} \geq 0, \qquad i \in \{1,..,n^{(M)}\}$$

Matrix **C** is rectangular. This means that there are infinitely many solutions to the system of equations. How to pick the right one?

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Optimality

Minimize

$$G(\mathbf{f}^{(\mathbf{M})})$$

Subject to

$$\mathbf{Cf} = \mathbf{d}$$

$$f_i^{(M)} \geq 0, \qquad i \in \{1,..,n^{(M)}\}$$

Objective function. Different choices give different muscle recruitment patterns.

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Choices of objective function

$$G(\mathbf{f}^{(\mathbf{M})}) = \sum_i \left(\frac{f_i}{N_i} \right)^p$$

Contraction dynamics

- p = 1: This will fail to produce muscle synergism for small loads.
- p > 1: Muscle synergism but additional constraints are necessary to avoid overloaded muscles
- p →∞: Maximum synergism.
- All criteria with p > 1 predict synergism (and sometimes antagonism)
- Criteria converging for MVC!

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AnyBody Basics

ELSEVIER
Journal of Biomechanics 34 (2001) 409–415
JOURNAL OF BIOMECHANICS
www.elsevier.com/locate/jbiomech
www.JBiomech.com

Technical note

Muscle recruitment by the min/max criterion — a comparative numerical study

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Accepted 4 May 2000

Abstract

This paper introduces the min/max criterion for simulation of muscle recruitment in multiple muscle systems. The criterion is introduced and justified by comparison to two known criterion types: the polynomial criterion and the soft saturation criterion. The comparison is performed on a planar three-muscle elbow model performing a dumbbell curl. A generalized form of the soft saturation criterion is introduced, and it is shown that the min/max criterion can be interpreted as the limit of the classical criteria when the exponents in their mathematical expressions approach infinity. We finally show how the min/max criterion can be cast into a form that allows for efficient and robust numerical solution by linear programming. It is concluded that the min/max criterion possesses a number of attractive physiological as well as algorithmic advantages.

Keywords: Simulation; Optimization; Dumbbell curl; Inverse dynamics; Multiple muscle systems

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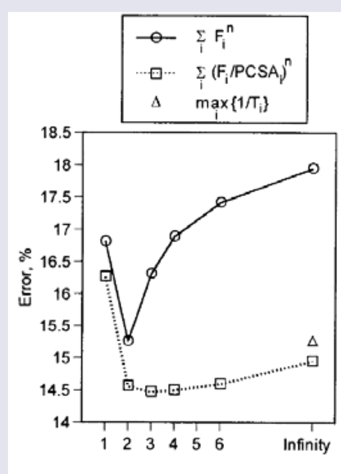
Prilutsky & Gregor

IEEE Transactions on Rehabilitation Engineering, Vol. 8, No. 3, September 2000

- Comparison between a bicycle model and EMG.
- Muscle stress rather than muscle force must be used.
- Criterion orders between 2 and ∞ are almost equally good.



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Activation dynamics as an error source?

Journal of Biomechanics 34 (2001) 153–161

JOURNAL OF BIOMECHANICS

www.elsevier.com/locate/jbiomech
www.JBiomech.com

1999 ASB Pre-Doctoral Award

Static and dynamic optimization solutions for gait are practically equivalent

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Accepted 3 July 2000

Abstract

The proposition that dynamic optimization provides better estimates of muscle forces during gait than static optimization is examined by comparing a dynamic solution with two static solutions. A 23-degree-of-freedom musculoskeletal model actuated by 54 Hill-type musculotendon units was used to simulate one cycle of normal gait. The dynamic problem was to find the muscle excitations which minimized metabolic energy per unit distance traveled, and which produced a repeatable gait cycle. In the dynamic problem, activation dynamics was described by a first-order differential equation. The joint moments predicted by the dynamic solution were used as input to the static problems. In each static problem, the problem was to find the muscle activations which minimized the sum of muscle activations squared, and which generated the joint moments input from the dynamic solution. In the first static problem, muscles were treated as ideal force generators; in the second, they were constrained by their force–length–velocity properties; and in both, activation dynamics was neglected. In terms of predicted muscle forces and joint contact forces, the dynamic and static solutions were remarkably similar. Also, activation dynamics and the force–length–velocity properties of muscle had little influence on the static

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Further research considerations:

ISB

INTERNATIONAL SOCIETY OF BIOMECHANICS
TECHNICAL GROUP ON COMPUTER SIMULATION

TGCS

Proceedings of the 12th International Symposium
on Computer Simulation in Biomechanics
Cape Town, South Africa
2 – 4 July 2009

Friday 3rd July 2009

9.00 – 9.15 welcome: Mark King, Thomas Franz

Oral presentations, chair: Serge van Sint Jan

9.15* Optimisation of performance in triple jumping
S.J. Allen, M.A. King, M.R. Yeadon

9.30 Mechanical advantage of crouch gait
J.A. Reinbolt, A. Seth, J.L. Hicks, S.L. Delp

9.45 Mesh generation from biomedical imaging data
P. Young, V.B. Xuan, D. Raymont, A. Harkara

10.00 Kinematics of elbow movements with unexpected inertial load are in line with predictions based on equilibrium point control
I. Pinter, M. Bobbert, A.J. van Soest, D. Kistemaker, J. Smeets

10.15 Salient properties of a combined minimum fatigue and quadratic muscle recruitment criterion
J. Rasmussen, M.de Zee, J. Dahl, M. Damsgaard

10.30 – 11.30 Computer demos and tea / coffee

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2/3: AnyBody Implementation

- Aim: Give maximum freedom of choice to the user.
- Constraint: Retain numerical efficiency.

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The AnyBody Study Structure

```
/// The study: Operations to be performed on the model
 AnyBodyStudy Study = {
   AnyFolder &Model = .Model;
   Gravity = {0.0, -9.81, 0.0};
   tEnd = Main.BikeParameters.T;
 };
```

- The study section is a part of every model.
- It contains “things to do to the model”.
- The standard study contains only a few specs.
- More can be added to control recruitment, kinematics and many other things.

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Implemented polynomial forms of $G(\mathbf{F}^{(M)})$

Non-physiological but useful for identification purposes.

$$\sum_i \frac{f_i}{N_i}$$

Useful for metabolism models (Praagman et al).

$$\sum_i \left(\frac{f_i}{N_i}\right)^2 + \varepsilon \sum_i \frac{f_i}{N_i}$$

$p = 3$ is a popular choice

$$\sum_i \left(\frac{f_i}{N_i}\right)^p, p = 1..5$$

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Demo:

Polynomial forms

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Min/max forms

$$\min \sum_i \left(\frac{f_i}{N_i} \right)^p \rightarrow \min \max \left(\frac{f_i}{N_i} \right) \text{for } p \rightarrow \infty$$

The min/max criterion can be interpreted as a minimum fatigue criterion because it reduces the maximum relative load on any muscle and hence postpones fatigue of the first muscle as far as possible.

The criterion is nonlinear and non-differentiable but can be reformulated to a very convenient form.

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Pure min/max

- Linear optimization problem.
- Ill-posed for submaximal muscle activations.
- Must be solved iteratively.
- Does not require upper bounds on muscle activations.
- Automatically makes independent subsystems independent.
- Forms a well-defined envelope of muscle activation.
- Attractive for ergonomic investigations.

$$\text{Minimize} \quad \beta$$

$$\text{Subject to}$$

$$\frac{f_i}{N_i} \leq \beta, \quad i = 1..n^{(M)}$$

$$\mathbf{Cf} = \mathbf{r}$$

$$f_i^{(M)} \geq 0$$

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Demo:

Pure min/max

Min/max with auxiliary terms

- The penalty terms can retain the benefits of min/max but soften the disadvantages.
- But they make independent subsystems dependent.

$$\text{Minimize } \beta + \varepsilon_1 \sum \frac{f_i}{N_i} + \varepsilon_2 \sum \left(\frac{f_i}{N_i} \right)^2$$

Subject to

$$\frac{f_i}{N_i} \le \beta, \quad i = 1..n^{(M)}$$

$$\mathbf{Cf} = \mathbf{r}$$

$$f_i^{(M)} \ge 0$$

Demo

Min/max with auxiliary terms

3/3: Conclusions

- Our kind of inverse dynamics is not "static optimization". It is very much dynamic.
- AnyBody offers much freedom for user-selected criteria.
- No clear answer on which criterion is the best one, but the resulting recruitment patterns are quite similar and the default criterion will give sensible results.
- Research employing coupled experiments and models with different criteria are necessary to find the "right" criterion if one exists.
- New PhD project beginning August 1 will work further on this.

Online resources

- The AnyBody Modeling System
  - Free demo license www.anybodytech.com
  - Email: anybody@anybodytech.com
- The AnyBody Research Project www.anybody.aau.dk
- Community: www.anyscript.org
  - Open source library of body models and applications
  - List of publications.
  - Collaborative modeling project space.
  - Support.
  - Wiki section.

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Thank you!
Q & A

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