Musculoskeletal Computation from Robotics

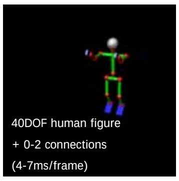
Yoshihiko NAKAMURA
Department of Mechano-Informatics
University of Tokyo

Many thanks to my colleagues and students:

K. Yamane, T. Inamura, M. Otake, I. Suzuki,
Y. Fujita, H. Tanie, A. Murai, M. Uchihara

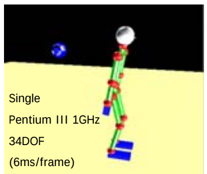
Dynamics Simulation
structure-varying kinematic chains
collision/contact

Efficient Dynamics Computation for Closed Kinematic Chain

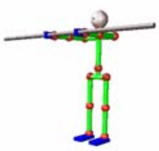


Structure-Varying Kinematic Chain, Nakamura and Yamane IEEE Trans R&A 2000

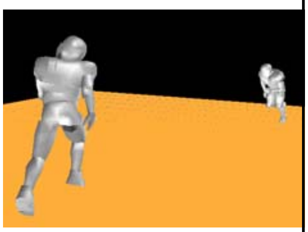
O(N) computation for OKC, Yamane and Nakamura, IEEE ICRA 2001



O(logN) parallel computation for SVKC + contact dynamics Yamane and Nakamura IEEE ICRA 2002



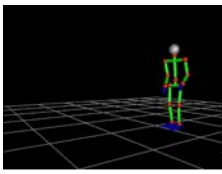
structure-varying systems

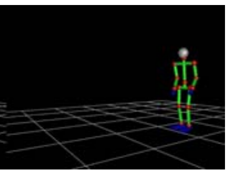


collision/contact

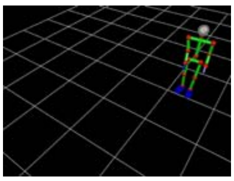
Dynamic Filter

filtered

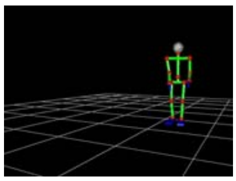




captured



modified hip trajectory



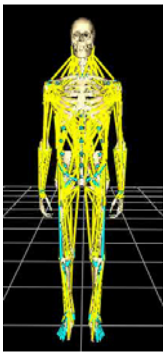
modified mass property

Musculoskeletal Computation

model

forward/inverse dynamics

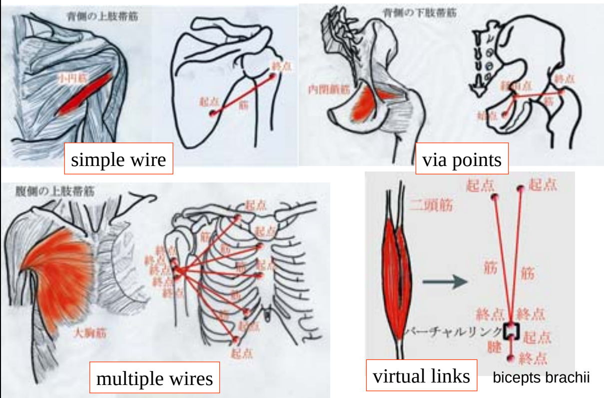
Musculoskeletal Model



number of bones:	200 (approximate)
number of links:	51(group of bones)
number of virtual links:	28
DOF:	321
without virtual links:	153
number of elements:	547
muscles:	366
tendons:	91
ligaments:	34
cartilages:	56

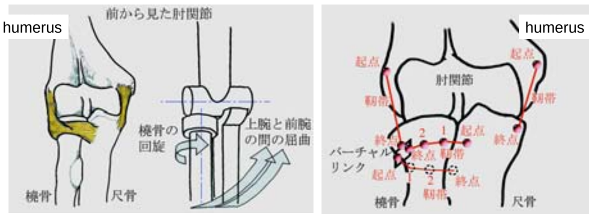
IPA未踏ソフトウェアプロジェクト
(2001-2002 金出 PM)

Wire model of muscles



bicepts brachii

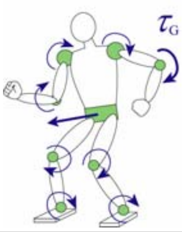
Wire model of ligaments



Modeling elbow joints

Inverse Dynamics Flow

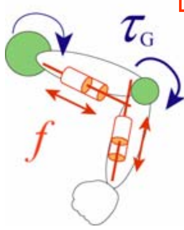
$\theta, \dot{\theta}, \ddot{\theta}$ → τ_G → wire force ＋ contact force (f, τ_C)



1) τ_G Newton-Euler inverse dynamics

Inverse Dynamics Flow

$\theta, \dot{\theta}, \ddot{\theta}$ → τ_G → wire force ＋ contact force (f, τ_C)



2) $\tau_G = J_L^T f + J_C^T \tau_C$

τ_G DOF < f DOF
(323) (547)

Solve Actuation Redundancy for f

Physical consistency of wire tension

$\tau_J = \tau_G - J_C^T \tau_C = J_L^T f$

Rigid Body Mechanics

$E_{mtl} f \leq 0$

+

Physiological Properties

Model of muscle properties

Quadratic Programming

Cost function:

$$Z = w_{QP} \, | \tau_J - J_L^T f |^2 + | f - f^* |^2$$

Inequality constraints: $E_{mtl} f \leq 0$

f 547 variables

Linear Programming

a_f^T, a_τ^T : positive vectors (weighting)

Cost function: $Z = a_\tau^T \delta_\tau + a_f^T \delta_f$

Inequality constraints:

$$-\delta_\tau \leq \tau_J - J_L^T f \leq \delta_\tau \qquad \delta_\tau \geq 0$$

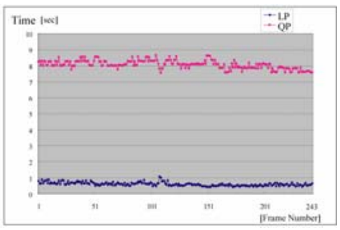
$$-\delta_f \leq f - f^* \leq \delta_f \qquad \delta_f \geq 0$$

$$E_{mtl} f \leq 0$$

f, δ_τ, δ_f 1417 variables

Experiments

QP vs LP computational cost



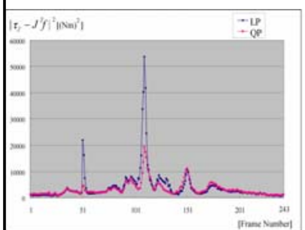
[QP(R), LP(B)]

PentiumIV 3GHz single processor

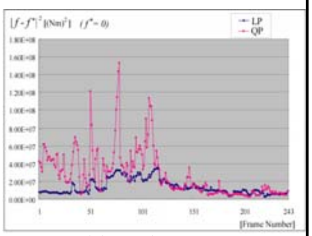
Cf. τ_C 0.0088 [sec/frame]

	QP	LP	
Average time per frame	8.06 [sec/frame]	0.609 [sec/frame]	LP is 13.2 times faster
Number of optimized variable	547 (f)	1417 $(f, \delta_f, \delta_\tau)$	LP has 2.59 times more variables

QP vs LP computational accuracy



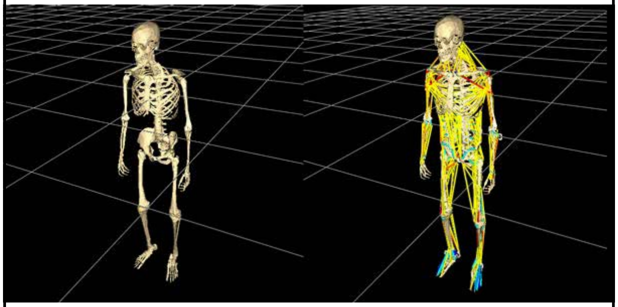
$|\tau_J - J_L^T f|^2$ [QP(R), LP(B)]



$|f - f^*|^2$ $(f^* = 0)$ [QP(R), LP(B)]

QP is more suitable for rapid movements.
Otherwise, LP is stable and sufficiently accurate

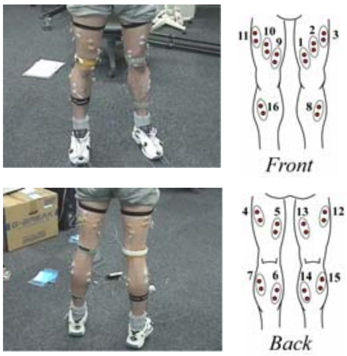
Results of computation



Use of force plate and EMG

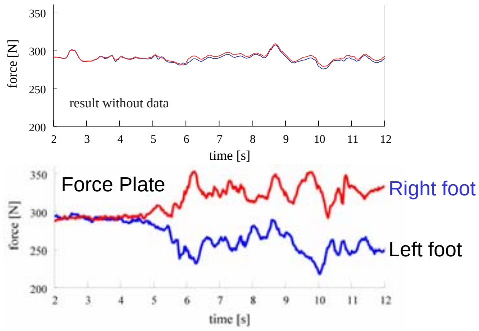
Motion capture＋EMG＋force plate

Placement of Electrodes



Estimation of Foot-Contact Force

Optimized without force-plate information



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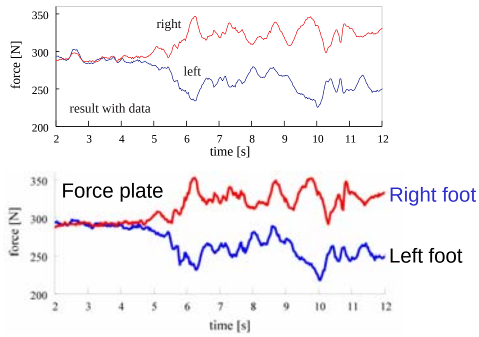
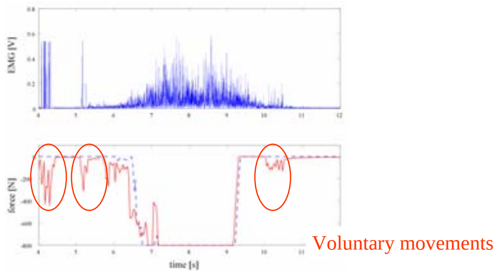
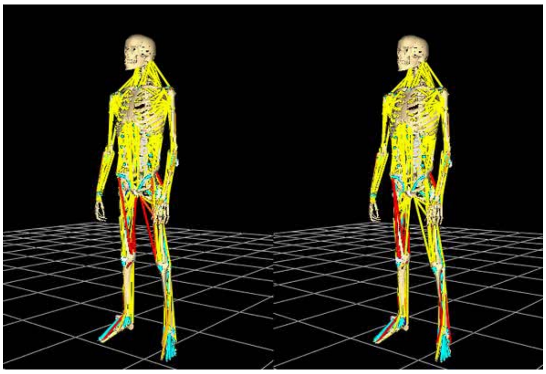


Effects of the use of EMG



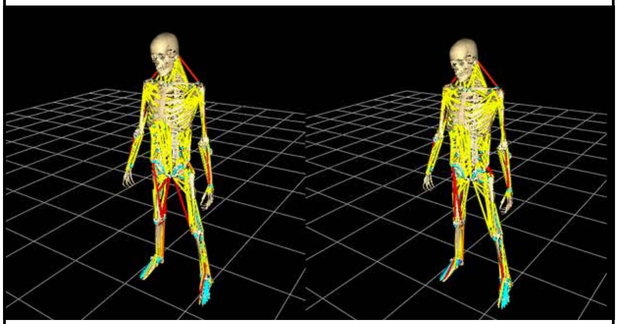
Blue line : motion data only,
Red line : concurrent use of motion data and EMG

Results of computation



Motion data only　　Motion data + Force information

Results of computation



Motion data only　　Motion data and Force information

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f 547 variables

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$$E_{mtl} f \le 0$$

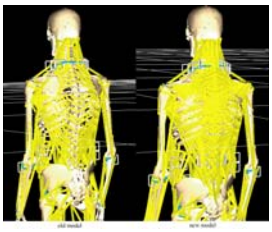
f, δ_τ, δ_f 1417 variables

Improved Model

脊柱起立筋群の付加:
　脊柱起立筋(深部筋)は体幹の屈曲，姿勢維持に重要

	旧モデル	新モデル
筋	336	989
腱	50	50
靭帯	117	117
軟骨	34	34
V.L.	48	72

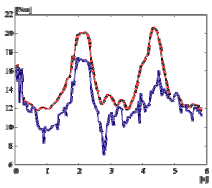
(2005 Murai, Yamane, Nakamura)



Improved Accuracy of Estimation

前後屈運動において一般化力→筋張力→一般化力を
行った際の一般化力

黒:必要トルク
青:従来モデル
赤:新モデル



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脊柱起立筋群の付加により筋骨格情報算出の精度が向上

(2005 Murai, Yamane, Nakamura)

Somatosensory Information
（体性感覚情報）

• tensions, lengths, velocities of muscles
• tensions of tendons and ligaments
• pressure of cartilages
• stress of bones

- Information deep inside the human body.
- Paid not much attention to applications other than medicine and rehabilitation.

Visualization of inside human body

• X Ray
• MRI, fMRI
• Somatosensory Imaging

Neuro Musculo Skeletal System Modeling

解剖学　Anatomy
生理学　Physiology
情報学　Informatics
力学　Mechanics

Neuro-Informatics
Computational Neuroscience
（M. Kawato）

Applications and Scope

• Medicine
• Neuroscience
• Rehabilitation
• Sports
• Digital Mannequin