2011 summer school on impedance

extrodution

DLR Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

leftovers from this week

1. do robots need biarticulate muscles?

2. what impedance do we need, really?
   let us
   - measure human arm impedance
   - measure impedance during movement
   - estimate impedance from EMG

3. can we control position out of pns/cns signals?

my issue

learn, but do not copy or mimic!

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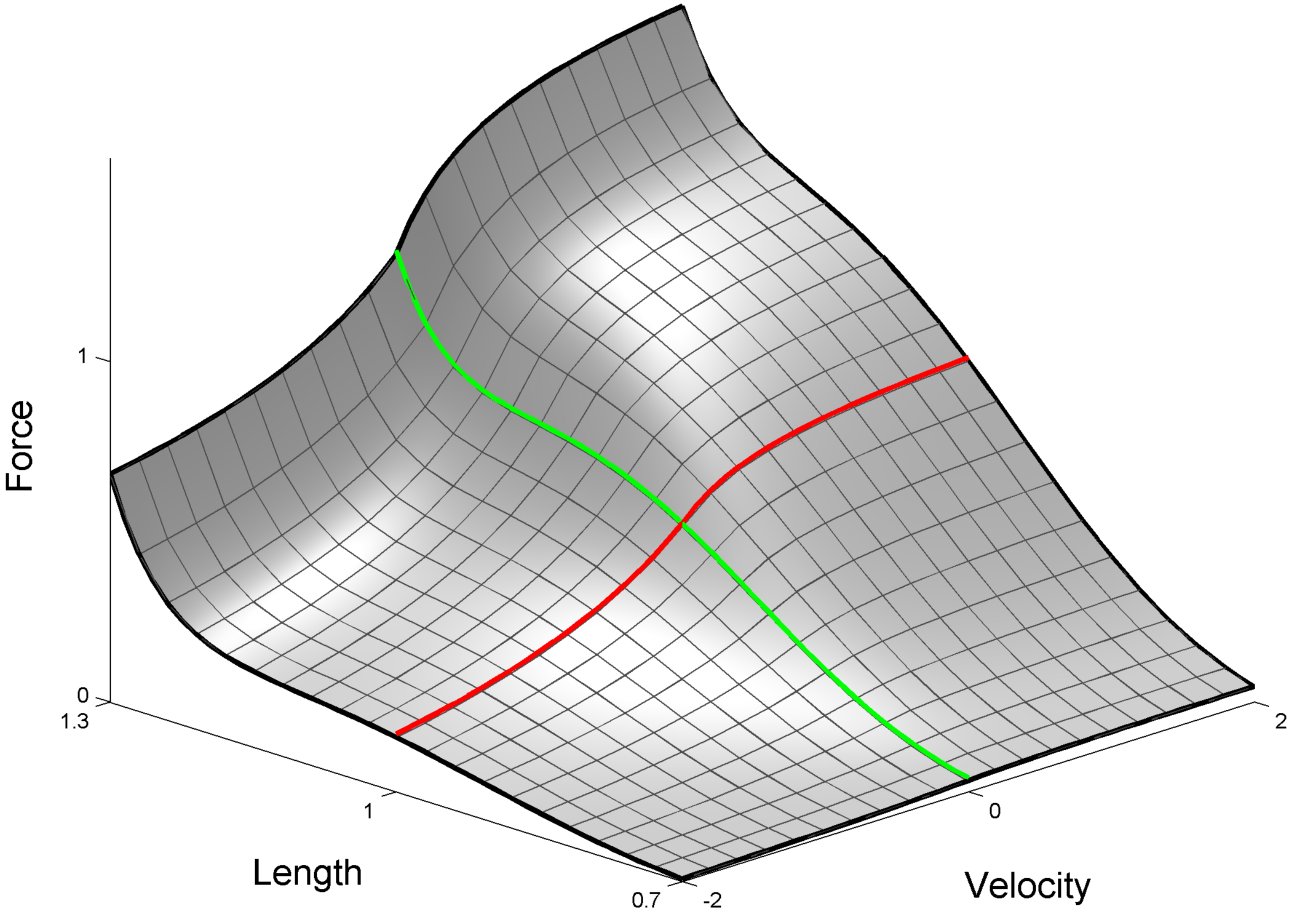
do robots need biarticulate muscles?



muscle ≠ torque motor

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dominic lakatos

☐Ph.D candidate

☐research topic: human impedance & control of variable-impedance robots

arm model

☐ **rigid body dynamics of the arm**

$$\boldsymbol{\Gamma}(\mathbf{q}, \dot{\mathbf{q}}, \ddot{\mathbf{q}}, \boldsymbol{\xi}) = \mathbf{M}(\mathbf{q}, \boldsymbol{\xi})\, \ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q}, \dot{\mathbf{q}}, \boldsymbol{\xi})\, \dot{\mathbf{q}} + \mathbf{g}(\mathbf{q}, \boldsymbol{\xi})$$

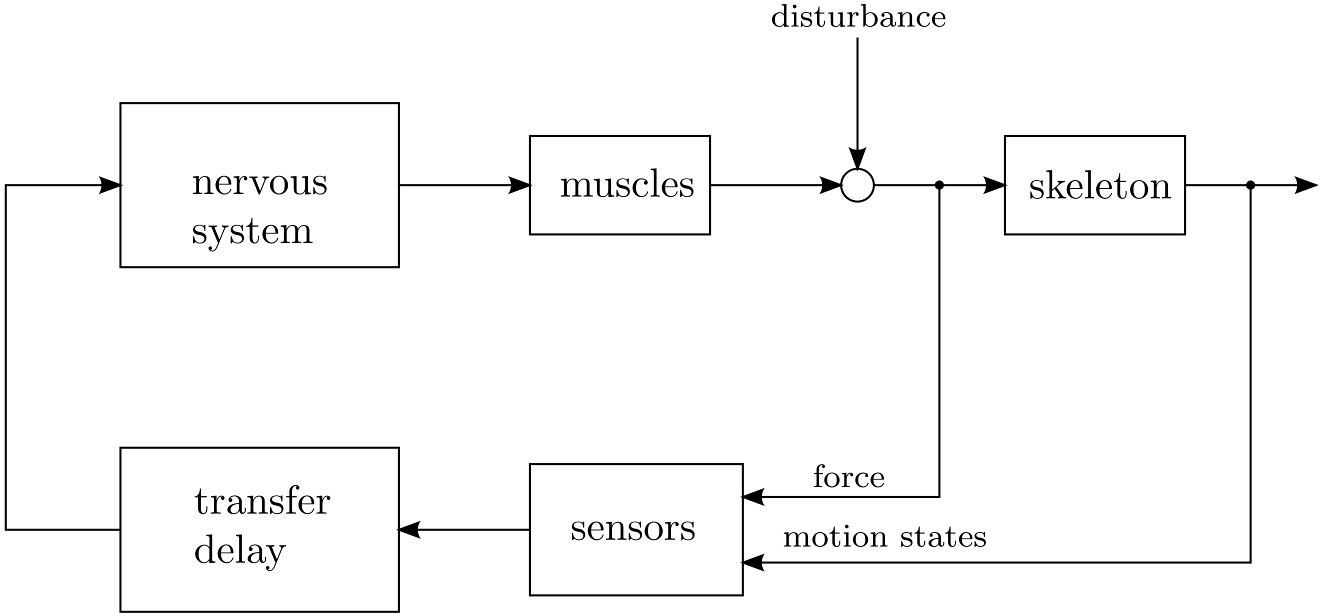
☐ **muscle impedance**

$$\boldsymbol{\tau}_{\text{muscles}} = \mathbf{h}(\mathbf{q}, \dot{\mathbf{q}}, \mathbf{a})$$

☐ **complete system torque**

$$\mathbf{M}(\mathbf{q}, \boldsymbol{\xi})\, \ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q}, \dot{\mathbf{q}}, \boldsymbol{\xi})\, \dot{\mathbf{q}} + \mathbf{g}(\mathbf{q}, \boldsymbol{\xi}) + \mathbf{h}(\mathbf{q}, \dot{\mathbf{q}}, \mathbf{a}) = \boldsymbol{\tau}_{ext}$$

we want to measure the arm, not the brain



☐ **stretch reflex: 25-50ms**

☐ **spinal reflex: 70-110ms**

☐ **long-latency reflex: >110ms**

locally linearised impedance

☐ Taylor approximation to h can be written as

$$\begin{aligned}\mathbf{h}^\star \quad = \quad & \mathbf{h}\big|_{\mathbf{q}_0,\mathbf{a}_0} + \left.\frac{\partial \mathbf{h}(\mathbf{q},\dot{\mathbf{q}},\mathbf{a})}{\partial \mathbf{q}}\right|_{\mathbf{q}_0,\mathbf{a}_0} \Delta\mathbf{q} \\ & + \left.\frac{\partial \mathbf{h}(\mathbf{q},\dot{\mathbf{q}},\mathbf{a})}{\partial \dot{\mathbf{q}}}\right|_{\mathbf{q}_0,\mathbf{a}_0} \Delta\dot{\mathbf{q}} + \left.\frac{\partial \mathbf{h}(\mathbf{q},\dot{\mathbf{q}},\mathbf{a})}{\partial \mathbf{a}}\right|_{\mathbf{q}_0,\mathbf{a}_0} \Delta\mathbf{a}\end{aligned}$$

☐ since the activation is assumed to be constant

$$\mathbf{h}^\star = \mathbf{K}\,\Delta\mathbf{q} + \mathbf{D}\,\Delta\dot{\mathbf{q}}$$

☐ in the transversal plane the gravity=0

$$\underbrace{\mathbf{M}(\mathbf{q},\boldsymbol{\xi})\,\ddot{\mathbf{q}} + (\mathbf{C}(\mathbf{q},\dot{\mathbf{q}},\boldsymbol{\xi}) + \mathbf{D})\,\dot{\mathbf{q}} + \mathbf{K}\,\Delta\mathbf{q}}_{\boldsymbol{\Psi}(\ddot{\mathbf{q}},\dot{\mathbf{q}},\Delta\mathbf{q},\boldsymbol{\xi},\mathbf{D},\mathbf{K},)} = \Delta\boldsymbol{\tau}_{\mathrm{ext}}$$

linear parameter identification model

☐ parameter vector

$$\zeta = [\xi_1, \xi_2, \xi_3, D_{11}, D_{12}, D_{21}, D_{22}, K_{11}, K_{12}, K_{21}, K_{22}]^T$$

☐ identification model

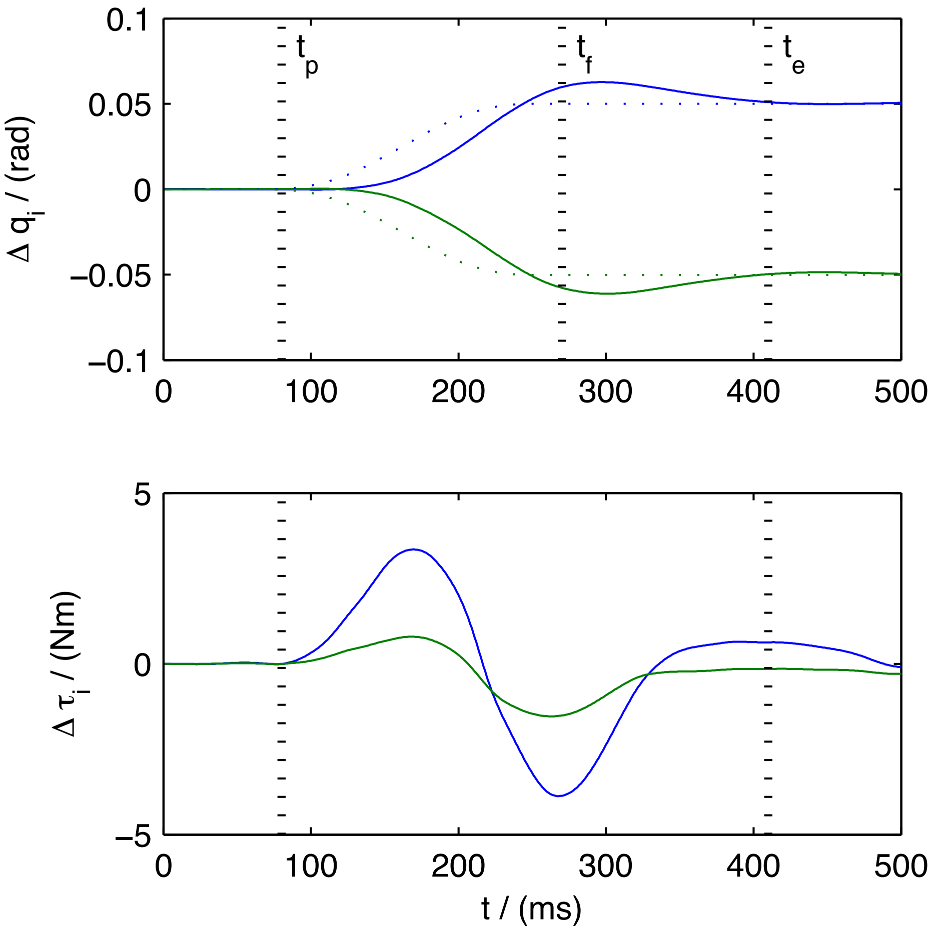
$$\mathbf{W}\,\zeta = \mathbf{y}$$

$$\mathbf{W} = \begin{bmatrix} \mathbf{X}(1) \\ \mathbf{X}(2) \\ \vdots \\ \mathbf{X}(N) \end{bmatrix}, \quad \mathbf{y} = \begin{bmatrix} \Delta\boldsymbol{\tau}_{\text{ext}}(1) \\ \Delta\boldsymbol{\tau}_{\text{ext}}(2) \\ \vdots \\ \Delta\boldsymbol{\tau}_{\text{ext}}(N), \end{bmatrix}$$

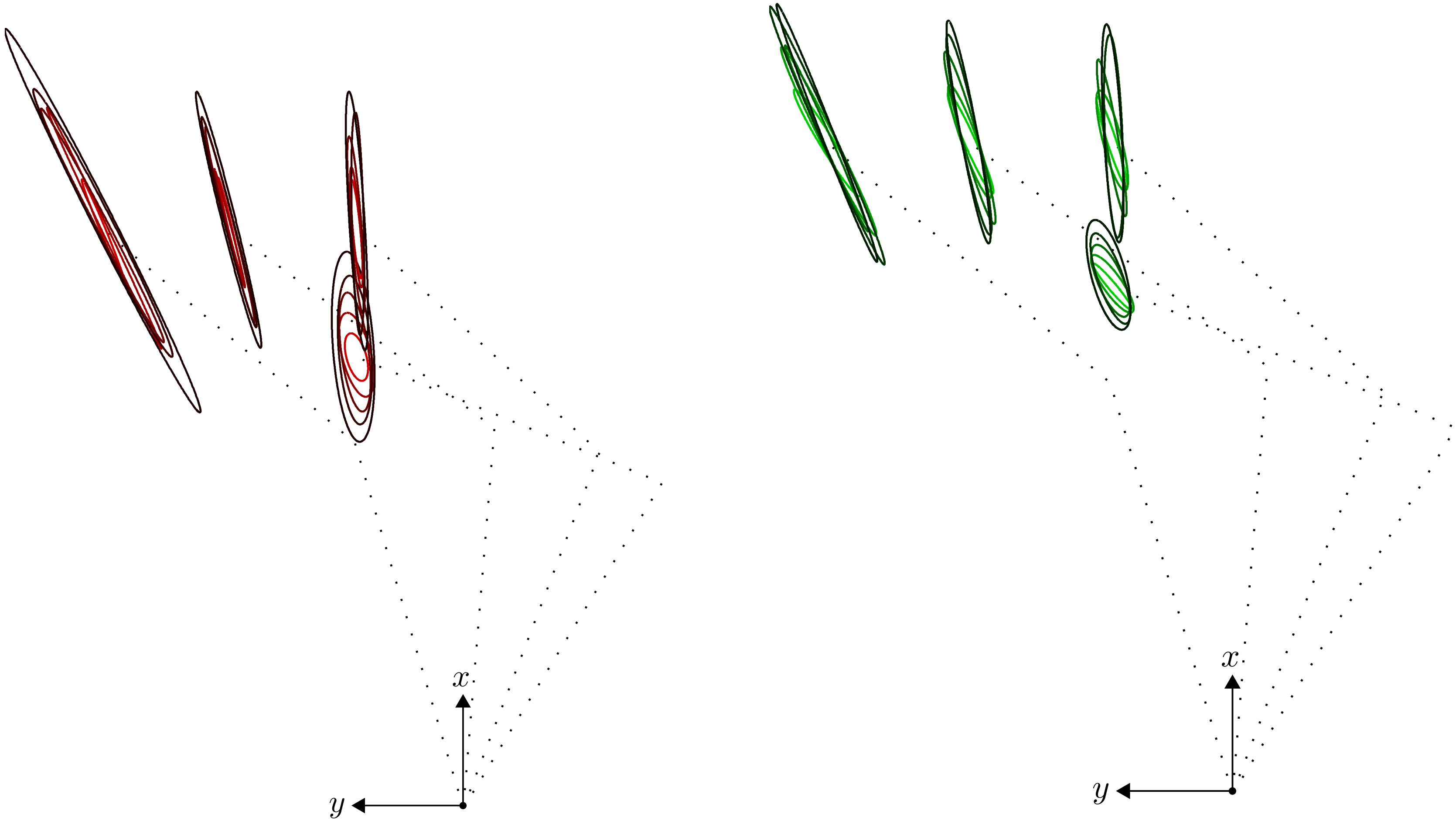
$$\mathbf{X} = \left(\frac{\partial \boldsymbol{\Psi}(\ddot{\mathbf{q}}, \dot{\mathbf{q}}, \Delta\mathbf{q}, \boldsymbol{\xi}, \mathbf{D}, \mathbf{K},)}{\partial \zeta} \right)$$

experimental setup

perturbations



resulting stiffness and damping



we're not there yet…

☐ what will these look like in 3D?

☐ how do we measure intrinsic tendulomuscular properties?

☐ how can we map these to EMG activities?

leftovers from this week

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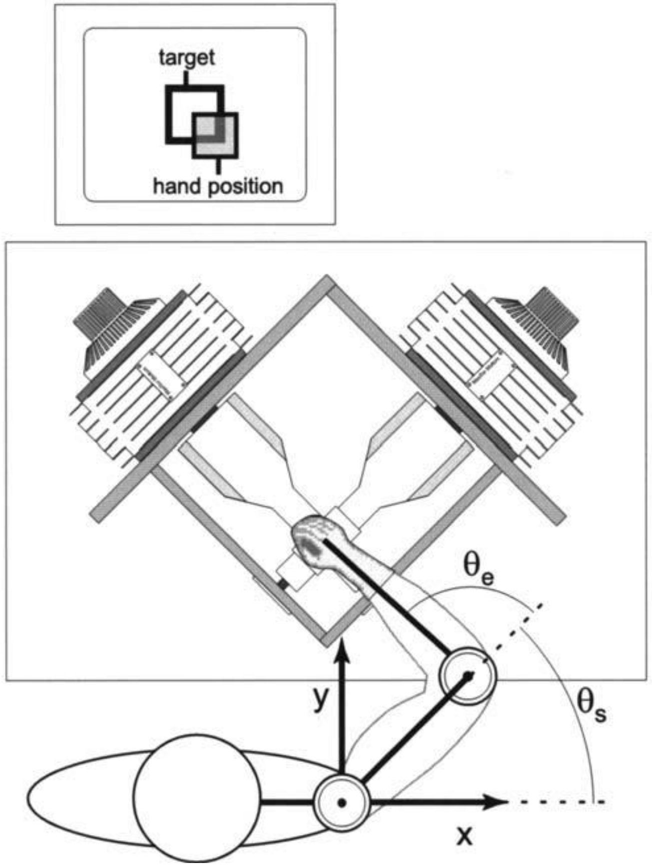
2. what impedance do we need, really?
   let us
   - measure human arm impedance
   - **measure impedance during movement**
   - estimate impedance from EMG

3. can we control position out of pns/cns signals?

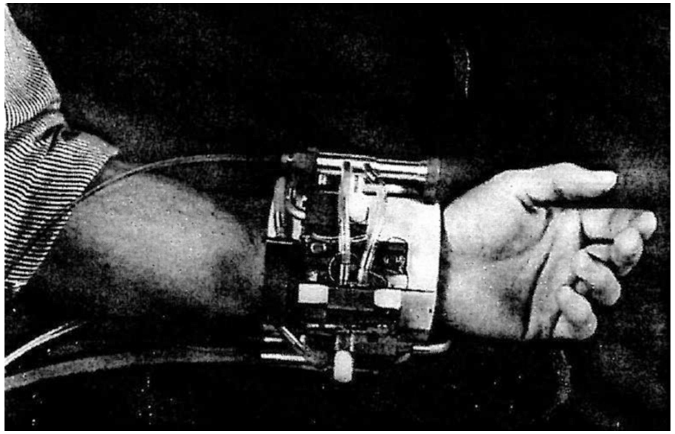
hannes höppner [hupna]

- Ph.D candidate
- research topic:
  intrinsic human impedance

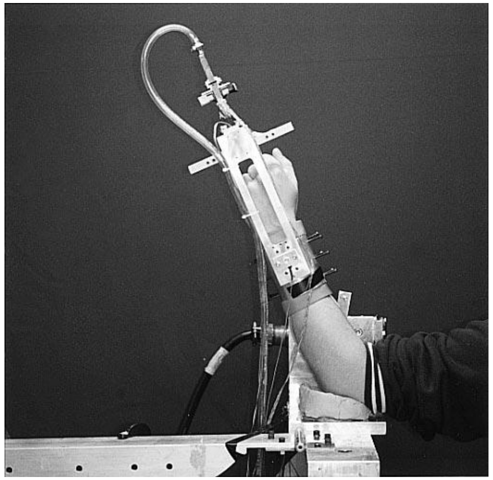
related work



Adaptive control stiffness to stabilize hand position with large loads [Franklin03]



The Design of a Dynamics Measuring Device [Colg86]



A Robust Ensemble Data Method for identification of Human Joint Mechanical Properties During Movement [Xu99]

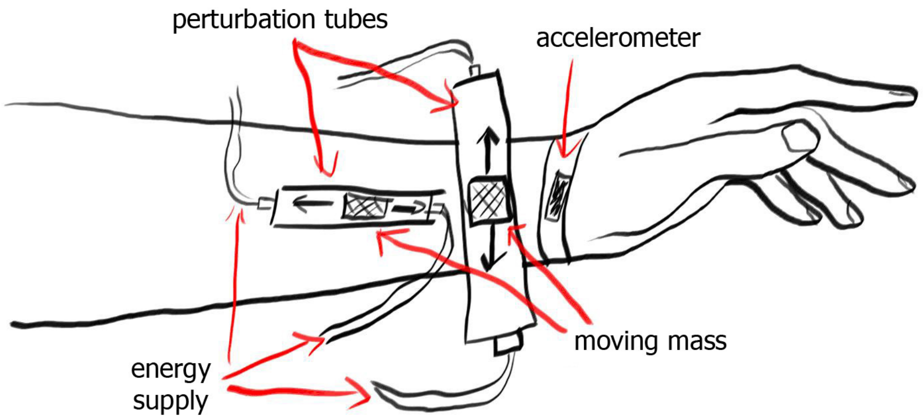
related work

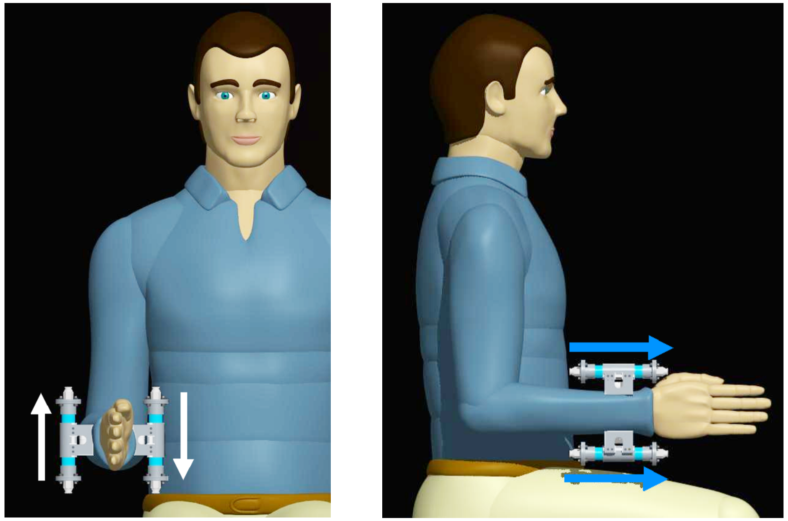
drawbacks of existing solutions measuring arm stiffness

☐ *position-perturbation setups*
  - not wearable
  - unnatural constrained and only planar movements

☐ *wearable force-perturbation setups*
  - only force less than 6N
  - Influence of heavy loads during common tasks can not be identified clearly
  - Precise control of this devices seems to be problematic

Idea and Specifications





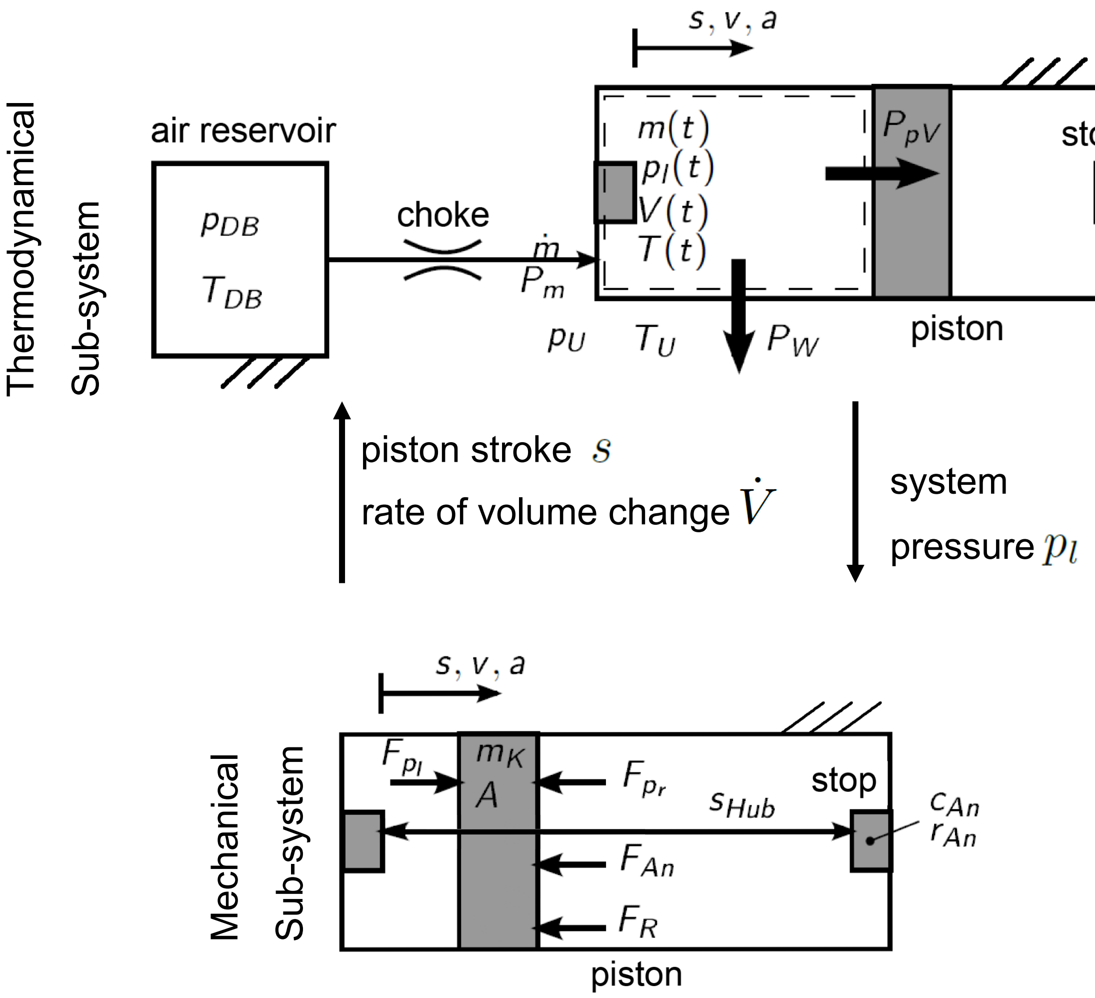
☐ accelerating and decelerating a mass inside a tube fixed to the limb

☐ energy is induced using external energy reservoir; here: compressed air

☐ using defined impact <25ms

☐ 2 perturbator tubes to induce clear rotations and translations

modeling and simulation



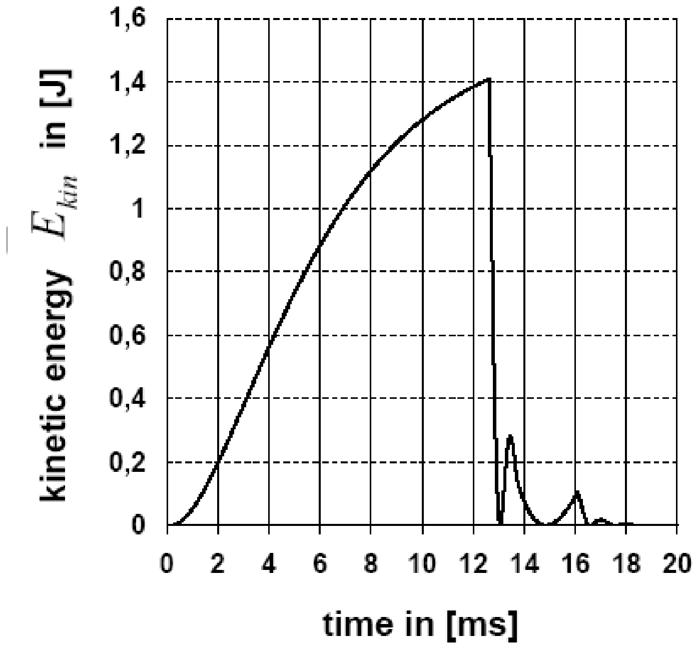
piston stroke s

rate of volume change $\dot{V}$

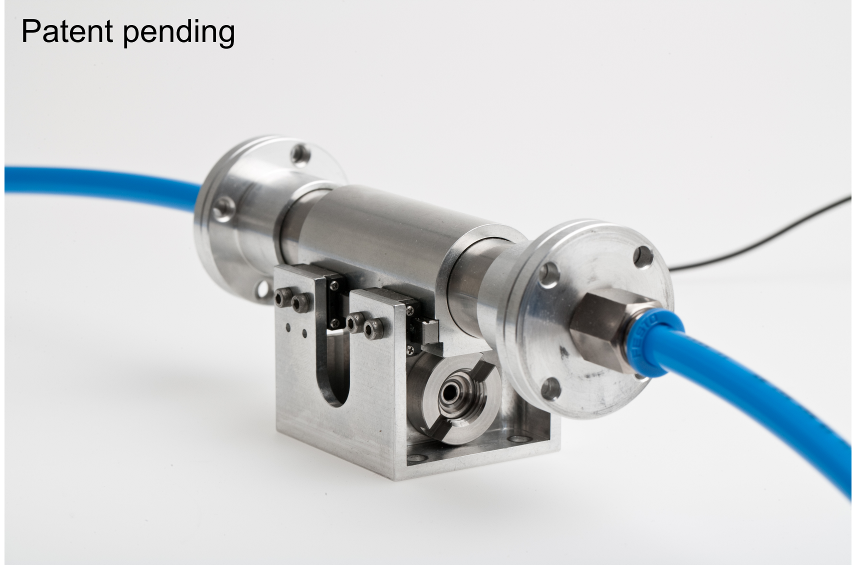
system

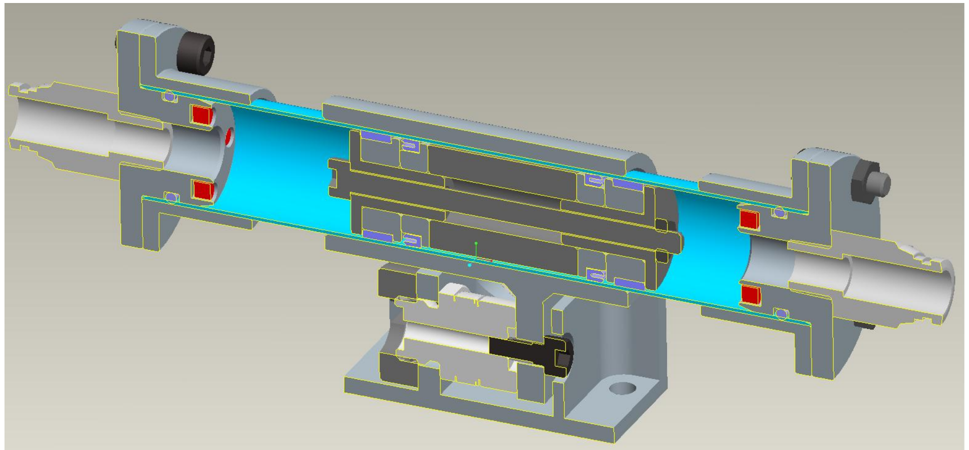
pressure p_l

Goal: optimize measurement time and total mass



implementation

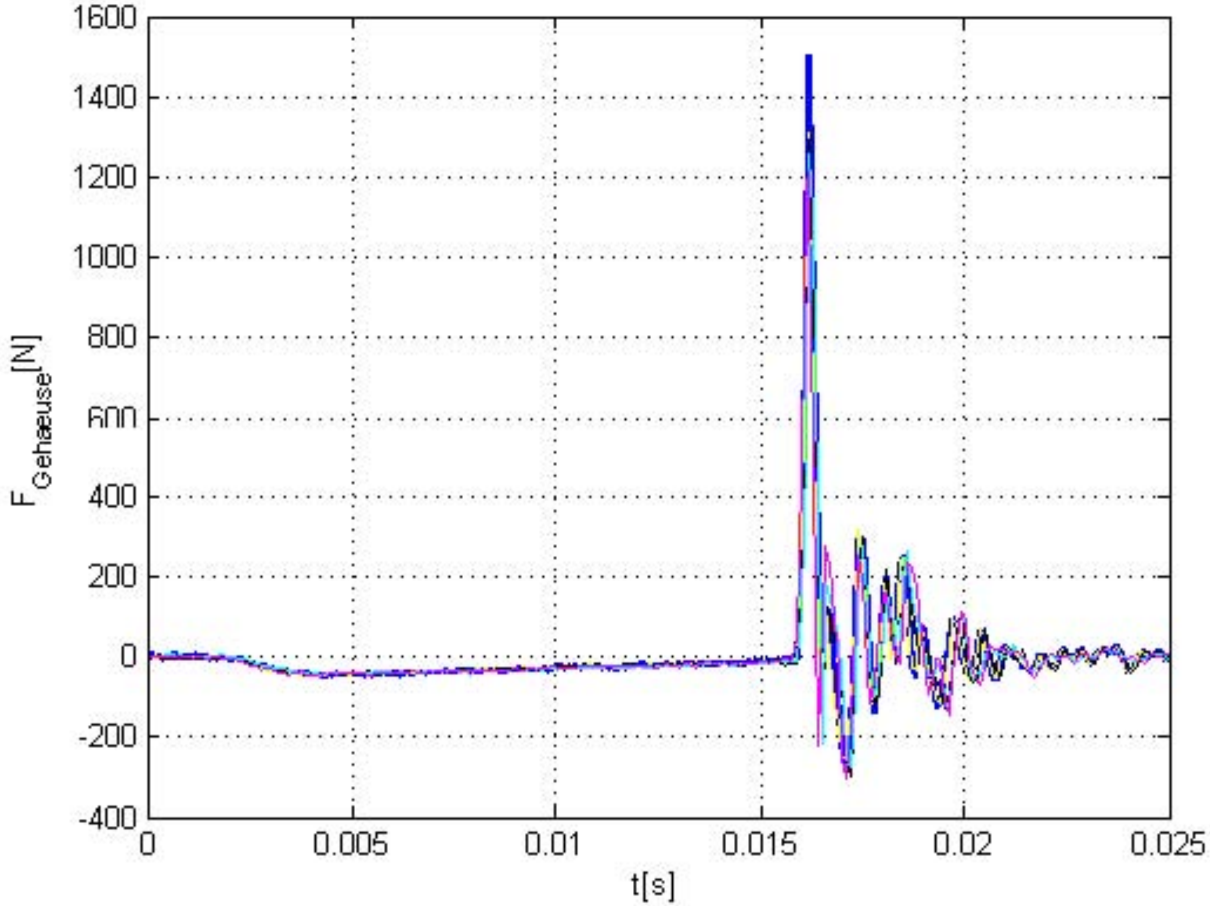

Patent pending



- ☐ steel tube length of 130mm and 300g weight
- ☐ two external relays
- ☐ mass consists of sealing, sliding and inertia elements
- ☐ magnets to increase the counterforce against the air pressure
- ☐ additional force sensor between arm and Perturbator tube

results on device properties

Measured and simulated force



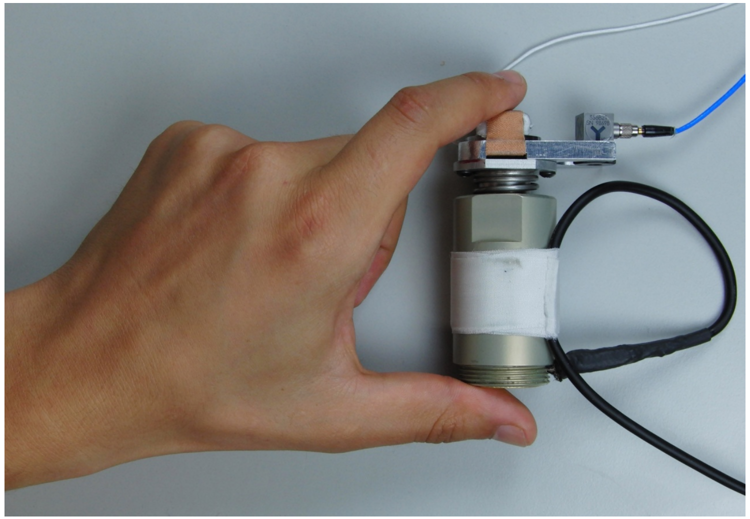
measuring human grasp stiffness

Requirements

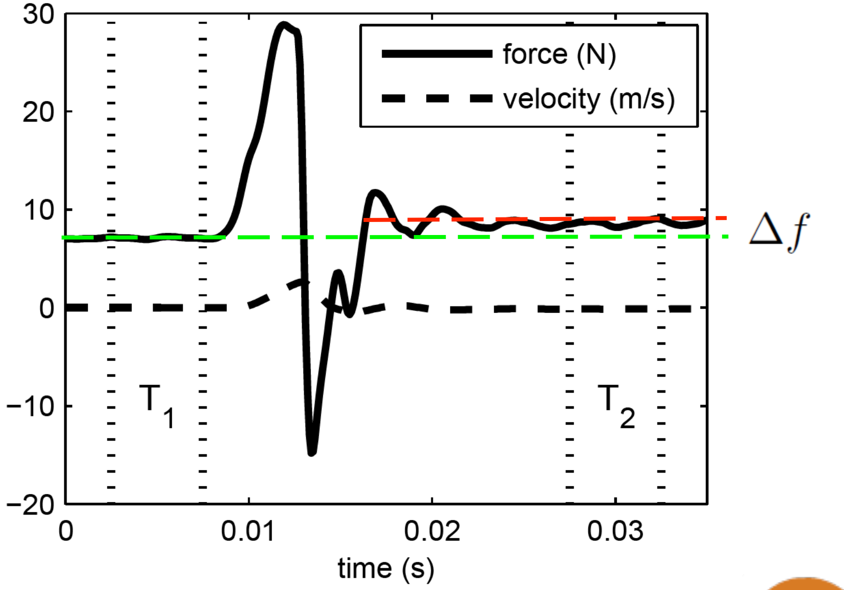
- ☐ Static measurement [Mussa-Ivaldi85] $\dot{x} = \ddot{x} = 0$

$$m\ddot{x}(t) + r\dot{x}(t) + kx(t) = f(t) \longrightarrow k = \frac{E_{T_2}(f) - E_{T_1}(f)}{E_{T_2}(x) - E_{T_1}(x)}$$

- ☐ Measurement time *t ≈ 30 ms* and thus below human finger reflex time
- ☐ Constant initial position and displacement $\Delta x = const. \quad x_0 = const.$

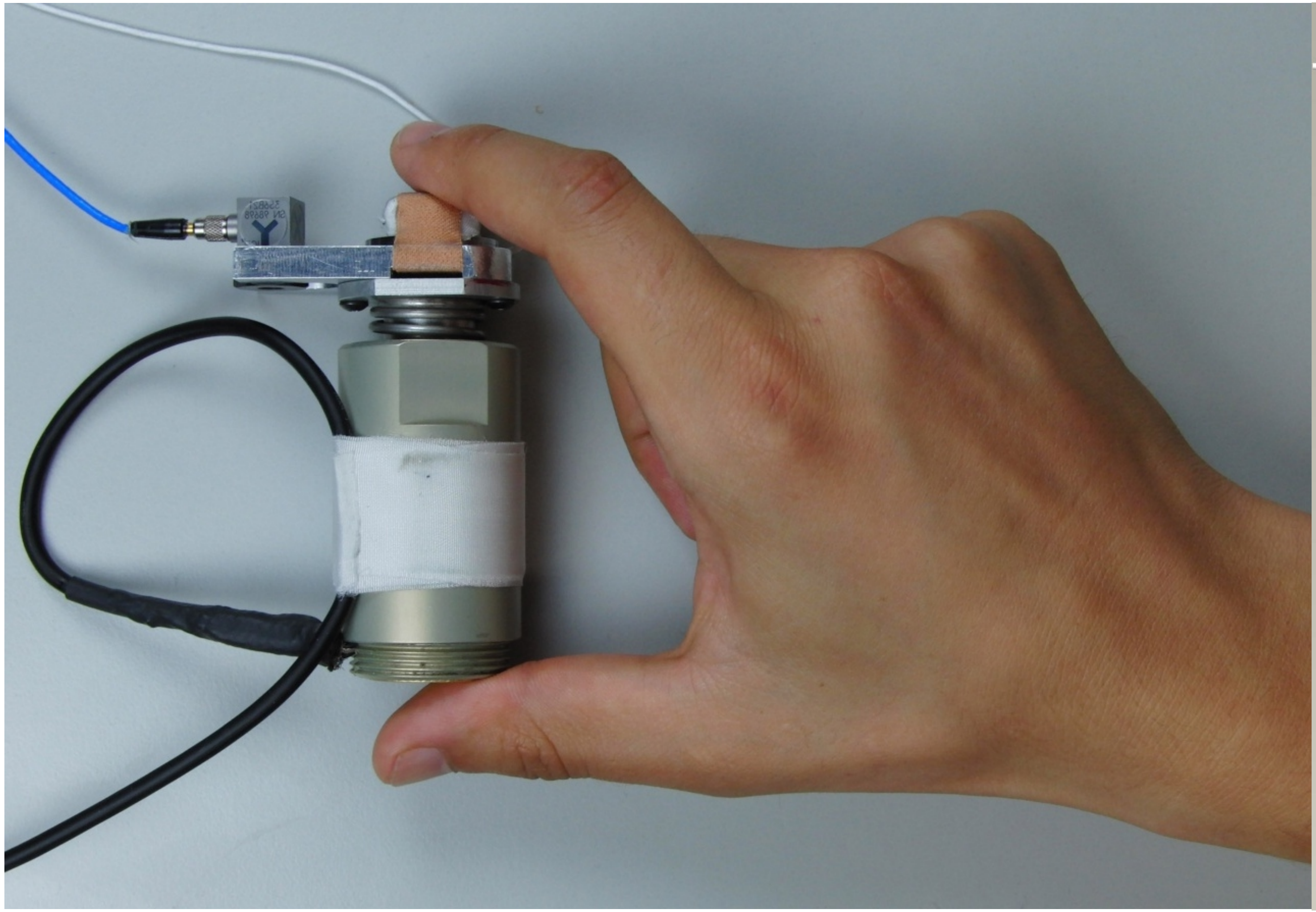


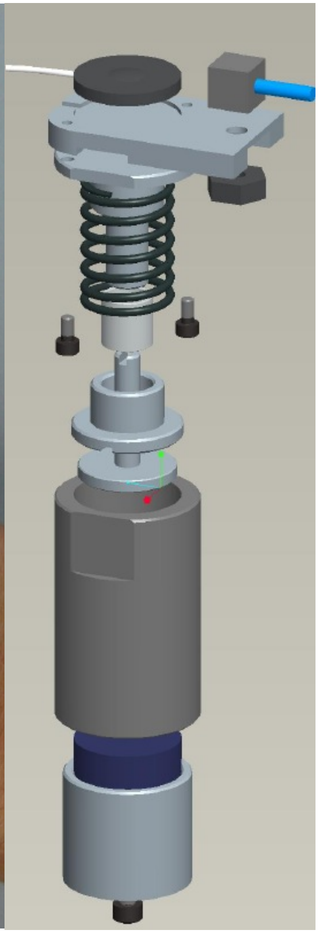
patent pending



Höppner et al, Proc. ICRA 2011

measurement device





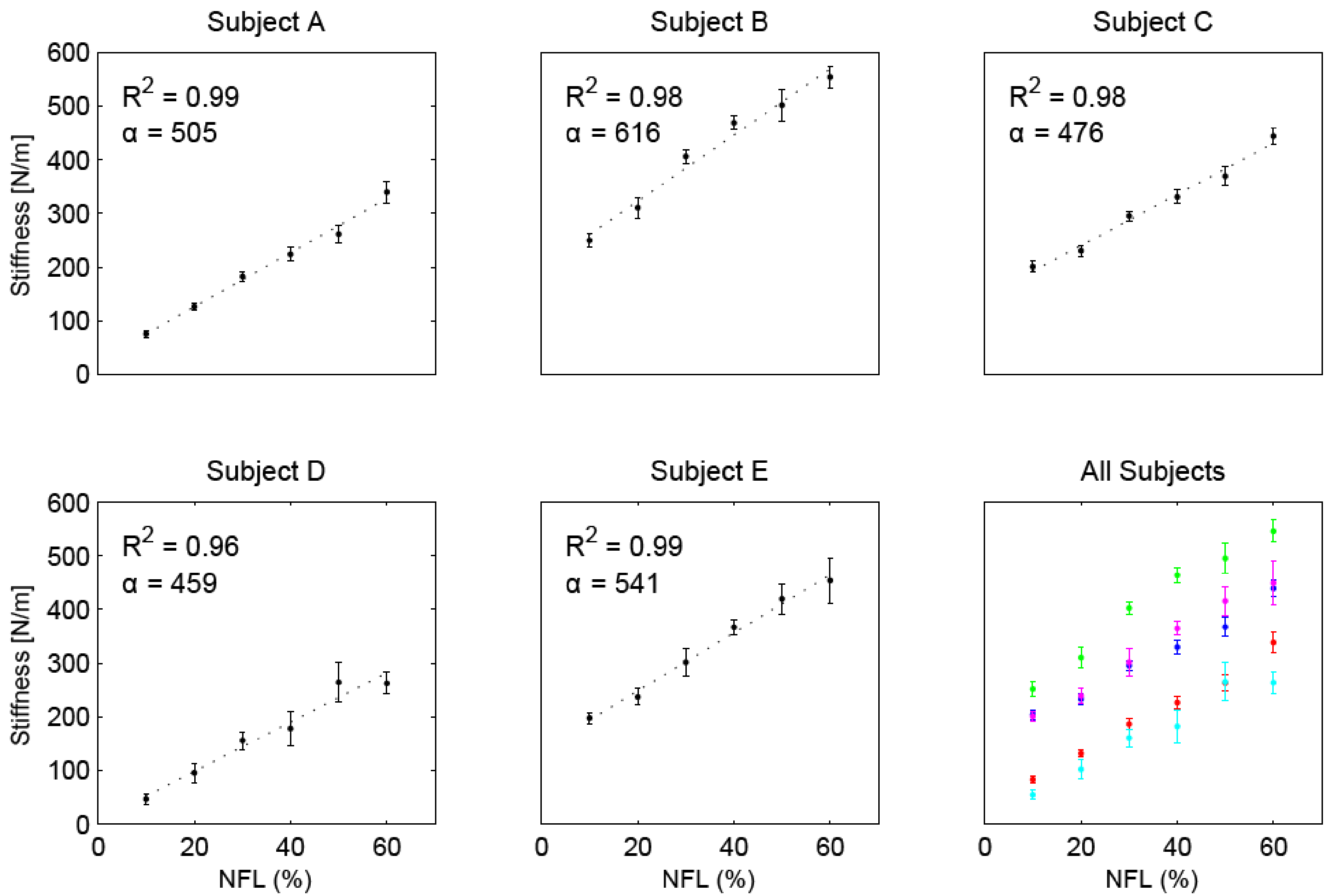
experiment and measurement procedure

☐ 5 healthy male subjects using Pinch Grasp

☐ Grasp Perturbator without any fixation

1. Subjects Maximum Gripping Force is estimated
2. Subject is asked to apply Normalized Force Levels ***NFL***
   - Reaching NFL using 2 Bands (85% and 115%)
3. 2<T<4 seconds after the force is reached a Perturbation is applied

Results


Subject A
Subject B
Subject C
Subject D
Subject E
All Subjects
R^2 = 0.99
α = 505
R^2 = 0.98
α = 616
R^2 = 0.98
α = 476
R^2 = 0.96
α = 459
R^2 = 0.99
α = 541
Stiffness [N/m]
0
100
200
300
400
500
600
NFL (%)
0
20
40
60

conclusion

☐ **what does the linear relation imply?**

$$K = \frac{\partial F}{\partial x} = c_1 \cdot F(x) + c_2 \qquad \longrightarrow$$

linear relation at the elbow between torque and stiffness [Bennett93]

tendons can be assumed as exponential elements [Glantz74]

☐ **How does this contribute to robotics?**

guideline for VSA

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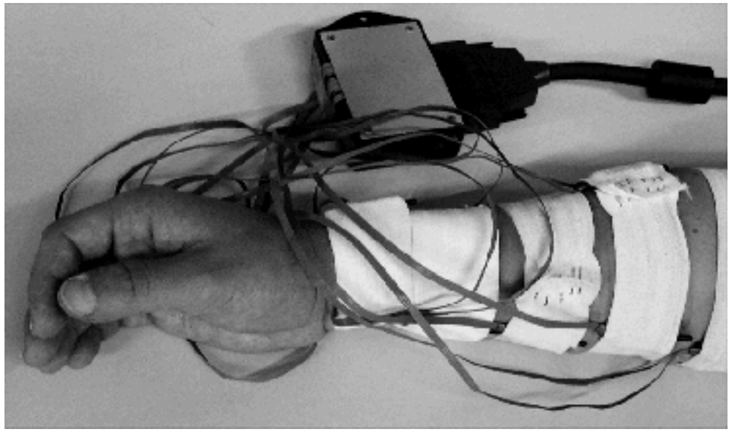
claudio castellini

□Ph.D, U. Edinburgh

□research topic:

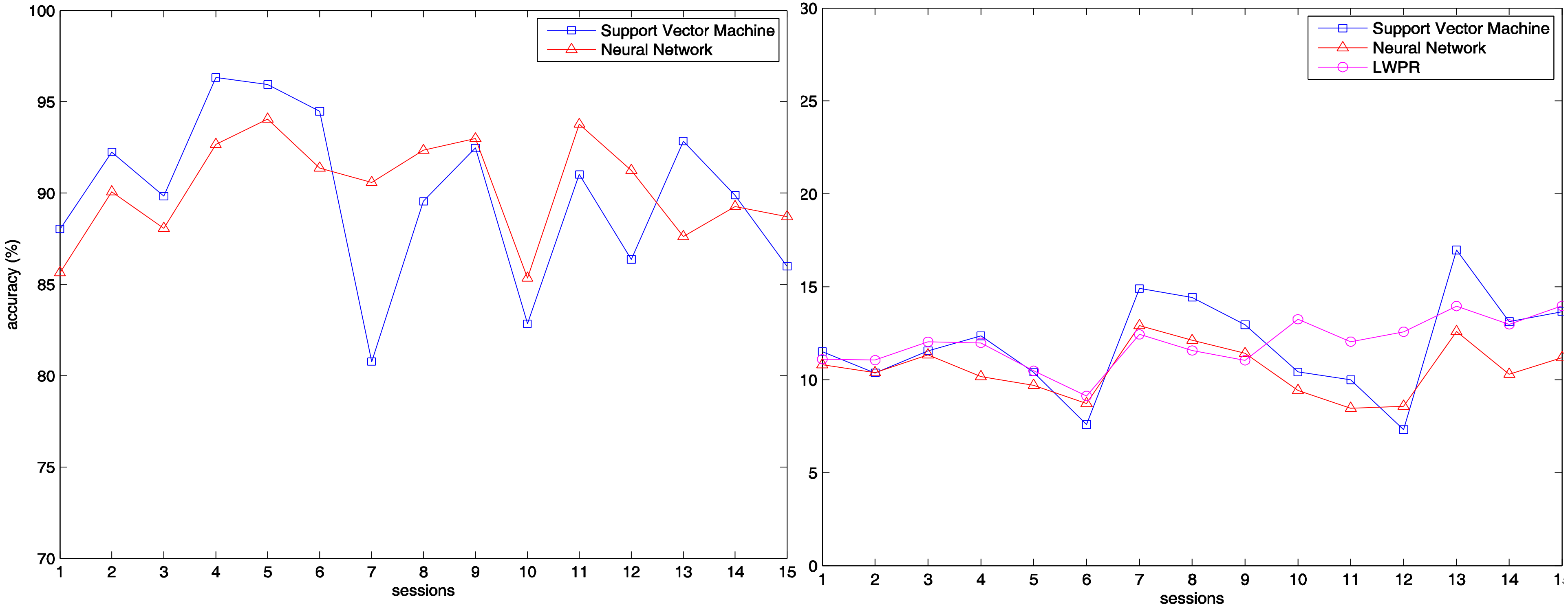
hand prosthetics and rehabilitation

finger position and force from EMG



- 10 Ottobock emg electrodes
- 1 force/torque sensor
- 4 fingertip force sensors

high-precision EMG



best models on day 1, classification accuracy (left) and regression NRMSE (right)

accuracy ~ 10%

PNS-based robot control: EMG

jörn [yearn] vogel

- Ph.D candidate

- research topic:
  semiautonomous
  robotics for
  brain-machine interfaces

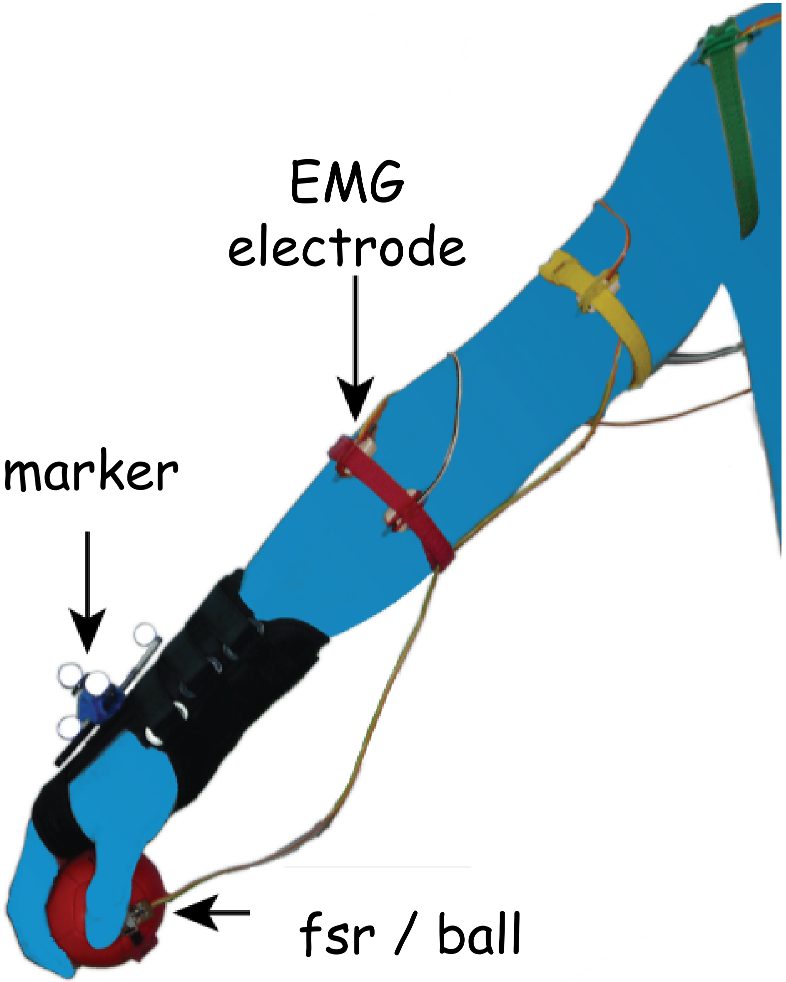
high-precision EMG

hand emg:

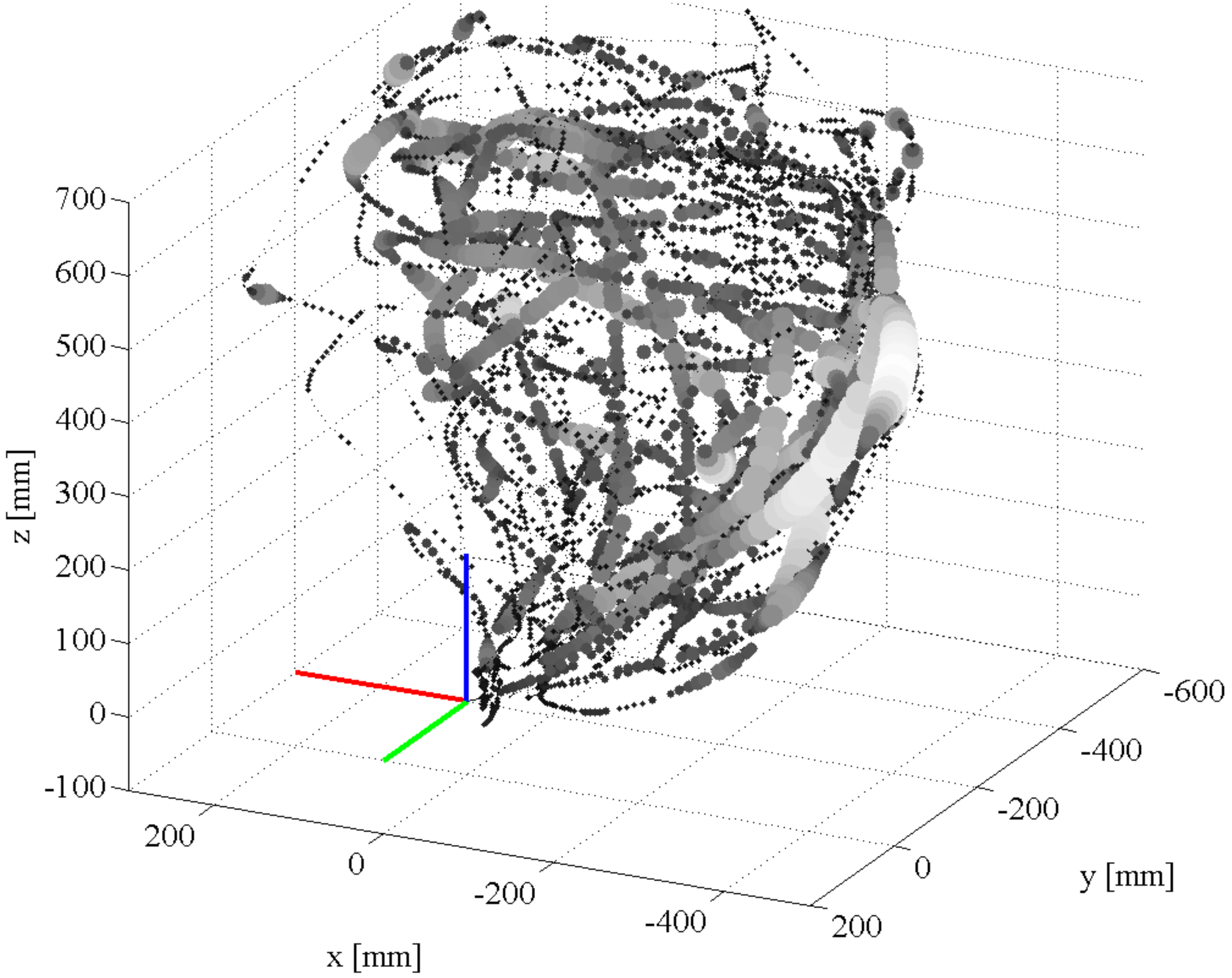
☐ static finger forces
☐ limited accuracy (~10%), but this is not evident
☐ qualitative visual feedback solves limited accuracy

arm emg:

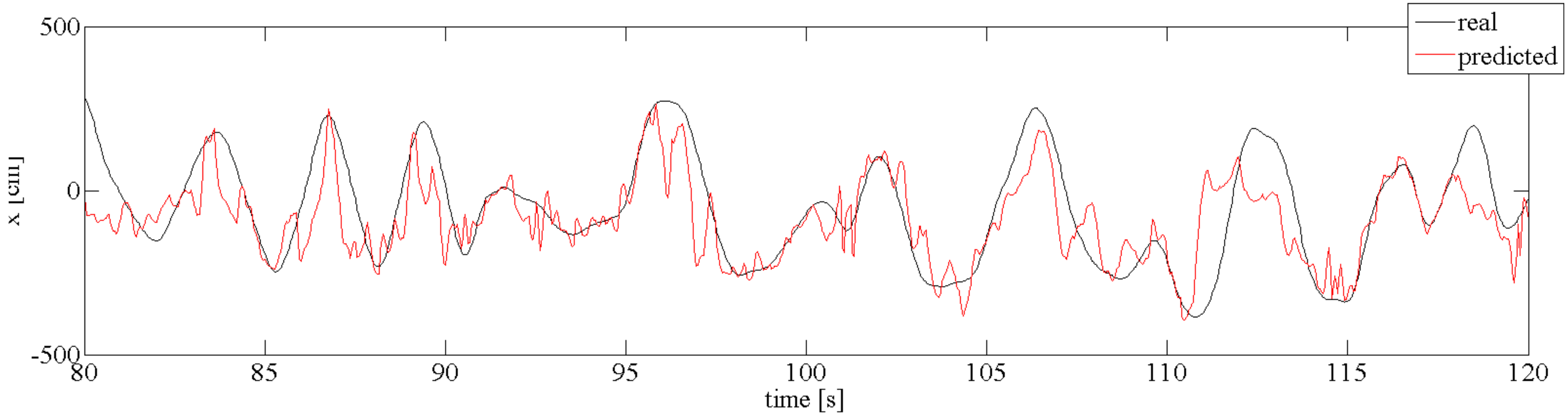
extension by adding 6-DoF arm dynamics

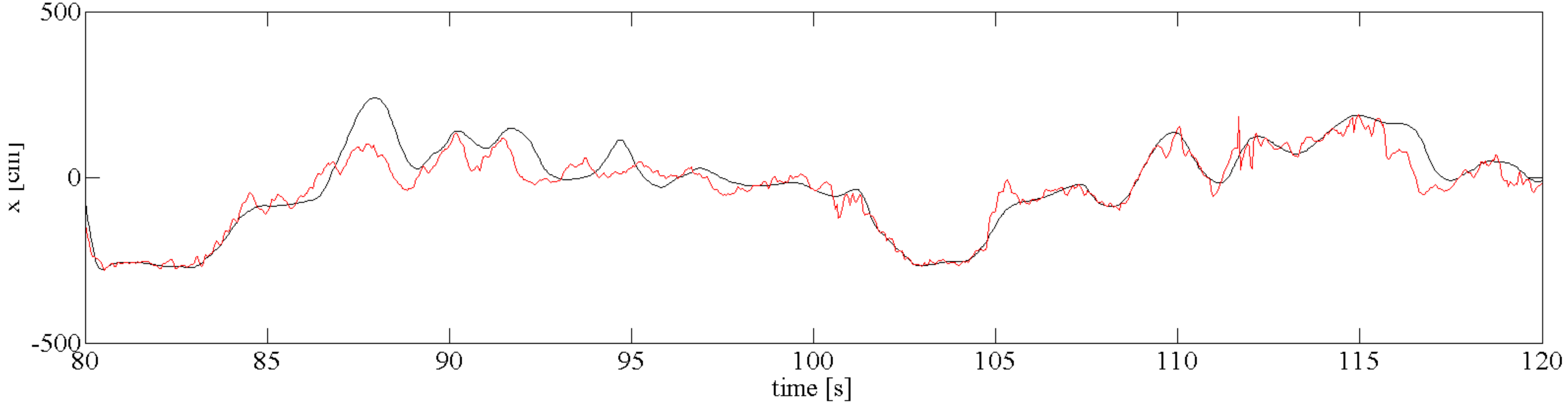


- ☐ emg signal no longer statically related to position or force
- ☐ emg activity related to gravity, commanded impedance, and acceleration
- ☐ we expect increased muscle activity close to target (Burdet *et als*, Nature, 2001: increased stiffness in divergent fields)
- ☐ task-oriented training (TA)



larger and lighter indicates a larger error


real
predicted
500
0
-500
x [cm]
80
85
90
95
100
105
110
115
120
time [s]


500
0
-500
x [cm]
80
85
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105
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120
time [s]

high-precision EMG

hand emg:

☐ static finger forces
☐ limited accuracy (~10%), but this is not evident
☐ qualitative visual feedback solves limited accuracy

arm emg:

increase emg complexity to dynamic arm control

limited accuracy (~5%) is eminent (high accuracy is required)

qualitative feedback required!

how can we improve the accuracy of the system?

☐ remove “static” emg signal related to gravity by using blind source separation

☐ improve the accuracy by introducing *acceleration-based* control out of the remaining emg signal

☐ applicability to robotic rehabilitation

Vogel et al, IROS, 2011