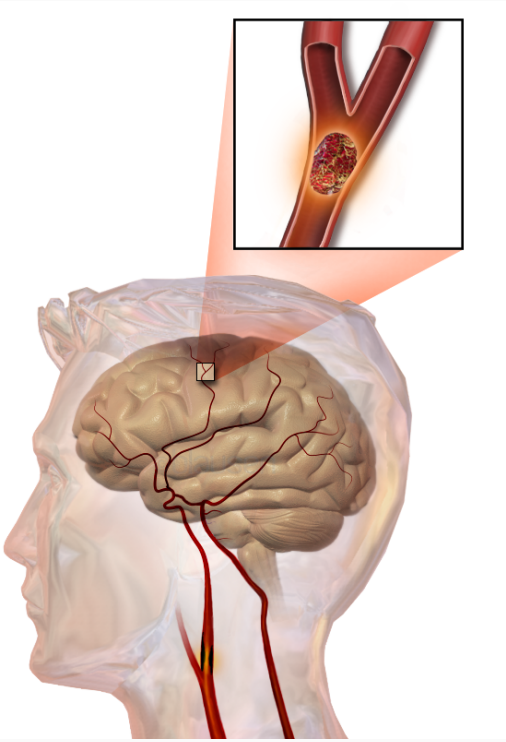
Rehabilitation using robotic arms

BETER REHAB & TRUE REHAB

09 April 2021

Universitatea Tehnica din Cluj-Napoca
Robotics and Nonlinear Control

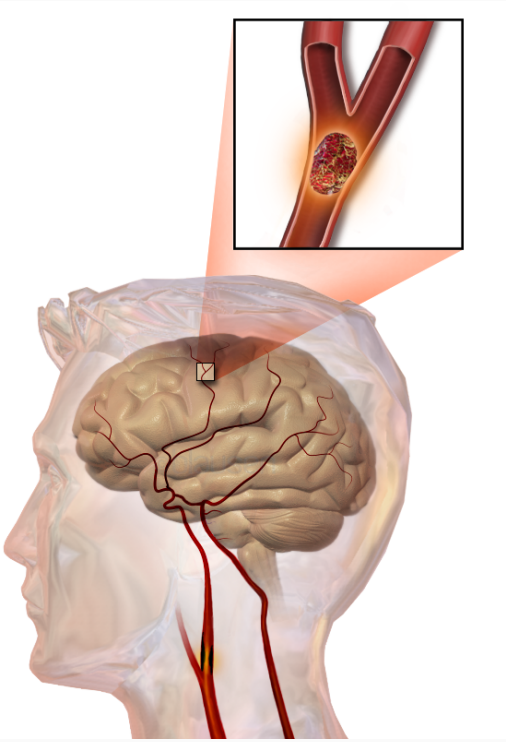
The need for rehabilitation



By Blausen Medical Communications, Inc.

- Strokes are a leading cause of disability [Glo]

The need for rehabilitation



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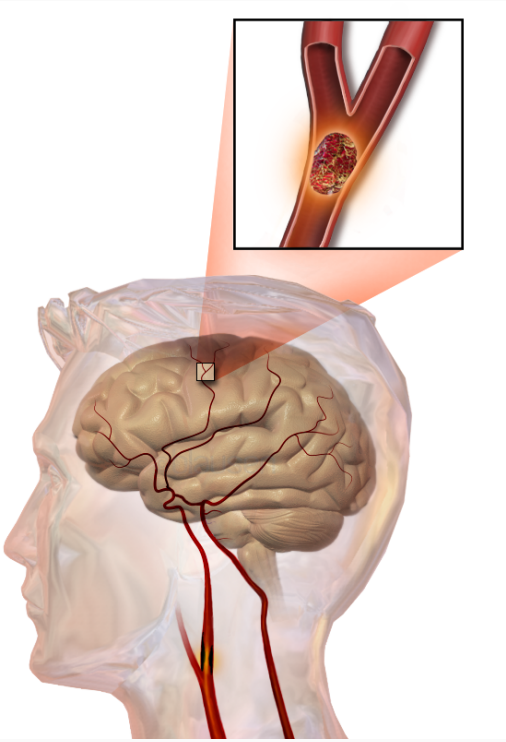

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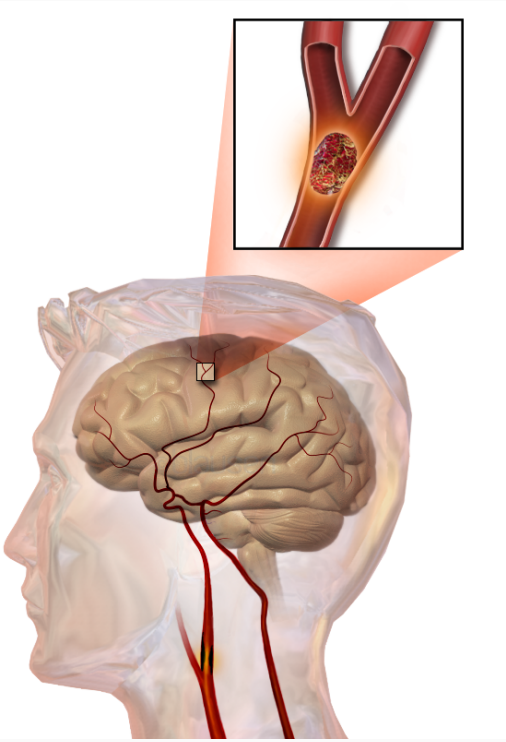

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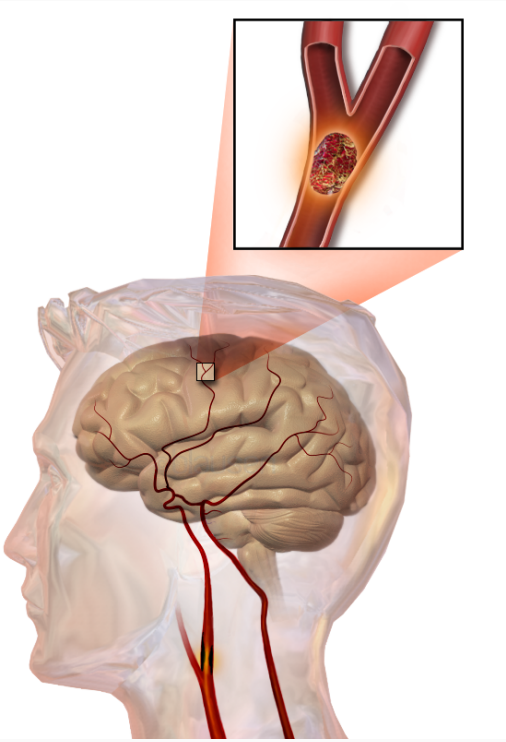

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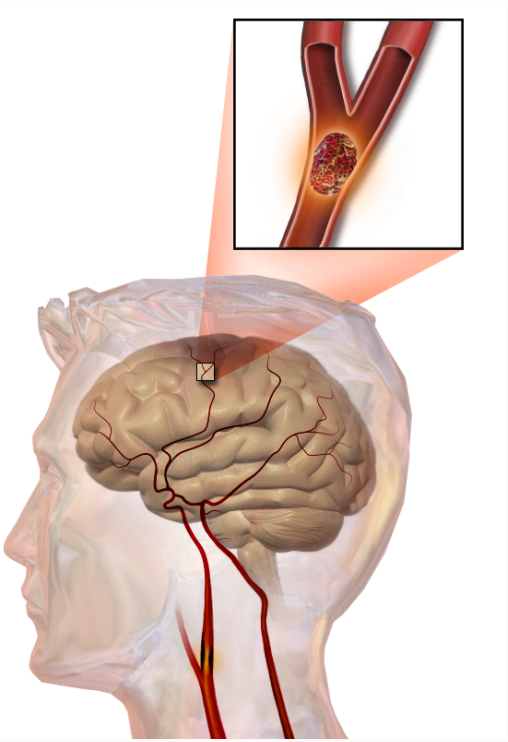

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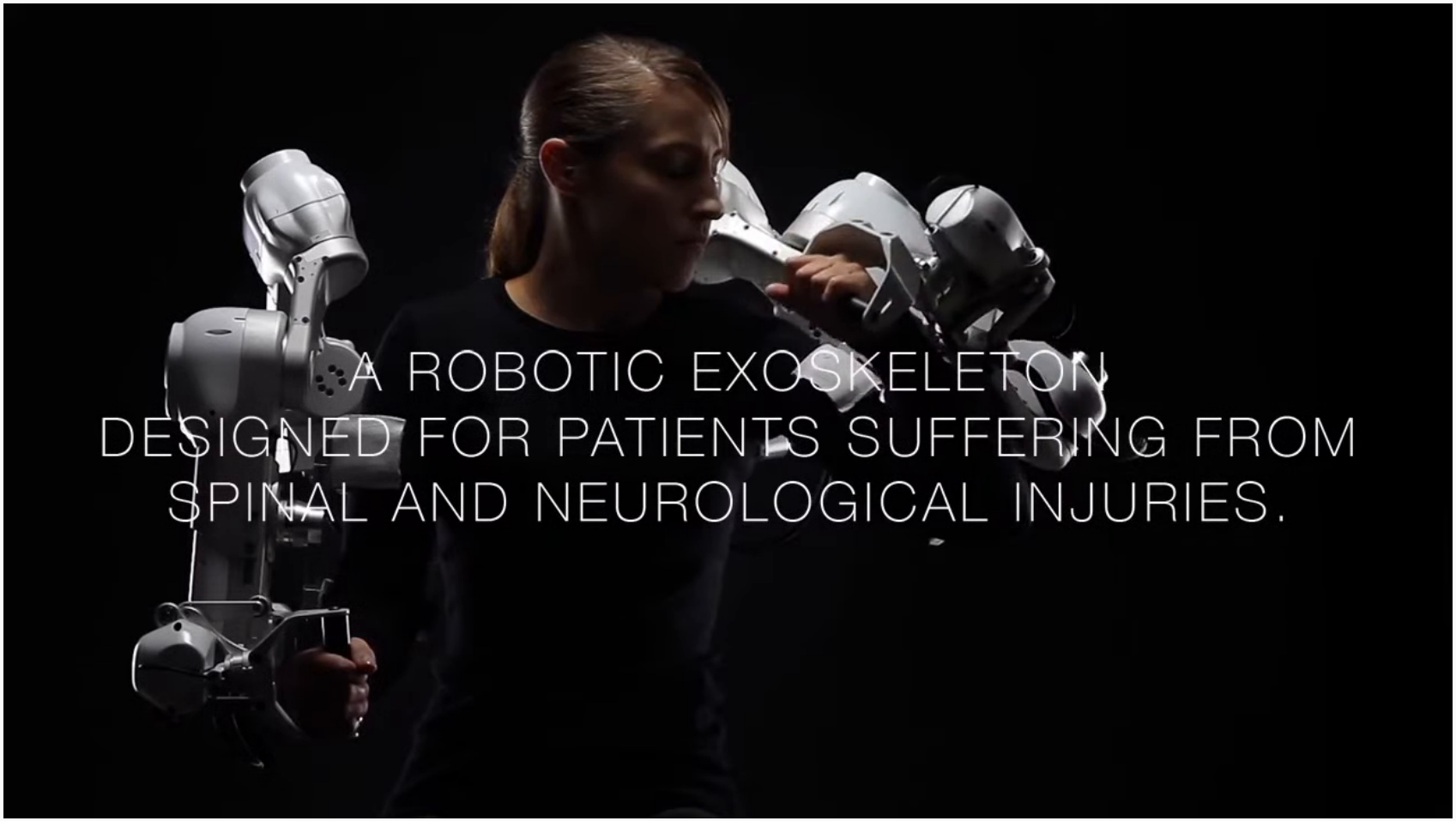
- Impact on quality of life of **physiotherapists**

Rehabilitation::Traditional rehabilitation

Robotic rehabilitation::Exoskeletons



Harmony: Upper-limb Exoskeleton for Stroke Rehabilitation

Robotic rehabilitation::Exoskeletons

- Very complex mechanics

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- Long development times

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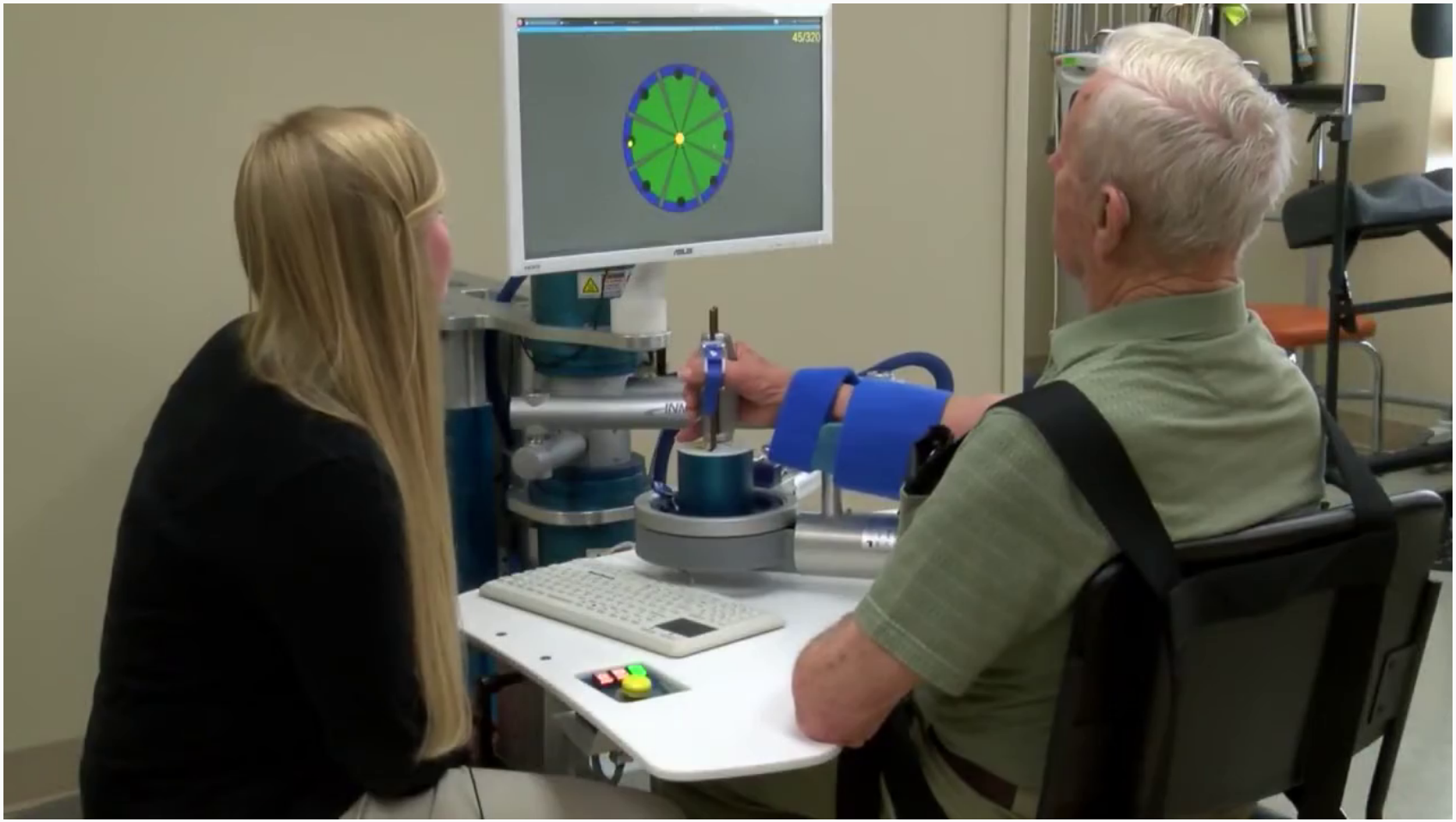
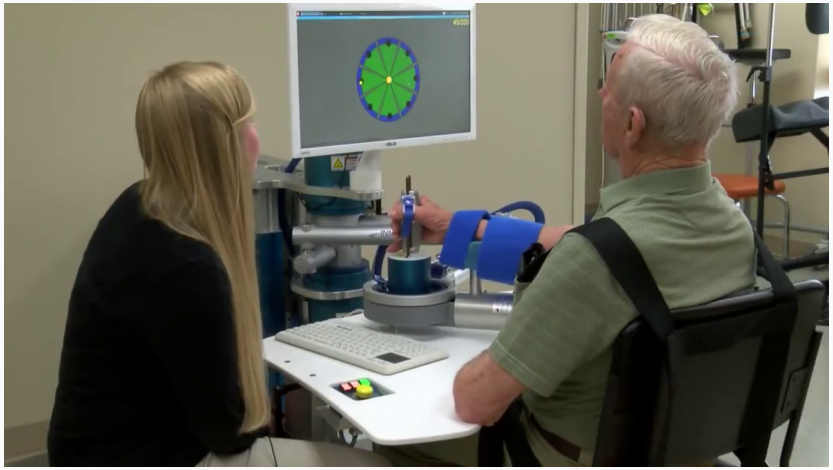
- Long attachment/detachment times (dead time)

Robotic rehabilitation::End-effectors



InMotion Robot

Robotic rehabilitation::End-effectors



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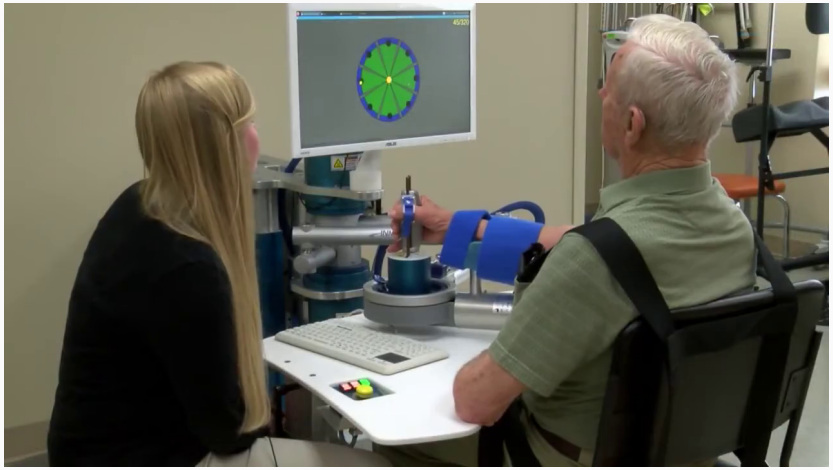
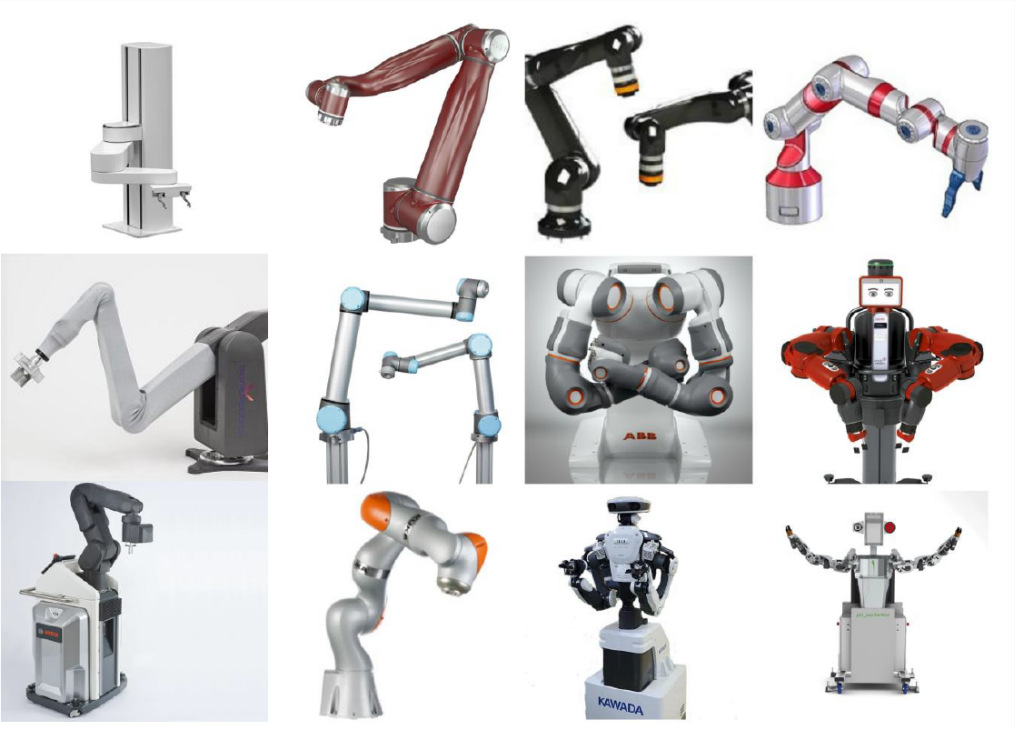


- Very specific types of motion

Robotic rehabilitation::Collaborative robotic arms



- Lower development costs

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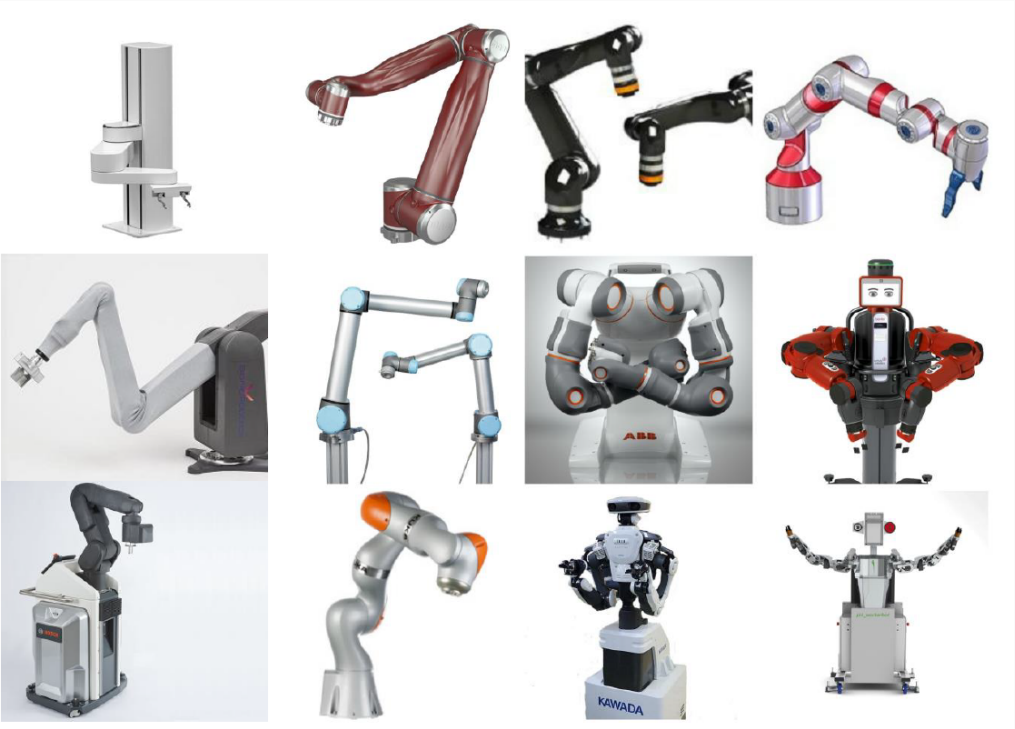

- Lower development costs
- Much faster attachment

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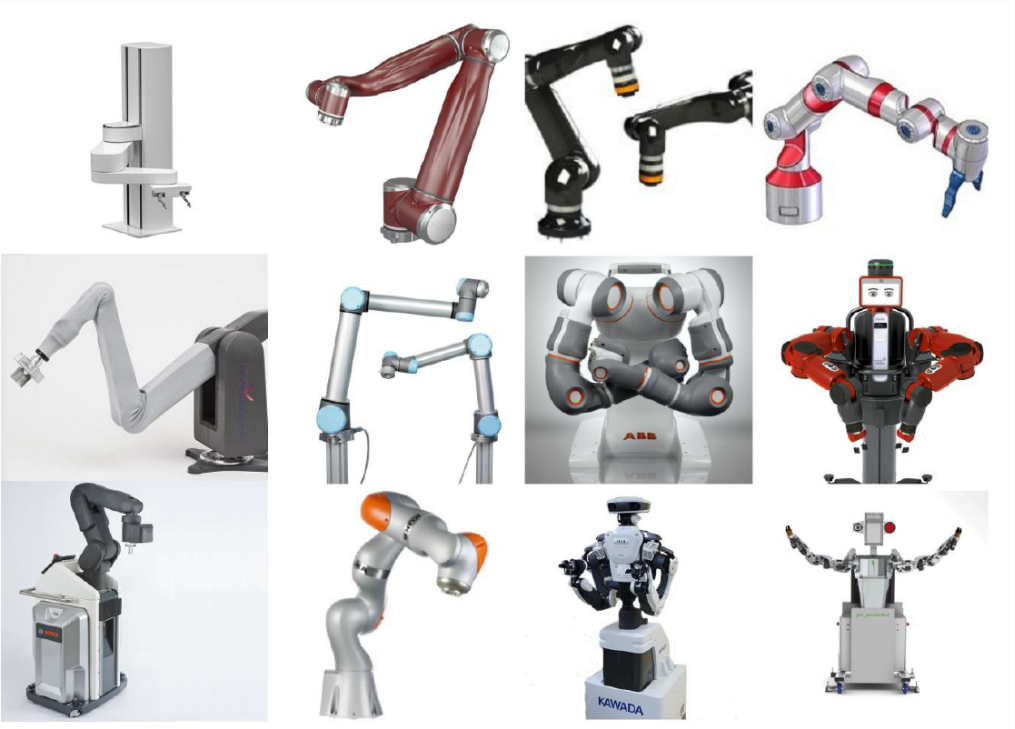

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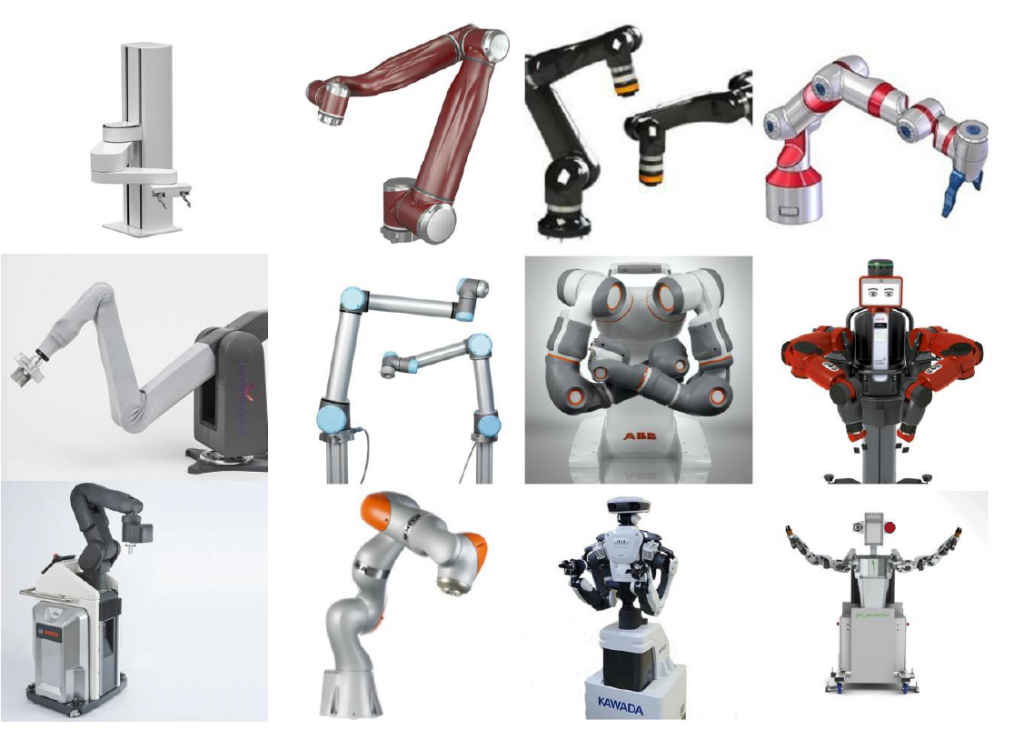

- Lower development costs
- Much faster attachment
- Patient specific
- Safe

Disadvantage
More complex control is necessary

Robotic rehabilitation

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- Goal of BETER REHAB project: assist patient along intented trajectory
- Goal of TRUE REHAB project: patient along muscle optimized trajectory [Caiozzo et al.]

Talk Overview

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- Intention of motion

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- Muscle force quantification

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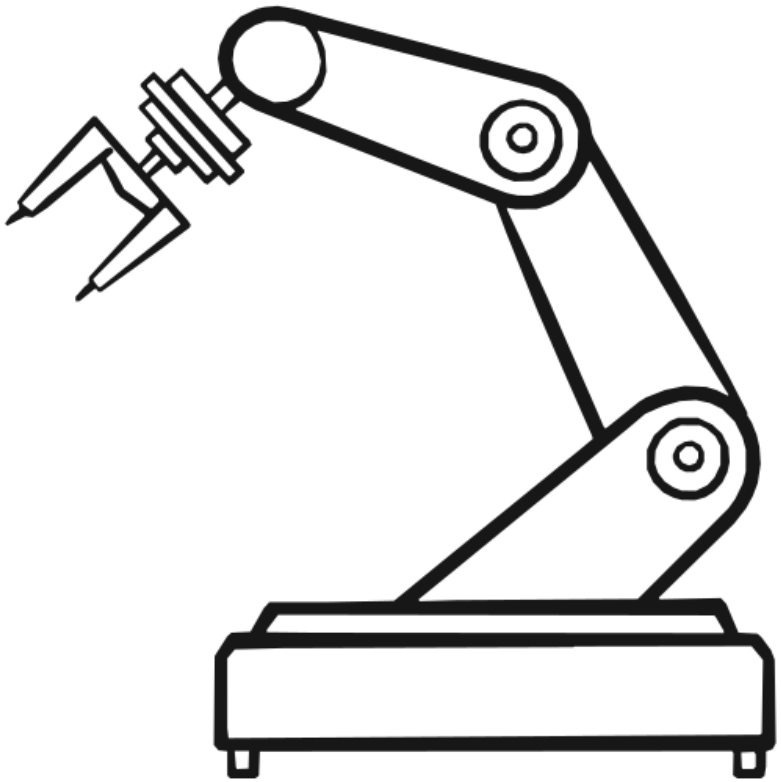
- Robot control

Intention of motion

Intention of motion::How?



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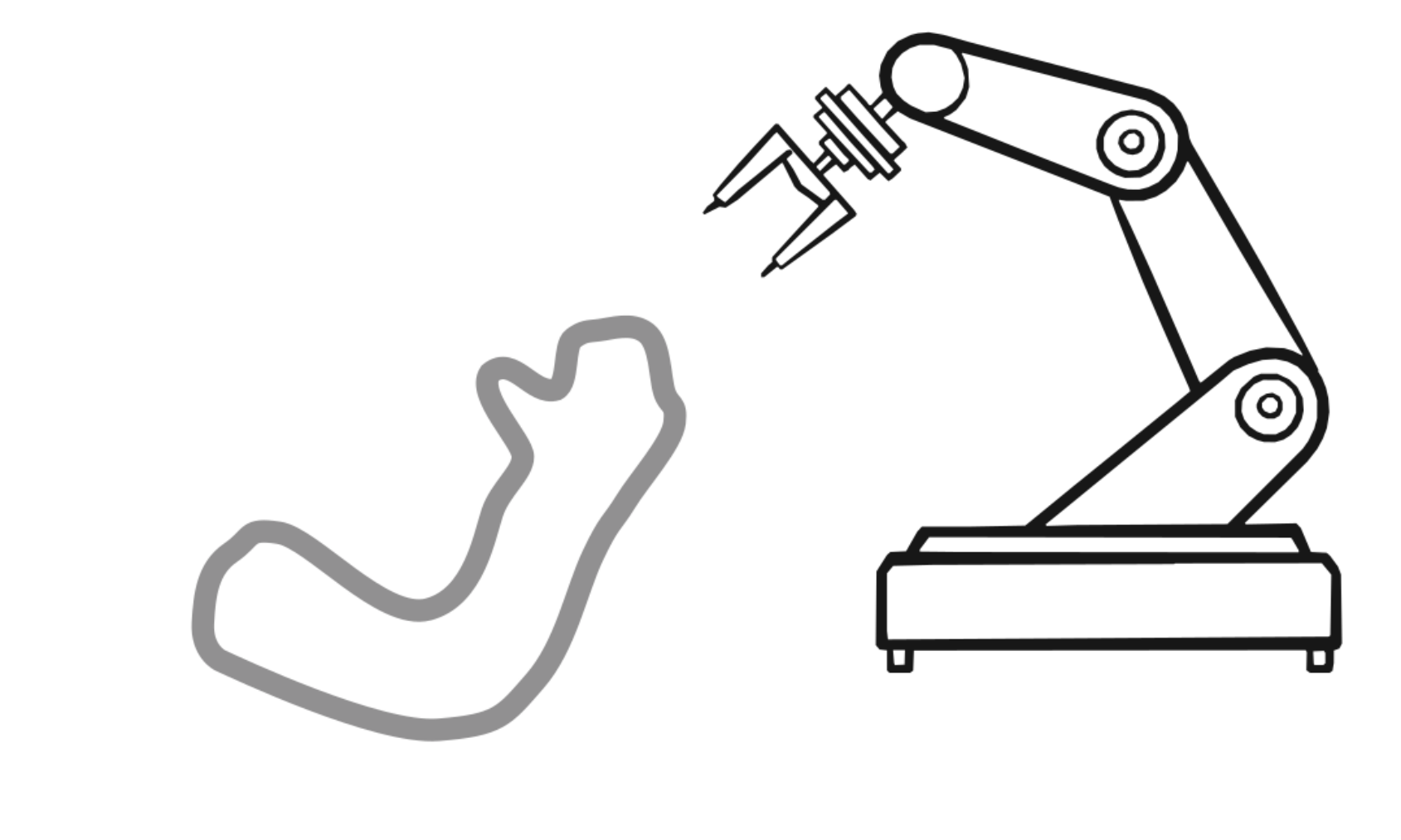

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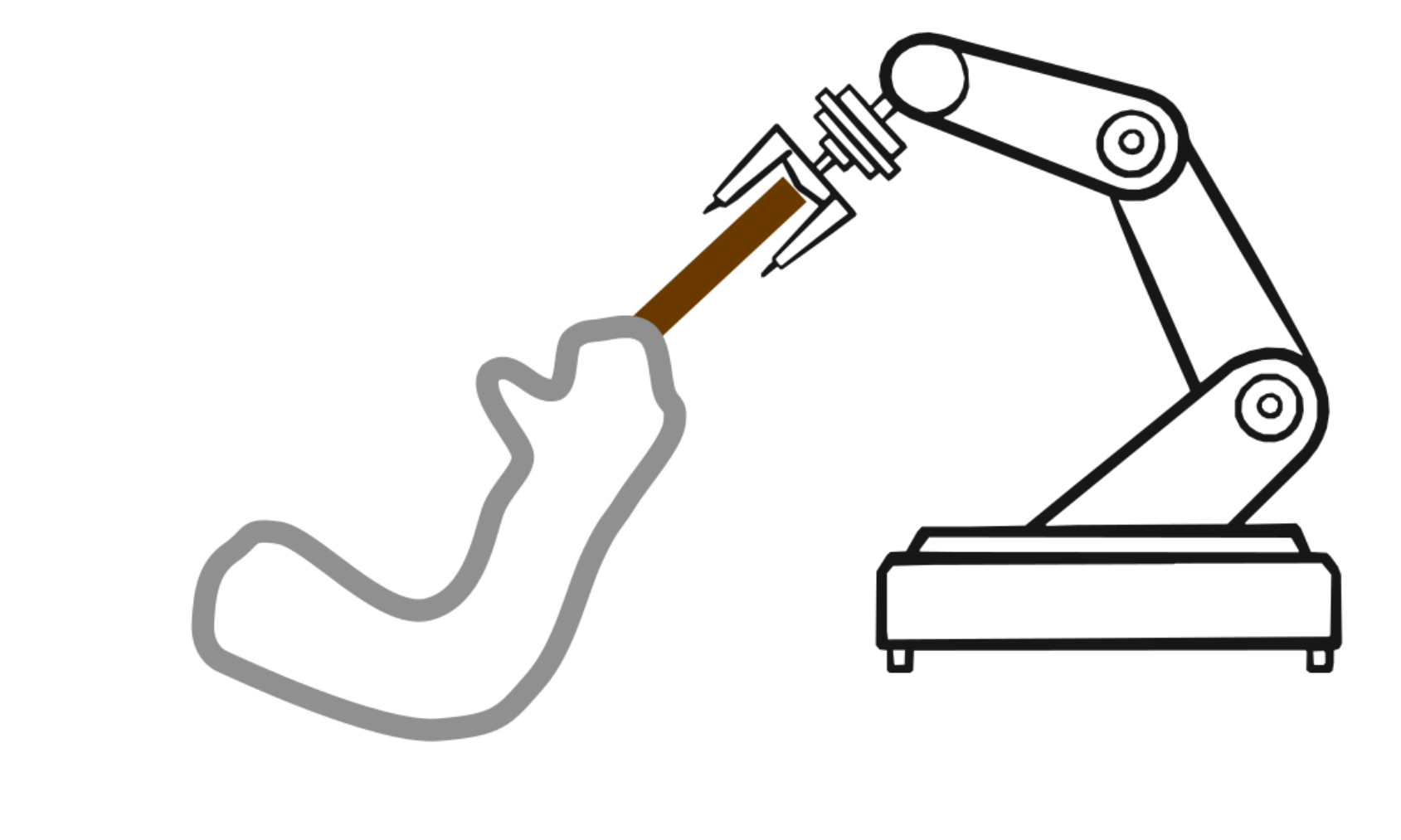

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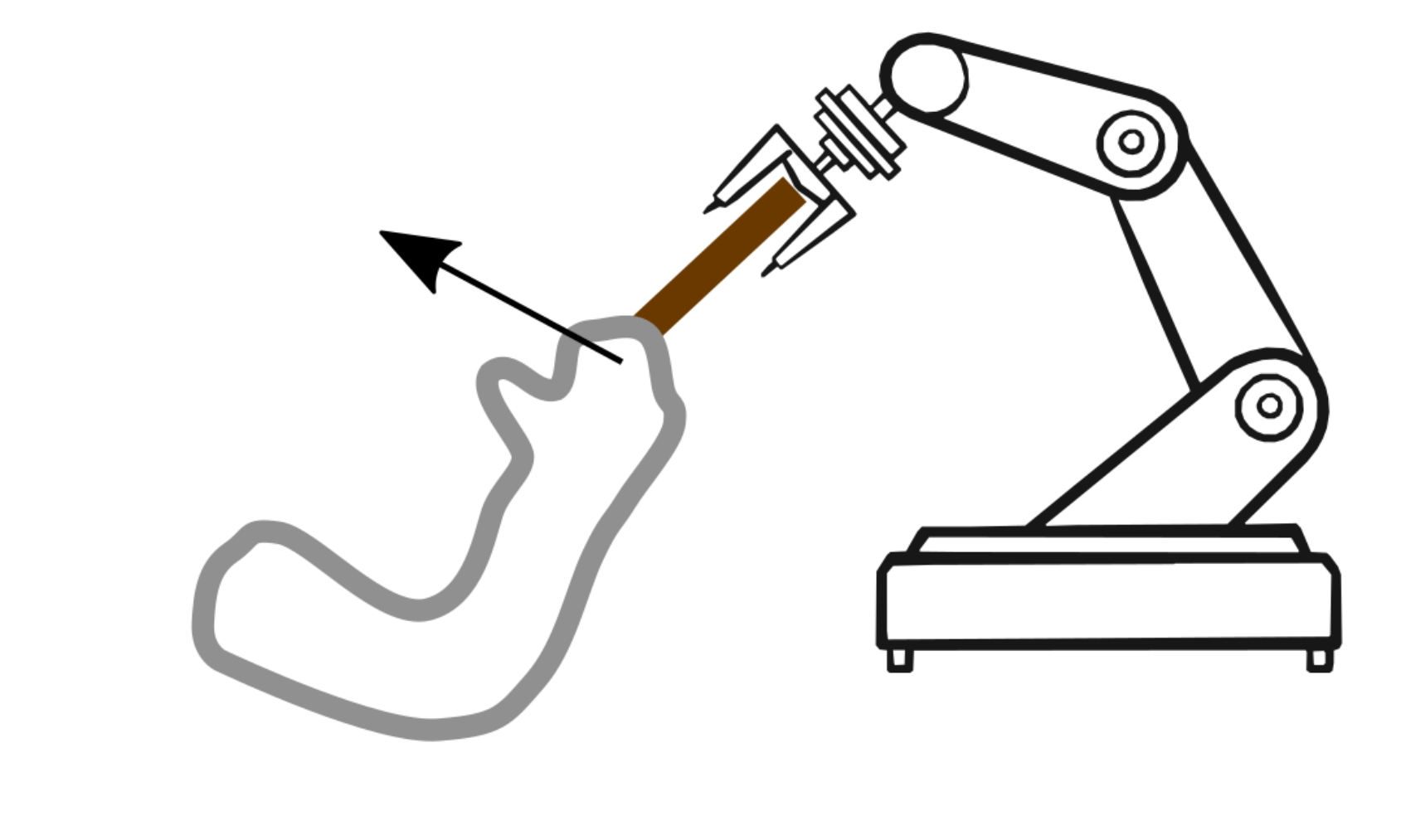

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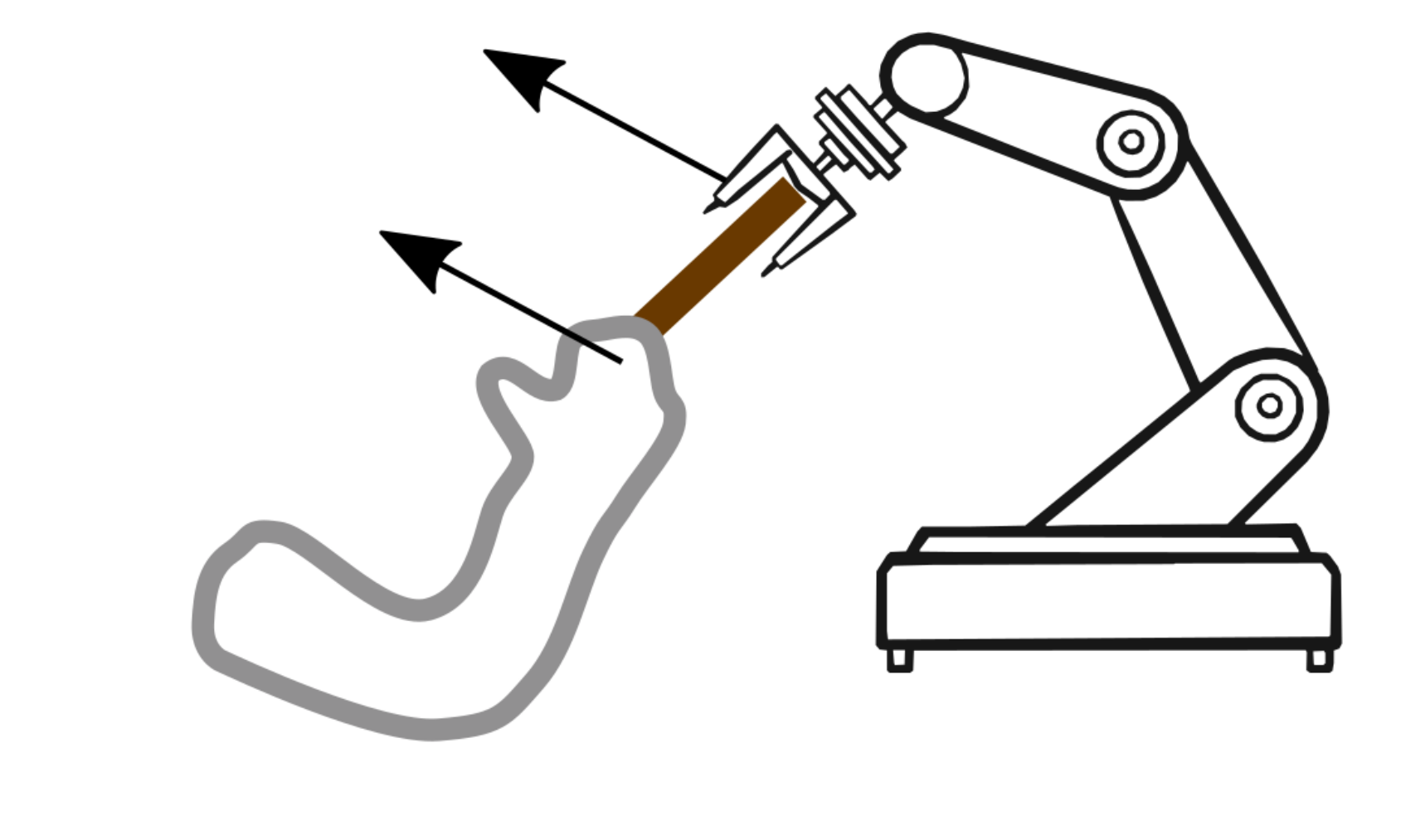

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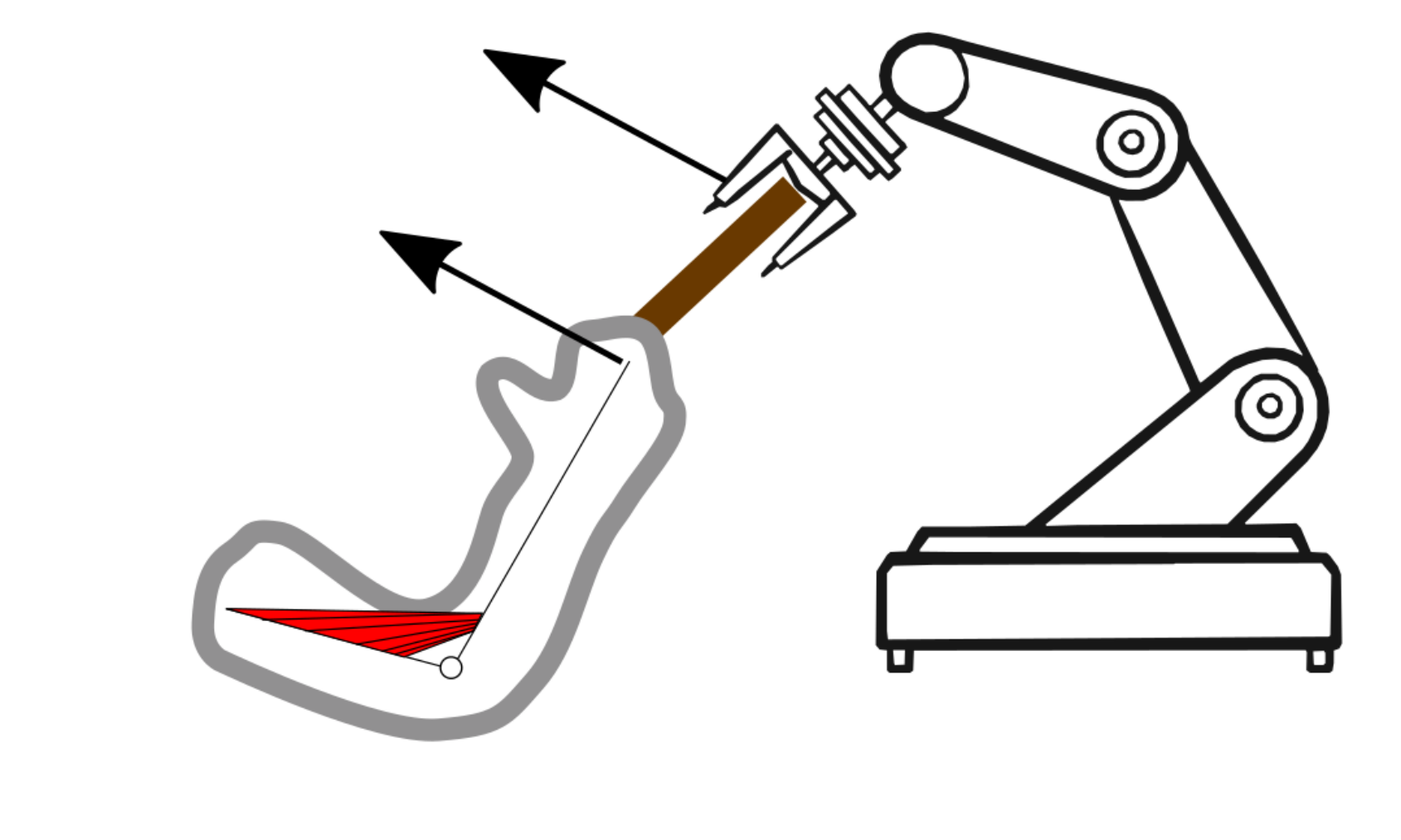

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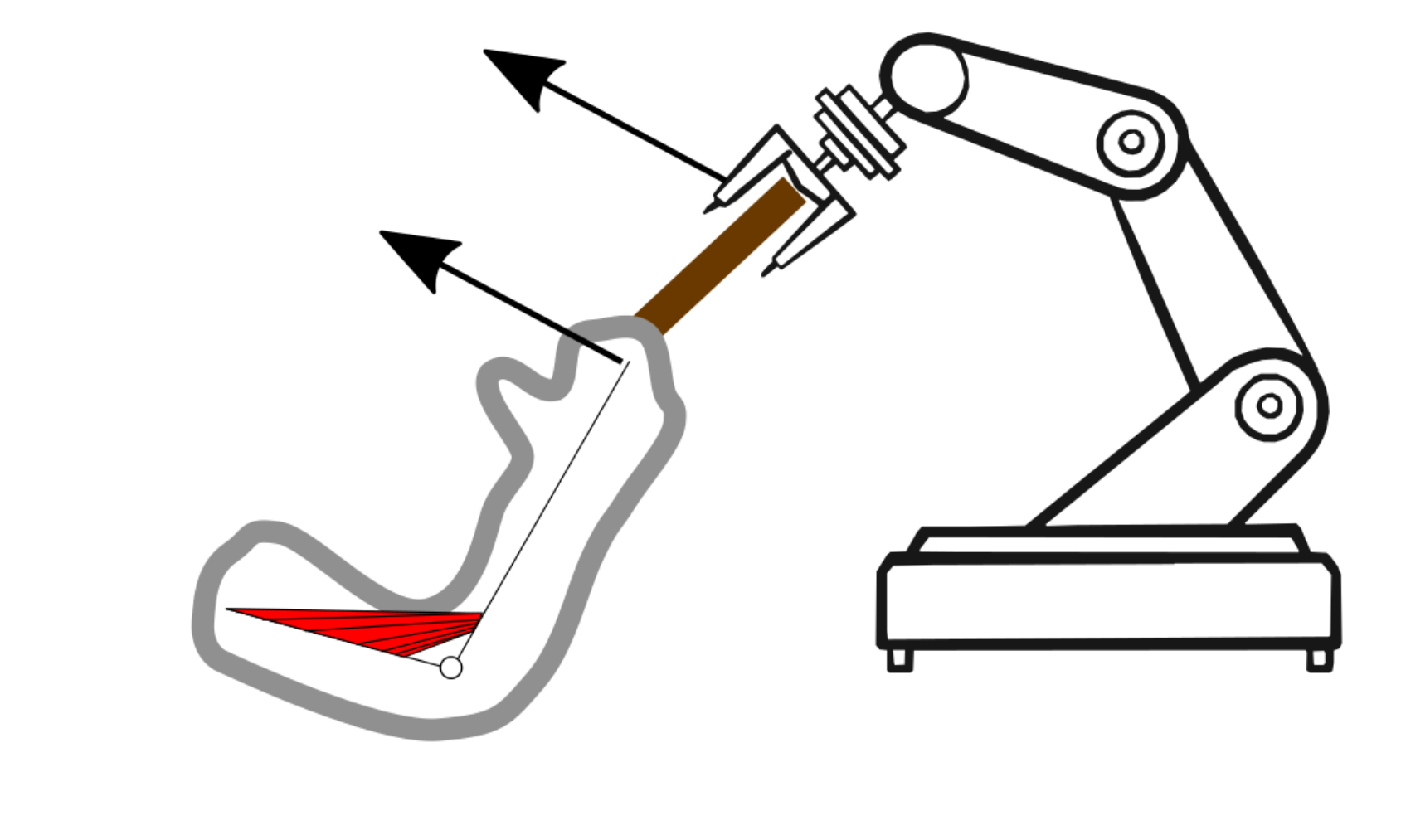
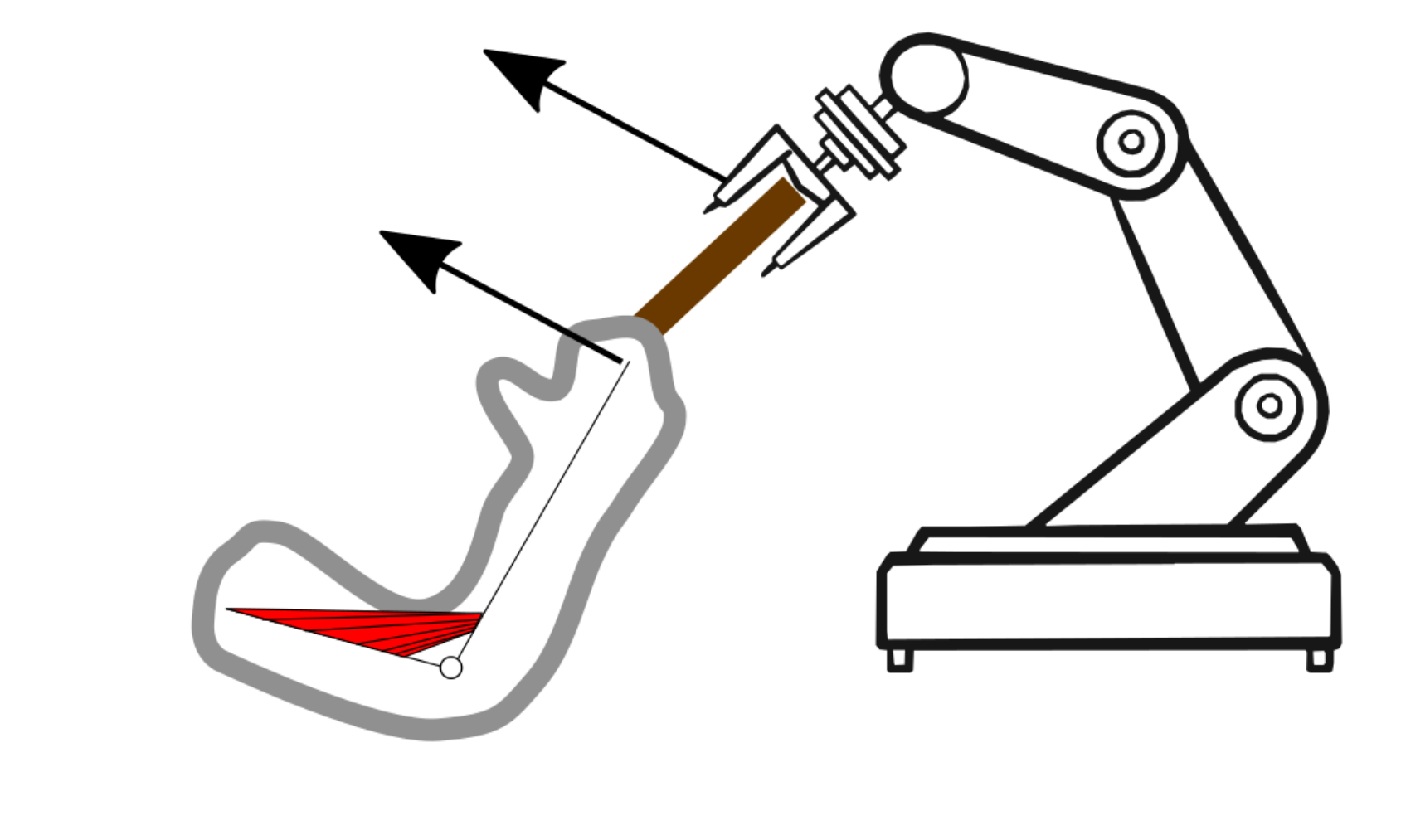


EMG can help us predict the intention of a person

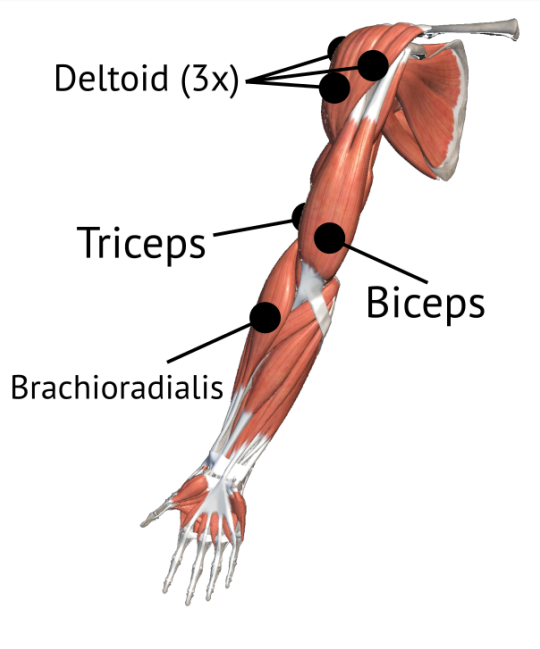
Intention of motion::How?



EMG can help us predict the intention of a person

The robot can then assist in the right direction by the desired amount

Intention of motion::Measurements



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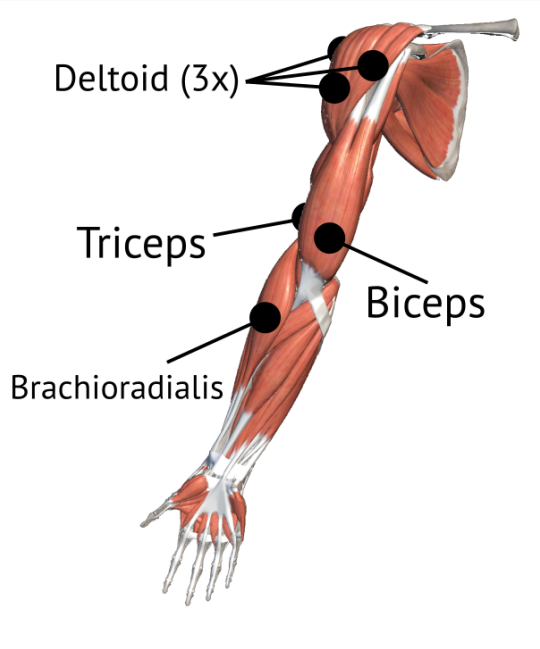

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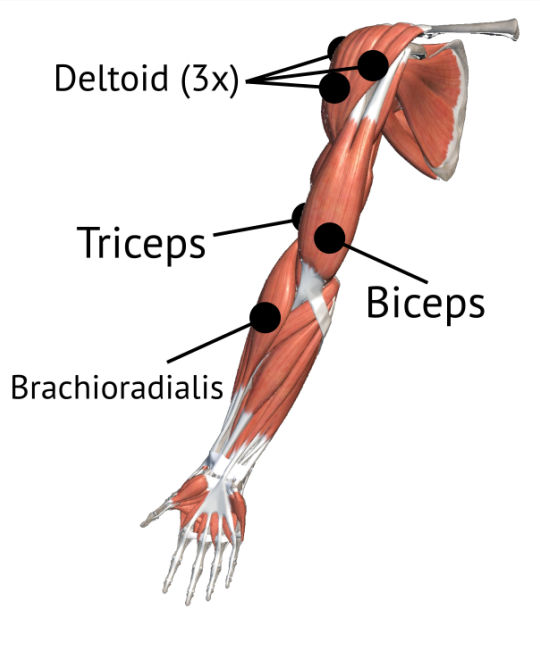

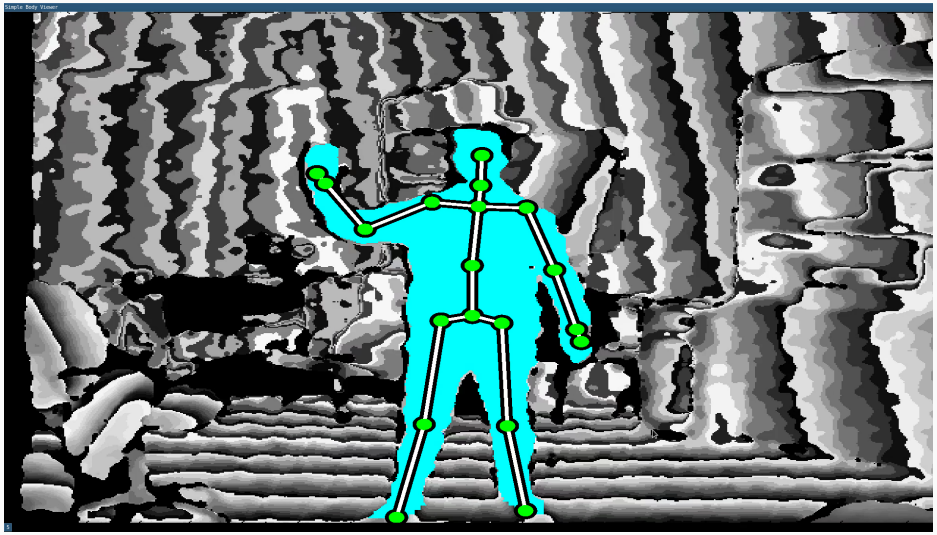

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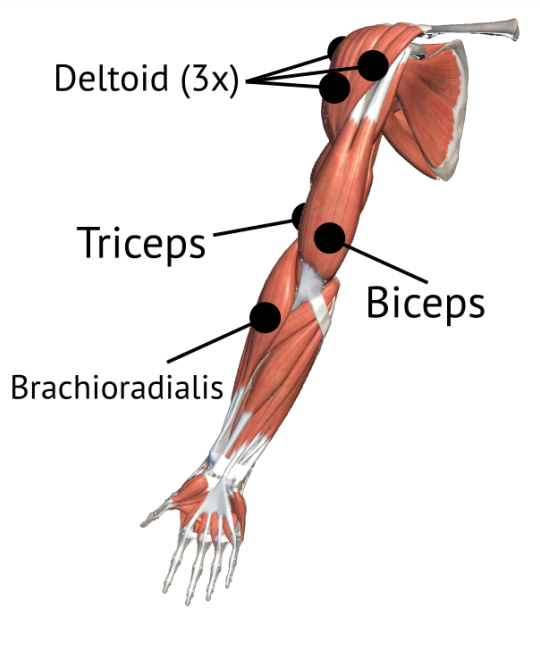

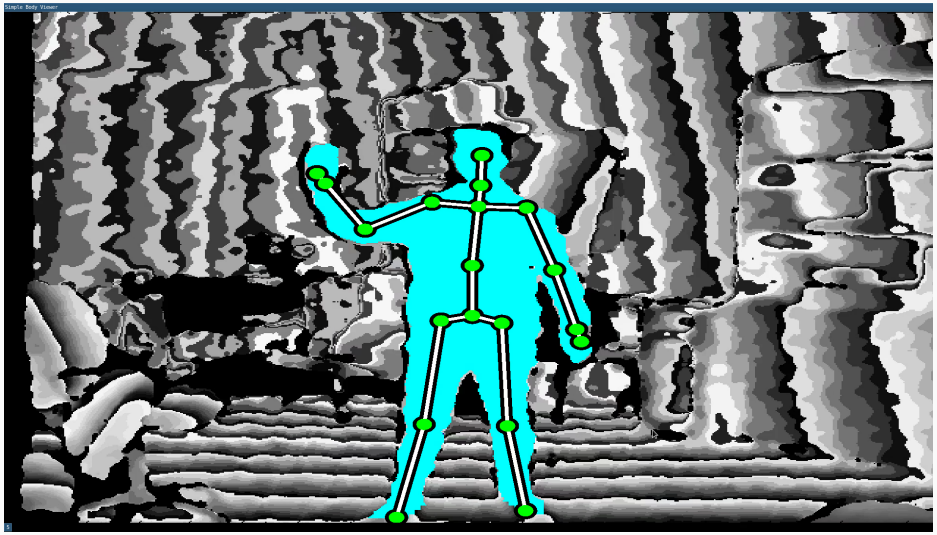

Intention of motion::Measurements

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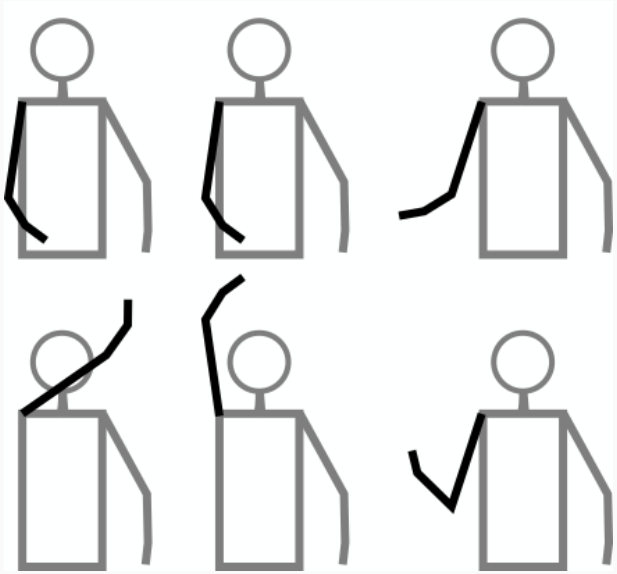
  (Arm raise, Arm cross, Elbow flexion)



Intention of motion::Measurements

- 5 volunteers (4 male, 1 female)
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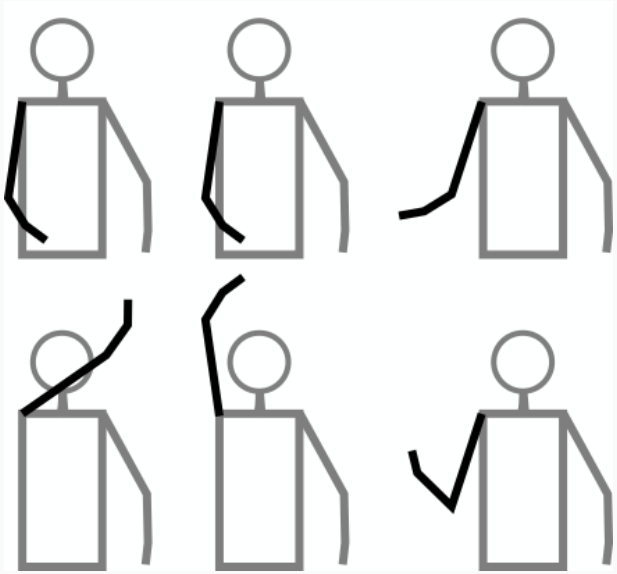
- 10 repetitions



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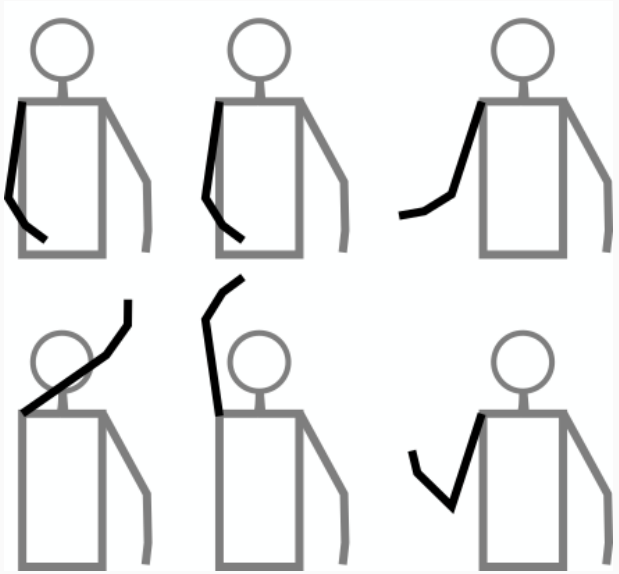

Intention of motion::Measurements

- 5 volunteers (4 male, 1 female)
- 3 types of motion
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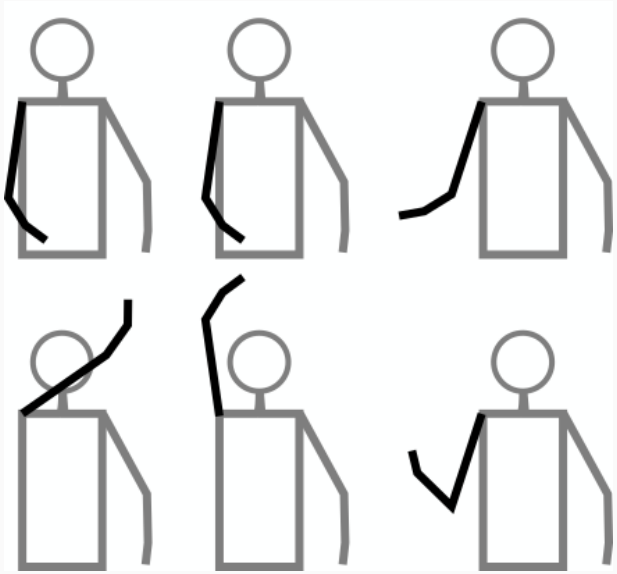
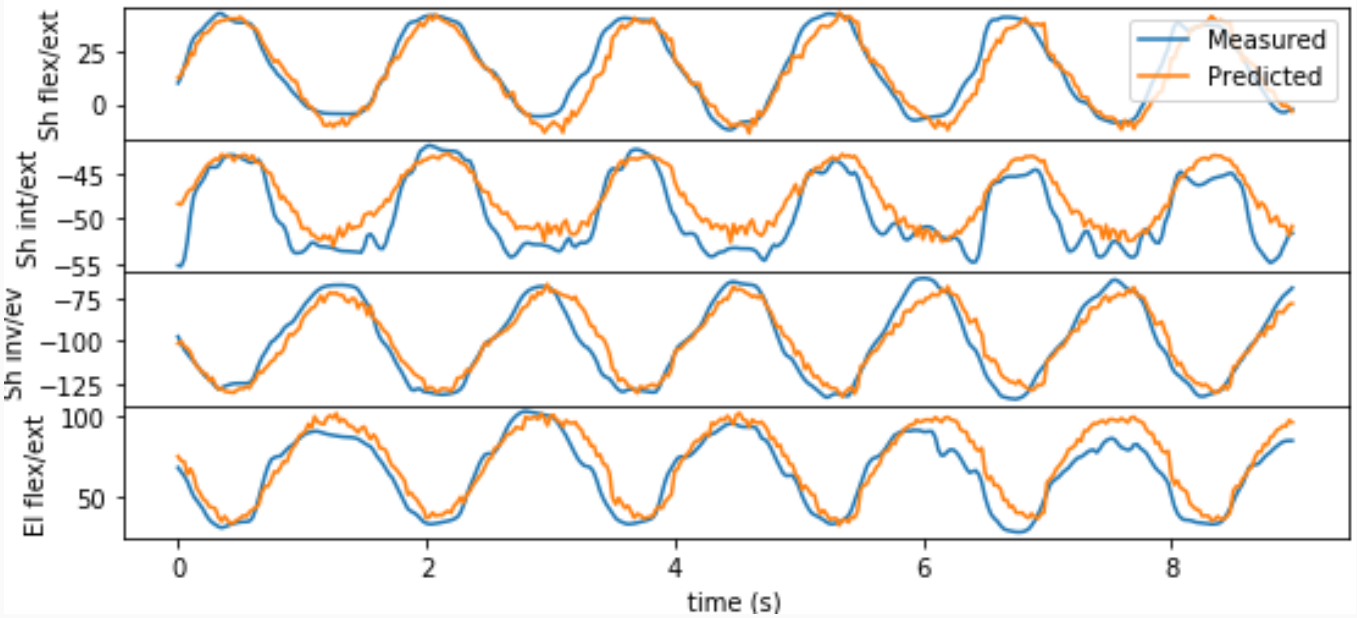
- 10 repetitions
- 3 trials
- LSTM network



Intention of motion::Prediction



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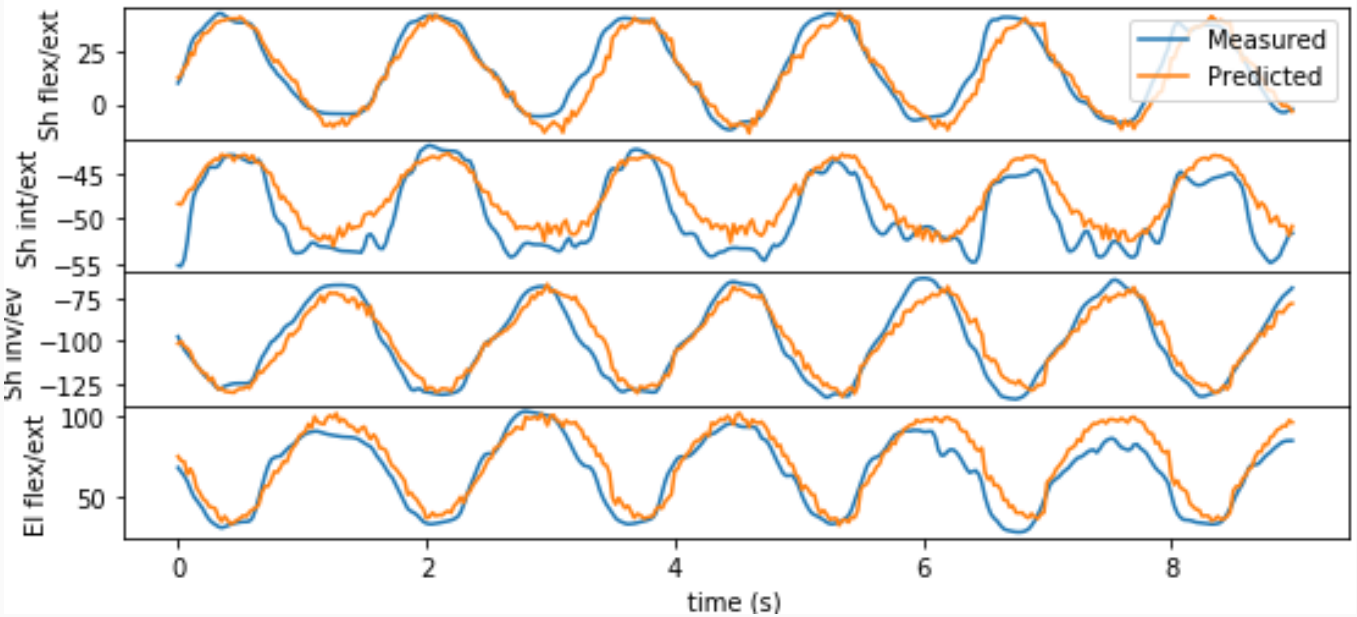
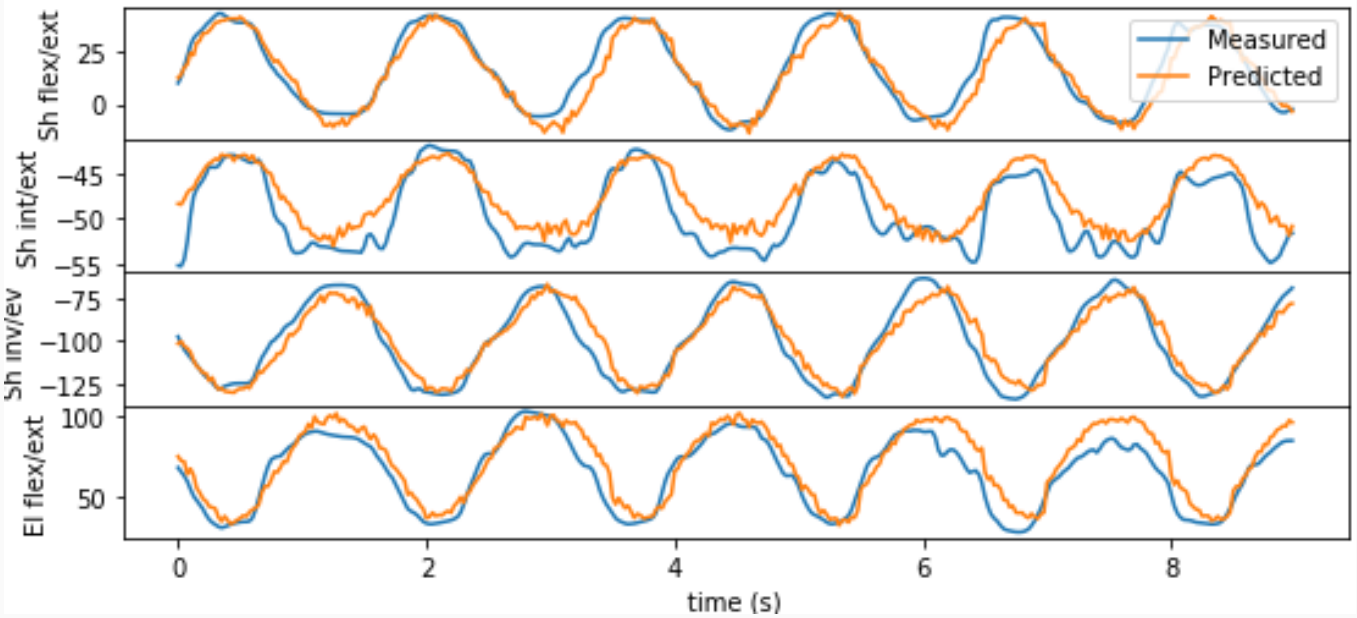


Prediction is real-time!

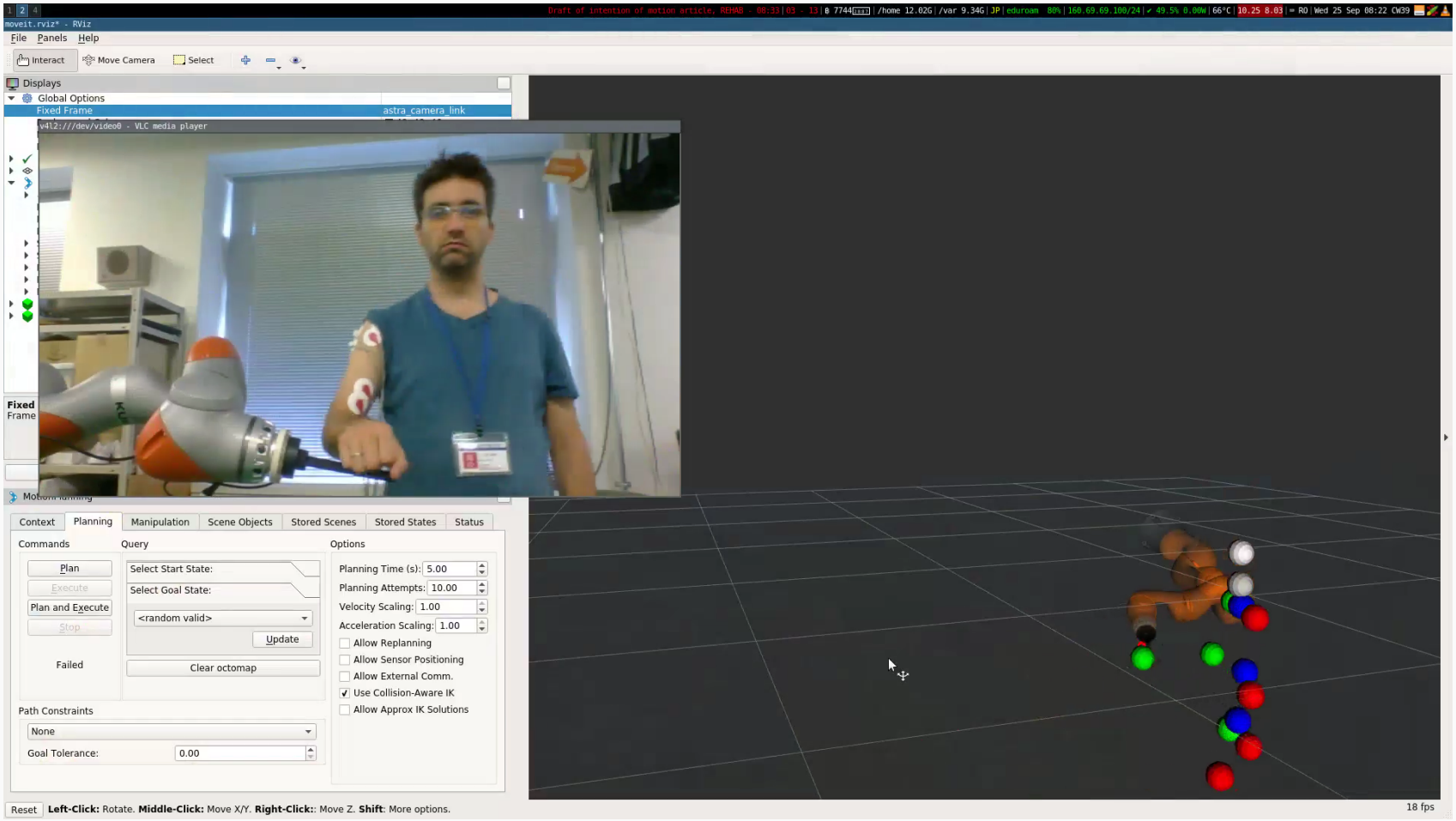
Intention of motion::Prediction



Prediction is real-time!

Prior measurements are necessary (person specific model)

Intention of motion::Prediction

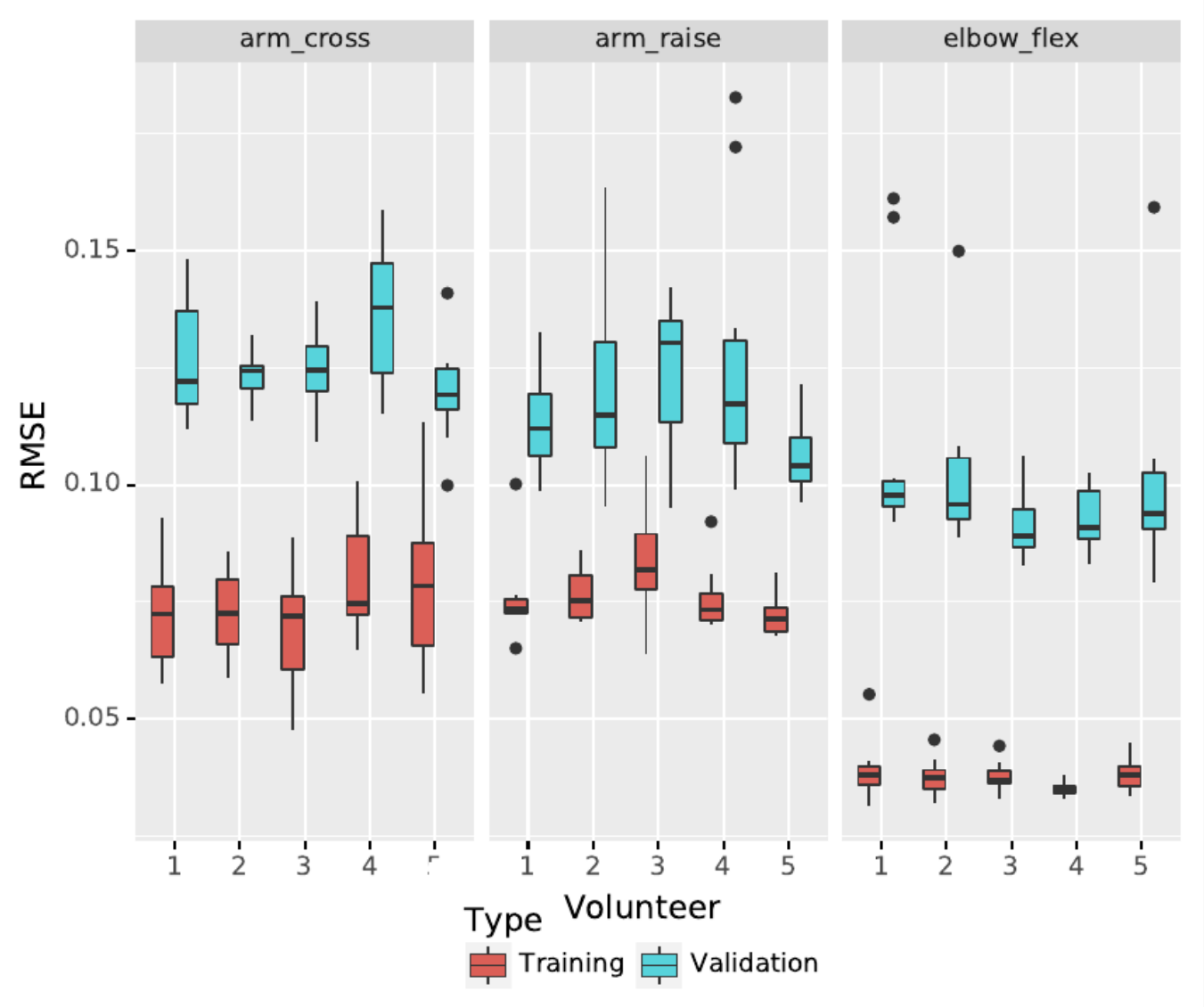


Intention of motion::Generic Prediction

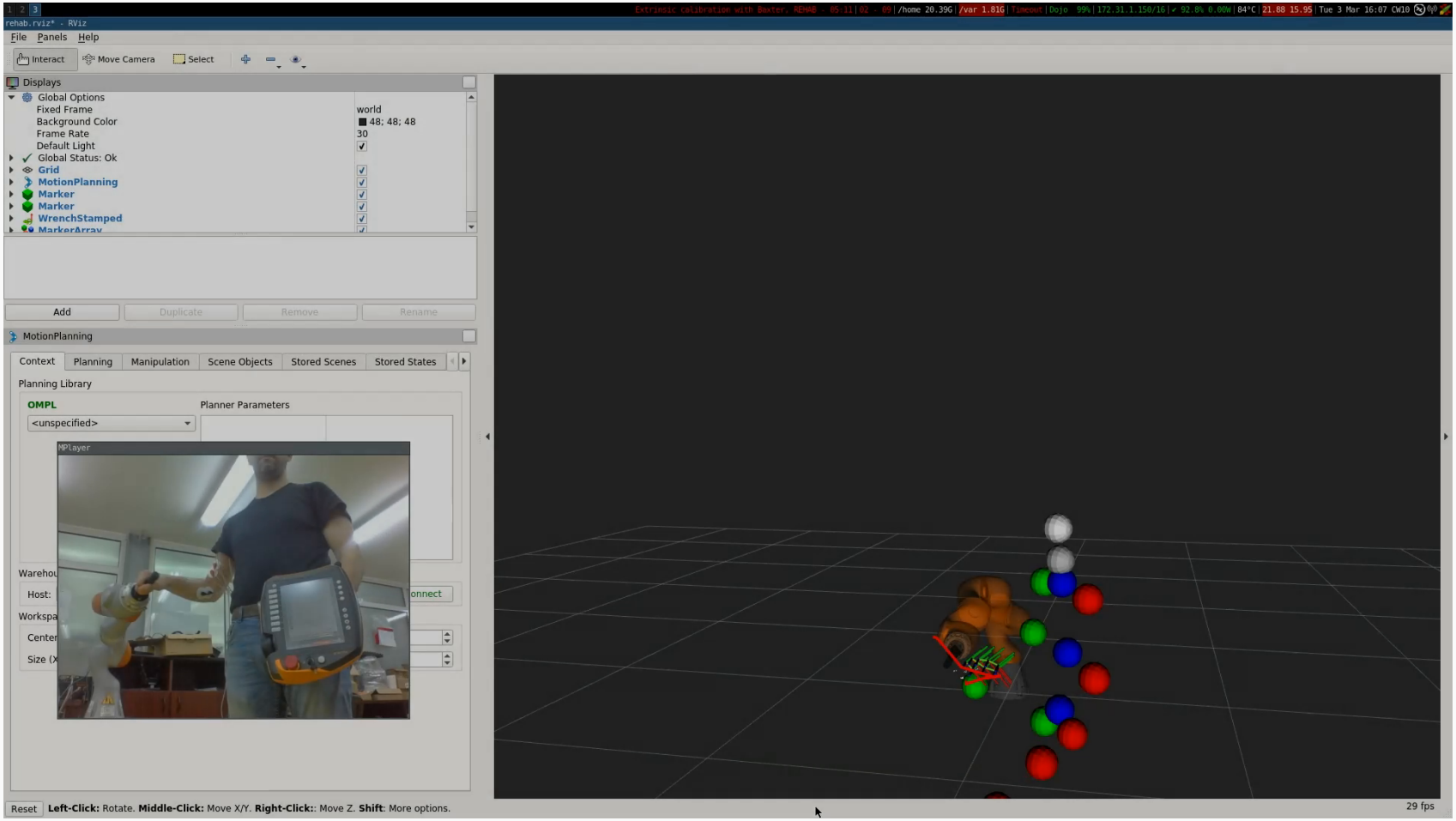
Leave-one-out training

Intention of motion::Generic Prediction

Leave-one-out training



Intention of motion::Experimental validation



Experimental validation

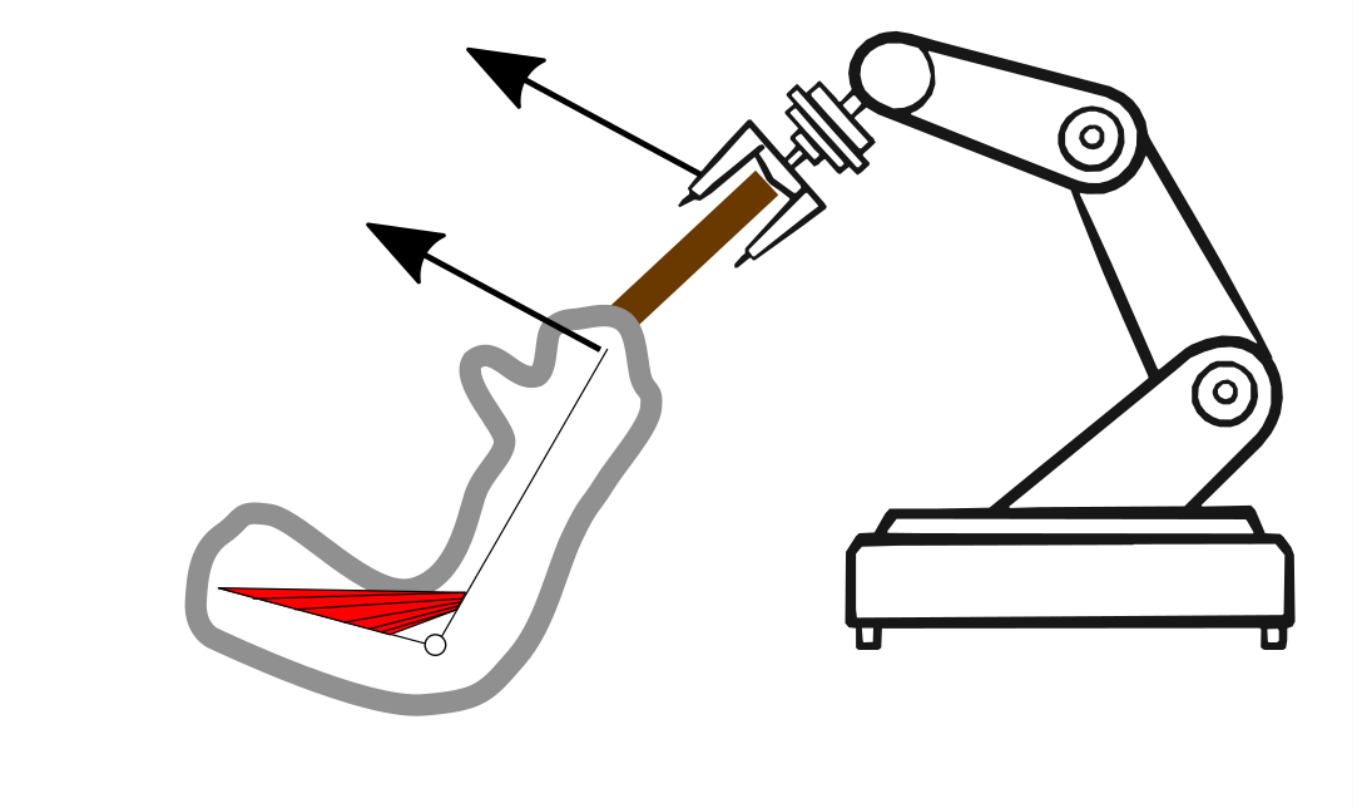
Quantifying the human-robot force interaction

Intention of motion::Experimental validation

Comparing angle between intention and force

Intention of motion::Experimental validation

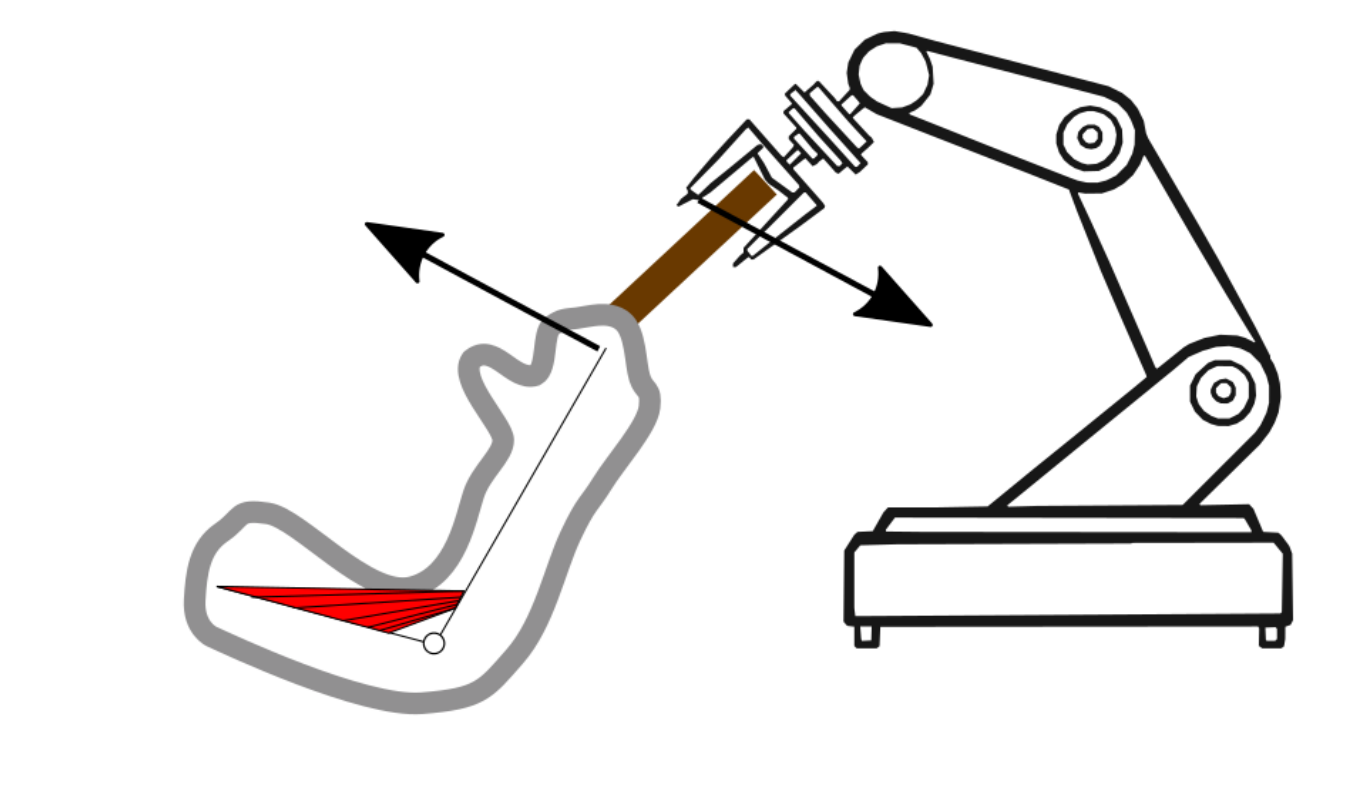
Comparing angle between intention and force



Passive motion

Intention of motion::Experimental validation

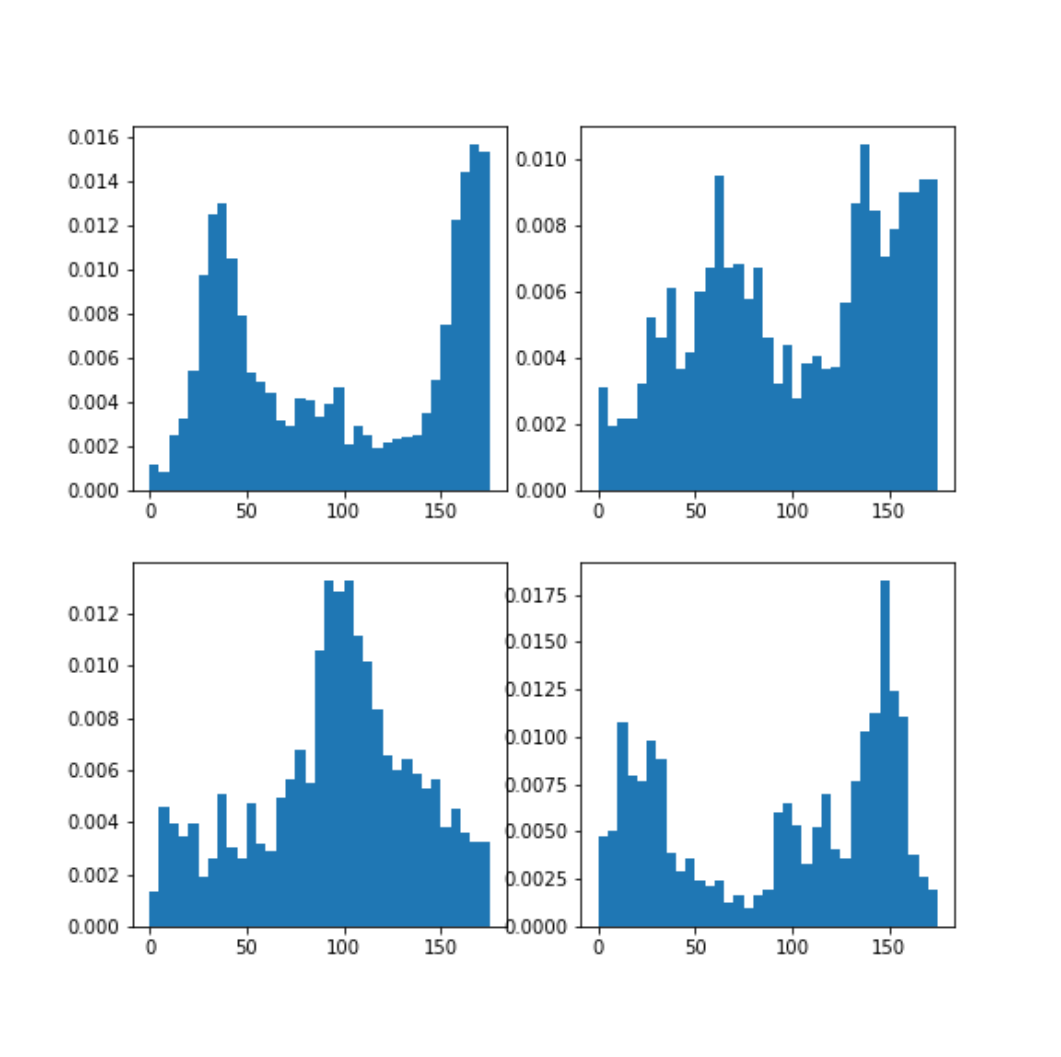
Comparing angle between intention and force



Active motion -> Assistance!

Intention of motion::Experimental validation

Comparing angle between intention and force



Muscle forces optimization

Operation principle

Calculate trajectories for maximizing/minimizing force production of specific muscle forces

Operation principle

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Then provide assistance along the path

Rehabilitation::Muscle forces optimization

Operation principle

Calculate trajectories for maximizing/minimizing force production of specific muscle forces

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- Increase effeciency of rehabilitation

Operation principle

Calculate trajectories for maximizing/minimizing force production of specific muscle forces

Then provide assistance along the path

- Increase effeciency of rehabilitation
- Train specific muscles

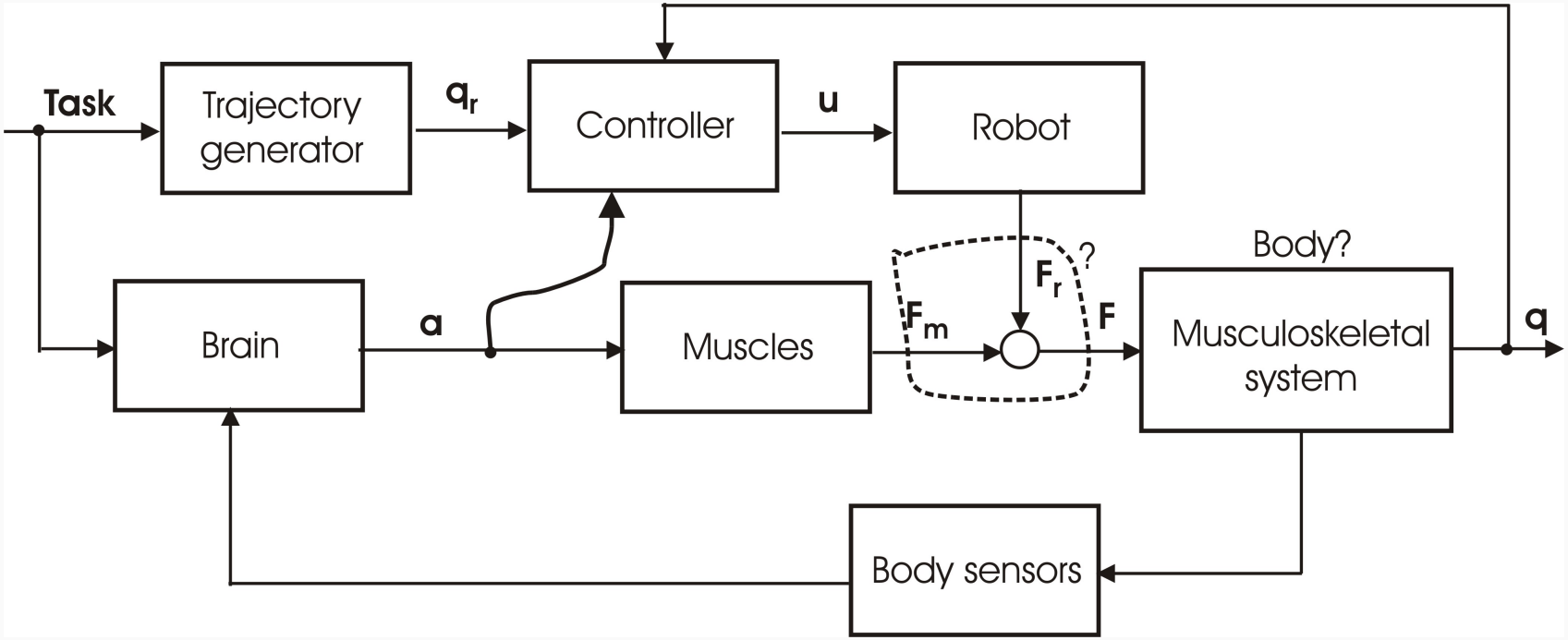
Operation principle

Calculate trajectories for maximizing/minimizing force production of specific muscle forces

Then provide assistance along the path

- Increase effeciency of rehabilitation
- Train specific muscles
- Minimize load on sensitive areas (e.g. surgery)

Rehabilitation::Muscle forces optimization



Muscle forces::Estimation

Muscle activation (EMG) and force relationship is not known

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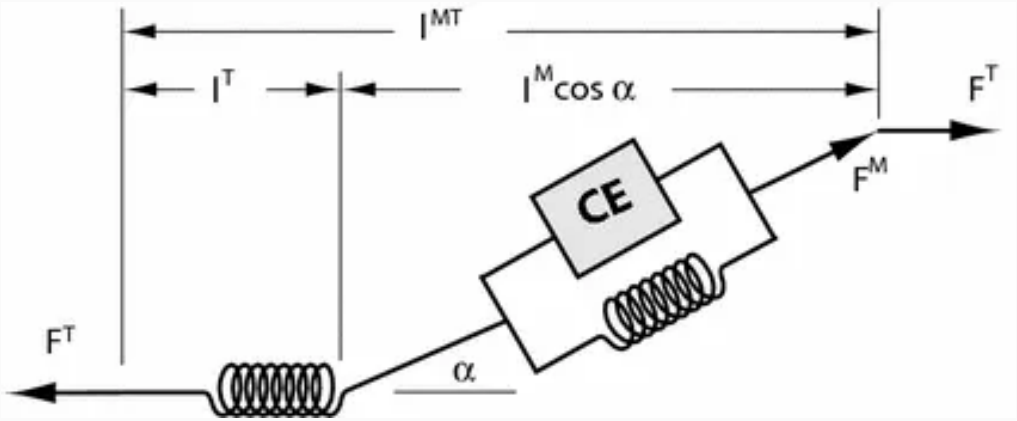

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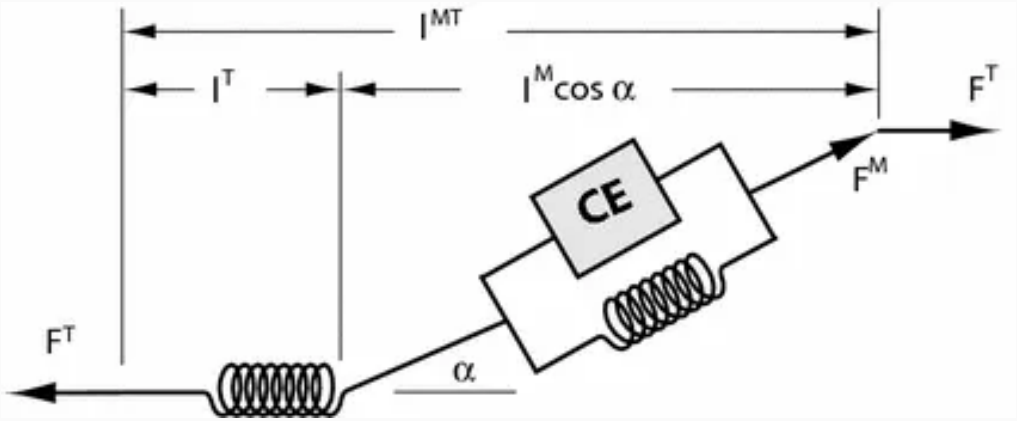

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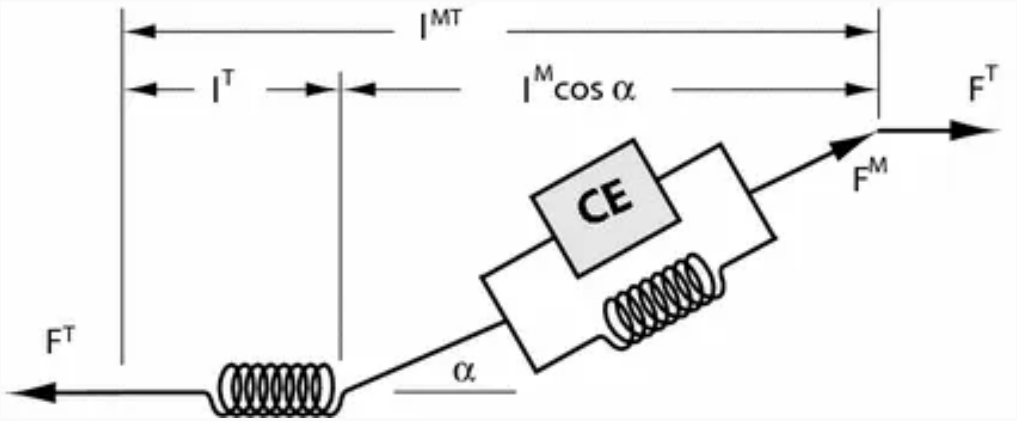

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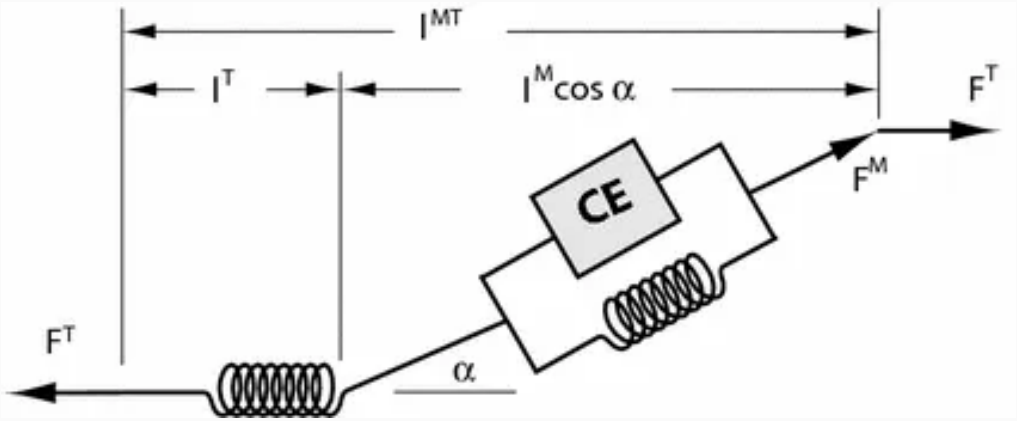
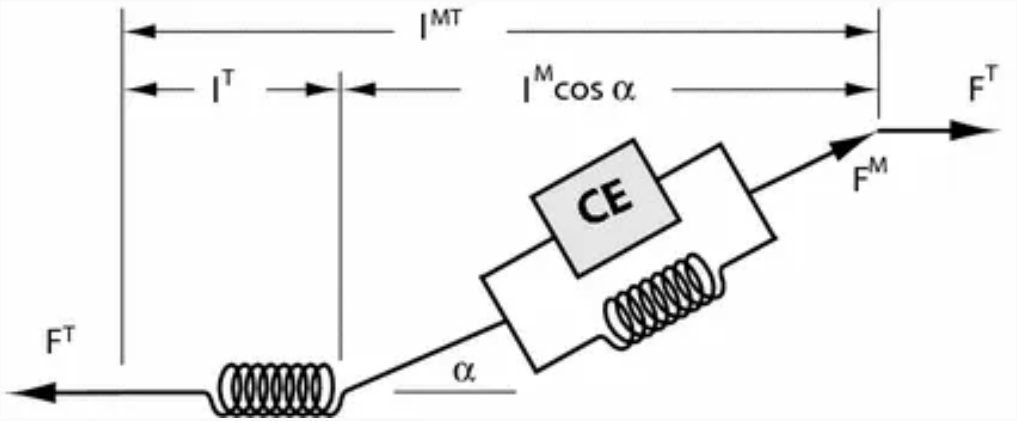


Several parameters that we should identify [Thelen]

- Maximum isometric force
- Tendon slack length

Muscle forces::Estimation

Muscle activation (EMG) and force relationship is not known



Several parameters that we should identify [Thelen]

- Maximum isometric force
- Tendon slack length
- Pennation angle

Muscle forces::Estimation

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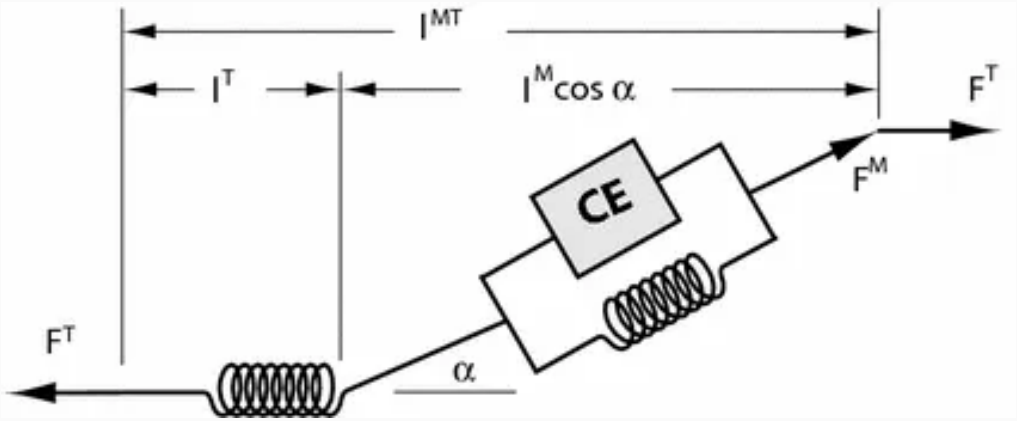

Several parameters that we should identify [Thelen]

- Maximum isometric force
- Tendon slack length
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- Fiber length

Muscle parameters::Identification

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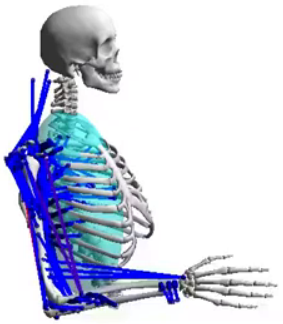
Musculoskeletal modelling [Blana et al.]



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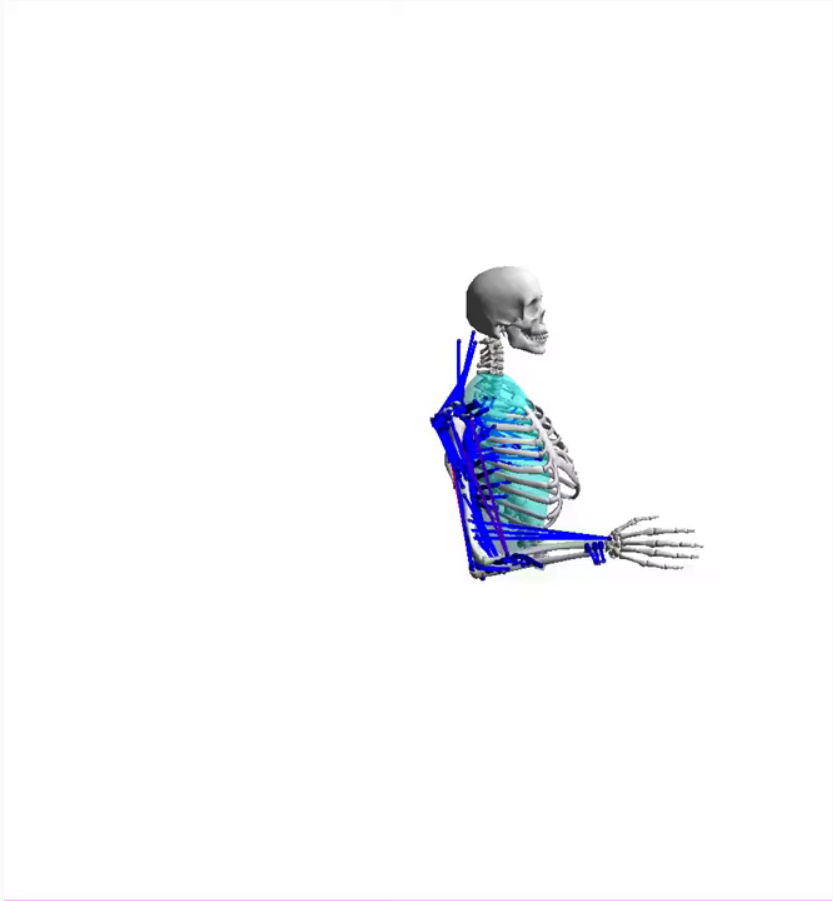
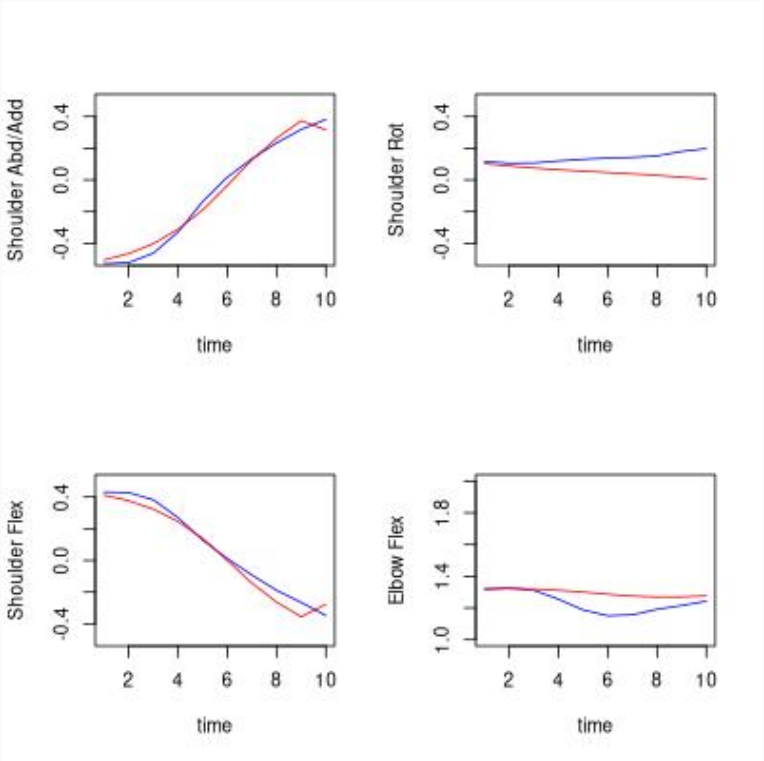


Optimization methods [Falisse et al.]

Muscle parameters::Identification



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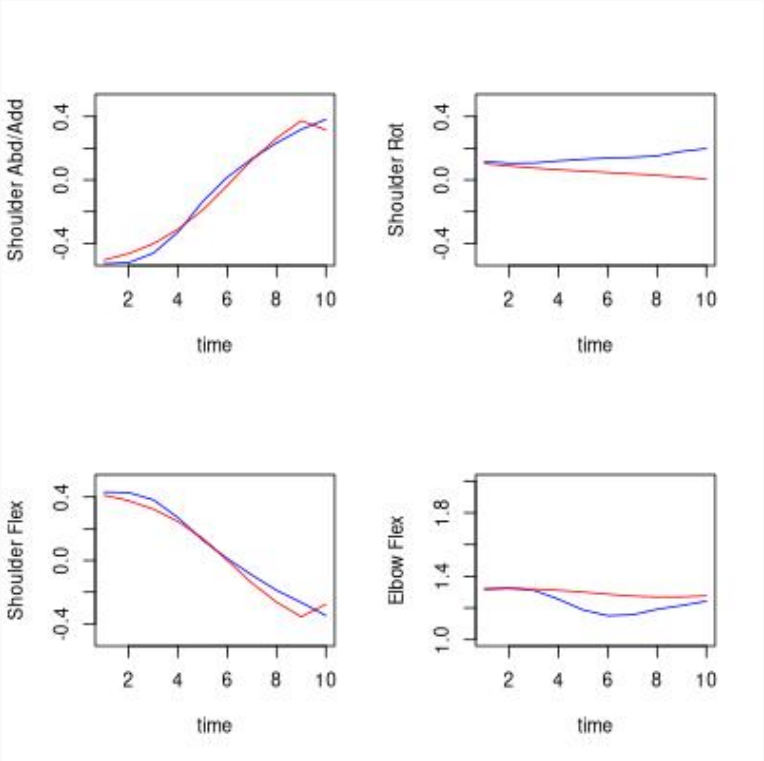

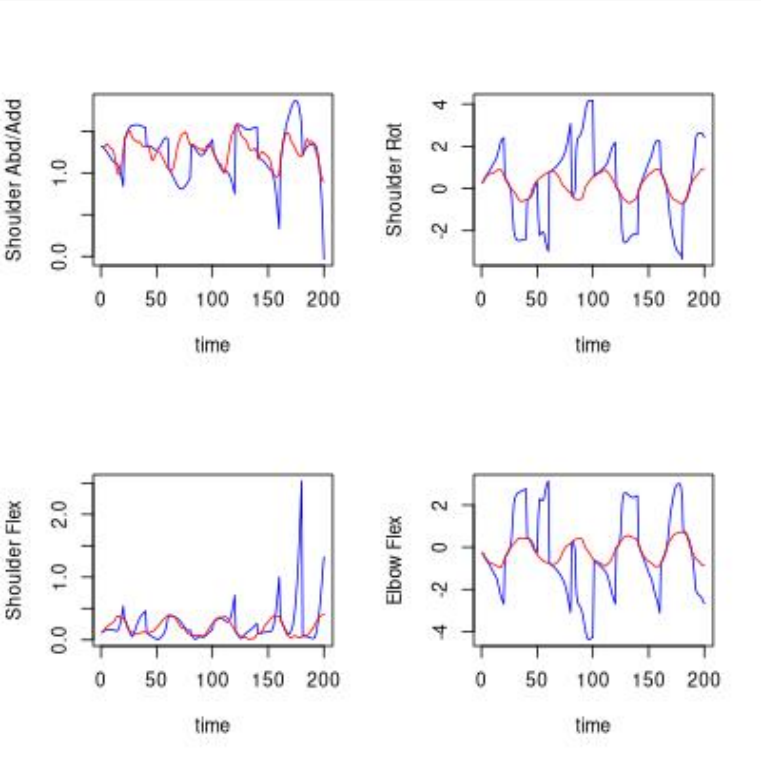

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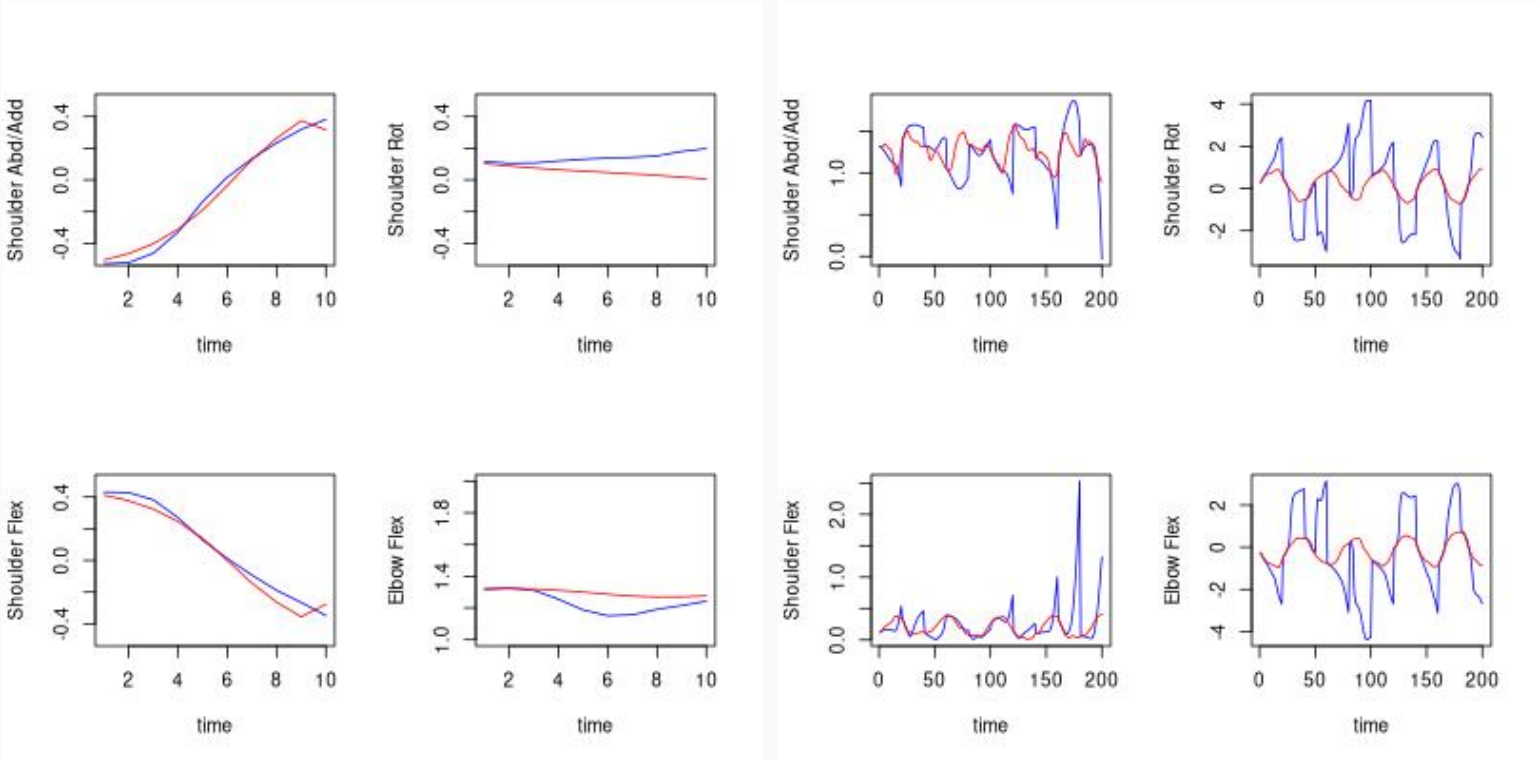

Work in progress

Path planning

Path planning::Record hand movements

- Record hand motion

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- Record hand motion
- Solve inverse kinematics

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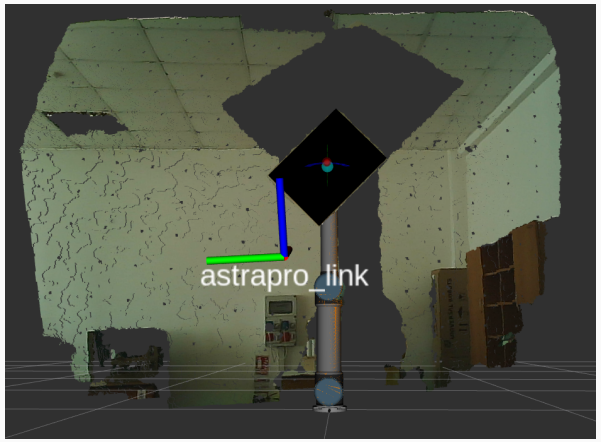
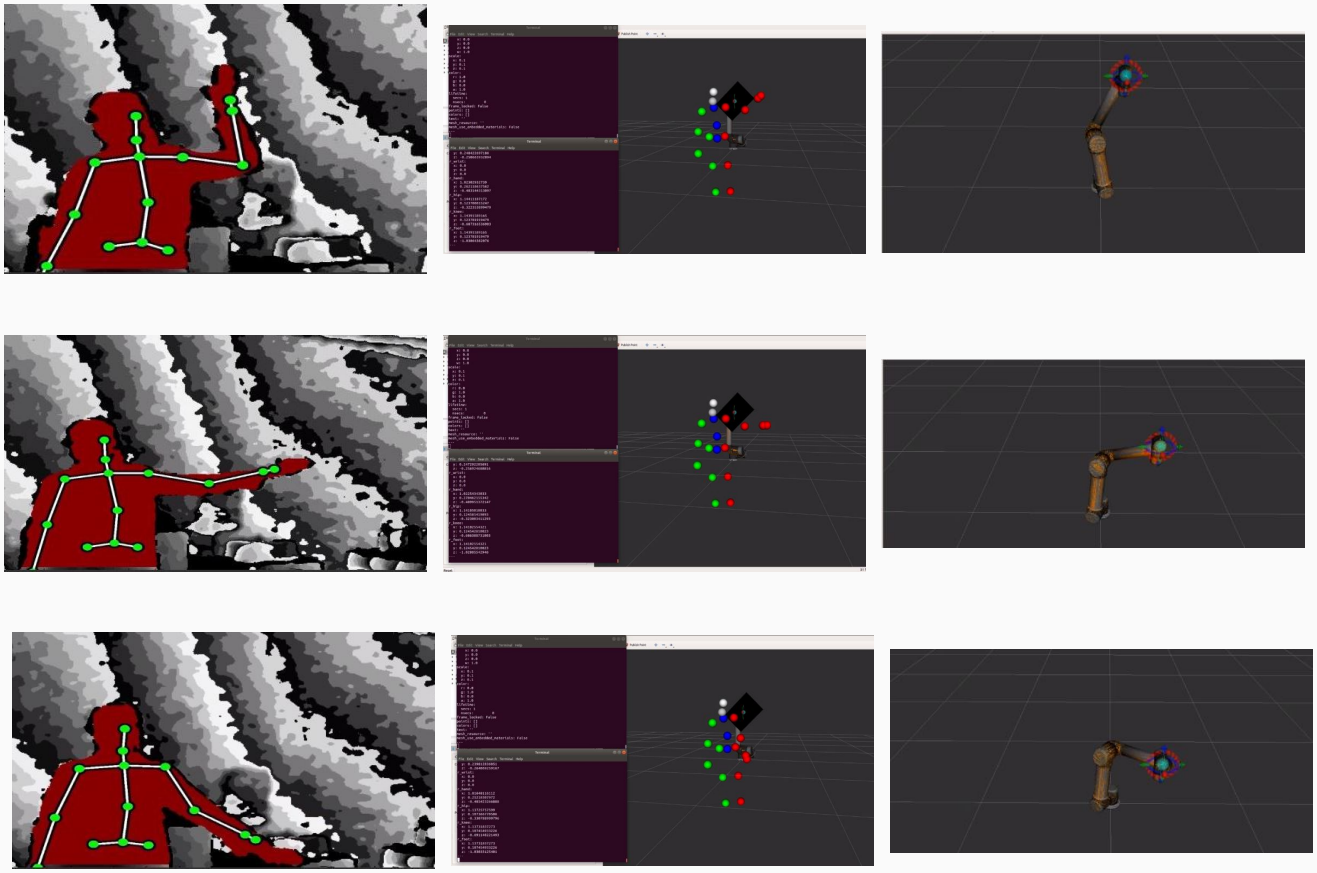


The feed of the camera together with its TF w.r.t. the robot

Path planning::Replay movements



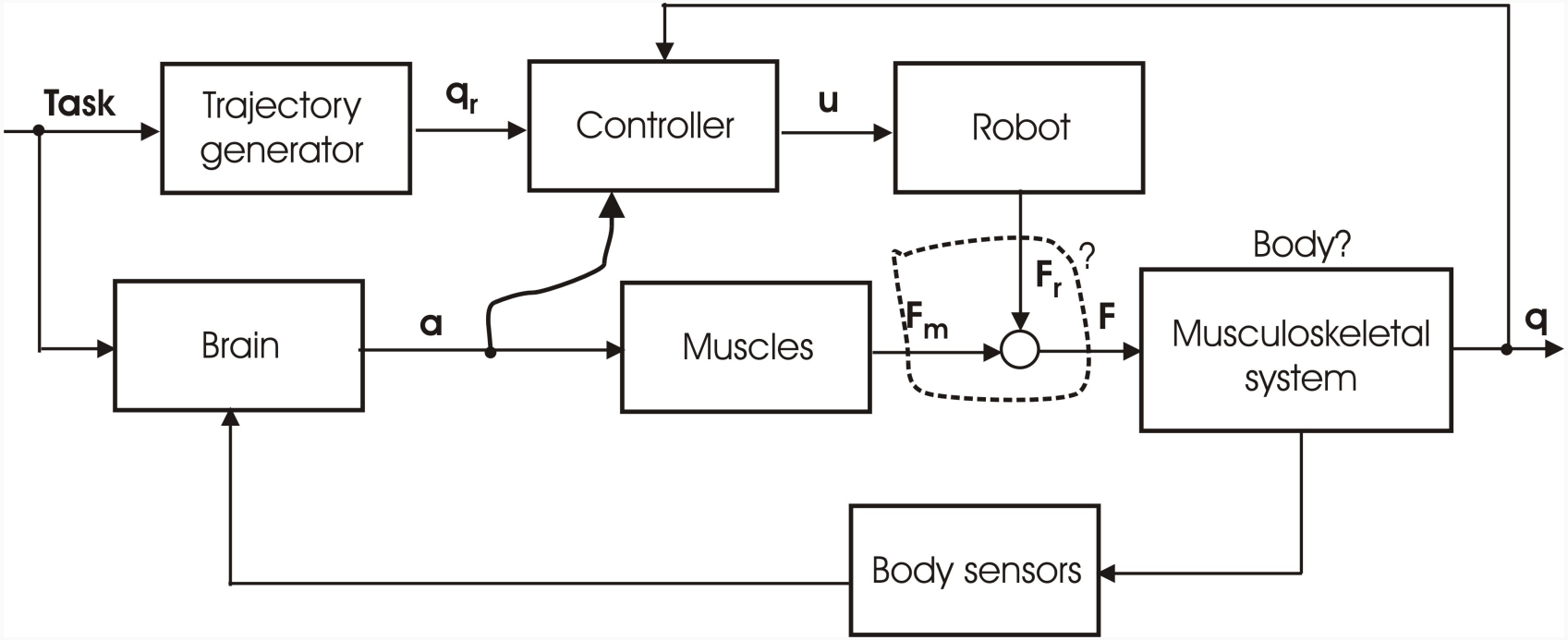
Workflow in images: camera feed (left), body tracker integration with the robot (middle), replay of hand path (right)

Path planning

Muscle optimization path planning expected to start work during summer 2021

Robot control

Rehabilitation::Muscle forces optimization



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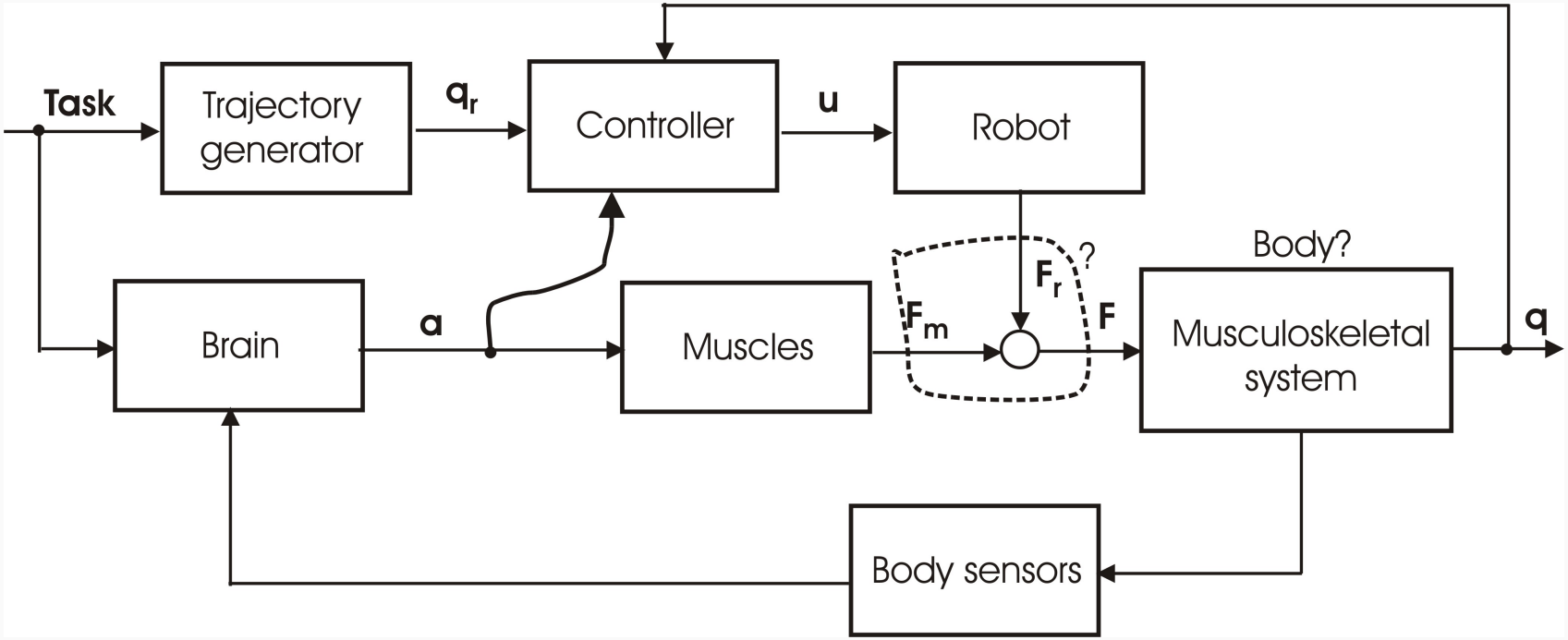
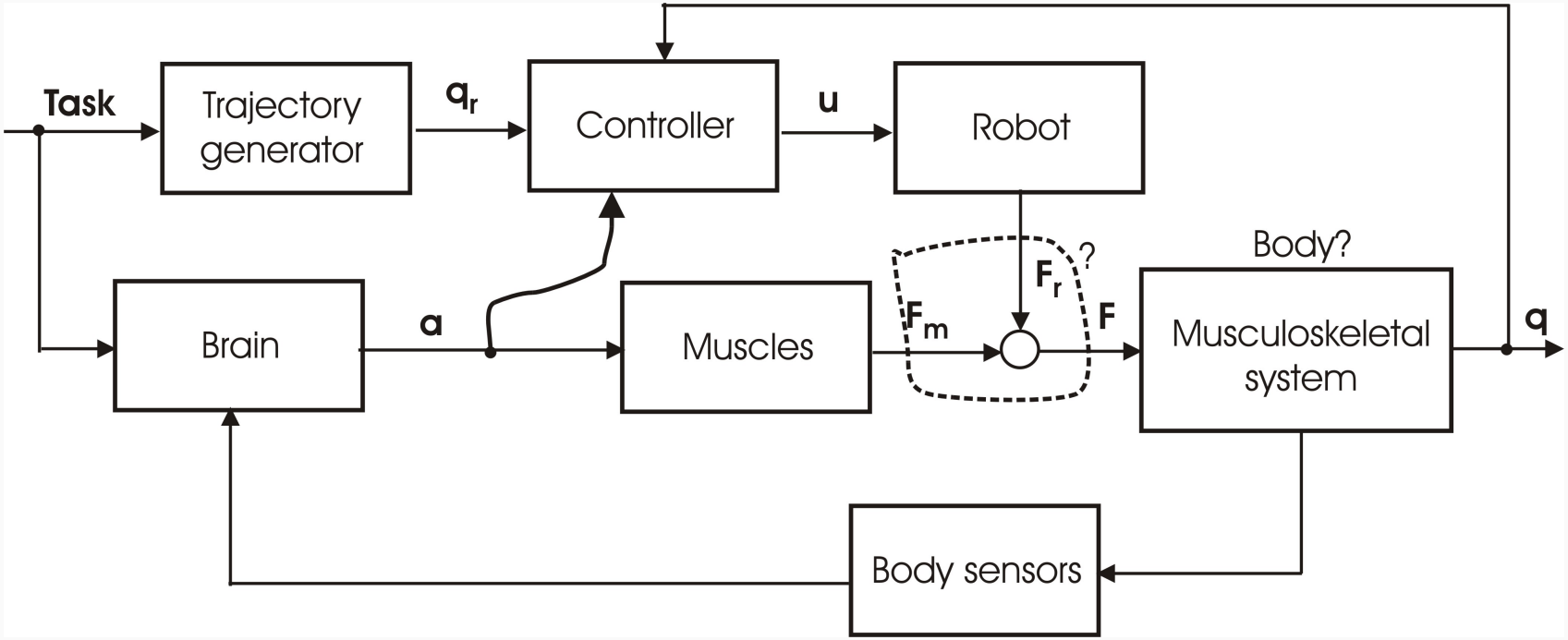


Hybrid position-force control

Rehabilitation::Muscle forces optimization



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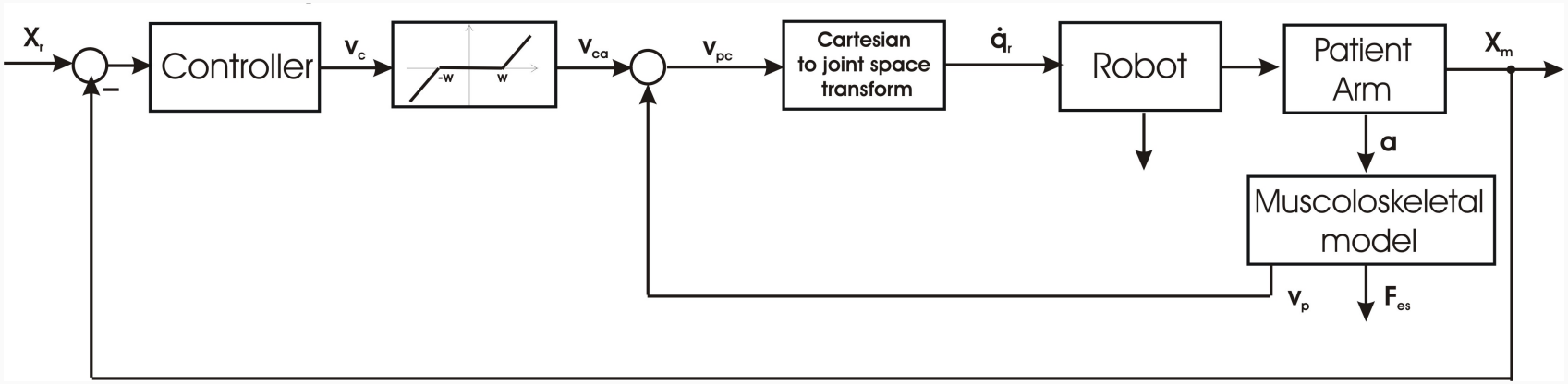

Control::Robot model

Control::Robot model

Nonlinear model (Euler Lagrange)

$$D(q)\ddot{q} + C(q, \dot{q})\dot{q} + F(\dot{q}) + G(q) = \tau \tag{1}$$

τ – control torque, q – joint position
D- inertia matrix, C – Coriolis and centripetal forces, F –friction forces, G- gravitational forces

Linearized model (equilibrium point 0)

$$\dot{x} = Ax + Bu \tag{2}$$

$$y = Cx \tag{3}$$

$x = [q\ \dot{q}]^T$, $y = q$, $u = \tau$

Control law

$$u = -Kx + K_i \int_0^t (r - y)\, dt \tag{4}$$

r is de reference signal

K is designed through pole placemenet or via LQR (optimisation) in order to ensure a stable and fast enough response

K_i can be designed empirically or through optimisation based on specified the settling time and overshoot

Computer torque method:

Inner feedback loop (dynamic linearization)

$$\tau = D(q)(\ddot{r} - u) + C(q, \dot{q})\dot{q} + F(\dot{q}) + G(q) \tag{5}$$

Outer feedback loop (stability and tracking)

$$u = -Kx_e + K_{ie} \int_0^t e \, dt \tag{6}$$

$x_e = [e \ \dot{e}]^T$, $e = r - y$.

Computer torque with sliding mode (robust approach):

We define:
-the sliding surface $s = \Lambda e + \dot{e}$, where $\Lambda = diag[\lambda_1, \lambda_2, ..., \lambda_n]$
-the variable $\dot{q}_r = \Lambda e + \dot{r}$
-the vector function $sgn(s) = [sgn(s_1)\, sgn(s_2) ..., sgn(s_n)]^T$ with $sgn(s_i) = +1$ if $s_i > 0$, or $sgn(s_i) = -1$ if $s_i < 0$.

The control law:

$$\tau = M\ddot{q}_r + C\dot{q}_r + G + Ksgn(s) \tag{7}$$

with $K = diag[k_1\, k_2 ...k_n]$

Λ and K are the design parameters

Control::Practical problems

- No torque control available on the UR5

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Sliding mode controller can be implemented for the outer postion feedback loop (cartesian coordinates) - based on the linearised closed loop model from v_{co} to x_m

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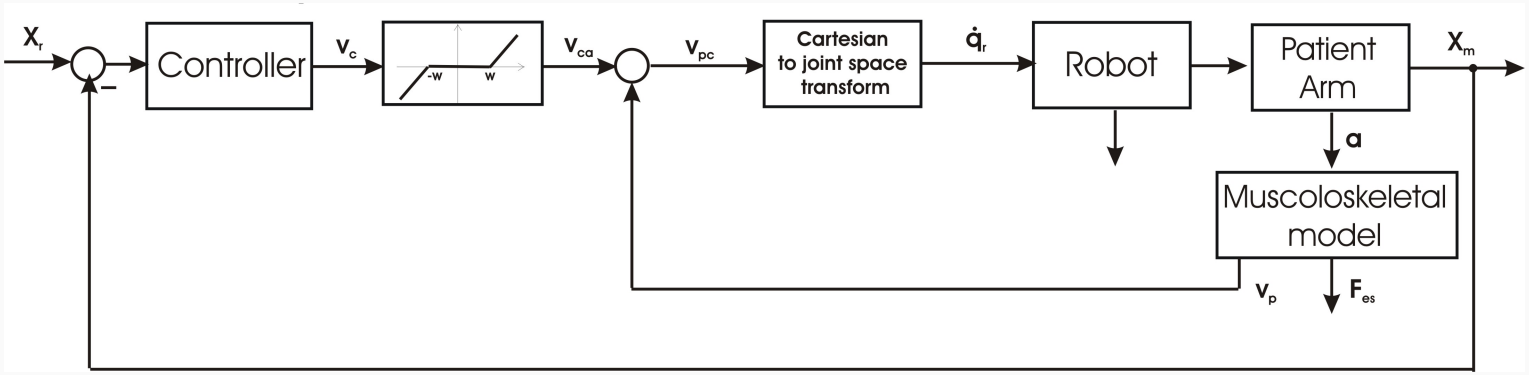

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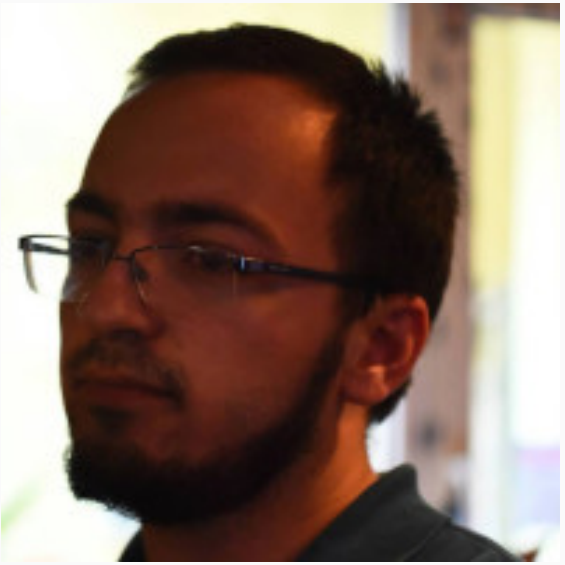

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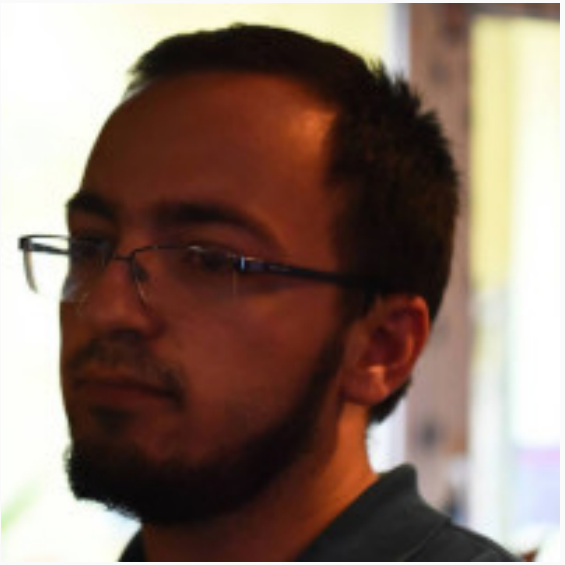

Questions?

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