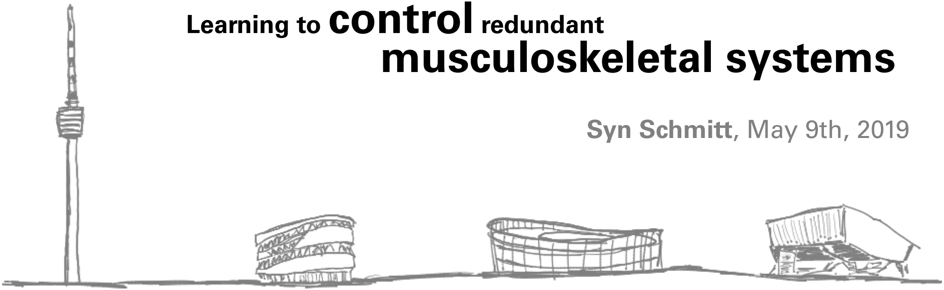
University of Stuttgart
Institute for Modelling and Simulation
of Biomechanical Systems

Motion in Man and Machine

Learning to control redundant musculoskeletal systems

Syn Schmitt, May 9th, 2019



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Home Program Application Courses People

International Max Planck Research School for Intelligent Systems

Application

We seek students who want to earn a doctorate while contributing to world-leading research in areas such as:

- Computational Cognitive Science
- Computer Graphics
- Computer Vision
- Control Systems
- Haptics
- Machine Learning
- Micro- and Nano-Robotics
- Perceptual Inference
- Robotics

Application will open soon

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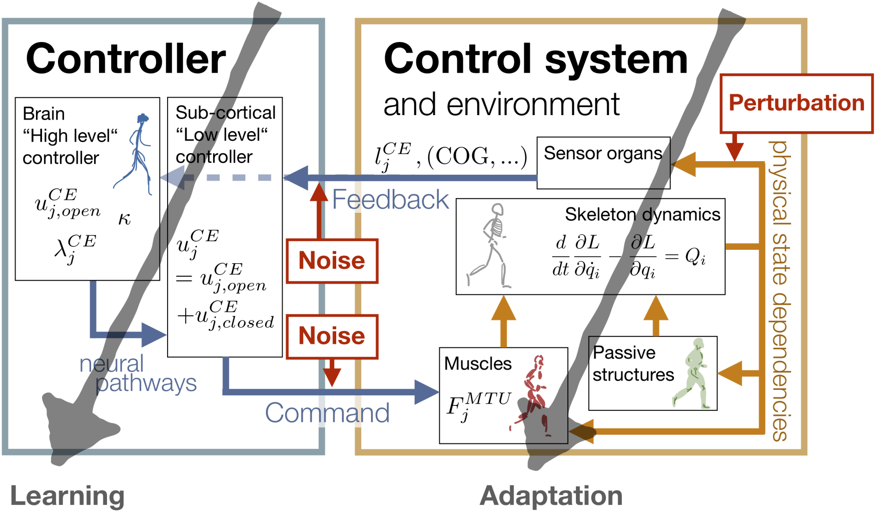

Controller
Brain
“High level“
controller
$u_{j,open}^{CE}$
κ
λ_j^{CE}
Sub-cortical
“Low level“
controller
u_j^{CE}
$= u_{j,open}^{CE}$
$+ u_{j,closed}^{CE}$
neural
pathways
Noise
Noise
Feedback
Command
Control system
and environment
$l_j^{CE}, (\mathrm{COG}, \ldots)$
Sensor organs
Perturbation
Skeleton dynamics
$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = Q_i$
Muscles
F_j^{MTU}
Passive
structures
physical state dependencies
Learning
Adaptation

Model of high-level motor control

(Schmitt, Günther, and Haeufle 2019)

EP control
$$\Lambda_i^{\mathrm{move}} = \{\vec{\lambda}_1, \vec{\lambda}_2, \vec{\lambda}_3, \ldots, \vec{\lambda}_n\}$$

Joint space control

continuous vs. intermittent

model-based control

learning-based control

Model of skeletal muscle

Hill-type model

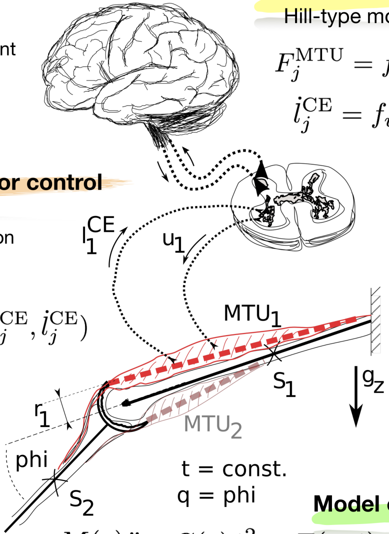
$$F_j^{\mathrm{MTU}} = f_f(l_j^{\mathrm{MTU}}, \dot{l}_j^{\mathrm{MTU}}, l_j^{\mathrm{CE}}, a_j)$$
$$\dot{l}_j^{\mathrm{CE}} = f_v(l_j^{\mathrm{MTU}}, \dot{l}_j^{\mathrm{MTU}}, l_j^{\mathrm{CE}}, a_j)$$
$$\dot{a}_j = f_a(a_j, l_j^{\mathrm{CE}}, u_j)$$

Model of low-level motor control

monosynaptic reflex

alpha-gamma co-activation

$$u_j = u_j^{\mathrm{open}} + u_j^{\mathrm{closed}}$$
$$u_j^{\mathrm{closed}} = f_n(\kappa, \lambda_j^{\mathrm{CE}}, l_j^{\mathrm{CE}}, \dot{l}_j^{\mathrm{CE}})$$



Numerical solution

$$\vec{q}(t) = ?$$

Parameters

Initial conditions

Model of skeletal structure

$$M(q)\ddot{q} = C(q)\dot{q}^2 + E(q,\dot{q}) + G(q) + R(q)F^{\mathrm{MTU}}$$

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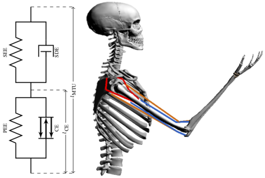
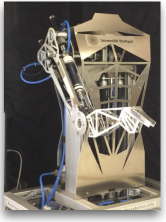
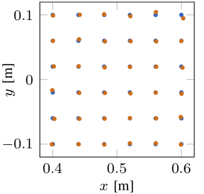
Deep control using a biosimulator and a biorobot

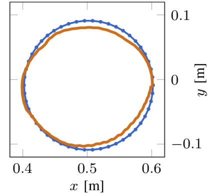


Simulation model including 6 MTU
16 states, hand position $\mathbf{x} \in \mathbb{R}^2$





(a) Point reaching evaluation.



(b) Circle trajectory following.

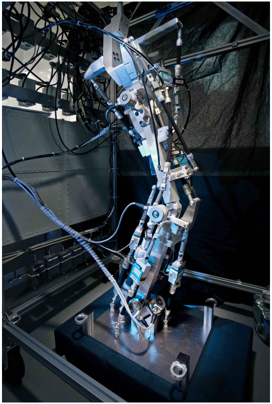
Goal: $\pi : \mathbf{x}_{ref} \in \mathbb{R}^d \to \mathbf{u} \in [0,1]^m$, $\pi(\mathbf{x}_{ref}) = \mathbf{u}_x$, data $\mathscr{D} = \{(\mathbf{u}_i, \mathbf{x}_i)\}_{i=1}^n$

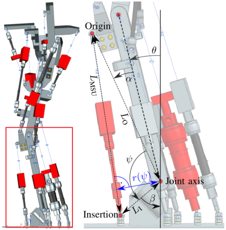
Forward model to learn: $\boxed{\phi : \mathbf{u} \in 0,1^m \to \mathbf{x}_{ref} \in \mathbb{R}^d}$, initial data: $\mathscr{D} = \{(\mathbf{u}_0, \mathbf{x}_0)\}$

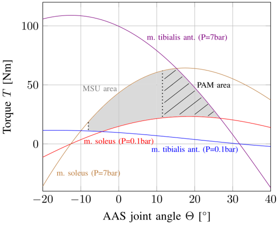
Control policy: $\boxed{\mathbf{u}_x^* = \underset{\mathbf{u} \in \mathbb{R}^m}{\operatorname{argmin}} \|\mathbf{u}\|_{\mathbf{W}}^2 + \lambda \|\mathbf{u} - \mathbf{u}_0\|_2^2 \quad \text{s.t.} \quad \phi(\mathbf{u}) = \mathbf{x}_{ref}}$

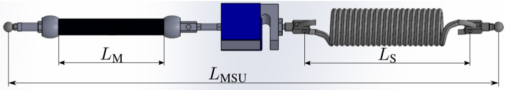
(Driess et al. 2018)

Muscle-spring units as bio-inspired actuators









$$\boxed{\mathbf{F}^{MSU} = f_F(\mathbf{p}, \mathbf{l}^{MSU})}$$

(Wolfen et al. 2018)

References

Driess, Danny et al. (2018). "Learning to Control Redundant Musculoskeletal Systems with Neural Networks and SQP: Exploiting Muscle Properties". In: *Proc. of the International Conference on Robotics and Automation*.

Schmitt, Syn, Michael Günther, and Daniel F.B. Haeufle (2019). "The dynamics of the skeletal muscle: a systems biophysics perspective". In: *Journal of Applied Mathematics and Mechanics (ZAMM)* accepted.

Wolfen, S. et al. (2018). "Bioinspired pneumatic muscle spring units mimicking the human motion apparatus: benefits for passive motion range and joint stiffness variation in antagonistic setups". In: *25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)*, pp. 1–6. DOI: 10.1109/M2VIP.2018.8600913.