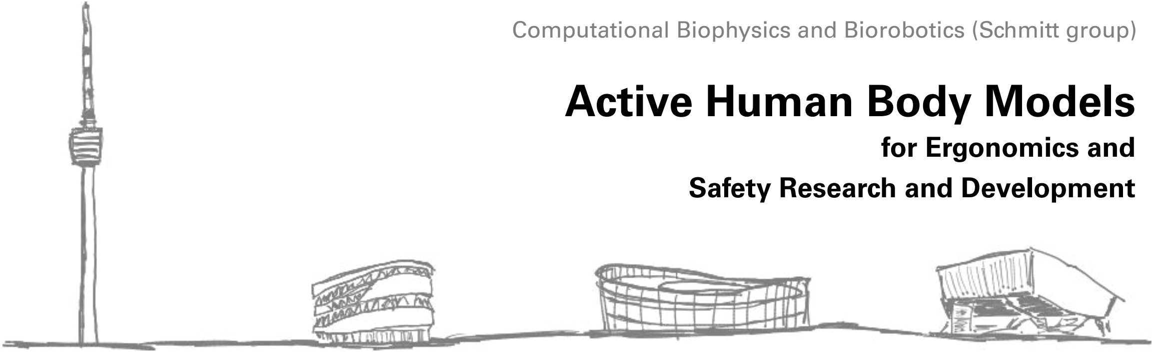
University of Stuttgart
Institute for Modelling and Simulation
of Biomechanical Systems

Computational Biophysics and Biorobotics (Schmitt group)

Active Human Body Models

for Ergonomics and
Safety Research and Development



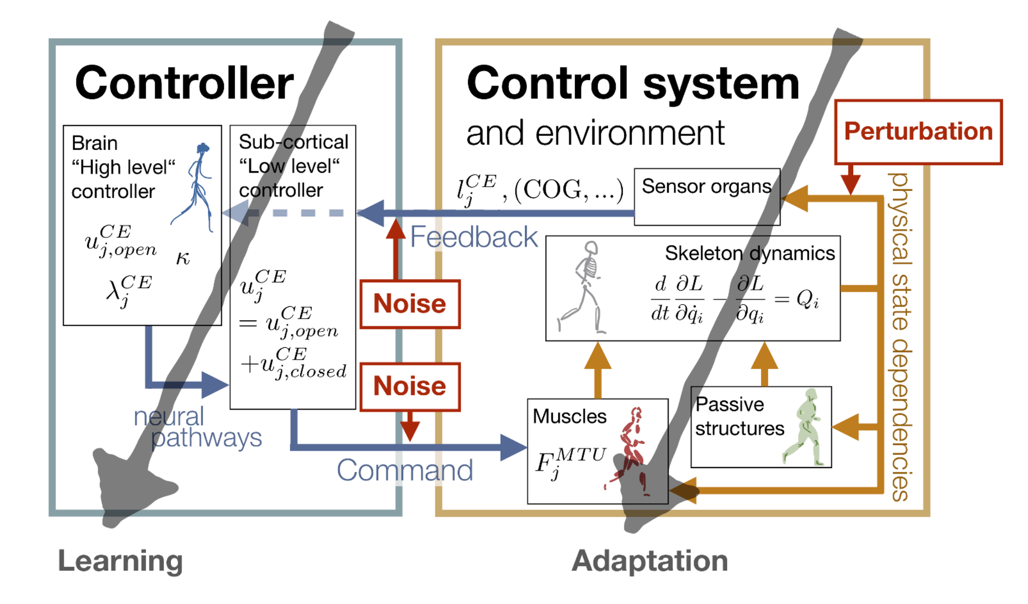
cbb Computational Biophysics and Biorobotics

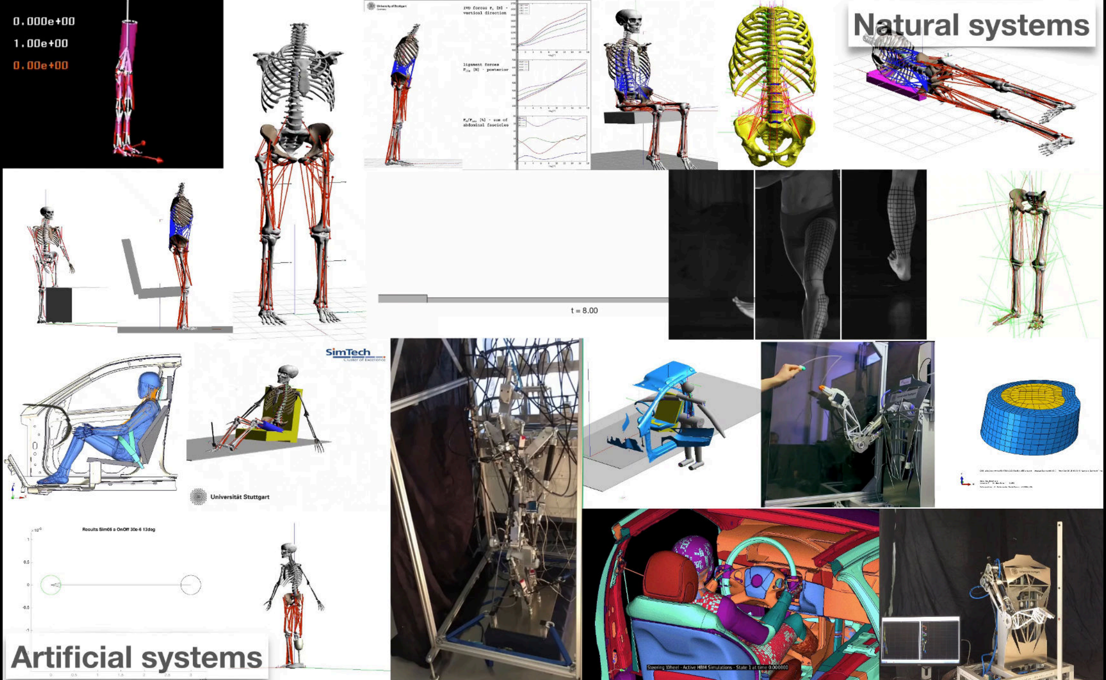
QUT

imprs-is

SimTech

(Schmitt, Günther, and Häufle 2019)





Natural systems
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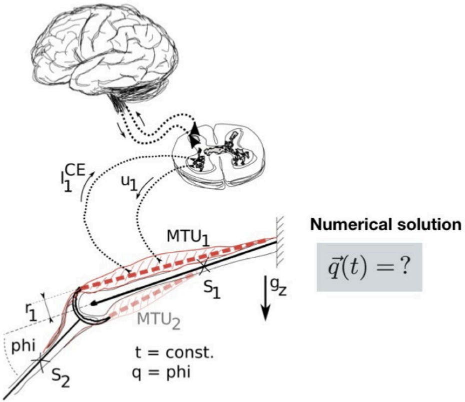
t = 8.00
SimTech
Cluster of Excellence
Universität Stuttgart
Results Sim06 a OnOff 30e-6 13deg
Steering Wheel - Active HBM Simulations - State 1 at time 0.000000
Artificial systems

Goal: generate human motion based on biological signals, <u>purely synthetic</u> but realistic

Method: Theory and computer simulation to combine neuroscience and biomechanics



Models to account for:

motor control (CNS)
sensor-actuator loop (muscles)
skeleton (bones and soft tissue)

NOTE:

no inverse calculation
no kinematic input data needed
AI heavily involved
similar to any other CAx method

A window into the functioning of the **central nervous system**?

(Schmitt, Günther, and Häufle 2019)

Model of high-level motor control

EP control

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

Joint space control

- continuous vs. intermittent
- ***model-based control***
- ***learning-based control***

Model of skeletal muscle

Hill-type model

$$F_j^{\text{MTU}} = f_f(l_j^{\text{MTU}}, \dot{l}_j^{\text{MTU}}, l_j^{\text{CE}}, a_j)$$

$$\dot{l}_j^{\text{CE}} = f_v(l_j^{\text{MTU}}, \dot{l}_j^{\text{MTU}}, l_j^{\text{CE}}, a_j)$$

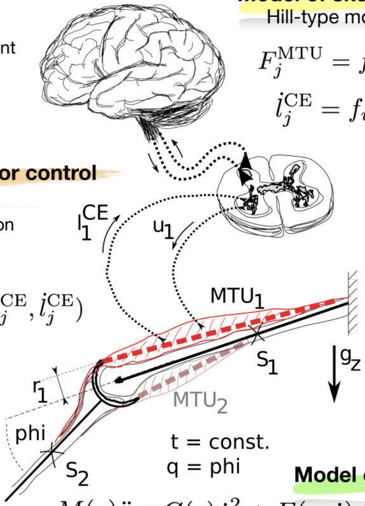
$$\dot{a}_j = f_a(a_j, l_j^{\text{CE}}, u_j)$$

Model of low-level motor control

- monosynaptic reflex
- alpha-gamma co-activation

$$u_j = u_j^{\text{open}} + u_j^{\text{closed}}$$

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



Numerical solution

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

Parameters

Initial conditions

t = const.
q = phi

Model of skeletal structure

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

SimTech

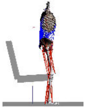
The **elementary biological drive**

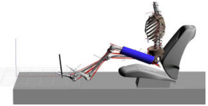
Learning? **Maybe, a rather naive and simple approach!**

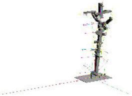
Given a specific control idea, learning is ...

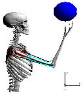
- finding appropriate **muscle stimulation pattern**, time to **change pattern**, etc., using *trial and error* (heuristics) or *fmincon* (gradient-based methods)
- **optimising controller** gains using *Bayesian optimisation*,
- balancing **feedforward and feedback contributions** using *heuristics*,
- **autonomously learn** the control policy using an *artificial neural network* and *sequential quadratic programming*.

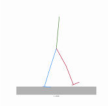
(Günther & Ruder, 2003)


(Bayer, 2017)


(Walter & Schmitt, 2012)


(Le Mouel, Martin et al., in prep)


(Suissa, 2018)

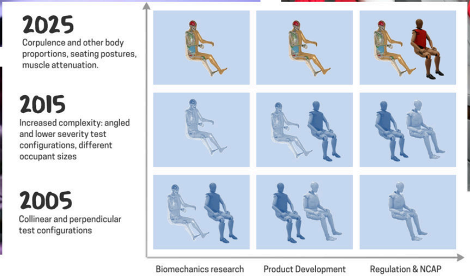

(Häufle et al., 2019)


(Driess et al., 2018)

Vehicle safety assessment

Crash tests with ATDs vs virtual testing with HBMs

- HBMs – Human Body Models
- ATDs – Anthropomorphic Test Devices



Source:
Toyota Central R&D Labs Inc.;
https://youtu.be/OanQCc_Obj4
Daimler AG.

M. van Ratingen, Saving Lives with Safer Cars: The Past, Present and Future of Consumer Safety Ratings. Bertil Aldman Memorial Lecture, in: Proceedings of the IRCOBI Conference, Malaga, Spain, 2016. https://prezi.com/rfo1donwal66/bertil-aldman-lecture-2016/

One of the possible solutions: Autonomous Cars

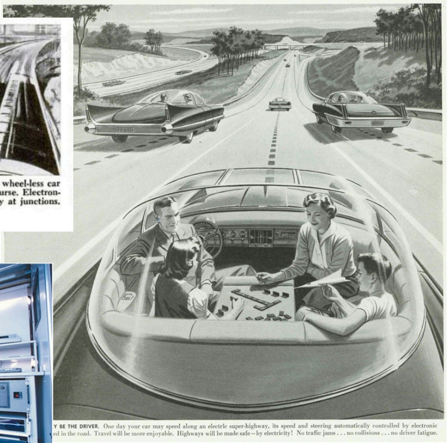
University of Stuttgart

A History of Autonomous Vehicles

Flying Carpet, 1880

NO-HANDS DRIVING is easy with wheel-less car —roadway groove holds it on course. Electronic controls would be needed only at junctions.

68 POPULAR SCIENCE AUGUST 1961



Driverless Cars of the Future, 1950s-60s

Mercedes van, Bundeswehr University Munich, 1986-2003

http://www.computerhistory.org/atchm/where-to-a-history-of-autonomous-vehicles/

aHBM: a finite element approach

Control system and environment

Bones
Structure

Deformable bodies

Ligaments, cartilage, fat
Springs

Passive forces

Linear elasticity
Viscous damping
Inertia forces

$$M\ddot{v}_n + C\dot{v}_n + K v_n = P_n(t)$$

THUMS AM50 Occupant Model Version 5.0

Muscles
Motors

Active forces

Hill-type 1d muscle elements

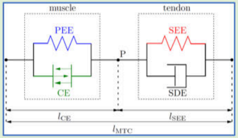
$$F_{MTU,i} = f_f\left(l_{MTU,i}, \dot{l}_{MTU,i}, l_{CE,i}, a_i\right)$$

Neurons
Wires, CPU

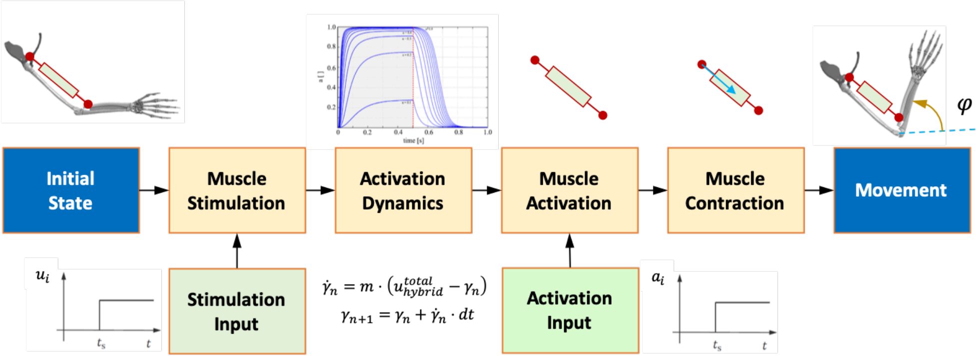
Reflexes, commands

Activation/stimulation signal for muscle

$$u_{hybrid}^{total}\Big|_0^1 = u_\lambda^{closed} + u_\alpha^{open}$$



Controller



Possible Muscle Activation Schemes:

- Normalized EMG
- Engineering judgment
- Reflex activation (vestibular and spindle)
- PID controllers
- Optimization
- Reinforcement learning

ÖsthEtAl2015,
MartynenkoEtAl2019 PAMM

MAT_MUSCLE vs Extended Hill-type Muscle Model

Mechanics

- Full-text access: http://rdcu.be/vw5G
- DOI: dx.doi.org/10.1186/s12938-017-0399-7
- Supplementary material: dx.doi.org/10.5281/zenodo.826209

Kleinbach *et al. BioMed Eng OnLine (2017) 16:109*
DOI 10.1186/s12938-017-0399-7

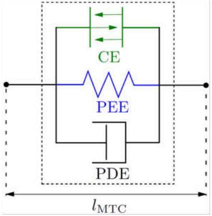
BioMedical Engineering OnLine

SOFTWARE Open Access

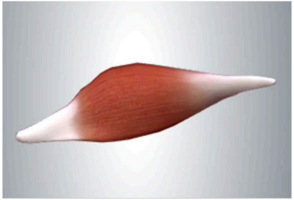
CrossMark

Implementation and validation of the extended Hill-type muscle model with robust routing capabilities in LS-DYNA for active human body models

*MAT_MUSCLE

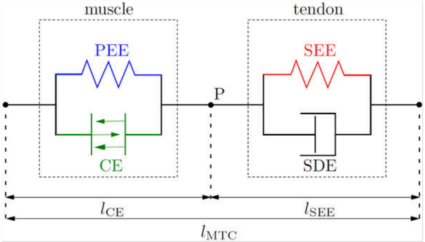


Real human muscle



Source: biodigital.com

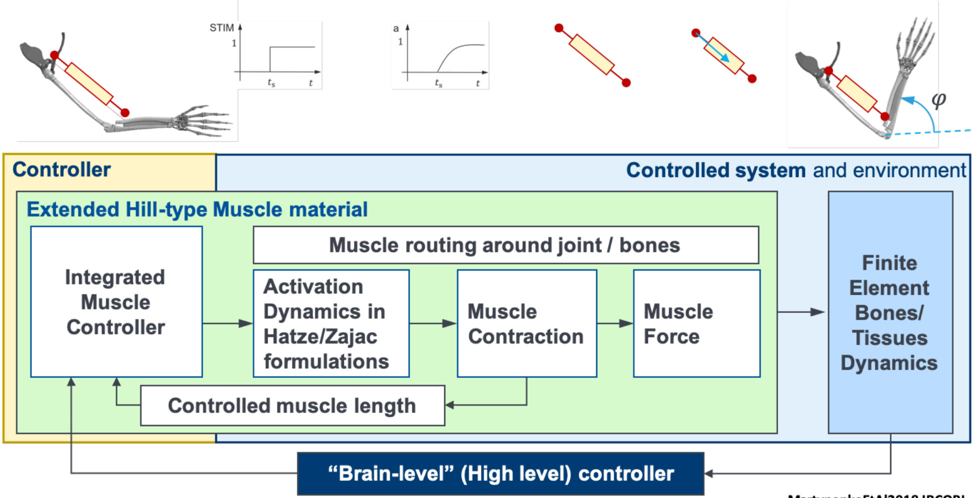
Extended Hill-type muscle material



MartynenkoEtAl2017 IRCOBI, Kleinbach2017

Extended Hill-type Muscle Model with internal controller

Flowchart of the Muscle Controller Code



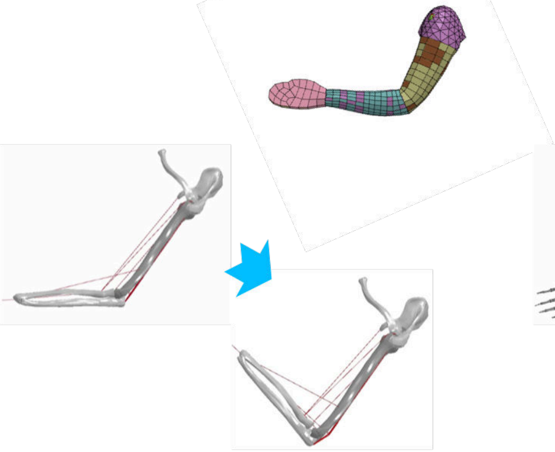
MartynenkoEtAl2018 IRCOBI

Extended Hill-type Muscle Model example simulations

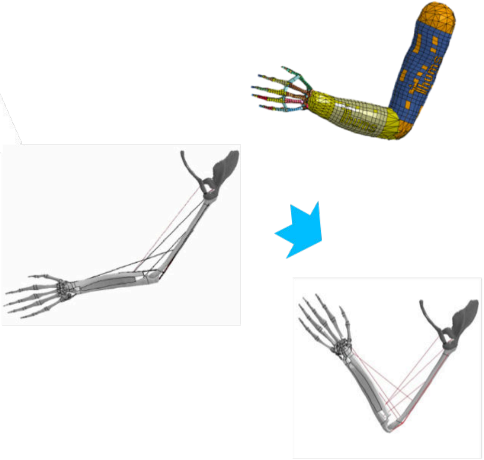
University of Stuttgart
Germany

Changing angle for an arm with finite element multibody models

Movement simulation for ViVA arm model



Movement simulation for THUMS3 arm model

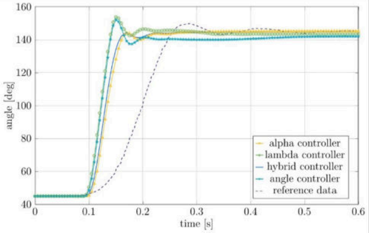


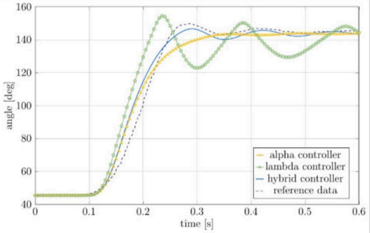
MartynenkoEtAl2018 IRCOBI

Extended Hill-type Muscle Model example simulations

Comparison of different controllers with reference data

- Angle response for different controllers with the reference data from KistemakerEtAl2006 for *MAT_156 (left) and EHTM (right)



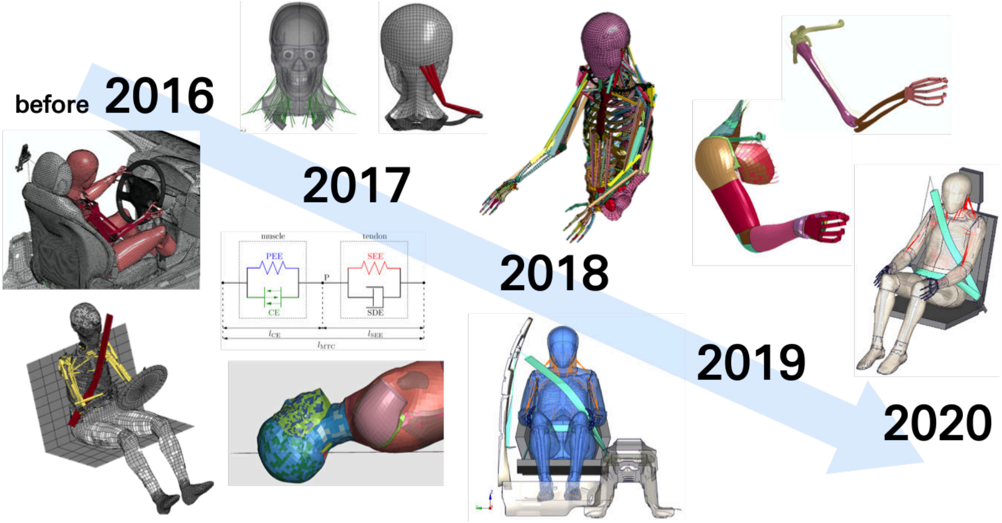


- CPU time in seconds for simulations with different models

	α, EHTM	α, *MAT_156	λ, EHTM	λ, *MAT_156	Hybrid, EHTM	Hybrid, *MAT_156	Angle, *MAT_156
Element processing	0,719	6,386	0,724	6,751	0,748	6,729	6,808
Rigid Bodies	1,137	13,771	1,141	14,196	1,151	14,361	14,262
Time step size	2,010	23,521	2,004	23,638	2,006	24,061	23,709
Misc. 1	0,976	10,547	0,961	11,057	0,972	11,137	10,989
Misc. 4	2,797	33,255	2,781	33,965	2,786	34,478	33,886
Problem cycle	45001	517624	45001	549290	45001	548631	549303
Total CPU	9,021	97,897	8,987	100,650	9,074	101,730	100,490

WochnerEtAl2019 IRCOBI

aHBM: **development within our group**



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