Active Human Body Models
for Ergonomics and
Safety Research and Development
Goal: generate human motion based on biological signals, purely synthetic 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?
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.
Vehicle safety assessment
Crash tests with ATDs vs virtual testing with HBM

- HBM - Human Body Models
- ATDs - Anthropomorphic Test Devices

2025
- Congruence and other body proportions, seating postures, muscle attenuation

2015
- Increased complexity: angled and lower severity test configurations, different occupant sizes

2005
- Collinear and perpendicular test configurations

Source:
Toyota Central R&D Labs Inc.;
https://youtu.be/0anQCP_Obj4
Daimler AG.

One of the possible solutions: Autonomous Cars

A History of Autonomous Vehicles

Flying Carpet, 1880

Mercedes van, Bundeswehr University Munich, 1986-2003

Driverless Cars of the Future, 1950s-60s

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

**Bones Structure**
- Deformable bodies
  - Linear elasticity
  - Viscous damping
  - Inertia forces

**Ligaments, cartilage, fat Springs**
- Passive forces
  - $M\ddot{v}_n + C\dot{v}_n + K\nu_n = P_n(t)$

**Muscles**
- Active forces
  - Hill-type 1d muscle elements

**Motors**
- Forces

**Neurons Wires, CPU**
- Reflexes, commands

**Controller**
- Activation/stimulation signal for muscle

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

$u_{\text{total}}^{\text{hybrid}} \bigg|_0^1 = u_{\lambda}^{\text{closed}} + u_{\alpha}^{\text{open}}$
Possible Muscle Activation Schemes:

- Normalized EMG
- Engineering judgment
- Reflex activation (vestibular and spindle)
- PID controllers
- Optimization
- Reinforcement learning
**MAT_MUSCLE vs Extended Hill-type Muscle Model**

**Mechanics**

- DOI: dx.doi.org/10.1186/s12938-017-0399-7
- Supplementary material: dx.doi.org/10.5281/zenodo.826209

*MAT_MUSCLE*  
![MAT_MUSCLE diagram](source: biodigital.com)

**Real human muscle**  
![Real human muscle image](source: biodigital.com)

**Extended Hill-type muscle material**  
![Extended Hill-type muscle material diagram](source: biodigital.com)

Implementation and validation of the extended Hill-type muscle model with robust routing capabilities in LS-DYNA for active human body models.
Extended Hill-type Muscle Model with internal controller

Flowchart of the Muscle Controller Code

Controller

Extended Hill-type Muscle material

Integrated Muscle Controller

Muscle routing around joint / bones

Activation Dynamics in Hatze/Zajac formulations

Muscle Contraction

Muscle Force

Finite Element Bones/ Tissues Dynamics

Controlled system and environment

“Brain-level” (High level) controller

Controlled muscle length
Extended Hill-type Muscle Model example simulations
Changing angle for an arm with finite element multibody models

Movement simulation for VIVA arm model

Movement simulation for THUMS3 arm model
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
aHBM: development within our group
References: aHBM development within our group


