STIFF:

Enhancing biomorphic agility through variable stiffness

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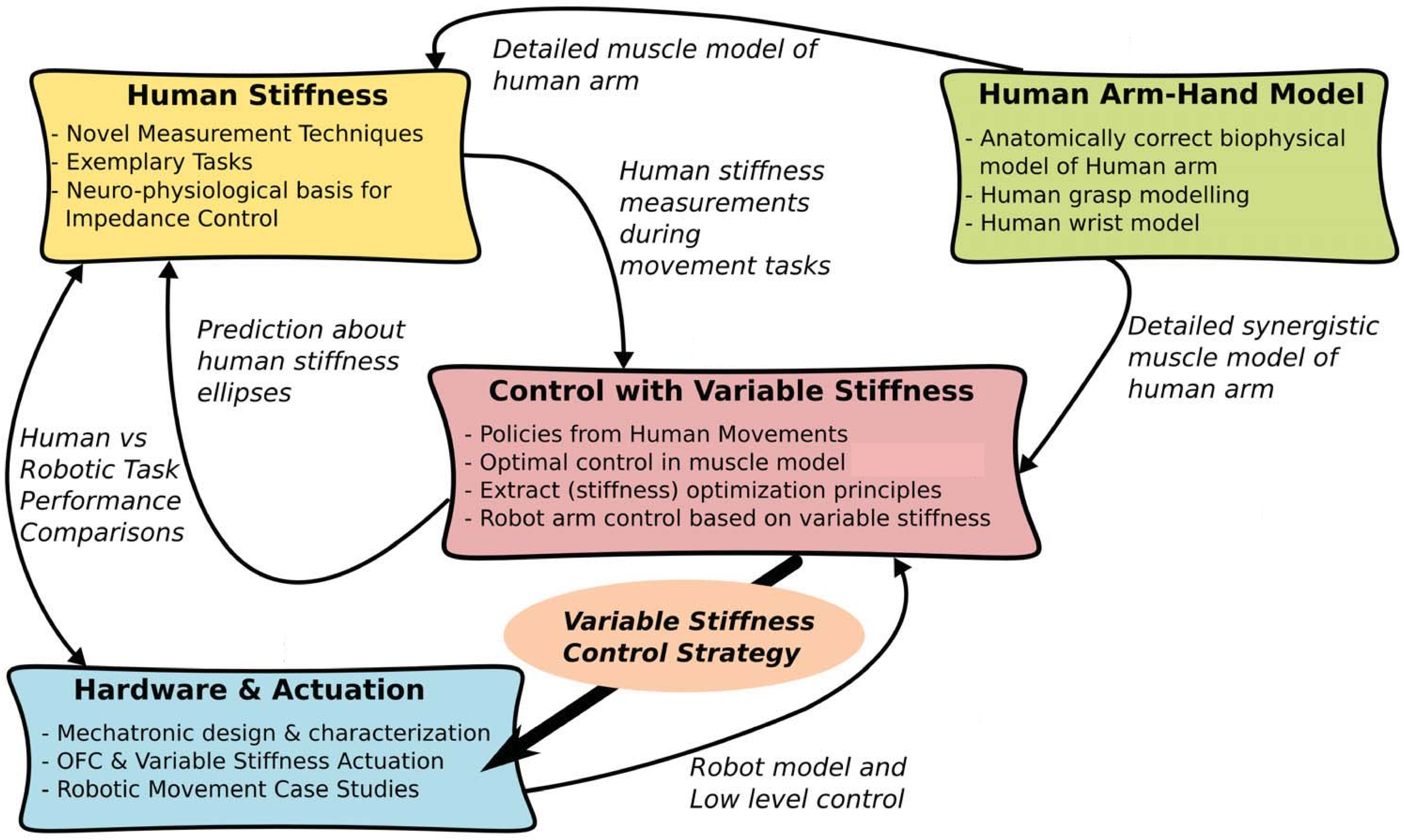
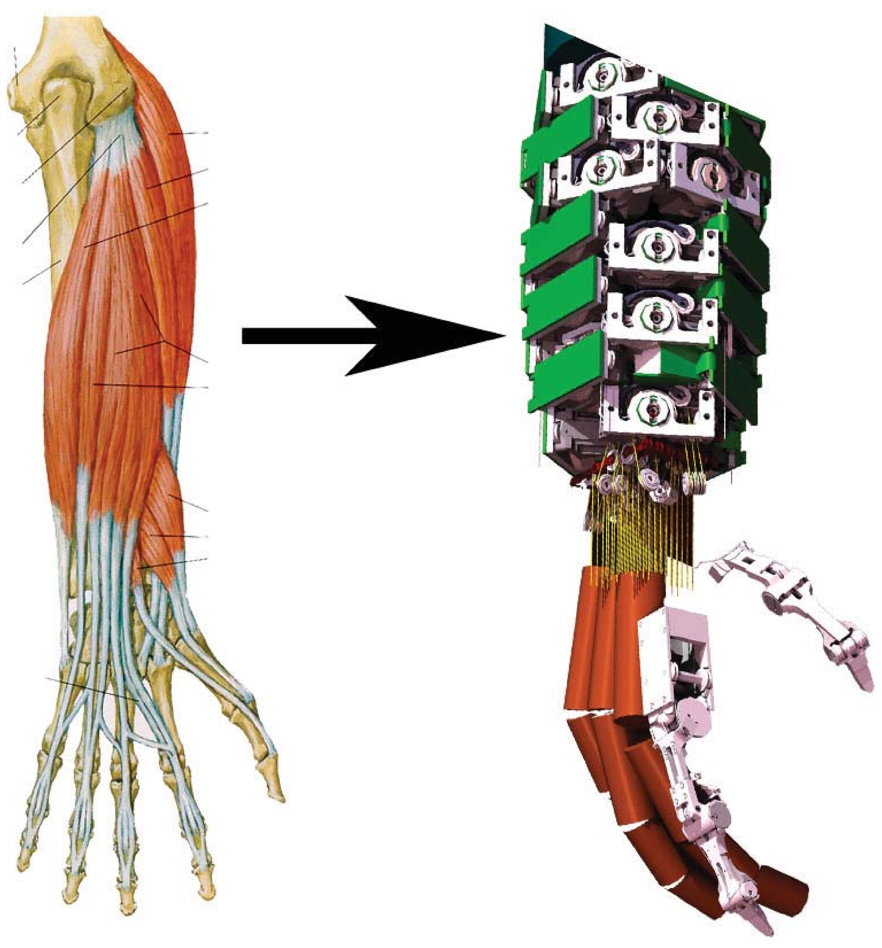
We equip a highly biomimetic robot hand-arm system with the agility, robustness and versatility that are hallmarks of the human motor system by understanding and mimicking the variable stiffness paradigms that are so effectively employed by the human CNS. This is done by developing novel methodologies to comprehend how the human arm can adapt its impedance, by measuring that during natural tasks like throwing a ball or inserting a peg in a hole. Cost functions are defined based on these detailed biophysical models and transferred to the variable impedance actuation of the novel biomorphic robotic system. The central question we focus on for both the human and robotic arm is: 'how is stiffness used to enhance performance?'



We investigate the stiffness of the human arm and hand (i.e., grasp force) involving detailed skeletomuscular models thereof, to serve as a basis for the development and control of a highly biomimetic robotic hand-arm system. A detailed skeletomuscular model of the human arm and hand is developed based on a deep biological understanding and used as an interface. Cost functions for motor actuation are learned from the results of the human stiffness experiments and used for an optimal controller.



To achieve that, impedance tasks are defined and test platforms built. After developing identification techniques for time-variant measurement techniques, an EMG map between muscle activity and arm stiffness will be generated, and experiments to investigate human hand and arm stiffness behaviour during natural tasks will be executed. Results of those experiments will be used to design the robot's variable impedance actuator to match human characteristics. The low level control of the joints will be optimised to reproduce human-like damping characteristics and an iLQG will be implemented and tested for high dimensional movement plans. Based on this, scalability of the iLQG-ID with variable stiffness will be added and tested. The result is a successfully controlled simulated robot arm for reaching and grasping tasks as well as ball throwing.

To be able to learn feasible motor actuation out of the results form the human experiments, a framework is needed that is perpendicular to optimization. Thus the human hand-arm model will be expanded with neural feedback pathways. To use this model for human grasping, a hand model has to be integrated to the arm model. This hand model will be based on cadaver studies (as the arm model is) and include all degrees of freedom. Generic cost functions will be derived from the muscle model. Methods to apply policy search on those cost functions will be explored and evaluated in a simplified low DoF simulation; the milestone is to reliably solve simple reaching and grasping tasks in simulation. The variable stiffness optimization using the OFC framework will be extended to the full-scale muscle model and implemented on 6 DoF. In the next step, we extract optimality principles from human models and transfer it to the variable stiffness robot arm control model using different cost functions, derived from sample trajectories. Map plans and cost functions to variable stiffness control models will be resolved into force-torque plans and stiffness modulations on both the muscle model simulation (to compare and verify against human experimental data) and onto the robotic hand-arm system to generate optimized variable impedance movement plans that will be fed into the low level controller. Finally it will be possible to generate high level plans for lower level controls in specified tasks in convincing human-like manner.

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Institutional Partners:

German Aerospace Center (DLR), Germany:
Project coordinator. Responsible for integrating a variable-impedance robotic system in the project. Development of a novel EMG system for human impedance measurements. Integration of human and robotic impedance control approaches.

Technische Universiteit Delft, Netherlands:
Responsible for modelling the human neuromuscular system from muscle to joint level. Development of time varying system identification and parameter estimation techniques to quantify the model parameters from recorded data using haptic manipulators.

IDSIA, Switzerland:
Responsible for learning high-level task-specific controllers based on reinforcement signals for the flexible variable-impedance robot arm developed by DLR, and for inverse reinforcement learning to extract cost functions in collaboration with UEDIN.

University of Edinburgh, United Kingdom:
Responsible for the development of 'Optimal Feedback Control' based closed loop control paradigms, specifically tailored to redundant and variable impedance actuators. Developing methods to extract cost functions and comparing control policies to evaluate improvement in performance when modulating impedance optimally.

Université Paris Descartes - CNRS, France:
Responsible for studies of impedance control in humans, using a variety of techniques including direct physiological measurements (EMG, H-reflex), mathematical modeling and robotic simulation. The main emphasis is 1) to suggest biologically-inspired strategies to be applied to robotics control and 2) to use analogies with robotic devices to better understand human behaviour in terms of impedance.