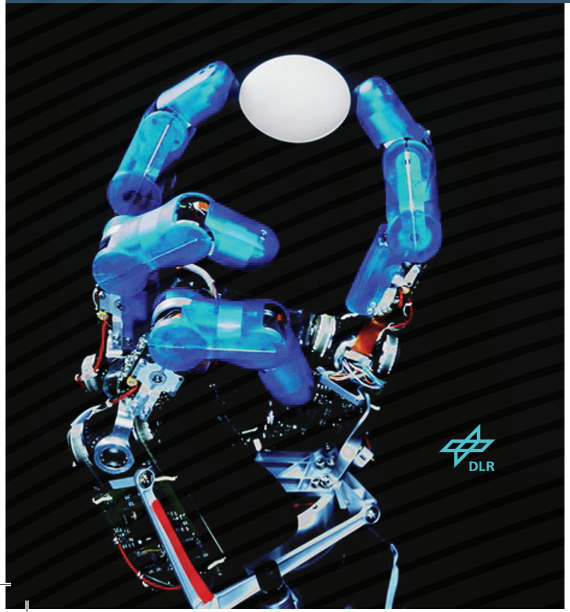
Industrial robots are much stronger than humans, but also very rigid. For example, humans can throw objects much further and catch them much more gracefully than robots, temporarily storing energy in elastic tendons and muscles. Such flexible actuators, however, require more sophisticated control algorithms than those used by traditional robots.

The goal of the STIFF consortium is to endow a highly biomimetic robot hand-arm system with the agility, robustness and versatility of the human motor system, by understanding and mimicking the variable stiffness principles that are so effectively employed by the human central nervous system. A key component of our study will be to produce an anatomically accurate musculoskeletal model of the human arm and hand.

The project will develop novel methodologies to understand how the human arm can adapt its impedance, e.g., by changing the co-contraction level or by adapting reflex gains. The impedances of the arm and hand will be investigated using powerful robot manipulators capable of imposing force perturbations. While stiffness and elasticity are currently exploited in the context of artificial laboratory tasks, we will investigate stiffness-dependent behaviour in natural tasks such as throwing a ball or inserting a peg in a hole.

Existing closed-loop system identification techniques will be extended by non-linear time-variant techniques to model the behaviour during reaching and grasping tasks. Grasp force modulation and hand muscle activity correlations will be acquired through machine learning techniques and then transferred to the robotic system. Finally, optimization techniques gleaned from and validated on the detailed biophysical model will be transferred to the variable-impedance actuation of the novel biomorphic robot.

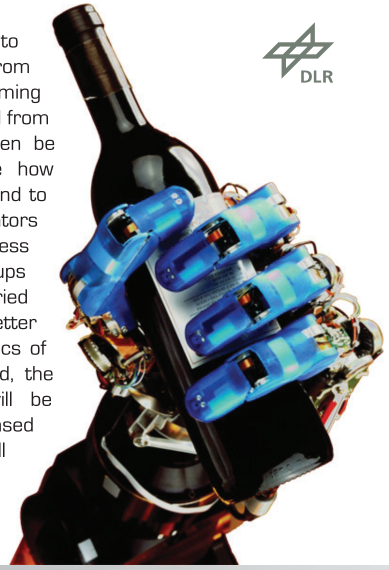
Funded by the 7th framework programme of the EU (STREP grant agreement No: 231576)



Biomorphic robotic limbs can, in principle, perform with the skill and dexterity of human limbs by exploiting variable stiffness. However, control schemes developed for conventional rigid robots do not directly apply.

By studying the human musculoskeletal system, and extracting the principles that underly its behavior, more suitable robot control can be realized by optimizing these principles to bridge the gap between the two systems.

Part 1 (responsible: UPD)
A major objective of the STIFF project is to understand how humans benefit from controlling joint stiffness while performing different manipulation tasks. Insights gained from studying human motor behaviour can then be transferred to artificial systems to see how performance can be improved in robots, and to determine the benefits of biomimetic actuators that allow for the control of passive stiffness properties. This part of the project groups together the experimental studies to be carried out with healthy human volunteers. First, better estimates of the time-varying characteristics of human stiffness will be developed. Second, the study of human stiffness behaviour will be extended beyond what is currently known based on artificial laboratory tasks. Finally, we will look at the neural mechanisms underlying stiffness control in humans. These activities will have a close interplay with other parts of the project: human behaviour will inspire control schemes to be implemented on robotic systems, while models of the human musculoskeletal system and implementations on robotics systems will be used to better understand the observed human behaviour. Human (stiffness) performance during the experiments will be quantified as a benchmark system for the robotic performance with and without the controller developed in Part 4.



Part 2 (responsible: DLR)
Building on a variable impedance integrated hand-arm system currently under development at DLR and funded elsewhere, this Part mainly deals with the challenge of (i) using variable impedance actuators and (ii) modeling the control and actuation in this novel robotic hardware. Optimal Control of this actuator system is investigated in detail (without considering optimality of stiffness at this stage) since this has, to date, only been done efficiently, in a variable impedance scenario, for toy systems. Various demonstrator robotics tasks will be used to mimic and compare the results of the human impedance measurements from Part 1, including ball throwing.

Part 3 (responsible: TUD)
This Part deals with detailed modeling of the arm-hand musculoskeletal system with biomechanical fidelity. Why? Because we want to use results from the studies of Part 1 in a more quantitative framework that is conducive to optimization studies. The musculoskeletal model can be treated as a physically realistic plant (like a robot!) in which the geometric, actuator and reflexive properties are well-defined, thereby allowing optimization principles and strategies to be gleaned (done in Part 4) from the movement study data generated in Part 1.

Part 4 (responsible: UEDIN)
This Part will first extract key optimality principles used in biological systems by combining data from the human studies (Part 1) in the context of the bio-mechanically realistic human arm models (Part 2). These optimality principles can then be implemented on (a kinematically slightly different) variable stiffness robotic system. Working with optimality principles, rather than specific control laws, ensures that the mismatch between the exact human arm model and the tendon-based robot arm will not be an issue. High level control goals will be specified through reinforcement learning, followed by low level optimization of redundant joint angles and stiffness parameters based on the optimal feedback control framework. Results will be benchmarked according to the criteria developed in Part 1.