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Title: System Identification of Human Neuromuscular Control at the Spinal Cord and at the Brain.

Abstract: Humans are highly capable of moving their limbs and exerting forces to cope with a wide variety of tasks in daily life. The neuromuscular control system consists of muscles, joints, position, velocity and joint sensors in the muscles and the Central Nervous System (CNS) as the controller. Basically two feedback loops are present, one through the intrinsic visco-elasticity of the muscles, modulated by the co-contraction level of the muscles, and the various neural reflex loops through the spinal cord and higher brain areas. During motions, the reflex gains are continuously modulated by the CNS.

The goal of our research is to determine the role of the CNS in generating motions and modulating the reflex gains during a wide variety of tasks, using system identification techniques.

We are using force-controlled robot manipulators to impose force perturbations at the limbs during functional tasks, whereas the position and force of the hand and activation level of the muscles (EMG) is being recorded. With closed-loop system identification methods Frequency Response Functions (FRF) are being assessed between the force perturbations and the hand position and force. Using neuromuscular models the intrinsic stiffness and viscosity of the muscles can be assessed, as well as the gain and time-delay of the position, velocity and force reflex loop.

The methodology has been applied to investigate normal neuromuscular control in a wide variety of conditions, as well as pathological behaviour in patients with stroke, Parkinson's disease and dystonia. We have robot manipulators to investigate the shoulder, wrist, shoulder-elbow-wrist, ankle, head-neck and low-back systems. In addition, we have investigated human control behaviour during functional tasks as car driving and airplane control.

Using small force perturbations allowed us to apply linear system identification methods to investigate neuromuscular control. Newly developed methods using the robust and fast method (Pintelon & Schoukens, 2012) and Linear Parameter Varying techniques (Verdult & Verhaegen, 2002) will enlarge the scope towards identifying non-linear and time-varying behaviour.

New techniques also employs recording of the EEG signal at the cortex. Using high-density EEG systems with 256 electrodes, the EEG sources at the brain can be estimated. Preliminary results indicate that the EEG signal variance contains about 80% non-linear contributions and 20% linear contributions. The development and parameter estimation of appropriate non-linear model structures will be a huge challenge in the near future.

It is concluded that the application of rigorous system identification techniques enables to achieve good insight in human neuromuscular control, and can assess the role of muscle dynamics, sensor dynamics and the reflex modulation through the Central Nervous System.