

Lower-extremity movement restoration through muscle closed-loop FES control using natural sensor feedback

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The objective of the project was to explore the feasibility of controlling a skeletal muscle state (force / length) via functional electrical-stimulation (FES) using afferent fiber neural activity as unique feedback. This implies to be able to on-line extract information from neural signal in a form usable by the FES controller. For this purpose, we used the technology of thin-film longitudinal intrafascicular electrodes (LIFEs)

FES allows for restoring motor activity of paralyzed limbs by applying electrical stimulation to sensory-motor systems *via* electrodes which are placed at the skin, or implanted (epimysial, intramuscular, nerve cuff, intraneural). Improvements in FES systems rely on the development of interfaces to record from and to stimulate neural tissue. Our research is mainly concerned with **implanted neuroprostheses for both restoring sensory-motor functions and recording at neural level.**

The previous work with LIFEs was able to achieve linear control of the ankle joint angle using LIFEs to stimulate and actuate the muscle and LIFEs to record activity from natural sensors in the muscle. The approach using a simple PID controller and a lookup table mapping the sensory information to an angle was able to achieve ankle position control to within 3° of the target angle (Yoshida and Horch 1996). Several questions can be asked? 1) If the crude lookup table estimator were replaced by a 1st or 2nd order model based estimator, would better control be achieved? 2) Does muscle fatigue alter the sensitivity of the muscle afferent sensors? 3) Could the signal to noise be further improved, and will this improvement further increase the performance of the controller?

The ultimate objective of our work is to use natural sensors, such as muscle afferents, to give feedback information for the FES artificial controller. The Longitudinal Intrafascicular Electrode (LIFE) is a promising solution. It is implanted longitudinally within individual peripheral nerve fascicles. These electrodes are more selective than nerve cuff electrodes but remain multi-unit.

We have explore 3 aspects: 1) the estimation of skeletal muscle state using Intrafascicular ENG recordings, 2) evaluating the fatigue effect on afferent neural activity, 3) tentative to improve signal-to-noise ratio in peripheral nerve recordings with thin-film longitudinal intrafascicular electrode.

1) Towards a model-based estimator of muscle length and force using muscle afferent signals for real-time FES control

10 New-Zealand anesthetized white rabbits were involved in this study. The left leg of the rabbit was anchored at knee and ankle joints and tendon of Medial Gastrocnemius muscle (MG) was attached to the arm of a motorized lever system. The position of the lever arm was controlled and both force and relative position were recorded. A LIFE was implanted in the tibial branch innervating MG muscle and allowing us to record from the nerve activity (electroneurogram (ENG)). Muscle was stretched using the lever arm and presenting sinusoidal stretches. A partial analysis of the data leads to the definition of relationship for the firing rate as a function of length could be found. It is based on a simple and fast method for unit separation and firing rate estimation with the big advantage that it could be easily implemented for online application in order to estimate muscle length from ENG. The method could be used to generate a robust length estimator that maps the muscle afferent firing rate to a position. We are currently working on spike discrimination based upon detected peak shapes. This would certainly help to improve with the outliers detected spikes. These results have been published in EUROCON 2005 conference proceedings. We are currently analyzing the remaining data.

2) Fatigue effect on ENG recordings

10 anaesthetized New Zealand white rabbits were involved in the study. The same experimental setup as defined in previous section was used. A TF-LIFE was implanted in the tibial branch innervating the MG muscle. We investigate the potential effect of fatigue on the parameters of the model found in the previous study (see section 1) comparing the coefficients before and after fatiguing the muscle. The muscle was fatigued by electrical stimulation using 60Hz pulses. The muscle was considered fatigued when the maximal force it produced fell under 50% of its initial value. This study is still on going and results should be published in short future.

3) Improvement of signal-to-noise ratio of peripheral nerve recordings with thin-film longitudinal intrafascicular electrodes

Compared to nerve cuff electrodes, LIFE electrodes provide higher recording signal-to-noise ratio. In the context of FES systems, stimulation and recording have to be done simultaneously. Since the neural interface is located in the proximity of the neuromuscular structures of interest, the EMG artefact limits the gain that can be set for signal acquisition, which in turn limits the recording signal-to-noise ratio. Stimulation artefact additionally corrupts the recorded signals. We investigated a new approach to improve the signal-to-noise ratio, study is still on going and results should be published in short future.