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Tremor attenuation based on joint impedance modulation using FES

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Abstract

In this work we describe experiments to validate an alternative method to attenuate the effects of pathological tremor using FES. The method is based on co-contracting antagonist muscles in order to increase joint impedance and hence improve the joint stability for trembling movements. Both open-loop and closed-loop trials involving tremor patients and healthy subjects were conducted, and the results indicate that an effective functional benefit may be obtained.

Keywords: Pathological tremor, Impedance modulation, Closed-loop FES control

Introduction

Tremor may be defined as an involuntary, approximately rhythmic and roughly sinusoidal movement [1] for which an absolutely effective treatment is not yet available. Although pharmacological and surgical therapies exist for the two most prevalent types of tremor, essential tremor (ET) and the tremor associated with Parkinson's Disease (PD), they still present limitations and hence one important alternative is the use of electrical stimulation to reduce the effects of tremor.

In this scenario, different technologies based on electrical stimulation have been proposed as an alternative for pathological tremor management. These therapies range from invasive interventions targeting specific structures in the brain, such as Deep Brain Stimulation (DBS) [2], to the stimulation of muscles involved in tremor using surface electrodes [3]. However, the costs, effectiveness, and particularly the risks involved may vary greatly among these solutions.

In this work, we focus on the use of surface electrodes, such as in [3], but with the main difference that FES is not used to generate an anti-phase motion to counteract tremor, such as in the work from Prochazka. Our strategy here is to use FES to increase the impedance of the trembling joint in order to provide an effective functional benefit to the patient, i.e., reduce the effects of tremor while improving joint stability and minimizing the total associated discomfort and fatigue.

In order to evaluate the effectiveness of this strategy, open-loop and closed-loop trials were conducted involving one tremor patient and two healthy subjects.

Material and Methods

Methodology

The main compensation strategy applied in this work was based on the use of FES in order to increase joint impedance by co-contracting antagonist muscles and hence attenuate tremor. In a first moment, the validity of this approach was evaluated in open-loop experiments, i.e., the corresponding stimulation levels were tuned manually, and not in response to real-time readings from sensors measuring tremor. In this trials, the overall stimulation level was defined subjectively based on the subject's sensitivity, while the individual muscle FES intensity was chosen in order to reduce the induced motion on the joint.

Later, a closed-loop strategy based on the same general idea was developed. Within this approach, which was first detailed in [4], portable sensors are used for online tremor estimation, and this information is then used by the control algorithm, which automatically sets appropriate stimulation levels that will increase joint impedance without affecting its motion.

In the scenario of assistive technologies for tremor attenuation, it is essential to use closed-loop strategies, since long-term use require constant evaluation of tremor onset.

Subjects and FES normalization

The experimental data discussed in this work refer to two different classes of subjects. First, the proposed approach was evaluated on open-loops trials involving one patient with ET. In the following stage, tests were conducted on two subjects with no neurological impairment, where tremor on the target joint was induced by an independent electrical stimulator.

Within the tests on healthy subjects, the target joint was the wrist, particularly the dorsi/palmar flexion. Two antagonist muscles were chosen for each subject to compose the pair of antagonist muscles to be controlled, such as the *Flexor Carpi Ulnaris* (FCU) and the *Extensor Carpi Ulnaris* (ECU). FES-induced tremor was produced by stimulating other muscles, such as the *Flexor Carpi Radialis* (FCR), the *Palmaris Longus* (PL), or the *Extensor Digitorum Communis* (EDC).

Due to inter and intra-subjects variations of electrically controlled muscles, each trial was preceded by a procedure where the maximum and minimum FES levels were set. The normalized stimulation level was computed based on these subjective limits. Stimulation frequency was constant in all experiments.

Experimental Setup

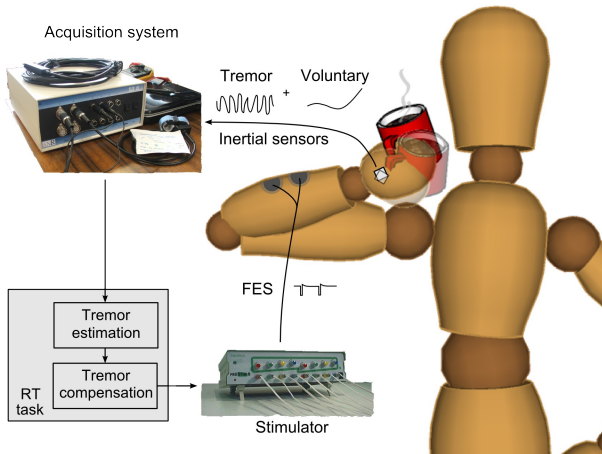


Fig. 1: The experimental setup used in this work.

The experimental setup is illustrated in Fig. 1. The stimulator is an 8-channel stimulator, the Prostim, designed jointly by the LIRMM and Neuromedics. The main sensor used in the control loop is the IDG-300, an angular rate sensor from Invensense, whose measurements are acquired by a National Instruments acquisition card. Both tremor tracking and tremor attenuation algorithms are executed in a 50 Hz-loop running in a Linux system. The whole system is electrically isolated to ensure the subject's safety.

In order to produce FES-induced tremor in trials involving healthy subjects, a commercial stimulator from CEFAR, the Physio 4, was used. It produces biphasic square pulses, opposed to the biphasic pulses with capacitive discharge generated by Prostim.

Results

In Figs. 2 to 4, motion data from tremor attenuation experiments involving one ET patient and two healthy subjects. For both open-loop and closed-loop trials, the periods when the compensatory FES system is turned on is highlighted using grey rectangles. Additionally, key features of each data set are indicated using black horizontal lines.

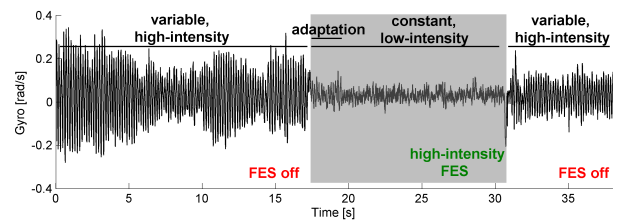


Fig. 2: Open-loop trial on ET patient.

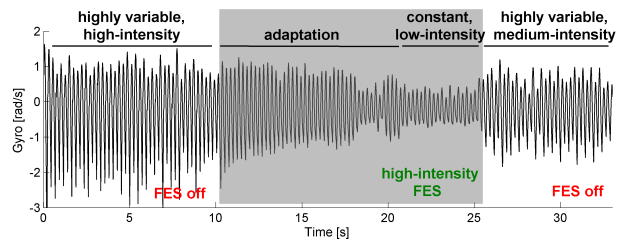


Fig. 3: Closed-loop trial on subject A.

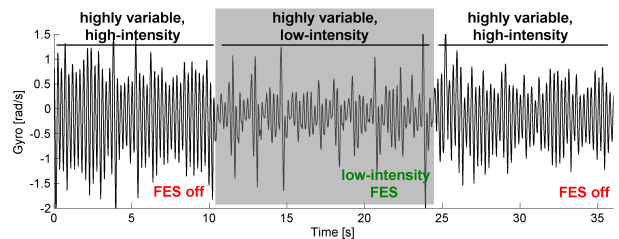


Fig. 4: Closed-loop trial on subject B.

Among the several trials conducted in this work, here we have chosen to illustrate those where a representative behaviour is observed. Those are qualitatively discussed within the Discussion. A more quantitative analysis of the method performance was conducted in [4].

Discussion

The experimental results have illustrated the feasibility of attenuating the amplitude of tremor by co-contracting antagonist muscles acting on the concerned joint using FES. In this section, we discuss the scope of these results, focusing on the qualitative analysis of the different behaviours and on the limitations of the current protocol.

Concerning those limitations, important difficulties still prevent a complete evaluation of the method for different types of tremor. Some of these limitations refer to constraints of the stimulation technology used in the experiments. Indeed, since surface electrodes were used, correct positioning in order to minimize diffusion for other forearm muscles was a challenge.

Other limitations, however, were related to the very essence of the experiment. For instance, since pathological tremor is naturally variable in time, in some cases it is difficult to discern if tremor was attenuated due to the effect of FES, or if its amplitude was naturally decreased. Moreover, both patients and healthy subjects often react spontaneously to compensate tremor, while in ideal experimental conditions we would like to evaluate the effect of the stimulation only on tremor reduction.

However, even with those difficulties, the conducted trials have led to interesting conclusions. First, we have observed that the applied attenuation method is a feasible alternative for tremor patients, since no major complaints concerning pain or discomfort were made, and effective reduction on tremor amplitude was observed. Also, this attenuation on tremor amplitude was observed using both open-loop and closed-loop strategies on experiments involving both tremor patients and subjects with no neurological impairment.

Beyond those first conclusions, the obtained data may help us to further understand the effects FES may produce on joint impedance and consequently on tremor attenuation.

The data from Figs. 2 and 3, for instance, illustrate that an adaptation period may exist between the first applied stimulation pulses and the consequent effect on tremor reduction. Since those adaptation periods were considerably longer than the expected values for the electromechanical delay between FES and muscle action, it is possible that the reaction from the subjects to the stimulation cause this effect. Indeed, in Fig. 4, an instantaneous tremor reduction was observed, indicating that this was probably a subject-dependent effect.

The data also enable further discussion on the modulation of joint active viscoelasticity due to FES and how this may affect tremor. Indeed, it may be inferred from Figs. 2 and 3 that a high-intensity stimulation level may increase joint impedance such that stronger oscillations may also be attenuated. This observation is in accordance

with the data from Fig. 4, where low-intensity stimulation parameters were chosen by the subject, in such a way that the faster peaks of tremor were barely attenuated.

Based on this discussion, it is likely that the performance of the proposed strategy is considerably dependent on the subject. First, in order to reduce the adaptation periods for tremor attenuation, and secondly for enabling higher stimulation levels that will produce more effective tremor attenuation.

Conclusions

In this work, we have presented an alternative method to attenuate the effects of pathological tremor using FES. The strategy is based on the use of electrical stimulation to modulate the joint impedance, and hence reduce the effects of tremor.

The strategy was evaluated on both patients and healthy subjects and satisfactory results were obtained. Furthermore, different interesting behaviours were observed on the tests, which may help on the improvement of the method.

Future works will focus on the evaluation of the proposed method on longer trials involving daily tasks. In this way, we expect to compare the effectiveness of the approach with respect to alternative methods.

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