Title of Entry: Neural oscillator based control for pathological tremor suppression via functional electrical stimulation

Innovation:
This work is a novel application of the EMG signal at present, and it may also become a novel device or technique in near future. It is a promising technique to suppress pathological tremor with functional electrical stimulation (FES) compared with the traditional methods (medicine or surgery). We are the first group who adopts EMG signal as bio-feedback to design the biomimetic controller (neural oscillator) for tremor suppression via FES. EMG feedback can provide more instant information of tremor than other motion feedback information. In addition, we have proposed a technique named as two-step filter for EMG signal processing in this study.

Description:

Background: Pathological tremor is defined as involuntary, approximately rhythmic, and roughly sinusoidal movement with high frequency of human body parts among the patients with Parkinsonism, stroke, traumatic brain injury, multiple sclerosis, etc. This work aims at developing an FES assistive system to suppress the pathological tremor. The novelty is about the controller design based on EMG bio-feedback. Compared with the previous methods on tremor suppression, the predictive and adaptive functions are the most attractive features.

Methodology: The block diagram of the whole system is shown in Fig. 1, which contains two major parts: a controller and a musculoskeletal model (controlled plant). The core of the controller is the neural oscillator, which generates appropriate motor patterns (stimulation patterns) for the FES stimulator. Two neural oscillators in charge of pattern generation for agonist and antagonist are designed. The FES component is mainly controlled by the neural oscillators. A pair of antagonist muscles can be actuated by FES and generate the anti-tremor force to attenuate the pathological tremor. The appropriate stimulation patterns for muscles should contain phasic activation and tonic activation (intensity pattern) according to the EMG patterns observed in human motion. The phasic pattern generation is mainly determined by neural oscillator, and the tonic pattern is mainly achieved from the EMG bio-feedback. In addition, a feedback regulator provides a fine regulation for the stimulation pattern with the online feedback signals (e.g. motion information).

The neural oscillator has four functions in this work: (1) regulating the frequency pattern of stimulation, (2) adaptive on/off function, (3) regulating the phase of stimulation via EMG feedback, (4) full coupling of the musculoskeletal system. "Oscillator'' is viewed as a main source of the pathological tremor in some patients from a general point of view, and the tremor EMG of muscles is the subsequent outcome. In theory, the pattern of neural oscillator is thought to be similar to that of EMG. At present, it is impossible to develop a neural oscillator model using direct information from the brain with current technology. But EMG can be measured and recorded, so EMG may be a good alternative to entrain the artificial neural oscillator in order to get the desired stimulation patterns.

The EMG acquired from patients contains both involuntary EMG (from tremor) and voluntary EMG (from volitional motion), which are mixed. Therefore, the raw EMG should be processed before it is used to entrain the neural oscillator. A two-stage filter is proposed in as shown in Fig.2 [1]. At the first stage, the artifacts caused by FES are filtered. At the second stage, the involuntary (tremor) EMG is distinguished from the voluntary EMG in case the volitional movement is performed. The second step can be realized using a high pass filter or other advanced algorithms. There is one more step, i.e. the tremor EMG should be rectified and a smooth EMG envelope is needed in order to get the accurate EMG patterns of tremor. The tonic (intensity) pattern of neural oscillator is also achieved from EMG signal. If the envelope of EMG is used as the tonic pattern of neural oscillator directly, some information will be lost during the period where EMG is zero due to the phasic difference between EMG pattern and output of neural oscillator. A simple way is proposed to pick up the burst peaks of raw EMG without considering the phasic pattern.

Results: Under the configuration as shown in Fig.1, when electrical stimulation is on, tremor is significantly suppressed as shown in Fig.3. The average rates for tremor suppression using data from nine patients are shown in Table.1. The measurement system of data collection on tremulous limb is shown in Fig.4.

Conclusion: A biologically inspired system for tremor suppression is designed. The neural oscillator aims to generate the appropriate anti-tremor patterns for the two muscles in charge of flexion/ extension or pronation/supination. Surface EMG is adopted as biofeedback to regulate the neural oscillator reciprocally, i.e. entrain the neural oscillator and shape the patterns of stimulation. The feedback regulator (PID controller and compensator) is designed to refine the intensity pattern of stimulation. The musculoskeletal models of elbow joint and wrist joint are constructed separately as the controlled plant for simulation study. The results are satisfactory because the tremor attenuation of 90% is achieved on average.

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Supporting Material:

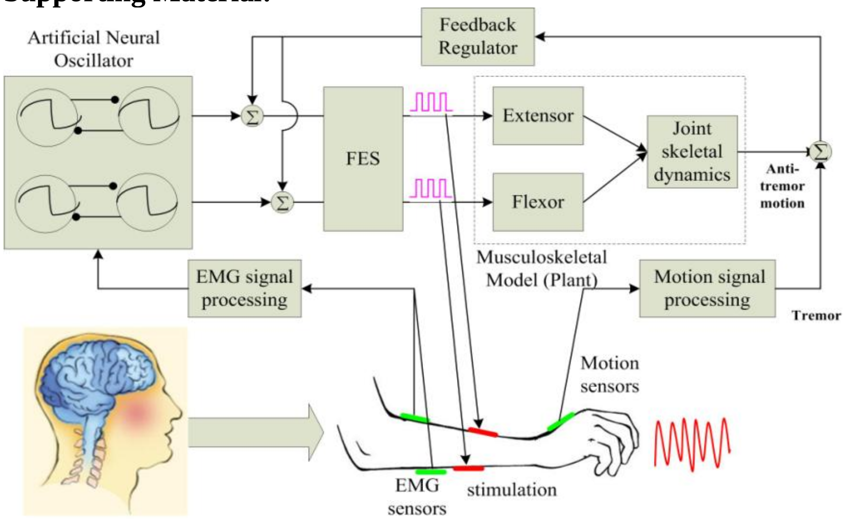

Fig.1 Schematic diagram of pathological tremor suppression system using EMG bio-feedback.

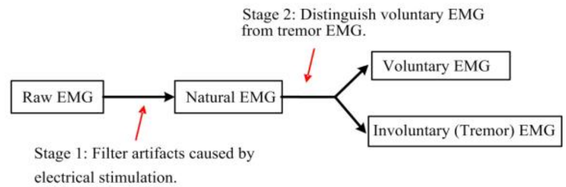

Fig.2 Two-stage filter for EMG processing.

Table 1. Tremor suppression rates.

Subject	Age	Sex	Tremor sources or types	Targeted tremor	Results (mean attenuation %)
A	66	M	Parkinson (resting) tremor	Elbow (F/E)	89.79
B	41	M	Psychogenic (postural) tremor	Wrist (F/E)	91.58
C	44	M	Parkinson (resting) tremor	Wrist (F/E)	92.17
D	49	F	Parkinson (resting) tremor	Wrist (F/E)	88.32
E	61	M	Rubral (kinetic)tremor	Elbow (F/E)	90.13
F	63	F	Parkinson (resting) tremor	Elbow (P/S)	89.21
G	70	M	Parkinson (resting) tremor	Elbow (P/S)	87.02
H	68	M	Parkinson (resting) tremor	Wrist (F/E)	85.75
I	40	F	Rubral (kinetic) tremor	Wrist (F/E)	93.43

Note: F/E, flexion/extension; P/S, pronation/supination.

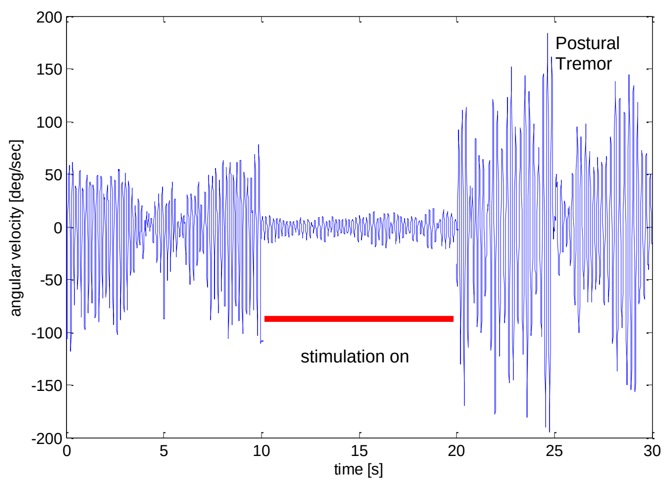

Fig.3 Tremor is successfully attenuated when stimulation is on.

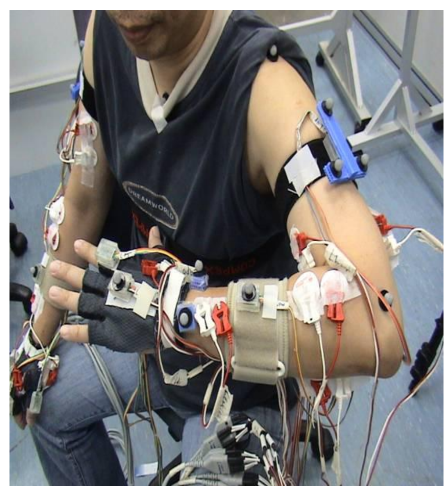

Fig.4 Tremor measurement system.

Reference: **[1] Dingguo Zhang**, Wei Tech Ang, "Reciprocal EMG controlled FES for pathological tremor suppression of forearm," The 29th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), pp. 2359–2369, 2007.

History of Dissemination**：** **Dingguo Zhang, P. Poignet, F. Widjaja, W.T. Ang, "Neural oscillator based control for pathological tremor suppression via functional electrical stimulation,"** ***Control Engineering Practice*****, vol.19, pp.74-88, 2011.**