Wearable Orthosis for Tremor Assessment and Suppression – A tutorial
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The material in this tutorial is based in part on Wearable Robots: Biomechatronic Exoskeletons (1st Ed., 2008) by Jl Pons and my own research. For more information, please write to matinrusta7213@gmail.com. © 2019 K. N. Toosi University of Technology

Tremor is defined as rhythmic, involuntary oscillatory activity of body parts. There are mainly two types of tremor based on patient examination which are as follow:

- **Rest tremor** is a tremor present in a body part that is not voluntarily activated and is completely supported against gravity (ideally resting on a couch).

- **Action tremor** is any tremor that is produced by voluntary contraction of a muscle. It includes postural, kinetic, intention, task specific, and isometric tremor.

We are going to explain different types of action tremor and then we describe different mechanisms that result in tremor.

- Kinetic tremor is tremor occurring during any voluntary movement. Simple kinetic tremor occurs during voluntary movements that are not target directed.

- Intention tremor or tremor during target directed movement is present when tremor amplitude increases during visually guided movements towards a target at the termination of that movement, when the possibility of position specific tremor or postural tremor produced at the beginning and end of a movement has been excluded.

- Postural tremor is present while voluntarily maintaining a position against gravity.

- Isometric tremor—tremor occurring as a result of muscle contraction against a rigid stationary object.

- Task specific kinetic tremor—may appear or become exacerbated during specific
activities. Occupational tremors and primary writing tremor are examples of this.

As tremor research has developed rapidly in the past few years because of clinicians and basic neuroscientists willingness and interests in the oscillatory phenomena occurring under normal and abnormal conditions, four physiological basic mechanisms for such oscillatory activity have been described: mechanical oscillations; oscillations based on reflexes; oscillations due to central neuronal pacemakers; and oscillations because of disturbed feedforward or feedback loops that may occur when feedforward or feedback systems become unstable.

To give you more details about how a mechanism operates in the body and initiates the tremor Mechanical oscillations—the simplest cause of tremor—which is also so-called mechanical tremor of the extremity is described below. Consider a stretched-out hand with the extensor muscles tonically activated to counterbalance gravity. Assuming a completely flat spectrum of muscle activity, some of the muscle fibers will be activated at the resonance frequency of the hand. Thereby, the hand will oscillate at this resonance frequency, which is determined by the equation:

\[ \text{frequency} \approx \frac{K}{\sqrt{\text{Inertia}}} \]

with \( K \) being a constant determined mainly by the stiffness of the muscle and the inertia of the oscillating limb. Worth noting that resonance frequency is different for different body parts; for example, 25 Hz for the fingers, 6–8 Hz for the hand, 3–4 Hz for the elbow, and 0.5–2 Hz for the shoulder joint.

**How to deal with tremor?**

Previous studies have shown that approximately 50 percent of ET (essential tremor) patients either do not respond to medications or do not have a good response. In general, 10 to 15 percent of patients can have extreme tremor. The worst case could be that they cannot do anything with their hands due to the tremor, such as eating, writing, and drinking.

Fortunately, help may be on the way for people who have hand tremors. There are many different products and devices as well as chemical treatments to deal with tremor in different body parts. In the following, we are going to discuss some of the newest orthosis and assistive devices that are invented and used in this area.

This tutorial has been developed to help you understand the basic mechanisms of wearable orthosis and assistive devices that are useful in helping the people who are suffering from brain disorders which are the main cause of tremors in different body parts. We explain the computational modeling for these devices. While the mathematics are included, we discuss about practical analogies and state-of-the-art technology that are implemented to make these devices more efficient.

**Wearable Assistive Devices**

There are different wearable assistive devices developed to deal with tremor mainly caused by brain disorders. Two new studies have shown that a wearable, noninvasive neuromodulation device may be of assistance to the 10 million people in the United States who deal with a condition called essential tremor. It’s the most common type of tremor disorder, affecting the hands, head, and voice. The ailment can
interfere with basic daily activities, including eating, shaving, and writing. We are going to discuss about two most famous commercially available devices in the market. GyroGlove and another assistive device developed by Microsoft company.

The first device (as you see in Figure 1) stimulates the median and radial nerves in the wrist and delivers a stimulation pattern that’s tuned to interrupt a person’s tremor. The second product, the GyroGlove, is a wearable device, based on a miniature gyroscope - a novel concept, which has the potential to offer significant improvements in their quality of life - to the back of the hand, that can help to stabilize these hand tremor. This means that everyday tasks – such as eating, drinking and writing – can be performed more easily.

A gyroscope is a spinning wheel or disk which is used to maintain orientation or stability with the basic approach of conserving angular momentum to stay upright in any plane of motion. And they are therefore able to counter any input of force in any direction, swiftly and proportionately.

Gyroscopes are used in cutting edge aerospace technology as well as guidance systems for planes and satellites. Gyroscopic effects are also responsible for the stability of a moving bicycle.

The GyroGlove utilizes gyroscope technology. According to GyroGear (developers of GyroGlove), gyroscopes are spinning discs inspired by bleeding edge aerospace technology, but no more different than children toy tops. gyroscopes do their utmost to stay upright – they conserve angular momentum. These spinning discs thus counter any input of force instantaneously and proportionally.

Voluntary-driven elbow orthosis for tremor suppression

Other than the devices developed to deal with body tremor, there also are more complex orthosis and robots developed. Robotic technology is gradually
becoming very popular in the medical sections. There are many medical conditions that have benefited from outstanding technological developments such as surgery with the help of robots (robo-surgery). Robotic devices have also been increasingly used in movement disorder assistive devices.

We are now going to discuss two suppression tremor orthosis and explain how they have been designed and function, in details. As you may know, neurological rehabilitation (rehab) is program designed for people with diseases, injury, or disorders of the nervous system. Neurological rehab can often improve function, reduce symptoms, and improve the suppression approach. In tremor suppression methods, with different approaches, we aim to suppress the tremor by resisting the respective motion, while simultaneously moving along with the voluntary motion.

![Figure 3. Suppression method block diagram][3]

The suppression approach responsible for tracking the voluntary motion of a human in elementary components.

- A force transducer measures the mechanical interaction forces between a human and the suppression device.
- The Filter block separates the voluntary from the total force signal.
- The admittance controller accepts a force input and output a velocity command.
- The velocity controller acts to reject tremor disturbances that may influence and interfere with the orthosis voluntary velocity motion.
- And finally, the tremor forces applied by the human are suppressed, while the voluntary component is tracked by the orthosis.
The actual orthosis system based on the suggested approach is shown in Figure 2. It is a one DOF system targeting the human elbow, composed of a suppression motor, gearing, sensors with force transducer, an encoder, and upper and forearm braces. The SM gearing includes an off the shelf spur gearbox the upper and forearm braces as well as the main body of the orthosis were 3D printed using an ABS plastic variant. An aluminum beam is used to connect the forearm brace to the main orthosis body. Upper arm length can be adjusted by sliding of the top and bottom supports, while adjustment for the forearm is done through two passive intersecting joints (P1, P2) in the forearm brace as shown in Figure 4A.

Figure 4. The orthosis simulation system connected to the DM. P1 and P2 indicate the two passive wrist joints. B) The completed orthosis [3]

How does the controller work?

The control of the orthosis was implemented using the feedback loops shown in the block diagram of Figure 5. The admittance block contains a PID force controller, and a PI controller was used as the speed controller corresponding to the elementary blocks (Figure 1). The filter block was implemented with a Kafman Filter, a stochastic estimator that is often employed in both tremor suppression as well as non-tremor-related application. G(s) refers to the SM and gearbox model, forming part of the suppressive system. To improve the speed controller tracking a state feedback was also included with the force sensor. Along with the human input labeled \( T_h \), the disturbance to the suppressive system also includes the orthosis forearm gravitational forces labeled \( T_g \). The top loop in Figure 5 is designed for compensation of the gravity disturbance component due to the orthosis forearm link so that the signal \( f_g \) and subsequently \( \Delta f \) entering into the admittance controller acts to impede the gravity component. The admittance controller can be represented as:

\[
\omega_c = K_{fp} \Delta f + K_{fd} \frac{d\Delta f}{dt} + K_{fd} \int_0^t \Delta f ds
\]

where \( K_{fp}, K_{fd}, \) and \( K_{fd} \) are PID gains and \( \omega_c \) is the velocity output of the system. The input to the controller is:

\[
\Delta f = f_d - f_{ext} - f_g
\]

where \( f_{ext}, f_d, \) and \( f_g \) are the estimated human voluntary interaction force, the desired interaction force and the gravitational force.
The second wearable orthosis

In this part, we describe another wearable orthosis and its work principle for the simultaneous assessment and treatment of essential tremor. This active orthosis is designed according to the shape and function of the human upper limb.

A set of rotary flat dc motors are fixed on the orthosis in the upper limb to help its activation which are controlled by a personal computer with real-time software processing. It also activates the elbow and wrist joints, being able to measure and apply forces on three movements of the upper limb: elbow flexion–extension, forearm pronation–supination and wrist flexion–extension.

The active orthosis aims to allow both monitoring of upper limb movements and implementation of tremor suppression strategies. Therefore, it is equipped with kinematics (angular velocity) and kinetic (interaction force between limb and orthosis) sensors.

The position and rate of rotation of the joint is detected by a chip gyroscope. The orthosis can be used in a monitoring mode and in an active mode.

How it works:
The active orthosis is controlled by a computer with a dedicated software application that implements an algorithm to be able to distinguish in real time tremorous from voluntary movement and to calculate the force applied by the active orthosis over the upper limb in order to change its biomechanical characteristics and, consequently, suppress tremor. In summary, the control system works as follow:

- The sensors coupled to the limb measure its motion.
- An error cancelling algorithm performs a real-time discrimination of the undesired component of motion.
• Tremor information is sent as the input to the controller in order to generate the desired exoskeleton performance to suppress the tremor.

In this approach, the musculo-skeletal system (each upper-limb joint contributing to tremor) is modelled as a second-order biomechanical system exhibiting a low-pass filtering behavior. The cut-off frequency of this second-order system is directly related to the biomechanical parameters of the second-order system, i.e. inertia, damping and stiffness. Our approach consists in selecting the appropriate modified values of inertia and damping of the musculo-skeletal system, so that the cut-off frequency lies immediately above the maximum frequency of the voluntary motion and well below the tremor. Another important aspect of the design of active orthosis that will apply dynamic forces through the soft tissues to the human skeleton. In order to minimize this difficulty, the orthosis is adoptable to each configuration of the joint between different patients owing to the use of thermoplastics, see Figure 6. In addition, a textile substrate was used to compress the soft tissues and enhance the performance of the fixation supports. In this approach, the musculo-skeletal system (each upper-limb joint contributing to tremor) is modelled as a second-order biomechanical system exhibiting a low-pass filtering behaviour. The cut-off frequency of this second-order system is directly related to the biomechanical parameters of the second-order system, i.e. inertia, damping and stiffness.

![Figure 6. Patient using the orthosis affixed on the right upper limb [6]](image)
Figure 7. (a) Tremor suppression control system. (b) The musculo-skeletal system is modelled as a second-order biomechanical system [6].

Our approach consists in selecting the appropriate modified values of inertia and damping of the musculo-skeletal system, so that the cut-off frequency lies immediately above the maximum frequency of the voluntary motion and well below the tremor frequency, see Figure 7(b).

For a successful active tremor absorption mechanism, a means for intelligent detection of tremor versus voluntary motion is required. To this end, a model of the tremor motion is proposed. The algorithm developed is based on a two-stage method that estimates voluntary and tremorous motion with a small phase lag. It is well known that the frequency of the voluntary motion of activities of daily living, ADL, occurs at frequencies lower than the tremorous movements. Based on this statement in the first stage of the algorithm, the voluntary motion is estimated using a Benedict–Bordner filter tuned to estimate low frequency movements. In the second stage, the estimated voluntary motion is removed from the overall motion and the assumption that the remaining movement is tremor is made. Next, an adaptive algorithm estimates tremor using a sinusoidal model, estimating its time-varying frequency, amplitude and phase. This algorithm developed was evaluated with 33 subjects presenting different tremor diseases. Results demonstrated the correct operation of the algorithm being able to estimate with a small phase lag (roughly 1 ms of time delay introduced) the voluntary and tremor components from the overall movement.

References


