Investigation of Hand-Mounted Tremor Reduction Devices (TRDs) to Combat Parkinson's Tremors

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***Abstract*—The TRD is used to combat Parkinson's tremors. The TRD attenuates the magnitude of a typical tremor of Parkinson's disease. The system implemented makes use of an electromagnetic accelerometer located within the aforementioned device to which the data from a Parkinson's tremor wave is transfered. This reduction can be simulated in a simulink model with a Proportional-Integral-Derivative Controller (PID). The controller effectively (66% reduction in velocity) reduces the output amplitude as compared to the hand model's response to the original tremor wave.**

***Clinical Relevance*— This device is particularly effective for the patients who suffer from hand tremors caused by Parkinson's disease. The tremors throughout the body of the patients can lead to depression and anxiety and social ostracization, and reduction of tremors can facilitate control of motor skills in patients who are no longer able to perform activities requiring better coordination.**

I. INTRODUCTION

Parkinson's disease (PD) is the one of the most common neurodegenerative diseases in the world, due to the neurodegenerative characteristics, it is also the most common movement disorder. The prevalence of this disorder calls for the investigation of solutions. Due to the impact that tremors from Parkinsons and disorders alike have, we have applied science and engineering to help mitigate these. A tremor is defined as an involuntary, rhythmic and sinusoidal movement of one or more body parts. There are three types of tremors: rest, action and kinetic. Rest tremors occur when the limb is fully at rest with no contraction, while action tremor occurs when there is voluntary muscle movement. Similarity a kinetic tremor is when there is movement of a limb. One of the most common is when a person suffering with PD is attempting to eat or drink.

Tremors occur with the accumulation of the entities known as lewy bodies in the central nervous system. Lewy bodies are large clumps of proteins that causes the random displacement of the organelles in the cytoplasm and as a result causes the death of the neurons of a section of basal ganglia known as SNc (substantia Nigra pars compacta). With the death of SNc, the dopamine neurotransmitter is reduced and this affects the lesser activity from the striatum. Understimulation of the subthalamic nucleus causes the GPi section of the brain to be more stimulated and results in activation of oscillatory central neurons. These neuron signals are transmitted to efferent peripheral neurons and cause mild tremors in various parts of the bodies. These neurons have the same frequency as the tremor frequency and accumulation of the lewy bodies causes the series of events that results in mild yet prolonging tremors.

Tremor reducing devices (TRDs) are designed to significantly reduce the effects of tremors in order to help patients regain fine motor control, though these devices don't cure PD they are still very useful in the battle against it. Hand mounted tremor reducing devices are most common since it is able to control the hand tremor when present while being relatively non-invasive. These devices work using purely mechanical techniques while others rely on nerve stimulation. One important aspect of TRD's is for the device to be able to differentiate between a tremor and voluntary movement. This is commonly done by tuning the apparatus's frequency to detect erratic movements such as tremors which range between 3 to 7 Hertz. The TRD is easily adjustable to different tremor frequencies within the range by having a system which changes the spring constant and damping coefficient. TRD is the most effective when its frequency of oscillation is equal to the frequency of the hand tremor and its amplitude is in the opposite phase. As mentioned earlier, TRD is purely mechanical and absorbs the kinetic energy of the hand tremors via a system of the springs and masses. The TRD creates a force in the opposite direction of the tremors and with equal frequencies.

II. BIOSYSTEM

Being the most versatile and useful tools where fine motor skills are concerned, the hands are a prime target for tremor reduction. To actively reduce a tremor as a TRD does, the goal becomes to propagate a tremor wave through an appropriate hand model, which experiences a displacement, velocity, and/or acceleration as a result of the wave, then have the device output a new corresponding wave. This second wave becomes the target wave to mitigate the tremor by means of the activity of the electromagnetic accelerometer within the TRD device, whose output is scaled by the controller system.

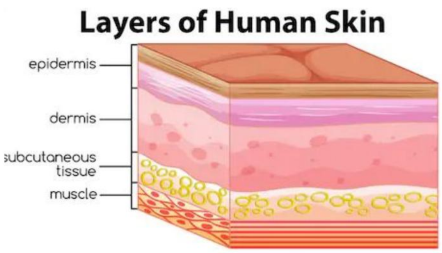
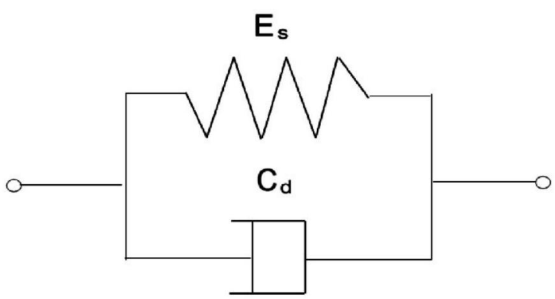


Figure 1. Four layers of hand considered in a typical 4-DOF model.

Source: Adapted from [9]



(b) Kelvin-Voigt Model

Figure 2. Kelvin-Voight viscoelastic model

Source: Adapted from [10]

The biosystem examined in this project is based on a Kelvin-Voight viscoelastic model of the hand; a damping coefficient as well as a spring coefficient serve to model the resilience and elasticity of the skin. The signal of the original tremor wave is integrated and scaled, and passed (as a force) into the hand model.

The classic hand model used is a 4-degree-of-freedom model which includes four separate layers of the hand concerned with the propagation of the signal: (1) the muscle, to which the signal is directly input; (2) the subcutaneous tissue; (3) the dermis; and (4) the epidermis. Layers are connected to each other in the given order viscoelastically; movements due to the tremor are initiated within the muscle and propagate outwards to the surface of the skin in the order listed above and therefore four separate spring coefficients, as well as four separate damping coefficients, are required to fully characterize the viscoelastic dynamics of each of the layers to match the approximation's specificity.

As the equations tend to become more complex with their interconnections when accounting for all these layers, we decided to first simplify a model by hand to have a single degree of freedom, and this is what we ended up using in our implementation. The force generated by the acceleration due to the tremor and the mass of the hand is propagated most directly through the muscle, which was the layer we decided to focus on; the equation derived based on the muscle parameters and Newtonian equations of motion turned out to be:

$$(1)\quad m\ddot{q} = -kq - c\dot{q}$$

Here, m represents the mass of the muscle, k represents the spring coefficient, and c represents the damping coefficient, all parameters being associated with the muscular level of the system. The q parameter represents the displacement, and its first and second derivatives represent the corresponding velocity and acceleration, respectively.

The above second-order differential equation serves to provide a usable output for the control system to work with and edit; outputs represent a figure characterizing how far movement is from the ideal assumed level of zero displacement.

Table 1. Parameters for 1 DOF Hand Model

Skin Layer	Mass (kg)	Damper Constant (Ns/m)	Spring Constant (N/m)
Muscle	4.3	3.99	34.6

III. CONTROL SYSTEM

Table 2. Parameters for Control System Found Using MATLAB PID Tuner App

Controller	**Proportional (Kp)**	**Integral (Ki)**	**Derivative (Kd)**
PID	70.49	207.50	5.95

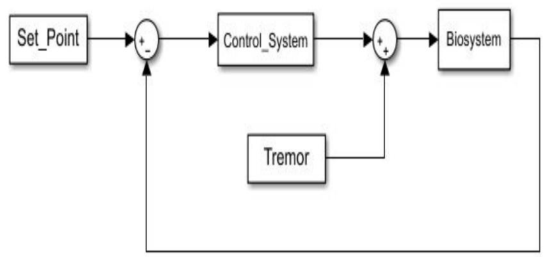


Figure 3. Simplified block diagram schematic for the TRD.

Figure 3 shows a simplified version of the control system that was developed. It consists of a setpoint (of zero velocity, illustrating that by default no tremor movement whatsoever should be visible), control system, a biosystem, and a tremor block. For the control system, a PID controller was used and tuned accordingly using the Matlab PID tuner app. The biosystem block represents the simplified one degree of freedom hand model derived from the four degree of freedom hand model while the tremor block is a hand tremor recording sample in terms of velocity which was obtained from a patient diagnosed with PD. The hand tremor data was obtained from an online database in a study regarding deep brain stimulation on PD tremors where the raw velocity data was collected with the use of a velocity-transducing laser [8].

Below is the full block diagram of the control system. The tremor was first introduced by a "simin" block to import a dataset into the system. This tremor, initially a velocity, was sent to a derivative block and changed to an acceleration. This was then inputted into the biosystem, being multiplied by the muscle mass to provide a force input.

The biosystem is based on the equation for viscoelastic motion given in equation 1). The velocity is taken from the output by using an integral block, multiplied by a gain block representing the damping constant of the muscle, and fed back into the sum block. The displacement was taken from an additional integral block, multiplied by a gain representing the spring constant of the muscle, and also fed back into the sum. Both the damping constant and the spring constant for muscle are taken from known literature values [1].

An output velocity was taken from the biosystem and compared to a constant zero to find the error. This error was then fed into the PID controller, and the correction was sent to a gain block to symbolize the actuator that implements the corrections of the TRD. These corrections are then fed back into the biosystem. All the while, the raw tremor velocity and the output velocity from the biosystem are being tracked by a scope block. The two are compared to measure the effectiveness of the control system. The results from this block are given in Figure 6.

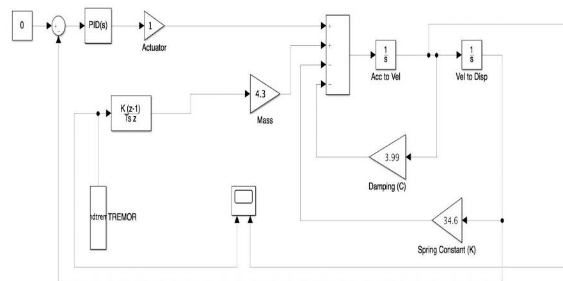


Figure 4. Simulink 1-DOF Hand Model with a PID controller schematic.

The closed loop transfer function was used to analyze the effect that the feedback loop had on the system's input signal. The closed loop transfer function was found using the given muscle layer parameters in Table 1. and the PID parameters as seen in Table 2:

(2)

$$Cls = \frac{5.955s^2 + 70.49 + 207.5}{4.3s^3 + 9.945s^2 + 105.1s + 207.5}$$

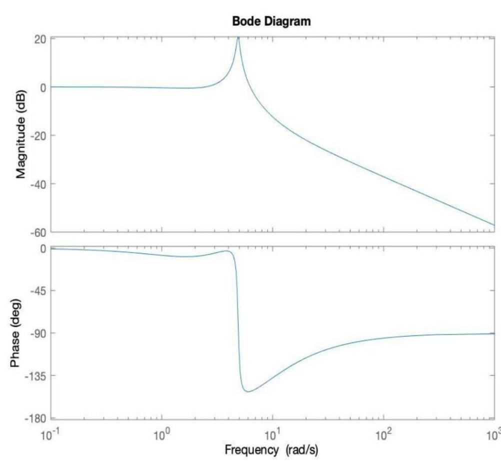


Figure 5. Bode Plot of the Closed Loop Transfer Function.

Figure 5. presents a bode diagram in which we were able to analyze a positive phase margin of the closed loop transfer function. The phase margin was found to be 28° as the 0 dB crossover on the gain diagram occurred at 0.9989Hz. The gain margin was found to be infinite since the phase diagram never crossed over -180° implying that the system will be stable even if the gain was increased drastically.

Thoroughly analyzing the gain and phase diagram, we were able to conclude that the system developed for the suppression of hand tremors is assured for stability.

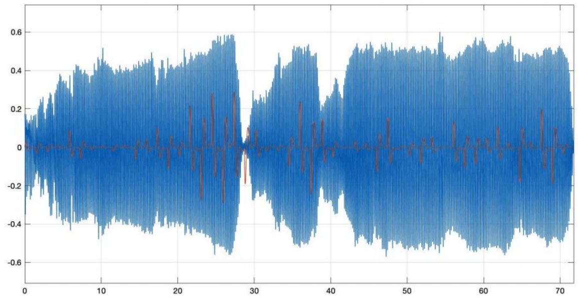


Figure 6. Plot of tremor(input-blue) and reduced tremor (output-orange). The sample duration was 71.76 seconds with a sampling rate of 100 samples per second.

The inputted (blue) tremor velocity was found to be oscillating about ±0.6m/s, while the outputted (orange) tremor velocity was found to be oscillating around ±0.2m/s. Thus, the system diminished the speed of the inputted tremor by about 66%.

V. LIMITATIONS

Although the system was found to be quite stable and reduced the velocity of the tremor by about 66%, the TRD system may not be completely accurate since the one degree of freedom hand model that was used was derived from the four degree of freedom hand model implying that the parameters that were used in this project may not mimic the characteristics of an actual human hand, but only the muscle layer. Based on the Figure 6., the output velocity signal appears to be not completely in phase with the input tremor which can be visibly seen at about 30 seconds where the output signal seems to be greater than the input signal in magnitude. In addition to this biosystem's limitations, the actuator itself was assumed to respond in a perfectly proportional fashion to its velocity input; i.e. it was a given that it would output a linearly scaled force. This is obviously a simplification and in a more robust study, we would characterize the transfer function of the actuator and see how it affected the overall signal, including its delay. The data received is under the assumption that the entirety of the input signal is due to involuntary movements although it is highly likely that the signal may contain voluntary movements.

VI. CONCLUSION

We are able to conclude that our experiment was successful regardless of the simplifications and limitations. By using the 1-DOF hand model and a PID controller, the system managed to intake real PD tremor data and mitigate its velocity while also assuring its stability through the Bode analysis. Future project development can include using the entire 4-DOF hand model rather than the simplified 1-DOF model. Additionally the project can be extended to a full scale implementation of a device that can function through Deep Brain Stimulation or a wearable product.

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