BioMech Hand: A hand tremor research platform

1. Background

Parkinson's disease (PD) and Essential Tremors (ET) are two of the most common neurogenerative disorders that cause involuntary oscillations and have negative impacts on patients. Compared to Parkinson's disease, essential tremor is a neurological condition that causes a rhythmic trembling on the patients' hands, head, voice, legs, and trunk. Both diseases have minor relationships and sometimes can be misinterpreted with one another. Although essential tremor is eight times more common, the two disease affect over 10 million Americans and millions more worldwide [1,2]. The tremors not only pose difficulty in completing daily tasks, such as drinking, eating, writing, but also impair patients' social confidence. Pathological tremor is typically more pronounced at the upper limbs in patients with movement disorders such as PD and ET [3]. Also, tremor is described by its characteristics in terms of frequency, amplitude, and regularity [4]. PD tremor (3-6 Hz) typically occurs at rest. ET (2-7 Hz) is mainly characterized by an action tremor, which is further divided into postural and kinetic tremors [4]. A subtype of the kinetic tremor is the intention tremor, which increases towards the end of a visually guided movement [5].

There are multiple approaches that have been developed primarily to understand the underlying characteristics of Parkinsonian tremor and other motion disorders in the field of robotics and assistive technology. In fact, many orthoses have been designed to minimize these involuntary movements in patients that suffer from Essential Tremors (ET), Parkinson's disease (PD), as well as other neurological conditions, and to avoid the side effects caused by medical treatments. However, the shortage of hand tremor data leads to ineffective design of tremor suppression device. We would like to help address the issue by implementing a multi-purpose tremor research platform.

2. Methods

2.1 Hardware design

The Hand model and Exohand model – designed by Youbionic, Italy – provides basic understandings of 3-D design and 3-D printing processes, as well as other fundamental concepts of engineering. This hardware design also allows us to redesign and optimize products that can be used in biomedical applications and automation industries. Unlike other commercially available products, the system architecture of this platform enables us to implement its functionalities.

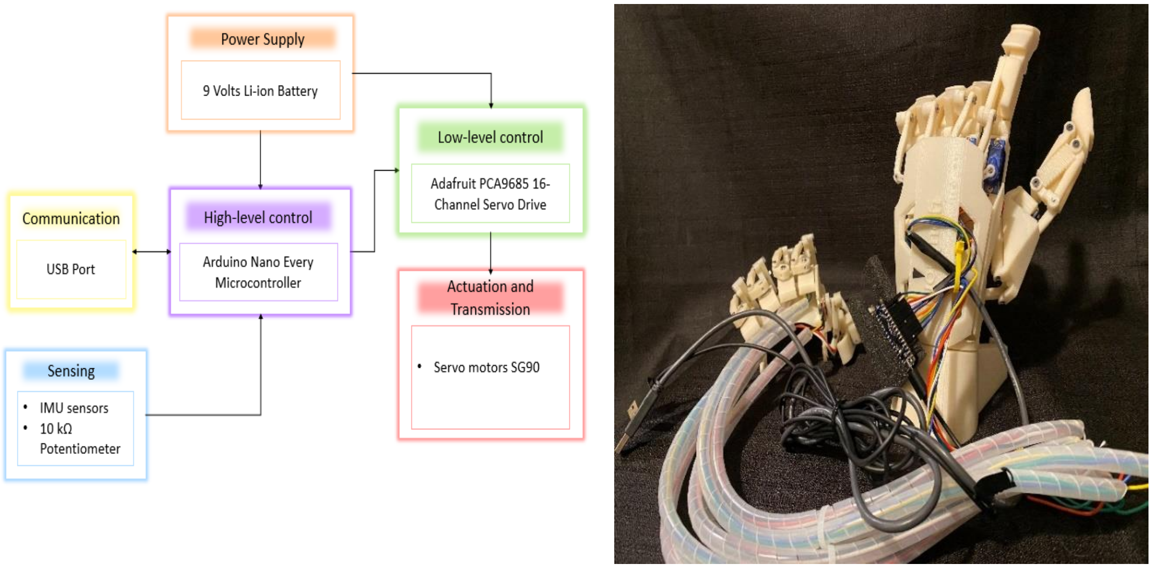

Figure 1. (Left) System architecture diagram of the mechatronic platform. Right) Exohand and Hand Model designed by Youbionic.

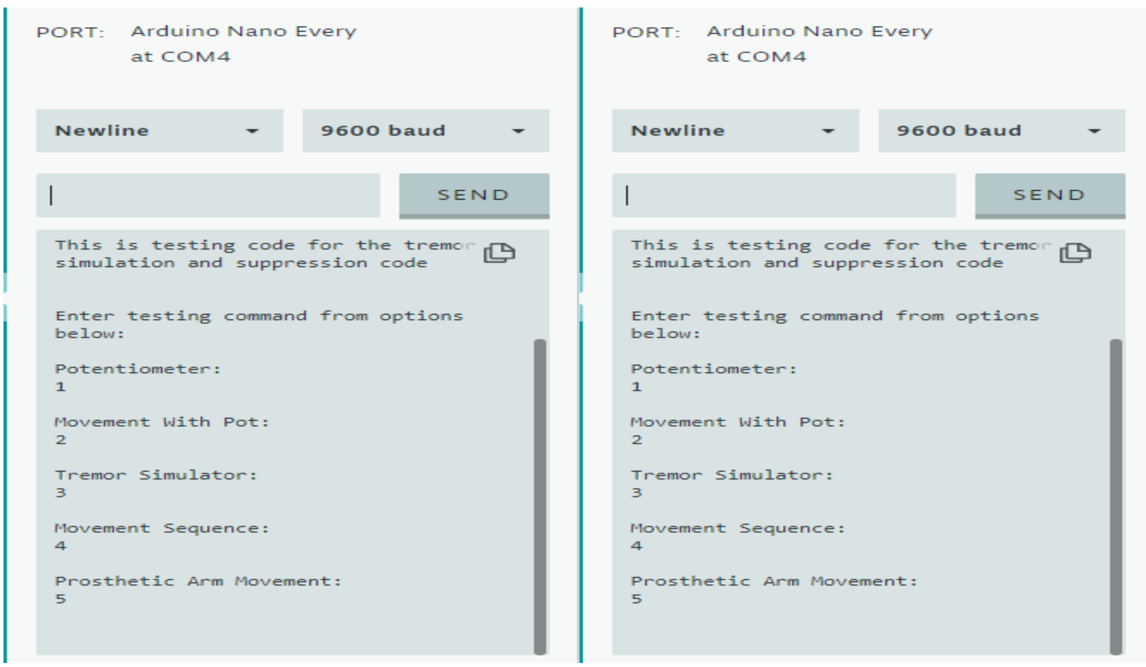

Figure 2. Serial monitor of the Arduino Web Editor. Left) Inputting commands to run the program. Right) Displaying multiples commands and functionalities.

2.2 Software design

The mechatronic platform software was developed primarily to achieve multiple functionalities that would allow us to collect Parkinsonian tremor data and motion characteristics caused by other neurogenerative conditions, and to analyze tremor motion data, and to validate concepts that can be used for the development and implementation of tremor suppression devices. The software design is based on front-end and back-end programming principles which uses the Arduino Serial Monitor for an interactive and user-friendly interface and Arduino embedded control algorithm to accomplish multiple functions as shown in figure 2.

a) Potentiometer: This command can be used to read the analog signals, calibrate the potentiometers as well as the servomotors.

b) Movement with Potentiometer: The Arduino IDE runs this program after a user inputs 2 and can be used to collect tremor motion data. In a clinical environment after approval from the Institutional Review Board (IRB), patients with hand tremor can wear the Exohand model to send tremor data to the microcontroller which then can be used for further analysis. This function can be used to diagnose and monitor tremor motion in a more practical and comfortable way.

c) Tremor Simulator: This program simulates Parkinsonian tremor that is represented by a mathematical model composed by a fundamental frequency, the 2nd and 3rd harmonics as shown in Equation 1 [6]. In resting tremors, the fundamental frequency (f1), the frequency of the 2nd harmonic (f2), and the 3rd harmonic (f_3) lies in a range of 3.5 Hz to 5.8 Hz, 6.9 Hz to 11.5 Hz, 10.4 Hz to 16.8 Hz, respectively. Whereas f_1, f_2, and f_3 in postural hand tremor ranges from 3.9 Hz to 7.7 Hz, 7.7 Hz to 11.2 Hz, 11.5 Hz to 16.8 Hz, respectively [7].

$$x(t) = \sum_{k=1}^{3} A_k \cos(2\pi f_k t + \varphi_k) \qquad (1)$$

Where x is a function of time equals to the sum of the fundamental frequency, the 2nd, and the 3rd harmonic in which A_1, A_2, and A_3 are the amplitudes of the fundamental, the 2nd harmonic, and the 3rd harmonic, respectively; φ_1 (phi), φ_2, and φ_3 are the phase shifts. We can also incorporate a Gaussian White Noise component to this mathematical model for a more realistic tremor representation. The Tremor Simulator command enables us to conduct multiple experiments and allows us to develop more effective hand tremor suppression devices by changing the estimation algorithm. Additionally, we can also integrate flex sensors, inertial measurement units (IMUs), and other sensing components which can be used to validate the theoretical tremor motion. This can lead us to extensive analysis through which we can determine the anti-vibration elements required to suppress unvoluntary oscillation without compromising voluntary movements.

d) Movement Sequence: Users can customize the movement sequences and characteristics of the hand model. This command allows us to understand basic concepts of electrical engineering, computer programming, robotics, and automation.

e) Prosthetic Arm Movement: This command allows users to wear the Exohand model and demonstrate their hand movements on the Hand model at the contralateral side. One important aspect of this command is that the hand model can be redesigned as a prosthesis than can enable upper-limb amputees to complete simple tasks such as holding, grasping, and other manual dexterities that essentially improves the level of independence in their daily lives.

3. Results

Throughout this project, time, safety concerns, and ethical protocols were some of the major constraints we encountered which led to insufficient user feedbacks. However, based on the literature review, we were able to conduct extensive analysis by generating sinusoidal signals that can describe Parkinsonian hand tremor. These motions were altered by changing the parameters in the tremor generation algorithm of the tremor simulator. Additionally, we were also able to imitate the movement characteristics of our left hand by sending the motion signals from the Exohand model. Using a specified command on the Arduino IDE user interface, we were able to achieve simple tasks such as grasping and holding objects. Figure 3 (top) shows a graphical representation of servo position vs time while opening and closing hand, whereas figure 3 (bottom) shows the displacement vs time using the tremor simulator platform. The data obtained can be imported to MATLAB for frequency analysis.

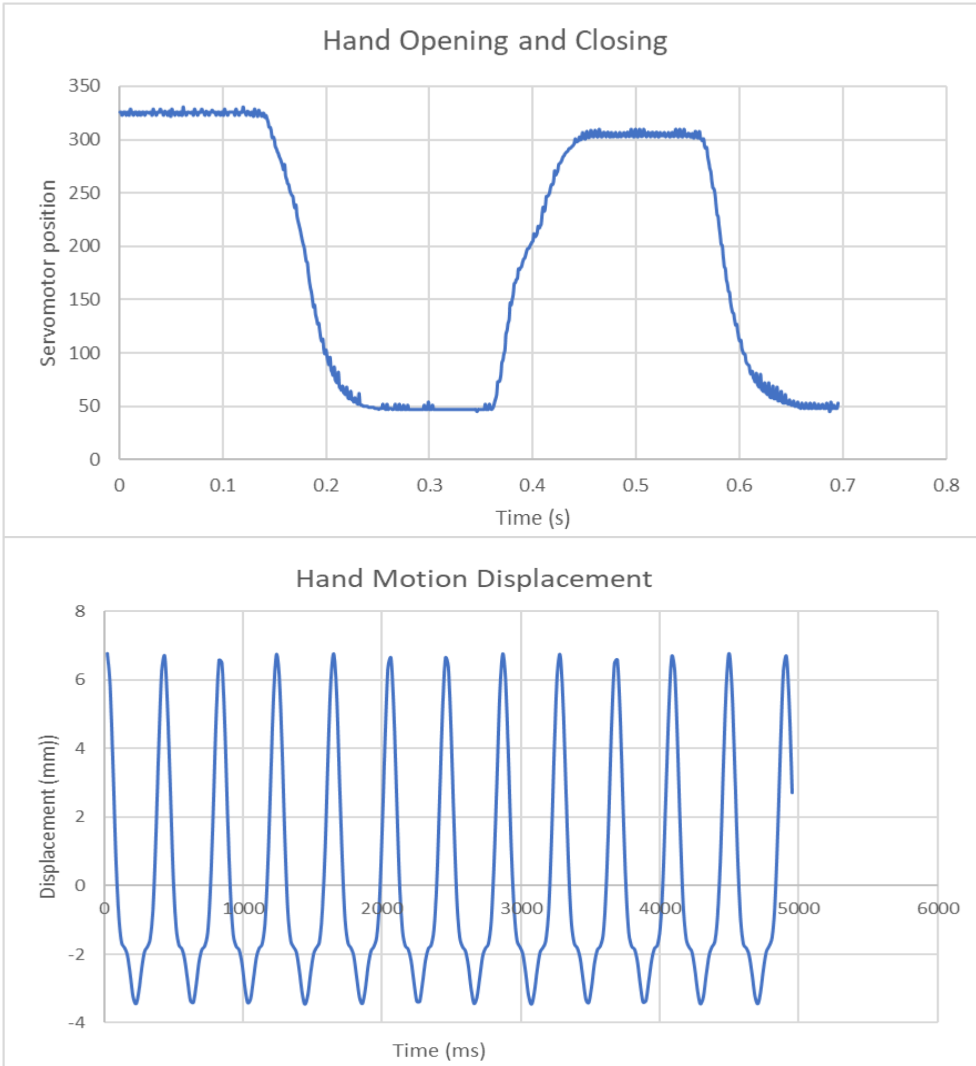

Figure 3. Graphical response of the hand model. Top) Servo position vs time while opening and closing hand using the Prosthetic Arm Movement function: Bottom) Graphical representation of hand tremor using the tremor simulator function.

4. Cost

In this project, we implemented an affordable commercially available product that had an approximate cost of $473.00 USD. This included the purchase of required components, such as the Youbionic hand and exohand 3D files, 10 kOhm potentiometers, servomotors, Adafruit 16-Channel Servo Drive, the Arduino Nano microcontroller, breadboard, and other electrical components. The total price can be significantly reduced by $359.00 USD if we design and develop our own prototype. However, we would need to take into consideration material, labor and machining costs which would not exceed $150.00 dollars. Current products with similar applications can be as high as $455.00 USD in the case of a Tremor Simulator designed by

Global Technologies Simulators. However, this product has a limited functionality compared to our proposed system. One of the most significant cost-wise advantage is the fact that tremor simulators for clinical assessments associated with Parkinson's disease and Essential Tremors are rarely commercially available.

5. Significance

Here we demonstrated the improvement of a commercially product that applies a variety of engineering concepts, and that can be further enhanced and utilized to understand the mechanism of hand tremor which can help develop effective tremor reduction orthoses and strategies.

This project provides a wide range of engineering concepts and skills that are encountered in many disciplines, such as mechanical, electrical, and software engineering, as well as mathematics. It helps us gain better understanding on additive manufacturing, mechanical assembly and disassembly, electronic design and troubleshooting, automation, and microcontroller-based programming, as well as data processing and analysis. The skills developed throughout the project enables us to apply assistive technology and robotics concepts not only to design, but also to optimize products that can be used in medical settings for tremor evaluation, in education for K-12 outreach programs, and for many other purposes.

6. Acknowledgment

This project was supported by the National Institute of Health (NIH) and the National Science Foundation (NSF) under grant 1R25AG067896 and 1700219, 1533479, and 1654474, respectively. We would also like to acknowledge the Catholic University of America for helping us with 3D printing.

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