Wearable Tremor Mitigation

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ABSTRACT

Roughly 7 million Americans suffer from some form of tremor, most commonly manifesting in their arms and hands. A Tremor is an involuntary rhythmic muscle movement. One of the major effects of tremors is on the patients' fine motor control ability, this causes difficulty in performing daily tasks. The decision to build a wearable device was made due to the lack of existing wearable technology to address this problem. Wearable tremor mitigation technology prototypes have been designed to decrease the intensity of tremors and increases the patient's dexterity and confidence in their daily life. Alpha prototype served as a proof of concept, while Beta served as a testing platform for the integrated system. The wearable glove senses for movement using gyroscopic sensors and processes the data using microcontrollers. Depending on the data, the microcontrollers send signals to the Mosfet to power the actuator system. The actuator system consists of multiple braking system containing an electromagnet and a ferromagnetic slide. The slide is connected to a network of lines transferring the forces to the PLA plates attached to the hand. The result was a 20 percent decrease in flexion vs extension movement when stimulated by a consistent movement of a team member's hand. This technology is currently operating on a preliminary control algorithm. This paper will outline the overall design and manufacture of the new system, along with an overview of prototypes, different custom designed parts description, and the results of preliminary testing.

1 BACKGROUND

Tremors can be caused by many different events and diseases including stroke, brain injury, Parkinson's, alcoholism, multiple sclerosis, brain disorder, drugs, and more. The right arm wearable was chosen due to the amount of researches reporting worse tremors in the dominant hand, and the majority of people are right hand dominant. A semi-active tremor mitigation wearable glove is a device that characterizes the tremor in a user's hand, and reacts to it by minimizing the displacement from the neutral resting axis of the hand. The closest technology used for an identical scenarios are benchmarked in table 1.1. Many devices have already been released to help mitigate tremors when it comes to certain functions, such as: drinking coffee, buttoning a shirt, holding spoons and utensils, using a dish, tip-resistant bottles and drinking soup. These technologies are available commercially and can be obtained relatively easy. Currently these tremors can be mitigated through various forms of drug treatments but often involve side effects, regular check ups and self monitoring. They also tend to lose their potency over time, requiring increases in daily dosage.

Table 1. Benchmarked Technologies

Technology	Description
Liftware	Actively stabilizing handle with spoon and fork attachments
Gyro Glove	MIT's gyroscopic stabilizing glove prototype.
NuVu	Active mitigation through a signal that stimulates the brain.
ReadiSteadi	Weighted glove to limit movement from tremors.
Rocker Knife	Easy and stable grip knife
Smart Textile	Tremor Suppression Using Smart Textile Fiber Systems.
Stay Bowl	Bowl with specially shaped handle and non-skid base.
Weighted Button Aid	A device that helps button shirts with a steady weighted handle.
Vibration Device For Tremors	A wearable device that uses vibratory stimuli to limit tremors.

2 DESIGN PROCESS

2.1 Mechanical System Characterization

The tremor targeted was a kinetic functional tremor with a maximum displacement from the resting neutral axis of 1 cm and ranges in frequency between 4 Hz to 8 Hz. The force analysis assumed a sample of total body weight of maximum 240 lbs and different genders. The hand weight was calculated as a 0.65% of total body weight for maximum using male percentage.

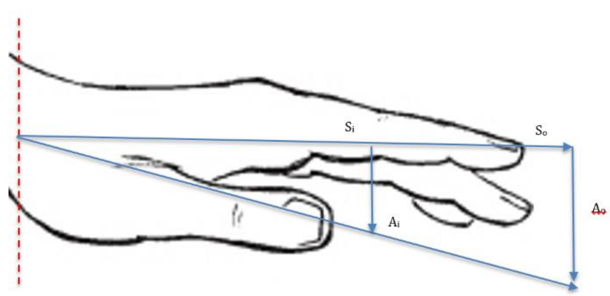

Figure 1. Hand parameters identified for calculation

The forces were analyzed from the parameters stated to give equation 1 as a representation of the force in the system and equation 2 as the uncertainty in the Calculation of equation 1.

$$\bar{F} = m\cdot\bar{a} = m\cdot\left(-y\cdot\sin(\nu\cdot 2\pi\cdot t)\cdot(\nu\cdot 2\pi)^2 + d\bar{V}_0\right) + m\cdot\bar{a}_0 \quad [N] \qquad (1)$$

$$d\bar{F} = \Big(\left(-y\cdot\sin(\nu\cdot 2\pi\cdot t)\cdot(\nu\cdot 2\pi)^2\cdot\partial m\right)^2 + \left(\left(-m\cdot y\cdot\cos(\nu\cdot 2\pi\cdot t)\cdot(\nu\cdot 2\pi)^4\right)\cdot\partial t\right)^2\Big)^{0.5} \quad [N] \qquad (2)$$

Where m = mass, t = time, ν = tremor frequency, V_0 = initial velocity, a_0= initial acceleration, y = max displacement of hand, and F = overall max tremor force at time t with hand modeled as point force.

The hand was assumed to not be uniform in weight, a mass percentage distribution was calculated to aid in finding the maximum force points on the hand. The tremor also is most contributed to by the more dominant muscles in the arm, therefore, the relevant region in the hand have active tremor, and is an active contributor while the irrelevant region would have passive tremor as shown in figure 2.

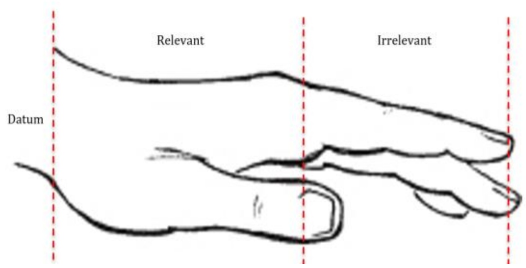

Figure 2. Relevant vs irrelevant vibrations

The calculated mass distribution was described at each point on the hand by equation 3 and used to calculate the actual mass at each point using equation 5 via equation 4. Equation 4 describes the mass percentage distribution of the point in relevance to the whole hand.

$$m_i = -4.4608\cdot S_i^4 + 16.199\cdot S_i^3 - 18.624\cdot S_i^2 + 6.7422\cdot S_i + 0.3644 \qquad (3)$$

$$m_{\%i} = m_i\cdot\left(\int_0^1 m_i\,.\,dS_i\right)^{-1} \qquad (4)$$

$$m_{actual_i} = m_{hand}\cdot m_{\%i} \qquad (5)$$

Where S_i = length segment of tremoring hand, m_i = normalized mass segment of tremoring hand, $m_{\%i}$ = normalized mass segment as a percentage from total hand length, m_{hand} = total mass of tremor hand, and m_{actual_i} = mass segment of length segment i.

The displacement of each point in the hand is represented by equation 6 to aid in the analysis of the acceleration at each point represented by equation 7 and total point force at each point represented by equation 8. The points and system parameters are mapped out as shown in figure 2.

$$x_i = S_i\cdot A_0\cdot\sin(2\pi\nu\cdot t) \qquad (6)$$

$$\bar{a}_i = \frac{d^2x}{dt^2}\left(S_i\cdot A_0\cdot\sin(2\pi\nu\cdot t)\right) \qquad (7)$$

$$\bar{F}_i = m_{actual_i}\cdot\bar{a}_i \qquad (8)$$

Where x_i = displacement of the hand at length segment i at time t, A_0 = max tremor displacement, a_i= acceleration of hand at length segment i at time t, and F_i = force of the hand at length segment i at time t.

2.2 Mechanical Components Design

Mechanical Brake:

Brake Pad (steel plate): Small magnetic metal piece that is free to move linearly along the forearm within the brake chassis and controlled by a line leading to the tremoring hand. During tremor, the hand displace the brake pad away from its starting position, the electromagnet turns on to hold the brake pad in place and resist the motion. Once the hand in its neutral resting axis the electromagnets turn off and a rubber band, anchored at the back of the chassis, retrieves the brake pad to its original position. The brake pad is held closest to the magnet by two leaf springs that are constantly pushing on it.
The rubber band and the friction of the unpowered magnet does not provide enough force to limit the motion of the hand. When a tremor is detected the magnets on specific brakes will activate, therefore increasing the friction with the brake pads. This damping friction is calculated be enough to dampen the rapid motion of a tremor.

Brake chassis: the assembly of the 3D printed housing that holds the magnet, springs and brake pad. It includes the top and bottom of the chassis, the lock, wire guide, and magnet cover; it is attached to the sleeve.

Return Spring: A rubber band that provides the force to pull the brake pad towards the back of the chassis into the neutral, starting, non-displaced position.

Leaf Springs: Two specifically geometrically shaped beams that keep the brake pad in contact with the magnet no matter the orientation of the chassis. They are essential since any air gap between the brake pad and the magnet exponentially limits the damping force.

Force Distribution elements

Plates: Two 3D printed plates that has a very specific geometry and a grid of holes that aid in the translation of the forces from the hand to the wires. The plates are designed in a specific geometry to avoid pinching and avoid back sliding of the plates.

Wearable pivots: two identical blocks that act as a tunnel for the lines to avoid entanglement and ensure proper tension and orientation in the line.

Lines: fishing polystyrene lines that are harder to stretch and have a breaking limit of 50 lbs. The lines are used in force translating through tension

Crimps: little circular metal pieces that ensures maximum pinching of the line and avoid slippage at connections.

Swivel: circular components that helps in dampening the undesired rotational forces in the line to ensure proper force translation

2.3 Electrical Components Design

The Controller subsystem: consists of an Arduino Uno that is paired with a screw terminal header expansion. The Arduino Uno is a microcontroller that is programmed in a C++ variant using the Arduino IDE. The Uno operates at 5v digital logic and can handle communications over SPI and I2C and read analog signals. The Uno was selected due to its simplicity. Although it is not the smallest device available it was the device that got the job done the fastest without any learning curve.

Termination: in this system is defined as the method of connecting wires to components. By default the termination of the Arduino Uno is an 0.1" pitch header that allows wires to be plugged into their individual socket. The pins are held in by friction which means that if the system is acted upon by any force it puts the wires in jeopardy. On the plus side, these pins allow for easy reconfiguration and repair. In order to maintain that repairability but reduce the likelihood of wires coming unplugged, the terminal shield was added to the Uno and all components were provided with screw terminal connection on all crucial connection points. This includes the mosfets and all control pins on the Arduino.

Sensors: In the Alpha there were two sensors planned for the system; the 9 Degree of Freedom board (9DOF), and elastic stretch sensors. The 9DOF is a gyroscope + accelerometer + magnetometer that measure angular velocity, angular acceleration, and angular displacement respectively. This device was placed on the backside of the hand in the glove in between the knuckles of the middle and ring finger. Currently only the gyroscope is used but the functionality remains for future development. The elastic stretch sensor was intended to measure the extension or retraction of different points on the glove. After much testing the sensor was eventually omitted. It required a fair amount of amplification and filtering in order to get stable signals and even then the measurements were not reliable.

The Magnet Brake System: involves an electromagnetic brake that clamps a metal plate to "brake" and resists the movement of the user's hand in a specific direction. When current is applied to the electromagnet it induces a magnetic field strong enough to clamp the metal brake pad. The magnets require a higher voltage than the rest of the system, meaning the 5v output of the Uno is not sufficient to drive the magnets. In order to overcome this, power MOSFETs are used. Power MOSFETs are electrical switches that are designed to be toggled with a low voltage in order to drive an electrical signal of a higher voltage or current. In our case, the signal being driven to the MOSFETs is around 11v from the battery. The MOSFET boards used in this build have screw terminals built in in order to be compliant with our self imposed termination rules.

Power: In order to power our system it was decided to try and find a simple reliable power source. The device chosen was the Talentcell 12v 3000mah LiPo Battery. This device features a safety certified design, protective plastic housing, built in charge circuitry, barrel jack termination, and a built in power switch. All of this for an affordable ~25$. This battery tests out at a steady voltage of about ~10.8v when fully charged which is sufficient for our means. The battery has proven reliable in worst case scenario tests and battery longevity tests.

2.4 Code and Controls

The code was not the focal point of this design. This decision was made to maintain the development of a rigid reliable test platform which could be used for future code development. That being said the code is very simple. The basic process is that gyroscope data is read in one direction from the 9DOF in the hand. That data is processed and when it is determined that the hand is moving in one direction, brakes opposing that direction turn on and resist motion for that direction. This code proves functionality of the system but is not intended for tremor mitigation. Code was written in C++ using the Arduino IDE.

2.5 Build Iterations

Alpha: a primary proof of concept for the integration of the components and feasibility with minimum component integration.

Beta: a testing platform optimized based on data collected from alpha with multiple component integration.

2.6 Integration and Assembly

Base-glove: The glove for the Alpha was purchased because of the sturdy build and defined silhouette. The glove needed to go up to the elbow to provide enough space to attach all of the systems. Unfortunately, this glove was not a very breathable material and was therefore very uncomfortable. For the Beta, we chose a glove that was double-layered, allowing us to hide the ribbing and some of the wires providing a sleeker silhouette. This glove is also a more breathable yet still durable material.

Ribbing: The Alpha had six long ribs along the outside of the glove. These ribs were made of a high-density polyethylene plastic (HDPE) and were intended to allow for some movement so that the glove could be easily put on, yet add stiffness to reduce the likelihood of the glove bunching up. For the Beta, the same material was used but twelve strips roughly half of the length of the forearm were used instead of six long strips. The ribs were also staggered on the inner layer of the glove to allow for more flexibility while maintaining stability which increases comfort for the wearer.

Figure 3. Stitched ribbing on the glove.

The brake chassis, hand plates and several other parts were made using 3D printing technology. This allowed for rapid prototyping and testing of these complex parts.

Hand Plates: The hand plates for the Alpha and the Beta were designed to stabilize the hand and provide attachments points for the cables. The hand plates were printed in PLA and the heat formed to the curve of a hand for comfort. With the use of swivels, crimps and the cables the braking system and the hand plates were able to work in conjunction to mitigate the tremor.

Brakes: The braking system parts were designed by Jamey. For the Alpha, the glove had two Mark 1 brake systems which included a electromagnet, a slide plate and a spring to pull back the slide plate. These brakes were longer and took up more space on the glove but provided a proof of concept. For the Beta, the glove has four of the Mark 4 brake systems. The Mark 4 is a much smaller design that includes a clip to keep the brake together, a guide to prevent lateral torquing, metal springs to keep the sliding plate against the electromagnet as well as all of the parts from the first assemblies. The Mark 4 design also included more attachment points and an arc along the bottom to conform better to the shape of the arm increasing the contact surface to reduce the movement of the brake when activated.

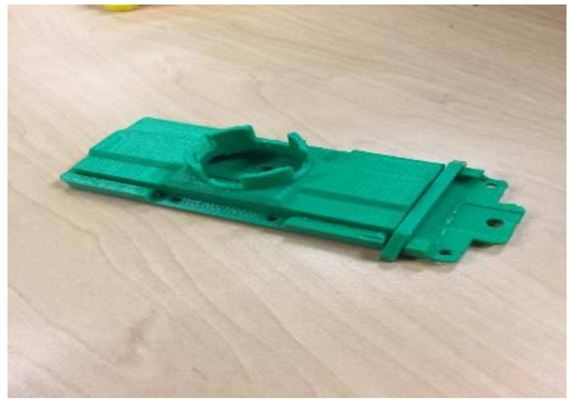

Figure 4. 3D printed brake chassis/skeleton.

Electrical: The electrical system includes a rechargeable battery, an arduino with a terminal shield, two 9DOF boards, four MOSFET’s and four electromagnets. These components will be discussed further in the electrical system section.

Assembly: Both iterations were assembled by sewing the components onto the glove. When constructing the Beta, fabric glue and rivets were investigated but the glue did not adhere to the ribbing due to the coating on the HDPE and rivets would have required more time to get the tools so sewing was the best option.

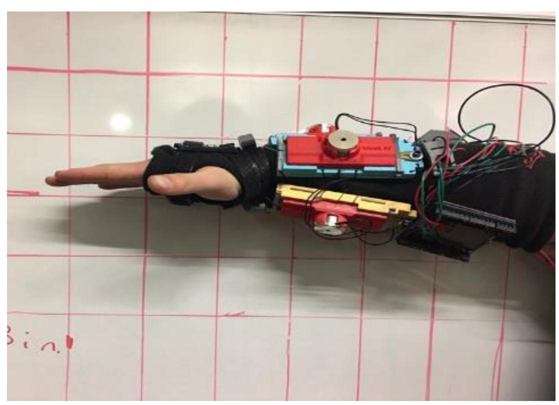

Figure 5. Overall glove integration mapped against an inch by inch grid

3 RESULTS

This section is devoted to the results of the planned process and mainly the showcasing of the Beta test results.

3.1 Mechanical Theoretical Results

All the of theoretical simulations are compiled to give the results below.

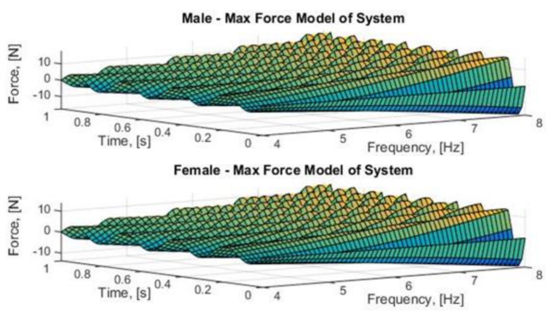

Figure 6. Max force curve along the hand simulation results assuming uniform mass distribution over 1 unit of time for a 240 lbs human.

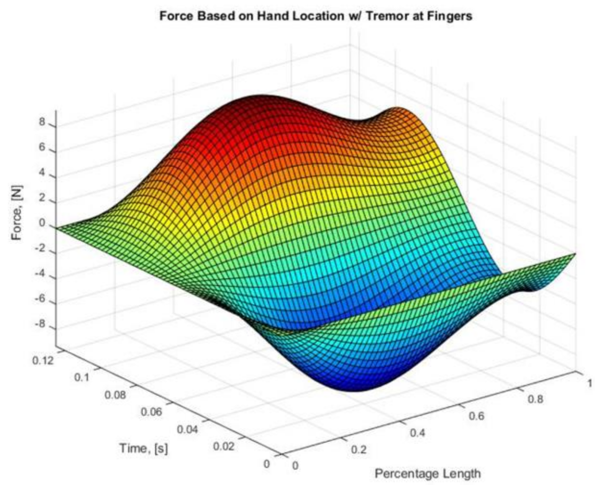

Figure 7. Force distribution curve along the hand simulation results.

Based on these results the design decision was taken and all components were designed. The values taken from the theoretical simulations were often multiplied by a 1.5 or 2 factor of safety to make sure that the design passes its engineering requirement for tremor mitigation.

3.2 Mechanical Components test results

Brake system: To test the effectiveness of the brake system we created a fixture that would measure the force the system could hold. Using a set of precision masses we tested the effective force of different magnets, ceramic and neodymium. We tested the electromagnet at several different voltages as well. The tests proved an electromagnetic braking system could reach the forces required by our theoretical model.
Each iteration of the brake design was put through several tests on this fixture. These tests allowed to determine the natural friction force of the system when the magnet was not activated. It also was used for testing the brakes systems at different orientations. The information from these tests allowed us to redesign the brake systems very rapidly and effectively.
The final brake design is not drastically different than the initial version in terms of function. After preliminary testing, we found the magnet was very capable of creating enough force to counter the motion of a tremor. Most of our iterations involved changes to size, usability, or attachment points. The largest addition came after testing at different orientations revealed that the brake pad could fall away from the magnet and force. To accommodate the leaf springs were incorporated into the design which, after further testing and adjustment, provided the stability needed.

Hand plates: The hand plates we created to allow full movement of the hand and fingers while still providing the support needed to control tremors. As mentioned earlier, the plates were heated and formed to the hand for maximum comfort. Multiple attachment holes are spread out across these plates. This spread the load allowing a more even distribution of force for better comfort and control. All of the attachments connect to one of two wires leading to different brakes. This allows the brake system to mitigate more than just flexion and extension. With this wire setup, by activating different brakes with different forces, the plates can be controlled in the radial and ulnar motion as well.

3.3 Electrical Results

The electrical components were tested as listed in figure 8, 9.

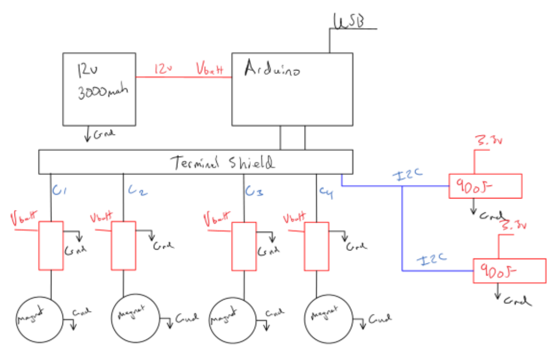

Figure 8. Beta Block Diagram

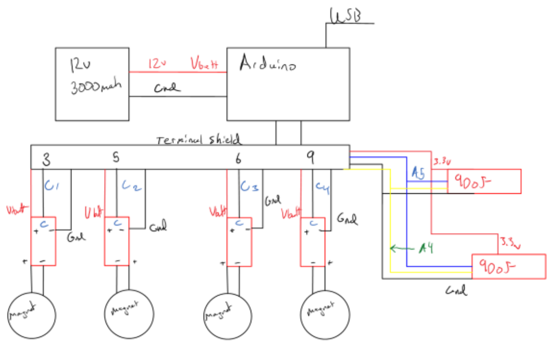

Figure 9. Beta Wiring Diagram

After the setup of the electrical components, the data in figure 10 was collected to compare the DOF output vs the magnet firing. The active range is when the magnet was firing in impulses to resist the tremor. It can be noticed that the signal experienced some dampening after the firing of the magnet in the magnet region.

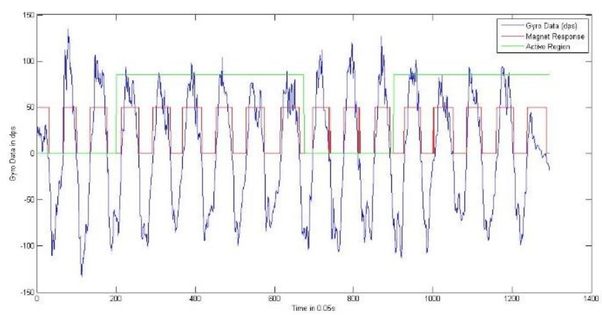

Figure 10. DOF output vs Magnet Firing for testing

4 CONCLUSION AND DISCUSSION

The concept of the glove is based on the effect of adding heavy weight on the dominant muscle in the hand to stop tremoring. The glove stimulate the forces of the masses by using electromagnets.

The glove is functional and is believed to have an effect on tremor mitigation. The gyroscopic sensors collect information about tremor parameters and characterization. The glove is somewhat sensitive but the exact sensitivity was not determined in this paper. One problem faced by the glove is the sliding of the electrometric slide on the fabric. A solution to the sliding would be to have an imaginary equilibrium point that would result from a torque couple created by the forces working on the brakes.

The code controlling the response of the glove is very basic. It only turns off and on when it detects a movement and a tremor coupled together. It turns the magnet to its full potential and locks the magnetic slide in. the plan is to have a code that detects tremor, movement and spatial form of the hand and reacts to it. The reaction is planned to have a range of potential to turn for different magnet strength based on data collected. Moreover, the glove would be able to mitigate different hand movements by controlling each magnet separately.

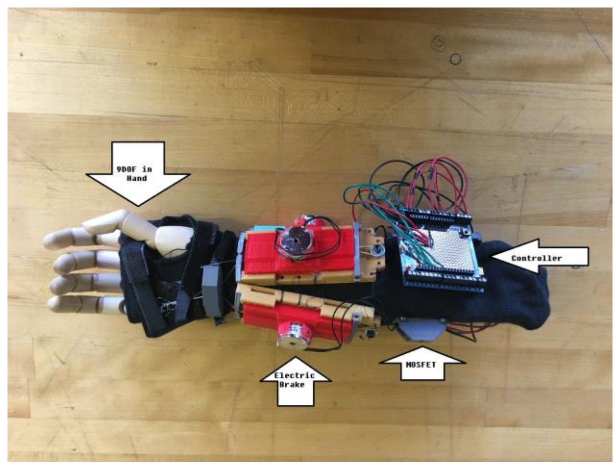

Figure 11. Force distribution curve along the hand simulation results.