Problem Statement: Loss of control over hand motor ability and voluntary movements, as well as tremor, is seen in numerous people including those with neurological diseases. This ranges from people that are healthy, aging, and have essential tremor to people who have Parkinson's Disease, Cerebral Palsy, Huntington's Disease, and multiple other neurological diseases. The loss of hand control leads to a lower quality lifestyle and makes it very challenging to accomplish everyday activities that are as simple and essential as eating, drinking, holding, and writing. It is paramount to have controlled hand ability since hand motion is the main factor for accomplishing everyday tasks.

Existing Solutions and My Innovation: Currently in the field of robotics, prosthetic hands are commonly developed in order to help people without hands. However, not much work has been done on developing a wearable device to assist with hand movements and tremors. Current treatments for involuntary hand movements and tremor include costly repetitive practice therapy, deep brain stimulation, and a variety of medicines. Yet, most tremors and involuntary movements have no cures. Soft robotics is an emerging field, but these concepts have not been applied for addressing crucial issues like hand tremor. To address this need, I wanted to develop a glove, *MyGlove*, which would help a wide range of people in overcoming the restrictions and challenges of involuntary hand movements and tremors. I also wanted to use the soft robotics concept for controlling hand tremors by designing a user-friendly wearable glove.

Objectives: The objectives of my project were to:

1) Develop a glove that can assist with hand movements and grip, leading to a higher quality lifestyle for many people suffering from the loss of hand motion control.
2) Design and develop a hand tremor detection and control features on this glove.

Requirements: The requirements of my project were to:

1) Design a hand glove model and develop program algorithms that would assist with closing the hand and improving grip by analyzing data from various sensors attached to the glove. This assist functionality should help in reducing the time required to close the hand.
2) Develop program algorithms that would detect hand tremors once the tremor frequency and amplitude exceed a set number of threshold values.
3) Once tremor is detected, the pneumatic actuators should inflate to control the hand tremor. This tremor control functionality should reduce the amplitude of the tremor.

Note: The initial objectives and requirements of my project were to assist hand movements, improve grip, and detect tremor. I had met all of these goals, but I wanted to go beyond my original requirements and enhance *MyGlove*'s functionalities by controlling hand tremors since tremor is a widespread and prevalent problem that affects various people.

Methodology and Design:

<u>Assist, Grip, and Tremor Detection</u>: Key design elements consisted of a glove, microcontrollers, various sensors, servos, and LEDs. I chose to test *MyGlove*'s functionalities on a modeled hand since it would improve measurement accuracy, remove human error factors, and address safety concerns for initial testing even though it would increase experimentation complexity. Then, I picked an optimal board and microcontroller that would meet the requirements (number of analog/digital inputs/outputs, number of PWMs, ease of use, size, cost, power, etc.). Based on my research, I chose two separate Arduino boards so that the control functionality (simulated hand model) is kept on one board and the assist functionalities (*MyGlove*) are kept on another. I selected the Arduino Micro as the control board and the Arduino Mega as the assist board.

After extensive research, I selected miniature sensors and other components. *MyGlove* consisted of flex sensors for sensing finger movements, Force-Sensitive Resistors (FSRs) for grip, accelerometers for detecting tremors, and servos for assisting hand movements (assist servos); all components were connected to the Mega board (assist board). The hand model consisted of servos connected to Micro board for simulating hand motion (control servos). The circuit connectivity diagrams for the control and assist boards were developed for connecting these various sensors to the analog pins via voltage divider circuits, switches for controlling various functionalities, tremor indication LEDs, and other support logic. Next, I developed the program algorithms for *MyGlove*'s functionalities using the portable Arduino C language. The algorithms read the sensor data and appropriately actuate the assist servos for assisting with hand movements and grip. The algorithms also detect tremor using the accelerometer data once the tremor frequency and amplitude exceed the set threshold values. The sensors were calibrated to optimize and improve *MyGlove*'s accuracy.

I went through numerous prototypes to attain the current model. Initially, I tested 1 finger on a simple modeled hand to learn the basics of engineering, programming, electronics, and the overall mechanism. Later, I tested all 5 fingers on the simple hand model and experienced a few obstacles in the setup and programming. I overcame these roadblocks after experimenting with many prototypes and debugging my program algorithms. Then, to improve the accuracy and setup robustness, a 3D printed hand was used to model the human hand. This model was constructed by mounting 5 control and 5 assist servos that were connected to the hand model with fishing wires so that they would open/close the fingers as they were rotated. After switching to the 3D hand model, I experienced a major issue with servo power. I debugged the issue through various power supplies and other options, and fixed it by optimizing power supply design based on the torque requirements.

<u>Tremor and Control</u>: After extensive research, I selected pneumatic actuators to control tremor. The actuators were created in 2 layers using Dragon Skin 30 and 20. The actuators have an inner chamber that allows air from the pump and solenoid valve to enter, therefore inflating and expanding the silicone actuator. The actuators also have a thread and fiberglass layer that limit expansion of the silicone, causing a bending motion of the actuator. This pneumatic actuator design is a novel concept for addressing widespread issues like controlling hand tremors. These actuators are light-weight, compact, and user-friendly.

The program algorithms for tremor generation (on the modeled hand) and tremor control (*MyGlove*) were developed. In the tremor control program, the pneumatic actuators inflated based on the tremor amplitude identified from the tremor detection program. Then, various actuator designs were developed and tested before getting to the current design. The initial prototype molds for the actuator construction were created using Legos, ice-trays, and electric pipe tubing. To improve the accuracy, I designed CAD models in Autodesk Inventor, 3D printed the molds, and fabricated the actuators using Dragon Skin. I optimized the actuator size and performance after multiple iterations. Key elements of the design for controlling tremor consisted of the Arduino Mega board, pneumatic actuators, solenoid valves, a manifold, air pump, power MOSFET, accelerometers, a glove, and LEDs. An Arduino Micro simulated tremor using servos that were connected to the fingers (tremor generation servos). The pneumatic actuators were attached on top of and underneath the fingers to reduce the amplitude and control the tremor. Since the fingers would be pressurized from above and below, the amplitude of the tremor would be dampened.

Testing and Results: I created detailed functional verification and test plans for testing *MyGlove*'s features. At least 25 trials were conducted for testing all the functionalities.

<u>Assist Functionality</u>: For verifying the assist functionality, I recorded the time taken to close the hand with and without the assist functionality. The functionalities were also tested at different strength factors. The control servos successfully simulated the opening/closing of the modeled hand. The average time required to close the hand with control servos only (without the assist functionality) was 23.81 seconds. The average time required for closing the hand with assist functionality was 17.72 seconds for a low strength factor and 8.21 seconds for a high strength

factor. Therefore, *MyGlove* effectively reduced the time needed for closing the hand as the average time required to close the hand with the assist functionality was 26% to 65% faster than without it.

Grip Functionality: *MyGlove's* grip functionality was tested for holding multiple objects such as a Styrofoam cup, heavy Toblerone box, water bottle, sunglasses case, sharpener, etc. The assist servos would move accordingly to improve grip based on the FSR values. Also, the results show that *MyGlove* successfully conformed to the shapes of various objects.

Tremor Detection Functionality: Tremor was generated on the modeled hand manually and with servos. It was observed that *MyGlove* consistently detected tremors and their frequencies as well as provided LED indications once the set tremor frequency and amplitude exceeded. Tremor was not detected when the hand was still or performing normal and voluntary motions.

Tremor Control Functionality: For verifying the tremor control functionality, different frequencies of tremor were generated manually and using the tremor generation servos. It was observed that the tremor control functionality reduced the tremor amplitude and the pneumatic actuators applied different pressures on the fingers based on the amplitudes. Testing the actuators on the hand model did not provide accurate results as the servos were more powerful in comparison to the pneumatic actuators' applied pressure. However, a human hand was also used to manually generate tremors. As observed through numerous trials on my hand, the tremor amplitude was effectively reduced and different pressures were applied on my fingers based on the tremor amplitude. Altogether, the pneumatic actuators inflated and controlled the tremor independently for each finger. Pneumatic actuator inflation magnitude was also directly proportional to the tremor amplitude.

Conclusion: *MyGlove*'s functionalities of assisting hand movements, improving grip, and detecting and controlling tremor have been fully developed and validated. Algorithms have been fine-tuned and re-verified. Based on the data, *MyGlove*'s assist functionality reduces the time needed to close the hand. The assist functionality will also be more effective on a real hand without the constraints of a modeled hand. *MyGlove* additionally improves grip to hold objects and it accurately detects and controls tremors. The pneumatic actuators effectively inflate based on the tremor amplitude, and as tested on my hand, *MyGlove* can successfully control various hand tremors by applying different pressures. Therefore, *MyGlove*'s design and program algorithms effectively met all of the requirements. I have also effectively tested the customization of the assist strength factor and tremor detect/control parameters. Thus, *MyGlove*'s functionalities can easily be personalized for an individual's needs based on the severity of involuntary hand movement and tremor.

One of my next steps is to productize *MyGlove*; its user-friendliness, customization, and features can be enhanced further during this process. *MyGlove* can be tested on people who have tremors and involuntary hand movements. Wi-Fi connectivity and a smartphone app could easily be added so that *MyGlove* could be used by doctors for monitoring and/or by patients for self-diagnosis. Altogether, *MyGlove* helps in solving key problems that have not been solved up until now. It can effectively assist with involuntary hand movements, grip, and tremors in order to accomplish everyday tasks that cannot be performed due to loss of hand motor control. Plus, the pneumatic actuator concept can be applied for multiple other wearables and medical usages. The use of *MyGlove* will greatly lead to a higher quality lifestyle for millions of people across the globe that are impacted with tremor and the loss of hand motor control.