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Closed Loop Wearable Device for Parkinson's Tremor Monitor and Suppression

Aryan Ganesh

[1]Christopher High School, Gilroy, CA
*Corresponding Author: aryanganesh.aiml@gmail.com

Advisor: Gyan Krishna Sreekar, gyankrishna06@gmail.com

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Abstract

Parkinson's disease does not have a permanent cure, medication is one of the primary methods used to manage tremors. However, the process of managing medication dosages can involve a lot of trial-and-error approaches, and tremors can still appear at different times of the day, requiring further dosage adjustments. Monitoring tremor patterns in Parkinson's patients is very important for accurate dosage planning. In this study, a simple, compact, and affordable sensor based closed-loop wearable device was developed to monitor and control tremor for assisting Parkinson's patients. The system detected tremors using an accelerometer and displays tremor data on a LED-display. This tremor data was read by a micro-controller prior and then preprocessed using moving average of the tremor intensity. The tremor count was then displayed on the LED-display and a dashboard using Adafruit cloud platform. The device was tested on a Parkinson's patient to measure tremor parameters such as tremor acceleration and tremor count. The system was tested fifteen times on a Parkinson's patient and was able to detect the tremors successfully every time it was tested. This system also includes a tremor suppression capability by applying a counterforce whenever the tremor count went past threshold count. In order to control the tremors, the threshold count is determined to be 27 counts. However, the repeatability of the amount of counterforce and tremor suppression needs to be improved.

Keywords: Parkinson's, Wearable device, Tremor monitor

1. Introduction

Parkinson's disease (PD) is a complex neurological disorder that involves both motor and non-motor symptoms resulting from the progressive loss of neurons in the brain. Unfortunately, there is currently no known cure for this degenerative disease, and only symptomatic treatment is available. Despite extensive research, the underlying cause of PD remains unknown (Dexter et al., 2013; Jose et al., 2010; Hughes et al., 2002). Gender appears to play a significant role in the frequency and severity of PD symptoms, although there are some inconsistent findings in the literature. Women with PD tend to present with a milder phenotype than men. Tremors are a common symptom of PD, often beginning in a limb and gradually spreading throughout the body (Pahuja et al., 2016; Heller et al., 2014).

Tremor refers to an involuntary and rhythmic oscillation of a body part, which can result in jerking movements or convulsions throughout the body. A common example of this is the hand tremor, which can make it challenging to grasp objects such as a glass of water or a pen for writing (Chinta et al., 2005; Park et al., 2009). There are two main categories of tremor: resting tremor and action tremor. Resting tremor occurs when the muscles are at rest and there is no intentional movement, while action tremor involves shaking of a body part during a voluntary act of moving that body part (Agarwal and Biagioni, 2022).

Although Parkinson's disease does not have a permanent cure, medication and surgery are two methods used to manage tremors. However, the process of managing medication dosages can involve a lot of trial-and-error

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approaches, and tremors can still appear at different times of the day, requiring further dosage adjustments. Additionally, caregivers of patients who have undergone Deep Brain Stimulation surgery may rely on their intuition when re-tuning the brain pacemaker, which is an unscientific approach. To address these challenges, there is a need to scientifically measure the tremor pattern so that more accurate dosage planning, and brain pacemaker re-tuning can be performed. This would help to improve the overall management of Parkinson's disease and enhance the quality of life for those affected by the condition.

Traditionally, tremor has been evaluated through physical examinations during clinical appointments. However, this approach can be subjective and may not capture the full spectrum of the symptom in a patient's daily life (Sigcha et al., 2021). In recent years, studies have been conducted on building systems for tremor suppression. However, these studies have typically used surface electromyography (EMG) burst signals from muscles, which can be prone to errors due to electrode positioning, changes in skin conductance, and crosstalk from other muscles.

To address these issues, needle EMG has been identified as the most reliable technique for precise characterization of tremor features. However, this method is invasive and costly (Xu et al., 2016). Closed-loop tremor suppression systems offer a more advanced alternative to conventional open-loop systems. They are able to deliver stimulation only when symptoms are present, providing greater comfort for patients (Khan et al., 2021).

Therefore, this research studied a simple, compact, and affordable inertial sensor based closed loop wearable device for tremor monitor and suppression system to assist Parkinson's patients can be developed.

2. Material and methods:

2.1 Materials

The components used in this study were NodeMCU, MPU6050, breadboard, LED display and vibration motors.

- NodeMCU: NodeMCU is an open-source development board and firmware based on the popular ESP8266 WiFi module. NodeMCU is one of the most popular IoT development platforms and is widely used to build IoT projects. NodeMCU also provides a rich set of libraries for interacting with different components. NodeMCU is a great platform for building connected devices. It is a great platform for prototyping projects and for developing embedded systems. NodeMCU is easy to set up and use, and it is compatible with a wide range of hardware and software. It is also open source and can be extended with custom code. NodeMCU is an excellent choice for anyone looking to build IoT projects.
- MPU6050: The MPU6050 is an inertial measurement unit (IMU). It combines a 3-axis gyroscope, a 3-axis accelerometer, and a Digital Motion Processor (DMP) all in a single chip. The device can be used to measure both linear acceleration and angular velocity.
- Breadboard: A breadboard is a construction base for prototyping of electronics. It is a reusable solderless device for testing circuit designs before committing to a printed circuit board. It is a great tool for prototyping and experimenting with circuit designs.
- Vibration motors: This study used mini vibration motors rated DC 3V current 85mA, and speed of 12000 RPM. The size is 10mm x 3mm/ 0.39" x 0.12" (D*T) with self-adhesive capability.

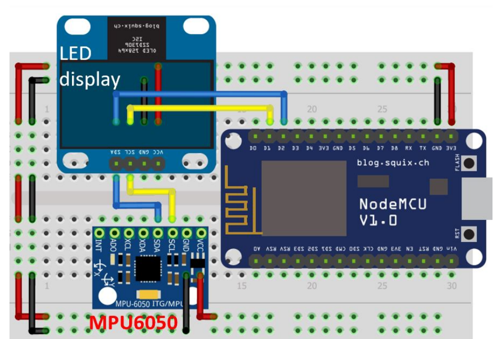

Figure 1: The design of the tremor monitoring system showing major components like NodeMCU, accelerometer and LED display.

2.2 Working principle

This study involved building a portable and wearable device based on inertial sensors (accelerometers and gyroscopes), which

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were interfaced with smartphones or tablets through wireless communication protocols (Bluetooth, Wi-Fi, etc.). The design for the tremor monitoring system included NodeMCU, accelerometer and LED display (Figure 1). The tremor suppression system added vibration motor and a few other components like transistors. NodeMCU is an open-source development board and firmware based on the popular ESP8266 Wi-Fi module. The NodeMCU was also used to read the data from the accelerometer and transmit it to a cloud platform after preprocessing. The system was programmed to detect tremors at certain thresholds and record the tremor data. If the tremor intensity crosses a certain limit the system applied a counter force to suppress the tremors. The system included a display to show the readings from the accelerometer and the current status of the tremor suppression system. The system was also programmed to keep track of the number of tremors over a period, thus allowing for monitoring of the patient's condition. After the tremor monitoring system was built, it was hooked up to a laptop to pre-process the raw data. To determine the tremor threshold to detect a tremor vibration was attached to a Parkinson's patient's wrist (Figure 2).

Figure 2: Example of a tremor monitor system hooked up to a patient's wrist.

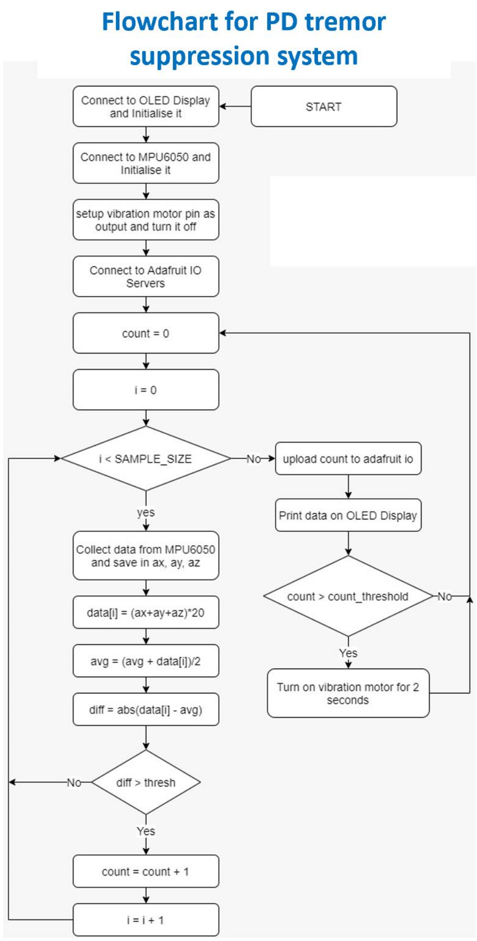

Figure 3: The flowchart showing the steps involved for the tremor suppression system. The left part of the flow chart shows the flow for curve smoothening and tremor count estimation. The right part shows the uploading the tremor count on the cloud (Adafruit) and LED display and also the tremor suppression system flow.

2.3 Methods

The data pre-processing for this study is shows in the left part of the flowchart (Figure 3). This study involved obtaining raw data of the vibrations (changes in acceleration) in all the three-directions. For simplicity the sum of all accelerations is measured as a parameter. Since the actual acceleration was small number it was multiplied by a random number 20 for making it easy to work with.

3. Results:

3.1 Data pre-processing

The movement of the hand is monitored for 4 to 5seconds. The acceleration data was affected by the position of the hand, so moving average was used to smoothen the data (Figure 4). Then the difference between the current data and the moving average was monitored as tremor intensity. This study used an Adafruit cloud platform to save the data and plotted on the dashboard.

3.2 Tremor monitoring:

The tremors were monitored (for a duration of 4 to 5 seconds), and acceleration was plotted for 10 runs using my system. A threshold of 15 m/s^2 was obtained that works for all the

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10 experimental runs (Figure 5). Then the test was run 15 times to see if the system was able to pick up the tremor vibrations correctly. My system was able to successfully detect the tremors as soon as the tremor threshold is above 15 m/s^2. We arrived with a threshold acceleration of 15m/s2 as this is the only whole number that separates the tremors and non-tremors (random hand movements) for all the 10 runs performed in this test.

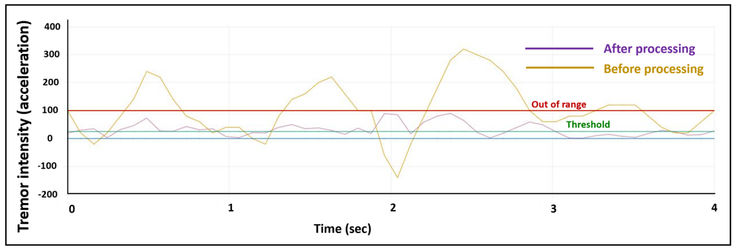

Figure 4: Plot showing the raw data of the tremors before and after smoothening the data.

To calculate the count threshold to determine if a tremor vibration is Parkinson's tremor or not, the device was attached to a Parkinson's patient's wrist again. Ten tremor runs were executed and plotted the data using my system. The number of tremors above 15 m/s^2 in a duration of 2 seconds were counted. The average of the counts for the 10 runs were taken. A count threshold of 27 counts (with a standard deviation of 2.1 counts) was obtained to determine if a particular tremor vibration is a Parkinson's tremor. Then the test was run 15 times to see if my system is able to pick up the Parkinson's tremor vibrations correctly. My system was able to successfully detect the Parkinson's tremors if the tremor count threshold is above 27 counts. The tremor count data is also tracked and plotted on a dashboard (Figure 6).

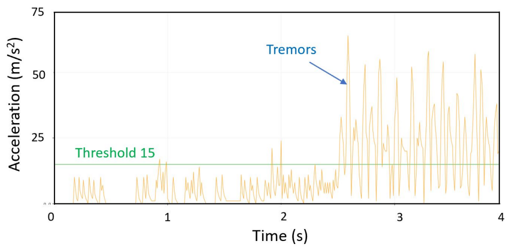

Figure 5: Plot of acceleration versus time showing the tremor threshold as 15 m/s^2

3.3 Tremor suppression:

After the tremor suppression system was built, it was tested on a Parkinson's patient. The test was run 15 times to see if my system was able to activate the vibrational motors as soon as the tremor count threshold is above 27 counts indicating that it i a Parkinson's tremor. My system was able to successfully turn on the vibrational motors whenever the tremor count threshold was above 27 counts. The vibrational motors help reduce the tremors. If the number of tremor counts is greater than 27 and if the acceleration of the tremors is >15 m/s^2 then two vibrational motor turns on using a transistor (connected to the controller). After the 2x motor are turned on if the acceleration of the tremors is still >15 m/s^2 then 2x more vibrational motor turns on (Figure 7). When the tremor acceleration comes below 15 m/s2 the motors are turned off. The vibration motors help reduce the acceleration but doesn't help reduce the tremor count frequency.

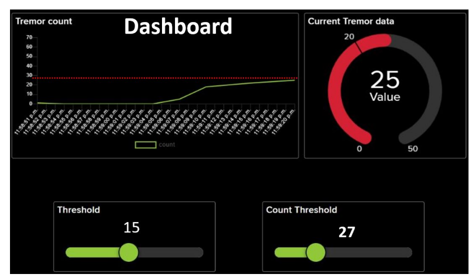

Figure 6: Dashboard tracking the tremor count data and showing the threshold and count threshold values.

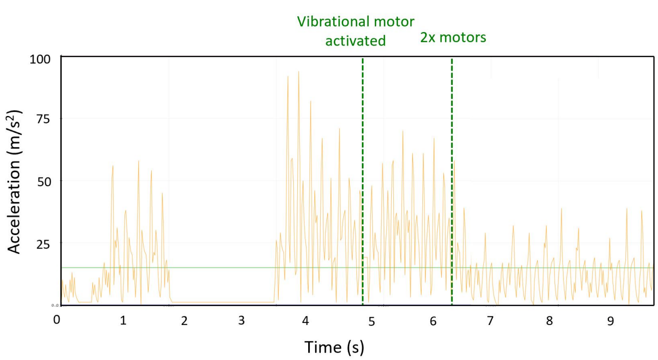

Figure 7: Plot of acceleration versus time showing the tremor acceleration going down when the first vibration motor is turned on. After the 1st motor is turned on, the acceleration of the tremors was still >15 m/s^2 then the second vibrational motor turns on to reduce the acceleration down to <15m/s^2.

4. Discussion:

The total cost of my system was less than $40 which is very affordable. The itemized cost of the components in my device includes a breadboard (~$4), an accelerometer (MPU6050 ~$9), a micro-

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controller (~$7), watch base (~$10), a watch strap (~$3) and a protective plastic cover (~$4). The software and cloud used for programing and storing the data are free for the study however these may add cost if the solution should be scaled up.

The tremor frequency for the Parkinson's patient was approximately 1 tremor every 100ms. The accelerometer in the MPU6050 measures the acceleration every 50ms and sent the data to the node-MCU (controller). The software/code in the controller runs the threshold check (Figure 5) every 50ms. This ran for 40 loops which took approximately 2 seconds. The number of tremors higher than the acceleration of 15 m/s^2 in these 2 seconds were tracked and plotted on the dashboard. If this count was greater than 27 counts, then it was flagged as a Parkinson's tremor. This method of determining if the tremors are Parkinson's is not an ideal method but works well because frequency of the Parkinson's tremors are much higher than the normal random hand movements.

Our tremor monitoring system can assist neurologists during dosage planning by providing. Based on the tremor acceleration and tremor count the care takers can adjust the medication dosage accordingly. The vibration motors generated anti-vibrations to compensate the tremor by actively applying a counterforce (equal and opposite forces) whenever the tremor count is exceeded 27 counts. The tremor suppression system was tested 15 times randomly; however, it only cancelled the tremors only four out of the fifteen times. The vibrational motors were installed on the backside of the wearable device that contacts the top of the wrist (Figure 6). If the contact of these motors with the hand was not good, then the impact on the tremors was less. I am currently working on an improved design to have a better contact of the motors with the hand.

Previous studies developed a wearable orthosis for tremor assessment and suppression using sensors that measure rotational motions around the joints. This device, which is placed parallel to the upper limb, suppresses tremor with a tremor suppression rate of 40% (Rocón et al., 2007). However, this device wasn't very popular because it was too large and bulky (Manto et al., 2007).

There are some drawbacks for my system and needs to incorporate the improvements in the future work. The tremor threshold and count threshold were calibrated on only one patient, so it needs to be tested on multiple patients to generate robust values. The vibration motors in my wearable device needs a better design to improve the contact between the hand and the motors. The actual counteracting mechanism of the vibration motors needs to be improved. The method of determining if the tremors are Parkinson's, needed to be improved.

5. Conclusions

A simple, compact, and affordable accelerometer sensor based closed loop wearable device for tremor suppression system to assist Parkinson's patients was built. The system was able to detect the tremors on a Parkinson's patient successfully all 15 times it was tested. The device generates anti-vibrations to cancel the tremors by activating the vibration motors whenever the count threshold was greater than 27 counts however the repeatability needs to be improved. The tremor count data is shown on the LED display and tracked/plotted on a dashboard for easy access.

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