A Closed-Loop System to Monitor and Reduce Parkinson’s Tremors

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13 December, 2017

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1. Introduction

Parkinson's is a neurodegenerative disorder that affects nearly 10 million people worldwide and is the 14th leading cause of death in the U.S. [1]. Tremors associated with Parkinson's prevent proper usage of hands and other extremities, impacting the daily life of those suffering from the disease. While there is currently technology to monitor these tremors, there is a dearth of devices that focus on their reduction [2].

2. Problem Statement and Proposed Solution

Parkinson's patients experience random, uncontrollable tremors, generally occurring in the hands and wrists. Current solutions to treat Parkinson's are not integrated with the monitoring of the symptoms, and often require invasive techniques such as deep brain stimulation. Technologies that are used to monitor daily symptoms are bulky and not suitable for daily use. This means that patient data is only collected sparingly (when the patient visits the doctor) and not often enough to make a consistent and meaningful impact on treatment customization. Similarly, devices that mitigate the uncontrollable effect of the tremors are not prevalent in day-to-day life.

The solution is a combined tremor-monitoring and tremor-controlling system that is suitable for daily use. A bracelet containing an accelerometer will be utilized to detect the tremors and interface with an EMS (Electrical Muscle Stimulation) machine to counteract the tremors. EMS machines provide a non-invasive method for stimulating muscles to counteract the tremors via electrodes attached to the arm. The fully designed PCB that monitors the tremors will communicate to a cell phone app to display tremor statistics to the user.

3. System Requirements

Goal: A safe, lightweight, tremor-monitoring bracelet suitable for daily use that interfaces to an EMS tremor reduction system.

There are quite a few constraints and specifications that the system needs to meet in order to function properly. To meet our goal, our system will implement a wearable bracelet, cell phone application, and EMS machine. The various parts of the device will communicate via Bluetooth.

Focusing first on the wearable bracelet, the bracelet needs to be small and light enough to fit comfortably on a human wrist. The bracelet will house the dsPIC, accelerometer, and Bluetooth module to allow for proper data collection. The accelerometer will measure X, Y, and Z acceleration based on the movements and tremors of the user. The dsPIC will collect this data and perform signal processing to determine the presence of tremors amongst other movement. A Bluetooth module will relay this information to a cell phone application and the EMS machine.

The bracelet components (dsPIC, accelerometer, and Bluetooth module) will be powered by a battery. The battery must be rechargeable, should have at a 48 hour lifetime (based on the battery life of a Fitbit), and a recharge time of 5 hours.

The cell phone application will communicate via Bluetooth with the bracelet module. The app will have a graphical user interface (GUI) that displays whether tremors are being detected. In addition, the app will save tremor data to memory to allow the user to review his/her tremor history.

The EMS machine will also receive data from the bracelet Bluetooth module. When tremors are detected by the bracelet, the EMS machine will apply an electric signal to mitigate the tremors. The EMS can be powered by either battery or a wall power supply. Adjustments will be made to the output of the EMS based on feedback (e.g. is the tremor reduced?) to allow for variations in the magnitude of muscle stimulation signals.

What is the nature of the required embedded intelligence?

The system requires communication between several subsystems. The embedded intelligence must be able to read data from the accelerometer and process it with DSP capabilities. The embedded intelligence must also be able to communicate with a Bluetooth module to send data to an EMS machine and a cell phone app.

How is the device powered? If it runs on batteries, what kinds of batteries are used, how long should the system be able to run on the batteries, etc?

The bracelet will be battery powered. The battery will be required to generate 3-3.3 V to power the microcontroller for up to 48 hours of continuous use. The battery will be rechargeable and able to regain full power with 5 hours of charge time. The EMS machine will be powered on its own. The cell phone will be powered with its own internal system.

There are lots of requirements related to wireless interfaces. How many devices need to be supported? What range is required?

Three devices need to be supported, including the dsPIC, the accelerometer, and the Bluetooth module. The dsPIC needs to wirelessly interface with the cellphone and the EMS machine (via Bluetooth). The distance required will be less than 4 meters, based on the assumption that the phone will be close to the patient during daily use.

What are the user interfaces?

The user interface will be a GUI on the cell phone app that allows the user to monitor his or her tremors. The EMS machine will also have a user interface to allow for additional control of the tremor reduction signals.

How is the system installed and used?

The cell phone app can be downloaded via an app store or loaded from a computer. The bracelet will be worn on the wrist and turned on or off with a switch. The EMS electrodes will be placed on the forearm and the machine itself will sit near the user.

If your project involves voltages and or currents that may be dangerous, what are safety requirements associated with your system?

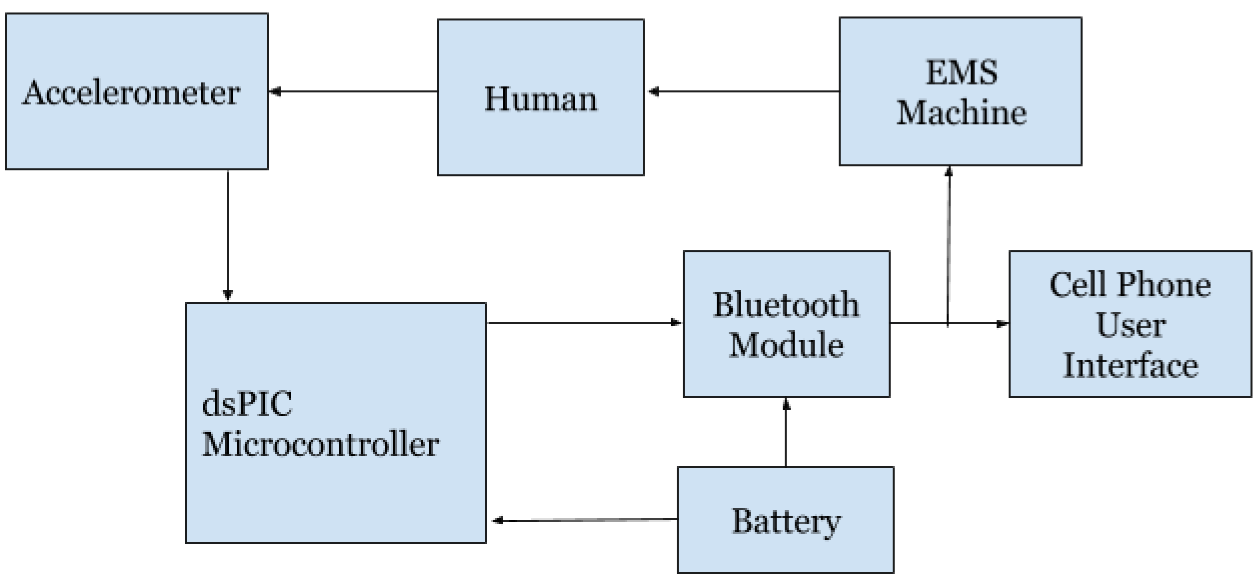
To mitigate risks, we will be purchasing a commercial, FDA-approved EMS machine for muscle stimulation. We need to ensure that we do not modify the EMS machine in such a way that it outputs signals not intended by the original device. We also need to ensure that the bracelet is adequately enclosed so that no harmful currents could discharge into the user's body. Additionally, there should be no high voltages. Heat from the bracelet electronics should also be taken into consideration since it will be worn by the user for an extended period of time. The bracelet must stay below temperatures that could be uncomfortable or harmful to the user.

What are the mechanical requirements, such as weight, size, etc.

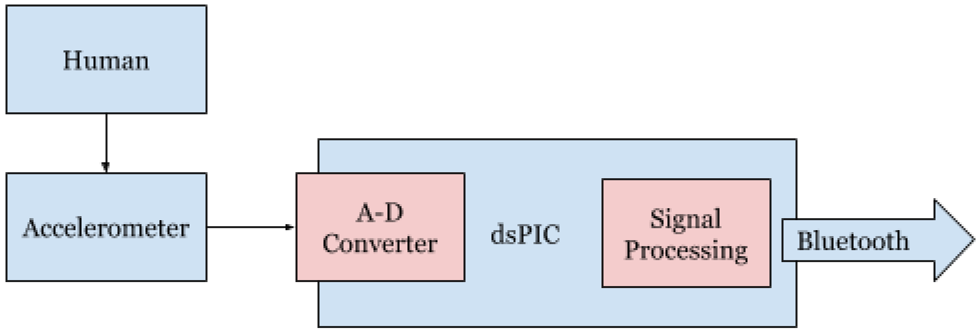
The bracelet needs to be lightweight and fit on a person's arm. The PCB needs to be small enough to fit on the bracelet. The bracelet should be adjustable in length to accommodate different users.

4. System Block Diagram

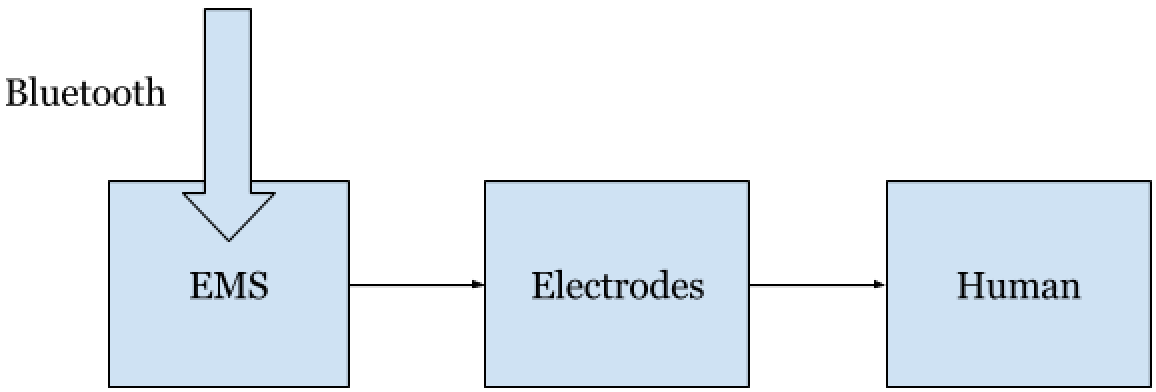
4.1 Overall System:



Bracelet Subsystem Block Diagram:



EMS Subsystem Block Diagram:



4.2 Subsystem and Interface Requirements:

1. Monitor tremors with a lightweight bracelet
    a. Use an accelerometer to track X, Y, and Z movement data
    b. Sample acceleration at a rate of, at minimum, 12 Hz, since tremors are known to usually occur at 4-6 Hz
    c. Send data to the dsPIC microcontroller
    d. Construct a PCB to hold all components together
        i. PCB should include space for the accelerometer, dsPIC, and bluetooth module
2. Select a battery to power the various devices on the bracelet
    a. Battery should be rechargeable
    b. Battery life of at least 48 hours
3. Bluetooth communication to send data between hardware components
    a. Bluetooth should be implemented on the bracelet with the dsPIC
    b. Communicate between the dsPIC and cellphone + dsPIC and EMS

4. Decision system to identify tremors and control an EMS tremor reduction system
    a. dsPIC includes DSP capabilities
    b. Perform a Fourier Transform on the X/Y/Z data
    c. Average frequency bins in tremor range and check if above threshold to determine if a tremor is occurring
5. Cellphone application to display the data
    a. Indicates whether or not tremors are occurring
    b. Stores tremor data on the phone to allow the user to review the information
    c. Uses Bluetooth to communicate with the bracelet
6. Interface and control of an EMS tremor reduction system
    a. Electrodes to communicate electric signals to the body
    b. Identify muscles/locations on the arm that allow for proper control of the tremors
    c. Develop attachment to control the output signal strength of the EMS

dsPIC acquiring data from accelerometer:
There will be three data signals from the dsPIC to the accelerometer to collect X, Y, and Z data.
dsPIC process the accelerometer data:
The dsPIC will obtain the analog signal from the accelerometer via the dsPIC's internal Analog-to-Digital Converter. The dsPIC will perform a DFT on the data. This will be used to determine the severity of the tremor by averaging the magnitude of the frequency data between 4-6 Hz, which corresponds to tremors' frequency content.
dsPIC sends processed data to cell phone app:
The dsPIC will take the output of its internal processing and send the data to the cell phone app. This will be done via the Bluetooth module.
Software and cell phone app user Interface:
The cell phone app will read in the data sent from the pic via Bluetooth. This data will then be processed. Then displayed via GUI to show the patient the severity of their current tremors.
dsPIC sends control signal to EMS machine:
The dsPIC will communicate with the EMS machine via Bluetooth. The dsPIC will send the EMS numerical data indicating whether or not to counteract a tremor and the strength at which to do so.
Battery powers the dsPIC:
The battery will power the dsPIC, which requires 3-3.3 V. The battery will only power the dsPIC, and provide the 3V required to power the accelerometer. The cellphone and EMS Machine will have their own separate power system. The battery will be charged via a usb and will require a recharging in circuit.

4.3 Future Enhancement Requirements

- **TENS machine use:** We decided on using an EMS machine for tremor mitigation at the advice of Dr. Bernstein, and after doing research, we discovered that EMS machines may be capable of mitigating tremors. An EMS machine also has an easily modifiable output, so the output can be varied in order to match the severity of detected tremors. However, a TENS machine could be a suitable or more-capable alternative to an EMS machine. A TENS machine floods nerves of an area with stimulating pulses in order to block pain signals. This blocking mechanism could possibly block tremor signals. A future test comparing the effectiveness of TENS and EMS for tremor mitigation would give a definitive answer to which method is more effective.
- **Neural signal monitoring:** An accelerometer is a fairly standard and useful method for monitoring tremors. However, monitoring the nerve or neural signals would directly show the cause and severity of the tremors. The data from this monitoring could be more accurate, useful, and easy to work with than accelerometer data. Still, an implementation of such monitoring would be complicated and potentially dangerous to test subjects. Such an implementation, done with the help of medically-experienced professionals, would potentially produce a fantastic method of directly monitoring tremors.
- **Scaling the prototype:** Currently, the project is largely to test the feasibility of creating a Parkinson's monitoring system. Therefore, the entire system will not be fully integrated onto one PCB. The EMS machine will be a completely separate system. In the future it would be ideal to scale down the EMS machine to only the components of it our system requires so that the whole system could be on the bracelet.
- **Real patient testing:** Due to time and budget constraints, we anticipate having little to no testing on patients who actually have Parkinson's and experience Parkinson's tremors. Extensive testing on such patients is absolutely vital to ensuring that our solution performs its job and could be released to the public.

5. High Level Design Decisions

Accelerometer: An accelerometer was chosen as the means to collect patient tremor data for a variety of reasons. An accelerometer allows for reliable characterization of the tremor magnitude, direction, and frequency, while being fairly low cost. Accelerometer chips are also easily integrated on a PCB and interface well with various microcontrollers.

Accelerometer to dsPIC: The acceleration data will be sent from the accelerometer to the A-D converters on the dsPIC. This will convert the data from analog to digital for further signal processing. The A-D converters on the dsPIC can run at speeds of hundreds of kHz, which will be sufficient for our data collection, which requires a sampling rate of 40 Hz.

Processor Choice: Our initial plan of using a PIC32 seemed to be sufficient for A-D conversion of the accelerometer data and Bluetooth communication. We would like to implement signal processing on the PIC microcontroller, therefore a dsPIC should be used instead of the PIC32. The dsPIC allows us to send the processed data to the cell phone application. The dsPIC has multiple inputs which will allow the accelerometer to properly send data on all three axis of movement. The PIC microcontroller family was chosen for its ease of use as well as our familiarity with the programming of the device. The TI CS3SP33 was considered as the processor for the board, but it would require us to learn an entirely new compiler and processing system. However, the TI microprocessor does include a built-in Bluetooth module, which would reduce the size of the PCB that goes on the bracelet.

Bluetooth: We chose to use Bluetooth as our wireless interface between the PIC, cell phone, and EMS machine for several reasons. First and foremost, Bluetooth generally will use less power than other wireless options, particularly wi-fi. Secondly, our research showed that Bluetooth chips are cheaper and easier to work with than other wireless options. Lastly, Bluetooth more than satisfies our range requirements for wireless communications.

Cell phone app: We decided that since data processing and EMS control can occur on the PIC, the whole processing power of a computer is not necessary. Furthermore, a user is highly unlikely to have a computer powered and with them at all times, making a live transfer of the data impractical. Having a cell phone app take data from the bracelet solves both of these problems. Further decisions should be made as to whether the cell phone application will be on an Android or an Apple device. Our group members only have Apple cell phones, which may force us to choose an iphone application for testing purposes.

EMS machine: The EMS machine was chosen opposed to other stimulation machines because it results in a direct contracting force from the stimulated muscle. TENS machines were considered, but they affect nerves, not muscles. When choosing an EMS machine to use, we will have to consider further the level of access and customization that the EMS provides. In addition, we should consider looking for an EMS that is able to communicate via Bluetooth or wifi to allow for easier integration with the rest of the modules. Many also allow for built in intensity adjustments that could be interfaced and used to give finer control over the stimulation.

6 Open Questions

Will the EMS Machine effectively counteract Parkinson's tremors?

Our biggest open question is whether or not Parkinson's tremors can be reduced using an EMS machine as our method of non-invasive tremor reduction. Research papers claim that electrical nerve stimulation can be used to reduce Parkinson tremors, but the bulk of the papers use invasive stimulation methods. If the EMS machine is not effective, we will need to investigate other avenues for reducing tremors.

Would a Bluetooth-enabled microprocessor be a better choice than the dsPIC?

For space and power considerations, we looked into using a microprocessor that had a built-in Bluetooth module. The TI CP3SP33 was a device that we looked into since it is a microprocessor that is both DSP and Bluetooth enabled. However, the TI device is a microprocessor instead of a microcontroller, which would make programming the device more difficult. The RSL10 is also a device that we would be interested in learning more about, but are concerned that its development environment would not be ready in time for our project.

How will we control the EMS Machine's power output?

Each individual EMS machine has its own interface. Some have buttons on the front, some have Bluetooth or wifi connections for controlling them, and so on. Also, each EMS machine has its own unique output levels and signals as chosen by the manufacturer. Depending on the EMS machine we choose, we will have to choose how to tap into the EMS machine and how to utilize the machine's output.

What will happen to tremor data when no cell phone Bluetooth connection exists?

As the project is currently planned, we have no way to save tremor data if the cell phone is off or disconnected. Adding flash memory to the bracelet would be a potential solution to saving data in these cases. However, we do not know if we have time to implement a process that incorporates saving data that could be lost to flash memory, then communicating it to the cell phone once a Bluetooth connection is re-established. We also do not know how adding flash memory would affect the size and power requirements of the bracelet.

What information will be available to the user on the cell phone interface?

An FFT of a person's tremors may be too complicated for the average user to understand, but it may be useful to a doctor. A plot of when a user experienced tremors throughout the day may be useful to the average user. It is theoretically possible to calculate the amplitude of the tremors by double-integrating the acceleration; this could also be a useful insight for both users and their doctors if the data is displayed simply and accurately. A score based on the difference between the average magnitude of the observed frequency bins and the threshold could be used to illustrate tremor severity could be potentially useful. The user could track the changes in their tremors over time by first taking a calibration measurement without the EMS machine. Then the future tremors could be compared to the baseline. This could be used to monitor and calibrate the system.

What is the best way to simulate tremors? Can we test on an actual patient?
Currently the methods we have been using involve creating a 4-6 Hz oscillation using a speaker driven with a function generator. Another potential method is using a motor with a weight attached to create a vibration at 4-6 Hz. Although these create similar FFT to the shaking of Parkinson's tremors, they may deviate slightly in the subtleties of the data. Is it possible to find a Parkinson's patient that will allow us to perform testing on them?

7 Major Component Costs

Board:

- Microcontroller (dsPIC32): $8.24
- Accelerometer (ADXL335): $5.70
- Battery (3.7 Lipo): $6.95
- Bluetooth Module (Texas Instruments CC2564MOD): $11.27
- PCB: ~$30

Tremor Control:

- EMS Machine: $35.99 (basic model) to $249.99 (advanced model)
- Electrodes: 50 for $18
- Electrode Connections: $0 if Dr. Howard lets us have one, $5.98 if not

Total Estimated Cost: $116.15 - $336.13

8 Conclusions

The end result of this project will be a closed-loop system that both monitors tremors and uses feedback to reduce the tremors of a Parkinson's patient. Our project addresses many issues present in current Parkinson's treatments: the bracelet is suitable for daily use; the bracelet is non-invasive; and the bracelet performs constant data collection to allow for quick recalibration of feedback. The three main tasks our project performs (data collection, data analysis, and tremor reduction) will provide Parkinson's patients with relief from tremors and allow them to better operate in their daily lives. An open issue that remains to be solved is whether an EMS machine will perform as we expect to reduce tremors.

Appendix:

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