Signal Processing Application to Tremor Quantification and Diagnosis

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Tremors can be described as involuntary and uncontrollable movements of parts of the body. They are classified based on characteristics like frequency, amplitude and activation. Such parameters are essential to identify so that better treatment can be provided to patients suffering from tremor conditions. Electromyography (EMG) is a diagnostic procedure to assess the health of muscles and motor neurons. Though used in the past, EMG is expensive, invasive, and potentially painful. Therefore, there is a need to create an affordable, fast, painless and effective apparatus that can gather, quantify and classify tremor parameters from patients, resulting in a short list of possible diagnoses which can be narrowed down by a physician. This research aims to create a Tremor Diagnosis Device (TDD) using an accelerometer, Raspberry Pi 4, and Python code. Due to the COVID-19 pandemic, gathering tremor data directly from patients was not possible. Consequently, the tremors were simulated using the PASCO string vibrator. After several test cases, we proved that the TDD measured the correct tremor frequencies and provided a list of diagnoses based on the quantified tremor data, the testing method, and personal information from patients. This research paper describes how the TDD was made and the results of numerous trials using simulated tremor data. We expect this new approach to be further explored on patients so that in the future, it can replace current procedures.

INTRODUCTION

Tremors are involuntary, rhythmic muscle contractions generally caused by a problem in the deep parts of the brain that control movement, such as the basal ganglia. They are often seen in the hands but can also be seen in the legs, head, arms, vocal cords, and torso (Charles et al., 1999). Some of the causes of tremors are genetic, while other causes are secondary to neurological disorders or are idiopathic. There are different ways to classify tremors, but the two main tremor divisions most relevant to this research are the classification based on tremor activation (resting or action) and the classification based on the tremor's appearance and origin.

A tremor's diagnosis is based on the location, activation, and appearance (frequency and amplitude) that the tremor

is presented on (Bhatia et al., 2018). Because of its broad classification, making an accurate diagnosis can be difficult. Physicians have tried different methods and equipment, like EMG, to help them make a diagnosis. However, tremor activity through EMG is sometimes recorded using needles and wire electrodes, leading to more invasive and painful procedures (Grimaldi and Manto, 2010). In addition to costing several hundreds of dollars, there is evidence that infections, bruising, tingling, soreness, and swelling may result from this procedure (Farrell et al., 2003).

Different technologies have been examined in the past to try to quantify tremors and provide a diagnosis. Smartwatches, for example, were used to try to record tremor activity and distinguish between two different types of tremors (Wile et al., 2014). Similarly, smartphones have also been evaluated for such purposes. The latter involved using three Apple-based mobile devices to monitor different settings for 20 minutes (Varghese et al., 2019). Both of the mentioned methodologies are limited to hand tremor analysis, which shows a clear disadvantage when compared to the body-part adaptability of the TDD. In addition, they involve a longer testing time and more expensive equipment compared to the MPU6050 accelerometer used by the TDD. Consequently, there is a need to create an affordable, fast, painless, and effective apparatus that can detect tremor frequencies and amplitudes based on different parameters like activation for a better diagnostic assessment. This research aims to create a Tremor Diagnosis Device (TDD) using an accelerometer, Raspberry Pi 4, and Python coding. Combining such elements will create a device that can gather

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frequency and amplitude data from the tremor, connect such results with different parameters like activation method, store this data, and provide a narrow list of possible tremor disorders/diseases associated with the quantified data. With such a list, a physician will be able to give the patient a single, more accurate diagnosis which will lead to a better treatment.

MATERIALS AND METHODS

The hardware needed to develop the TDD includes a Raspberry Pi 4 and its respective charging cord, a touchscreen monitor for the Raspberry Pi, the triaxial accelerometer MPU6050, cables used to connect the sensor, the PASCO string vibrator, and a function generator with its respecting connection and charging cords.

The Raspberry Pi 4 can be thought of as a minicomputer. For the TDD, the Raspberry Pi 4 served the purpose of a CPU along with the EVICIV 7 Touchscreen Monitor. A mousepad and keyboard were attached to the Raspberry Pi to make the coding process faster.

Attached to the Raspberry Pi 4 was the MPU6050 accelerometer. This accelerometer was appropriate for the TDD because it is triaxial, small, and light and it can be interfaced with the Raspberry Pi 4. The weight and size of the accelerometer were significant since both could interfere with the tremors' motion. The MPU6050 provides a digital output with very sensitive readings based on a programmable full-scale range of $\pm2g$, $\pm4g$, $\pm8g$, and $\pm16g$.

To ensure the frequency readings' accuracy and simulate tremors, the TDD used the PASCO string vibrator. String vibrators are usually used to study frequency, wavelength, and resonance. We powered the string vibrator using the Instek AFG-2125 function generator, which allowed us to output a frequency of our choice through the string vibrator. By placing the accelerometer on the string vibrator, the accelerometer moved at a specific frequency which we gathered in our program. As a result, we were able to test the readings of the TDD. Figure 1 shows the different components of the setup, in which we can see the various connections made to ensure that the communication within all the equipment was successful.

In the Raspberry Pi, a Python script was created on the Thonny IDE, which implemented multiple libraries to read and manipulate the data from the sensor. The data are read continuously every 0.01sec for a total of 20sec. The Fast Fourier Transform (FFT) was used to convert the time signal into individual spectral components. Thus, we obtained the frequency spectrum of the time signal. In addition, through this code, the user was able to input necessary information like name, age, gender, the body part being tested, tremor activation method, and tremor action test. The code included multiple conditional statements that determined which disease or disorder was associated with the specific frequency obtained and test performed.

Figure 1. Experimental Setup. A Raspberry Pi 4, along with a monitor and its charging and connection cords, was used to interface with the MPU6050 (not shown) to record frequency and amplitude values of tremors. The PASCO String Vibrator, powered by the Instek AFG-2125 function generator, was used to input frequencies for trial testing.

The frequency values for each of the different diagnoses were obtained from a research done by Vanderbilt University School of Medicine for tremor classification (Charles et al., 1999).

Every test using the TDD starts the same. The user inputs their first name, last name, age, gender, and the body part being tested. The user is also able to input which activation method they are using: resting or action activation. Next, the user inputs which action test is to be performed: postural action or kinetic/isometric action. The system gives a countdown of 10sec for when the system will start recording data. For all the trials performed, the PASCO string vibrator was used to simulate tremors of desired frequencies.

Based on the quantified data received from the sensor and the information input by the user, the TDD can make a narrow list of possible diagnoses that can help a physician evaluate a patient who presents tremors. As shown in Figure 2, the cycle begins with the patient having a specific tremor and ends with the patient having a particular diagnosis. It goes through the different steps of the process, like the tremor quantification, so that a physician can examine the gathered data and assess the patient as best as possible.

One of the aims of the TDD was to be low in cost. Most of the equipment used for the project was borrowed from the Physics and Engineering Department at Eastern Nazarene College. An approximate total cost can vary depending on the Raspberry Pi and monitor obtained but averages $170-$200 with the MPU6050 having a price of $4. However, the TDD can be used an unlimited number of times, reducing the
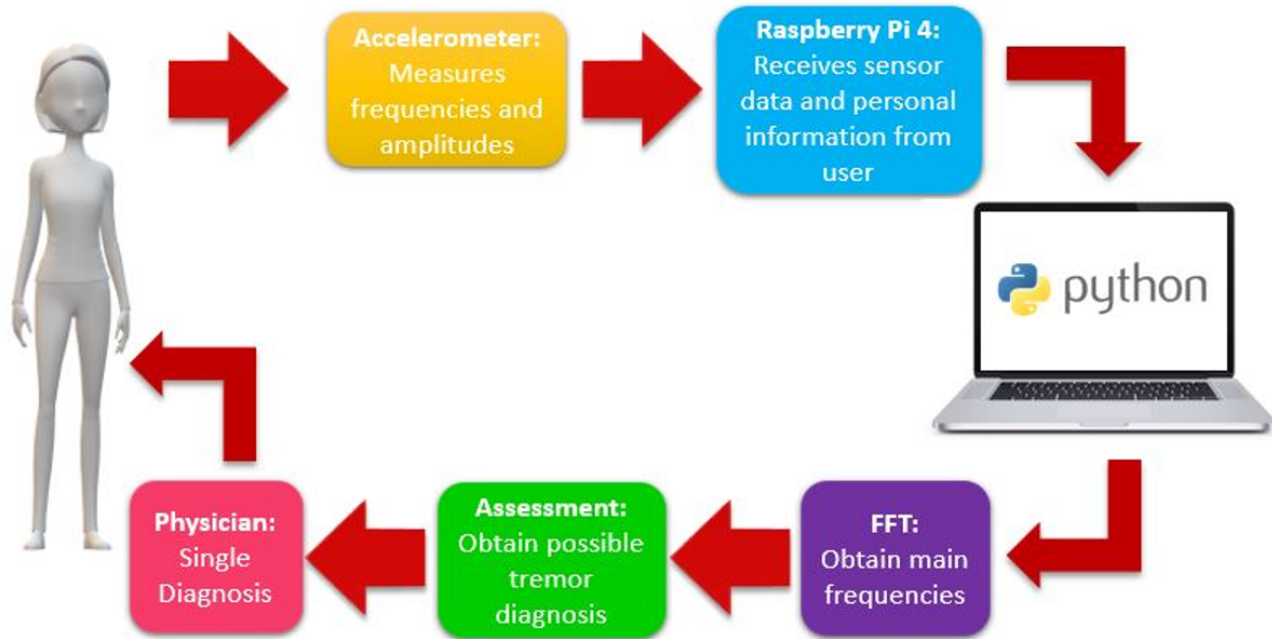
Figure 2. Concept of Operation. The system is based on a cycle that starts with a patient presenting a tremor. Information from the patient and tremor is obtained through the different system processes so that a physician can assess a patient with the most accurate diagnosis.

cost per diagnostic test.

RESULTS

The TDD provided different results depending on the parameters measured and the activation method selected. For example, when we set a trial to a resting activation method with a 5Hz simulated tremor, the TDD gave the following list of possible diseases/disorders associated with that specific tremor: essential tremor, psychogenic tremor, and Holmes tremor. Similarly, when we set a trial to an action activation method, specified as postural action, with a 5Hz simulated tremor, the TDD yielded the following list of possible diseases/disorders associated with that specific tremor: psychogenic tremor, drug- and metabolic-nduced tremor, Holmes tremor, alcohol or drug-withdrawal tremor, and physiological tremor. Though the quantified data were very similar as shown in Table 1, the results were different because they considered the kind of test performed. With the graphs from both trials of the time and frequency signal as shown in Figure 3 and Figure 4, we were also able to visually observe the similarities in the quantified data, specifically when noticing the spike at 5Hz on both frequency

spectrums. Once the list of possible diagnoses is obtained from a specific test, a physician can interpret the results based on other information like age and gender or other symptoms presented on the patient. The physician can find this information saved in an Excel spreadsheet so that the patient's information and assessment are recorded.

In addition to simulating a tremor with a frequency of 5Hz, we simulated tremors with higher and lower frequencies. For example, when performing an action test specified to be kinetic of an 8Hz-simulated tremor, the tremor-induced conditions were psychogenic tremor and Holmes tremor only. Once again, the time graph and frequency spectrum, as shown in Figure 5, allowed us to visually verify our frequency readings' accuracy and analyze this quantified parameter visually.

DISCUSSION

Tremors are a very common symptom of medical conditions, especially those that involve a neurological defect. Given that there is no established standard test to classify and denote tremor type, evaluating the condition can be challenging (Crawford and Zimmerman, 2018). The TDD
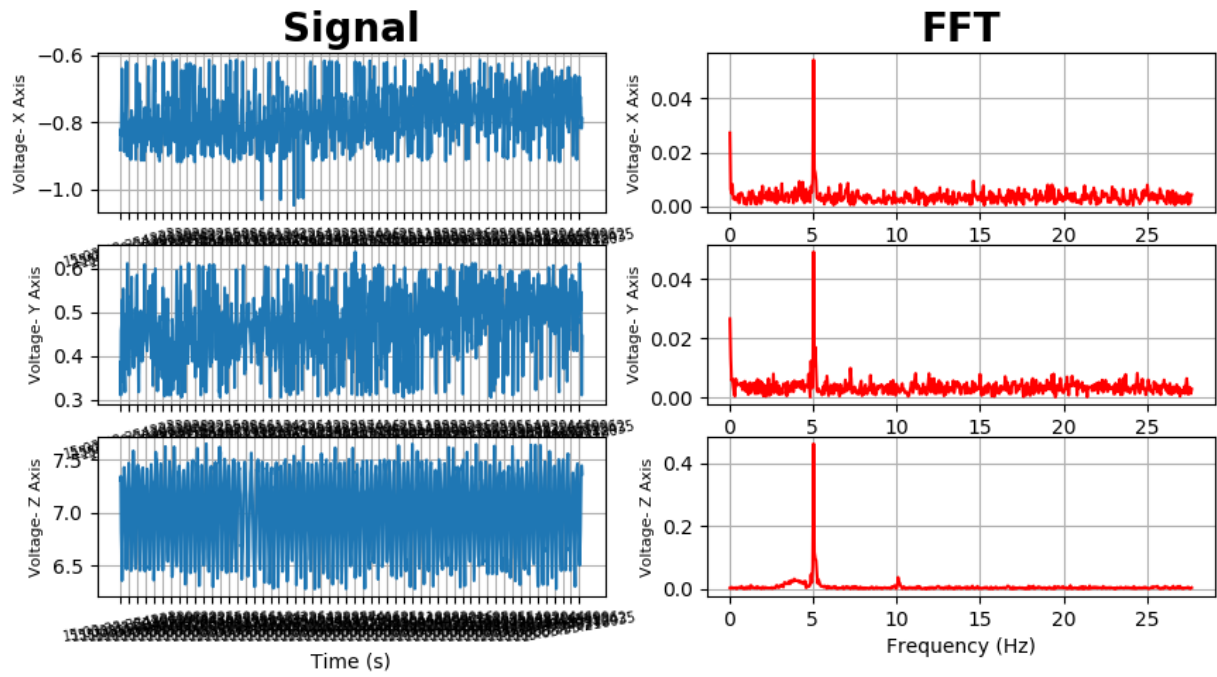
Figure 3. Graph of a 5Hz signal for a resting activation method. A 5Hz tremor was simulated using the PASCO string vibrator. The setting for this trial was that of a resting activation method. Data were recorded every 0.01sec for 20sec total. As seen on the frequency graph, there is a spike at 5Hz, which shows that the system is recording the correct values.
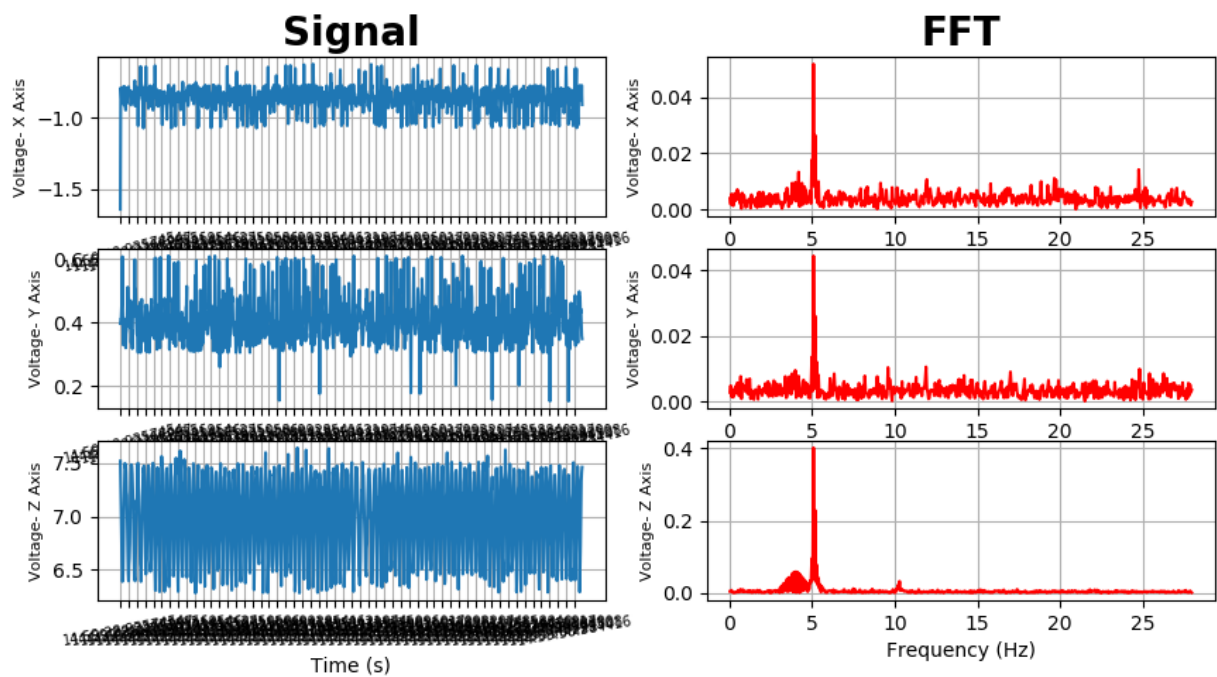

Figure 4. Graph of a 5Hz signal for an action activation method. A 5Hz tremor was simulated using the PASCO string vibrator. The setting for this trial was that of an action activation method with a postural action test. Data were recorded every 0.01sec for 20sec. As seen on the frequency graph, there is a spike at 5Hz, which shows that our system is recording the correct values.

Table 1. Comparison of 5Hz signal results for resting and action activation method. The frequency and amplitude values were extracted from each of the simulated tremors. These data are similar yet yield to different medical conditions because of the activation method used.

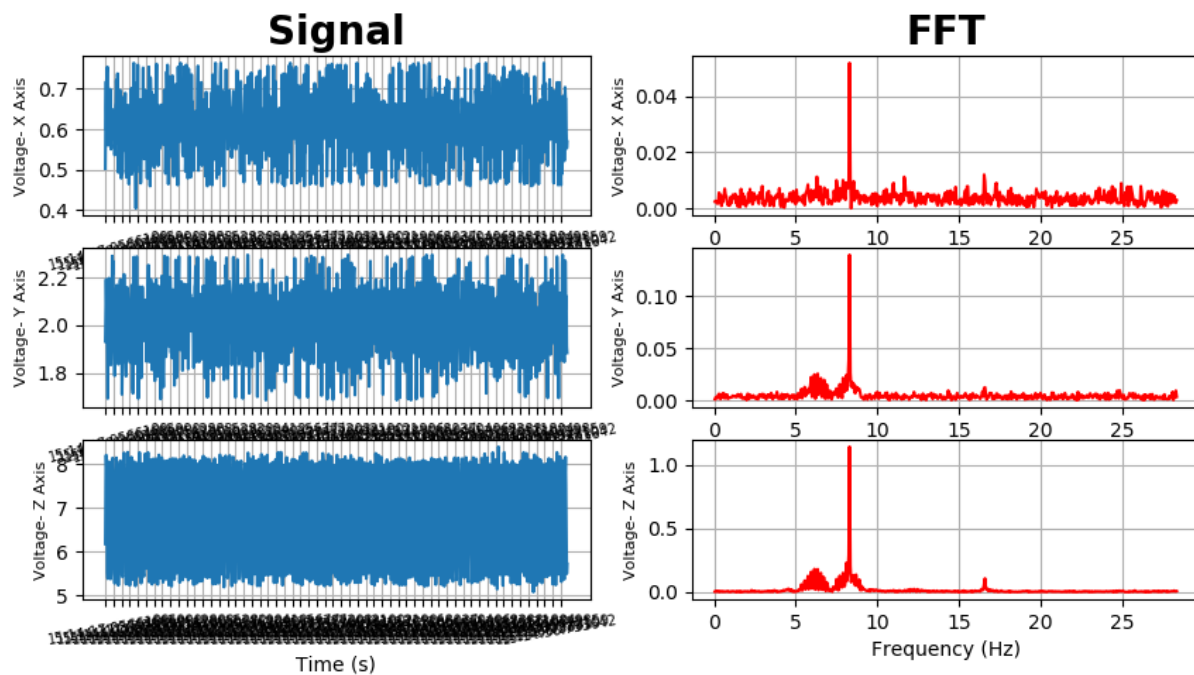|		5Hz Tremor					
Activation	Specification	Frequency (Hz)			Amplitude		
Method	Method	x	y	z	x	y	z
Resting	Relaxed	5.05	5.05	5.05	0.054344	0.049102	0.461995
Action	Postural	5.1	5.1	5.1	0.051774	0.044437	0.401104

Figure 5. Graph of an 8Hz signal for an action activation method. An 8Hz tremor was simulated using the PASCO string vibrator. The setting for this trial was that of an action activation method with a kinetic/isometric action test. Data were recorded every 0.01sec for 20sec total. As seen on the frequency graph, there is a spike at 8Hz, which shows that our system is recording the correct values.

aimed to solve this problem by providing a narrow list of possible diagnoses based on the frequency and testing specifications of the tremor. Once testing is performed in actual patients, a physician may use the TDD as a rapid and effective method for tremor diagnosis and condition evaluation.

One of the primary goals of this project was to make the TDD noninvasive, cost effective, fast, and easy to use. The TDD does not involve any invasive procedures like with needles or electrodes. Although it requires an initial cost, the TDD can be used an unlimited number of times, reducing the cost per diagnostic test. One test takes no more than one minute, ensuring that the physician can almost immediately obtain results. Lastly, the system is user friendly; besides answering the initial questions collecting

personal information, the user is not required to perform any additional steps to set up the system.

CONCLUSIONS

Numerous trials were performed, varying the input frequency and the type of activation and action test. We were able to see the different diagnoses based on the specified conditions and quantified results. Among the main advantages of the TDD is that the procedure requires no invasive mechanism to obtain results in less than one minute.

This research is limited to results obtained from simulated signals that may significantly differ from the actual signals received from a patient's tremor. The TDD was not able to be tested with real patients because of the COVID-19 pandemic. All the results were obtained from simulated tremors

created by the PASCO string vibrator, which likely have less noisy signals than those of an actual patient's tremor. However, since the proof of concept still stands, more tests need to be performed in the future to thoroughly evaluate the effectiveness of the device. To begin with, the TDD needs to be tested on patients with a known diagnosis. This kind of test will help determine how accurate the list of possible diagnoses presented by the TDD is. Once these tests are performed, additional sensitivity and specificity analyses should be completed. Clinical studies should be conducted to analyze the TDD's performance further.

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