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Active tremor control in human-like hand tremor using fuzzy logic

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ABSTRACT

Tremor is the vibration in sinusoidal orientation that is experienced regularly by a person with Parkinson's disease (PD), which disturbs their daily activities. One solution that may be used to counter this tremor effect is by developing an active tremor control system in LabVIEW for linear voice coil actuator (LVCA), where the system uses proportional (P) controller and various types of fuzzy logic controller (FLC) as a hybrid controller to reduce tremor vibration. From this research, it can be concluded that the best controller for tremor reduction is the P+FLC 1st set of rules, compared to P+FLC 2nd set of rules, and P controller only, with the highest percentage of 88.39% of tremor reduction with the actual tremor vibration of PD patients as the reference result. The P+FLC 2nd set of rules has the highest percentage of tremor reduction with a value of 86.81%, whereas P controller only has the highest tremor reduction percentage of 67.10%. This percentage of tremor reduction is based on the power spectral density (PSD) values, in which it represents the intensity of the tremor vibration. This experimental study can be used as an initial step for researchers and engineers to design and develop an anti-tremor device in the future.

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1. INTRODUCTION

Tremor can be defined as an oscillatory movement that occurs involuntary and in a rhythmical manner on one or more body parts at a certain frequency and amplitude characteristics [1], [2]. These characteristics can provide significant information in terms of clinical aspect for tremor diagnosis and monitoring [1], [3] Tremor is one of the most common features or symptoms of Parkinson's disease (PD). Hence, it is extremely vital to study the tremor amplitude and tremor frequency of patients with PD to develop a new method in the treatment of tremor [4].

PD is a disease that can be clinically described as a central nervous system disorder with extensive tremor symptoms (pathological and physiological tremor) due to the failure and degeneration of the basal ganglia [5], [6]. This study focuses on the tremor in Parkinson's. Specifically, Parkinson's tremor is a trembling movement that occurs in an involuntary manner at a frequency of 4-6 Hz, having a high amplitude at rest or along an intended movement, particularly in the hands [1], [7]. The PD has several different tremors with different frequency, amplitude, distribution, constancy, the context in which they occur, and situations that are provocative [8]. Commonly, resting tremor is the symptom of PD. Patients with an early-stage PD have claimed that this symptom is their second most bothersome symptom [9]. However, many PD patients also have postural tremor from various origins [10]. PD patients usually experience tremor in their limbs; however, it would sometimes occur in the lips, chin as well as thumb for pill-rolling tremor [11]. Some PD patients will experience tremor at the initial stage of the disease and observable during walking or in a situation where the arms are usually fully relaxed. However, some PD patients may encounter Parkinson's tremor that increases gradually from year to year as the disease progresses [12], [13]. Therefore, it is essential that the effect of this tremor is reduced, as it can disrupt the daily activities of PD patients and makes them prefer staying home [14].

Several efforts had been made by other researchers towards tremor suppression. Herrnstadt and Menon used proportional-integral-derivative (PID) controller to obtain 99.8% tremor vibration reduction [15]. Besides that, As'arry *et al.* had also managed to achieve 98.25% tremor vibration reduction using PI+AFCAIL [16]. Meanwhile, Stone *et al.* and Lavu and Gupta obtained 20% to 60% tremor suppression in 6-13 Hz bandwidth and 83.4% tremor suppression respectively by using PID [17], [18]. Lastly, As'arry *et al.* successfully achieved 96.77% tremor vibration reduction using PID+fuzzy logic via simulation study [19].

This study focuses on developing a control system that could help to minimise the effect of the Parkinson's tremor. The linear voice coil actuator (LVCA) will also be used to accommodate the control system and act as the main active element to dampen the tremor vibration, thus reducing the tremor vibration. The control system would be using the P Controller, one of the most common and classic controllers that could help to improve the system response and fuzzy logic controller (FLC) as the main control elements that use different set of rules of 9 membership functions for the control system. The main reason for using the FLC is due to the controller being relatively new in tremor reduction application, where it is recognised as a potential robust controller. Hence, the FLC had been implemented together with the P controller to provide a hybrid controller for tremor suppression. To the best of author knowledge, there is no study yet use PID+FLC with different set of rules of 9 membership functions experimentally in tremor reduction application. Besides that, it also provides a decent performance in handling inaccuracies and uncertainties, such as noise, vibration, and other types of system parameters [20].

- Hand tremor test rig

The hand tremor test rig was designed using aluminium as the main material. This is due to the material's ease of fabrication, high functionality, and lightweight. The actual tremor data was injected into the shaker to emulate the artificial hand bahaviour to mimic Parkinson's tremor. The completed tremor test rig is shown in Figure 1. It was designed to emulate the Parkinson's tremor on two-axes, which were the y-axis and z-axis. Both axes had their own linear guiding to move the test rig in both horizontal (y-axis) and vertical (z-axis) directions. The test rig was also equipped with two custom springs on the z-axis (vertical) in order to replicate the exact movement of tremor behaviour. Even though it can be operated on two axes (y-axis and z-axis), the hand tremor test rig was operated on only a single axis (z-axis). This is because the severe tremor vibration had been detected on the z-axis based on the Parkinson's tremor data collected previously [19].

The hand model test rig consists of shaker and amplifier, accelerometer, LVCA and amplifier, and the national instrument data acquisition (NI DAQ) device. The shaker used in this experiment was the electrodynamic shaker from TIRAvib (TV 50018-M). The main function of this shaker was to induce vibration at the test rig. The shaker can be operated at a frequency range of 2 Hz to 20 kHz, making it extremely suitable to emulate the tremor vibration because of the actual frequency of Parkinson's tremor that is usually at a low frequency range of 4-6 Hz [7]. The accelerometer used in this study was the DYTRAN single axis accelerometer with a sensitivity value of 99.46 mV/g. The LVCA and amplifier were also used as the main active elements to counter the tremor vibration.

- Designing active control system using LabVIEW

The designing of the active control system involved the controllers, the LVCA, the disturbance, the test rig, and the sensor for the feedback. For the controller element, two types of controllers were used, which were the P controller and FLC controller. The controllers are the most fundamental element in the control system, as they make up most of the block diagram to enable it to work in the 'online' mode. Other than that, other elements, such as LVCA, disturbance or tremor data, test rig, and sensor (accelerometer) are the additional elements that complete the control system.

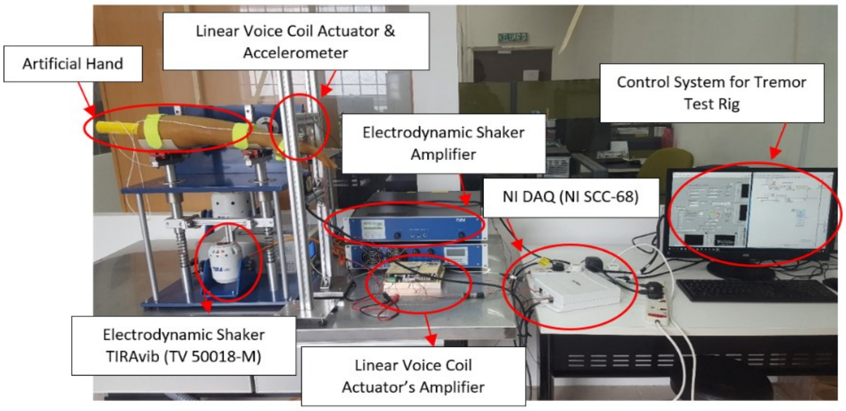


Figure 1. Hand tremor test rig

As shown in Figure 2, the control system would start by inducing the tremor vibration using the shaker. Then, the accelerometer would pick up the signal and transfer it through the controllers to produce a new output. Next, the output would be transferred to the LVCA, which is positioned at the upper part of the palm. Finally, the accelerometer would measure and record the signal into the LabVIEW measurement (LVM) file. All of the components in the control system were produced using the NI LabVIEW 2016 software.

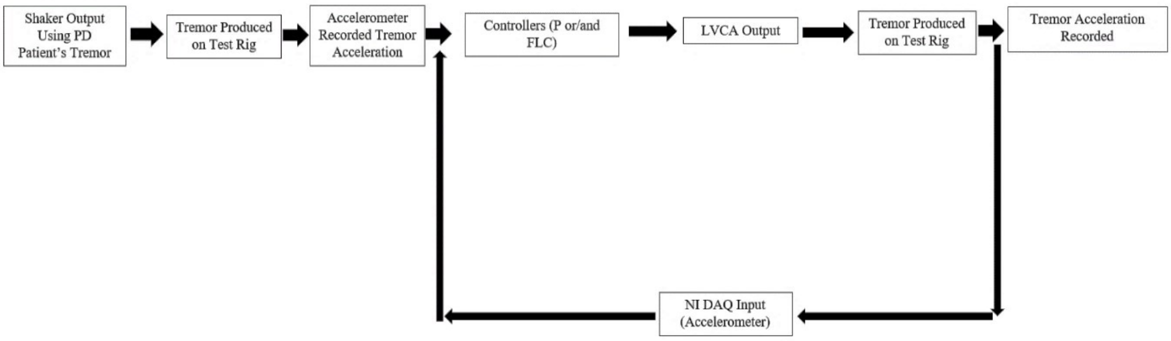


Figure 2. Schematic diagram of complete control system

2. DESIGNING CONTROLLER

2.1. P controller

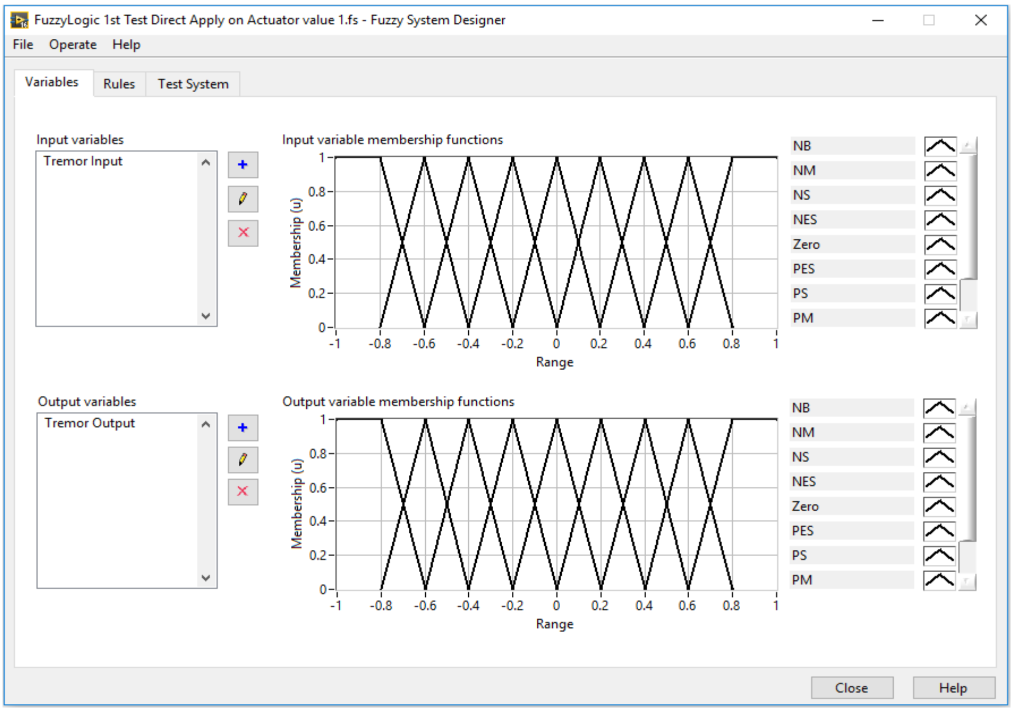
The P controller refers to the P action of a control error. It is a part of the PID controller that integrate with the integral (I) action and derivative (D) action. In this research, the I and D actions were excluded because both actions could cause the current control system to amplify the measurement, making the control system unable to run properly, thus producing no significant result. The variations of P values were set in the range of maximum voltage that the LVCA can experienced [16], [21], [22].

2.2. Fuzzy logic controller

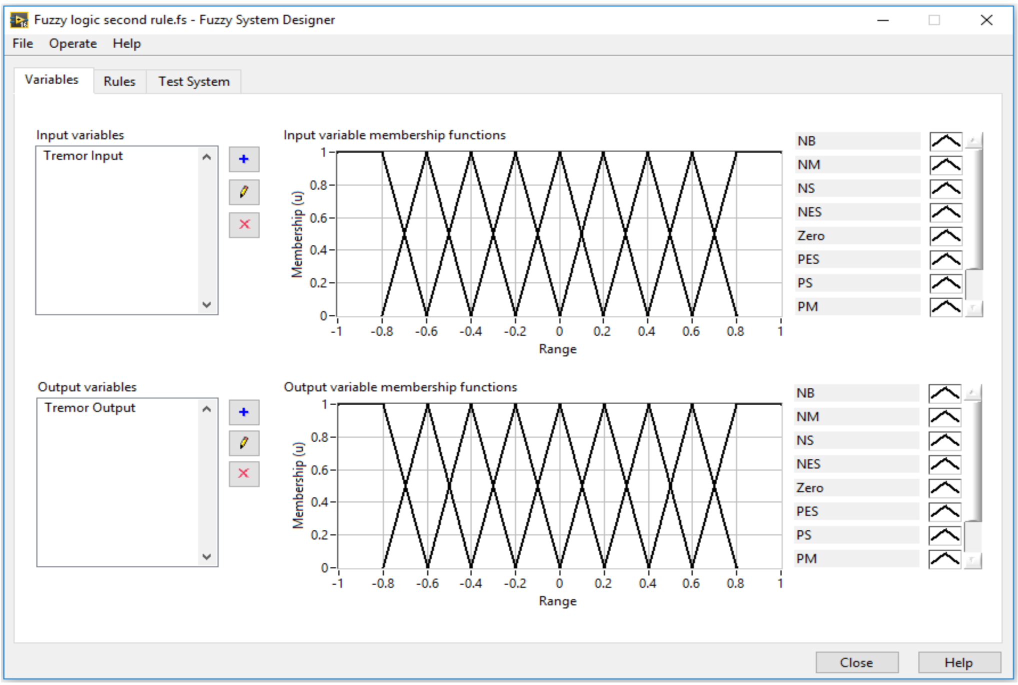
The FLC has been identified as an intelligent controller that is capable of producing the desired results. In other words, fuzzy logic is a popular technique used for its feasibility, robustness, and easy adaptation in different applications [23]. The fuzzy logic technique is made up of sets of fuzzy inputs, outputs, and inference with the system model represented using the fuzzy rules [24], [25].

In this study, the FLC had one input and one output for the control system. Several parameters were considered in the designing of the FLC, which were the input variable, output variable, range and shape of the membership functions, the total number of membership functions, defuzzification method, and one of the most important elements: the rule of the FLC.

As shown in Figure 3, one input in the FLC was the tremor vibration that was collected using the accelerometer. There were nine membership functions of the input and output of the FLC, which were the negative big (NB), negative medium (NM), negative small (NS), negative extra small (NES), zero, positive extra small (PES), positive small (PS), positive medium (PM), and positive big (PB). The reason why 9 membership functions instead of the common 7 membership functions being used is because this study wants to increase the sensitivity of the controller [19].



(a)



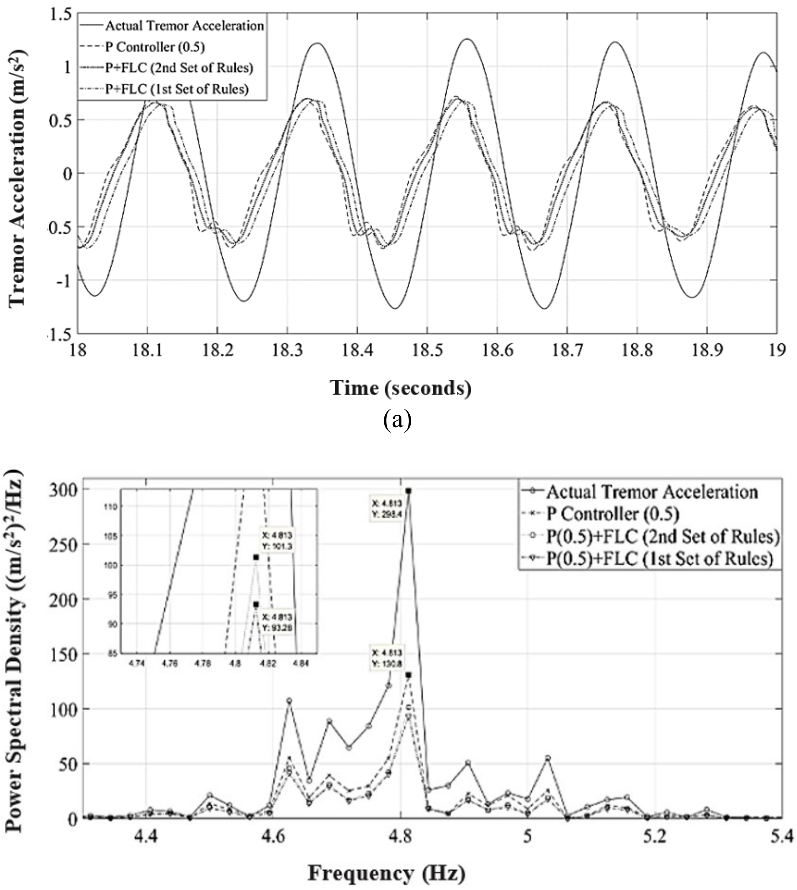
(b)

Figure 3. FLC (a) 1st set of rules and (b) 2nd set of rules of input and output

For the range of the membership functions, they had been set according to the input range that was entered through the FLC after passing through the P controller. In this study, the triangular shape had been chosen due to the shape was commonly used by other researchers [19], [26], [27]. There were two sets of rules that were implemented to test the sensitivity of the controller. The term used for the sensitivity test of FLC is the ‘inverse polarity’ test. ‘Inverse polarity’ means that the FLC input and output predicted values would be an opposite of another. For instance, for the 1st set of rules, when a value of positive voltage is entered as the FLC input, the FLC output would produce a negative value due to the rules that had been set beforehand. However, for the 2nd set of rules, when a value of positive voltage is entered as the FLC input, the FLC output would produce a positive value. Consequently, the difference between the two sets of rules was observed, thus developing the ‘inverse polarity’ term for the sensitivity test.

3. RESULTS AND DISCUSSION

The proposed controller system was applied and tested in an experimental environment. For this real-time study, the controllers that were used were the P control and the combination of P control and FLC (P+FLC). The performances of the controllers were investigated in terms of the percentage reduction in tremor vibration. For sensible comparison and analysis of tremor reduction, the RMS value of tremor acceleration and power spectral density (PSD) graph were used using the m-file MATLAB R2017a. The experiment used 512 Hz as the rate for 1 second of sample size data for the control system and measurement results in terms of the acceleration. There were three different values that were used for the P controller, which acted as the amplification values with reference to the acceleration behaviour. Values of 0.5, 1.5, and 2.5 were set for the P controller based on the heuristic method due to the LVCA limitation to avoid from overvoltage that can damage the actuator. However, for peak-to-peak RMS values of tremor acceleration, the data were analyse from 18-19 seconds in time domain as shown in Figures 4-6.



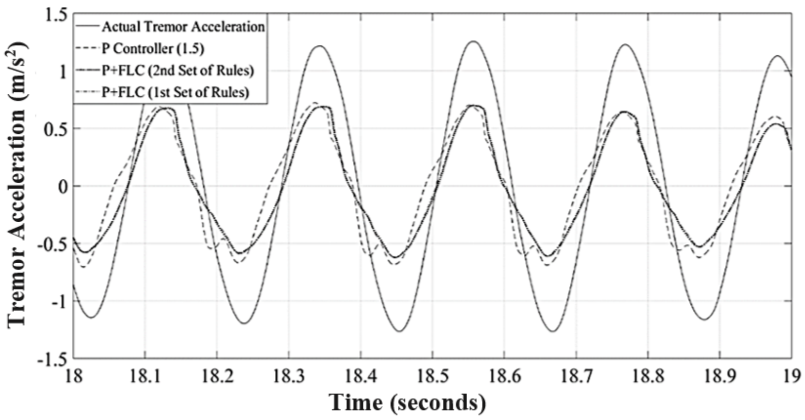
(a)

(b)

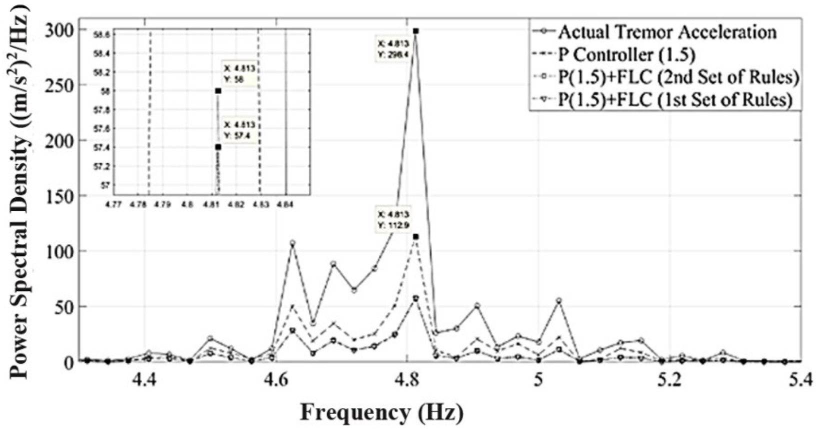
Figure 4. Effect of controller gain P (0.5) on acceleration and power response: (a) time domain and (b) frequency domain

Based on Figure 4(a), the results observed that the actual tremor acceleration of PD patients was reduced when P controller, P+FLC 1st set of rules, and P+FLC 2nd set of rules were used at a controller value of 0.5. There was another data that could be extracted from Figure 4(b), which was the intensity of the tremor vibration based on the maximum amplitude value of each tremor frequency. The maximum amplitude of the actual tremor acceleration frequency was 298.4 $(m/s^2)^2/Hz$. However, when P controller was used, the value of the maximum amplitude was reduced to 130.8 $(m/s^2)^2/Hz$. Hence, it showed there was 56.17% reduction in tremor vibration. When P+FLC 2nd set of rules and P+FLC 1st set of rules were utilised, the maximum amplitude was at 101.3 $(m/s^2)^2/Hz$ and 93.28 $(m/s^2)^2/Hz$, respectively. Thus, it showed 66.05% reduction of tremor vibration for P+FLC 2nd set of rules and 68.74% for P+FLC 1st set of rules.

According to Figure 5(a), the actual tremor vibration was observed to have reduced when the P controller, the P+FLC 1st set of rules, and the P+FLC 2nd set of rules were used at a controller value of 1.5. On the other hand, for intensity of the tremor vibration based on Figure 5(b), the use of P controller had managed to reduce the value of the maximum amplitude to 112.9 $(m/s^2)^2/Hz$ or alternately, a 62.16% reduction in tremor vibration. The application of P+FLC 2nd set of rules and the P+FLC 1st set of rules provided a maximum amplitude at 58.0 $(m/s^2)^2/Hz$ and 57.4 $(m/s^2)^2/Hz$, respectively. Conclusively, the reading was recorded at 80.56% reduction of tremor vibration for the P+FLC 2nd set of rules and 80.76% for the P+FLC 1st set of rules.



(a)

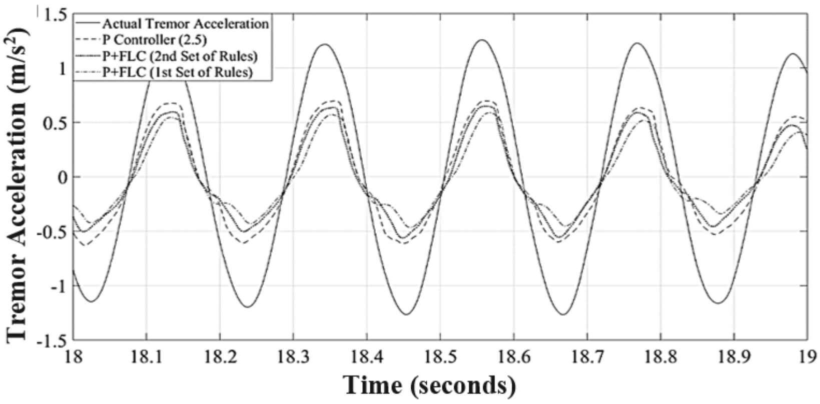


(b)

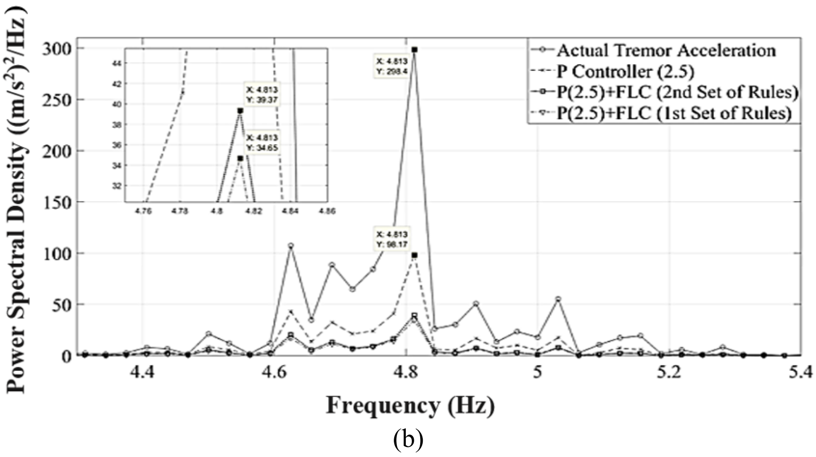
Figure 5. Effect of controller gain P (1.5) on acceleration and power response:
(a) time domain and (b) frequency domain

From Figure 6(a), by using the P controller, the P+FLC 1st set of rules and the P+FLC 2nd set of rules at the controller value of 2.5, the actual tremor vibration of PD patients can also be seen to have reduced. In terms of the intensity of the tremor vibration based on Figure 6(b) when using the P controller, the value of the maximum amplitude managed to be reduced to 98.17 $(m/s^2)^2/Hz$. In other words, 67.10% reduction in tremor vibration was recorded. When using the P+FLC 2nd set of rules and P+FLC 1st set of rules, the maximum amplitude was at 39.37 $(m/s^2)^2/Hz$ and 34.65 $(m/s^2)^2/Hz$, respectively. Consequently, a reading of 86.81% reduction of tremor vibration for the P+FLC 2nd set of rules and 88.39% for the P+FLC 1st set of rules.

The tremor vibration was best reduced by using the P+FLC 1st set of rules, followed by the P+FLC 2nd set of rules, and lastly, by the P controller only. Each type of controller showed an optimal performance in tremor reduction for controllers that implemented a value of 2.5 for the P controller. However, the optimum controller that produced the most tremor reduction was the P+FLC 1st set of rules when used at a value of P controller of 2.5. The controller had a percentage of 88.39% of tremor reduction in the actual tremor vibration of PD patient as the reference result. This percentage of tremor reduction was based on the PSD values, which represented the intensity of the tremor vibration.



(a)



(b)

Figure 6. Effect of controller gain P (2.5) on acceleration and power response: (a) time domain and (b) frequency domain

4. CONCLUSION

This study aims to investigate the capabilities of using P controller and FLC in reducing the human hand tremor vibration. Based on the findings, the combination of the P controller and the FLC as a hybrid controller able to reduce the tremor vibration successfully with a percentage up to 88.39% and showing an excellent performance in suppressing the tremor vibration of PD patients.

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