A Feasibility Study on a Cost-Effective Iot-Based Tremor Monitoring System for Early Parkinson's Assessment in Malaysia

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DOI: https://doi.org/10.47772/IJRISS.2026.100300340

Received: 19 March 2026; Accepted: 24 March 2026; Published: 08 April 2026

ABSTRACT

Parkinson Disease (PD) is a progressive neurodegenerative problem in Malaysia that has a severe influence on the quality of life, and its cost to the healthcare system is also a great burden to the national healthcare. With the increase in the number of the aging population, the conventional clinical diagnostic systems, including the Unified Parkinson's Disease Rating Scale (UPDRS), have key implementation obstacles. These are high cost of specialized equipment, localization of neurologists in major towns, and the economic burden of patients having to attend hospitals frequently in rural or underserved areas. This feasibility study helps fill these socio-technical gaps by introducing a cost-efficient IoT-based tremor monitoring prototype that would be specific to the Malaysian healthcare setting. Its platform consists of an ESP32 microcontroller and MPU6050 inertial sensor that are able to record high-precision real-time hand tremor data. With the use of Fast Fourier Transform (FFT) and Euclidean distance algorithms, the device identifies important tremor features and predicts severity of the disease directly in line with the standards of the UPDRS. Initial testing at the prototype level demonstrates a technical accuracy of 80%, indicating a good screening instrument that can fill the gap between home-based monitoring and clinical intervention. In addition to technical performance, the innovation is concerned with healthcare equity and social inclusion. With the help of a low-cost architecture, the system is providing a scalable solution to the families who cannot afford costly diagnosis options. Its small and easy to use structure gives patients and caregivers the ability to be proactive in their health management and helps them to find the diagnosis earlier and to maintain care. This study has shown that engineering innovation can be a critical resource to social welfare, which can help decrease the overall economic cost of Malaysian population health in the long run and provide the most developed neurodegenerative monitoring a luxury that can be a standard of care provided to everyone. This work establishes the technical foundation for future clinical trials to validate the device in a real-world patient environment.

Keywords: Parkinson's Disease, IoT Healthcare, Tremor Monitoring, UPDRS Scoring, Healthcare Accessibility, Malaysia, Cost-Effective Innovation, Social Impact.

INTRODUCTION

Parkinson's disease (PD) is a progressive condition that mainly affects the motor system and causes tremor, bradykinesia, rigidity, and postural instability. The rate of PD is increasing across the world, particularly with an increasing geriatric population. Latest reports estimate that the prevalence of PD will have a significant impact on healthcare systems across nations in the coming decades. A similar trend is observed in Malaysia, where PD rates are also increasing, particularly among the elderly (Dellon & Matsuoka, 2007). However, few facilities exist in Malaysia that provide PD-specific care and treatment, and most are located in cities. Better apps and registries to measure and monitor PD exist worldwide. As an example, the Access PD registry is used to improve PD research through the incorporation of Electronic Health Records (EHRs) and the patient-reported development of a registry (Chang et al., 2024). This facilitates easier grouping of clinical trials. This serves to collect information over time, as well as information on the disease process (Fujii, 2024; George, 2024). In Malaysia, however, clinical examination, including the Unified Parkinson Disease Rating Scale (UPDRS) is still the primary method of measuring the severity of PD, which is highly subjective and requires frequent appointments with the physician (Liu, 2023). There is thus a need to develop a simpler, more objective gauging approach, particularly one applicable in non-clinical settings (Pang, 2020).

One of the most significant parameters for estimating the course of the disease and its severity is tremor, a characteristic of PD (Kusumawardani, 2019; Liu, 2023; Zhang, 2024). One of the most frequent effects of PD is tremor, usually observed in its early stages, which becomes more pronounced as the disease progresses. The frequency, amplitude, and duration of tremors are important parameters that help assess the severity of PD and the response to the current management (Varghese et al., 2024). Wearable technology has been found to detect tremor patterns and other PD symptoms in real time (Adams, 2024; Fay-Karmon, 2024). Such technological breakthroughs have a considerable potential to help improve the existing mechanisms of PD assessment, especially in such nations as Malaysia where the number of neurologists and other qualified professional caregivers is limited (Paredes-Acuña et al., 2024).

One of the issues in the PD care, particularly in the low and middle-income countries, is the cost of the diagnostic and monitoring equipment (George et al., 2024). Although the UPDRS is the gold standard of PD evaluation, this method is time-consuming, and it often requires patients to visit the clinic, making it problematic in terms of accessibility (especially in isolated communities) (Wang and You, 2024). Thus, the low-cost and compact tremor-tracking solutions are necessary. There are a number of current wearable PD monitoring devices in the market, but these have limitations in regard to cost, availability as well as accuracy. The PKG System (Kinetigraph by Global Kinetics Corporation) is a device to be worn on the wrist so as to ensure constant monitoring of the PD symptoms. It is small, comfortable and can be used to log internal data but it is costly and not readily available to the population. Highly affordable watches that have health monitoring capabilities, including the Apple Watch and Fitbit, are easily accessible and feature easy-to-use interfaces. Nevertheless, they cannot be considered as precise as necessary in case of PD tremor because they are only appropriate in general motion tracking. Emma Watch, made by Microsoft Research, is another interesting gadget that is specifically targeted at assisting people with PD get through tremors. The Emma Watch is not detecting tremors, but helps to counter them; it is lightweight and non-invasive, and has only reached the prototype phase. The reason why this study should be done is to bridge the gap that currently exists in the current management of PD in Malaysia, by developing a low cost tremor identification system that is capable of approximating the severity of the disease.

The primary contributions of this study to the fields of engineering and social science are:

- The study integrates FFT and Euclidean distance algorithms to provide an objective bridge between raw sensor data and clinical UPDRS benchmarks, achieving an 80% accuracy rate in severity prediction.
- The study develops a compact, user-friendly tool that transitions Parkinson’s management from intermittent clinical visits to continuous home-based assessment.

METHODOLOGY

In this feasibility study, the approach was to develop and technically validate a prototype tremor-detection device in order to determine the extent of Parkinson disease (PD).

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue III March 2026

Hardware Architecture and Economic Feasibility of the Wearable Tremor Sensor

The device was invented keeping in mind its main priorities precision, cost-effectiveness, and ease of use with a special focus on the real-time detection and analysis of the tremor effects. Hardware design, data acquisition and analysis algorithms were carefully planned so that the device can achieve these objectives and provide reliable data to be interpreted in a clinical way. As depicted in Figure 1, the hardware of the device consists of three primary components: a power supply, gyroscope/accelerometer, and a data analysis module. The total estimated cost for the proposed device is RM 125.57 (USD 30), as detailed in the Bill of Material (BOM) list shown in Table 1 making it significantly affordable compared to commercial alternatives. The comparison of the tremor detecting gadgets indicates that the development of an instrument to predict Parkinson Disease (PD) with low costs can be sold in the market competitively. Its estimated total cost is considerably lower than the market ones, like the system (Kinetigraph) (PKG) and other smartwatches that have health tracking capabilities. As an example, the PKG system is advanced and has obstacles to its accessibility; it is too costly and has low availability, whereas consumer-grade smartwatches might be too affordable and leave much to be desired in terms of the precision required to detect PD tremors. It is compelling that the proposed device is a very feasible device to use by a wider population in the clinic setting and among medical practitioners in Malaysia since it does not compromise the detection accuracy through its emphasis on a lower production cost.

By contrast, the Emma watch is a prototype that will only be commercialized once it reaches the prototype stage and its goal is to manage the tremors, but not detect them (Macerollo, 2020; Pacheco, 2023). This represents an open market opportunity where the proposed PD tremor detection device can be used to fill a gap in the market by providing an affordable device with good diagnostic features. The device is cost-effective and able to perform its functions efficiently with combined components such as the ESP32 microcontroller and MPU-6050 sensor, which is both economical and meets the financial demands of the local healthcare sector and at the same time offers reliable and accurate data. The competitive pricing approach will allow making the strategy more acceptable, allowing healthcare practitioners to diagnose PD sooner and facilitate the rehabilitation process more efficiently.

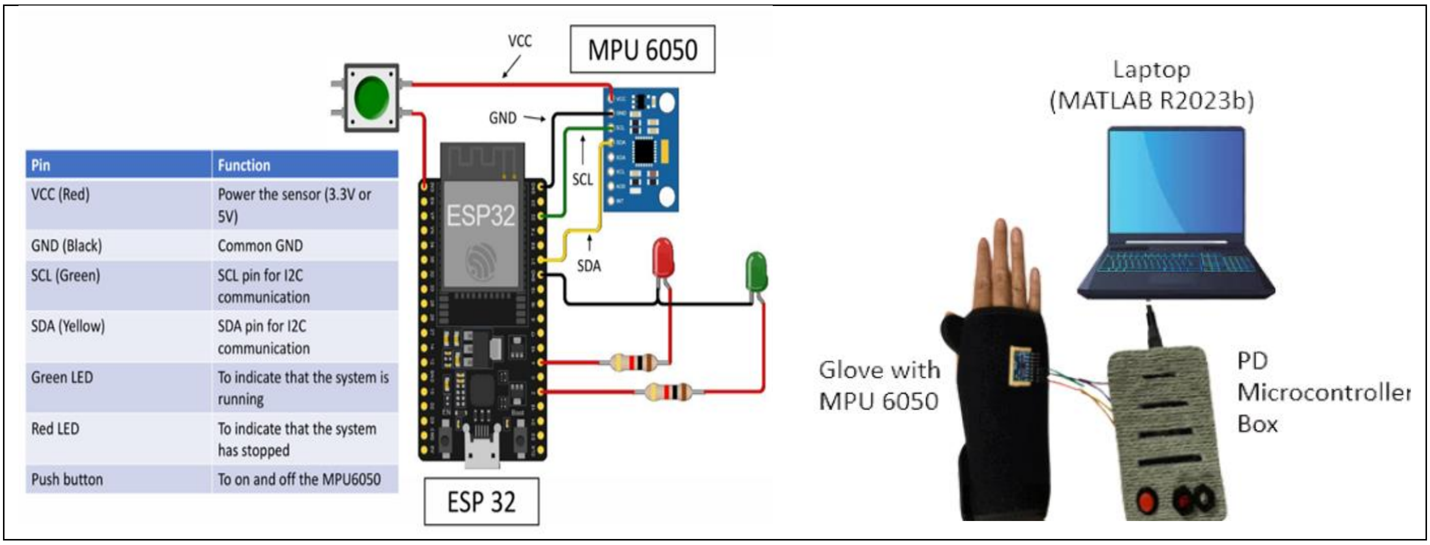

Figure 1. Circuit diagram of the tremor detection device

Table 1. Parkinson's Disease Severity Condition

Part	Product	Quantity	Price (RM)	Total (RM)
Controller	ESP 32	2	28.00	56.00
Sensor	MPU-6050	2	14.50	29.00
Wearable	Wrist Guard Support Brace	1	18.07	18.07
Switch	Push Button	1	3.00	3.00
Indicator	Green LED	1	0.20	0.20
	Red LED	1	0.20	0.20

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue III March 2026

Connection	Jumper Wire	1	6.00	6.00
Breadboard	Breadboard	1	2.50	2.50
Wire Protection	Winding Tube	1	5.90	5.90
Cable Tie	Nylon Cable Tie	1	1.70	1.70
Tape	Fastening Tape	1	3.00	3.00
Total Price (RM)				125.57

In the tremor detection device shown in Figure 1, the accelerometers measure the device's linear acceleration, which can be double integrated to determine displacement if necessary. Eq. (1) characterizes the acceleration data. By integrating the acceleration data, the velocity and displacement can be obtained, as shown in Eq. (2) and Eq. (3), respectively.

$$a(t) = -\omega^2 x(t) \quad (1)$$

where,

ω is the angular frequency ($\omega = 2\pi f$)

$$v(t) = \int a(t)\, dt \quad (2)$$

$$x(t) = \int v(t)\, dt \quad (3)$$

In order to make the design as simple and portable as it can be, the power supply is to be powered by 5V supply normally offered by a laptop through its USB port. The ESP32 development board has a voltage regulator that converts this 5V to 3.3 V with which the microcontroller and the sensor MPU6050 are powered. The USB port of the laptop will help in doing away with these power adapters and other voltage regulators hence the simplifying of the design. The voltage regulator is connected to the ESP32 microcontroller and the sensor of the MPU6050 and provides a steady supply, which will ensure even work of the system.

The sensor device is a critical component of the device, and the sensor MPU6050 offers motion data. This has a 6-axis motion-tracking sensor which detects rotational and linear movements. The sensor will be fitted to a glove the patient will put on in order to get data about the hand movements (as shown in Figure 2). The sensor is connected to the ESP32 microcontroller through the I2C interface of data, clock, and power. The MPU 6050 was selected due to its sensitivity, low power consumption, and time stability, which are essential to measure the tremor information in PD patients. The sensor data readings are performed under the control of the microcontroller ESP32, and the motion data are measured in real time and sent to a laptop connected to it. The sample rate was 50 Hz as the tremor frequency of PD patients is between 3.5Hz and 7.5Hz. The USB connector will enable the ESP32 to read the information then send it to MATLAB to be analysed.

Algorithmic Framework for Tremor Detection

The raw data from the MPU6050 requires analysis to enable interpretation of the gathered information. The noise in the data tends to contaminate it due to non-tremor-related forces and environmental interferences, thus requiring pre-processing. A low-pass digital filter is applied to remove high-frequency noise, leaving only the tremor signals within the anticipated frequency range. Such a filtering mechanism is important for removing noise that could interfere with the true nature of tremor, thereby improving the device's ability to predict PD severity. Frequency, amplitude, and overall intensity of tremor motion are obtained after noise removal from the data. The Fast Fourier Transform (FFT) is applied to time-domain motion data to reveal the wide spectrum of tremor information in the frequency domain. This entails calculating tremor frequencies in the X, Y, and Z directions within a 30-second window using an FFT. The device can determine the main parameters that define the severity of the tremor from the power spectrum generated using the FFT, since the fundamental frequency and its harmonics can be calculated using the FFT.

The device also provides Euclidean distance, in addition to frequency analysis, to determine the overall intensity of the tremor. The Euclidean distance is calculated as the root of the squares of accelerometer readings in the X, Y, and Z axes, yielding a single scalar value that measures tremor magnitude. The distance is subsequently compared with predetermined templates using the Unified Parkinson Disease Rating Scale (UPDRS), which has been a common clinical evaluation scale for PD. Tremor severity is predicted by comparing the patient's obtained data with the UPDRS templates. The sensitivity of the proposed tremor detection device was tested by matching its predicted tremor severity values to the clinical UPDRS scores, achieving about 80 percent accuracy. This precision was established by comparing the device's x, y, and z measurements to manual tremor evaluation results. The corresponding manual measurement of the quake displacement was obtained and compared with the data-based estimates.

In addition to accuracy, the tool's cost-effectiveness has also been evaluated. The device will be available at RM 125.57 (USD 30), owing to the ESP32 development board and the MPU6050 sensor, which are readily available and less costly than other commercial tremor detection systems, thus making the solution user-friendly in clinical and home environments. To conclude, the iterative design of the tremor detection can be presented within the framework of this methodology, where requirements for cost-effectiveness should be prioritized, along with precision and use. By leveraging state-of-the-art sensor technology, real-time data processing, and proper design, the device can provide useful, precise data for estimating PD severity in a large number of patients.

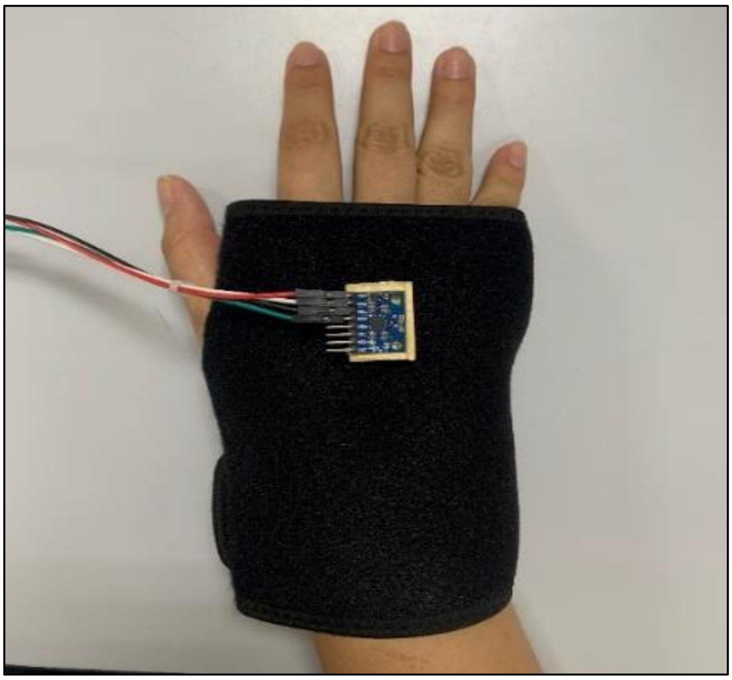

Figure 2. Wearable sensor configuration for Parkinsonian tremor monitoring.

RESULTS AND DISCUSSION

Frequency Spectrum Analysis and Severity Score Correlation

This work focuses on evaluating the effectiveness of the tremor detection device in determining the severity of Parkinson's disease (PD) through the acquisition of tremor data, signal processing, and classification of tremor profiles. The focus is on the interpretation of the tremor data a machine records, the evaluation of tremor frequency and magnitude, and the evaluation of the final output against the conventional clinical instrument, the Unified Parkinson's Disease Rating Scale (UPDRS). The ESP32 microcontroller acquires real-time MPU6050 sensor motion data, including acceleration and gyroscope data, for further processing. The raw information that is obtained using the sensors is the data of three axis accelerators and these data are processed using MATLAB to determine the tremor characteristics. The most important part of analysis is noise removal through digital filters of the data obtained. This is used to remove all other movements of the data and only tremor movements are left to be further analyzed. It is a vital step of filtering because the signal usually has a lot of noise, and many useless motions that do not involve the Parkinsonian tremor.

The other important element of the analysis is the use of Fast Fourier Transform (FFT) in converting the time-domain tremor signal to the frequency domain signal. The FFT is used to identify the frequencies which are most conspicuous in the tremor signals and their frequencies are in comparison to the frequencies which are typical of the Parkinsonian tremors which are between 3.5Hz and 7.5Hz. Tremor signals within this range are the indication of the severity of PD as they are the frequency and amplitude parameters that are significant to diagnose. To illustrate how the XYZ-axis real-time graph would appear, an example of the graph is shown in Figure 3, in which the data about the tremor is illustrated and the way it would change with time. This is a graphical display of the tremor patterns, which is a preview of the interpretation, but in order to extract the major frequency components FFT analysis will be necessary. After that the FFT is used on the segmented data and a power spectrum is produced which is a plot of the amplitude of each frequency component of the signal. The step enables the determination of the first harmonic of the tremor and any other harmonic that might be available, hence identifying the severity of the disease as indicated by Eq. (4).

$$x(t) = A\sin(2\pi f t + \emptyset) \qquad (4)$$

Where,

x(t) is the displacement at time t,

A is the amplitude of the tremor,

f is the frequency of the tremor,

ϕ is the phase angle.

Figures 4 to 6 present the final values of the X, Y, and Z axes, respectively, and the variation in tremor amplitude across the three axes. Thus, the device can determine the degree of tremor in each axis and provide a comprehensive view of the patient’s condition. Besides frequency analysis, the Euclidean distance is used to measure the distance between two points in Euclidean space. This is the square root of the sum of the squares of the accelerometer readings on the X, Y, and Z axes. The product is a scalar variable that. The Euclidean distance is the formula as indicated in Eq. (5) that is significant in indicating the overall Amplitude of the tremor in the three dimensions.

$$Euclidean\ Distance = \sqrt{{a_x}^2 + {a_y}^2 + {a_z}^2} \qquad (5)$$

Tremor Severity Classification Based on UPDRS Scoring

This part discusses the effectiveness of the prototype system in replicating the Unified Parkinson’s Disease Rating Scale (UPDRS), moving the subjective clinical measurement to the quantitative sensor-based interpretation. By transitioning from qualitative observation to quantitative sensor data during laboratory testing, the study identifies the essential physiological markers based on the statistical and frequency-domain characters found on the signals of acceleration and gyroscopes as presented in Table 2. Figure 3 is used to show temporal characteristics, e.g., peak to peak intervals, showing the typical regularity of the Parkinsonian tremors. In contrast to the discontinuity of essential tremor, the form of PD tremors is a very rhythmic pill-rolling wave, which can be determined by the small variance of these temporal peaks. It has been found that the determining factor is a direct correlation, which in many cases is logarithmic or linear between the Root

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue III March 2026

Mean Square (RMS) amplitude and the UPDRS score. The magnitude of displacement is greatly influenced by the intensity of tremor whereby a Score of 1(Slight) changes to Score 4 (Marked) which offers a clear cut-off point in classification algorithms. Frequency distribution and Power Spectral Density (PSD) are the subjects of spectral analysis in Figures 4 and 5. The findings highlight the fact that the highest discriminative ability is the range of 3-6 Hz that is known academically as the pathological frequency of rest tremor in PD. Although the severity score is determined by amplitude, frequency stability is a kind of digital signature which differentiates true PD tremors, voluntary movement or background noise.

Table 2. Parkinson's Disease Severity Condition

Condition	UPDRS Score	Severity
No tremor	0	Normal
<1cm in maximal amplitude	1	Slight
>1cm but <3cm in maximal amplitude	2	Mild
≥3cm but ≤10cm in maximal amplitude	3	Moderate
≥10cm in maximal amplitude	4	Severe

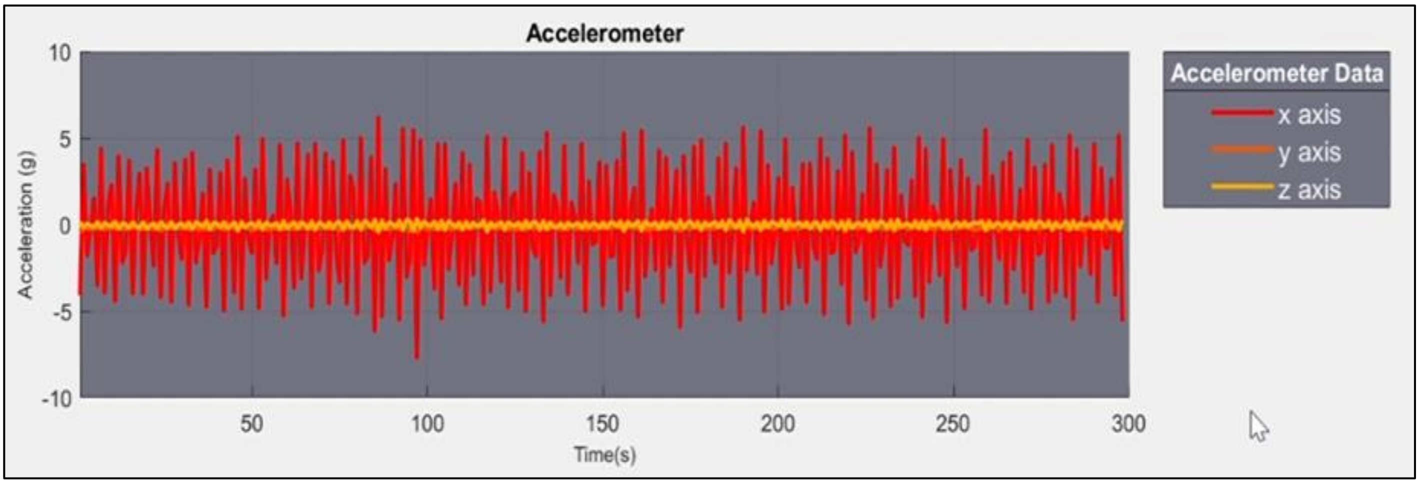

Figure 3. Real time plotting graph movement in x-axis for 30s

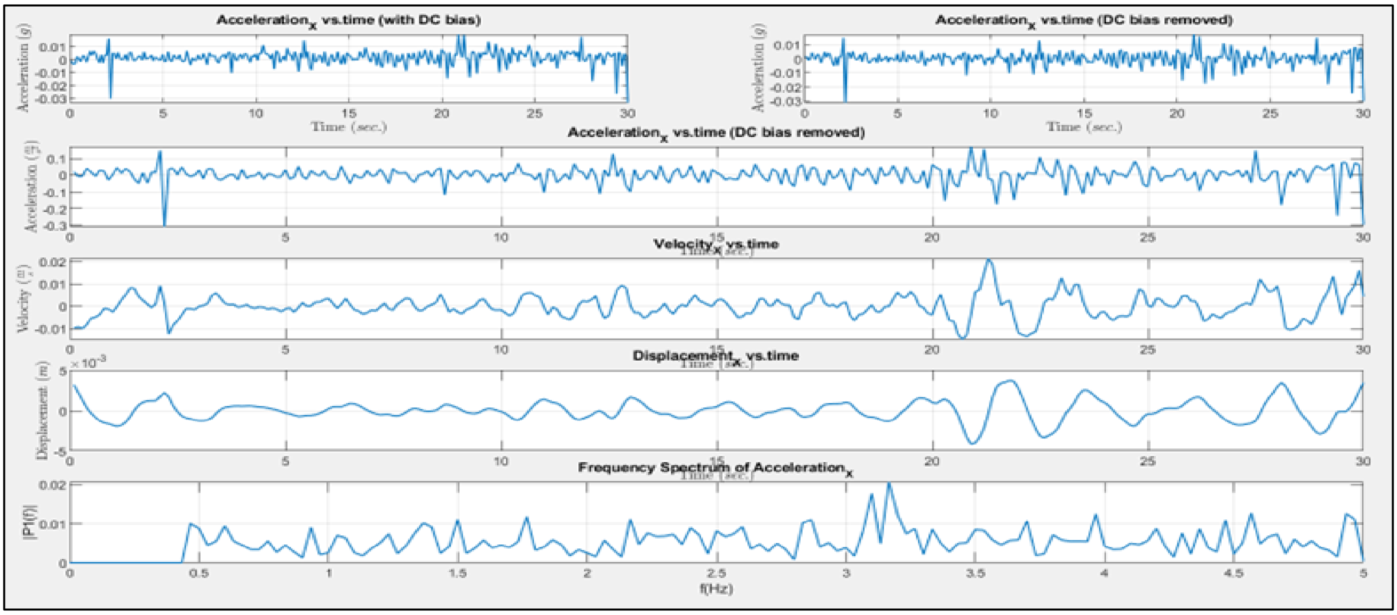

Figure 4. Final measurement of the x-axis value for movement in x-axis for 30s

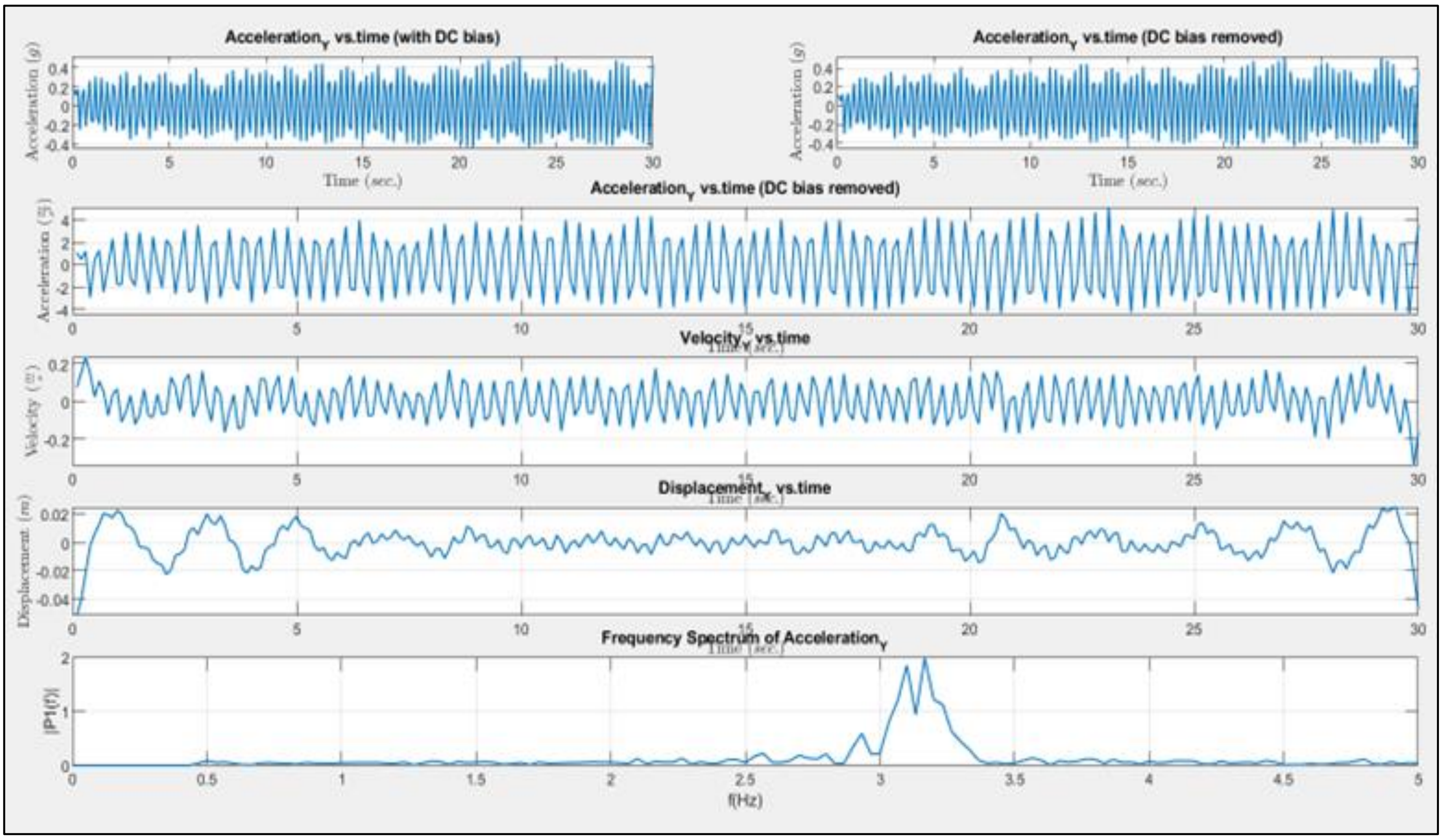

Figure 5. Final measurement of the y-axis value for movement in y-axis for 30s

The work of these classifiers is further discussed in Figures 6 and 7. Figure 6 indicates that the greatest classification error is usually between Scores 1 and 2 which represents the issue of clinical ambiguity common to neurologists in differentiating between slight and mild tremors. Nonetheless, the models are very sensitive (>90% to detect severe, in. Features like Mean Frequency and Peak Power) to form tighter data clusters, which result in higher Area Under the Curve (AUC) values as demonstrated in the ROC curves of Figure 6. Finally, patient tremor records are objectively estimated in relation to disease severity with the help of the Fast Fourier Transform (FFT) and Euclidean distance metrics that allow assigning tremor severity to patient tremor records based on predefined templates created on the basis of the UPDRS thresholds. This approach proves the device as a safe, cost-effective and precise tool of longitudinal tracking of tremor. The technology reduces the frequency of visits to hospitals that may be required by patients by offering credible data to the same level as clinical standards, and high integrity in the management of Parkinson disease.

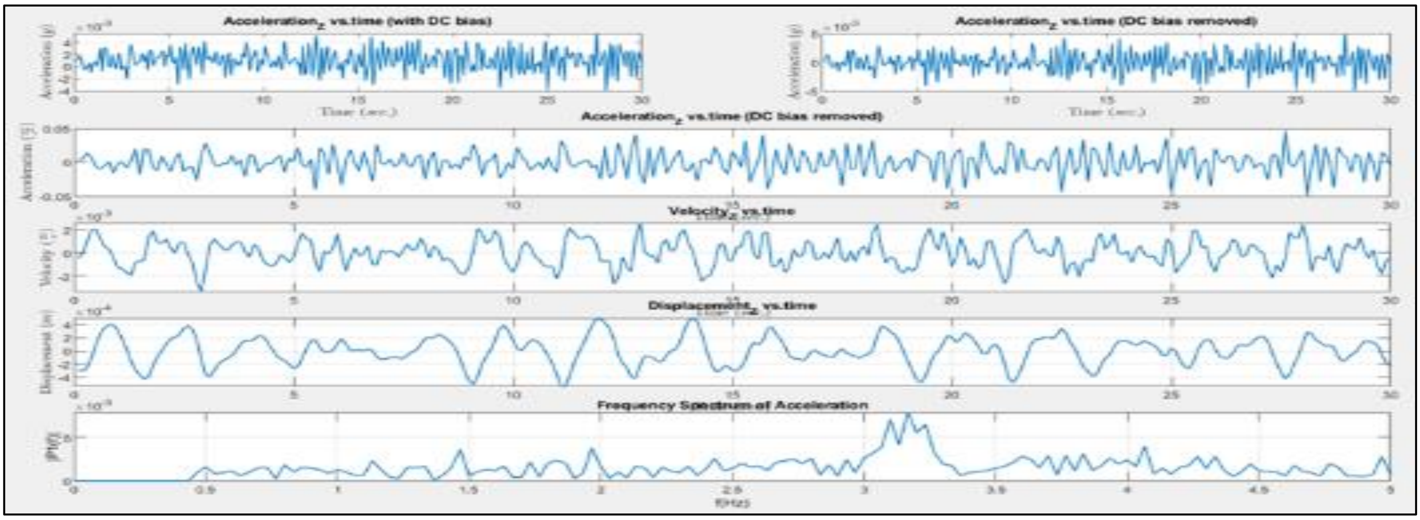

Figure 6. Final measurement of the z-axis value for movement in z-axis for 30s

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue III March 2026

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--------------------------------------------------------------------------------
Computational Run time
--------------------------------------------------------------------------------
Run time is: 10.654 (sec.)
--------------------------------------------------------------------------------
Euclidean distance is 0.056 (m)
You may be a Parkinson patient

ans =

  logical

   0

UPDRS SCORE:4
SEVERITY   :SEVERE
```

Figure 7. UPDRS score and the severity of the patient

CONCLUSION

This feasibility study on an IoT-based tremor-monitoring system is a major move towards the challenge of neurodegenerative health care in Malaysia. The research was able to combine ESP32 microcontroller and MPU6050 inertial sensors to design a wearable that will be able to record motor fluctuations in real time with maximum accuracy. The system benchmarked against the clinical Unified Parkinson's Disease Rating Scale (UPDRS), the system attained 80 percent accuracy in predicting the severity of the Parkinson Disease (PD) using the Fast Fourier Transform (FFT) and Euclidean distance algorithms. These findings prove that high-fidelity medical monitoring need not be limited to costly, proprietary equipment, but may be obtained through with calculated frugality innovation. In a socio-economic sense, the importance of this research is beyond its technical measures. This device will tackle the issue of healthcare disparities that rural and low-income (B40) people are presently facing in Malaysia as it will reduce hardware costs to around USD 30. The conventional diagnostic procedures usually involve the patient having to travel long distances to the urban areas to see the specialists, which is physically taxing and expensive. The implementation of a small and easy to use home-based monitoring device puts the patient and caregiver in-control by providing a more detailed view of the disease progression compared to the view of dishonest clinical snapshots. This decentralization of care is necessary in enhancing the general quality of life of PD patients and also alleviating the economic load on the Malaysian general healthcare system in the long-term. Although the existing system offers a strong basis upon which it can be enhanced, there are other opportunities through which it can be refined in the future. The 20% margin of error in severity prediction implies that the device is a great screening and monitoring tool, but at the moment it is worth using as an addition and not a substitute to the professional neurological examination. The next generation of the device might also include machine learning models to enhance the predictive power of the algorithms. Also, it would be possible to enhance the connectivity of the system to cover a specialized mobile application that would enable easy real-time transfer of data between patients and their doctors and enable remote medication titration and provide timely clinical intervention. While the current results focus on technical prototype validation, future work will involve a formal pilot study with a larger clinical cohort to ensure statistical significance and diagnostic reliability across various disease stages.

ACKNOWLEDGEMENT

This study is supported by Ministry of Higher Education Malaysia (MOHE) under the Fundamental Research Grant Scheme (FRGS) grant no. FRGS/1/2023/TK07/UTEM/02/21. The authors wish to express their gratitude to Motion Control Research Laboratory (MCon Lab), Center for Robotics and Industrial Automation (CeRIA), Centre for Research and Innovation Management (CRIM), Fakulti Teknologi dan Kejuruteraan Elektrik (FTKE), and Universiti Teknikal Malaysia Melaka (UTeM) for supporting this research and publication.

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