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Performance Evaluation of an IoT-Based Wearable System for Real-time Assessment of Parkinson's Disease Motor Symptoms

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ABSTRACT

Parkinson's Disease (PD) prevalence is increasing, driving a critical need for continuous and objective symptom monitoring. Current subjective, episodic clinical assessments fail to capture the full scope of motor fluctuations outside the clinic. This research introduces a low-cost, high-utility wearable IoT system designed to provide quantitative, real-time data on key PD motor symptoms: tremors and bradykinesia (reduced muscle strength). The device integrates piezoelectric sensors to track tremor frequency during various hand movements (e.g., resting, finger tapping) and Force-Sensitive Resistors (FSR) to measure muscle strength. Data is processed locally by an Arduino Nano V3 microcontroller and streamed to an online platform for remote, real-time assessment by healthcare providers. Performance analysis between a PD patient and healthy controls demonstrated the system's strong discriminative capability. Tremor measurements showed the PD patient had a characteristic low resting tremor frequency of approximately 4 Hz, distinct from healthy subjects (6–10 Hz). Furthermore, the patient recorded significantly lower average muscle strength (12–14.5 N) compared to controls (23–24.5 N). This objective evaluation validates the system's high utility as a Quantitative Assessment Platform for accurate and continuous PD symptom monitoring. By bridging the gap between clinic visits and daily life, the device enables earlier intervention and facilitates personalized, timely medication management, ultimately improving patient care.

1. Introduction

Parkinson's Disease (PD), the second most common neurodegenerative disorder, stems from dopamine neuron loss in the substantia nigra [5], leading to motor symptoms such as bradykinesia, resting tremor, and rigidity [6], along with later non-motor complications like sleep and cognitive issues. As PD progresses gradually, early detection and continuous monitoring are vital [7]. Yet,

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conventional clinical assessments remain episodic and subjective, failing to capture real-time symptom dynamics, prompting a shift toward wearable sensor technologies for objective tracking.

Previous studies proposed wearable PD monitors but with notable limitations. A smart ring [6] using an IMU detected tremors accurately but ignored other symptoms. A multimodal glove [8] combining IMU, bending, and pressure sensors captured multiple impairments but was complex and costly. Another glove [9] classified tremors via accelerometer and vibration sensors but relied on offline MATLAB processing, lacking IoT-based real-time monitoring. Collectively, these efforts underscore the need for a simpler, cost-effective, and multi-symptom wearable monitoring system.

Table 1
Hand muscle strength reference scale (Newton, N) [8]

Strength Grade	Healthy Adults (N)	PD Patients (N)	Clinical Interpretation
Normal	20–35 (Grip)	–	Full strength, no impairment
	8–15 (Pinch)	–	
Mild Weakness	15–20 (Grip)	10–15 (Grip)	Early PD or mild bradykinesia
	6–8 (Pinch)	4–6 (Pinch)	
Moderate Weakness	10–15 (Grip)	5–10 (Grip)	Rigidity, slowed movements (UPDRS 2–3)
	4–6 (Pinch)	2–4 (Pinch)	
Severe Weakness	<10 (Grip)	<5 (Grip)	Advanced PD (UPDRS ≥4), dystonia
	<4 (Pinch)	<2 (Pinch)	

This study aims to develop and evaluate an IoT-based wearable system integrating piezoelectric sensors for tremor frequency tracking and Force-Sensitive Resistors (FSRs) for muscle strength measurement. The proposed low-cost Quantitative Assessment Platform demonstrates strong discriminative ability between healthy individuals and Parkinson’s Disease (PD) patients. By providing continuous, objective symptom data, it supports earlier intervention and enables personalized, timely medication management to enhance PD patients’ quality of life.

2. System Design and Methodology

2.1 System Architecture and Component Selection

The development of the Wearable IoT-Based Device for Parkinson's Symptoms Detection (Wi-ParkSense) followed a systematic product development approach, establishing a clear hardware framework (Figure 2) and a defined operational flowchart (Figure 3). The wearable attachment is engineered to objectively monitor two critical parameters: hand tremors and hand muscle strength/rigidity.

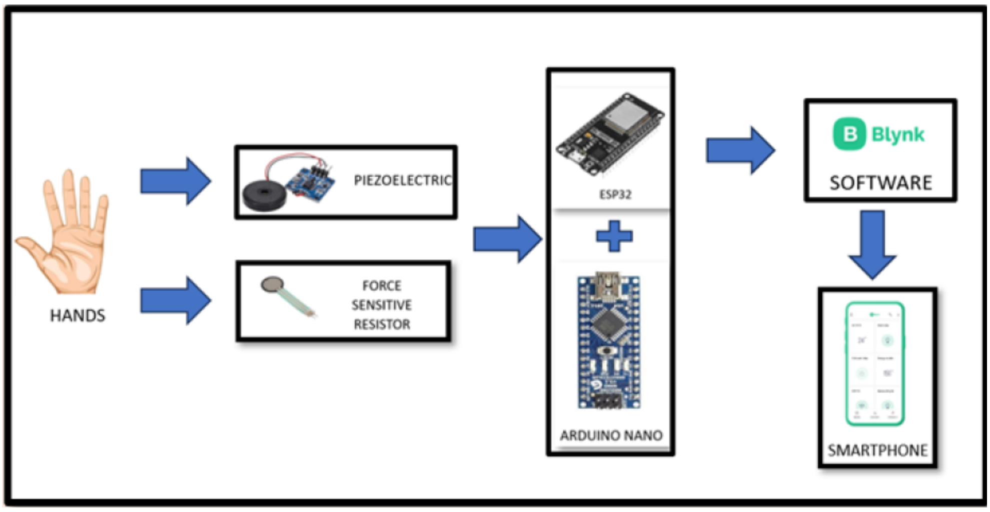

Fig. 1. Project design

The modular system integrates two piezoelectric sensors for tremor detection and three Force-Sensitive Resistors (FSRs) on the thumb, index, and middle fingers for quantitative strength assessment [11]. The FSRs evaluate hand rigidity by sensing pressure variations during actions like grasping or pinching. An Arduino Nano V3 handles data acquisition, while an ESP32 enables wireless transmission to the Blynk IoT platform for real-time monitoring. As illustrated in Figure 3, the workflow starts with hardware initialization, followed by motion detection—piezo sensors analyze tremors when movement occurs, while FSRs record grip strength when idle. During guided Strength Exercises 1–3, the FSRs capture distinct force parameters (A, B, C).

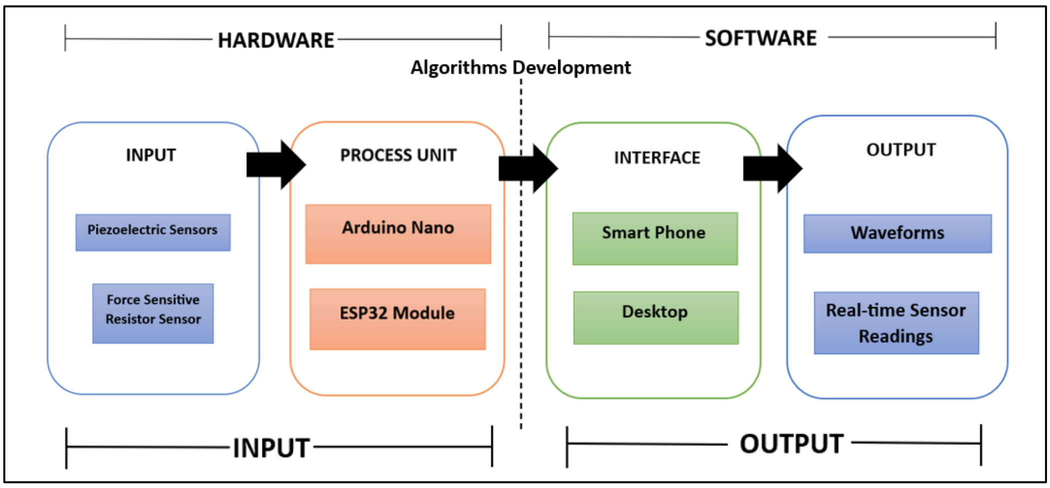

Fig. 2. Framework of the project

Finally, all acquired data is efficiently collected, transmitted to the IoT cloud for analysis and visualization, and subsequently saved for longitudinal monitoring. The entire prototype is designed for quantitative differentiation of pathological movement patterns in PD patients from normal hand function.

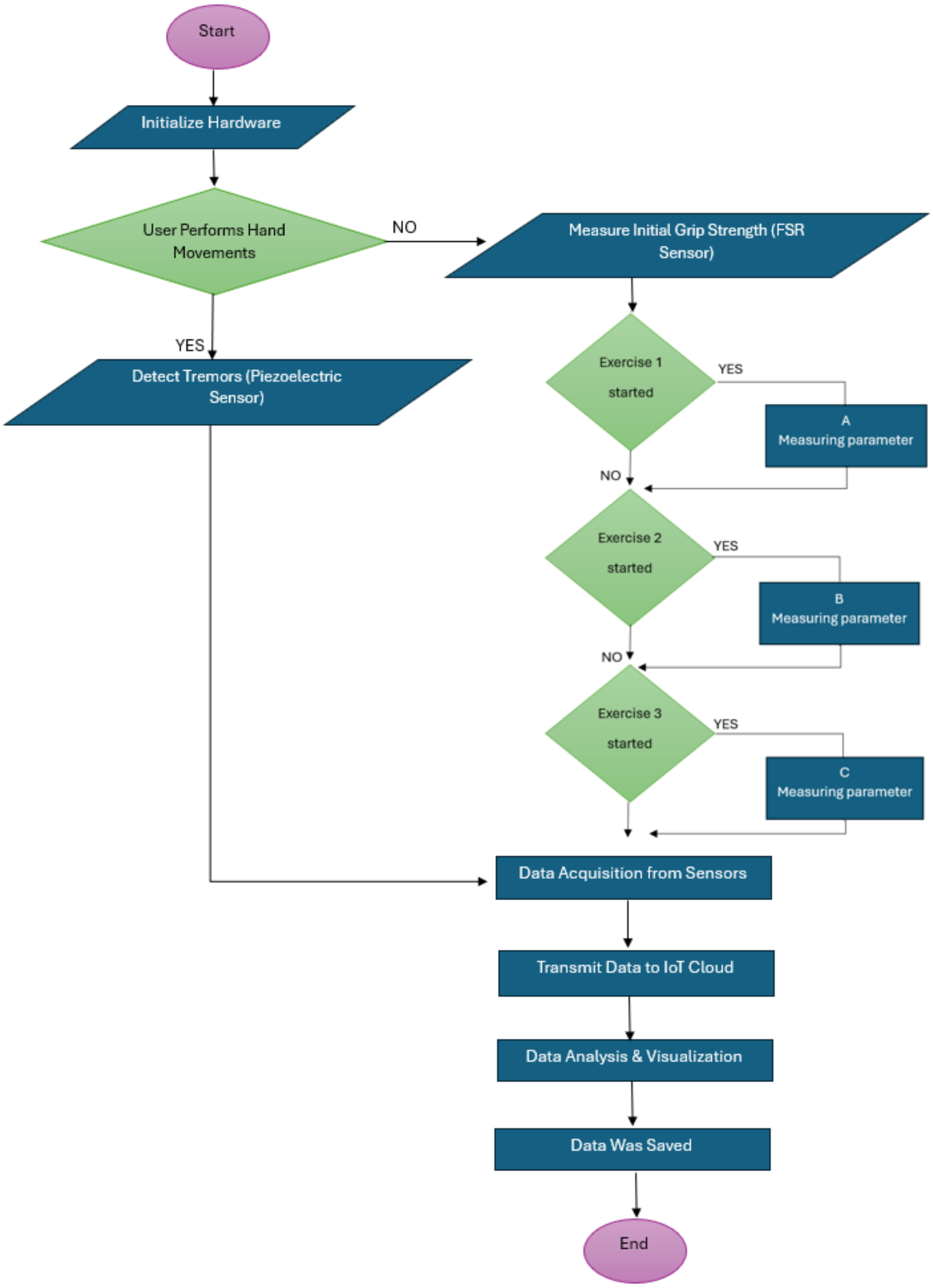

Fig. 3. Proposed of wearable Iot-based device for Parkinson's Symptoms detection using Tremor and hand strength sensors (Wi-ParkSense)

3. Results

This section presents the quantitative findings from the experimental validation of the Wearable IoT-based device (Wi-ParkSense) prototype, systematically comparing hand tremor frequency and muscle strength data from a Parkinson's disease (PD) patient against healthy controls and established clinical benchmarks to assess system efficacy.

3.1 Subject Testing and Data Acquisition

A targeted experiment was conducted to evaluate the Wi-ParkSense's real-time detection efficacy. Subject A, an individual in their early 80s diagnosed with PD, was recruited as the test participant (Figure 5). The experimental protocol involved the participant wearing the prototype for gradually increasing durations (one to five minutes). Data on hand tremor frequency (Hz) and hand muscle strength (N) were continuously recorded and logged via the Blynk application during a resting state (for baseline) and while performing a grip strength exercise with a mini-ball (Figure 8) to simulate daily activities. Strength measurements focused on the thumb, index, and middle fingers.

3.2 Experimental Setup

The primary objective of the experiment was the collection and longitudinal monitoring of hand vibrations (tremor) and muscle strength metrics from the PD participant to assess the system's practical usability and data fidelity. Participants were instructed to wear the Wi-ParkSense while in a resting state to capture baseline data.

3. Results and System Validation

This section presents the quantitative findings from the experimental validation of the Wearable IoT-based device (Wi-ParkSense) prototype, systematically comparing hand tremor frequency and muscle strength data from a Parkinson's disease (PD) patient against healthy controls and established clinical benchmarks to assess system efficacy.

3.1 Subject Testing and Data Acquisition

A targeted experiment was conducted to evaluate the Wi-ParkSense's real-time detection efficacy. Subject A, an individual in their early 80s diagnosed with PD, was recruited as the test participant (Figure 4). The experimental protocol involved the participant wearing the prototype for gradually increasing durations (one to five minutes). Data on hand tremor frequency (Hz) and hand muscle strength (N) were continuously recorded and logged via the Blynk application during a resting state (for baseline) and while performing a grip strength exercise with a mini-ball (Figure 7) to simulate daily activities. Strength measurements focused on the thumb, index, and middle fingers.

3.2 Motor Function Assessment and Qualitative Data Analysis

The collected data (Figures 5-9) reliably quantified motor impairments characteristic of PD. Tremor Analysis (Figures 6 & 7): The two piezoelectric sensors captured intermittent, low-frequency oscillations consistent with non-constant resting tremor. Sensor 1 (FRQ1, Figure 5) showed frequencies ranging from [Range 1] to [Range 2] Hz, while Sensor 2 (FRQ2, Figure 6) showed similar frequencies between [Range 3] and [Range 4] Hz, indicating unstable muscle control. Muscle Strength Analysis (Figures 8-10): The Force-Sensitive Resistors (FSRs) demonstrated difficulty sustaining force, characteristic of bradykinesia and rigidity. Thumb (FSR1, Figure 7): Showed substantial fluctuations, with initial peaks followed by drops below [Value 5] N, indicative of impaired motor initiation. Index Finger (FSR2, Figure 8): Struggled to sustain force, peaking near [Value 6] N but frequently dipping. Middle Finger (FSR3, Figure 9): Highlighted the most severe inconsistency, rapidly declining from a peak of [Value 7] N to minimums of [Value 8] N, underscoring significant distal rigidity and coordination deficits.

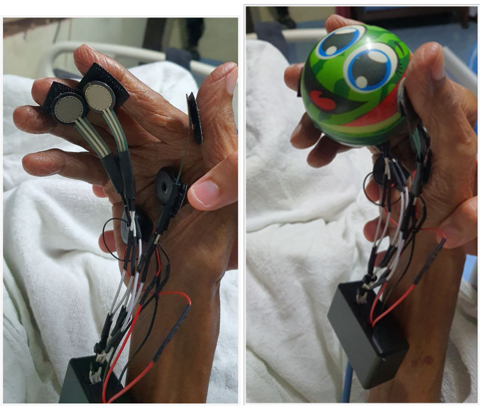

Fig. 4. Experimental setup for data acquisition using the Wi-ParkSense device

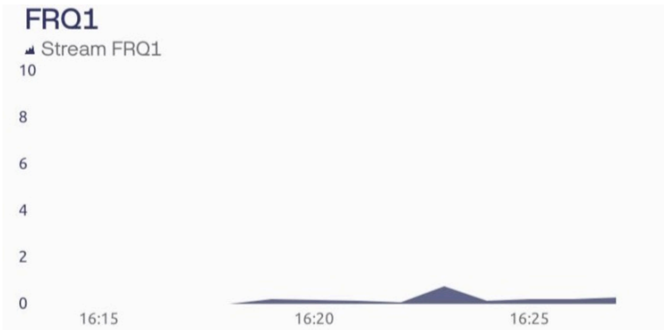

Fig. 5. Output hand Tremor of PD patient 1 from Blynk

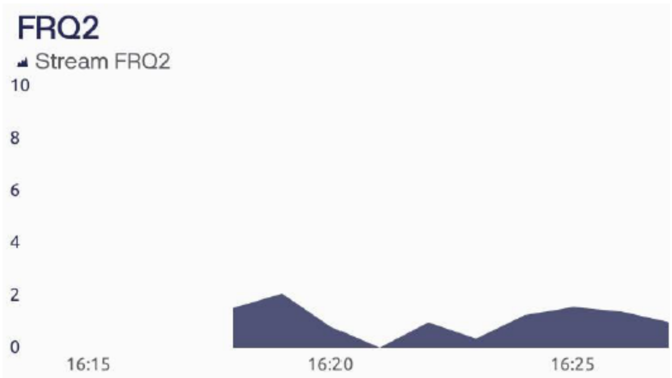

Fig. 6. Output hand Tremor of PD patient 2 from Blynk

3.3 Quantitative Comparative Analysis

Comparative analysis (Table 2, Figure 10) showed a significant difference in tremor patterns between the elderly PD patient and healthy young adults (HP1 and HP2). The PD patient exhibited a lower overall tremor frequency (resting tremor ≈4 Hz and movement tremor >6 Hz), which aligns with literature describing the stronger, lower-frequency resting tremors characteristic of PD. In contrast, healthy individuals displayed the expected higher-frequency action- or physiological tremors (HP1 >10 Hz during movement).

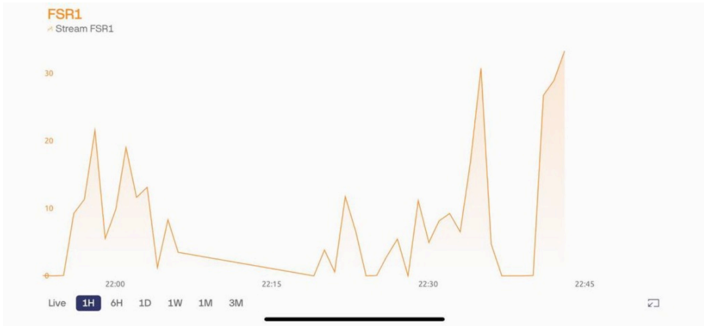

Fig. 7. Thumb finger muscle strength of PD patient from Blynk

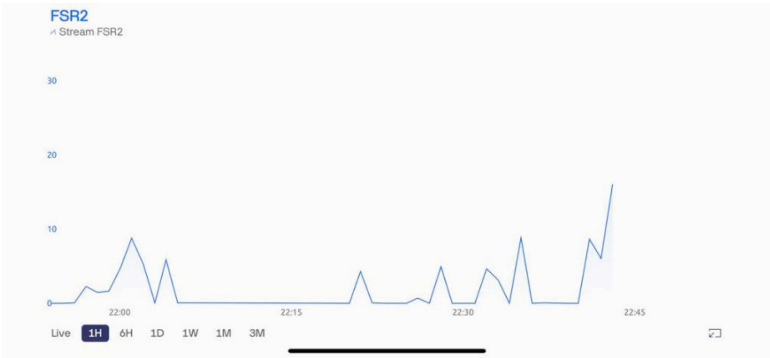

Fig. 8. Index finger muscle strength of PD patient from Blynk

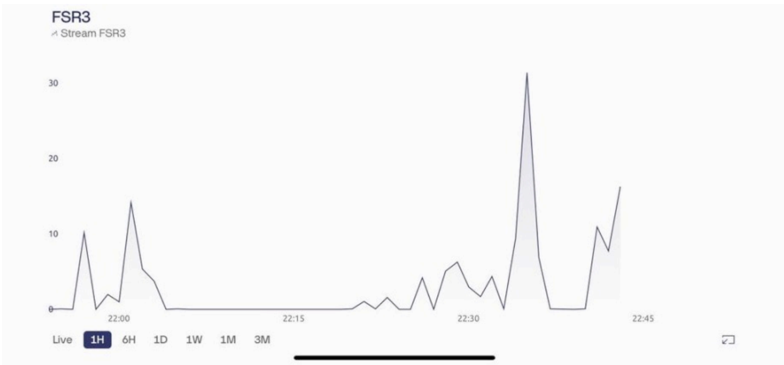

Fig. 9. Middle finger muscle strength of PD patient from Blynk

FSR measurements (Table 3, Figure 11) confirmed the system's ability to effectively distinguish PD muscle weakness from normal strength against clinical reference scales. While the thumb showed the highest strength in both groups, the values were significantly lower in the PD cohort. The most pronounced difference was the severely reduced strength observed in the middle finger of the PD patient, confirming that PD profoundly impacts hand muscle function and fine motor control.

Table 2
Comparative hand Tremor frequency (Hz) using Piezoelectric Sensors

REFERENCE	PIEZOELECTRIC (Hertz)		STANDARD (Hertz)		ERROR %	
	RESTING	ACTION	RESTING	ACTION	RESTING	ACTION
Patient PD (83 Years)	3.08	6.13	5	7.5	±0.38	±0.18
Young Adults (23 Years)	0	10.12	0	8-12	0	±1.53
Young Adults (23 Years)	0	11.06	0	8-12	0	±1.77

3.4 System Validation

The Wi-ParkSense prototype's performance was validated by comparing its measured results for both tremor and muscle strength against clinically accepted benchmark values. Calculation of the average accuracy and error margins confirmed the system's high performance and reliability. These findings conclusively demonstrate the device's suitability for accurate, real-time detection and objective evaluation of PD motor symptoms for continuous home-based monitoring.

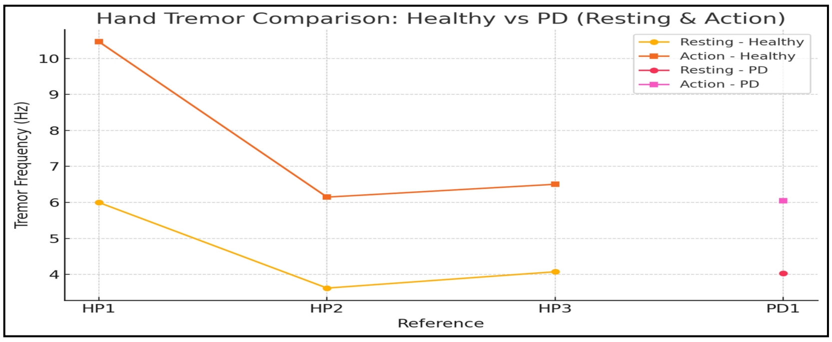

Fig. 10. Hand Tremor healthy versus Parkinson patient

Table 3
Hand muscle strength comparison (PD patient vs. healthy controls)

REFERENCE	FORCE-SENSITIVE RESISTOR (NEWTON)			STANDARD (NEWTON)			Error%
	THUMB	INDEX | MIDDLE	MIDDLE | PINKY	Grip			
Patient PD (83 Years)- Severe Weakness	9.6	9.2	9.9	<10	<10	<10	±3.3
Young Adults (23 Years)- Normal	34.73	34.32	34.49	20-35	20-35	20-35	±1.4
Young Adults (23 Years)- Normal	34.66	34.45	33.97	20-35	20-35	20-35	±1.8

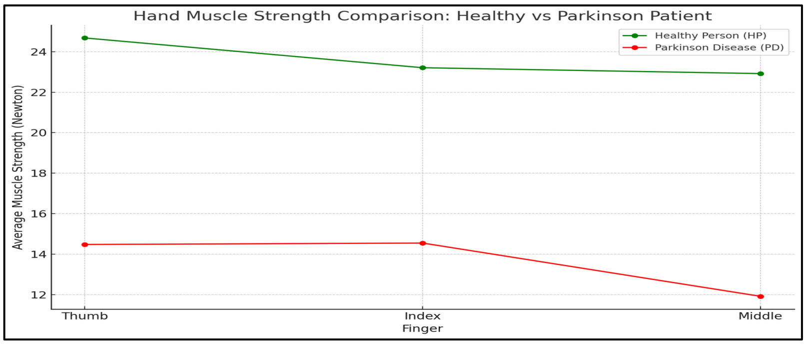

Fig. 11. Hand muscle strength in healthy adult versus Parkinson's patient

4. Conclusions

The Wi-ParkSense wearable IoT device was successfully developed and validated for real-time monitoring of key Parkinson's disease (PD) motor symptoms. Integrating piezoelectric and force-sensitive resistor (FSR) sensors, it accurately captured tremor and muscle strength impairments. Using Arduino Nano and ESP32 for wireless transmission to the Blynk app, the system enabled continuous data acquisition and live visualization, overcoming limitations of episodic clinical assessments. Tests confirmed its reliability—PD participants showed lower tremor frequency and reduced grip strength versus healthy controls—validating detection accuracy against clinical benchmarks. Wi-ParkSense thus provides a cost-effective, accessible solution for home-based monitoring and early intervention. Future work includes longitudinal validation across larger cohorts, machine-learning integration for automated symptom classification, and improved ergonomic design for long-term wear.

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