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Design and Development of Tremortrack: A Wearable Tremor Monitoring System for Parkinson's Disease

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ABSTRACT

Hand tremor is one of the most visible symptoms of Parkinson's disease, but doctors usually see it only during short clinic visits. It can look very different at home, during a task, or later in the day. In this work we built TremorTrack, a glove that records finger and hand tremor using five ADXL345 accelerometers. An ESP32 reads the sensors and does two things at once: it shows the readings live over a local Wi-Fi link, and it saves them to a MicroSD card. The saved files can be analysed later and compared from one session to the next. A rechargeable Li-ion battery powers the glove, so it can be worn without wires. The analysis steps are checked on synthetic tremor-like and normal-like signals, and no patient data are reported. TremorTrack is meant to support a doctor's assessment, not replace it.

Key Words: Parkinson's Disease, Tremor Monitoring, Wearable Sensors, ADXL345, ESP32, Accelerometer, Signal Processing.

I. INTRODUCTION

Parkinson's disease is a progressive neurological condition that mainly disturbs movement. Shaking of the hands and fingers is among its familiar signs, with rest tremor typically oscillating at about 4–6 Hz. The size of the tremor and the way it changes over time give useful clues about how a patient's condition is progressing.

At present, tremor is usually rated by a clinician who observes the patient for a short time during a consultation. Such an observation is only a snapshot: it reveals little about daily activities or other hours of the day, and small differences between two visits are difficult to express as numbers.

Body-worn motion sensors offer a way to close this gap, since accelerometers and IMUs can detect tiny movements and convert them into numerical data. A practical system, however, needs well-chosen sensor positions, dependable sampling and a method of keeping the recordings for later study.

TremorTrack was designed around these requirements. It takes the form of a glove carrying motion sensors on the fingers and hand. Readings are saved for later analysis and can also be viewed live through a local Wi-Fi interface. Low-cost, easily available hardware was used so that the system can serve as a supplementary aid to routine clinical assessment.

II. CLINICAL BACKGROUND: PARKINSON'S DISEASE AND TREMOR

The Disease:

Parkinson's disease (PD) is a long-term condition in which the nervous system degrades step by step. The underlying cause is the slow loss of dopamine-producing cells in the substantia nigra, a small area of the midbrain. Dopamine helps the brain start movements and keep them smooth, so as it declines, movements become slow, stiff and poorly controlled. The condition mostly begins in older age, advances over years, and shows up differently from one person to another. Its progress is commonly grouped into stages, such as those of the Hoehn and Yahr scale, which run from mild one-sided signs to marked trouble with balance and walking.

Motor Symptoms:

The symptoms that affect movement are the ones most often noticed by patients and their families:

- **Rest tremor:** a rhythmic shaking of a body part that is relaxed and supported, most often a hand. In the hand it can look like rolling a small pill between the thumb and index finger. It usually starts on one side, typically lies in the 4–6 Hz range, becomes weaker or stops during purposeful movement, increases with stress or mental effort, and disappears in sleep.
- **Bradykinesia:** slowness of movement, together with a gradual drop in the speed and size of repeated movements such as finger tapping. It is the main feature used to diagnose PD and makes tasks such as buttoning a shirt or writing difficult.

- **Rigidity:** stiffness of the arms, legs or neck, felt by the examiner as resistance when the limb is moved passively. It can come with a "cogwheel" catching sensation and with muscle ache.
- **Postural instability:** poor balance and a weak reaction to being pushed off balance. It usually appears in later stages and leads to falls.

Other signs include small, cramped handwriting (micrographia), reduced facial expression, a soft voice and short, shuffling steps.

Non-Motor Symptoms:

PD also affects functions other than movement. Common non-motor symptoms are loss of the sense of smell, constipation, disturbed sleep, low mood, anxiety, fatigue and, in later years, problems with memory and thinking. Some of these can appear years before the movement symptoms. TremorTrack does not measure them; it addresses only the motor symptom of tremor.

Characteristics of Parkinsonian Tremor:

Parkinsonian tremor is best known as a rest tremor. It appears when the hand is relaxed, for example when it lies on the lap, and tends to reduce when the person reaches for an object. Some patients also have a postural tremor, which appears when the arms are held out against gravity, and in some cases this tremor reappears a few seconds after the posture is taken up. The shaking is regular, with a frequency usually between 4 and 6 Hz, but its size is not constant. It differs between patients, between the two sides of the body, and from one finger to another; the thumb and index finger are often the most prominent.

Tremor also changes within the same person over a day. Emotion, tiredness, concentration and the timing of medicine can all make it stronger or weaker. This variation is the main reason a single short observation can be misleading, and it is why TremorTrack records the fingers separately and stores sessions for comparison.

Other Tremors and the Normal Hand:

Not every tremor is Parkinsonian. Every healthy person has a very small physiological tremor, usually at about 8–12 Hz, which is normally too weak to see. Essential tremor, a different condition, mostly appears while the hands are held in a posture or used for a task, often on both sides, and it can cover a wider frequency range (roughly 4–12 Hz). Because frequency, size and the situation in which the tremor appears all differ among these cases, a measured spectrum and amplitude can give useful information. They cannot, however, diagnose a condition on their own; diagnosis rests on the clinical examination.

Clinical Assessment of Tremor:

In clinical practice an examiner grades tremor with the motor part of the MDS-UPDRS, the Movement Disorder Society version of the Unified Parkinson's Disease Rating Scale. The patient is observed at rest, in a held posture and during movement, and the tremor receives a score from 0 (absent) to 4 (severe). This is fast and familiar to clinicians, yet the result is a whole number that depends on the examiner's judgement, reflects only the minutes of the visit, and may differ between two examiners. A numerical record of frequency and amplitude for each finger across several sessions can add the detail a visit score lacks, and this is what TremorTrack is meant to supply.

III. LITERATURE SURVEY

A number of research groups have studied wearable devices for Parkinsonian tremor. In [1], Rodriguez et al. fitted patients with IMU sensors and applied supervised machine learning to follow tremor during ordinary daily activity. The study indicates that wearables can provide objective tremor measurements, although this depends on clinical datasets and a trained model.

Reardon et al. [2] evaluated several sensor configurations and placements for tremor assessment and reported that both the location and the number of sensors affect what can be measured. This is one reason TremorTrack uses sensors at more than one point on the hand.

Fay-Karmon et al. [3] followed people with advanced Parkinson's disease in their homes using a smartwatch–smartphone combination, which supports the idea of tracking symptoms outside the clinic.

Ukasi et al. [4] developed a wristwatch-style triboelectric sensor for continuous tremor monitoring. Although the sensing principle is specialised, the work shows that a dedicated wearable can support long-term observation.

Problem Definition:

Reading these studies, we see four problems:

- Tremor changes with activity and time of day, while a clinic visit covers only a short period.
- Fingers can shake differently, so one sensor on the whole hand may miss individual finger tremor.
- Many existing systems need special sensors, commercial devices or heavy processing, which raises cost and complexity.
- The data has to be stored so that sessions can be compared later.

TremorTrack tries to address these with off-the-shelf parts: several sensors on one glove, live viewing, and logging on the device itself.

Objectives:

The objectives of this work are:

- To build a low-cost glove with one accelerometer for each finger.
- To show the readings live on a nearby phone or laptop over a local Wi-Fi link.
- To store every reading on a MicroSD card with its time and sensor number.
- To analyse the stored data offline for tremor frequency, amplitude and band power.
- To verify the analysis steps on simulated tremor-like and normal-like signals.

IV. METHODOLOGY

System Design:

TremorTrack follows a simple sense–process–display–store layout (Figure 1). Five ADXL345 accelerometers sense movement, an ESP32 DevKit processes the readings and handles communication, a MicroSD card stores the data, and a Li-ion battery with a charging module and 3.3 V regulator supplies power.

The ADXL345 is a digital sensor, so it already delivers its measurement as a number. No analogue conditioning or external converter is needed, and the signal is less exposed to noise picked up in the glove wiring. All five sensors share the same SPI clock and data lines, which keeps the wiring on the glove short and light; each sensor is selected by its own chip-select line.

Software Used:

TremorTrack was built using the Arduino IDE, in which the ESP32 firmware was written to acquire sensor data over SPI, run the Wi-Fi monitoring interface, and log readings to the MicroSD card. The hardware schematic and circuit layout were designed in KiCad.

At start-up the firmware sets up the SPI bus, the SD card and the Wi-Fi interface and configures each sensor. It then repeats the same cycle: read the three axes from every sensor, attach the sensor number and the time, send the record to the live display, and write it to the card.

Sensor Placement:

One sensor is placed at each of the five fingers of the glove: thumb, index, middle, ring and little finger. With a sensor at each location, individual fingers can be compared instead of only the hand as a whole. This matters because Parkinsonian tremor is not equal in all fingers, and reference [2] shows that the number and position of sensors change what can be measured.

Since the glove turns with the hand, the direction of gravity relative to each sensor axis changes as the hand rotates. For this reason the sensors should be mounted with the same axis orientation, and the slow, gravity-related part of the signal is removed during analysis instead of being treated as tremor.

Data Acquisition:

The ESP32 reads three-axis acceleration (X, Y and Z) from every ADXL345 over a shared SPI bus, and each sensor has its own chip-select line, so only the selected sensor talks at any moment. The ADXL345 communicates over SPI (mode 3) and can output data at rates from below 1 Hz up to 3200 Hz; its output rate and measurement range are set through its registers. In full-resolution mode it gives about 3.9 mg per count, which is fine enough to see finger tremor, since tremor acceleration is generally much smaller than 1 g.

The sampling rate is 100 Hz. Parkinsonian tremor lies near 4–6 Hz and the analysis band ends at 8 Hz, so by the sampling theorem the rate must exceed 16 Hz; 100 Hz is about twelve times the upper band edge and leaves a wide margin. Every sample is stamped with the sensor number and the time, so that the spacing between samples can be checked and missing samples can be found.

Real-Time Monitoring:

The ESP32 also runs a local Wi-Fi interface, so a nearby phone or laptop can view the live readings. This lets the person recording the session confirm at once that all five sensors are working and see the tremor as it happens. Because a local network is used rather than the internet, no cloud service is needed for live viewing.

Data Storage:

At the same time, each reading is written to the MicroSD card as a record with the time, the sensor number and the X, Y, Z values. These files let us compare tremor across sessions later. Keeping a copy on the glove itself is intended to make the recording independent of the Wi-Fi link, and the card can be read on any computer for analysis.

Signal Processing and Analysis (Offline):

Analysis is done offline on the stored files. The steps are:

- **Separate the channels:** the records are split by sensor number so that each finger is analysed on its own. The three axes can be analysed separately or combined into one vector magnitude.
- **Remove the constant component:** the mean of each signal is subtracted. This removes the steady 1 g of gravity and any fixed offset.
- **Band-pass filter (about 3–8 Hz):** a filter, for example a Butterworth band-pass applied forwards and backwards so that it adds no time shift, keeps the tremor band. The low edge removes slow voluntary movement and posture changes; the high edge removes noise and the faster 8–12 Hz physiological tremor. The band covers the 4–6 Hz range of Parkinsonian rest tremor with some margin on both sides.
- **Spectrum (FFT or Welch's method):** Welch's method splits the signal into overlapping segments, applies a window to each, takes the FFT, and averages the results. This gives a smoother estimate than a single FFT. With 512-sample segments at 100 Hz the frequency step is 100/512, about 0.2 Hz.
- **Features:** the dominant frequency (the frequency of the largest spectral peak inside the band), the RMS amplitude of the filtered signal (the square root of the mean of the squared samples), and the band power (the area under the spectrum between 3 and 8 Hz).
- **Comparison:** the features are compared between fingers, between sessions, and between conditions such as rest and posture.

Power Management:

A rechargeable Li-ion battery of 3000 mAh feeds the system through the charging module and a 3.3 V regulator, which supplies the ESP32 and the sensors. A single Li-ion cell gives roughly 3.0 to 4.2 V depending on its charge, so the regulator is needed to give the sensors a steady 3.3 V, within the 2.0–3.6 V supply limit of the ADXL345. The sensors and the ESP32 then share the same logic level, so no level shifting is needed. The run time depends on the average current, most of which is drawn by the Wi-Fi radio of the ESP32, and can be estimated as battery capacity divided by average current. This keeps the glove wireless and easy to wear.

Performance Metrics:

The prototype is described by four measures:

- **Dominant-frequency error:** the difference between the frequency found by the analysis and the frequency of a known reference motion.
- **Sample loss:** the percentage of expected samples that are missing from the log, found by comparing the number of records with the sampling rate multiplied by the recording time.
- **Display delay:** the time between a movement and its appearance on the live display.
- **Battery run time:** the hours of continuous operation from a full charge.

Tremor behaves differently at rest, while holding a posture and during simple actions, so recordings are grouped by these conditions. Recordings from patients need ethical approval and informed consent. No patient or volunteer recordings are reported in this paper.

V. BLOCK DIAGRAM AND CIRCUIT DIAGRAM

Figure 1 shows the functional blocks of TremorTrack and how data and power move between them. Figure 2 gives the circuit connections between the ESP32, the five sensors, the MicroSD module and the power section. Figure 3 shows the glove prototype.

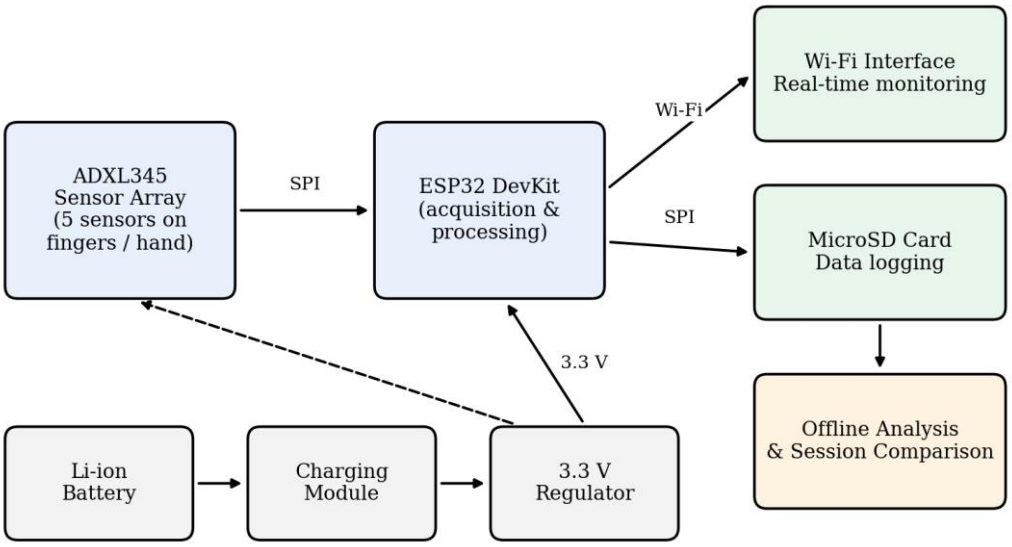


Figure 1: Block diagram of the proposed TremorTrack system

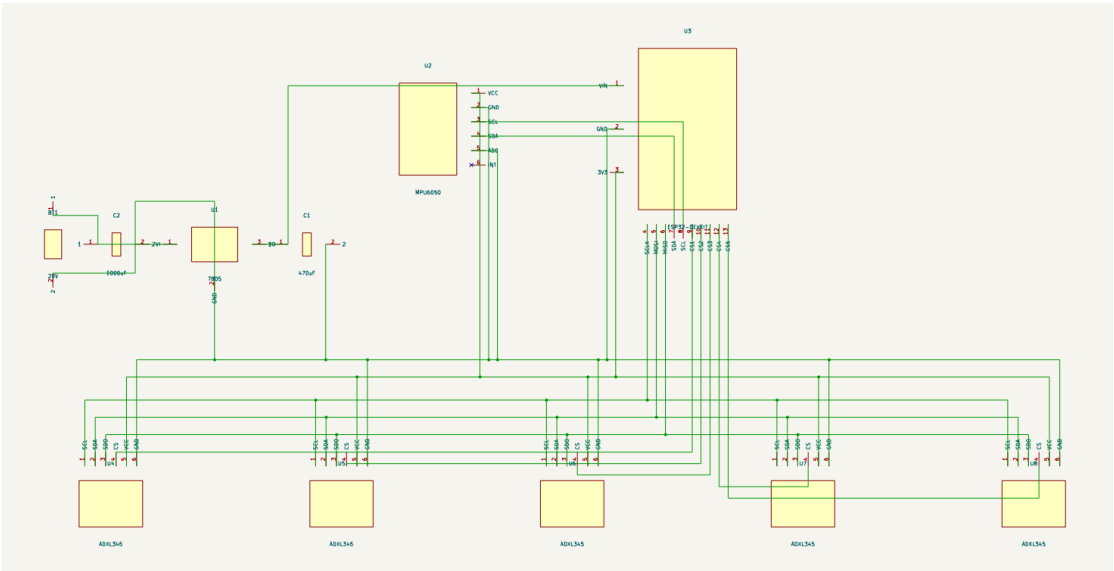


Figure 2: Circuit diagram

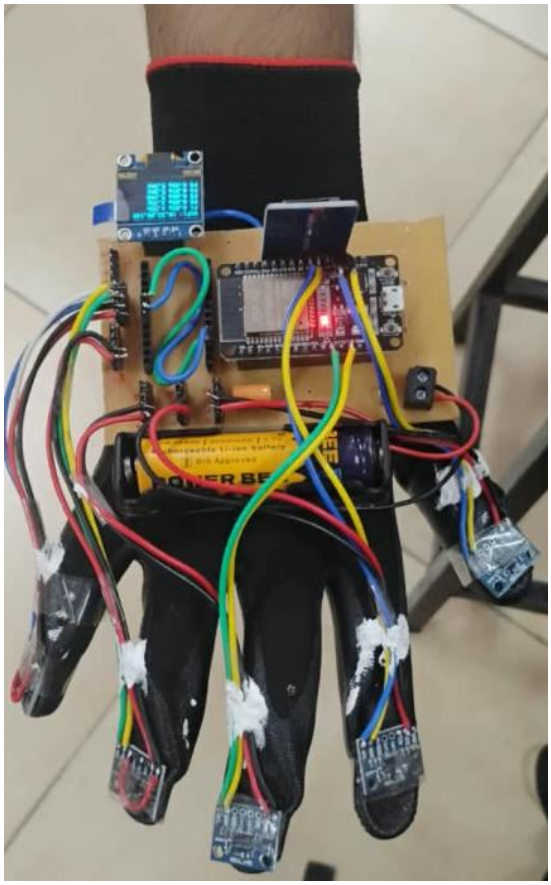


Figure 3: Proposed system (glove prototype)

VI. COMPONENTS

Table 1 lists the major components. The main ones are described below.

Table 1: Major components and their functions

Sr.	Component	Function in TremorTrack
1	ESP32 DevKit	Reads all sensors, processes data, hosts Wi-Fi monitoring, writes to MicroSD
2	ADXL345 accelerometer (×5)	Digital 3-axis sensing of finger and hand tremor movement
3	MicroSD card module	Non-volatile logging of time-stamped readings for offline analysis
4	Li-ion battery	Rechargeable portable power source
5	Charging module	Safely charges the Li-ion battery
6	3.3 V regulator	Supplies regulated 3.3 V to the ESP32 and sensors

1. ESP32 DevKit

A low-cost microcontroller with built-in Wi-Fi and Bluetooth. It has two 32-bit processor cores running at up to 240 MHz, 520 KB of SRAM, and hardware support for SPI, I²C and a 12-bit analogue-to-digital converter. Here it collects the sensor readings, serves the live Wi-Fi view and saves the

records to the MicroSD card. Each device on an SPI bus needs its own chip-select pin, so the ESP32 can serve all five sensors on one shared bus, and its built-in radio removes the need for a separate wireless module.

2. ADXL345 Accelerometer

A compact, low-power digital accelerometer that measures acceleration along three axes. The measurement range can be set from ±2 g to ±16 g, the resolution reaches 13 bits, and the device can be read over SPI or I²C from a 2.0–3.6 V supply. Its small size allows several units to be fixed on a glove. The data rate can be set up to 3200 Hz, full-resolution mode gives about 3.9 mg per count, and the current drawn while measuring is very small, which suits battery operation.

3. MicroSD Card Module

Stores the time-stamped readings so tremor data can be reviewed and compared after each session. The card is removable and can be read on a computer. It gives a permanent copy of the session, whereas the live Wi-Fi view is gone once the session ends.

4. Li-ion Battery, Charging Module and 3.3 V Regulator

The Li-ion battery makes the glove portable, the charging module lets it be recharged, and the 3.3 V regulator gives the ESP32 and sensors a stable supply. A single Li-ion cell has a nominal voltage of about 3.7 V and reaches about 4.2 V when full, which is why a regulator is needed to give the 3.3 V that the sensors and the ESP32 require. The charging module controls the charging current and voltage so that the cell is not overcharged.

VII. WORKING

The five ADXL345 sensors detect finger and hand movement, including tremor, as changes in three-axis acceleration. They send their readings to the ESP32 over the SPI bus. The ESP32 time-stamps the readings and organises them by sensor. It then makes them available over the local Wi-Fi interface for live viewing and, at the same time, saves them to the MicroSD card. The battery, through the charging module and 3.3 V regulator, powers everything. Later, the stored data is analysed offline to study tremor frequency and amplitude and to compare sessions.

A typical session runs as follows. The glove is worn and switched on, and the ESP32 starts the sensors, the SD card and the Wi-Fi interface. A phone or laptop connects to the local interface, and the examiner checks that all five sensors are sending data. The person then keeps the hand at rest or in the required posture while the readings are shown live and saved at the same time. When the session ends, the card is removed and the files are analysed on a computer as described in Section IV.



Figure 4: Overall system flow

VIII. APPLICATIONS

- **Parkinson's tremor monitoring:** records hand and finger tremor so that its frequency and amplitude can be followed finger by finger. Recordings taken at different times of day, or before and after medication, can be compared when a clinician asks for it.
- **Rehabilitation and physiotherapy:** tracks hand movement during exercises so that progress can be compared over time and it can be seen whether movements become steadier.
- **Research:** provides recorded movement data for studying tremor patterns and developing better monitoring methods. The low-cost hardware also suits teaching in sensor and signal-processing courses.
- **Other movement disorders:** the same hardware can record tremor of other origin, such as essential tremor, although telling such conditions apart needs clinical examination.

IX. ILLUSTRATIVE ANALYSIS ON SYNTHETIC DATA

Real patient recordings need ethical approval and informed consent, and are not part of this paper. To check that the offline analysis can tell a Parkinson-like tremor from a normal hand, we therefore used synthetic (computer-generated) data. All numbers, tables and figures in this section come from simulation; no patient or volunteer was recorded.

Simulated Subjects:

Two five-channel recordings were generated with a Python script (NumPy and SciPy), each 20 s long at 100 Hz, with one channel per finger. Simulated Subject A stands for a person with Parkinsonian rest tremor. Its fingers oscillate at 5 Hz, inside the typical 4–6 Hz range, with a different strength on each

finger and the largest amplitudes on the index and middle fingers, to reflect that fingers do not shake equally. Simulated Subject B stands for a normal hand. It contains only a very small physiological-type oscillation at 10 Hz, inside the usual 8–12 Hz range, with an amplitude of only 10–15 mg.

Both signals also contain what a real glove records in addition to tremor: the steady 1 g of gravity, a slow 0.4 Hz drift that represents voluntary movement and posture change, and random sensor noise. The parameters are listed in Table 2.

Table 2: Parameters used to generate the synthetic recordings

Parameter	**Subject A (tremor-like)**	**Subject B (normal-like)**
Sampling rate, duration	100 Hz, 20 s	100 Hz, 20 s
Channels	5 (thumb to little finger)	5 (thumb to little finger)
Tremor frequency	5 Hz	10 Hz
Tremor amplitude (peak) per finger: thumb, index, middle, ring, little	100, 180, 150, 90, 70 mg	12, 15, 14, 10, 10 mg
Slow voluntary drift	150 mg at 0.4 Hz	150 mg at 0.4 Hz
Gravity offset	1 g	1 g
Sensor noise (standard deviation)	12 mg	12 mg
Processing	Butterworth band-pass 3–8 Hz (4th order, zero phase); Welch spectrum, 512-sample segments	Same

The processing described in Section IV was then applied to every channel: band-pass filtering (3–8 Hz), the Welch spectrum, and extraction of the dominant frequency and the RMS amplitude. Table 3 and Figure 5 show the output.

Table 3: Analysis of synthetic recordings (simulated, not patient data)

Finger	**A: Dom. freq (Hz)**	**A: RMS (mg)**	**B: Dom. freq (Hz)**	**B: RMS (mg)**
Thumb	5.08	70.6	6.64	3.6
Index	5.08	127.0	4.88	3.9
Middle	5.08	105.6	6.25	3.6
Ring	5.08	63.8	3.52	3.4
Little	5.08	49.9	7.23	3.4
Mean	5.08	83.4	5.70	3.6

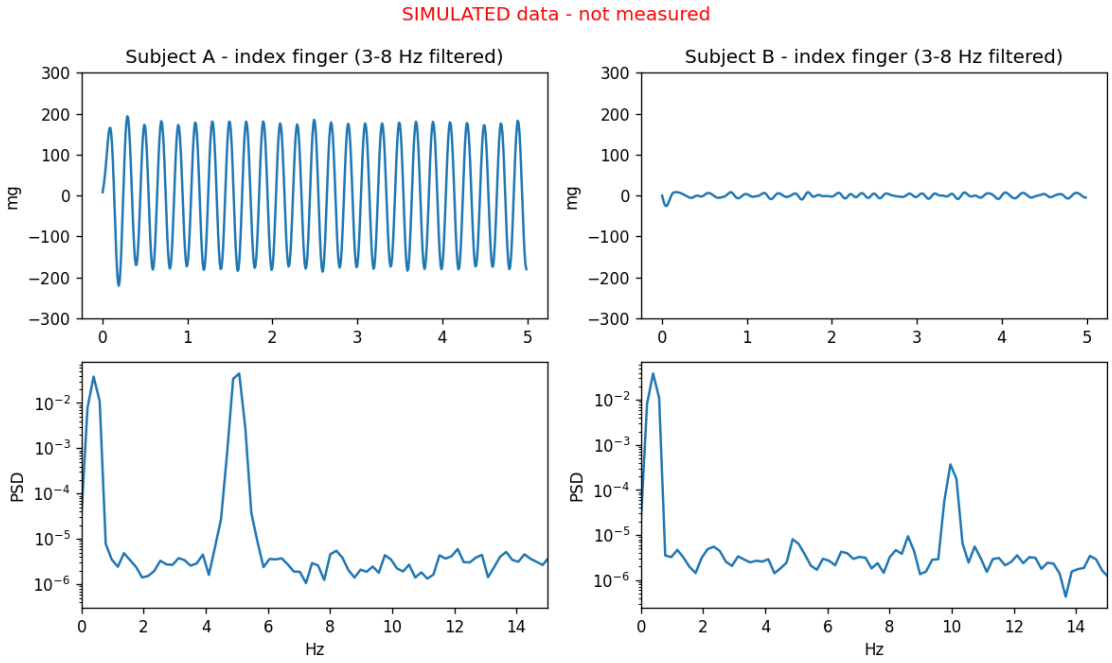


Figure 5: Simulated index-finger signal (top) and spectrum (bottom) for Subject A and Subject B

Results and Discussion:

Subject A (the Parkinson-like case) shows a sharp, consistent spectral peak at 5.08 Hz on all five fingers. This is the frequency bin nearest to the 5 Hz that was put into the simulation (the frequency step is about 0.2 Hz). Its mean RMS amplitude is 83 mg, about 23 times that of Subject B. The fingers differ as designed: the index finger is the largest (127 mg), followed by the middle finger (106 mg), thumb (71 mg), ring finger (64 mg) and little finger (50 mg). The top panel of Figure 5 shows the regular, repeating waveform of the index finger, and the spectrum below it shows one clear peak near 5 Hz.

Subject B (the normal case) shows no stable peak. Its "dominant" frequency changes from finger to finger (3.5–7.2 Hz) because the 10 Hz component lies outside the 3–8 Hz band and is removed by the filter, leaving only the noise that passes through the band. This residual noise is about 3.4–3.9 mg RMS, close to the 3.8 mg expected from the noise setting. In the spectrum plot, the small 10 Hz peak of Subject B can still be seen before filtering, far below the peak of Subject A.

As a check on the processing, the RMS of a sine wave equals its peak value divided by $\sqrt{2}$. The index finger of Subject A was generated with a peak of 180 mg, which gives 127 mg, and the thumb with 100 mg, which gives 71 mg. These match Table 3 (127.0 and 70.6 mg), so the filter and the scaling behave correctly.

The pattern of Subject A is what the analysis is expected to flag as Parkinson-like tremor: a clear peak inside 4–6 Hz, the same frequency on all fingers, and an amplitude far above that of a normal hand. Subject B lacks all three and is read as normal.

Limitations of the Simulation:

A simulation can confirm that the analysis steps work, but it cannot show how well TremorTrack works on people. Real tremor is not a perfect sine wave: its frequency and amplitude drift, it comes and goes, and it can contain harmonics. Real recordings also contain arm movement, glove slip, skin and cable motion, and differences between individuals, and conditions such as essential tremor can overlap the same frequency band. Because Subject A and Subject B were built to be different, the clear separation in Table 3 is expected and is not evidence of diagnostic accuracy. Clinical accuracy can only be judged on real recordings from patients and healthy volunteers, collected with ethical approval.

X. CONCLUSION

This paper presented TremorTrack, a low-cost glove that records hand and finger tremor with five ADXL345 sensors and an ESP32. It shows the data live over Wi-Fi, logs it with the time and sensor number on a MicroSD card, and runs on a rechargeable battery. Having one sensor per finger and local storage makes it a practical extra tool beside clinical assessment, because it can show how tremor differs between fingers and how it changes from one session to the next.

The offline analysis (band-pass filtering at 3–8 Hz, Welch spectrum, dominant frequency, RMS amplitude and band power) was checked on synthetic signals. The tremor-like signal gave a stable peak at 5.08 Hz on all five fingers and a mean RMS of 83 mg, while the normal-like signal gave no stable

peak and 3.6 mg. These results show that the processing behaves as designed. No patient or volunteer recordings, accuracy figures or clinical conclusions are reported here, and TremorTrack is intended to support a doctor's assessment, not replace it.

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