SEDENTARY DETECTION CHAIR WITH WEARABLE IMUS

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Abstract

Prolonged sedentary behavior is common among students and office workers and is associated with negative health effects. This project designs a chair-based system that detects extended sitting and encourages verified physical activity before resuming sitting. Chair-mounted seat occupancy and vibration sensors determine whether a user is seated, while two wearable IMU nodes attached to the ankle and waist/thigh measure body motion and transmit synchronized motion packets to a chair-mounted ESP32 via Bluetooth Low Energy (BLE). The ESP32 fuses chair and wearable data to trigger an alarm after a configurable sitting interval and clears the alert only after sufficient movement is detected.

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1. Introduction

1.1 Problem

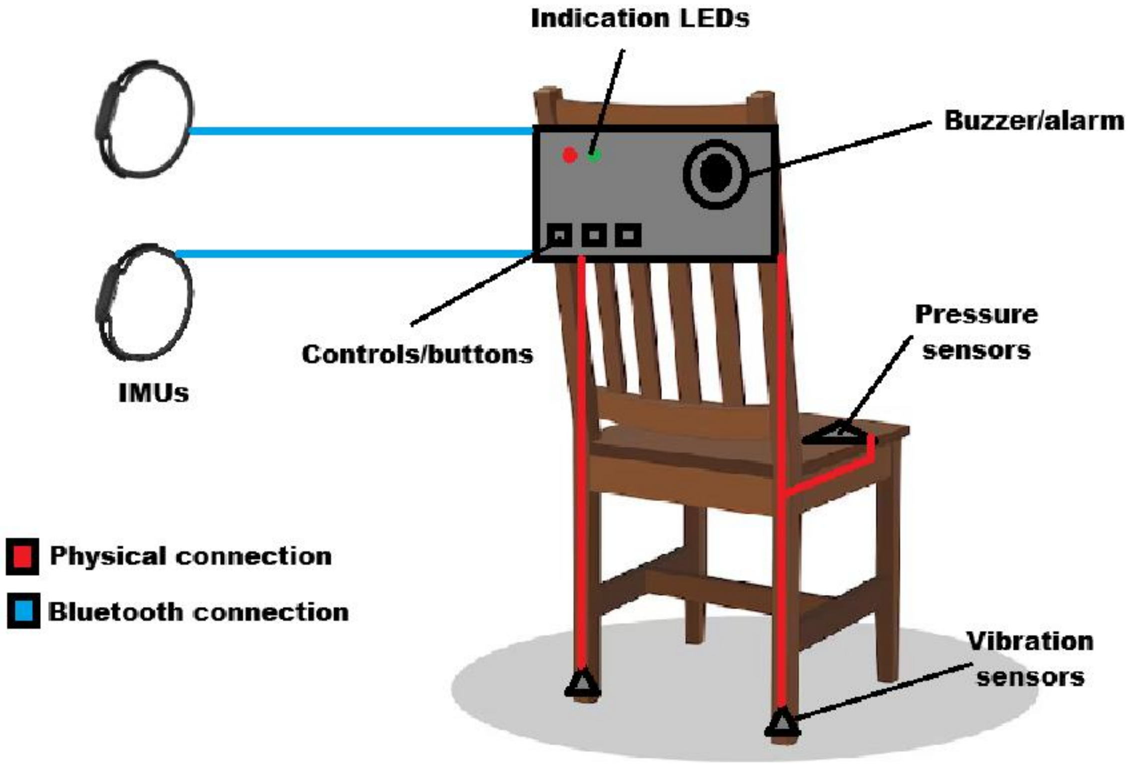
Extended sitting is common in academic and office settings and can reduce daily physical activity. With reduced daily physical activity over long periods of time, observable health complications may arise as a result. This is a big problem because it is easy to overlook physical health when the threat is not imminent and is a problem not caused by action but rather inaction. Because of this, it should be a big concern since the negative effects are readily present. Health complications from sedentary behavior incurs demand on health resources that could be better spent elsewhere, and invisibly decreases the quality of life of many people who are not actively thinking about how their sedentary behavior is resulting in health complications. Furthermore, reminder-based solutions (e.g., phone apps) rely on user compliance and typically cannot verify whether a person is adhering to being physically active. Because of this, it is necessary to develop a system that detects prolonged sitting and verifies genuine activity before allowing the user to sit again.

1.2 Solution

We propose a chair mounted device accompanied by two wearable sensors that can monitor one's physical movement to determine when a person has been sitting for too long and is able to compel physical activity from a person through a buzzer that will not stop making an annoying noise until adequate physical activity has occurred. This will be implemented through IMU sensors attached to wearable bands that can easily fit onto a person's leg and can send movement information to the mounted board via Bluetooth. The chair will have a pressure sensor in the seat cushion (or perhaps another location) that will determine if a person is sitting and sends such feedback to the board to determine if a person has been sitting for too long. If a person has been sitting for too long, the buzzer alarm will go off and will continue to do so until the person stands up and completes an adequate amount of activity. The activity is determined by the wearable sensors and the vibration sensors mounted to the chair, this is to add redundancy to the design and prevent people from trying to find methods that make the device think they've adequately moved when they have not. Once completed, the buzzer turns off and the person can be seated again and the timer will be set back to zero, whereupon the system essential repeats and continues the previous functions as described.

The system includes two wearable IMU nodes (ankle and waist/thigh) and a chair-mounted unit. Wearable nodes sample IMU data and transmit motion packets over BLE. The chair unit measures seat occupancy, runs the main state machine on an ESP32, and drives an audible/visual alert. The alert is cleared only when IMU-based movement criteria are satisfied.

1.3 Visual Aid



1.4 High-level Requirements

1. Seat detection. The device must be able to determine if a person is sitting and cease counting if a person is no longer sitting. It also must be able to make these determinations in context of previous and later data so that fluctuations0020in a person's sitting position or idle movements do not cause the timer to turn off for a meaningful amount of time when sitting or be on for a meaningful amount of time when standing. We determine a meaningful amount of time to be around 1-2 seconds.

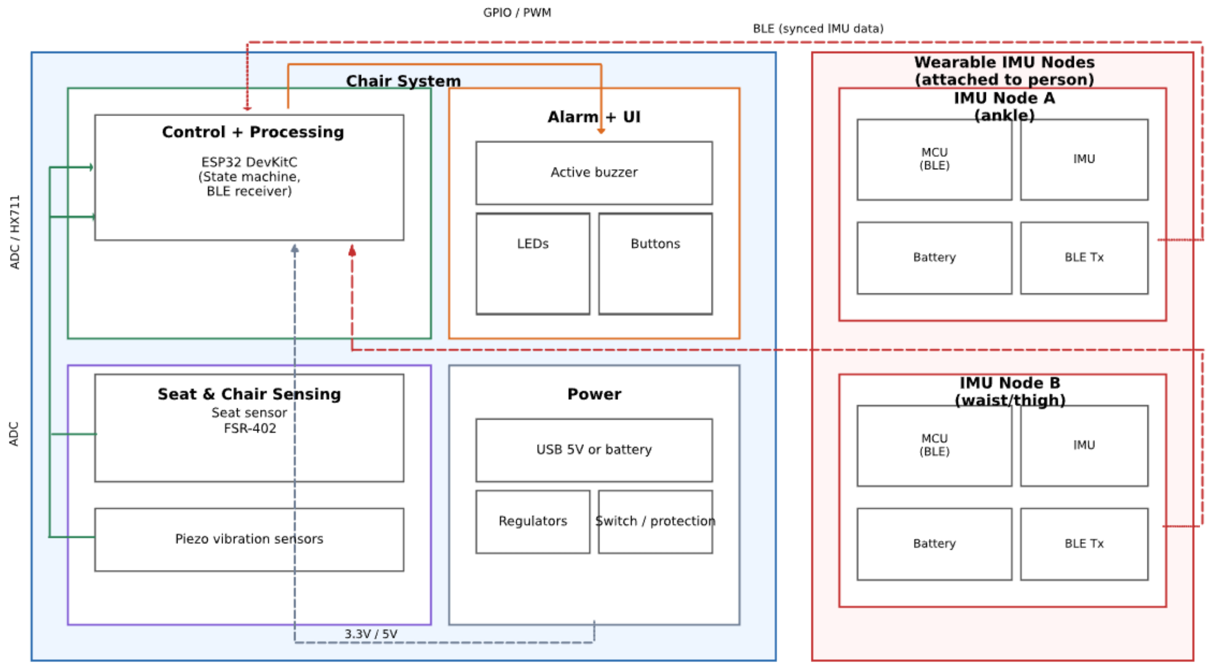
2. Movement detection. The device must be able to accurately determine the kinds of movements a person is doing and determine whether they have been done for a long enough period. It must not think random noise from the pressure sensors is movement, and it must be able to determine that the movement from the sensors is rigorous enough to constitute physical activity. It also must be able to determine how long a person has been active within a 10% range of accuracy.

3. Controls. The system shall respond to any button input within 0.5 seconds and correctly execute the corresponding state transition in at least 95% of 50 test presses per function. The system shall reject power-off or disable requests while the alarm is active (0% successful bypass in 20 attempts) and shall

allow the user to change the alert interval using the buttons in no more than 3 inputs, with the updated interval taking effect on the next timing cycle.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 Seat & Chair Sensing Subsystem

The chair-mounted sensing subsystem is responsible for determining whether a user is seated and for reducing false detections caused by small chair movements. This subsystem provides the primary indication of sedentary behavior and serves as the trigger for timing prolonged sitting periods

Seat occupancy is detected using either a force-sensitive resistor (FSR-402) placed beneath the seat cushion or load cells mounted under the chair supports in combination with an HX711 amplifier. These sensors produce signals proportional to the applied load, which are sampled by the ESP32 microcontroller. The system establishes a baseline for the unoccupied state and applies thresholding and hysteresis to reliably distinguish between occupied and unoccupied conditions. This approach ensures robustness against slow shifts in weight and sensor noise.

Piezoelectric vibration sensors are mounted on the chair frame to detect small disturbances such as chair shaking, repositioning, or leg movement while seated. These sensors provide an additional input used to gate state transitions and prevent false alarm clearing. By combining vibration sensing with seat occupancy data, the system can better distinguish between actual standing events and minor movements that do not represent meaningful physical activity.

2.2.2 Control + Processing

The control and processing subsystem is implemented using a chair-mounted ESP32 microcontroller. The ESP32 runs the main system state machine, tracks the duration of continuous sitting, and receives motion data from wearable IMU nodes over Bluetooth Low Energy (BLE). Chair sensor data and wearable motion data are fused to determine when an alarm should be triggered and when it can be safely cleared. The ESP32 also controls user feedback components such as the buzzer and LEDs.

2.2.3 Wearable IMU Nodes

Two wearable IMU nodes are attached to the user, typically at the ankle and waist or thigh. Each node consists of an ESP32 microcontroller, an inertial measurement unit (IMU), and a rechargeable battery. The IMUs measure acceleration and angular velocity, allowing detection of body movement patterns. Motion data is transmitted wirelessly to the chair-mounted ESP32 using BLE. The use of two IMUs enables verification of coordinated motion consistent with walking or light exercise, reducing the likelihood of false positives from isolated movements.

2.2.4 Alarm + UI

User feedback is provided through an active buzzer and visual indicators such as LEDs mounted on the chair. When prolonged sitting is detected, the buzzer produces an audible alert and LEDs indicate the alarm state. Optional push buttons allow basic user interaction, such as acknowledging an alarm or resetting the system. These components are controlled directly by the ESP32 using GPIO and PWM signals.

2.2.5 Power

The chair-mounted electronics are powered by a 5 V USB supply or a rechargeable battery pack. Voltage regulation is used to provide stable 3.3 V power for digital components. Each wearable IMU node is powered by its own rechargeable battery with charging and protection circuitry, allowing untethered operation during movement verification while maintaining safe battery usage.

2.3 Tolerance Analysis

An aspect that poses a possible risk to successful completion is the piezo vibration sensors. The sensors output a voltage in a possible range of -20 [V] to 20 [V], but the ADC of the ESP32 is only able to accept voltages in the range of 0 [V] to 3.3 [V]. Because of this, there is a risk of damaging the microcontroller if we do not implement a method that not only protects the microcontroller. We also must manage to convert the output voltage of the sensor into a range that still maintains the information it is providing in a form that is still useful to the ESP32 for determining movement. We have considered a few possible implementations. The most important aspect is protecting the ESP32, which we plan to do so with a high value series resistor (100 [kΩ] – 1[MΩ] range) to limit current and hopefully protect the ADC pin. Furthermore, we would have two diodes, one to 3.3V and one to ground so that the voltage never goes below 0 [V] or above 3.3 [V]. Then we would bias the signal around 1.65 [V] (midpoint of 0-3.3) since the sensor is AC centered at 0 [V]. We'd do this with two equal resistors between 3.3 [V] and ground and have a capacitor connecting the sensor to the 1.65 [V] reference so that the sensor's fluctuations go through, not the raw voltage. And then lastly we would convert it to an envelope with the use of a diode that rectifies the voltage to be only above 1.65 V, then use a capacitor and resistor to store and slowly release charge so that the sharp peaks from the vibration sensor are smoothed out into a more slowly varying voltage that may have better use by the microcontroller in determining steps as compared to sharp spikes which are more difficult to analyze.

3. Design Verification

Design verification focuses on validating correct seat occupancy detection, reliable wireless communication, and accurate verification of user movement. Verification procedures are designed to be repeatable and measurable.

3.1 Chair Sensor Verification

Chair sensor verification ensures that seat occupancy and vibration sensing operate correctly under typical usage conditions. Repeated sit and stand trials are conducted to confirm reliable detection of occupancy transitions. Controlled chair disturbances are introduced to verify that vibration sensing does not cause false alarm clearing.

3.1.1 Occupancy Detection Timing and Accuracy

Requirement: The system shall detect transitions between occupied and unoccupied states within 1 second.
Verification: Perform 50 sit and stand trials while recording detection timing. The requirement is met if at least 45 out of 50 transitions are detected within 1 second.

3.2 BLE Communication Verification

BLE communication is verified by measuring packet reception rate and latency between each wearable IMU node and the chair-mounted ESP32 under typical indoor conditions. Motion data is streamed continuously while the user moves within a normal operating range. Communication is considered acceptable if packet loss remains below a predefined threshold and no disconnections occur during testing.

3.3 Movement Verification Using Two IMUs

Movement verification testing evaluates whether the system correctly distinguishes meaningful physical activity from minor seated movements. Users perform walking or light exercise routines to verify that alarms are cleared appropriately. Additional tests involving seated leg shaking or chair movement are performed to ensure that alarms are not cleared by insufficient activity.

4. Ethics, Safety and Societal impact

A possible concern may be the storage of user data, given that the device would be taking in some biometric data. However, the system processes motion and occupancy data locally and does not identify users or transmit personal information to external servers. The design minimizes privacy concerns and avoids continuous monitoring beyond what is necessary for activity verification. We believe because of this, our design follows the concepts of integrity and responsibility as laid out in the IEEE code of ethics.

We also recognize that a device involving the user to engage in physical activity may be more difficult to use for people with disabilities, especially those struggling with mobility issues. It is unfortunate if an individual is unable to use our device for this reason, but we do not believe it violates the idea of fairness and non-discrimination in and of itself. And we intend to avoid any conflicts in this regard by specifying that our device is designed for able-bodied users and we would never advertise our device as a universal health solution, but rather a specific health device that can assist those capable of exercise to be more engaged in doing exercise

Another point of ethical concern may come from the coercive nature of the device. We are implementing a device that intends to force a person who may not be in the mood to exercise, to exercise. We don’t believe this violates the idea of avoiding harassment and treating others fairly because the device is intended to be voluntary. If marketed, we will not advertise it as a tool for a manager to impose on their workers, for instance, but as a device that an individual should decide if they wish to use or not.

There is always a possibility of injury when engaging in physical activity. To mitigate this issue, we wish to clearly inform users that this device should be done at the discretion of the individual, and that people should consult with a physician if unsure if they would be able to use our product safely.

That said, we firmly believe that our proposed device will have a positive impact on society. We will attempt our best to mitigate any issues, especially in regards to health and safety, so that it has the highest amount of potential for good in hopes that we may accomplish our goal: improve the physical health of our potential future users.

5. Costs

Table 1 summarizes the estimated cost of all major hardware components used in this project. All costs are based on typical retail pricing unless otherwise noted. The total estimated cost remains within the $150 project budget.

5.1 Parts

Estimated costs are based on common retail pricing for development boards and sensor modules.

Part	**Manufacturer**	**Retail Cost ($)**	**Bulk Purchase Cost ($)**	**Actual Cost ($)**
ESP32 Development Board (x3)	Espressif	24.00	20.00	20.00
IMU Module (MPU-6050) (x2)	InvenSense	10.00	8.00	8.00
Load Cells (x4)	Generic	12.00	10.00	10.00
HX711 Load Cell Amplifier	Avia Semiconductor	5.00	4.00	4.00
FSR-402 Seat Sensor (alternative option)	Interlink	10.00	8.00	8.00
Piezo Vibration Sensors (x2)	Generic	4.00	3.00	3.00
Active Buzzer	Generic	2.00	1.50	1.50
LEDs (x3)	Generic	2.00	1.50	1.50
Push Buttons (x2)	Generic	2.00	1.50	1.50
Li-ion Batteries (x3)	Generic	18.00	15.00	15.00
Battery Charging Modules (x3)	TP4056 / Generic	6.00	5.00	5.00
Voltage Regulators (AMS1117 / Buck Converter)	Generic	6.00	5.00	5.00
Protection Diodes & Passive Components (R, C)	Generic	5.00	4.00	4.00
PCB Prototyping / Perfboard	Generic	8.00	6.00	6.00
Wiring & Mounting Hardware	Generic	10.00	8.00	8.00
Total				**100.50**

5.2 Labor

Labor costs are not included, as all work is performed by the project team as part of course requirements.

6. Conclusion

6.1 Accomplishments

This project proposes and designs a sedentary behavior detection chair that combines chair-mounted sensing with wearable IMU nodes. The system architecture integrates multiple sensing modalities and Bluetooth Low Energy communication to verify meaningful physical movement before clearing prolonged sitting alerts. The design achieves increased robustness compared to chair-only sensing approaches.

6.2 Uncertainties

Potential uncertainties include variability in user movement patterns and differences in how individuals perform physical activity. Sensor calibration and threshold selection may require adjustment to accommodate different users and seating behaviors.

6.3 Ethical considerations

The system processes motion and occupancy data locally and does not identify users or transmit personal information to external servers. The design minimizes privacy concerns and avoids continuous monitoring beyond what is necessary for activity verification.

6.4 Future work

Future work may include adaptive movement thresholds based on individual user behavior, additional activity classification using IMU data, and optional data logging for long-term activity analysis.

References

[1] World Health Organization, “Guidelines on physical activity and sedentary behaviour,” 2020.

[2] Espressif Systems, “ESP32 Technical Reference Manual.”

[3] InvenSense, “MPU-6050 Product Specification.”

Appendix A Requirement and Verification Table

Table X System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Requirement a. Subrequirement b. Subrequirement c. Subrequirement	1. Verification a. Subverification b. Subverification c. Subverification	
2. Requirement a. Subrequirement b. Subrequirement c. Subrequirement	2. Verification a. Subverification b. Subverification c. Subverification	
3.	3.	
4.	4.	