ECE 445
Insole for Gait Monitoring and Fall Risk Research in Older Adults

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1 Introduction

1.1 Problem

Falls are a major cause of injury, especially in older adults. Each year, 8 million adults over 65 experience fall-related injuries, with 3 million requiring emergency care. In the U.S., falls result in an average of 32,000 deaths annually [1]. Worldwide, falls are the second most common cause of unintentional death. Early smart home fall detection technology for high-risk adults is currently lacking, failing to incorporate relevant data from monitoring changes in fall risk and frailty.

1.2 Solution

Dr. Manuel Hernandez's lab developed a TENG (Triboelectric Nanogenerator) sensor designed for use in an insole. Our goal is to integrate this sensor into a wearable device to monitor gait, improve sensor characterization, and collect data for research on fall risk and frailty. The device should be portable and allow the user to walk naturally. It should accurately convert signals from the sensor into a digital format and transmit them via Bluetooth for use in a mobile app.

1.3 Visual Aid

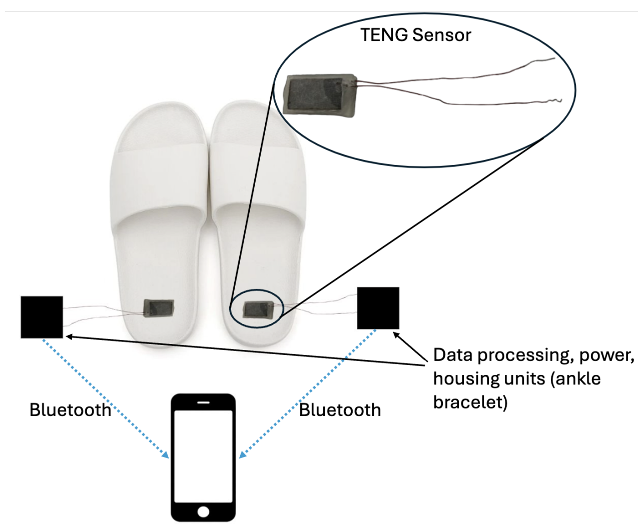

Figure 1: Gait Monitoring System Design

1.4 High-Level requirements

- The system must be durable and user-friendly, with no more than one malfunction or error occurring per 1,000 steps.
- The system must be able to synchronize two sensors to collect data from both feet with an error margin of no more than 12 ms.
- The system must categorize load as low, medium, or high based on the voltage produced by the sensor, with an accuracy of 95% at stepping rates of up to 5 Hz.

2 Design

2.1 Block Diagram

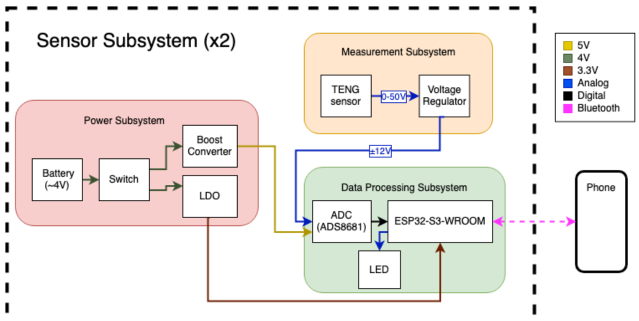

Figure 2: System Block Diagram

2.2 Subsystems

2.2.1 Measurement Subsystem

Overview: The Measurement Subsystem is responsible for detecting step data and converting it into a usable electrical signal. It consists of the TENG (Triboelectric Nanogenerator) sensor, provided by Dr. Manuel Hernandez, and a custom voltage regulator. The TENG sensor responds to changes in loading by generating an electrical signal, which can reach up to 40 V. The voltage regulator is designed to regulate this signal, stepping it down to within ±12 V, filtering out unwanted frequencies, and protecting against unexpected voltage surges. This subsystem is self-powered.

Requirements: The Measurement Subsystem must output a signal within ±12 V that accurately corresponds to the applied load in both timing and voltage level.

2.2.2 Data Processing Subsystem

Overview: The Data Processing Subsystem receives the signal from the Measurement Subsystem, converts it into a digital format, and transmits it over Bluetooth. This subsystem consists of an ADC (ADS8681), an ESP32-S3-WROOM module, and a status LED. The ADC processes the analog signal from the Measurement Subsystem, making it suitable for the ESP32. The ESP32 then transmits the data via Bluetooth to a mobile device and controls the LED to indicate the system's status.

Requirements: The Data Processing Subsystem must be able to accurately transmit 99.9% of the measured data via Bluetooth. It must also display power and error status using the LED.

2.2.3 Power Subsystem

Overview: The power subsystem delivers power to the ADC and ESP32 components of the data processing subsystem. It contains a 4 V battery in series with a switch to control when power is delivered to the rest of the device, ensuring an on and off state for device usage and battery life optimization. It then routes through a power distribution board which is composed of a boost converter and a low-dropout regulator, who feed 5 V to the ADC and 3.3 V to the ESP32 microcontroller respectively.

Requirements: The power subsystem should efficiently manipulate the voltage from a 4 V battery to deliver power aligning to the rating of the ADC and ESP32 components efficiently (within 0.1 V of rating), to ensure part safety and functionality.

2.3 Tolerance Analysis

TENG Sensor Voltage Regulation: The TENG sensor generates a high voltage signal of up to 40 V, however, the measurement subsystem must regulate this to ensure compatibility with the ADC. The voltage regulator circuit must maintain an output range of ±12 V to ensure the ADC collects all the relevant data to prevent data clipping and signal distortion.

ADC Sampling and Signal Conversion: The ADC converts the TENG signal from analog to digital. Given a step rate of < 5 Hz, the ADC must accurately capture each voltage fluctuation. Based on the Nyquist criterion $fs \geq 2f_m$, the ADC must sample at least 10 Hz. However, since the TENG sensor is a custom made device, it likely contains higher frequencies, which must also be accounted for, so we will oversample by 10 times to a frequency of 100 Hz.

Synchronization Between Sensors: Since two TENG sensors will be used, one for each foot, synchronization between the two sensors must be achieved to ensure accurate timing and gait analysis. The sensors should be synchronized between 12 ms.

Bluetooth Data Transmission: Data is transmitted from the ESP32 microcontroller to a mobile device via Bluetooth. The system must transmit 99.9% of data packets successfully, and achieve a transmission delay of ≤ 50 ms per packet.

3 Ethics and Safety

In developing our gait monitoring system, we will prioritize the safety, health, and privacy of the users based on ethical engineering principles. A primary safety concern is the TENG sensor's capability to produce up to 40 V under high loads. To ensure user safety, we must design a secure enclosure that prevents exposure to this voltage, mitigating any potential risk. In alignment with the IEEE Code of Ethics Section 1, we have a responsibility to protect the well-being of users and transparently disclose any safety considerations associated with the sensor.

From an ethical standpoint, since our project is being developed in collaboration with Professor Hernandez's research group, we must properly acknowledge and credit all prior and ongoing contributions, in accordance with ACM Code of Ethics Section 1.5. The sensors used in this project are custom-made and thoroughly documented, so we must recognize the efforts of those who designed and developed them. As we continue working alongside Professor Hernandez and his team, we must ensure that all contributions are fairly attributed. By adhering to these ethical standards, we uphold integrity in our professional activities while ensuring our technology benefits society responsibly.

References

[1] Curtis S. Florence et al. "Medical Costs of Fatal and Nonfatal Falls in Older Adults". In: *Journal of the American Geriatrics Society* 66.4 (2018), pp. 693–698. DOI: https://doi.org/10.1111/jgs.15304. eprint: https://agsjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/jgs.15304. URL: https://agsjournals.onlinelibrary.wiley.com/doi/abs/10.1111/jgs.15304.