IMPACT INSOLES

INSOLE PRESSURE SYSTEM FOR RUNNING SHOES

By

Joseph Casino

Aarush Sivanesan

Matthew Weng

Introduction

Problem

Running is one of the most popular and accessible forms of physical activity worldwide, offering significant cardiovascular and mental health benefits. However, running is also associated with a high incidence of overuse injuries, with studies estimating that 30–80% of runners experience an injury each year. Common causes include excessive impact forces, poor foot-strike mechanics (e.g., heel striking vs. midfoot striking), asymmetrical loading between feet, and inconsistent cadence. Many of these issues stem from improper gait mechanics that go unnoticed by runners until pain or injury develops.

Currently, accurate measurement of foot-ground interaction requires gait laboratories equipped with force plates, pressure mats, or instrumented treadmills. These systems are expensive, stationary, and typically limited to clinical, research, or elite athletic settings. While some consumer wearables can estimate cadence or pace using wrist or hip mounted inertial sensors, they do not directly measure foot pressure or impact forces, which are critical indicators of injury risk and running efficiency.

There is a societal need for an affordable and wearable system that provides runners with direct insight into how their feet interact with the ground during real outdoor runs. Such a system has implications for public health by helping reduce injury rates, economic welfare by lowering healthcare and physical therapy costs, and athletic accessibility by democratizing biomechanical feedback previously limited to professionals. By enabling runners to better understand and adjust their foot force, this project addresses broader concerns related to health, safety, and long-term physical well-being.

Solution

We propose a thin-film pressure sensor insole system that integrates directly into the running shoes that measures the force applied by the foot to the ground throughout each step. A flexible sensor array of thin film force sensors embedded on top of the shoe foam (or placed under the insole) will capture pressure through the foot's main contact points (forefoot, heel, and midfoot) and track the pressure distribution of the foot throughout the run.

A compact electronics module will attach to the shoe heel or tongue and contain the microcontroller, battery, and Bluetooth modules. The MCU will sample the pressure sensor data, detect foot-strike events, and compute basic metrics such as step count and contact time. Optionally, an inertial measurement unit (IMU) can supplement pressure data to improve robustness and stride estimation. Data is transmitted wirelessly to a smartphone, where it can be visualized, logged, and analyzed. This approach provides runners with direct, actionable feedback on their running mechanics without requiring expensive lab equipment or professional supervision.

Visual Aid
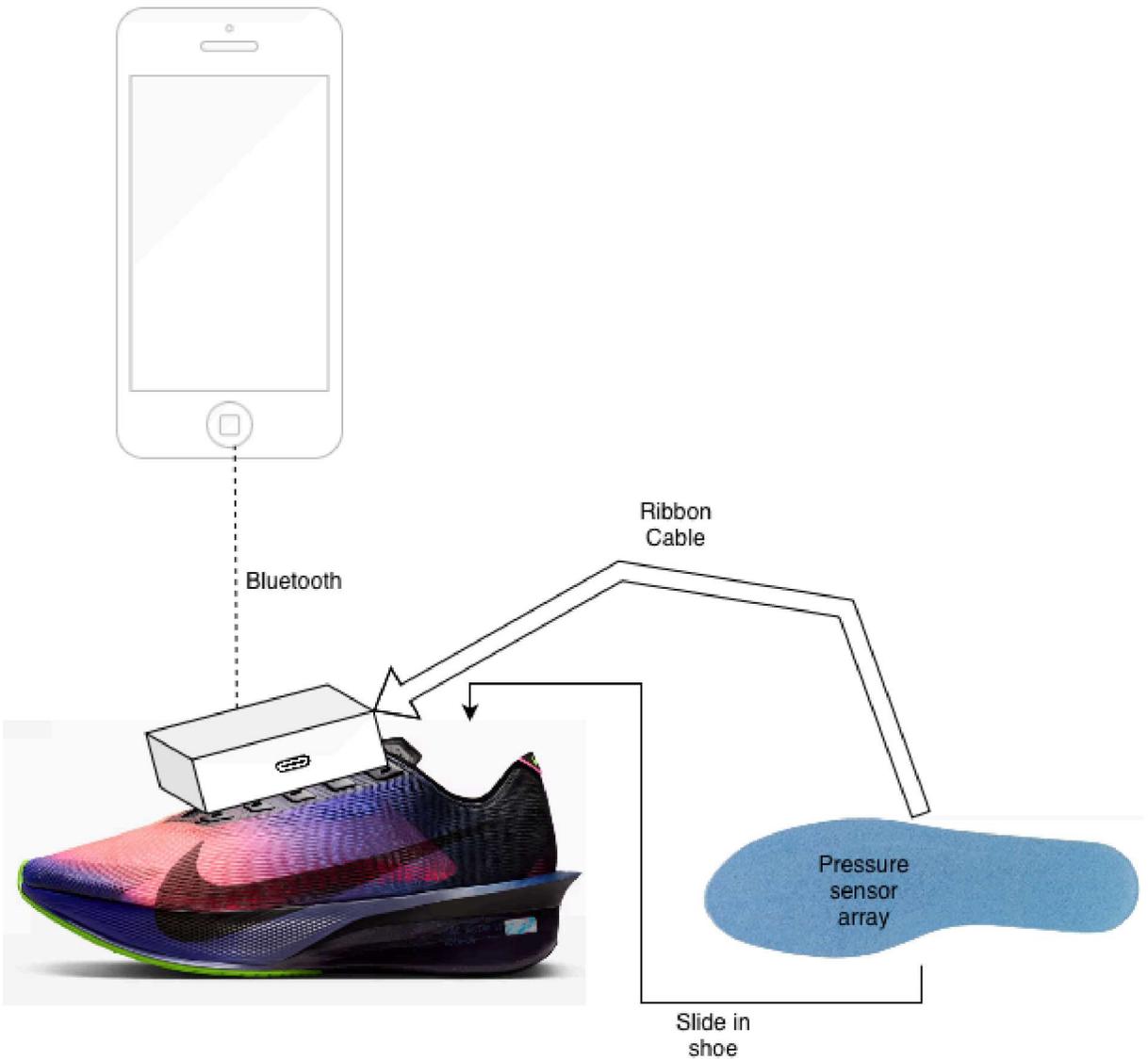
This figure represents the pressure sensor array that will be incorporated into a foam insole, which can slide inside a running shoe and connect to a small module that houses the PCB. This PCB will communicate via bluetooth to record all the pressure sensor data.

High-level requirements list:
- Efficiency: The system shall sample plantar pressure sensor data at a minimum rate of 100 Hz and transmit the data over Bluetooth Low Energy with no more than 5% packet loss during continuous operation.
- Accuracy: The system shall detect foot-strike events and report running cadence with an accuracy of ±3 BPM compared to a stopwatch or smartwatch reference over a controlled running trial.
- Continuity/Longevity: The device shall operate continuously for at least 1 hour on battery power while performing active sensing and BLE data streaming.

Block Diagram
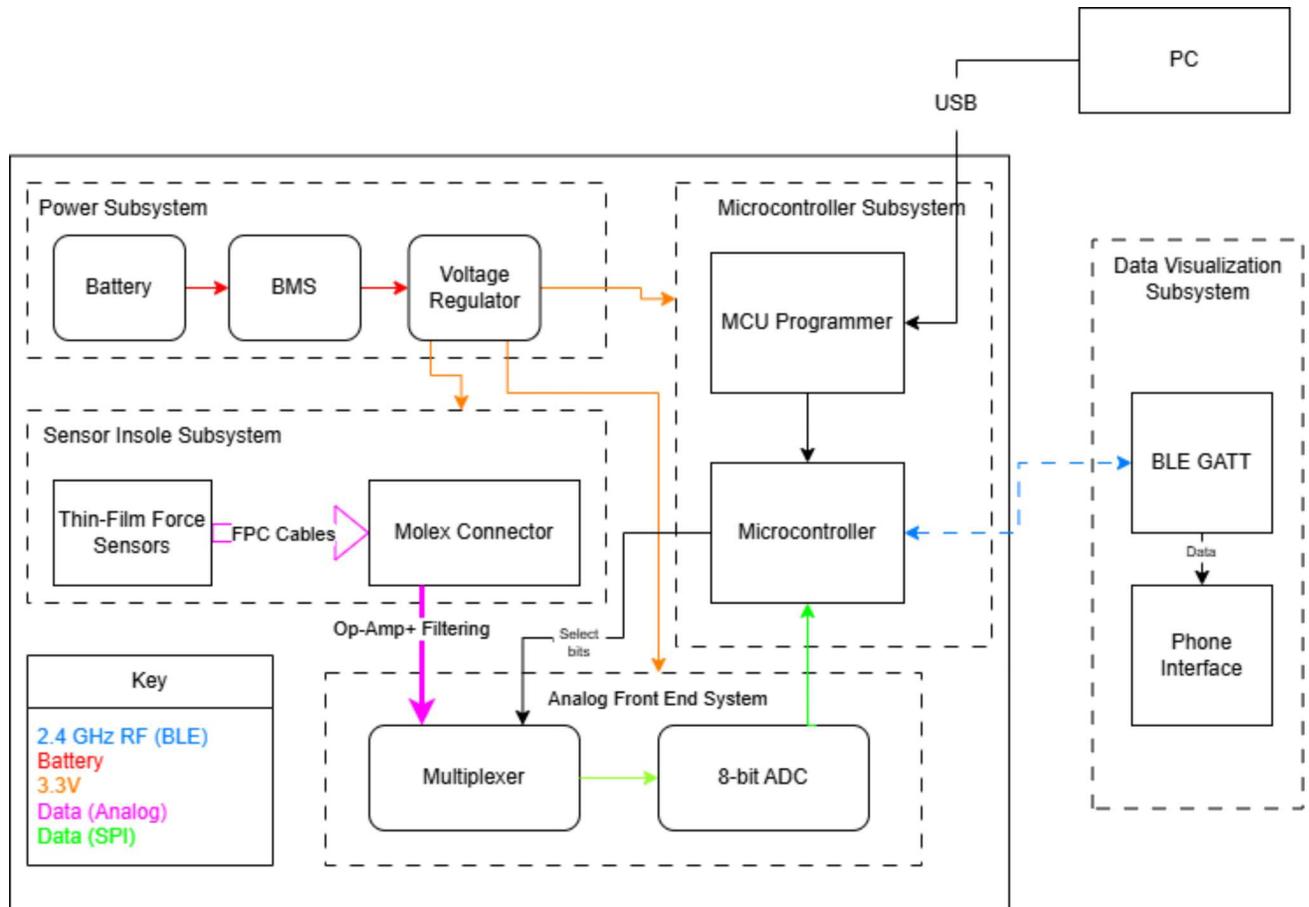
Subsystem 1: Thin-Film Pressure Sensor Insole Array

Overview: This subsystem senses foot pressure at key regions of the shoe to capture impact patterns and pressure distribution during stance. As the runner's foot strikes the ground, each sensor produces a varying resistance proportional to the applied force. The sensor insole would fit either on top or bottom of the foam insole of the shoe. (add sampling freq)

Components:
- Thin-film force sensors: Interlink Electronics FSR 402
  - Digikey Link
  - Interlink Electronics Link
  - Datasheet
- Flexible interconnect/cabling: FFC/FPC cable (0.5 mm pitch) (generic)
  - Mouser Link (need to exact sizing before buying)

- Connector (board-side): Molex 503480-0490 (4-pos FFC/FPC connector) (size can be adjusted based on channel count)
    - [Molex Link](#)
    - [Digikey Link](#)

Requirements: The subsystem will incorporate at least 3 sensors at each part of the foot (heel, midfoot/arch, balls of the foot, toes) to capture comprehensive pressure data. There is an active sensing range covering typical running forces (~0.2 N to 20 N for each FSR via the datasheet) for relevant gait events. The sensor array interfaces with the analog front-end subsystem through flexible cabling and connectors, ensuring the insole remains lightweight.

Subsystem 2: Analog Front-End + ADC Data Acquisition

Overview: This subsystem converts each sensor data to data that can be read to the MCU. To sample all the sensors on the foot, we sample between all the sensors with a MUX. We then properly filter and amplify the data from the sensor through the op-amp. This data then gets digitized through an ADC.

Components:
- 8-bit ADC: TI ADC081S021
    - [Mouser Link](#)
    - [Datasheet](#)
- Analog multiplexer: CD74HC4067SM96
    - [Digikey Link](#)
    - [Datasheet](#)
- Op-amp: TLV9062IDR
    - [Digikey Link](#)
    - [Datasheet](#)

Requirements: The MUX selects one of up to 16 analog sensor channels, the op-amp performs buffering/filtering, and the MCP3425 converts the selected channel to digital data delivered to the MCU via I²C. To meet the ≥100 Hz sampling requirement, the subsystem is designed so the effective per-channel sampling rate remains ≥100 Hz across the active sensor count. The ADC shall operate over I²C and deliver ≥12-bit effective resolution (16-bit nominal). The MUX control interface from MCU shall use 4 digital select lines + enable at 3.3 V logic.

Subsystem 3: Microcontroller + BLE Wireless Telemetry

Overview: This subsystem houses our MCU which will control sampling, collect data, timestamp data, and transmit results via BLE. Digitized pressure samples arrive via I²C; the MCU formats data into notifications/packets and transmits them over BLE at a sustained throughput sized for the chosen channel count and sampling rate.

Components:
- MCU module: ESP32-C3-WROOM-02-H4 MAKE SURE MCU HAS ENOUGH PINS
  - [Digikey Link](#)
  - [Datasheet](#)
- Programming/debug interface: Tag-Connect TC2030-IDC
  - [Digikey Link](#)

Requirements: The MCU will ingest ADC data over I²C at ≥400 kHz bus speed (removing bus speed risks buffer overflows at ≥100 Hz multi-channel). The BLE link will be able to sustain streaming such that packet delivery is ≥95% at 5 m line-of-sight The subsystem will run from a regulated 3.3V rail.

Subsystem 4: Optional Motion Sensing (IMU)

Overview: This extra subsystem provides accelerometer/gyro data to gather speed data, estimate and improve stride data and length, and improve cadence robustness when the pressure signals are noisy.

Components:
- 6-axis IMU: ST LSM6DSOXTR or equivalent
  - [Digikey Link](#)
  - [Datasheet](#)

Requirements: The IMU should be able to poll translational and rotational force at the same rate as the pressure sensors—i.e., up to 100 Hz.

Subsystem 5: Power Management + Charging

Overview: This subsystem powers the in-shoe electronics safely and supports rechargeable operation if applicable. The design regulates battery voltage to stable rails for the MCU and sensors. We have a wide range of batteries that we would like to work with initially to weigh out the pros and cons of each.

Components:
- Battery: 3.7V Li-Po (300–500 mAh)
- BMS IC for Li-Po : MCP73831T-2ACI/OT
- 3.3V regulator : MCP1700T-3302E/TT

Requirements:
The subsystem shall provide a regulated 3.3 V ±5% supply to all electronics and support continuous operation for at least 1 hour during active sensing and BLE transmission. The battery and charging circuitry shall include overcharge, overdischarge, and short-circuit protection to ensure safe wearable operation.

Subsystem 6: Phone Interface / Data Visualization

Overview: This subsystem provides the wireless interface between the device and a smartphone or website which displays metrics to the runner and logs sessions. Initial versions can use a simple BLE GATT service viewed in a standard BLE app; a custom website or phone UI can be added if time permits.

Components:
- BLE GATT profile (firmware-defined)
- Prototype viewer: nRF Connect app or alternative

Requirements:
The subsystem shall stream sensor data over BLE with ≥95% packet delivery and will be able to retrieve information from the microcontroller when requested.

Tolerance Analysis:

A big consideration on the data transmission side of this project is the balance between battery life, transmission rate, and memory. When lowering the transmission rate between the phone and the insole system to conserve battery, more data needs to be stored on device before it can be cleared. This means that the flash storage size and speed will set the limits for our battery management approach. Additionally, these storage parameters will determine if the device can be used headless, an important feature for runners running light. On top of this, to decrease complexity and size of the final product, it is highly preferable to only use the inbuilt flash memory for these roles, rather than external solutions.

If each sensor generates 1 byte of data per poll, one foot's insole array generates 16 bytes of data per poll. At our max poll rate of 100 Hz, the array will generate data at a rate of 1.6 kB/s max. This is within spec of the ESP32 flash memory, meaning that the flash memory can handle the writing and storage of this data. Additionally, this means that if we set aside 14 MB of the 16MB flash memory in the ESP32, we can store 8750 seconds (~145 minutes) of raw data max before clearing. For data transmission considerations, this is more than enough space to conduct transmission events at any feasible rate we desire. For headless mode, this duration is long enough to accommodate a standard two-hour run with headroom. Therefore, it is feasible to use the inbuilt flash memory of the ESP32 to implement long battery life and headless operation in our device.

Ethics, safety and societal impact

The main source of ethical consideration in this project is the potential misunderstanding of this system as a medical device. Since the system tracks biometrics and may offer interpretation of that data in the form of statistics or algorithmically-calculated suggestions, users could assume it can assess clinical injury or provide medical recommendations. In accordance with the IEEE Code of Ethics, which emphasizes holding paramount the safety, health and welfare of the public, we will need to clearly present the device as a training and performance aid only. This means we may also have to include disclaimers describing the product's limitations, as well as advising users to make their own personal medical judgment with the data.

The IEEE Code of Ethics also requires engineers to be honest and realistic in their claims based on the available data. Due to this, the reported metrics from our device will have to be validated against reference measurements. Safety is also a top priority, as an electronic device will be attached to the foot, a crucial part of the human body. The system must remain lightweight, securely mounted, and low-profile to not interfere with normal movement or create a tripping or discomfort hazard. Since the device will operate with a battery, a proper enclosure must be created to prevent overheating and electrical risks during use.

The societal impact of this system is not necessarily widespread, but can still be significant. This product appeals to a niche market of those who care about improving their running stride and maintaining good form. This system can provide a more accessible option for users outside of expensive laboratory environments.The positive effects compound with more miles run, so avid runners in particular can benefit greatly from this.

References

[1] Interlink Electronics, "FSR 402 Round Force Sensing Resistor," product highlight page. Available at:
https://www.digikey.com/en/product-highlight/i/interlink/fsr-402-round-force-sensing-resistor
. Accessed Feb. 11, 2026.

[2] Interlink Electronics, "FSR Model 402 Force Sensor," web store page. Available at:
https://buyinterlinkelectronics.com/products/fsr-model-402
. Accessed Feb. 11, 2026.

[3] Interlink Electronics, "FSR 402 Force Sensing Resistor Datasheet," datasheet, 2019. Available at:
https://files.seeedstudio.com/wiki/Grove-Round_Force_Sensor_FSR402/res/FSR402.pdf
. Accessed Feb. 11, 2026.

[4] Molex LLC, "Premo-Flex FFC/FPC Jumper Cables," product category page. Available at:
https://www.mouser.com/c/wire-cable/ffc-fpc-jumper-cables/?m=Molex&tradename=Premo-Flex
. Accessed Feb. 11, 2026.

[5] Molex LLC, "5034800400 FFC/FPC Connector," product page. Available at:
https://www.molex.com/en-us/products/part-detail/5034800400
. Accessed Feb. 11, 2026.

[6] Molex LLC, "5034800440 Connector, 0.50 mm Pitch," Digi-Key product page. Available at:
https://www.digikey.com/en/products/detail/molex/5034800440/5021353
. Accessed Feb. 11, 2026.

[7] Texas Instruments, "ADC081S021CIMF/NOPB 8-Bit ADC," Mouser product page. Available at:
https://www.mouser.com/ProductDetail/Texas-Instruments/ADC081S021CIMF-NOPB
. Accessed Feb. 11, 2026.

[8] Texas Instruments, "ADC081S021 8-Bit Analog-to-Digital Converter," datasheet, 2015. Available at: https://www.ti.com/lit/ds/symlink/adc081s021.pdf
. Accessed Feb. 11, 2026.

[9] Texas Instruments, "CD74HC4067SM96 Analog Multiplexer," Digi-Key product page. Available at:
https://www.digikey.com/en/products/detail/texas-instruments/CD74HC4067SM96/390310
. Accessed Feb. 11, 2026.

[10] Texas Instruments, "CD74HC4067 High-Speed CMOS Analog Multiplexer/Demultiplexer," datasheet, 2017. Available at: https://www.ti.com/lit/ds/symlink/cd74hc4067.pdf
. Accessed Feb. 11, 2026.

[11] Texas Instruments, "TLV9062IDR Operational Amplifier," Digi-Key product page. Available at:
https://www.digikey.com/en/products/detail/texas-instruments/TLV9062IDR/7364940
. Accessed Feb. 11, 2026.

[12] Texas Instruments, "TLV9062 Low-Power, Rail-to-Rail Operational Amplifier," datasheet, 2018. Available at: https://www.ti.com/lit/ds/symlink/tlv9062.pdf
. Accessed Feb. 11, 2026.

[13] Espressif Systems, "ESP32-C3-WROOM-02-H4 Wi-Fi/BLE Module," Digi-Key product page. Available at:
https://www.digikey.com/en/products/detail/espressif-systems/ESP32-C3-WROOM-02-H4/14553028
. Accessed Feb. 11, 2026.

[14] Espressif Systems, "ESP32-C3-WROOM-02 Datasheet," datasheet, 2022. Available at:
https://documentation.espressif.com/esp32-c3-wroom-02_datasheet_en.pdf
. Accessed Feb. 11, 2026.

[15] Tag-Connect LLC, "TC2030-IDC Programming/Debug Cable," Digi-Key product page. Available at: https://www.digikey.com/en/products/detail/tag-connect-llc/TC2030-IDC/4571121
. Accessed Feb. 11, 2026.

[16] STMicroelectronics, "LSM6DSOXTR 6-Axis IMU," Digi-Key product page. Available at:
https://www.digikey.com/en/products/detail/stmicroelectronics/LSM6DSOXTR/9841882
. Accessed Feb. 11, 2026.

[17] STMicroelectronics, "LSM6DSOX iNEMO Inertial Measurement Unit," datasheet, 2021. Available at: https://www.st.com/resource/en/datasheet/lsm6dsox.pdf
. Accessed Feb. 11, 2026.

[18] Institute of Electrical and Electronics Engineers (IEEE), "IEEE Code of Ethics," IEEE Board of Directors, June 2020. Available at:
https://www.ieee.org/about/corporate/governance/p7-8.html
. Accessed Feb. 11, 2026.