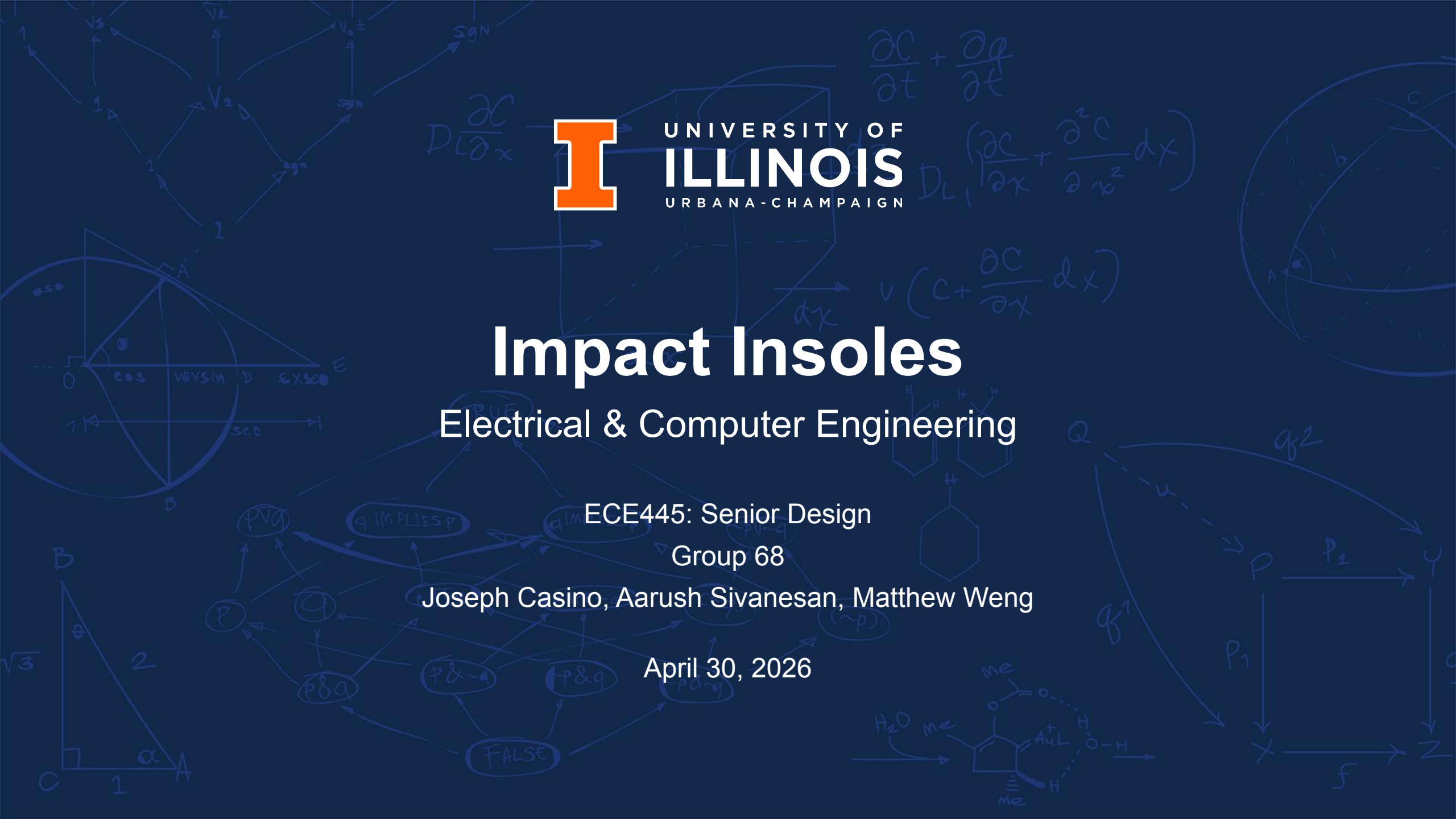


UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Impact Insoles

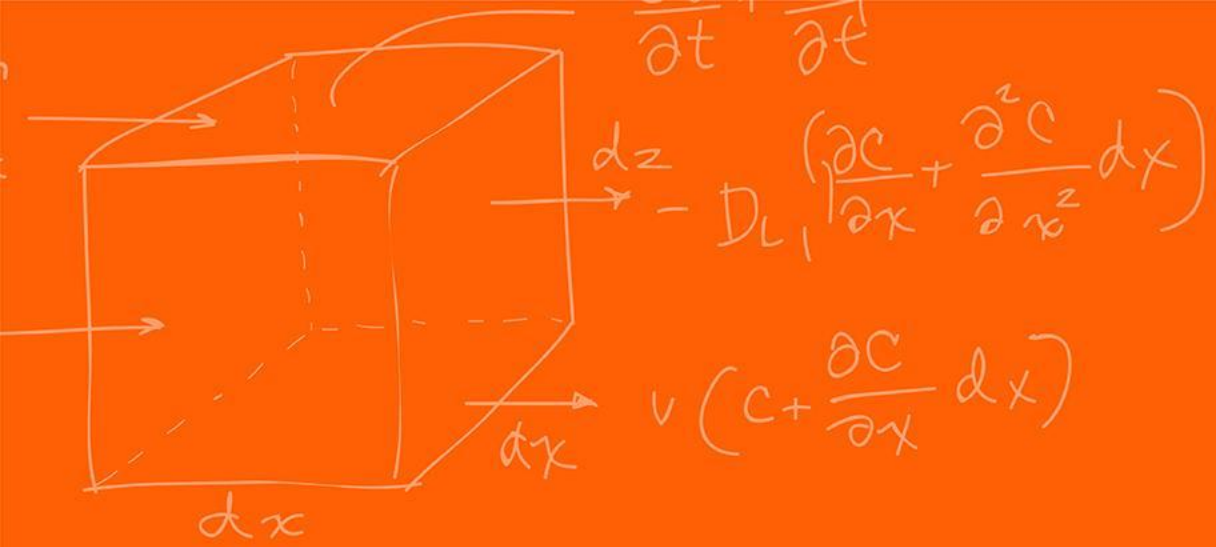
Electrical & Computer Engineering

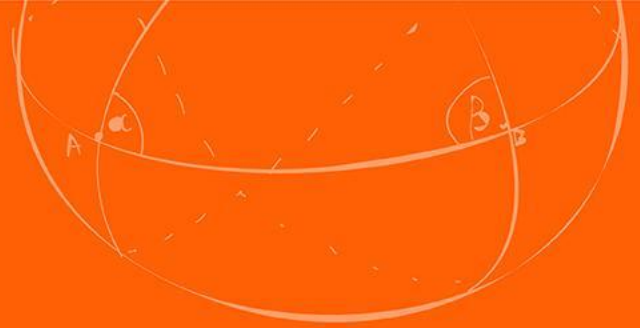
ECE445: Senior Design

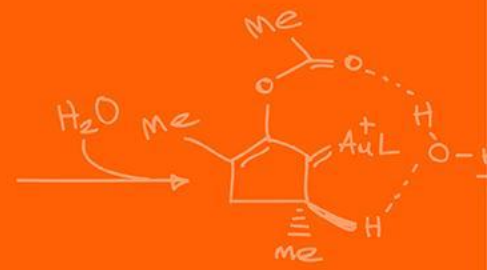
Group 68

Joseph Casino, Aarush Sivanesan, Matthew Weng

April 30, 2026

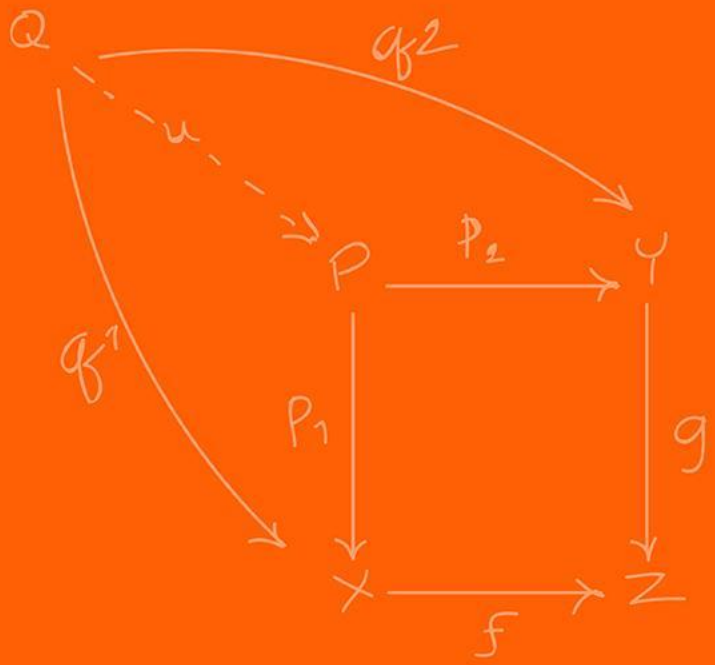






Introduction

Problem, Motivation & Requirements



Introduction

The Problem: Running Injuries & Gait Analysis

- Running has high injury rates, yet gait analysis tools are stationary and expensive
- Force plates and pressure mats are inaccessible to runners, coaches, and PTs

Our Objective: Impact Insoles

- Wearable insole that captures plantar pressure during real outdoor runs
- Stream data wirelessly via BLE to a phone app for live visualization
- Detect foot-strike events and report cadence in real time

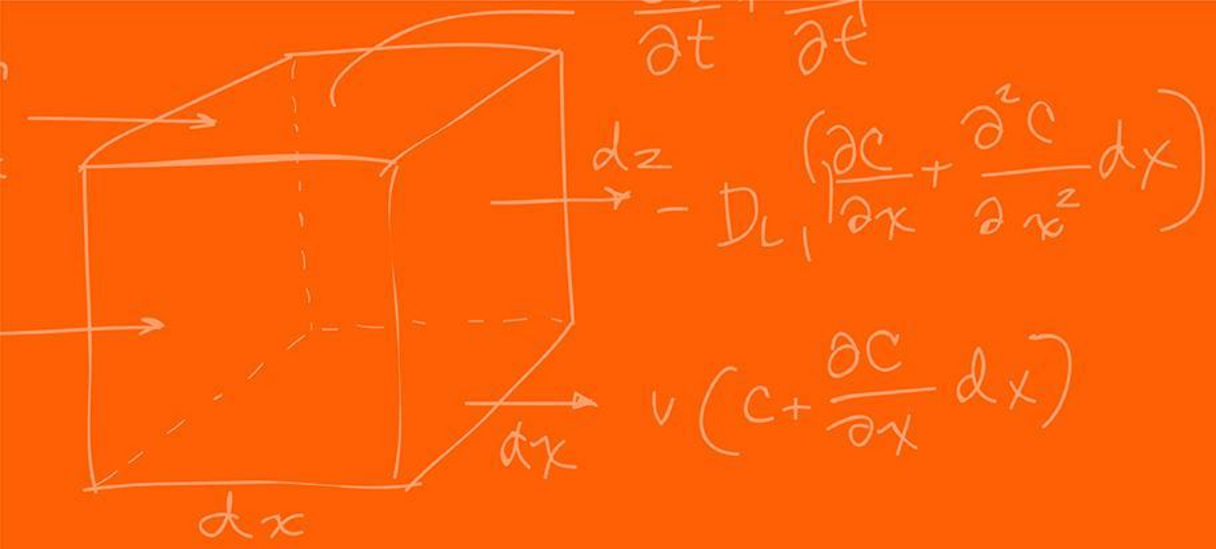
Requirements & Design Goals

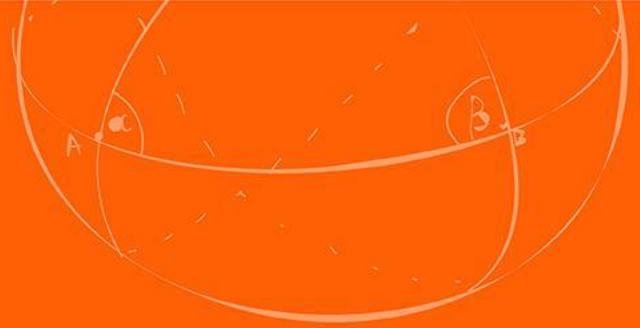
High-Level Requirements

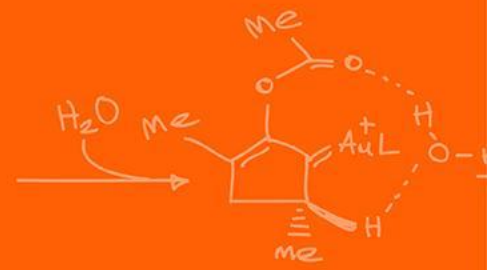
- **Efficiency**: sample 12 FSRs at ≥100 Hz with <5% BLE packet loss
- **Accuracy**: cadence within ±3 SPM vs. stopwatch reference
- **Longevity**: ≥1 hour continuous battery operation

Physical Design Targets

- Insole thickness: ~0.3 mm (non-intrusive in shoe)
- Target PCB module size: 50 mm x 50 mm
- Total system weight: ~50 grams
- 12 FSRs across heel, midfoot, and forefoot zones
- BLE range: smartphone within 1 m

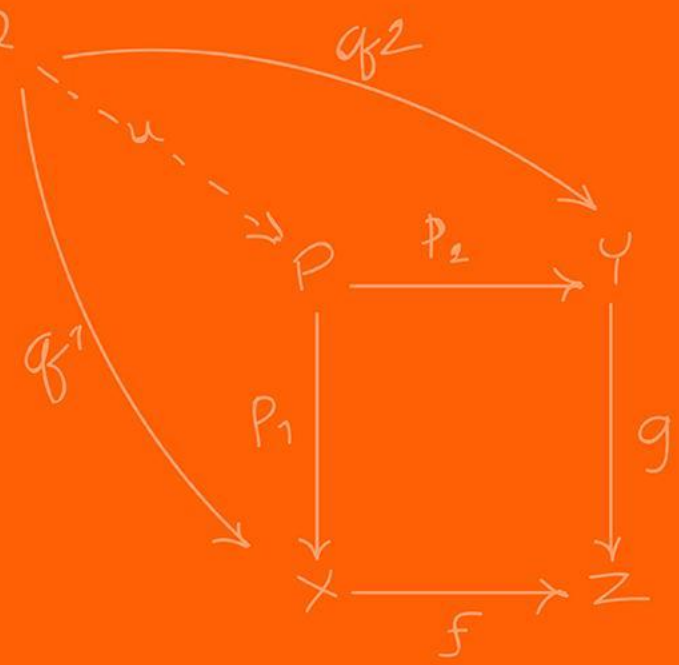




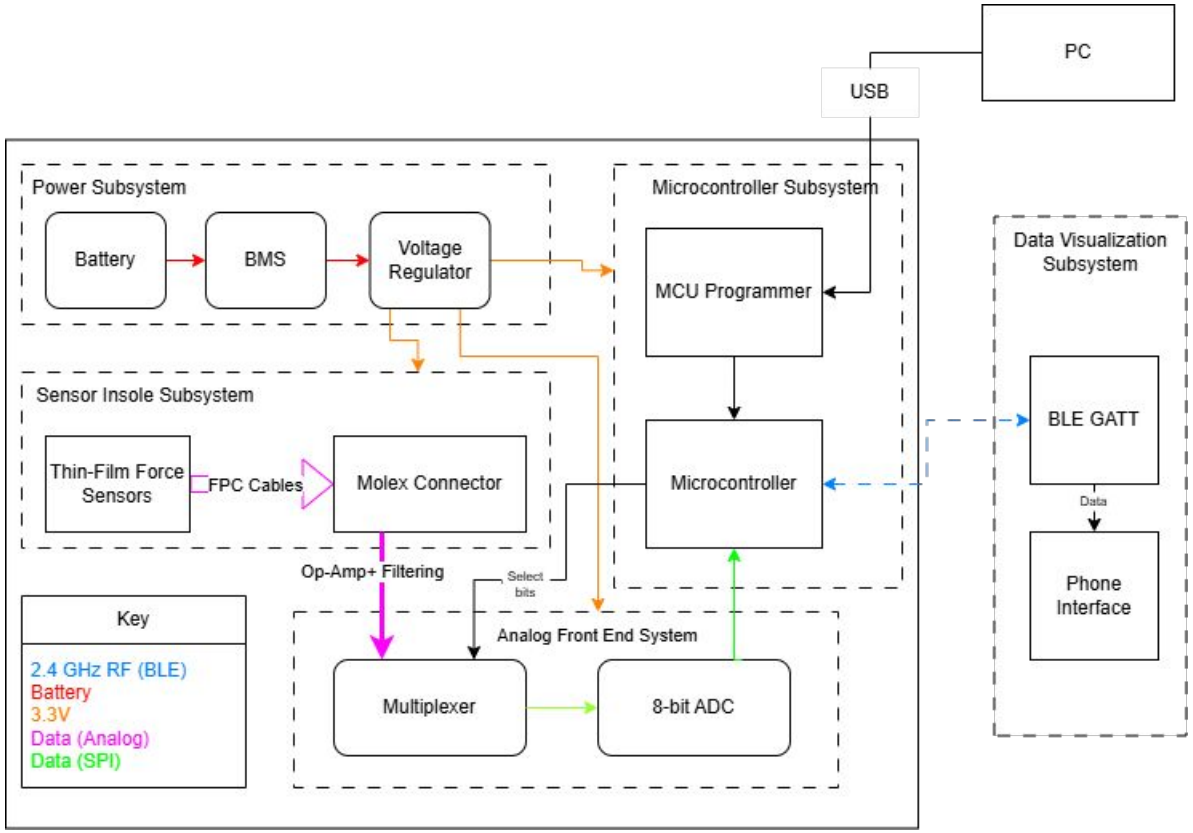


System Design

Block Diagram & Subsystems



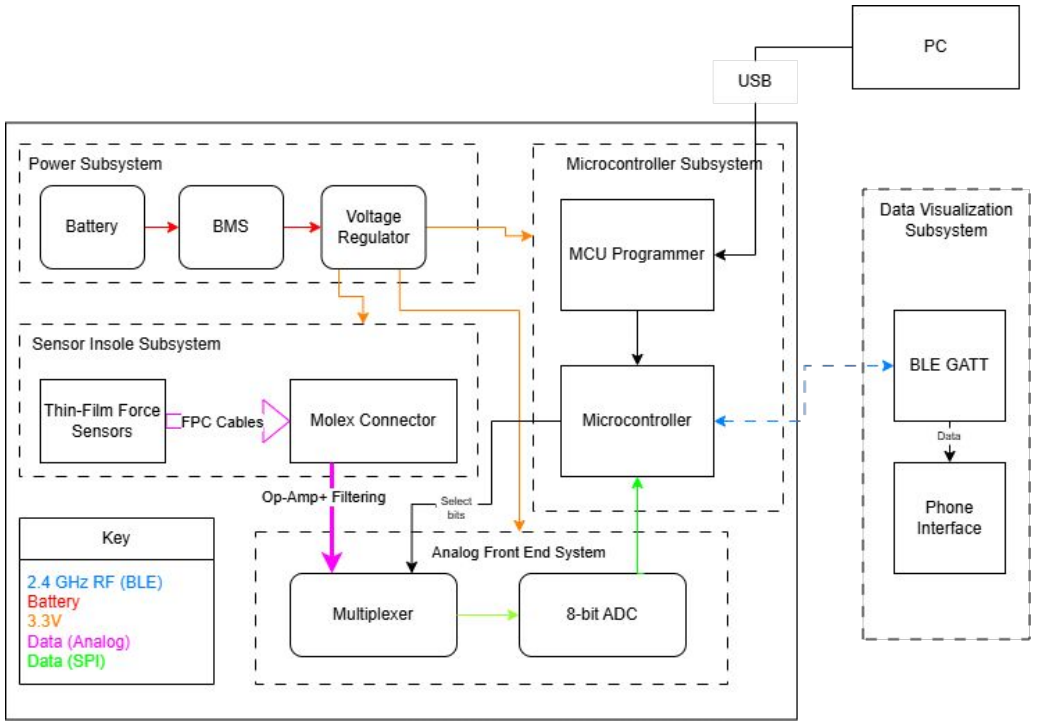
System Design



System Architecture

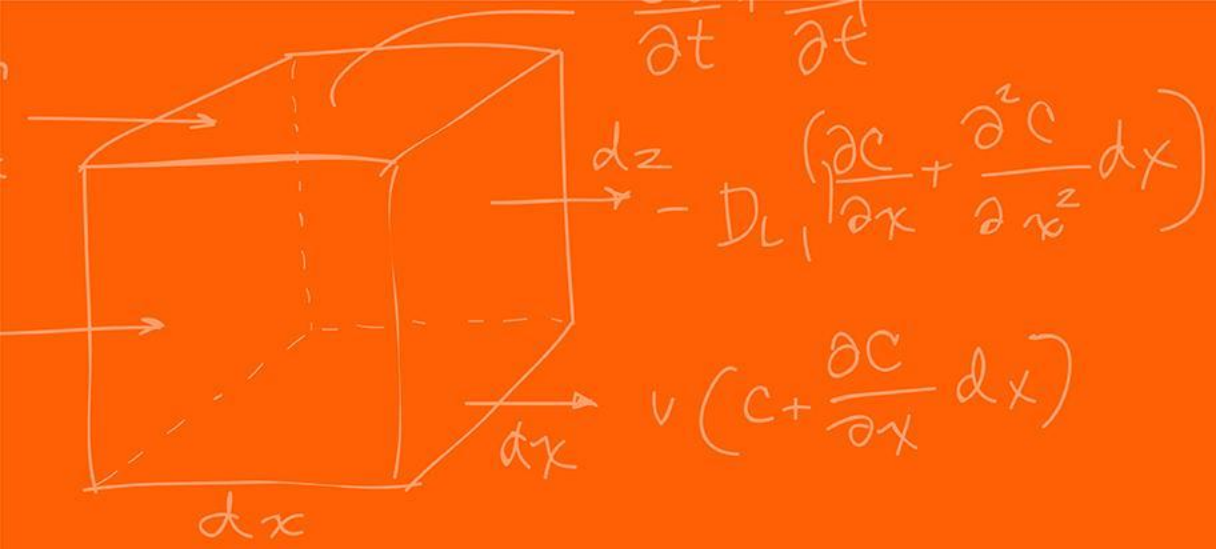
- **FSR Array:** 8-16 Interlink FSR400/402 thin-film sensors on a flexible PCB insole
- **Analog Front-End**: CD74HC4067 16:1 MUX feeds one FSR at a time to a 12-bit ADC
- **MCU**: ESP32-C3 handles MUX control, ADC sampling, and BLE wireless telemetry
- **Power**: 3.7V 400mAh LiPo battery + BQ24075 USB-C charging IC
- **App**: Smartphone BLE central for real-time pressure visualization and data logging

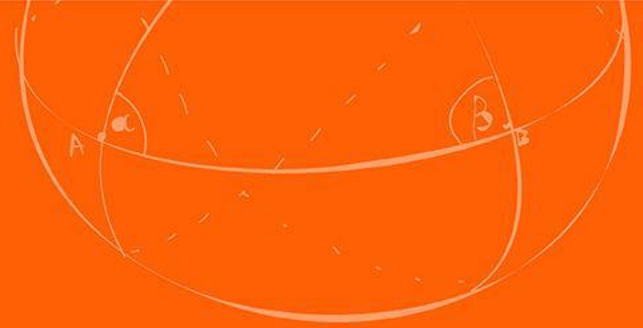
System Design

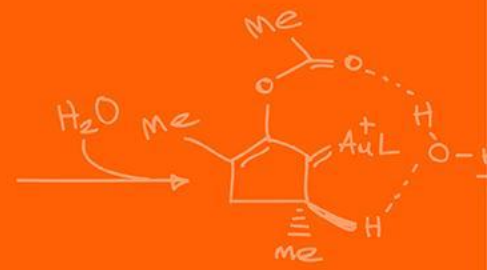


Functional Requirements

- **FSR Array:** 8–16 pressure sensors across heel, midfoot, and forefoot. Each sensor reads ~5000 Ω under 10 N ± 0.5 N load. Joints withstand ≥100 flex cycles at 45°
- **Analog Front-End**: Sample all channels concurrently at ≥100 Hz with sufficient resolution to track gradual pressure shifts.
- **MCU**: Stream sensor data at ≥100 Hz per channel via BLE with ≥95% packet delivery at 5 m. Sustain operation for ≥1 hour without reset or data stall.
- **Power**: Charge at 200 ± 5 mA via USB-C. Maintain stable 3.3 V. Support ≥1 hour runtime.
- **App**: Decode BLE packets per channel without corruption. Display live data with no perceptible lag. Compute cadence within ±3 SPM of reference.

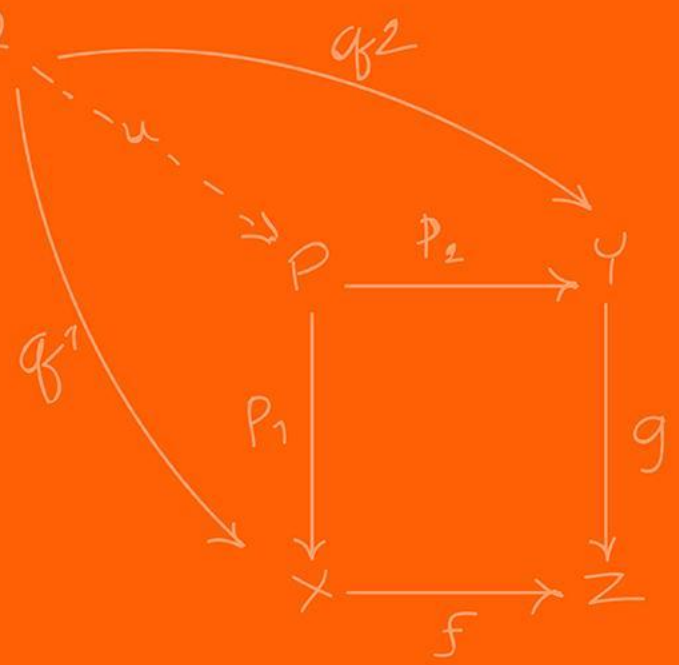






Implementation

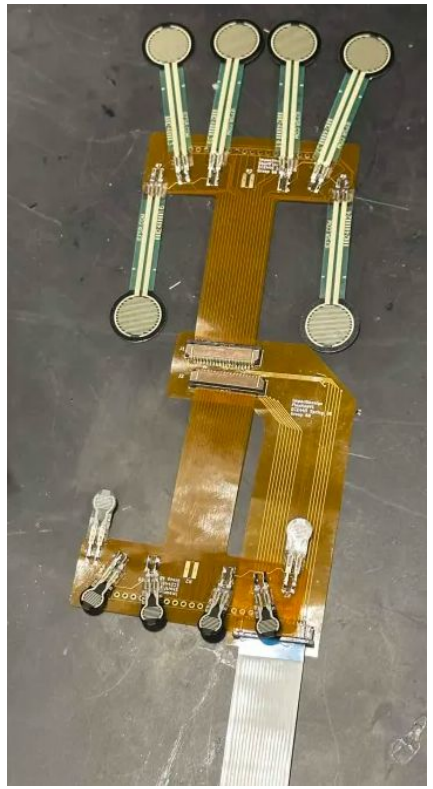
PCB Design, Physical Build, Software App

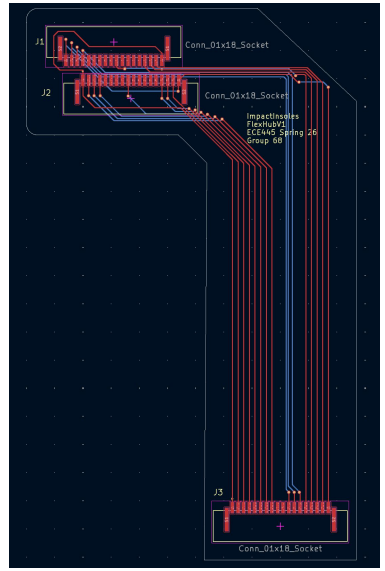


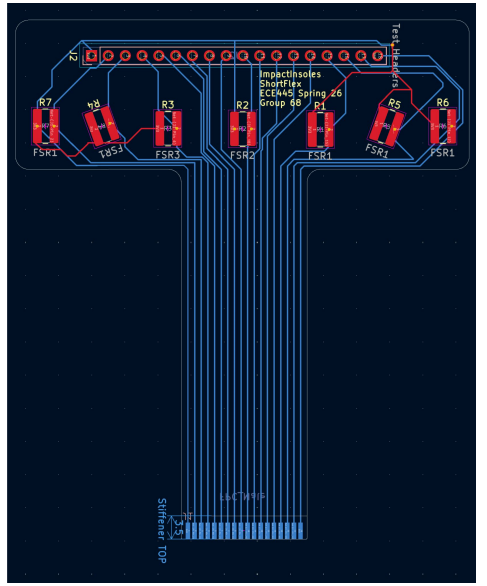
Sensor Array Fabrication

Pressure Sensor Array

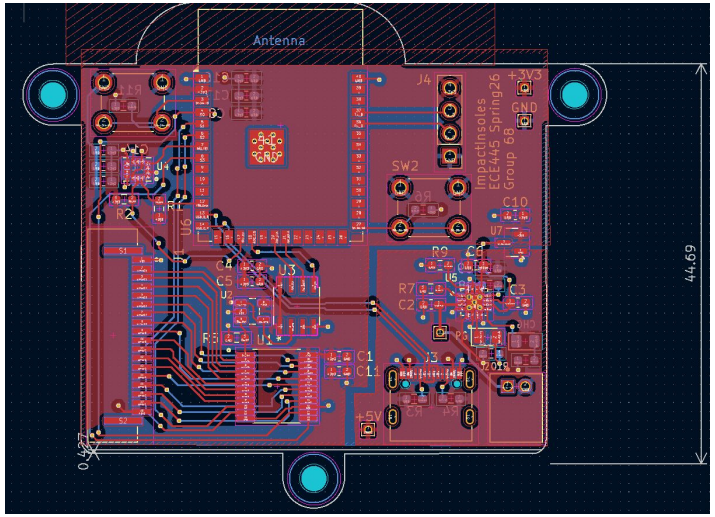
- 6/6 Interlink FSR400/402
  - Reduced from original 16 to simplify routing and match insole geometry
- FSRs arranged across heel, midfoot, and forefoot zones on a flexible PCB
- Each FSR forms a voltage divider
  - Resistance drops with applied force, read by ADC
- 2 symmetrical sensor PI Flex PCB hubs connected to output hub
  - Lower cost versus full insole PCB
  - Amphenol Female SFW18R-1STE1LF 1mm pitch, 18 pin

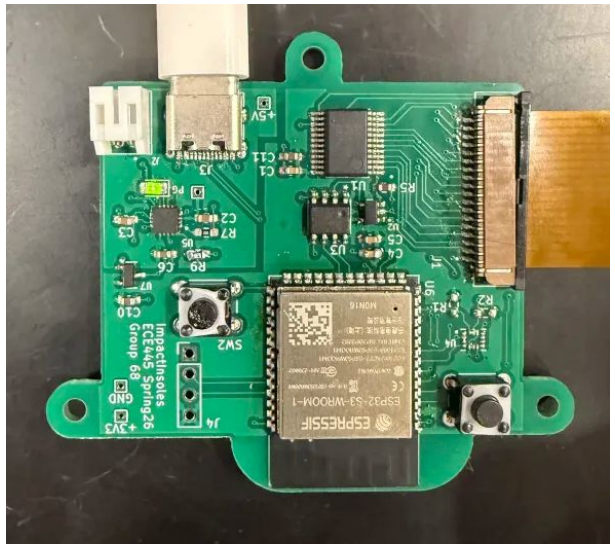






PCB Layout & Fabrication





Final PCB Layout

- 2-layer PCB KiCad design ~50 mm x 50 mm
- Components: ESP32-C3, CD74HC4067 MUX, BQ24075 PMIC, USB-C, JST battery connector
- Status LEDs, reset/boot buttons, programming headers, and BLE antenna keep-out zone

Hard PCB Bring Up

- Optimized for size to ensure ability to be put on the side of the shoe
- Used oven for soldering surface mount devices, especially the BMS IC with a QFN package

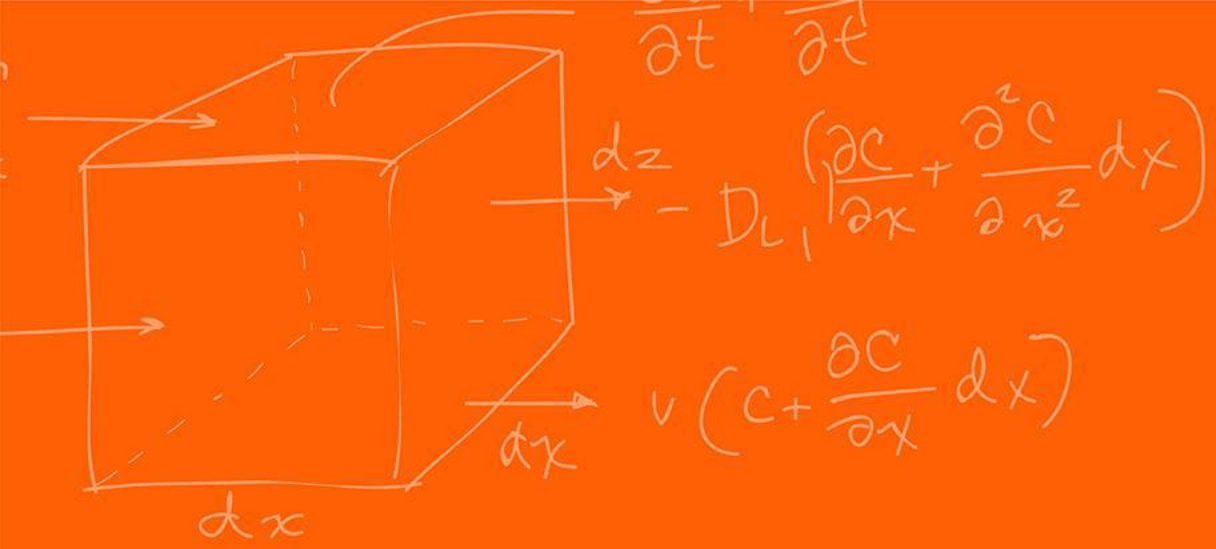
Phone App & Demo

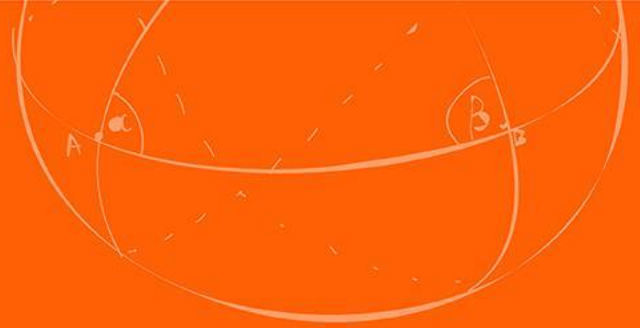
Web App Interface

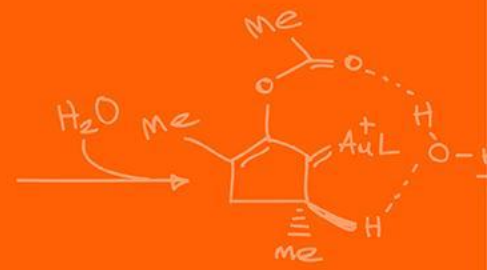
- Browser-based dashboard using Web Bluetooth API
- Live foot pressure heatmap rendered on insole silhouette
- Cadence (SPM), foot-strike events, and packet counter shown live
- Session recording feature showing averages of data collected

Data Flow & Packet Structure

- 28-byte BLE packets:
  - 12 × 2-byte sensor values (12 bit raw ADC value)
  - 4-byte counter (for packet counting)
- Packet loss monitored via sequence number gaps
- 100 Hz stream = ~2.8 kB/s, well within BLE 4.2 limits

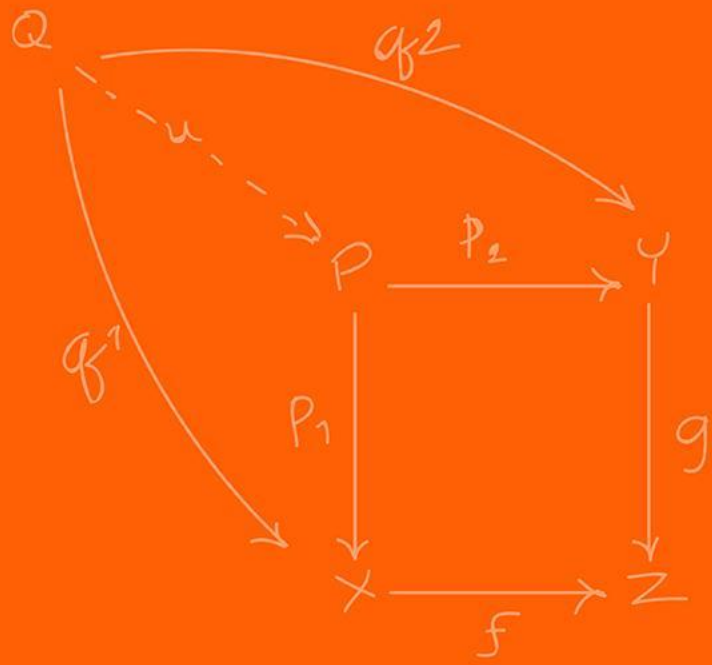






Results

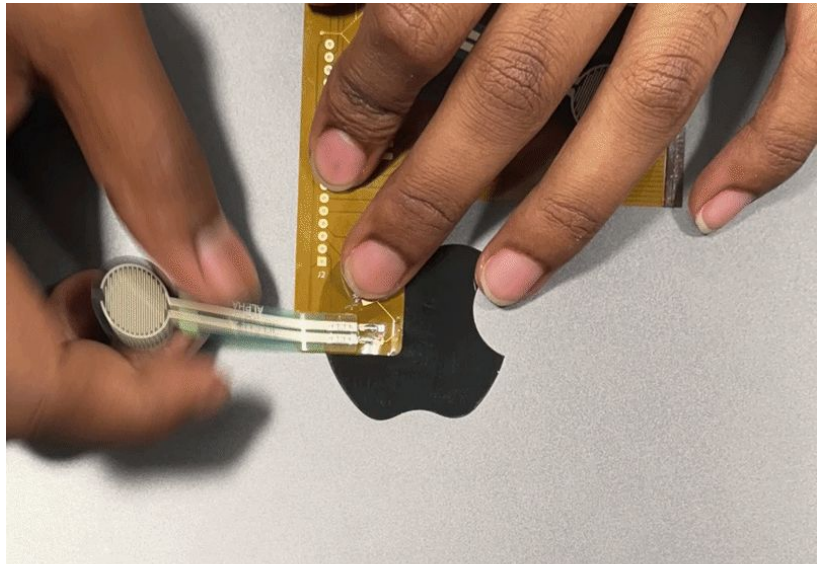
Successes and Challenges

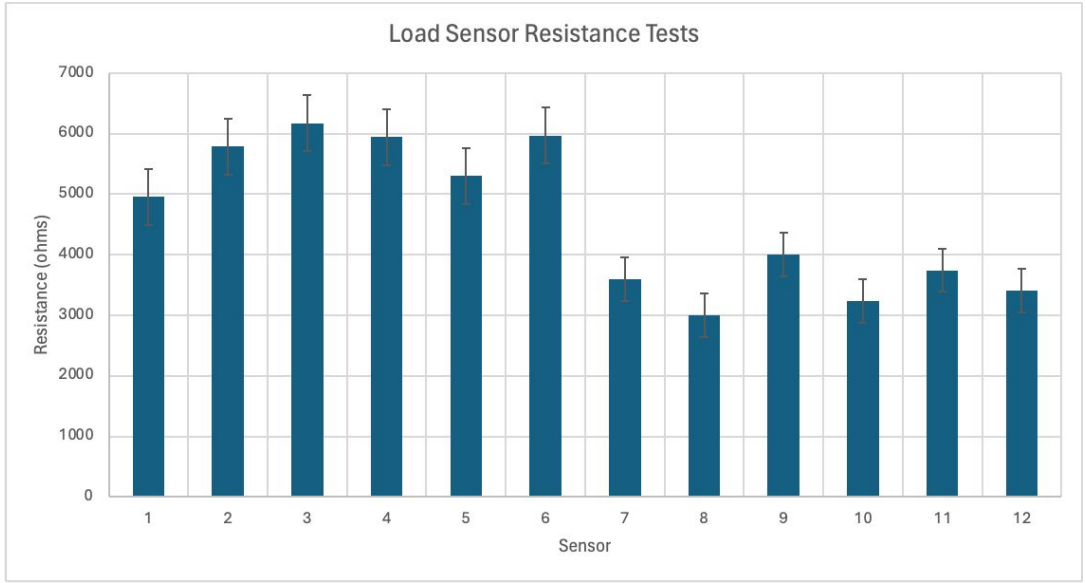


Pressure Sensor Array

Functional Test Results

- All 12 sensors transmit data to the ADC
- Repeated load measurements within software-correctable margins
  - FSR 400 - Mean 5686 Ω, SD 463 Ω
  - FSR 402 - Mean 3497 Ω, SD 359 Ω
- Artificial flex cycle (45°) and real-world stress test passed

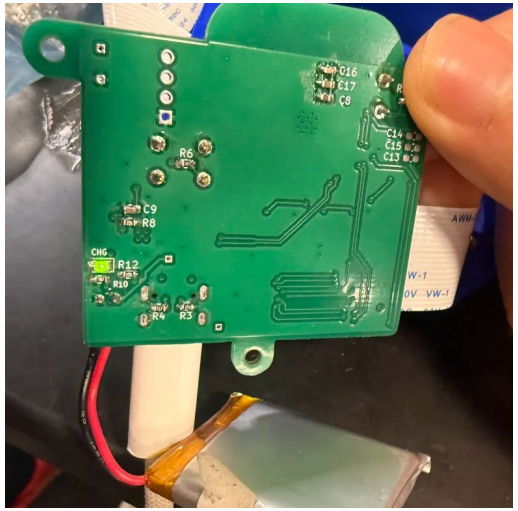


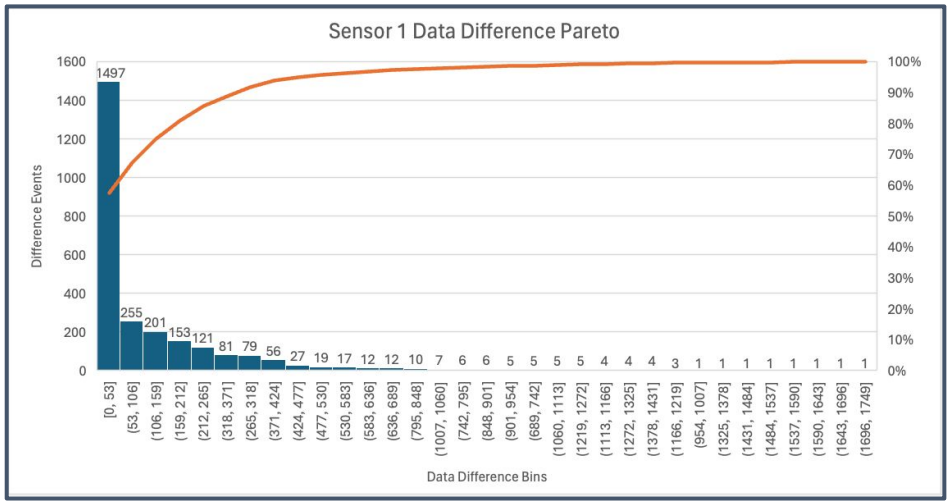


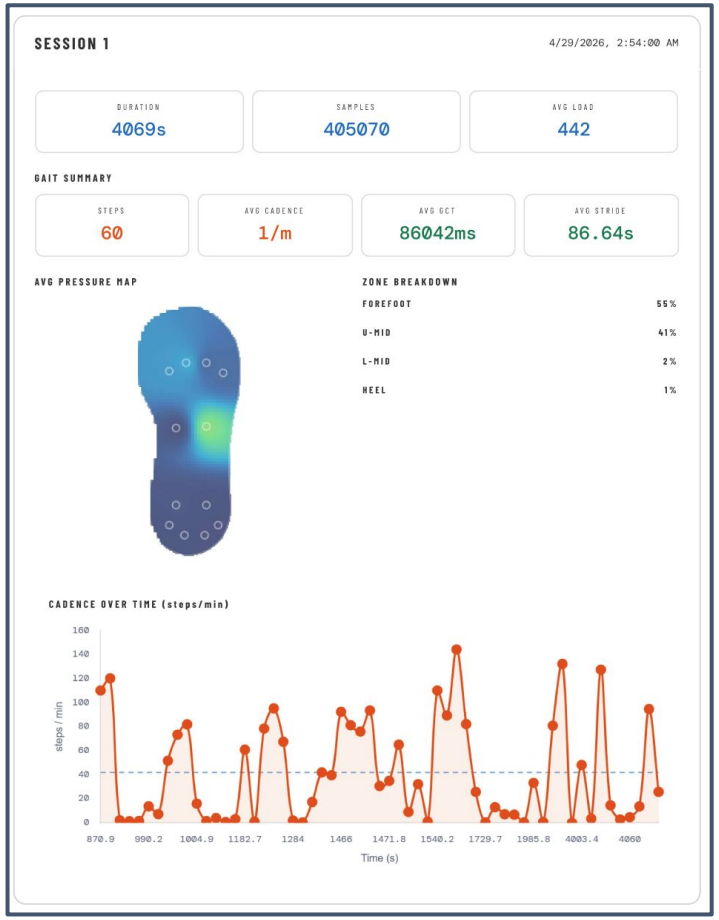
Hard PCB and Data Transmission

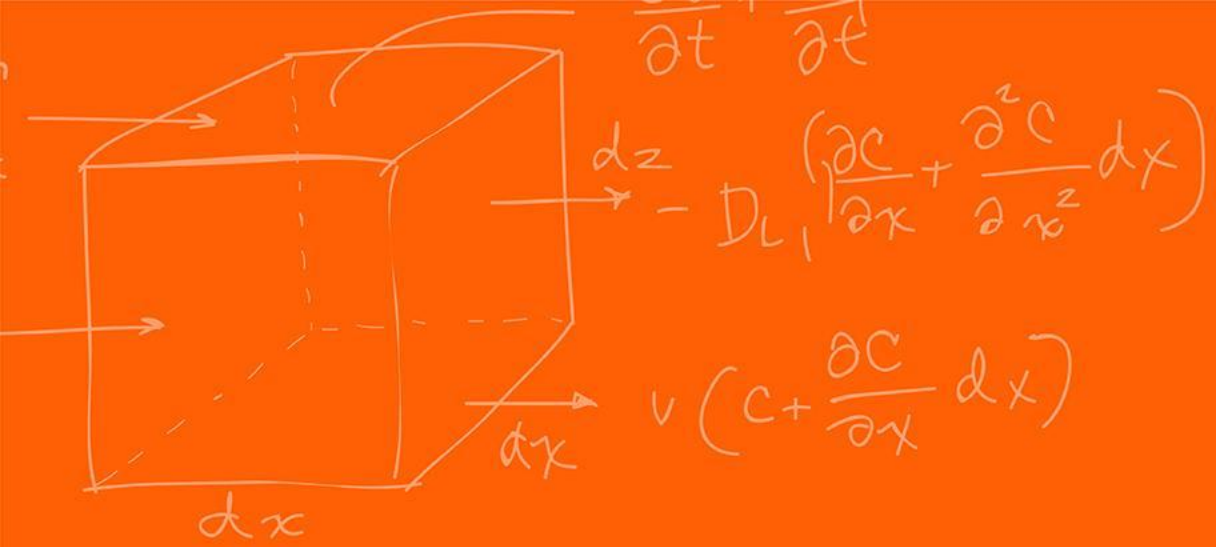
Functional Test Results

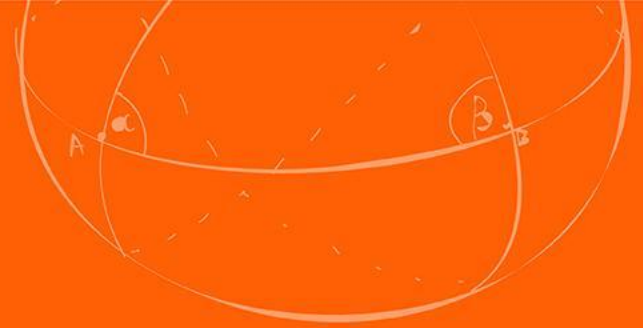
- ESP32-C3 programs successfully over USB-C with reset/boot buttons
- Power management IC charges LiPo and regulates 3.3V rail; 1-hour battery target met
- BLE advertising confirmed with smartphone, connects reliably within 1 m
- FSR voltage divider outputs respond correctly to applied pressure across all sensor zones
- MUX channel selection verified with UI Display
- 100 Hz sampling rate and <5% packet loss requirement met during BLE streaming test

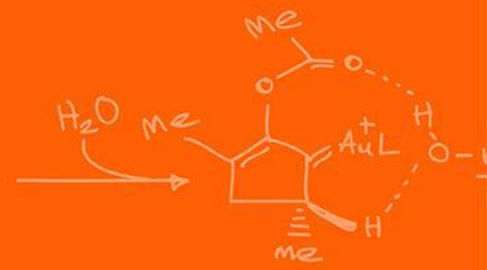






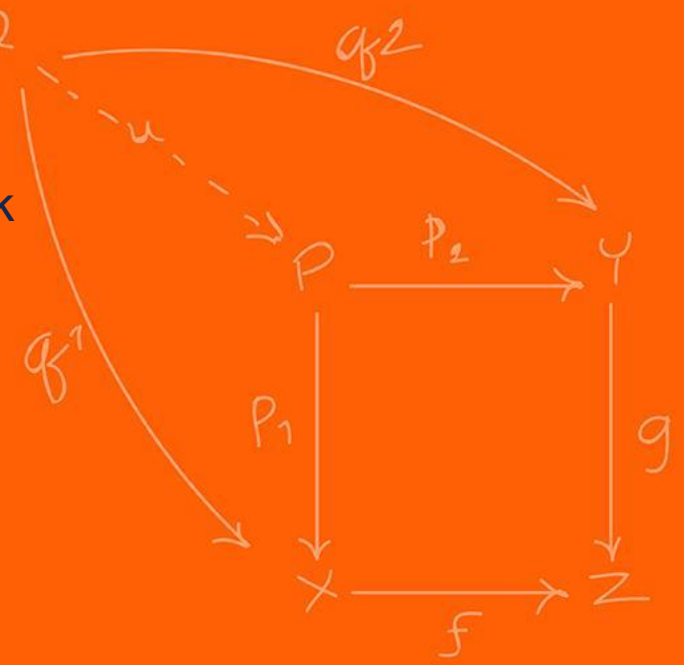






Conclusion

Ethical Issues, Recommendations for Future Work



Conclusions

Ethical Considerations

- User health data stored locally; not shared without consent (IEEE Code of Ethics)
- Device is not FDA-cleared - marketed as a training aid, not a medical diagnostic

What We Learned

- Mechanical constraints (FPC routing, shoe geometry) drive PCB layout
- Verify every footprint against the manufacturer datasheet
- Firmware and hardware bugs often look identical - isolate with scope first

What We Would Do Differently

- Plan FPC cable routing and PCB placement before finalizing board dimensions
- Verify every connector footprint against the manufacturer datasheet before ordering
- Include test points on every critical net to speed up debugging
- Order spare FPC connectors and FSRs early to allow rework without waiting on parts

Recommendations for Further Work

- **Miniaturization**: Streamline main PCB to make it seamless when attached on the shoe
- **AI Gait Analysis**: Give feedback to the user based on the data taken
- **Bilateral Sensing**: stream both feet simultaneously for complete running statistics
- **Clinical Validation:** Partner with professionals to validate against gold-standard gait lab equipment
- **Power Optimization**: Explore longer-life battery configurations for multi-hour sessions

Thank You

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