IoT Based Smart Sock for Foot Health Monitoring Early Foot Ulcer Detection

22AIE211 INTRODUCTION TO COMMUNICATION IoT

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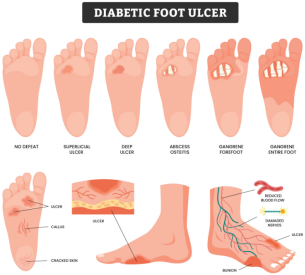
What is a Diabetic Foot Ulcer?

- A Diabetic Foot Ulcer (DFU) is an open wound that develops on the foot of a person with long term diabetes
- It occurs mainly due to nerve damage (diabetic neuropathy) and poor blood circulation
- Loss of sensation prevents patients from noticing minor cuts or injuries
- Over time, these untreated injuries develop into ulcers
- If not detected early, DFUs can lead to infection or amputation



Factors Influencing Diabetic Foot Ulcers

- **Temperature:** Local increase in foot temperature indicates inflammation and early tissue damage
- **Plantar Pressure:** Continuous high pressure on specific foot regions causes skin breakdown
- **Gait Pattern:** Abnormal walking patterns lead to uneven pressure distribution
- **Blood Oxygen Level:** Reduced oxygen supply delays healing and increases ulcer risk
- Monitoring these parameters enables early detection of ulcer formation

Smart Sock System

What Are We Doing?

- We propose a smart wearable sock to continuously monitor foot health in diabetic patients
- The sock contains multiple sensors placed at critical regions of the foot

How the System Works

- Sensors measure temperature, pressure, gait movement, and blood oxygen level
- Sensor data is collected by an ESP32 microcontroller embedded in the sock
- Data is transmitted wirelessly using Bluetooth Low Energy (BLE)
- A mobile application displays the data and alerts the user if abnormal conditions are detected

Objectives

- To design and develop a smart wearable sock capable of monitoring foot health parameters in diabetic patients.
- To collect plantar pressure, foot motion, and blood oxygen data using integrated sensors.
- To wirelessly transmit sensor data to a Flutter-based mobile application using BLE.
- To store and manage data securely using Firebase / Firestore with real-time visualization.
- To predict diabetic foot ulcer risk using on-device machine learning (TensorFlow Lite) and provide early warnings.

Literature Survey

S No	Paper Name	Methodology	Contributions	Year
1	Smart Compression Sock for Early Detection of Diabetic Foot Ulcers	A smart compression sock with temperature, pressure & blood oxygen sensors that transmit real time data to a mobile app via an ESP32.	A novel wearable sock monitors (SpO_2, pressure, temperature) for early diabetic foot ulcer detection, addressing a gap in current single-sensor market solutions	2024
2	Diabetic Socks for Foot Ulcer Prediction and Monitoring	The proposed system integrates an ESP8266 with temperature sensors, pulse sensors & vibration motors in socks to monitor foot sensitivity, temperature, heart rate.	A low-cost, non-invasive wearable solution that uses vibration motors for sensitivity testing to predict diabetic foot ulcers.	2025
3	Automatic Diabetic Foot Ulcer Recognition Using Multi-Level Thermographic Image Data	The study utilizes plantar thermogram data at image, patch, combined levels to train and evaluate machine learning classifiers (SVM, RF, etc.).	A custom CNN model that outperforms state of the art and pre trained models, achieving 97% accuracy and 0.976 AUC in diabetic foot ulcer recognition.	2023

Literature Survey

S No	Paper Name	Methodology	Contributions	Year
4	The role of foot pressure measurement in the prediction and prevention of diabetic foot ulceration A comprehensive review	Uses In-shoe plantar pressure measurement techniques to measure shear stress and daily activity patterns.	Continuous monitoring of cumulative pressure using smart feedback devices offers a more accurate strategy for DFU prevention	2019
5	An Evaluation of Real world Smart Sock–Based Temperature Monitoring Data as a Physiological Indicator of Early Diabetic Foot Injury	The researchers analyzed the data to determine if temperature differences and variability between affected and unaffected feet could distinguish active foot injuries from remission.	It provides clinical evidence supporting the use of wearable remote monitoring technology to prevent diabetic foot ulcer recurrence and improve patient outcomes.	2022
6	Diabetic foot ulcer mobile detection system using smart phone thermal camera: a feasibility study	A smartphone-connected thermal camera to capture foot thermograms, to analyze thresholding and point-to-point mean difference techniques on the MATLAB Mobile platform.	The system detects temperature asymmetries greater than 2.2°C, a clinical indicator of potential ulceration for preventative home monitoring without continuous clinical supervision.	2017

Problem Statement

- Diabetic patients often lack foot sensation, causing early injuries to go unnoticed and progress into ulcers.
- Current foot care relies on manual checks or hospital visits, which do not provide continuous monitoring.
- Key risk factors such as high pressure, low blood oxygen, and abnormal gait are not jointly monitored in low cost systems.
- Threshold based methods can delay detection and fail to capture gradual ulcer development.
- A low cost wearable system with intelligent early risk prediction is needed to prevent severe complications and amputations.

Why is this Problem Important?

- Diabetic foot ulcers are a leading cause of lower-limb amputations worldwide.
- Late detection results in higher medical costs and long recovery times.
- Continuous monitoring can significantly reduce complications through early intervention.
- Early alerts improve patient self-care and reduce hospital dependency.
- Affordable wearable solutions can increase access to preventive healthcare.

Scope

- Design of a smart sock prototype with pressure, SpO_2, and IMU sensors.
- Real time data acquisition using ESP32 and Bluetooth Low Energy (BLE).
- Mobile application for live data display and risk alerts.
- Cloud storage of sensor data using Firebase.
- Machine learning based ulcer risk prediction using sensor features.

Key Deliverables / Milestones (Current Phase)

Completed

- Implemented ESP32-based hardware setup with BLE for wireless sensor data transmission (all sensors integrated except temperature).
- Developed a base Flutter application to read, visualize sensor data, and perform threshold-based foot risk prediction.
- Defined the overall system architecture and end-to-end data flow.

Upcoming

- Actual BLE data integration with the Flutter mobile application.
- Firebase Authentication and Firestore integration for secure data storage.
- On-device ML model integration in Flutter using TensorFlow Lite.

End-of-Phase Outcome

- Functional prototype enabling reliable sensor data collection and wireless communication.
- Strong foundation for ML-based foot ulcer risk prediction and alert generation.

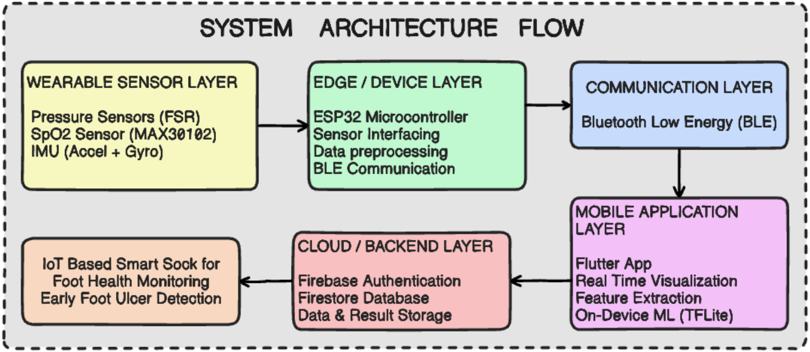
Methodology (Proposed Approach)

- The project follows a sensor driven IoT and machine learning–based methodology for early detection of diabetic foot ulcers.
- Multiple physiological and motion parameters are continuously monitored using wearable sensors embedded in a smart sock.
- Sensor data is transmitted wirelessly to a mobile application using Bluetooth Low Energy (BLE).
- Machine learning techniques are applied to analyze patterns in the collected data and predict ulcer risk.
- The system provides real-time risk assessment and early warnings to the user.

Core Concept

Combine wearable sensing + mobile computing + machine learning + cloud data management (Firebase/Firestore) to move from threshold-based detection to intelligent, real-time prediction with offline support.

System Architecture



Our Demo Video

Tools, Technologies & Techniques Used

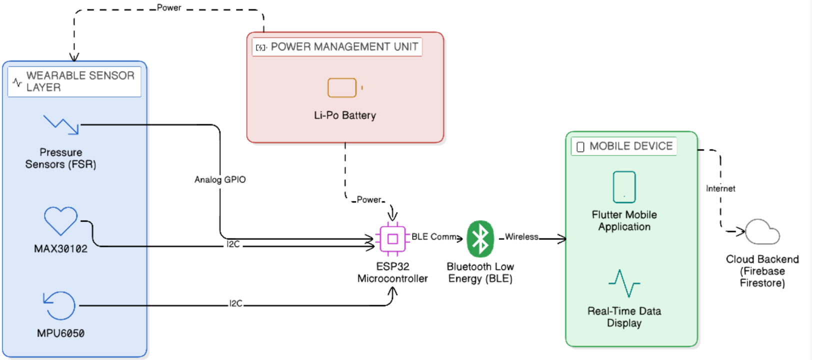
Hardware Technologies

- ESP32 microcontroller – sensor interfacing and BLE communication
- FSR-402 pressure sensors – plantar pressure measurement
- MAX30102 sensor – blood oxygen (SpO_2) and heart rate monitoring
- MPU6050 IMU – gait and foot movement analysis
- Li-Po battery + TP4056 – portable power supply

Software & Frameworks

- Flutter – cross-platform mobile application development
- Firebase Authentication – user identity management
- Firebase Firestore – cloud-based data storage
- TensorFlow Lite – on-device machine learning inference
- Arduino IDE – ESP32 firmware development

Hardware Flow Diagram



End-to-End Methodology Workflow

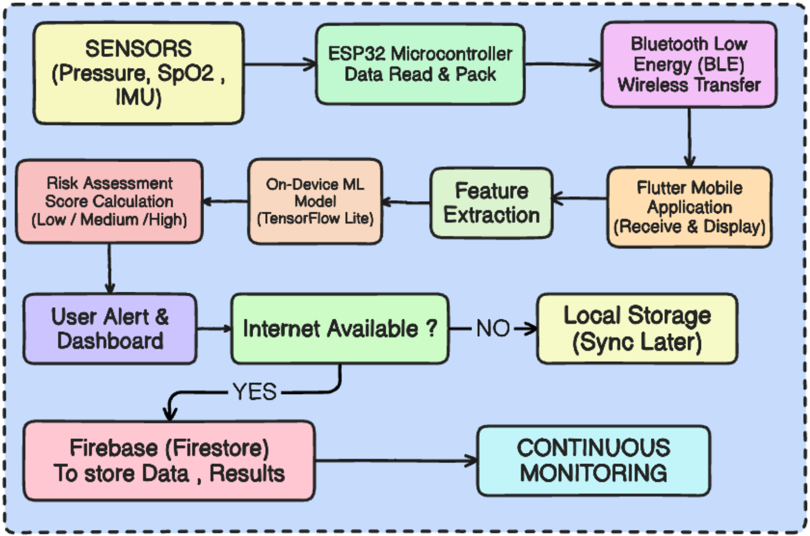
System Workflow

1. Sensors in the smart sock collect pressure, motion, and blood oxygen data.
2. ESP32 processes sensor data and sends it to the mobile device using Bluetooth Low Energy (BLE).
3. Flutter mobile application receives data and shows real-time visualization.
4. Sensor data is stored in Firebase Firestore when internet connectivity is available.
5. A TensorFlow Lite ML model inside the app analyzes sensor features.
6. The model predicts diabetic foot ulcer risk level in real time.
7. Risk score and alerts are displayed and synced to Firebase when online.

Methodological Advantage

- Offline support using on-device machine learning.
- Real-time prediction without internet dependency.

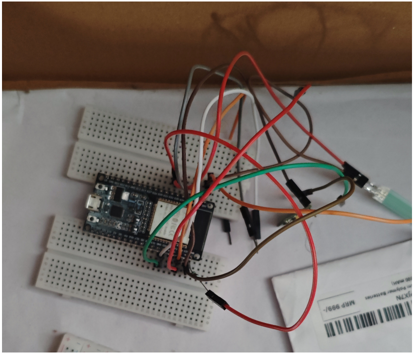
Process Flow Diagram



Progress So Far – Hardware Development

Progress

- ESP32-based hardware prototype with BLE support for wireless communication.
- Integration of multiple foot related sensors for data acquisition *(temperature sensor not included at this stage)*.
- Initial validation of BLE data transmission and hardware stability using nRF Connect with raw sensor data.

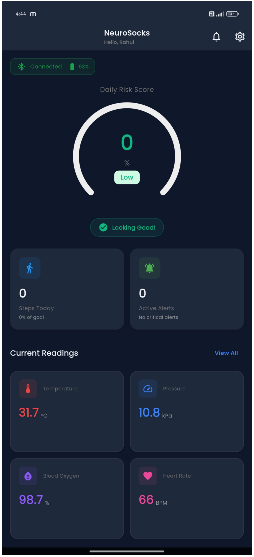


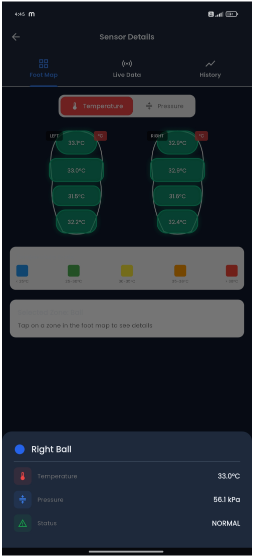
Visual Evidence

- Hardware prototype showing ESP32, sensor connections, and BLE setup.

Progress So Far – Software & BLE Mock Integration

- Flutter mobile application developed with Bluetooth Low Energy (BLE) support.
- BLE connection status implemented using a mock interface (always connected state).
- Sensor readings (pressure, blood oxygen, etc.) generated as mock data for UI and flow validation.
- Real time visualization of mock sensor values within the mobile application, with user specific.





Challenges and Risks

- No suitable numerical datasets: Most available datasets are image-based (ulcer photos), not sensor time-series (pressure, motion, SpO_2).
- Lack of labeled risk data: Clinical labels like pre-ulcer or risk level are difficult to obtain without medical validation.
- Low data diversity: Small or synthetic datasets may not represent different users and gait patterns, reducing generalization.
- Sensor–dataset mismatch: Public datasets may not match the prototype's sensors, requiring extra feature engineering and preprocessing.

Next Steps

- Collect real sensor data from the prototype to build a small numerical training dataset.
- Extract meaningful features (pressure peaks, gait stability, SpO_2 trends) for better model learning.
- Train and validate ML model offline using Python and convert it to TensorFlow Lite format.
- Integrate the ML model into the Flutter app for real-time, on-device risk prediction.

Conclusion and Summary

- Developed a smart wearable sock using multi-sensor data and AI for early ulcer risk prediction.
- Machine learning detects subtle abnormal patterns beyond fixed thresholds.
- Multi sensor fusion (pressure, SpO_2 , motion) improves accuracy and reliability.
- Generates personalized risk scores based on individual behavior.
- Activity aware and trend-based monitoring enables proactive prevention before ulcers form.

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QA's

Questions and Answers