Embedded Systems Super Thesis Project: Storage Locker Monitoring

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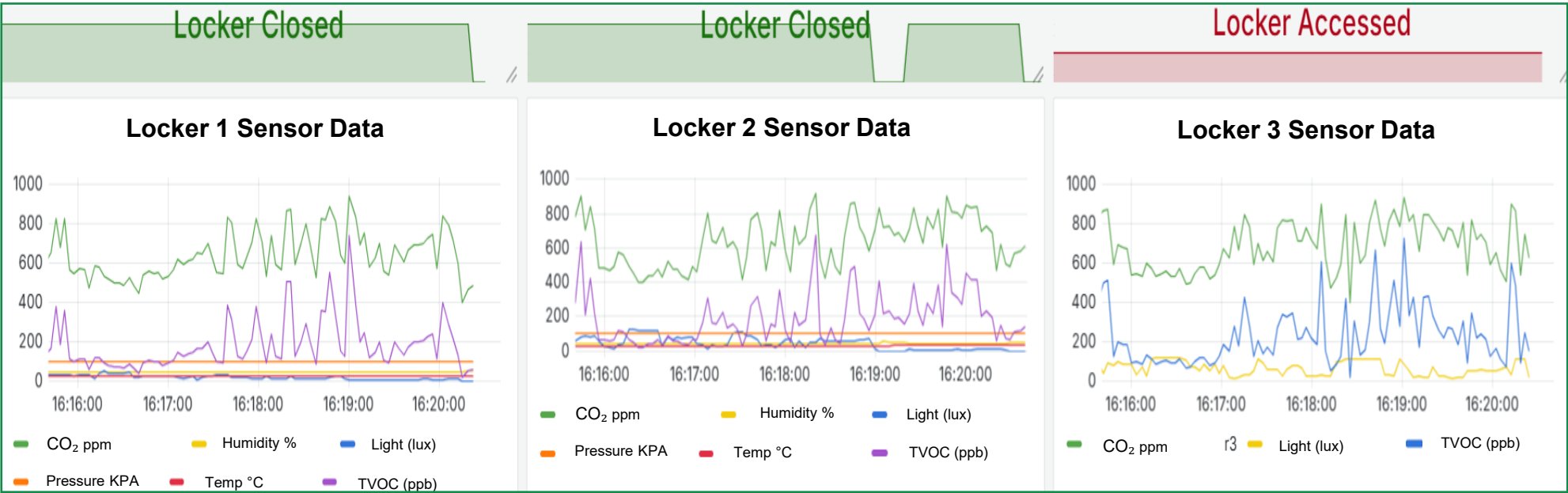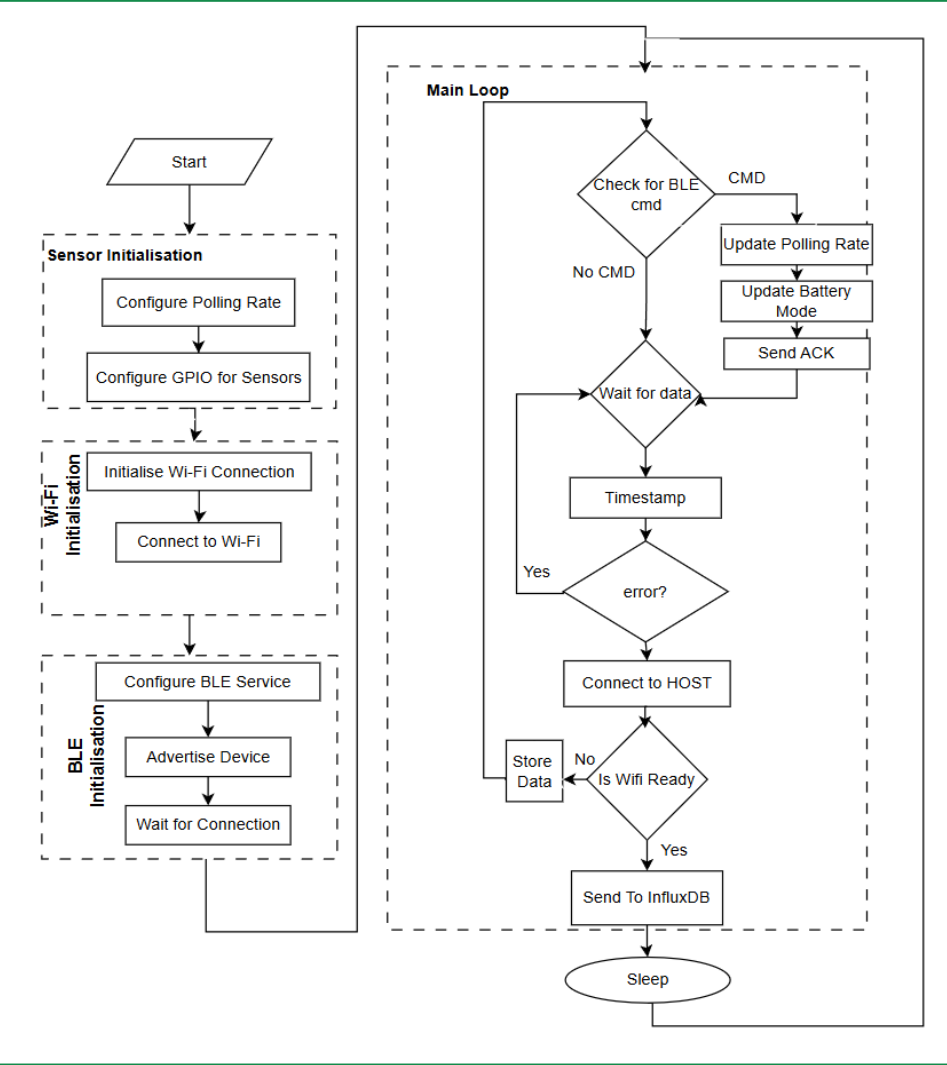
Introduction

Storage lockers are widely used for secure storage in workplaces, universities, and parcel delivery systems, but current monitoring methods are costly and ineffective at detecting unauthorised access or environmental risks.

This project develops a wireless, low-power locker monitoring system using sensors for temperature, humidity, pressure, CO_2, TVOC and light to detect access events and track climatic conditions.

Data is transmitted via Wi-Fi to a web dashboard, with Bluetooth diagnostics, and machine learning used for intelligent access detection.

Figure 1: Firmware Flow Chart

Locker Closed   **Locker Closed**   **Locker Accessed**

Locker 1 Sensor Data

- CO₂ ppm
- Humidity %
- Light (lux)
- Pressure KPA
- Temp °C
- TVOC (ppb)

Locker 2 Sensor Data

- CO₂ ppm
- Humidity %
- Light (lux)
- Pressure KPA
- Temp °C
- TVOC (ppb)

Locker 3 Sensor Data

- CO₂ ppm
- r3
- Light (lux)
- TVOC (ppb)

Web Dashboard with Access Detection

Results

Locker Monitoring System Key Features

- Accurate Access Detection using K-means clustering algorithm within 1s of locker state changing
- Deep sleep mode enables 4+ months of battery operation
- Data transmitted to InfluxDB and visualised in Grafana dashboard over Wi-Fi
- BLE Control using the Adafruit Bluefruit App
- 5 different Sampling modes and 3 different power modes with the ability for more to be added in future
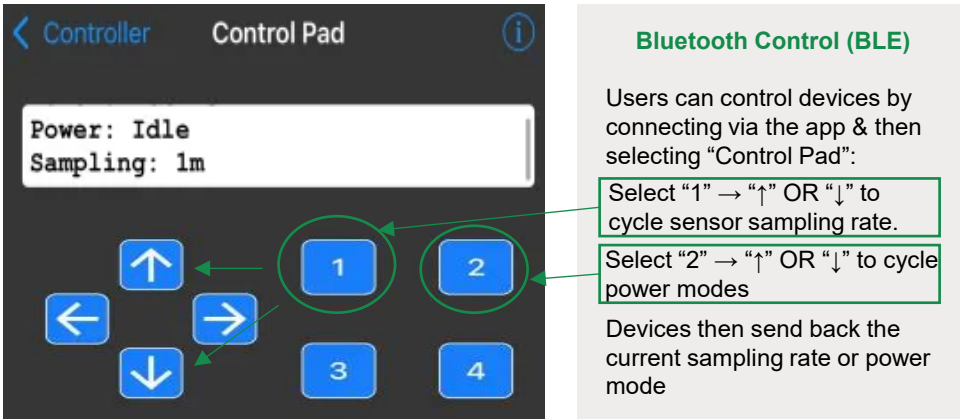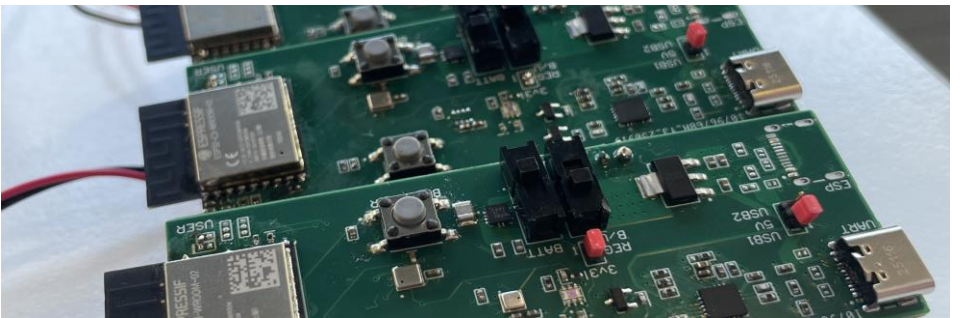- One sensor platform costs $60 with further possibility of cost reduction

Figure 3: Sensor Platforms

Component Choice

- **Core Controller:** Custom PCB with ESP32-C3-MINI-1-N4, a low-power RISC-V MCU supporting Wi-Fi, BLE 5.0 and Zephyr RTOS, providing efficient processing for ML inference and low-power operation.
- **Sensors:** BME280 (temperature, humidity, pressure), ENS160 (air quality), and OPT3001 (light). Selected for fast response, high accuracy, and Zephyr driver support.
- **Data Processing & ML:** Periodic sensor readings are processed locally and analysed using K-means clustering to detect locker access events from environmental anomalies.
- **Connectivity & Interface:** Sensor data transmitted via Wi-Fi to an InfluxDB server, using Grafana for visualisation on a web dashboard, with BLE interface allowing configuration of the devices.
- **Power System:** Powered by two 1.5V AA cells, chosen for cost-effectiveness and stable voltage

Control Pad

Power: Idle
Sampling: 1m

Bluetooth Control (BLE)

Users can control devices by connecting via the app & then selecting "Control Pad":

Select "1" → "↑" OR "↓" to cycle sensor sampling rate.

Select "2" → "↑" OR "↓" to cycle power modes

Devices then send back the current sampling rate or power mode

Figure 2: BLE Control interface

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