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SSNS - Final Project Presentation

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Final Presentation - Application Overview

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Problem:

- Indoor air pollution significantly affects health—especially in poorly ventilated spaces. It can:
  - Lead to fatigue, reduced cognitive performance for a normal person
  - Serious short/long term respiratory issues in sensitive groups like children, the elderly and asthmatic patients

Our Goal/Solution:

- Build a scalable, adaptable IAQ monitoring system prototype, suitable for settings like healthcare, workplaces, and safety-critical environments.
- Can be tailored for:
  - Healthcare (asthmatic/sensitive patients/hospitals)
  - Schools / Offices
  - High-risk zones: Labs, factories, control rooms etc

Key Features

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- Real-Time Web-Dashboard (live sensor data)
- 24 Hour Data Visualization with Key Insights (can be tailored for any type of environment)
- Alert System based on guidelines by WHO, ASHREA, EPA, RESET, WELL
- **Basic Error Diagnosis & Fault Tolerance**
  - Independent sensor handling: one failure doesn't affect the other
  - Fault indication sent to server on pin/config errors
- **Sensor Data Validation**
  - Discards invalid readings (zeros or out-of-range values)
  - Collects 3 readings per minute $\rightarrow$ computes average, to minimize random measuring errors
- Mesh-based Thread network enables auto-rejoining of sensor nodes after failure and allows easy scalability with additional nodes.

Hardware Architecture

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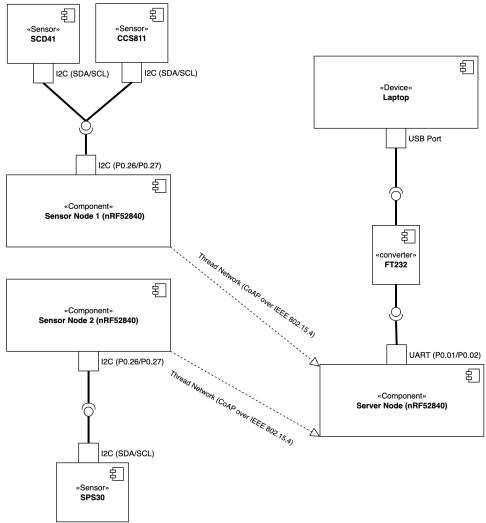
The setup includes:

- 3x nRF 52840 Development Kits
- Sensors:
  - SCD41 - CO2, Temperature, Humidity
  - CCS811 - TVOC, Equivilent CO2 (eCO2)
  - SPS30 - Particulate Matter (PM1.0, 2.5, 10)
- FT232 - USB to serial UART interface
- Laptop

Hardware Architecture - Component Diagram



Software Architecture - Overview

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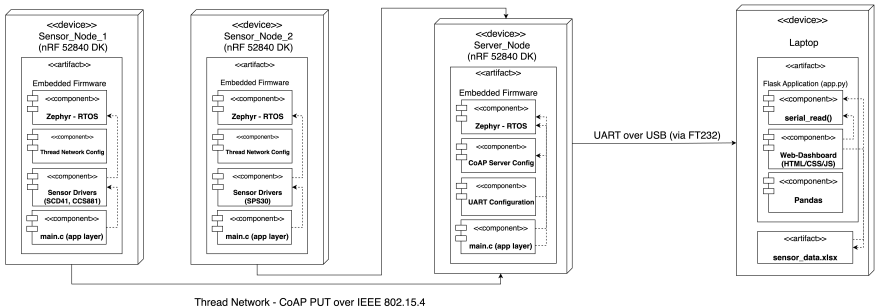
- **Sensor Nodes**:
  - Runs on Zephyr RTOS
  - Read data via I2C from SCD41, CCS811, SPS30
  - Format sensor readings into JSON
  - Send JSON formatted data in string data type to Server via CoAP PUT (Thread Network)
- **Server Node**:
  - Acts as CoAP Server
  - Sends raw JSON over UART (FT232) to laptop
- **Laptop (Host)**:
  - Runs Web Dashboard using Flask Application
  - Reads data from Serial Comms via FT232
  - Logs data into Excel and Updates real-time dashboard (HTML/CSS/JS)
  - Renders 24-hour IAQI stats

Software Architecture - Deployment Diagram



Network Architecture

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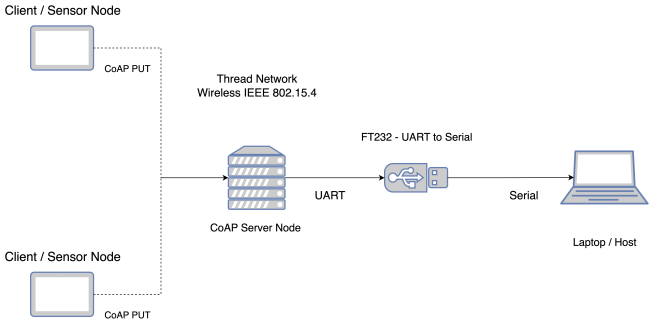
Sensor Nodes to Server Node:

- Communication is established over Thread Network based on IEEE 802.15.4 (Low-power wireless).
- Sensor Nodes send data to the Server Node using CoAP (Constrained Application Protocol).
- Data is transmitted as CoAP PUT requests to a fixed IPv6 address.

Server Node to Laptop:

- Server Node forwards received data to the Laptop using FT232 UART to USB.
- This link uses serial communication, providing a bridge between embedded system and the data logging/visualization layer.

Network Architecture - Network Diagram



System Behavior - Use Case Diagram

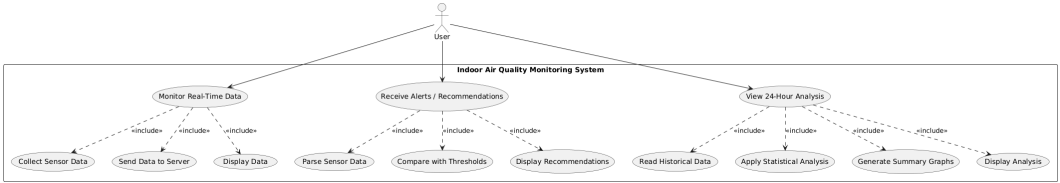


Figure: System Use Case Diagram

Sequence Diagram - Monitor Real Time Data

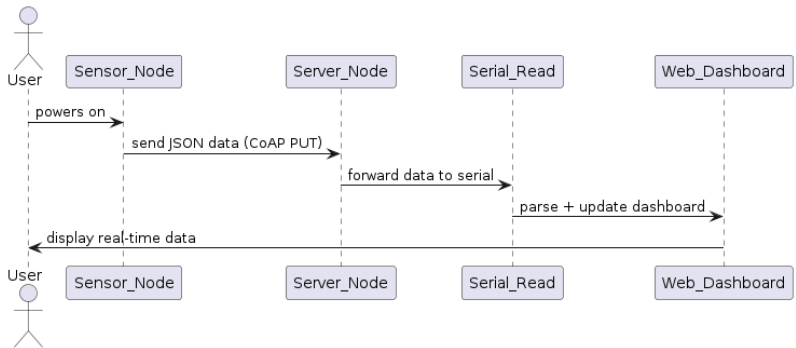


Figure: Monitor Real-Time Data

Sequence Diagram - Receive Recommendation/Alert

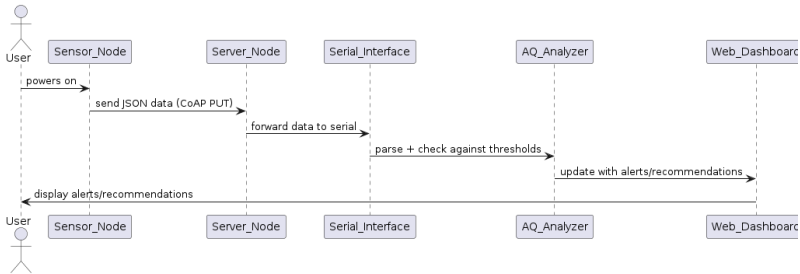


Figure: Receive Recommendation/Alerts

Sequence Diagram - View 24 Hour Analysis

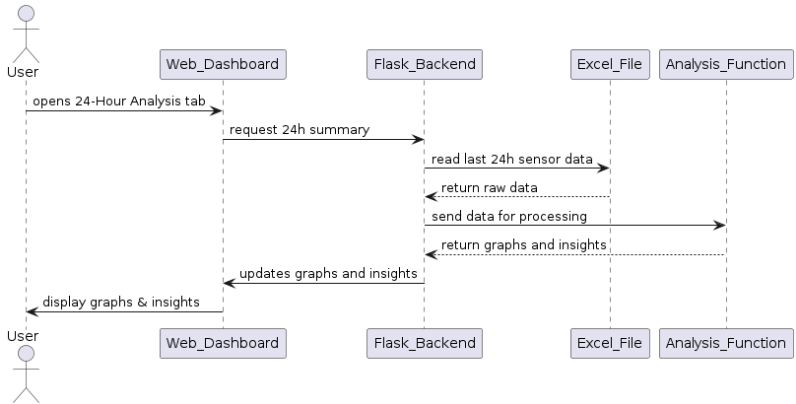


Figure: View 24 Hour Analysis

Toolchain

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Following tools were used for the development:

- **nRF Connect SDK v2.6.2**: Firmware Development for nRF 52840 DK
- **VS Code**: Firmware Development and Web-Dashboard development
- **Git/GitHub**: Version controlling and Code Maintenance
- **Python v3.13.3 (Pandas, Flask)**: Web Dashboard, Statistical Analysis
- **HTML/CSS/JS**: Frontend for Web-Dashboard
- **Flask**: Backend for Web-Dashboard
- **MS Excel**: Data logging, Data Filtering, Data Visualization

Demo

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- Development Setup
- Live Demo

Reliability

The setup was tested continuously for:

- 2x 12 Hours Data Acquisition
- 1x 24 Hours Data Acquisition

The setup worked continuously without causing any issue, except for:

- CCS811 stopped working both times in 2x 12 Hours Data Acquisition, rebooting the DK fixed the issue.

Data Acquisition and Statistical Analysis

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Data Acquisition Environment:

- Private Room
- **Duration**: 24 Hours (12.00 - 12.00)
- **Sampling Rate**: Collect 3 times every 15 seconds and average it - send to server after every 1 Minute
- **Ventilation**: via Tilted/Opened Window
- **Outdoor Weather**: Hot Sunny Day with Max 31°C

Data Acquisition

Time	Activity Description	Window Status
12:00	Monitoring started	Tilted
12:50	Sprayed deodorant	Tilted
13:12	Hung washed clothes to dry	Tilted
19:16	Left room	Closed
19:23	Briefly returned and left again	Closed
19:45	Brought dinner and consumed	Tilted
20:15	Felt hot, fully opened window	Open
22:00	Cleaned room using a brush	Open
23:30	Went to sleep	Tilted
03:50	Woke up and fully opened window	Open
04:05	Went back to sleep	Tilted
07:30	Woke up and resumed activity	Tilted
08:15	Went to kitchen for Breakfast	Tilted
09:05	Returned to room and resumed work	Tilted
10:05	Felt hot, fully opened window	Open
11:00	Sprayed deodorant	Open
12:00	Monitoring Stopped	Open

Figure: Activity Table

Statistical Analysis for Anomaly Detection

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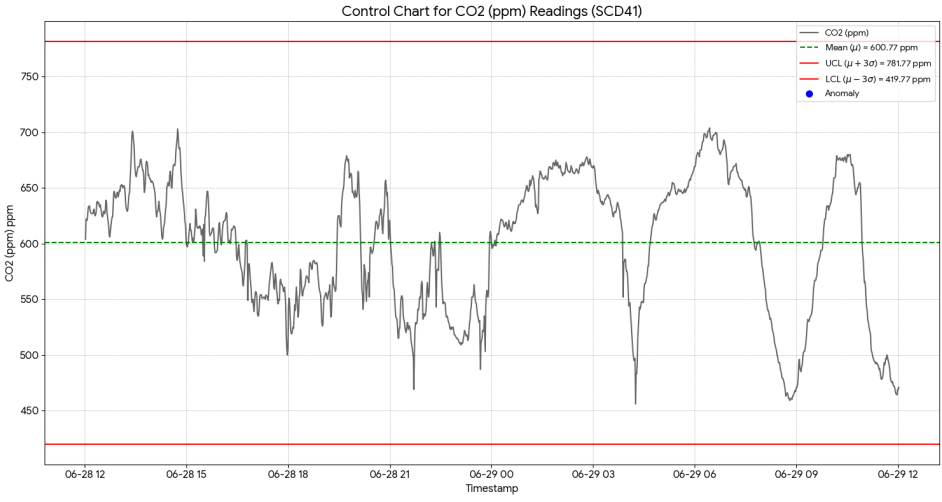
- **Statistical Method**: Shewhart Control Chart
- **Reason to chose:**
  - Well suited for Time Series Sensor Data
  - Lightweight and simple to implement on any microprocessor (Raspberry Pi, Nvidia Jetson Nano etc)
  - Easy to interpret
  - Doesn't require complex tuning and training data
- How it works?
  - Define Control limits using Mean and Standard Deviation:
    - UCL = μ +3σ (Upper Control Limit)
    - LCL = μ -3σ (Lower Control Limit)
  - Any data point outside these limits is flagged as an anomaly.

Statistical Analysis - CO2



Statistical Analysis - CO2

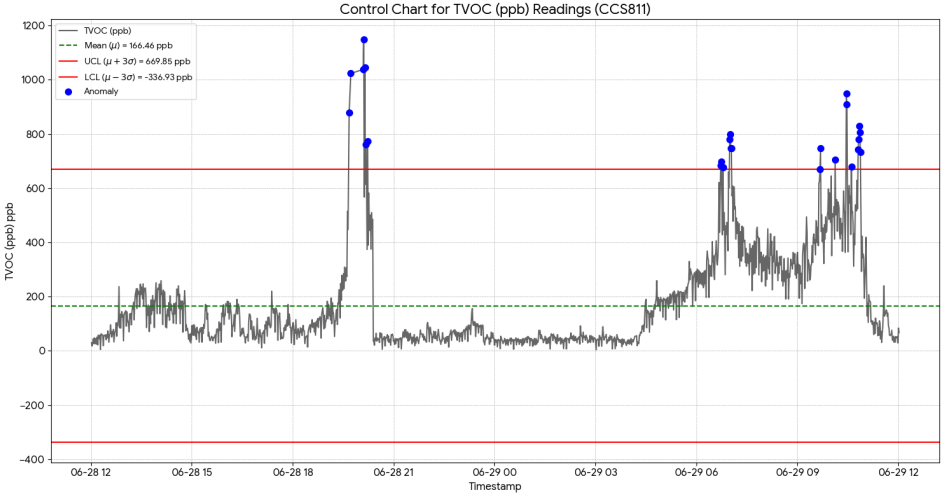
Summary:

- Statistically stable process, no data point exceeded the control limit.

Findings:

- Keeping the window tilted is enough to maintain CO2 levels.

Statistical Analysis - TVOC



Statistical Analysis - TVOC

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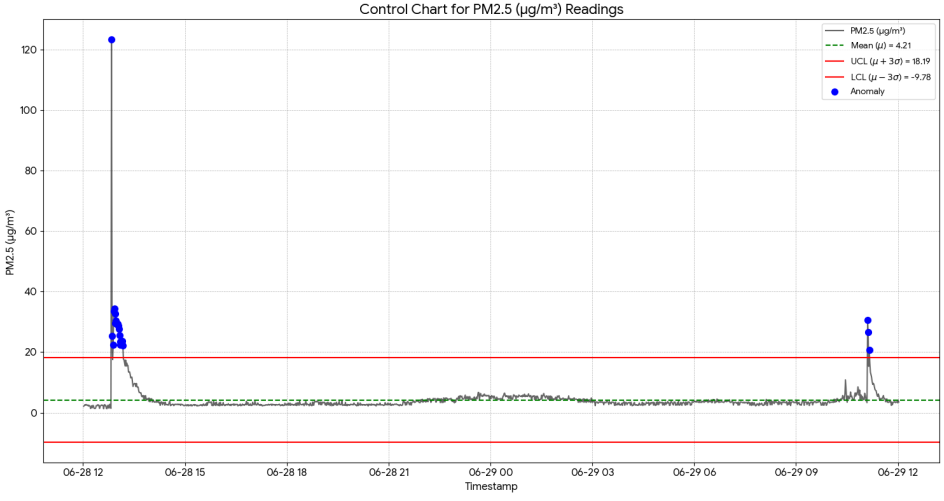
Summary:

- Recorded 3 sets of anomalies:
  - **19.00-20.00**: Student ate dinner, VOC emitted from food accumulated in the room.
  - **06.00-07.00**: No indoor activity, spike caused by outdoor air infiltration.
  - **09.00-11.00**: Caused by continuous bioeffluent accumulation bcs of sweat due to rising temperature and humidity

Findings:

- Tilted window not enough for reducing TVOC, while fully opened window quickly reduced!
- Natural ventilation helps in maintaining IAQ but have to be cautious about Outdoor AQ as well.

Statistical Analysis - PM



Statistical Analysis - PM

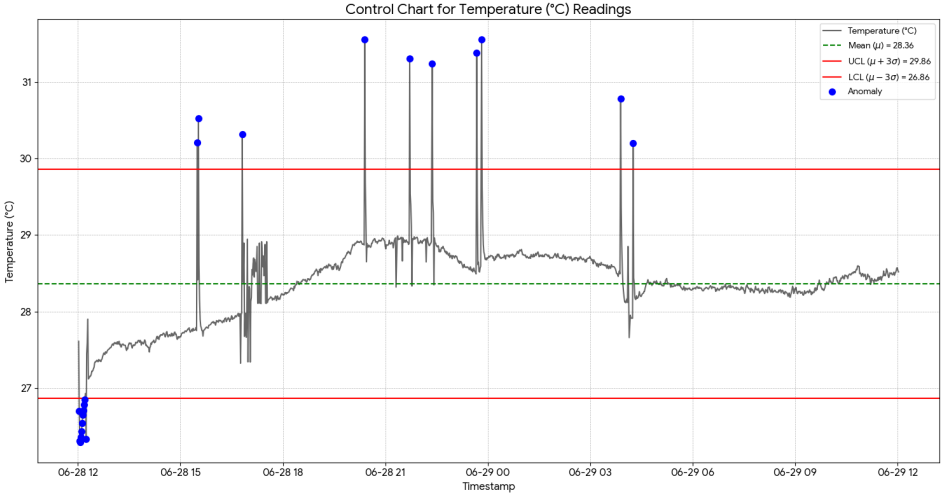
Summary:

- Recorded 2 sets of anomalies:
  - **12.00-01.00 & 10.00-11.00**: Spike caused when the student sprayed a deodorant.

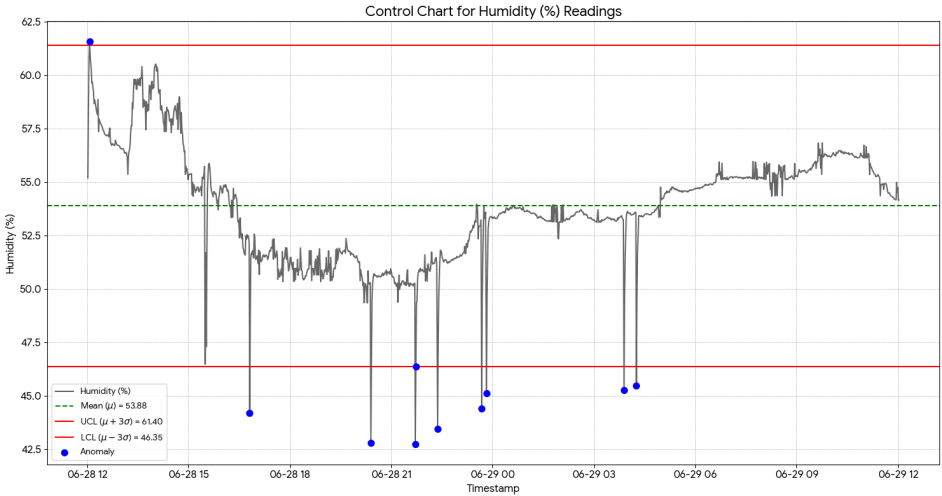
Findings:

- Well ventilated room can quickly mitigate high PM concentration, tilted window is sufficient.
- Aerosol products are significant source of indoor PM.

Statistical Analysis - Temperature



Statistical Analysis - Humidity



Statistical Analysis - Temp & Humidity

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Summary:

- Multiple individual data points out of Control boundaries, probably because of brief sensor malfunction.

Findings:

- Is SCD41 reliable for Temp/Humidity? Brief malfunction of integrated SHT4X (Integrated Sensor in SCD41) - while CO2 readings remain stable, adds question for further investigation.

Conclusion

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- The prototype is well-built, scalable, and adaptable to different environments — including hospitals, schools, and safety-critical systems.
- Data collected is statistically reliable, as confirmed through analysis using Shewhart Control Charts.
- CCS811 Limitation:
  - The sensor stopped working twice during the 12-hour test.
  - eCO2 values were consistently exaggerated and unreliable compared to SCD41 CO2 readings.
  - **Recommendation**: Better not to rely on CCS811 for CO2 values; use dedicated CO2 sensors (i.e: SCD41).

Conclusion - cont.

- Simply keeping the window tilted or open was enough to maintain IAQ within WHO, RESET, and WELL thresholds - **Natural Ventilation is effective.**
- Natural ventilation is only effective when outdoor air is clean. Poor outdoor AQ can negatively impact indoor air, as seen in elevated TVOC and PM levels during early morning hours.
- **Recommendation**: Always monitor outdoor AQ if relying on open windows for IAQ control.

Future Work

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- Adopt a more scalable IoT backend stack to support real-time analytics and remote access.
- Address following security vulnerabilities:
  - DoS attacks via rogue IEEE 802.15.4 packets disrupting communication
  - Replay attacks
- Improve basic safety features to reduce false alarms, ensure consistent sensor behavior, and define minimum safety guarantees.
- Improve dashboard usability and design to make insights more accessible for non-technical users.
- Implement multi-channel alerts (e.g., mobile app, email, push notifications) with context-aware guidance.
- Develop customized versions for hospitals, offices, schools, and safety-critical systems

References

- National Center for Biotechnology Information, "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments", PMCID: PMC4892924 PMID: 26502459.
- ASHARE, "ASHRAE Technical FAQ".
- Researchgate , "Indoor relative humidity: relevance for health, comfort, and choice of ventilation system".
- Kaiterra, "Understanding TVOC: What You Need To Know About Volatile Organic Compounds".
- Environmental Protection Agency "Particulate Matter (PM) Basics".
- ASHRAE, "Position Document on Indoor Carbon Dioxide," Apr. 2022.
- World Health Organization, "WHO Global Air Quality Guidelines: PM2.5 and PM10," Sep. 2021.

References

- ASHRAE Standard 55, “Thermal Environmental Conditions for Human Occupancy,” 2023.
- RESET / WELL Building Standards, “Indoor Air Quality: TVOC & PM1.0 Recommendations,” 2022.
- Muhammad Muzamil. (2025). indoor-air-quality-monitoring-system [Source code].
- Poonam Yadav; Nirdesh Sagathia; Dan Wade, ”Demo: Battery Depletion Attack Through Packet Injection on IoT Thread Mesh Network”, 2024.