Modular Wi-Fi Sensor Node for Indoor Environmental Sensing Applications

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Agenda

- Motivation
- Sensor Node Architecture
- Application 1: Air Quality Display
- Application 2: Spatial CO2 Concentration
- Conclusions
Motivation

Aerosol concentration correlates with CO2 concentration:

**Motivation**

Increased infection risk especially in poor ventilated rooms

Two persons (one infected): Critical particle inhalation is reached…

… after 30 minutes for **good ventilation** (1000 ppm CO2)

… after 15 minutes for **bad ventilation** (2000 ppm CO2)

*Source: A. Hartmann, M. Riegel, Risk assessment of aerosols loaded with virus based on CO2-concentration*
Sensor Node Architecture

IoTyze Wi-Fi Module:
- STM32 main processor for data processing and MQTT client
- ESP32 SoC as Wi-Fi modem with TCP/IP stack

Plus external components:
- SCD30 sensor (**CO2**, temperature, relative humidity)
- BME680 sensor (**VOC**, pressure, temperature, relative humidity)
- 4.3“ TFT display
Data Flow

External:
- Mosquitto MQTT Server as transport protocol
- Node-RED data processing
- InfluxDB as time-series database
- Grafana for web-based visualization

Internal:
- One or both sensors can be connected
- Sampling rate SCD30: 2 s
- Sampling rate BME680: 3 s
- BSEC sensor fusion estimates:
  - CO2 equivalent
  - Index Air Quality (IAQ)
- Protocol Buffers for payload encoding
- Transmission of collected data each 60 seconds
Application 1: Air Quality Display

Local display:

- Display of measurements
- Air quality indication according to DIN EN 13779
- Acoustical alert on critical CO² concentration
Application 1: Air Quality Display

Online display:

- Too high CO2 estimation in presence of other VOCs (e.g., paint, garbage)
- Too low CO2 estimation for other sources of CO2 except human breathing
Application 2: Spatial CO2 Concentration

Experimental setup:

Installation of 5 SN in a height of 1.5m in home office environment
Application 2: Spatial CO2 Concentration

Temporal sequence:

1. First measurements
   - Opening door and window a
   - 30 seconds
   - Second measurements
2. Closing door and window a
   - 5 minutes
3. Final measurements

$CO_2 \sim 1500$ ppm
Application 2: Spatial CO2 Concentration

Spatial Interpolation for sparse, irregular data points:

**Inverse Distance Weighting**

\[
F(x, y) = \begin{cases} 
\frac{\sum_{k=1}^{N} \left(\frac{1}{d_k}\right)^\mu f_k}{\sum_{k=1}^{N} \left(\frac{1}{d_k}\right)^\mu} & \text{if all } d_k \neq 0 \\
\sum_{k=1}^{N} \left(\frac{1}{d_k}\right)^\mu f_k(d_k = 0) & \text{if any } d_k = 0
\end{cases}
\]

- \(F\) = Estimation for coordinate \(x, y\)
- \(N\) = Number of samples
- \(d_k\) = Distance between estimation and sample \(k\)
- \(\mu\) = Power
- \(f_k\) = Value of sample \(k\)

**Example:**

\[
F = \frac{2}{1} + \frac{1}{2.5} + \frac{3}{5} = 2.625
\]

Interpolated values in range of sample points
Application 2: Spatial CO2 Concentration

Results:

- Increased concentration near the workspace.
- Concentration drop near the window.
- Slightly lower concentration near the door.
- Increased concentration near the workspace.

Before airing:

After 30s airing:

After 5 min. with closed door and window:
Conclusions

- Sensor node with local display supports the ventilating habits
- VOC sensors with sensor fusion can be a cheap alternative to NDIR CO2 sensors
- CO2 estimation is usually too high in case of additional VOC (e.g. paint, garbage)
- No uniform distribution of CO2 inside occupied space
- A drop in CO2 concentration is first observed at the windows when airing
- Increased CO2 concentration near workspaces shortly after airing was stopped
- Optimal position of a single sensor is near the workspaces in distance to windows

Future work:
- Measurements in crowded lecture rooms when possible
- Evaluate adjusted IDW (AIDW) to account for shielding effects
- Comparison of other interpolation techniques (etc. RBF, Kriging)
- Development of a planning tool for placement of sensors with real-time visualization