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# Realizing Mobile Air Quality Monitoring System: Architectural Concept and Device Prototype

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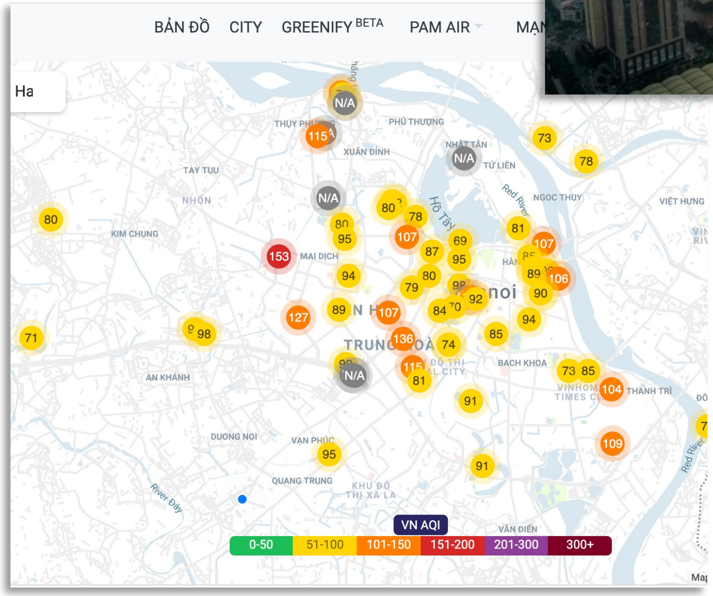
# Agenda

- Background
- Problem statement and goals
- Solution
- Preliminary results

# Current air quality monitoring systems

- Back-end
  - Mostly based on **static stations**
    - In Hanoi: ~ 50 stations in total; concentration in the central area
  - Using **UAV**: only at an **early stage**
- Front-end
  - Several apps: Air visual, PAM Air, etc.
    - Realtime indexes at **monitored locations**
    - **One-week** ahead forecast



# Problem statement

## Limitation of monitored regions

- The monitored regions are **very limited** compared to the total area.
  - In Hanoi: 50 stations vs. 3,329 $km^2$

## Lack of a fine-grained forecasting and analysis system

- **Only short-term** forecast is available.
  - E.g., within one week ahead
- **Only temporal** prediction is available.
  - No spatial prediction (no air quality information of unmonitored regions)

## Lack of a public database

- **No public database**
- Researchers **cannot access** the raw data.

# Goals

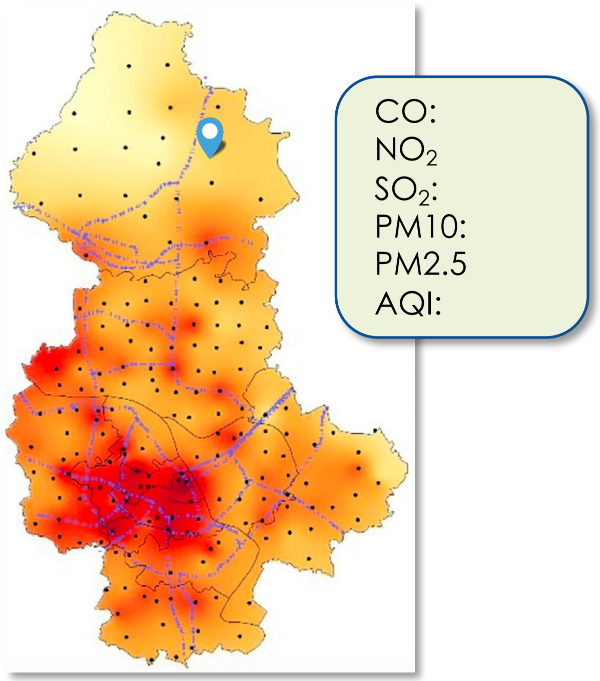



Illustration of the air quality map

- A **fine-grained real-time** air quality map
  - High accurate information at **anywhere anytime**
- APIs for **analyzing** and **forecasting** air quality
- An **optimal model** for deploying air quality systems

# Solutions

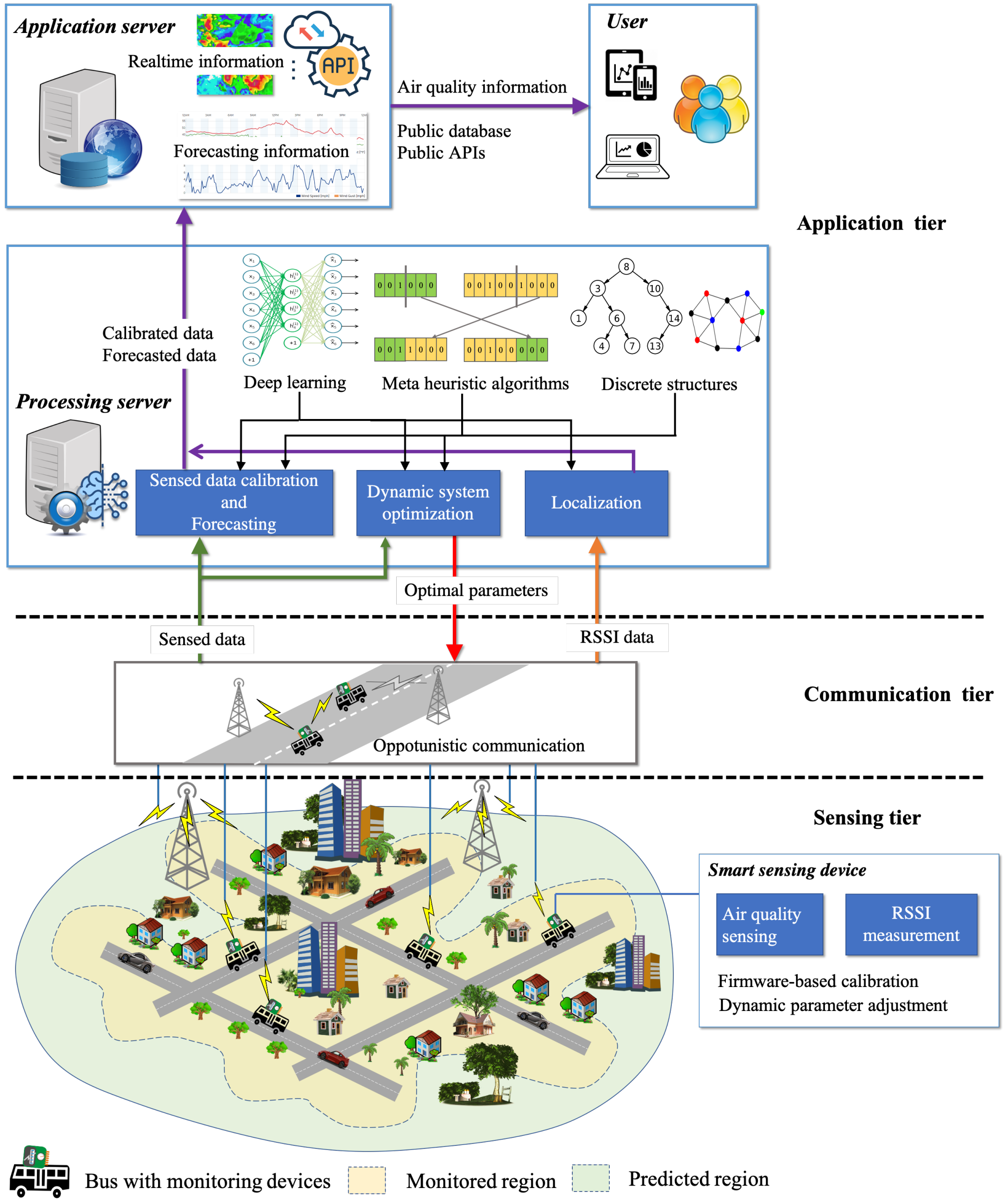
- Key points: How to provide air quality information everywhere, every time?

Mobile monitoring devices

Spatial-temporal prediction

- **Broadening** the monitored regions
- Monitoring large regions with **a limited number of devices**
- Enhancing the **prediction accuracy**

- Using **temporal information** to forecast future air quality at **anytime**
- Utilizing **spatial information** to predict air quality **anywhere**




# Fi-Mi's 3-tier Architecture

- **Sensing tier**
  - Collects **real-time** air quality data
  - Carried by air **monitoring devices** deployed on **vehicular devices** such as buses
- **Communication tier**
  - **Transfers data** between the monitoring devices and the servers
- **Application tier**
  - **Stores** the sensory data
  - **Forecasts** the **future** trend of the air quality
  - **Predicts** air quality in **un-monitored regions**
  - **Optimizes** the behaviors of the monitoring devices
  - Provides information to users through **smartphone applications** and **web portal**

# Device implementation

- Implementing real devices
- Runing field test

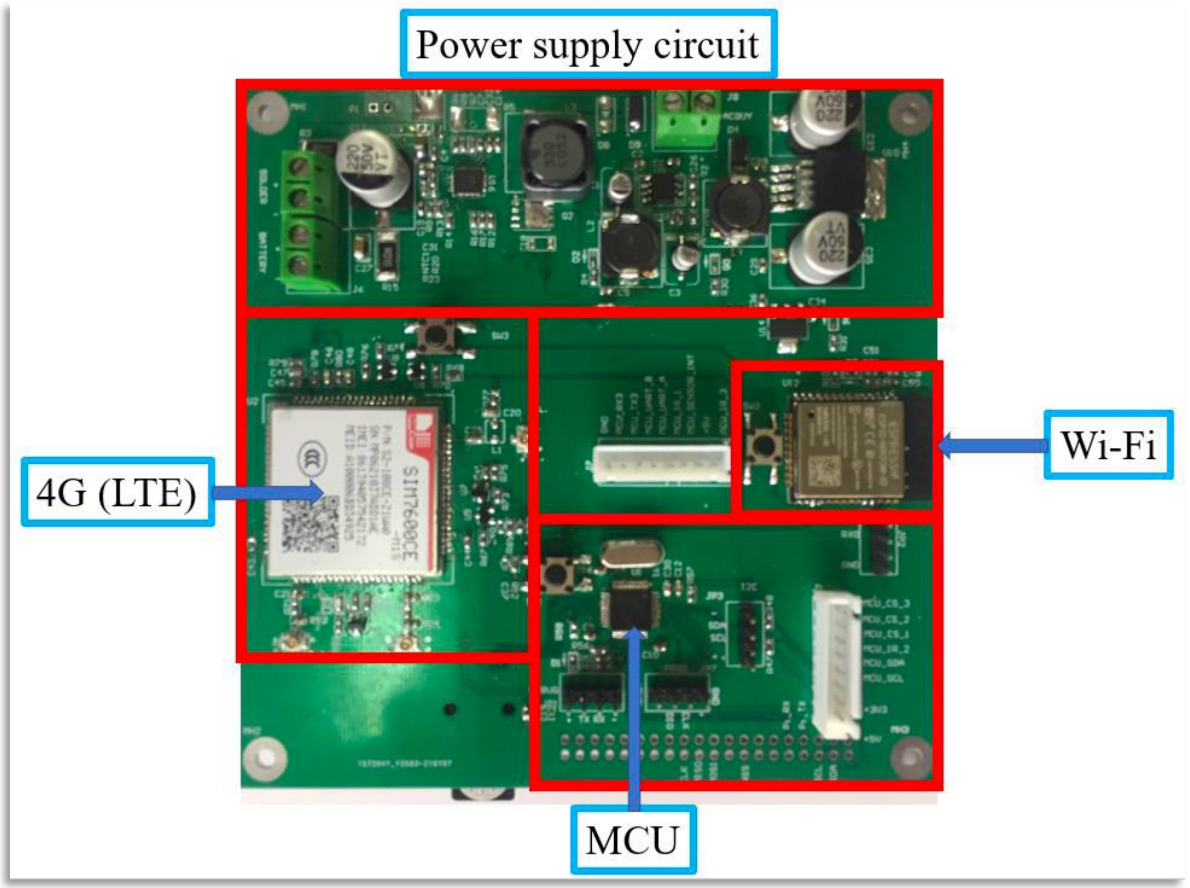
# Device requirements

- GPS: longitude, latitude
- Battery usage
- Low cost

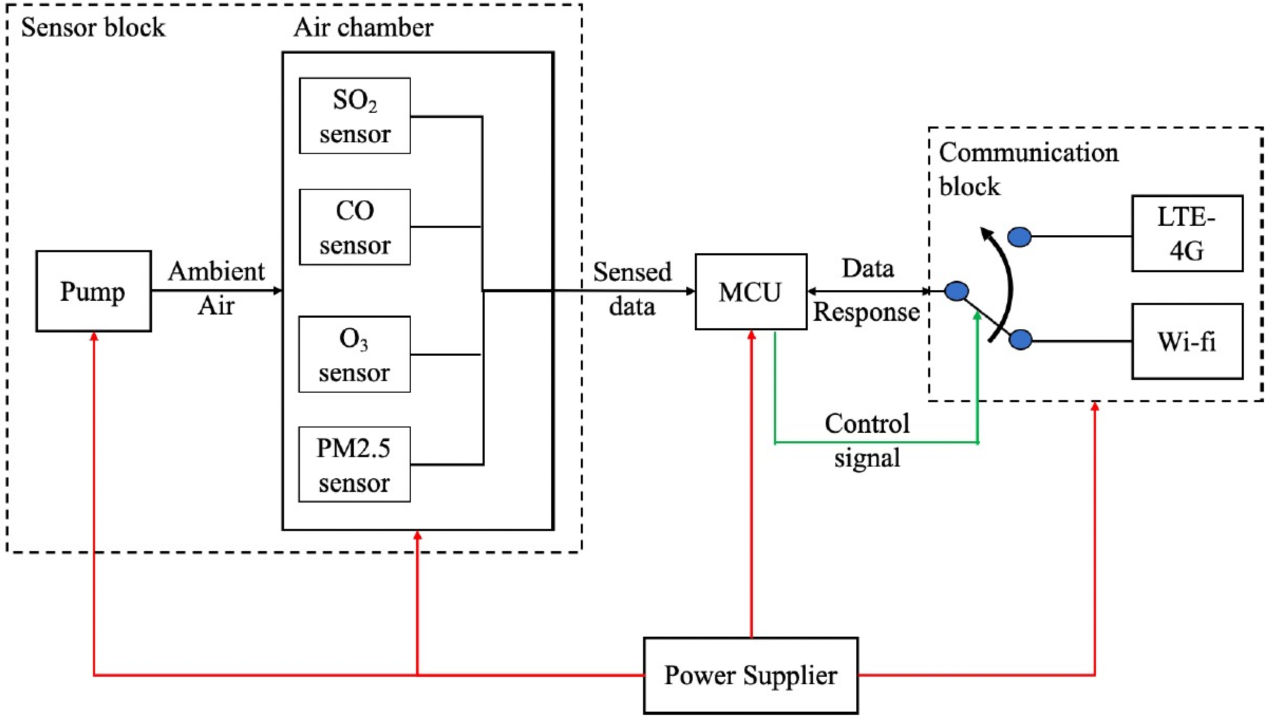
| Metrics | Range | Resolution | Accuracy | Correlation |
|---|---|---|---|---|
| PM2.5 | 0 ÷ 500 ug/m3 | 0.1 ug/m3 | 15% | 0.6 |
| CO | 0 ÷ 10000 ug/m3 | 0.1 ug/m3 | 10% | 0.6 |
| SO2 | 0 ÷ 1000 ug/m3 | 0.1 ug/m3 | 10% | 0.6 |
| NO | 0 ÷ 1000 ug/m3 | 0.1 ug/m3 | 10% | 0.6 |
| Nhiệt độ | -20 ÷ 70 °C | 0.1 °C | 5% | 0.6 |
| Độ ẩm | 10 ÷ 90 %RH | 0.1 %RH | 5% | 0.6 |

# Circuit layout

| Function | Device |
|---|---|
| MCU | STM32F103C6T8 |
| Wi-Fi | ESP32 |
| LTE | SIM7600CE |
| Power | LTC4162 |

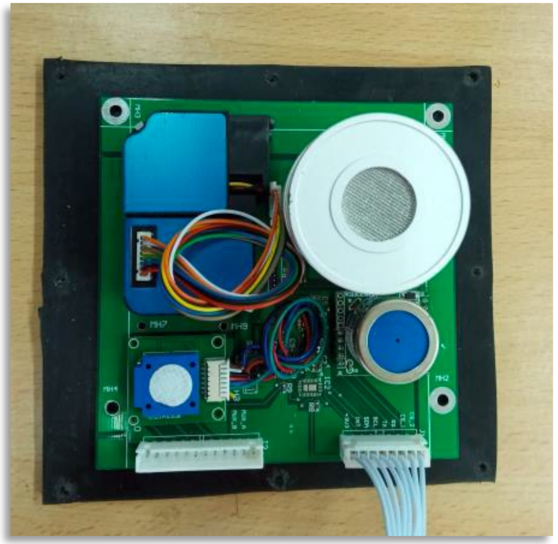


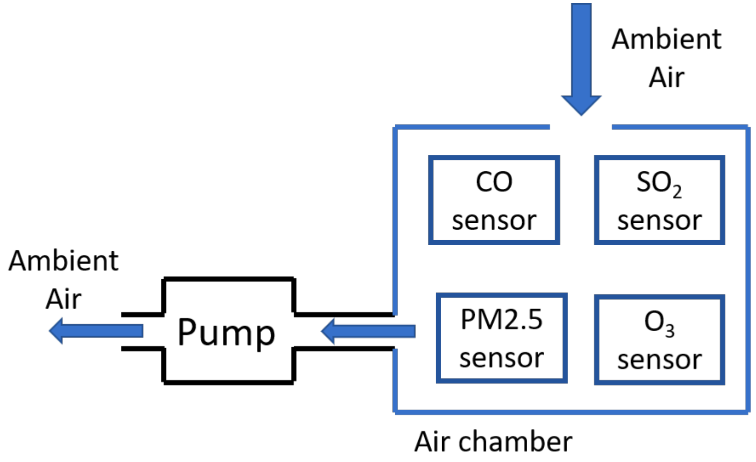
# Device and Functional Blocks



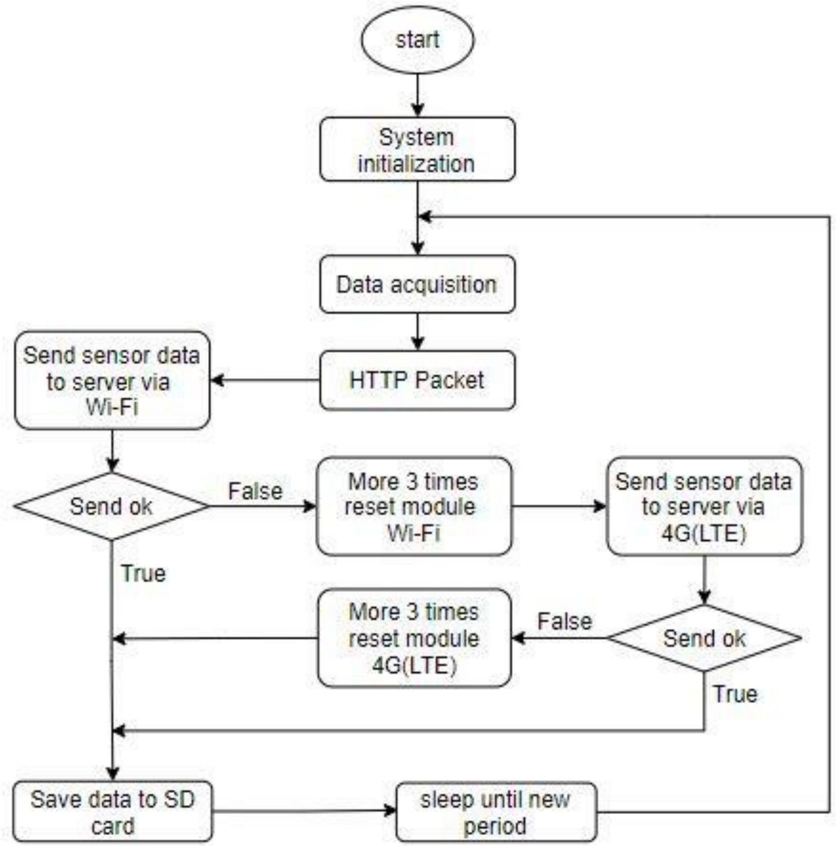
# Sensor modules

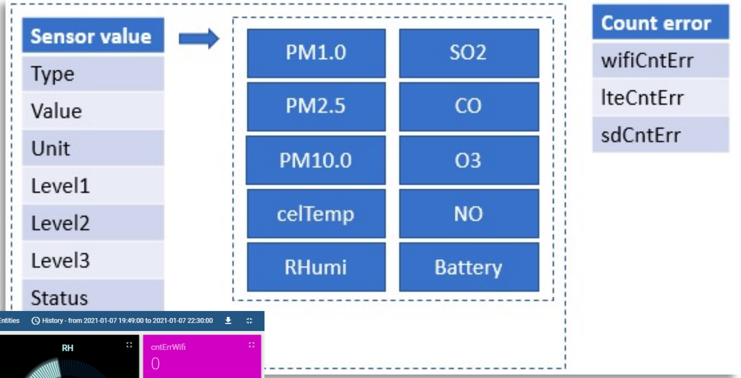
| | ZE-03B | ZE-12A | ZE-15 | ZE-25 | SHT21 |
|---|---|---|---|---|---|
| **Metrics** | PM2.5 | SO2 | CO | O3 | Temp., Humidity |
| **Interface** | UART | UART | UART | UART | I2C |
| **Range** | 0 ÷ 1000 ug/m3 | 0 ÷ 1 ppm | 0 ÷ 500 ppm | 0 ÷ 10 ppm | -40 ÷ 120 °C<br>0 ÷ 100 %RH |
| **Resolution** | 1 ug/m3 | 10 ppb | 0.1 ppm | 0.01 ppm | 0.01°C<br>0.04%RH |



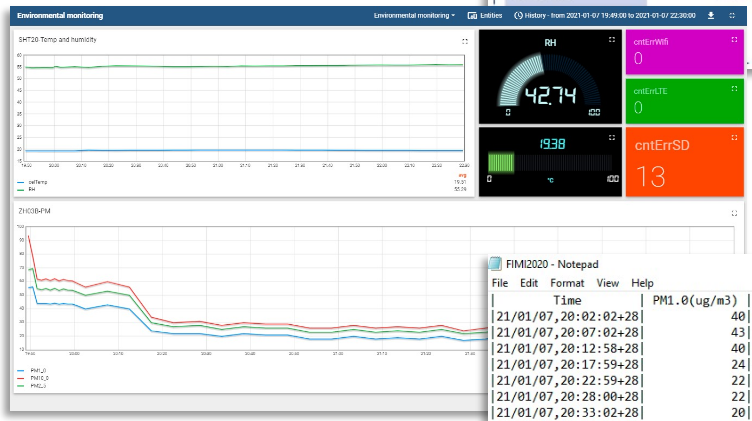


# Operation flowchart

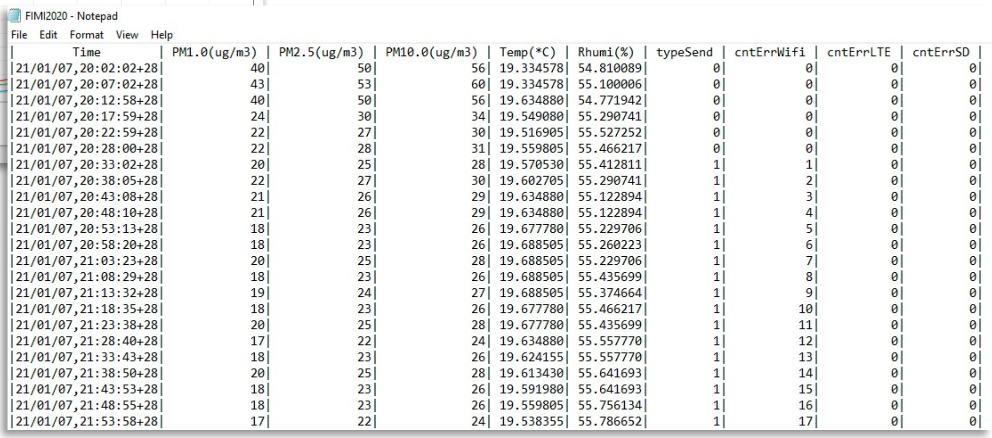



Data structure




Server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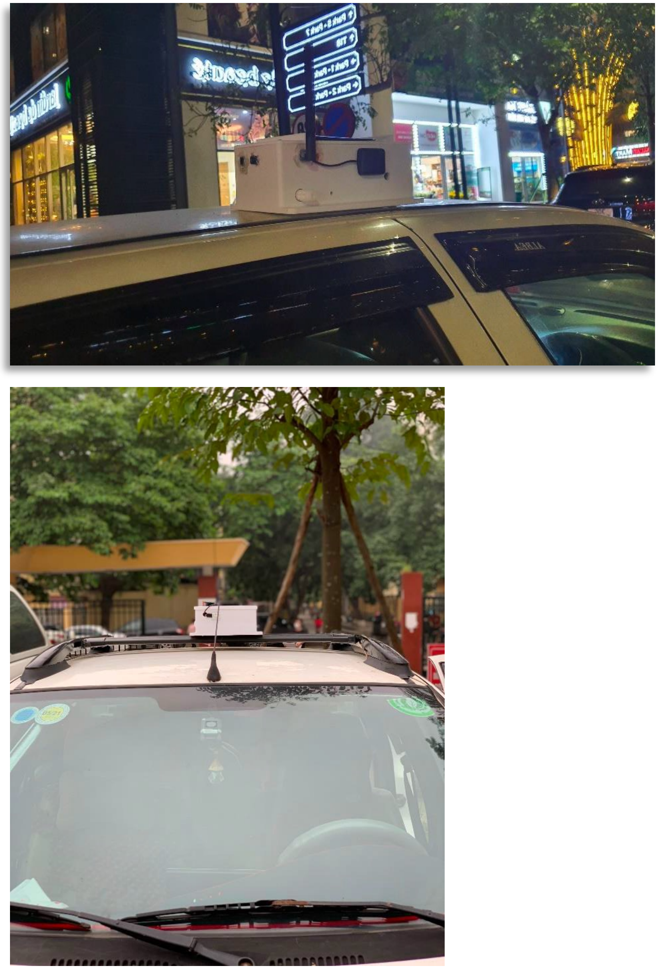
| Time | PM1.0(ug/m3) | PM2.5(ug/m3) | PM10.0(ug/m3) | Temp(*C) | Rhumi(%) | typeSend | cntErrWifi | cntErrLTE | cntErrSD |
|---|---|---|---|---|---|---|---|---|---|
| 21/01/07,20:02:02+28 | 40 | 50 | 56 | 19.334578 | 54.810089 | 0 | 0 | 0 | 0 |
| 21/01/07,20:07:02+28 | 43 | 53 | 60 | 19.334578 | 55.100006 | 0 | 0 | 0 | 0 |
| 21/01/07,20:12:58+28 | 40 | 50 | 56 | 19.634880 | 54.771942 | 0 | 0 | 0 | 0 |
| 21/01/07,20:17:59+28 | 24 | 30 | 34 | 19.549080 | 55.290741 | 0 | 0 | 0 | 0 |
| 21/01/07,20:22:59+28 | 22 | 27 | 30 | 19.516905 | 55.527252 | 0 | 0 | 0 | 0 |
| 21/01/07,20:28:00+28 | 22 | 28 | 31 | 19.559805 | 55.466217 | 0 | 0 | 0 | 0 |
| 21/01/07,20:33:02+28 | 20 | 25 | 28 | 19.570530 | 55.412811 | 1 | 1 | 0 | 0 |
| 21/01/07,20:38:05+28 | 22 | 27 | 30 | 19.602705 | 55.290741 | 1 | 2 | 0 | 0 |
| 21/01/07,20:43:08+28 | 21 | 26 | 29 | 19.634880 | 55.122894 | 1 | 3 | 0 | 0 |
| 21/01/07,20:48:10+28 | 21 | 26 | 29 | 19.634880 | 55.122894 | 1 | 4 | 0 | 0 |
| 21/01/07,20:53:13+28 | 18 | 23 | 26 | 19.677780 | 55.229706 | 1 | 5 | 0 | 0 |
| 21/01/07,20:58:20+28 | 18 | 23 | 26 | 19.688505 | 55.260223 | 1 | 6 | 0 | 0 |
| 21/01/07,21:03:23+28 | 20 | 25 | 28 | 19.688505 | 55.229706 | 1 | 7 | 0 | 0 |
| 21/01/07,21:08:29+28 | 18 | 23 | 26 | 19.688505 | 55.435699 | 1 | 8 | 0 | 0 |
| 21/01/07,21:13:32+28 | 19 | 24 | 27 | 19.688505 | 55.374664 | 1 | 9 | 0 | 0 |
| 21/01/07,21:18:35+28 | 18 | 23 | 26 | 19.677780 | 55.466217 | 1 | 10 | 0 | 0 |
| 21/01/07,21:23:38+28 | 20 | 25 | 28 | 19.677780 | 55.435699 | 1 | 11 | 0 | 0 |
| 21/01/07,21:28:40+28 | 17 | 22 | 24 | 19.634880 | 55.557770 | 1 | 12 | 0 | 0 |
| 21/01/07,21:33:43+28 | 18 | 23 | 26 | 19.624155 | 55.557770 | 1 | 13 | 0 | 0 |
| 21/01/07,21:38:50+28 | 20 | 25 | 28 | 19.613430 | 55.641693 | 1 | 14 | 0 | 0 |
| 21/01/07,21:43:53+28 | 18 | 23 | 26 | 19.591980 | 55.641693 | 1 | 15 | 0 | 0 |
| 21/01/07,21:48:55+28 | 18 | 23 | 26 | 19.559805 | 55.756134 | 1 | 16 | 0 | 0 |
| 21/01/07,21:53:58+28 | 17 | 22 | 24 | 19.538355 | 55.786652 | 1 | 17 | 0 | 0 |

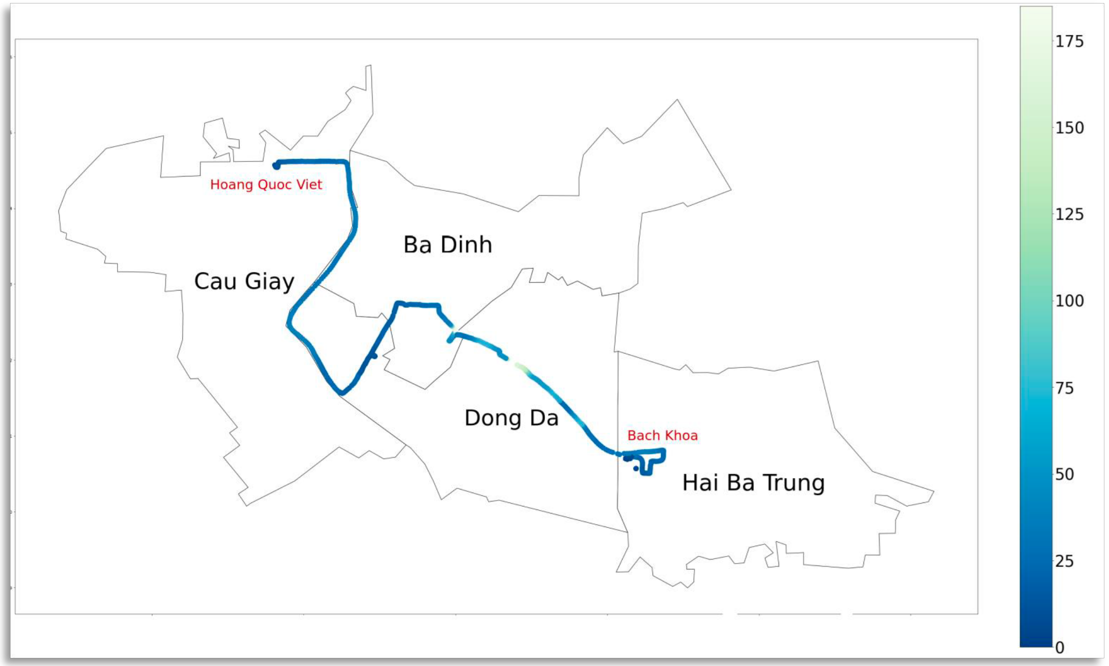
On-device SD card

# Trials



Mounting on a vehicle

| | Sen. (Pkts) | Rec. (Pcks) | Del. Ratio |
|---|---|---|---|
| Wi-Fi | 1200 | 1198 | 99.8% |
| LTE | 1200 | 1200 | 100 |




PM 2.5 monitoring in Hanoi

# Data calibration

- Method to calibrate data:
  - Put data in a machine learning model: XGBoost
  - Input data: PM2.5 (and temperature) of Zho3b

    Ground-truth data: PM2.5 of Grim03 and Grim07
  - The model will learn to make input data identical the ground-truth data

# Experiments

- Train/valid/test data: 60/20/20.
  **134** observations are used in testing process.
- Experiment scenario

**Table 2:** Experiment scenario

| Scenario | **Input** | **Ground-truth** |
|---|---|---|
| 1 | PM2.5 | PM2.5 |
| 2 | PM2.5 + temperature | PM2.5 |

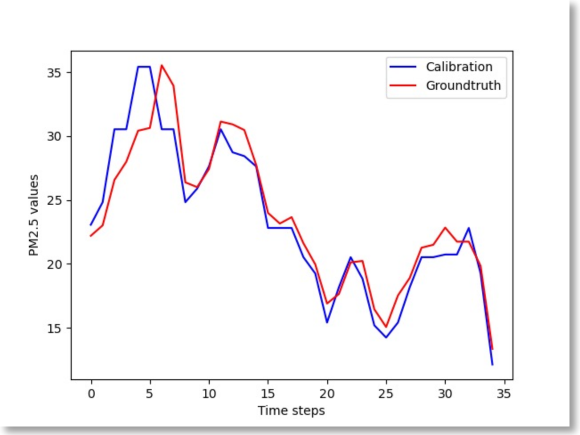
- Evaluation metrics:
  - R-squared (R2) score: $R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \mu)^2}$
  - Mean absolute error (MAE): $MAE = \frac{1}{N} \sum_{i=1}^{N} |y_i \ - \hat{y}|$

Where:
$y_i$ – prediction value
$\hat{y}_i$ – ground-truth
$\mu$ – mean value

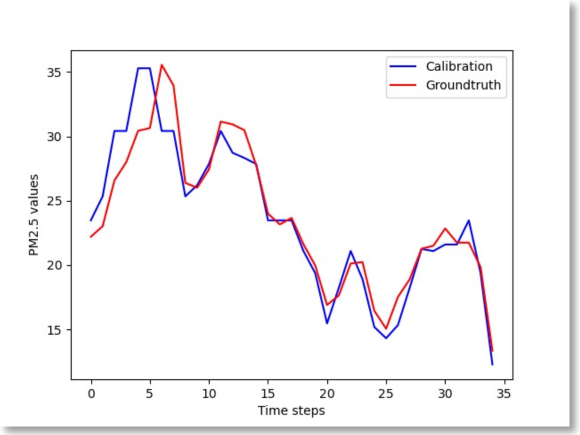
# Experiments Results

Experiment results using XGBoost

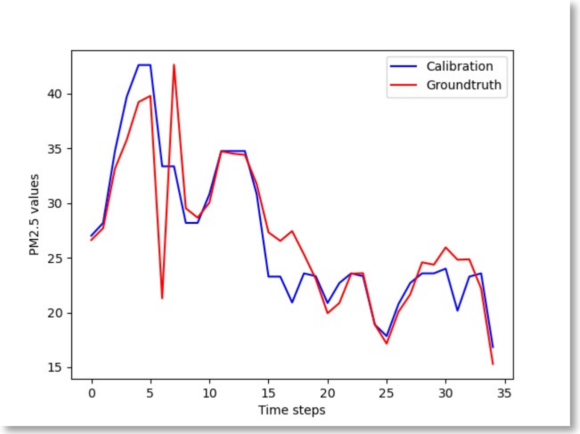
| Scenario using | Devices | MAE | R2 score |
|---|---|---|---|
| PM2.5 | Grim03 | 2.148 | 0.856 |
| | Grim07 | 3.751 | 0.662 |
| PM2.5 + temperature | Grim03 | 2.330 | 0.836 |
| | Grim07 | 3.434 | 0.726 |



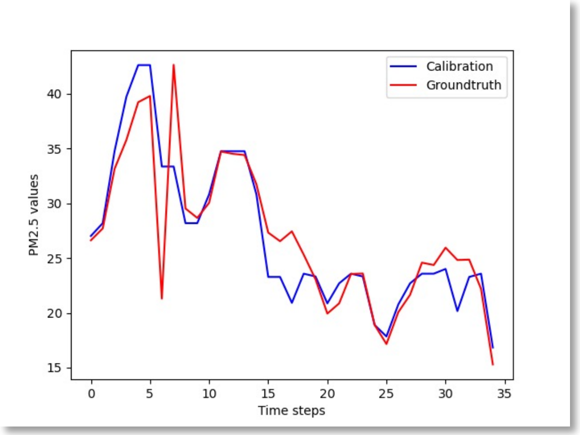
PM2.5 – Grim03



PM2.5 + temp – Grim03



PM2.5 – Grim07



PM2.5 + temp – Grim07

# Conclusion

- Proposed a mobile air quality monitoring system
  - Air quality monitoring devices are mounted on vehicles
- Finished prototyping
- Collecting and calibrating data at the server side


Thank
You!