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# Relatively Low-Cost Personal Mobile Device for PM2.5, CO, and $CO_2$ Measurements Coupled with Positioning, Cellular Network Cloud Computing and Storage, and Web Application UI

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## ABSTRACT

In recent years, several approaches have been made to find cheaper alternatives using low-cost systems for monitoring air pollution. These approaches have been somewhat lacking and are only applicable to stationary measurements, which usually employs accurate sensors, but bulky and expensive. This paper shows that a portable low-cost device that is capable of monitoring air pollutants is possible at a fraction of the cost. It uses a sampling mechanism with its sensors to gather PM2.5, CO, and CO2 air pollutants for measurement as well as a GPS sensor for location tagging. It comes with a web app user interface for tracking air pollutant readings with a database for data history.

**Key words:** Air Pollutants, Air Pollution, Air Quality, Carbon Compounds, Cloud Computing, Environmental Monitoring, Global Positioning System, Land Mobile Radio, Mobile Nodes, Pollution Measurement, User Interface.

## 1. INTRODUCTION

Nowadays, air pollution is becoming more prevalent due to the increasing number of vehicles on roads as well as the amount of traffic in which it allows vehicles to emit more gases. This is a major concern because air pollutants have several impacts on human health. Some most common gases that can be harmful are Particulate Matter (PM), Carbon Monoxide (CO) and Carbon Dioxide (CO2).

According to the Environmental Management Bureau (EMB), air quality in Metro Manila, Philippines has improved [1]. However, these results are only based on the data collected by stationary stations around the city, results are not a representative of the whole city due to its limited coverage capacity. From the data, it is said that 80% of the information comes from motor vehicles while the remaining 20% comes from stationary sources like factories. Since most of the air pollution comes from mobile sources, it shows that the stationary stations being implemented does not cover other areas vehicle travels.

With air pollutions as a growing threat, it is important to have a system for monitoring the air quality in the environment. Developments have been made, to make portals accessible by the public to raise awareness and to know the impact that it causes on health. These developments undertaken by the Philippine government provide access to data gathered by sensors within certain areas.

In March 2015, the Philippines' Department of Environment and Natural Resources (DENR) and (EMB), made their air pollution data from stationary stations available to the public. These seventeen (17) stations are located across Metro Manila. Each of these stations is limited to collect up to 2-kilometer radius from the station [2]. It monitors PM2.5, PM10 pollutants and total suspended particles. Even though there are existing government stations already been set around Metro Manila, the presently working stations are only few and limited in their coverage area.

Another approach done in the literature was done by tracking the air pollution levels of routes people take in their everyday lives. In [3], the authors developed a portable sensor that connects with the user's smartphone through Bluetooth to send sensor readings to a server where it is then mapped. They used metal oxide sensors to gather readings and a microcontroller with a Bluetooth module for communication with a smartphone. A sensor called OXA was used, which is an electrochemical sensor that provides more accurate readings of low concentration values. During the testing phase, the sensor was placed in a car and it was noted that the accuracy of the readings was affected when the windows were rolled down due to the sensors being sensitive to wind. The same problem was encountered when the sensor was placed outside the car. The most advanced mobile monitoring system is the project undertaken by Google with the University of Texas and Environmental Defense Fund [4].

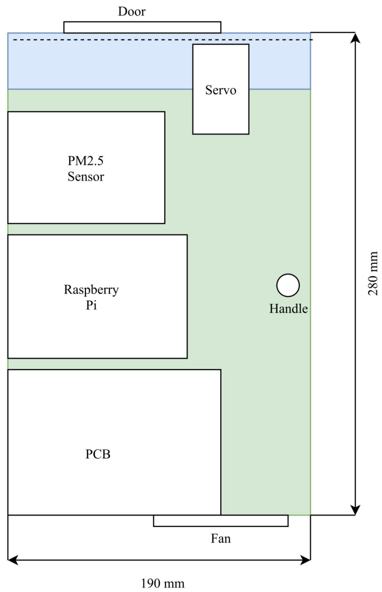


**Figure 1:** General flooring layout of the proposed device

This project uses the Google Street Car and has added sensors, The car roams around the streets of cities in the United States taking samples of the air initially. Sensors used on Google Cars are made by Aclima. Obtained data is plotted on Google Maps and is colored coded to show the air quality. The project has had some success and was capable of showing methane leaks in certain areas as well as hotspots for air pollution.

A study over a six-month period tested several low-cost sensors, particularly AQMesh sensor node [5]. The study tested 19 of these sensors in 3 different locations with varying traffic conditions. Results show that these sensors are capable of detecting accurate results as long as both temperature and humidity are predetermined. The other gaseous sensors such as the CO, CO2, and O3 had a correlation range from 0.3 to 0.7 depending on the environmental conditions. They concluded that in real-world scenarios, calibration is a major concern if readings are to be used for scientific research since the standards set by monitoring organizations are strict but these sensors can be used for citizen awareness and supplementary data.

Previous air pollution studies and statistics have been made based on stationary sensors. Such stationary sensors limit and may generalize an area. The main difference between the topics discussed is on the additional gases, methods of data transfer and data display, as well as the locality of the stations. The main contributors to air pollution that were common were PM, CO, CO2, and O3. These studies varied based on how each displayed data, combination of graphs, web and mobile applications. In addition, the medium of data transfer

**Table 1:** Cost (US$) of the components

| | |
|---|---|
| GPS Module | 5.00 |
| GSM Module | 15.00 |
| Carbon Monoxide Sensor (MQ-7) | 10.00 |
| Carbon Dioxide Sensor (CCS811) | 50.00 |
| Raspberry Pi Model 3B | 35.00 |
| Nova PM Sensor | 40.00 |
| Weather-proof casing | 10.00 |
| Miscellaneous (fan, wiring, PCB, power, antenna) | 25.00 |
| **Total** | **190.00** |

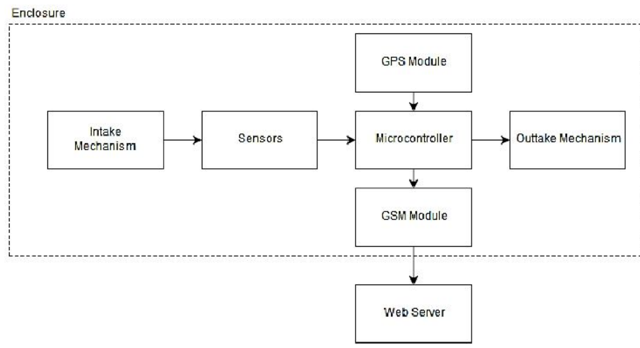


**Figure 2:** Block diagram of the major hardware structure

varied between GSM, Wi-Fi, and Bluetooth. There are currently few studies that have dealt with mobilizing the sensors as the accuracy of the sensors are affected while taking measurements on the move.

In addressing this issue, this research work aims to make a portable device that is equivalent to the stationary equipment that can be put on a moving vehicle and measure air pollutants at a specific time frame and routes to extend its coverage then generates a map that displays the concentration of PM2.5, CO, and CO2. Dissimilar to other outputs in the authors' departments [6]–[20], this work focuses on low-cost device development. According to the Department of Budget and Management, an estimate of 272 million pesos (~USD 5.44 million) was allotted for the calibration and maintenance of the 94 air quality stations across the Philippines which need to be maintained every year. In 2016, 280 million pesos (~USD 5.6 million) was allotted for building twenty-eight (28) real-time air quality monitoring stations, which means 10 million pesos (~USD 0.2 million) per station [21]. Table 1 shows the price breakdown of all the components; it shows the approximate total cost needed to make the air pollution measurement system. The cost listed is for one unit and are estimates of the prices found online. Each part listed in the table is necessary. Table 1 gives an estimate of the materials in producing one device based on the layout in Figure 1. In terms of inexpensive streams in the authors' department, it follows the resolve of achieving less costly solutions like [22]–[35].

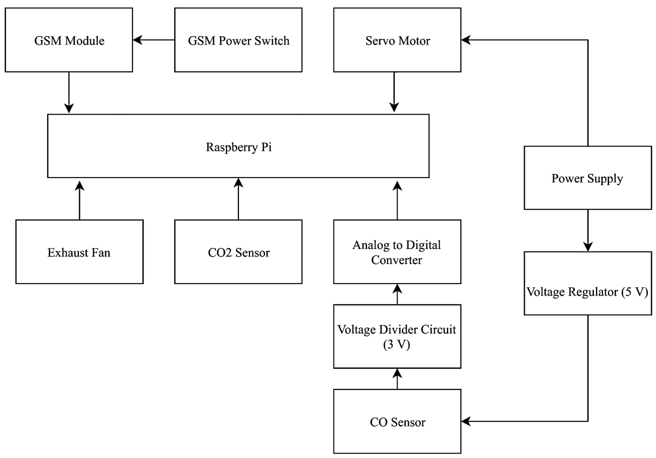


**Figure 3:** Hardware components and signal flows

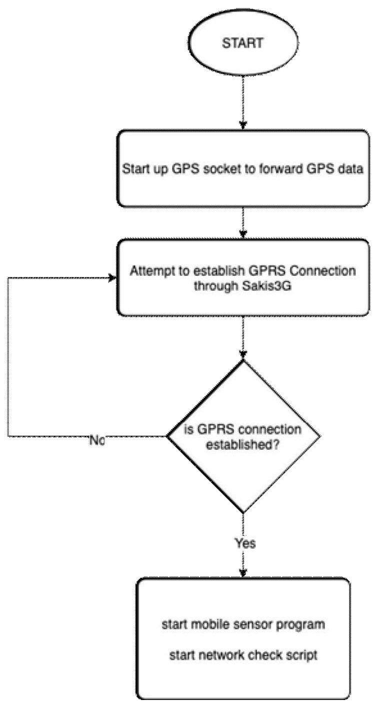


**Figure 4:** Initialization of the device

The authors' contribution is a portable device that is capable of gathering and mapping data on air pollutants, namely PM2.5, CO, and CO2. The resulting measurements conformed to international standards and were calibrated accordingly. The device is built in a weatherproof housing that is able to isolate the sensors from the environment and contains an intake and flushing mechanism in order to gather samples. The device includes a GPS localization and a GSM cellular module in order to record the location as well as send data back to the server to be displayed in a web application.

The rest of the paper then is organized as follows. Section 2 discusses the proposed device, followed in Section 3 by calibration results and their corresponding discussions. The summary of the outcomes is given in Section 4 including the authors' suggestions.

## 2. ARCHITECTURE OF THE WIRELESS PERSONAL MOBILE AIR POLLUTION MONITORING DEVICE AND THE SYSTEM

This section describes the components of the wireless personal mobile device and the system that include the paraphernalia, hardware fixtures, developed computer programs for the device and for the web-based application UI.

### 2.1 Materials

The prototype employed a Raspberry Pi model 3B as the main processing unit. The sensors for both systems consisted of the DHT-11 for measuring temperature and humidity, the SDS011 for measuring PM2.5, CCS811 for measuring CO2 and MQ-7 for measuring CO. The VK-172 GPS adapter was used for positioning. It is noted that it is connected via USB to the Raspberry Pi instead of other connection options. The GSM cellular module was the SIM800L for sending data to the server. For the air intake and exhaust, an SG90 servo motor was used to control the door and an exhaust fan was installed to expel previous air samples. The housing used in the mobile system has an IP rating of 65, rated to prevent ingression of any dust and water jets in any direction. The components were connected to the Raspberry Pi with a 5 V power supply.

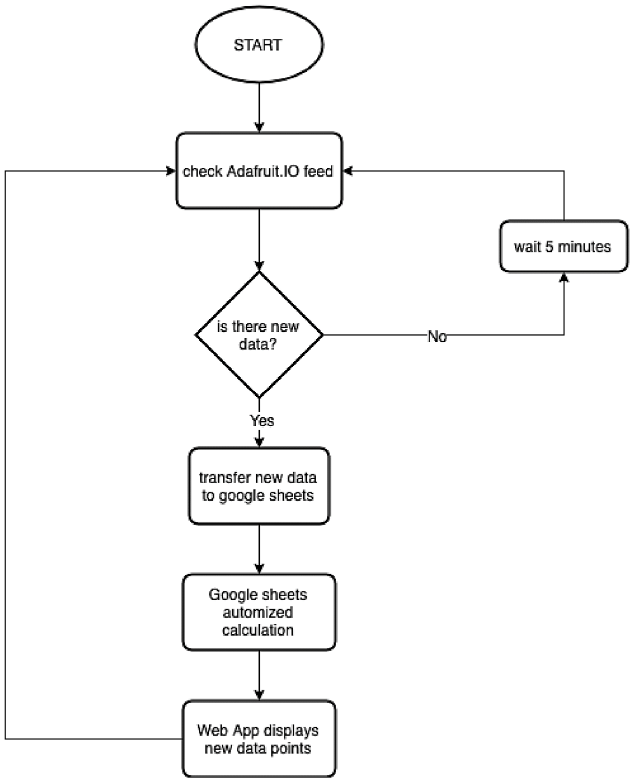


**Figure 5:** Flow of data to Web UI

### 2.2 Hardware Structure

The first consideration in the hardware implementation was the size of the PCB design. The PCB design has the CCS811, MQ7 and DHT11 sensors on it as well as the GSM module. The PCB also incorporated various components needed by the other parts to work (such as voltage reference resistors and transistor, an analog-to-digital converter, etc.). There were also provisions for the power supply for the sensors, servo motor, and exhaust fan. Pin assignment is dependent on the sensor, the CCS811 uses I2C pins, while the DHT11 and MQ7
only require GPIO pins to be occupied. The GSM module requires to be connected to the serial pins of the Raspberry Pi while the SDS011 and GPS module only require a USB port.

With the PCB design, an adequately sized housing was required that could hold the design as well as the Raspberry Pi and the components not on the PCB (see Figure 1). Inside the housing, a flooring was used to hold all the components rather than placing all the components on the floor of the housing itself. The batteries are placed beneath the flooring and can be changed by simply raising the flooring.

The integrated power supply of the mobile module is composed of the 20 Ah power bank directly connected to the Raspberry Pi and a micro USB module.


**Figure 6:** Map in the web UI showing 1 of the 3 raw data points that are available on the spreadsheet

**Table 2:** Calibration values for CO

| sensor resistance | load resistance | air ratio (ppm) |
|---|---|---|
| 1.3578 | 0.06279253352 | 0.9002815633 |
| 1.3581 | 0.06280640726 | 0.9002815633 |
| 1.3297 | 0.06149302683 | 0.9002815633 |
| 1.3781 | 0.06373132306 | 0.9002815633 |
| 1.4161 | 0.06548866308 | 0.9002815633 |
| 1.4037 | 0.06491521528 | 0.9002815633 |
| 1.4195 | 0.06564589876 | 0.9002815633 |
| 1.4059 | 0.06501695602 | 0.9002815633 |
| 1.4154 | 0.06545629102 | 0.9002815633 |
| 1.4054 | 0.06499383312 | 0.9002815633 |
| 1.4314 | 0.06619622366 | 0.9002815633 |
| 1.3795 | 0.06379606717 | 0.9002815633 |
| 1.3877 | 0.06417528264 | 0.9002815633 |
| 1.4115 | 0.06527593244 | 0.9002815633 |
| 1.3725 | 0.06347234664 | 0.9002815633 |
| 1.3795 | 0.06379606717 | 0.9002815633 |
| 1.3978 | 0.06464236512 | 0.9002815633 |
| 1.3895 | 0.06425852506 | 0.9002815633 |
| 1.3737 | 0.06352784158 | 0.9002815633 |
| 1.3545 | 0.06263992242 | 0.9002815633 |
| 1.3755 | 0.06361108401 | 0.9002815633 |
| 1.4174 | 0.0655487826 | 0.9002815633 |
| 1.3913 | 0.06434176749 | 0.9002815633 |
| 1.3783 | 0.06374057222 | 0.9002815633 |
| 1.3959 | 0.06455449812 | 0.9002815633 |
| 1.4099 | 0.06520193918 | 0.9002815633 |
| 1.3938 | 0.06445738196 | 0.9002815633 |
| 1.4121 | 0.06530367992 | 0.9002815633 |
| 1.3739 | 0.06353709074 | 0.9002815633 |
| 1.4378 | 0.06649219672 | 0.9002815633 |
| Average | 0.06436365716 | |

The Raspberry Pi acts as a power supply for the sensors that are connected to it, tapping to some of its available 5 V pins, while the micro USB module is outputting to the MQ7 sensor, servo motor, and fan. The module is estimated to last eight (8) hours on maximum load, however, the system is mostly used in power-saving mode with the Raspberry Pi and GSM module, thus it can last longer up to ten (10) hours. Figure 2 shows the major hardware connections and Figure 3 indicates how the signals connect to each major block.

### 2.3 Device Software Assembly

Each sensor has its own library in Python so that it can function properly with the Raspberry Pi. The libraries allow the Raspberry Pi to initialize and operate the sensors to retrieve the readings from the sensors. The codes for each operation of each sensor were compiled into one program.

The device requires extra components to enable location tracking and data sending. Both the GPS and GSM modules require libraries to be used in order to read GPS location as

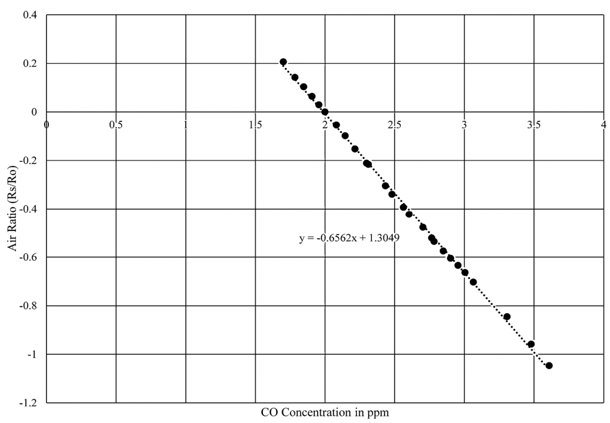


**Figure 7:** MQ-7 CO sensor sensitivity

well as send data via GPRS. The GPS library enables the program to read directly from the module, converting NMEA values into satellite time, latitude, longitude and can compute for speed based on location and time difference. The GSM library allows automated connection on startup for the Raspberry Pi. Adafruit.IO is used as a server in order to store the data sent by the Raspberry Pi as it uses MQTT protocol which allows the Raspberry Pi to send only a small amount of data containing the readings as well as location and time details. This mechanism works with the storage used by the user interface (UI) of the web app. Starting the device integrates the compiled codes and follows the flow in Figures 3 and 4.

### 2.4 Web-Based User Interface

The web application must first be able to read the data stored in the server in order to display the data gathered by the mobile system. The web application reads a Google Spreadsheet containing all the data. Google Spreadsheet automatically converts the raw sensor data to its equivalent Air Quality Index in order to save up on load time for the web application. In order to sync the spreadsheet and Adafruit.IO server, Zapier is used to watch for new data received and transfer to the spreadsheet at fifteen-minute intervals. The

(a) Air pollution monitoring station of DENR-EMB in Binan, Laguna

(b) Calibration setup beside the air pollution monitoring station

**Figure 8:** Calibration site and setup

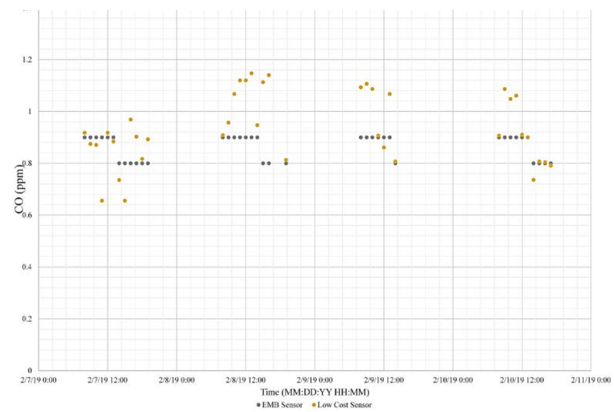


**Figure 10:** CO reading comparison between the EMB data and data obtained with the proposed device

web application makes use of Google Maps and Leaflet to display markers with pop-ups on the map (see Figure 6 for an example). Figure 4 shows how the collected air pollution data gets transferred from the device to the web application. The web application allows the user to specify the date range and select the pollutant to display. In addition, the user has the option to display the average of all data points within the set date range along the specified routes. In order to ensure that all data is synced, a small indicator is placed next to the refresh map button and indicates the status of the server data and the spreadsheet data whether both contain the same amount of data or not. The web app can be accessed at [36].

### 3. CALIBRATION, CORRELATION, RESULTS, AND DISCUSSIONS

Part of the CO sensor calibration, the load resistance must be considered. Figure 7 shows the air ratio of the CO sensor. The graph is plotted on the logarithmic scale to generate a linear relationship between the concentration and the air ratio.

$$y = -0.6563x + 1.3049 \quad (1)$$

To calculate for the load resistance, (2) is used with the values observed from Table 2.

$$\text{load resistance} = \text{series resistance} / \text{air ratio} \quad (2)$$

It is observed that when recalculating the concentration value, all readings return the same value despite having different readings across the sensor. This is because of the air ratio and trying to find the load resistance value.

The sensors were first calibrated based on the available government sensors used by DENR-EMB to monitor air quality in the Philippines. Setting up near one of the stations, the sensors' sensitivity was adjusted accordingly to get as close to what the government sensors were reporting in their Philippines Air Quality Index app which reports hourly readings of the available stations. Figure 8(a) shows a snapshot of the EMB air pollution monitoring station in Laguna. The readings from the station were compared with the proposed device. The proposed device was placed beside the station (see Figure 8(b)) in order to calibrate its sensor readings to achieve the same levels by normalizing the readings. Figures 9 and 10 show the actual readings that were normalized based on the station readings. The EMB data at the site (Binan, Laguna) were obtained from the official EMB app. Readings given by that app are updated hourly. The readings that were shown for the PM 2.5 and the CO are displayed as their AQI value and using the AQI formula we can calculate for the concentration of each. It is important to note that the AQI values are always displayed as an integer value and as such gives an approximate value of the current concentration. The EMB hourly readings were averaged for aligning the time scales of the proposed device readings and EMB data. Figures 8 and 9 show the corresponding readings. As can be seen, the trends obtained by the EMB sensor and the proposed device follow each other. The actual readings of the proposed device then are aligned by normalizing it with respect to the EMB readings.

Using the aligned values, we can calculate for the correlation (Pearson) for each sensor. For each sensor, there are thirty-nine (39) samples obtained for the duration of the testing period. However, seven (7) samples were removed for the CO correlation calculation since they were outliers. A correlation value of 0.761 was obtained for the PM2.5, whereas 0.664 for CO. The results indicate that the readings are adequate enough for achieving close values to the EMB readings.

## 4.CONCLUSION AND RECOMMENDATIONS

The development of the proposed portable low-cost air pollution reading device and its web application was successful and functional with the correct calibration and settings. The sensors are the main limiting factor as its readings are dependent on wind movement and whatever is surrounding the sensors at a current point in time. The unit must remain stationary for a set period for it to take a proper sample and checking and removing outliers is a must due to the number of sudden spikes the unit might receive due to external factors such as smoke-belching or on-going construction. The sensors also require constant calibration in order to obtain accurate data. Overall, the unit functioned as intended and was able to gather a considerable amount of data to give a general idea of its users the air quality in a given area. The low-cost personal mobile device for air pollution measurements and its web app monitoring can be improved in several ways. One improvement that can be made is the provision of a warning system for troubleshooting. Machine learning can also be implemented on the server-side to predict the trends for future air quality based on historical data. In addition, a proper server and site should also be implemented as the current system cannot display real-time data and is delayed by an estimate of 15 minutes from time of measurement to time to display due to latencies posed by third-party applications used in the system. Another improvement would be in the algorithm currently implemented in the system. The algorithm is heavily dependent on the GPS module having a lock on its location as it is its primary means of discerning if the unit is moving or not. The addition of an accelerometer would remedy this and be able to save the last known location would suffice as a temporary location while the GPS does not have a proper lock.

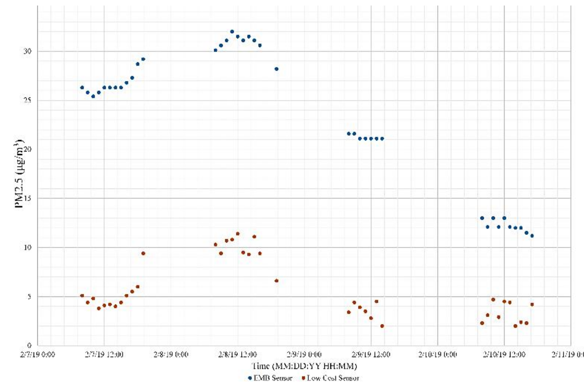


**Figure 9:** PM2.5 reading comparison between the EMB data and data obtained with the proposed device

## ACKNOWLEDGMENT

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