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Fixed and Mobile PM2.5, CO, and CO_2 Measurement Campaigns in Light, Dense, and Heavy Metropolitan Vehicular Traffic with a Low-Cost Portable Air Pollution Sensing Device

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ABSTRACT

Using a low-cost portable air pollution measurement device with positioning, and a monitoring station user interface via web application developed by the authors, stationary and in-motion measurements of particulate matter 2.5 (PM2.5), carbon monoxide (CO), and carbon dioxide (CO2) are reported. The measurement of the air pollutants was done along roads and roadsides in Metro Manila, Philippines at light, medium, and heavy vehicular traffic conditions. The outcomes show that the device and systems work well and can be used as a reference for air pollution data.

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

Air quality is affected by the location and by the density of activities in the area. Air pollution is prevalent nowadays and with the increase in vehicles on the roads combined with the amount of traffic; vehicles emit more gases. These gases combined with various particulate matter (PM) can make areas unhealthy for people to live in and pass through. With the rise of technology, we are now able to detect the amount of certain gas concentrations such as carbon monoxide (CO) and carbon dioxide (CO2) as well as PM in the air and determine the amount present in the air.

In the authors' country, existing structures and stations have already been set around Metro Manila but are stationary and are area limited. Previous developments to air quality monitoring had also been done before in the authors' department. For example, the work of [1] collected sample data around the authors' university. The sensors used collected data on the nitrogen dioxide, carbon dioxide, carbon monoxide and ozone content in the surrounding area. Another development in air quality monitoring was implemented by the Philippine government were nineteen air pollution monitoring stations were installed at various areas around Metro Manila. The data collected was made available to the public [2] as of the authors' last check at [3]. Other approaches to air quality sensing involved the development of low-cost stationary sensors that can be placed near traffic lights. These sensors collected data and sent it to a server through the use of a Global System for Mobile communications (GSM) module. The study focused on a particular area in the city that was known to have high concentrations of traffic and compared data during different times of the day [4]. Ten sensor stations were placed around a roundabout that connected three different districts within Taipei city.

According to the Environmental Management Bureau (EMB) of the Philippines, the air quality of Metro Manila improved [5]. The data was based on those collected by the stationary air quality sensors placed around the city. The readings, nonetheless, are not representative of the whole city due to the range limitations of the sensors. Most of the air pollution based on the data are from motor vehicles while the remaining comes from stationary sources such as factories. Given that the majority of air pollution is coming from moving sources, this means that the range of currently EMB sensors does not cover a lot of areas where vehicles pass through.

In this work, the authors made air pollution measurements campaigns in three vehicular traffic conditions, namely: light medium and heavy. The measurements were made at stationary points as well as in-motion. The authors use their developed low-cost portable air pollution measurement device with positioning, and a monitoring station user interface via web application [6]. The contribution of the work is the PM2.5, CO, and CO2 mobile measurements in three traffic types in Metro, Manila, Philippines, which includes the City of Manila being one of top five areas based on traffic index [7]. This contribution is seen as (i) an initial step for providing the public with specific information about specific

Air Quality Index Levels	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Fair	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy to sensitive groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Very unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Acutely unhealthy	201 to 300	Health alert: everyone may experience more serious health effects.
Emergency	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

Figure 1: AQI levels [37]

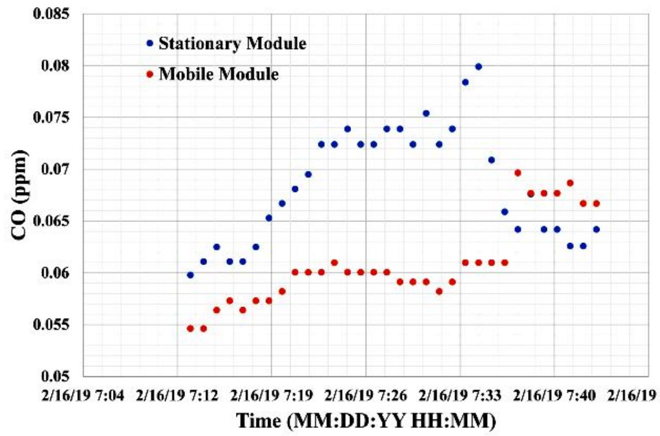

Figure 3: CO measurements

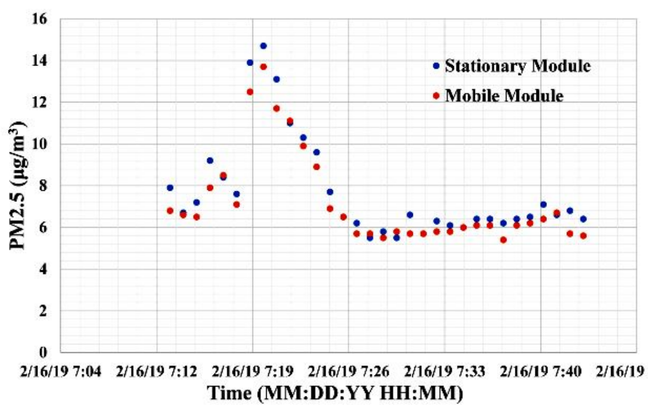

Figure 2: PM2.5 measurements. The Pearson correlation between stationary and mobile measurements is 0.8.

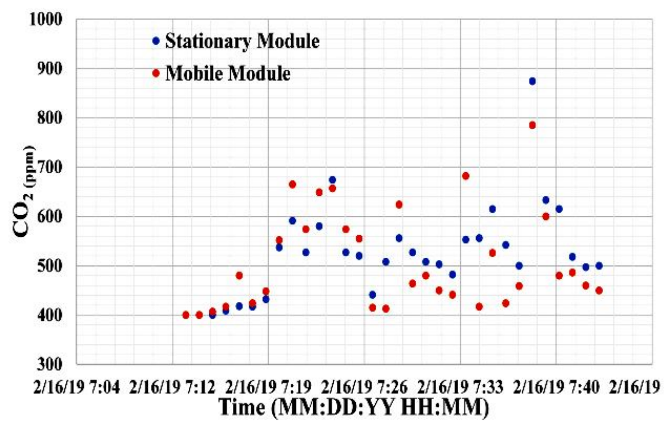

Figure 4: CO2 measurements. The Pearson correlation between stationary and mobile measurements is 0.7.

areas that may be unhealthy, air pollution-wise, to their well-being should they decide to live or walk in the area, as well as (ii) a means for achieving PM2.5, CO, and CO2 pollutant data with a low-cost device with a web-based monitoring station. Nonetheless, the authors recognize that extensive measurements in terms of time and area must be done to reflect the level of air pollution at desired locations. In terms of low-cost based measurement outcomes streams, their work follows the directions of [8]–[23] in the authors' department and laboratories, unlike [24]–[36]. The rest of the paper then is organized as follows. Section 2 discusses the measurement campaign, followed by Section 3 for the outcomes and their corresponding discussions. Conclusions on the work are given in Section 4 including the authors' recommendations.

2. MEASUREMENT CAMPAIGN

Data were measured from three different locations and for each location obtained data for different traffic levels. The traffic levels for each location were determined based on the time of the day and traffic levels as reported by news agencies. The readings are converted from the concentration values to their respective Air Quality Index (AQI) that indicate how bad the air quality is in an area (see Figure 1). The three locations considered are McKinley area in Taguig City, Ayala Avenue in Makati City, and Taft Avenue in Manila City. Using the system for the measurements [6], air pollutants were measured at the roadside for stationary measurements, and on a sedan car with open windows for the mobile ones. Both the height for stationary and mobile measurements were kept to the same level.

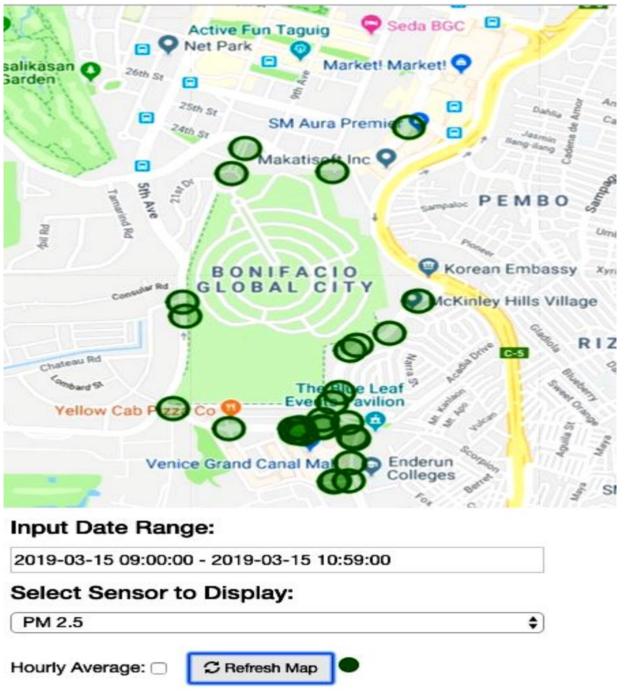

Figure 5: PM2.5 measurement points and routes in the light vehicular traffic area.

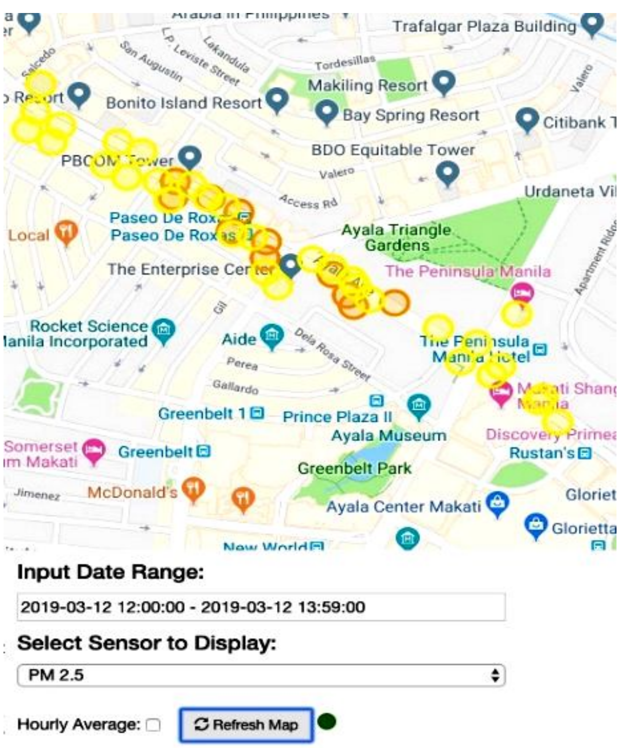

Figure 6: PM2.5 measurement points and routes in the medium vehicular traffic area.

3. RESULTS, AND DISCUSSIONS

The data of the mobile module is compared with the stationary module and the mobile readings have to be within 90% of the stationary readings. Thirty (30) sample points were used to test if the readings are the same. Each of the sensors was able to hit above the target of 90% accuracy. Figures 2 to 4 show the nearness of stationary and mobile measurements. For the CO measurements (Figure 3), the deviation was due to the sensor placement.

The data collected from McKinley at light traffic can be seen in Figure 5. The AQI (through the color code in Figure1) can be seen in a map-like GUI where the user can check historical as well as the latest available data [38]. Some observations gathering data at McKinley are that it is not practical to use a private vehicle for data gathering. The traffic density in the area. Pollution readings observed are mostly from stoplight areas where a number of cars have gathered and can affect the readings. The readings are relatively low due to the low amount of traffic in the area. The data collected from Ayala Avenue can be seen in Figure 6 at low to medium traffic. The data collection was done with constant traffic that moved at a very slow pace, which may not trigger the mobile module. The readings showed the rise of pollutants as the traffic density increased along the route.

The data collected along Taft Avenue at heavy vehicular traffic and can be seen in Figure 7. Jeepneys were used to collect the data along the route and data was collected each time the jeepney stopped for a passenger or at a stoplight. Out of all test locations, this provided the most realistic field testing. The air quality was notably worse compared to the two other locations, likely due to the construction and other road activities in the area.

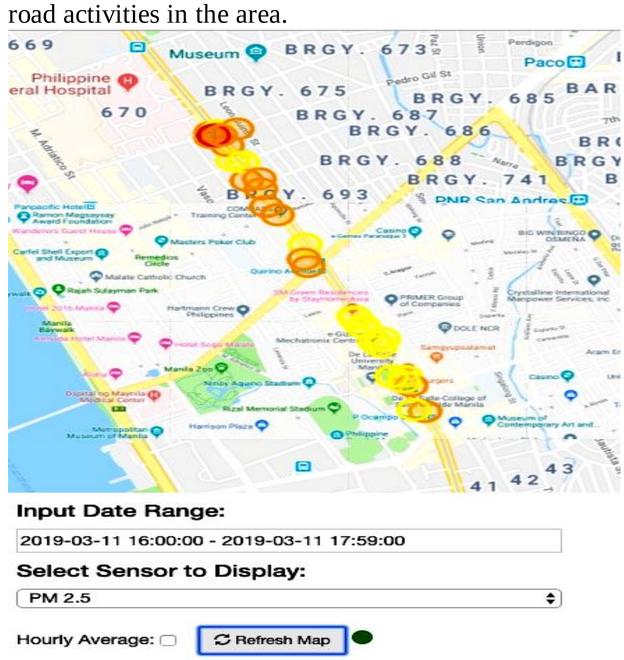

Figure 7: PM2.5 measurement points and routes in the heavy vehicular traffic area.

Within the three areas used to gather data, it was observed that McKinley had the best air quality with readings below all the other sites. Taft Avenue reported the highest readings for pollutants and Ayala Avenue lies in the middle depending on the amount of traffic encountered. This corresponds to the initial assumption that traffic affects the readings of the sensors with a higher density corresponding to worse air quality and higher readings in general. It also confirms the assumption that McKinley is the least polluted of the three locations and Taft is the most polluted. Of all the pollutants monitored, the most dangerous is PM2.5, as this is carcinogenic. CO and CO2 levels remained acceptable for all locations.

4. CONCLUSIONS AND RECOMMENDATIONS

The measurement results indicate that the entire system with its web application for the data monitoring which is coupled with the low-cost air pollution measuring device with positioning information could measure PM2.5, CO, and CO2 air pollutants. Calibration is key for enabling accurate measurements with the use of EMB data. The device is capable of sending data to the cloud database. On the database, the raw values are processed, and calculations are done to convert the values to AQI. The comparison between stationary and mobile measurements shows an accuracy of 90% for all pollutant sensors. As expected, higher AQI values were observed for areas with higher traffic density as compared to others. The web application user interface is available at [38].

The current UI of the web application can be improved upon with better pin tracking for each of the readings. With high traffic densities, multiple pins for a location are generated and though a lot of data is generated, it makes the interface cluttered and difficult to understand. The historical data can be changed as well to reflect only a month of old data to minimize the server load. Additional history data can be stored on a different server and made available only at request.

The data gathering can be improved upon by testing the data readings on vehicles of various heights to check for discrepancies in data. More modules can be deployed at the same time for this purpose and data gathered at the same time to ensure data consistency for comparison.

Air pollution measurements with the developed low-cost device and monitoring system can be used to cover a wider range than the currently installed government stationary sensors. Attaching these sensors to commercial vehicles can also further reduce the costs when compared to the stationary sensors. The commercial vehicles use the same route daily, and some several times in a day, this provides regularly updated pollution readings. The mobile sensors provide a more accurate experience for users at the street level where they are most likely to experience air pollution. This can also provide readings of areas with high pollution levels at different times of the day and allow users to plan their routes accordingly. The data provided by these sensors also help with future projects targeted at controlling air pollution. From the map history of pollution readings, air pollution cleaning machines can be placed at key locations around the city. These locations could be areas that experience the highest amount of air pollution. The mobile monitoring system can be summarized to have a significant impact on society in four key ways. These are; covering a wider range of area for air quality sensing, cutting down the cost of monitoring stations by mounting them on commercial vehicles, providing readings at the street level which users are more likely to experience and creating a detailed map with a history of high pollution areas for future air pollution management and cleaning.

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