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Particulate Matter Continuous Emission Monitoring System on Car Free Day Based on the Internet of Thing

Lina Warlina[1,*], Sri Listyarini[1], Aceng Sambas[2,3], Dian Syah Maulana[4]

[1]Department of Environment, Universitas Terbuka, Indonesia
[2]Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin (UniSZA), Besut Campus, Malaysia
[3]IoT, Machines, and Systems (IMachS) Special Interest Group, Universiti Sultan Zainal Abidin, Gong Badak Campus, Malaysia
[4]Sekolah Menengah Kejuruan PST Al-Huda, Tasikmalaya, Indonesia

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Abstract The escalation in the prevalence of petrol and diesel-powered vehicles within urban locales, coupled with the presence of industrial zones situated on the peripheries of major metropolitan areas, constitutes the primary catalyst for atmospheric pollution. Notably, particulate matter (PM) emerges as a preeminent constituent in the compendium of air pollutants. PM denotes minuscule particles, exhibiting a diameter falling within the range of 2.5 to 10 micrometers or less. It becomes imperative to devise a continuous ambient air PM concentration measurement apparatus to enable the perpetual scrutiny of air quality. The PM2.5 monitoring system necessitates a sensor characterized by affordability, compactness, and a commendable level of precision. To this end, researchers have conceived a sensor predicated on the light scattering methodology for the quantification of airborne particulates. Nevertheless, these sensors mandate a rigorous evaluation phase before their deployment in real-world scenarios. Consequently, there arises a need for a calibration system designed to assess their performance. In the present investigation, the GP2Y1010AU0F Dust Sensor Module was selected for PM assessment. This paper outlines the design of a PM2.5 monitoring system utilizing sensors that have undergone validation within an aerosol chamber. The monitoring system integrates the AVR Arduino Uno microcontroller as the data processing unit, while the Internet of Things (IoT) framework, denoted by ESP8266, was employed in this study. The results obtained through the monitoring endeavor reveal that Car-Free Day (CFD) events yield a reduction of 14.55% in PM concentrations compared to typical operational days. The findings derived from the air quality assessment undertaken during CFD activities substantiate the sensors' aptitude for accurately quantifying PM2.5 concentrations in ambient air.

Keywords Airborne Particulate, Aerosol Chamber, Pm Sensor, Air Particulate Monitoring

1. Introduction

The proliferation of gasoline and diesel-powered vehicles, coupled with the establishment of industrial zones on the peripheries of major urban centers, represents the principal factors driving air pollution. This predicament is particularly exacerbated in metropolitan areas [1]. Notwithstanding the implementation of air quality monitoring initiatives across 6,700 cities and communities spanning 117 countries, a staggering 99% of the global population remains exposed to deleterious concentrations of fine particulate matter [2]. The World Health Organization (WHO) has estimated that in 2019, an alarming 7 million untimely deaths were annually ascribed to the ramifications of ambient and household air pollution.

The deterioration in air quality precipitates an array of issues, including contributions to global climate change [3], ecological degradation [4-6], the exacerbation of respiratory conditions such as asthma [7], and an elevated incidence of lung cancer [8-9]. Within polluted atmospheres, noxious substances such as carbon monoxide (CO) and nitrogen dioxide (NO_2) coexist with diminutive pollutant particles, commonly referred to as Particulate Matter (PM) [10]-[11]. PM is categorized based on particle size into two primary subdivisions: PM10, which comprises particles smaller than 10μm, and PM2.5, encompassing particles with dimensions less than 2.5μm [12-13].

PM2.5 and PM10 denote particle sizes commonly encountered and dispersed within the environment. PM2.5 predominantly emanates from combustion processes such as forest fires and industrial operations, accounting for 80-90% of the total particle output. Conversely, PM10 primarily derives from emissions produced by motorized vehicles, constituting approximately 75-95% of the overall pollutant particles and is predominantly concentrated in urban areas, as exemplified by Bandung city. In a concerted effort to curtail pollutant emissions stemming from motorized vehicles, the local administration of Bandung city has implemented a Car Free Day (CFD) policy, effective every Sunday on the main thoroughfares. CFD represents a grassroots initiative aimed at diminishing society's reliance on motorized transportation. The overarching goal of the CFD initiative is to bolster public consciousness regarding the imperative need to mitigate fuel emissions from automobiles, thus ameliorating the deleterious health implications associated with air pollution, notably particulate matter.

Particles falling within the PM10 classification possess the capacity to infiltrate the respiratory system, causing harm to these vital organs. In contrast, PM2.5 particles exert a more profound impact, as they are capable of being deposited within the alveoli of the lungs. Consequently, there is an imperative need for the implementation of a monitoring system to mitigate or regulate the adverse consequences resulting from the influence of PM [14]-[16]. Notably, in 2021, the Minister of Environment and Forestry promulgated a regulation pertaining to the Information System for Continuous Emission Monitoring System (CEMS).

The surge in the prevalence of petrol and diesel-powered vehicles in urban areas, compounded by the establishment of industrial zones on the outskirts of major metropolitan regions, stands as a pivotal driver of atmospheric pollution. Among the myriad of pollutants, particulate matter (PM) emerges as a prominent constituent, comprising minuscule particles with diameters falling within the range of 2.5 to 10 micrometers, or even less. The imperative need for a continuous ambient air PM concentration measurement apparatus to facilitate ongoing air quality assessment becomes readily apparent. Specifically, the PM2.5 monitoring system demands a sensor that embodies the qualities of affordability, compactness, and a high degree of precision.

To address this challenge, researchers have pioneered a sensor grounded in the light scattering methodology, intended for the quantification of airborne particulates. However, the application of these sensors in real-world scenarios necessitates a rigorous evaluation phase. Consequently, a calibration system emerges as a critical requirement to gauge their performance effectively. In the context of the present study, the GP2Y1010AU0F Dust Sensor Module was chosen for the assessment of PM. This paper delineates the design of a PM2.5 monitoring system, which incorporates sensors that have undergone rigorous validation within an aerosol chamber. The monitoring system incorporates the Arduino Uno microcontroller as the central data processing unit, further enriched by the integration of the Internet of Things (IoT) framework, represented by the ESP8266 and Blynk platform.

2. Methodology

The PM monitoring system must be able to measure PM in various areas such as factory areas, housing, forests, and mountains; be resistant to weather conditions; be able to transmit data continuously; and be monitored by users who need the data anywhere. PM sensor testing systems usually use an aerosol chamber with physical parameters such as temperature, humidity, PM2.5 concentration, CO concentration, and Ozone concentration in the aerosol chamber that can be controlled properly [17-20]. However, this testing system requires a complicated procedure, so that it takes a long time to test many sensors [21]. The system developed in this research consists of a PM measurement system, a data transmission system, and a user interface.

This research employed a comprehensive methodology to assess air quality and the effectiveness of a PM2.5 monitoring system, particularly during Car-Free Day (CFD) events. The study utilized a quasi-experimental design, with a focus on urban areas experiencing increased air pollution due to the prevalence of petrol and diesel vehicles, as well as the presence of industrial zones on the peripheries of major metropolitan regions. The study utilized the GP2Y1010AU0F Dust Sensor Module for the measurement of PM2.5 concentrations. This sensor was selected based on its validation within an aerosol chamber, and its suitability for continuous monitoring of airborne particulates. Furthermore, the AVR Arduino Uno microcontroller served as the central data processing unit. It collected and processed data from the PM2.5 sensor, ensuring accurate and real-time monitoring. Finally, the ESP8266 IoT framework was employed to facilitate data transmission and enable remote monitoring capabilities. It ensured that the collected data could be accessed and analyzed in real-time.

The research flow is presented in Figure 1. The research begins by conducting a literature study of relevant materials. The first step is the process of making an aerosol chamber for PM sensor performance testing purposes. During the testing process, the PM sensor is stored in the aerosol chamber. Next is the process of testing the PM sensor using the Condensation Particle Counter (CPC) as the reference instrument. If the sensor still does not match the reference, a literature study will be carried out again.

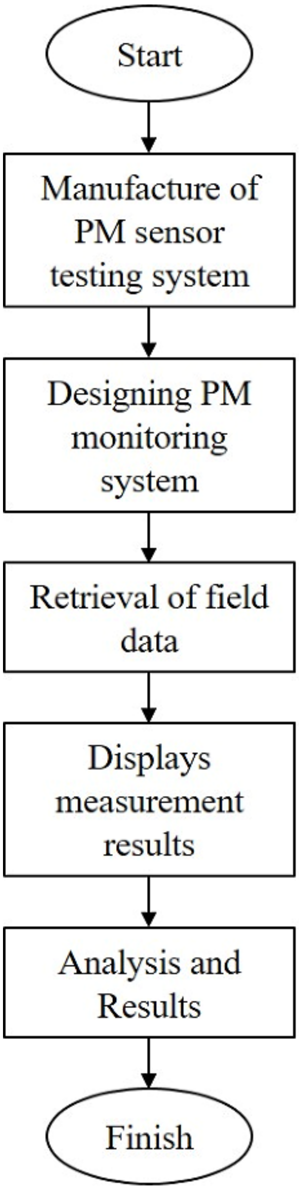

Figure 1. Research of methodology

Field testing of the tool produced in this research was carried out outdoors at several different points around the Car Free Day (CFD) in Bandung city. The goal is to monitor the level of air pollution on the road and find out the relationship of the CFD event to the concentration of PM. At the event, the concentration of PM changes with time. The factors that influence the change in PM concentration will be discussed in this paper. Through the testing system and monitoring system that were built, it is hoped that they can support and increase the independence of the Indonesian nation so that it can produce products that can be used for PM monitoring.

3. Result and Discussion

In this study, the GP2Y1014AU0F sensor is a particulate sensor that employs an infrared (IR) light-emitting diode (LED). When airborne particulate matter enters the sensor's vicinity, the incident particles cause the emitted light to scatter towards a photosensitive detector. This detection methodology is commonly referred to as laser scattering. The magnitude of the scattered or reflected light is contingent upon the concentration of dust particles present in the air. An increased concentration of dust particles results in a more pronounced scattering phenomenon. This modulation in the intensity of light incident on the photosensitive detector consequently leads to a corresponding alteration in the sensor's output voltage. This output voltage can be quantified and employed to ascertain the density of airborne dust particles within the environment. The sensor is acquired in the form of a comprehensive kit such as GP2Y1014AU0F sensor, Arduino Uno, ESP8266, resistor and capacitor.

For my IoT-based project, we have integrated the GP2Y1014AU0F sensor with an Arduino UNO microcontroller and an ESP8266 (ESP01) Wi-Fi module to enable internet connectivity (See Figure 2). To effectively visualize and monitor the data collected by the Arduino, we have employed the Blynk IoT platform. This versatile setup allows for real-time tracking and remote access to the sensor's readings, thus providing a comprehensive solution for monitoring airborne particulate matter density through the Blynk mobile application.

The IR emitter (LED) of the GP2Y1014AU0F sensor is connected to Arduino D7. This connection is likely used to control the sensor's IR emitter with pulses generated by the Arduino. By sending pulses to the sensor's LED, we can activate it as needed for dust detection. Furthermore, the sensor's analog output (VOUT) is connected to Arduino A5. This allows you to read the analog signal generated by the sensor, which is proportional to the dust density in the air. You can then use this analog signal to measure and monitor the dust levels. The hardware for particulate matter using GP2Y1014AU0F in the design box can be seen in Figure 3.

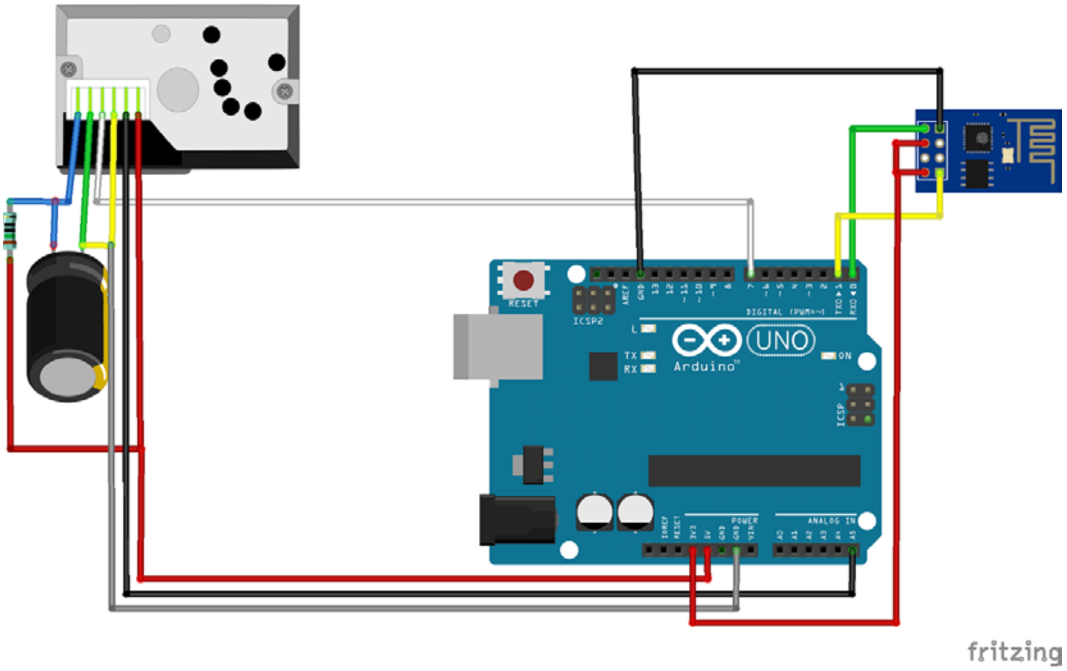

Figure 2. Schematics of Particulate Matter using GP2Y1014AU0F sensor with an Arduino UNO microcontroller

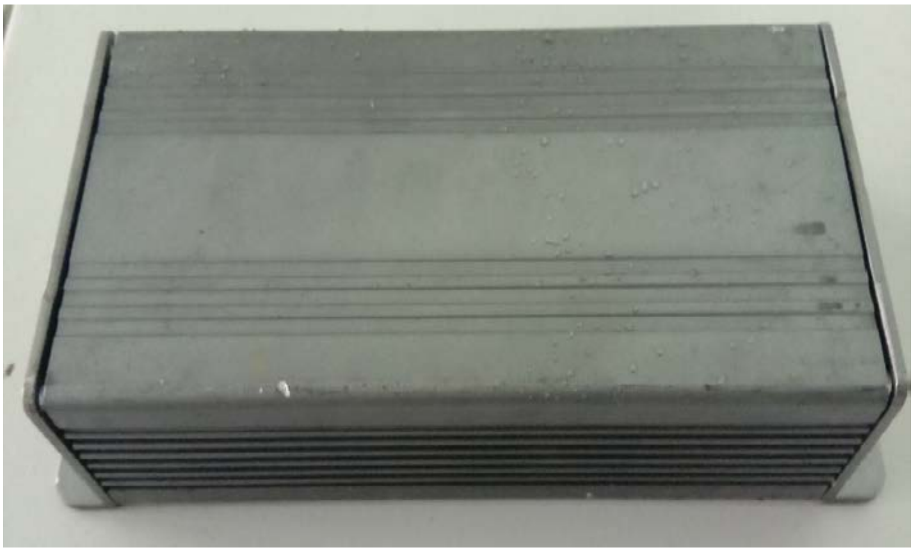

Figure 3. Hardware for Particulate Matter using GP2Y1014AU0F in the design box

Figure 4 illustrates the temporal variation in particulate matter (PM) mass concentration over the course of the study. The investigation encompassed two distinct instances, specifically, on dates 13 August 2023 (Sunday), and 14 August (Monday), each conducted over a 3-hour interval commencing at 07:00 a.m. and concluding at 10:00 a.m. On Sunday, between 7:00 a.m. and 7:53 a.m., the arrival of visitors for the Car-Free Day (CFD) event initiated, and this influx of individuals persisted until 8:48 a.m., coinciding with a discernible increase in PM concentration. Subsequently, from 8:48 a.m. to 9:44 a.m., a decline in activity was observed as CFD participants gradually dispersed, leading to a corresponding reduction in PM concentration. Post 9:44 a.m., vehicular traffic from the CFD area recommenced, marking the conclusion of the event. The transition from 7:00 to 8:48 a.m. during CFD hours witnessed heightened vehicular activity, which corresponded to an augmented PM concentration. Significant disparities were observed in the average time-based data collection between CFD (Sunday) and regular working days (Monday). Finally, the real-time mass concentration using IoT Platform can be seen in Figure 5.

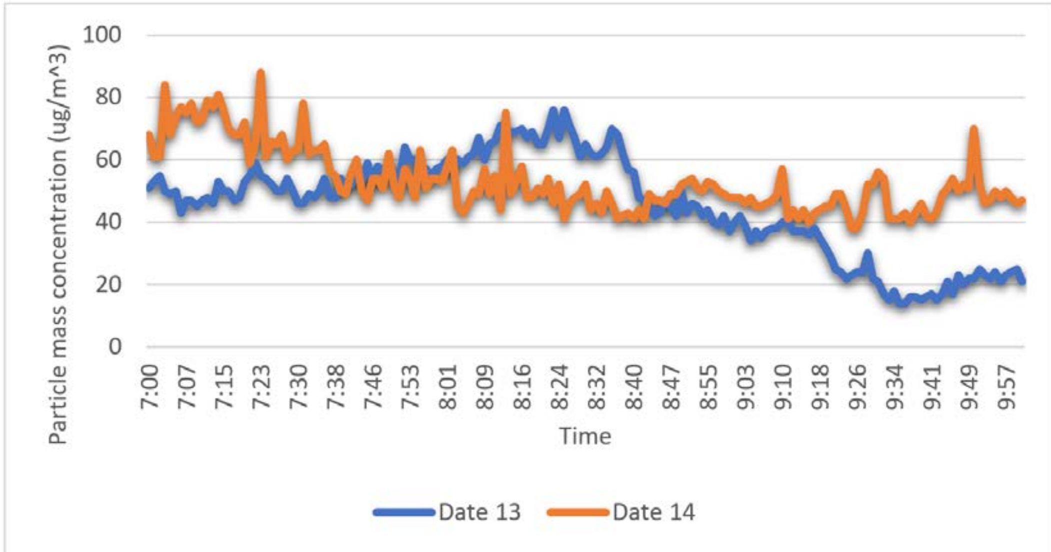

Figure 4. The mass concentration of particles during the Car Free Day (CFD) event

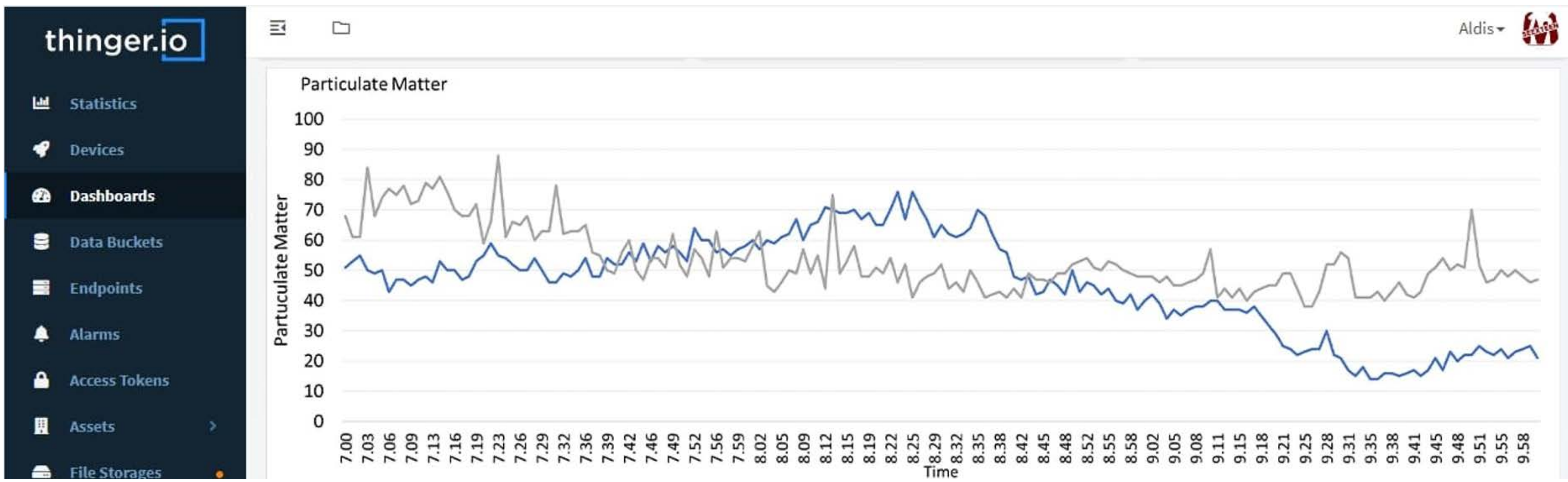

Figure 5. The real-time mass concentration using IoT Platform

The disparity in average data collection periods between Car-Free Day (CFD) events and regular working days is notably substantial. During CFD events, the average mass concentration of particles was 45.473 μg/m³, accompanied by a standard deviation of 16.267 μg/m³. In contrast, on weekdays, the average particle mass concentration registered at 53.218 μg/m³, with a standard deviation of 10.529 μg/m³. The higher standard deviation observed during CFD events is attributed to the dynamic and variable nature of CFD activities, encompassing fundraising promotions, World Cup-related promotions, and various marketing initiatives by multiple companies. Based on the findings of this study, it can be deduced that the impact of CFD events on particle concentration within a 3-hour time frame equated to an increase of 7.745 μg/m³ or 14.554%.

The results of field testing for air quality can be effectively benchmarked against the Air Quality Index (AQI), a standardized metric established by the Environmental Protection Agency (EPA) and accessible at https://airnow.gov. For the duration of the Car-Free Day (CFD) event, the AQI recorded a value of 10.8 μg/m³, categorizing it as "Good" according to the established standards. In contrast, on regular weekdays, the AQI registered at 13 μg/m³, designating it as being within the "Moderate" category. It is noteworthy that the EPA discourages frequent outdoor activities in areas where the AQI falls within the Moderate category, emphasizing the potential impact on air quality and public health.

4. Conclusions

In this study, the GP2Y1010AU0F Dust Sensor Module was chosen to assess particulate matter (PM). This research outlines the development of a PM2.5 monitoring system that utilizes validated sensors within an aerosol chamber. The system incorporates the AVR Arduino Uno microcontroller as the central data processing unit, while the Internet of Things (IoT) framework, represented by the ESP8266, is employed for connectivity and data transmission. Significant differences in data collection periods between Car-Free Day (CFD) events and typical workdays were observed. During CFD events, the average mass concentration of particles measured 45.473 μg/m³, with a relatively high standard deviation of 16.267 μg/m³. In contrast, on regular weekdays, the average particle mass concentration was 53.218 μg/m³, with a lower standard deviation of 10.529 μg/m³. Conclusively, this study suggests that CFD events had a measurable impact on particle concentration within a 3-hour timeframe, leading to an increase of 7.745 μg/m³ or 14.554%.

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