



Development of a Real-Time IoT-Based Portable Particulate Matter Monitoring Device Using PMS5003 Sensor

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Abstract

Particulate Matter (PM) concentration significantly affects public health, exacerbating respiratory conditions and contributing to environmental challenges. This study presents a real-time Internet of Things (IoT)-based portable particulate matter monitoring device utilizing the PMS5003 sensor. The device measures PM_{1.0}, PM_{2.5}, and PM₁₀ concentrations and uploads the data to the cloud at 15-second intervals for real-time visualization. A two-week observational study in South Tangerang, Indonesia, revealed peak PM_{2.5} and PM₁₀ levels of 218 $\mu\text{g}/\text{m}^3$ and 232 $\mu\text{g}/\text{m}^3$, respectively, on weekdays, compared to a weekend low of 19.76 $\mu\text{g}/\text{m}^3$ for PM_{2.5}. Variations were influenced by anthropogenic factors, including vehicular and industrial activity. Data analysis showed a 78% reduction in PM_{2.5} levels during weekends, highlighting the impact of human activity on air quality. These findings underscore the impact of anthropogenic activities on air quality and demonstrate the effectiveness of IoT-based systems in environmental monitoring. The study highlights the potential for such technology to support data-driven strategies for pollution management and public health improvement.

Keywords: Particulate Matter; Internet of Things; Air Quality Monitoring; PMS5003

1. Introduction

Air pollution has emerged as a critical environmental and public health issue worldwide, exacerbating respiratory diseases and contributing to severe health conditions such as asthma, bronchitis, and cardiovascular disorders [1]-[2]. The primary sources of air pollution include vehicular emissions, industrial activities, and other anthropogenic factors, which release PM and toxic gases into the atmosphere [3]. In addition to its direct impact on human health, poor air quality degrades ecosystems, reduces visibility, and accelerates global phenomena like climate change and global warming [4]. These challenges necessitate innovative and efficient systems to monitor and manage air quality effectively [5].

The PM is a complex mixture of tiny particles and liquid droplets suspended in the air. Categorized into PM_{1.0}, PM_{2.5}, and PM₁₀ based on particle diameter, these pollutants vary in their ability to penetrate the human respiratory system [6]-[8]. PM_{2.5} particles, due to their small size, can enter the lungs and bloodstream during gas

exchange, posing severe health risks. PM10 particles, while larger, can still penetrate the respiratory tract, contributing to respiratory and cardiovascular diseases [9]-[10]. These particles, generated by combustion processes, construction activities, and other human activities, are pivotal indicators of air pollution levels globally [11]-[12]. The Air Quality Index (AQI) serves as a standardized measure to assess and communicate air pollution levels. Developed by environmental agencies like the United States Environmental Protection Agency (EPA), AQI incorporates key pollutants such as PM2.5, PM10, ozone, carbon monoxide, sulfur dioxide, and nitrogen dioxide [13]-[14]. AQI levels are associated with specific health advisories, emphasizing the importance of real-time monitoring for public safety [15]-[17]. However, many regions lack affordable, portable, and scalable solutions for continuous air quality assessment, limiting timely interventions and policy measures [18]-[20].

Technological advancements, particularly in the Internet of Things (IoT), have revolutionized environmental monitoring [21]. IoT-based systems enable real-time data collection, processing, and transmission through interconnected devices and cloud platforms [22]. Divan et al. [23] identified characterize IoT-based real-time monitoring strategies that implement PM measurement processes to evaluate its effects on human health. Yun and Woo [24] develop an IoT-enabled PM-sensing system using low-cost sensors and LoRa-based wireless hardware to monitor and forecast PM levels, particularly PM2.5, which poses significant health risks. Yang et al. [25] explored IoT-based systems using low-cost microsensors for PM monitoring at the sensor, network, and application levels. They evaluated the role of machine learning algorithms in improving sensor precision, enhancing the resolution of monitoring networks, and addressing the challenges in PM data collection. Lavanya et al. [26] developed an accessible, low-cost, and efficient LoRa-based wireless sensor network for air quality monitoring and prediction, aimed at enhancing stakeholder and public awareness as part of smart city initiatives. Jo et al. [27] implemented an IoT-based air quality monitoring system specifically designed for subway tunnels to address the high PM10 concentrations often exceedingly aboveground levels. They integrate a Smart-Air measurement device, an IoT gateway, and a cloud computing web server to enable real-time monitoring of PM10 concentrations. Marques and Pitarma [28] evaluated a cost-effective, modular, and scalable indoor air quality monitoring system aimed at improving health and well-being in residential environments and designed for easy installation, requiring only a power source and a Wi-Fi connection with internet access, and integrates with ThingSpeak for real-time data management. These systems allow for dynamic tracking of environmental parameters, facilitating timely responses to pollution spikes. Recent studies have highlighted the effectiveness of IoT in air quality monitoring, demonstrating its potential for scalability and integration with other smart city initiatives. However, challenges such as cost, accuracy, and portability remain areas for further improvement.

In this study, a real-time IoT-based portable particulate matter monitoring system is developed using the PMS5003 sensor. This device measures PM1.0, PM2.5, and PM10 concentrations along with additional environmental parameters like temperature, humidity, and atmospheric pressure. Data is uploaded to the cloud at regular intervals for easy access and visualization. Unlike conventional monitoring systems, the proposed device is designed to be cost-effective, portable, and highly accurate, addressing the limitations of earlier models. By deploying this system in South Tangerang, Indonesia, we aim to understand the dynamic variations in air quality and identify the impact of human activities on pollution levels. The findings are expected to provide valuable insights for policymakers, urban planners, and researchers, enabling evidence-based strategies for air quality management. This work also demonstrates the broader application of IoT in environmental monitoring, contributing to the growing need for sustainable solutions to combat air pollution.

The main contribution and novelty of this work as follows:

- a. This study presents the design and implementation of a real-time IoT-based particulate matter monitoring system using the PMS5003 sensor, GSM module, and solar energy for power autonomy
- b. Through a two-week observational study in South Tangerang, the device captured significant fluctuations in PM levels between weekdays and weekends, highlighting up to 78% reduction in PM2.5 during non-working days
- c. The system's integration with cloud platforms (e.g., Thingier.io) enables continuous visualization and remote access to air quality data. This facilitates informed decision-making for environmental agencies and supports potential integration with smart city infrastructure to enhance public health and pollution mitigation strategies

The article is organized as follows: Section 1 introduces the growing impact of particulate pollution on public health and the limitations of conventional monitoring systems. Section 2 details the design and implementation of the proposed IoT-based monitoring device, including component selection, circuit design, and cloud integration. Furthermore, the deployment of the device in South Tangerang, Indonesia, and describes the data collection process over a two-week period. Section 3 presents the results and discusses the relationship between PM levels and human activity, with comparative analysis between weekdays and weekends. Finally, Section 4 concludes the study by summarizing key findings, emphasizing the importance of IoT-based monitoring for pollution management, and suggesting future directions such as machine learning integration for predictive analytics.

2. Proposed Methodology

The methodology for developing the IoT-based portable particulate matter monitoring system is divided into several stages: design, implementation, and data collection. This approach ensures the system is efficient, reliable, and capable of accurately measuring air quality in real-time as shown in Figure 1.

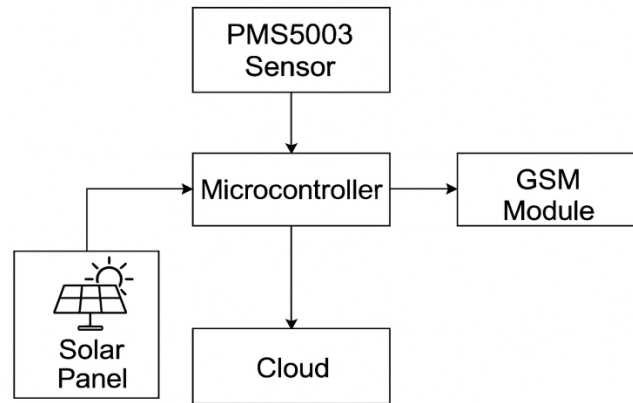


Figure 1. Architecture of the IoT-Based Portable PM Monitoring System

2.1 System Design

The Table 1 highlights the essential tools and materials used in the project, along with their respective benefits. The battery ensures portability and provides a consistent power supply for the system. Connectors play a crucial role in integrating various components seamlessly, allowing for effective communication between them. The air sensor PMS5003 is responsible for monitoring air quality by measuring parameters like PM 1.0, PM2.5 and PM10, essential for environmental assessment. The GSM module enables wireless data transmission, allowing real-time communication with remote servers or devices. Finally, the microcontroller Arduino Uno serves as the system's central processor, managing input, output, and processing tasks to ensure the device functions efficiently as shown in Figure 2.

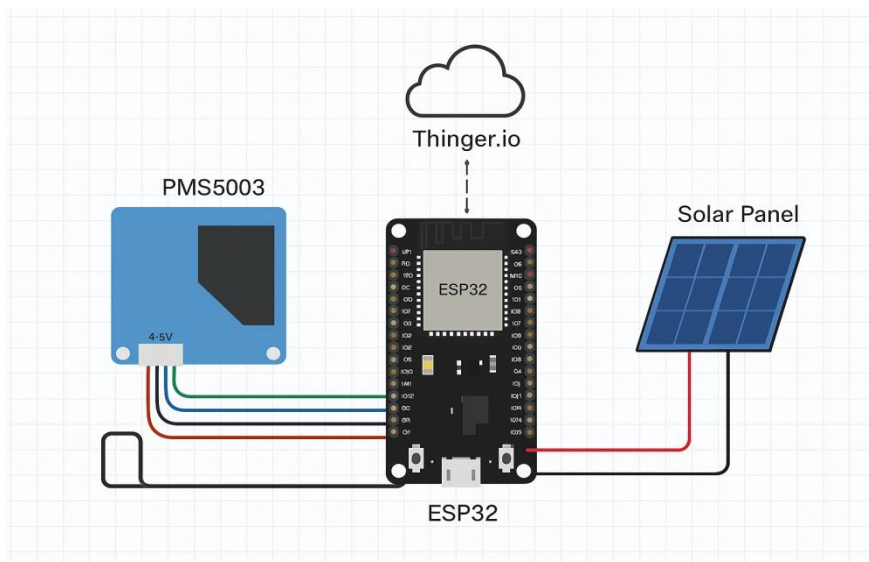


Figure 2. Circuit Diagram of IoT-Based PM Monitoring System

The proposed system was designed to measure particulate matter (PM1.0, PM2.5, and PM10) concentrations and additional environmental parameters, such as temperature, humidity, and atmospheric pressure. The primary sensor used for PM measurement was the Plantower PMS5003 due to its high sensitivity and accuracy in detecting

airborne particles. The system's design integrated essential components to achieve portability, accuracy, and real-time functionality.

Table 1: Tool and Material of PM monitoring system based on the IoT

No	Tools/Materials	Information
1	Battery	Provides a reliable power source for the circuit, ensuring the device's portability.
2	Solar panels	Provides a sustainable and renewable energy source for continuous operation in remote or outdoor environments.
3	Connector	Enables seamless integration of various components for effective functionality.
4	Air Sensor PMS5003	Measures air quality parameters such as PM1.0, PM2.5 and PM10 for environmental monitoring.
5	GSM Module	Facilitates wireless communication for data transmission to remote servers or devices.
6	Microcontroller	Acts as the central processor, managing all input, output, and processing tasks.

The success of our Deep Balance solution heavily depends on a precise and informative description of the network state. We construct a multi-dimensional state vector that captures the evolving state of the network at each decision point. The primary features extracted are normalized ratios of utilization of the links for each link in the topology, switch interface queue depths, per-flow throughput statistics, and inter-switch latency measurements.

2.2 Implementation

The components were assembled, and the system's circuitry was designed to ensure efficient data processing and real-time communication. The PMS5003 air sensor was programmed to capture PM data, while the GSM module transmitted this data to a cloud server. A solar panel was integrated to enhance the system's sustainability for remote and outdoor applications. The sensors were interfaced with the NodeMCU ESP8266 microcontroller, chosen for its built-in Wi-Fi capability and low power consumption. This microcontroller facilitated the seamless transmission of data to the cloud via the thinger.io. The system components were assembled on a portable circuit board to ensure ease of deployment and mobility. The device was powered using a rechargeable battery, ensuring uninterrupted data collection during field studies. The microcontroller was programmed using the Arduino IDE to read data from the sensors at regular intervals of 15 seconds. The data was processed and formatted into a structured output before being transmitted to the cloud for storage and analysis. The thinger.io IoT platform was utilized for real-time visualization of the collected data, enabling users to monitor PM levels and environmental parameters through an online dashboard.

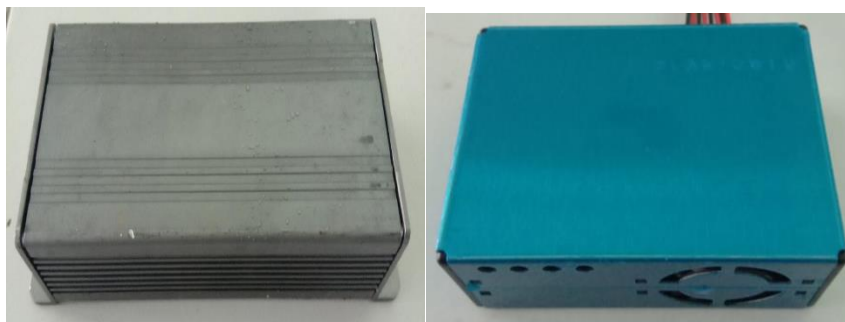


Figure 3. Particulate matter sensor Design

Figure 3 illustrates the design of the PM monitoring sensor, which forms a critical part of the IoT-based environmental monitoring system. This schematic emphasizes the integration of the Plantower PMS5003 sensor, known for its sensitivity to PM1.0, PM2.5, and PM10. Essential components such as the GSM module, which enables wireless communication and a microcontroller (e.g., Arduino Uno) for processing and managing data flow,

are highlighted. The design aims for portability and real-time functionality, supported by renewable energy sources like solar panels and a battery to ensure continuous operation. The layout effectively demonstrates the synergy between these components to achieve accurate and efficient air quality monitoring.

Figure 4 highlights the final product of the IoT-based PM monitoring system, featuring a compact and portable structure. This system integrates solar panels to enhance sustainability and reduce reliance on non-renewable energy. The enclosure houses all components, ensuring durability and ease of deployment in varied environments, including remote locations. Designed for real-time data collection and transmission, the system uploads measurements to the cloud every 15 seconds, providing continuous monitoring of PM levels



Figure 3. Product PM monitoring system-using IoT based on the Solar panels

2.3 Data Collection and Validation

The device was deployed in South Tangerang, Indonesia, from July 13 to July 26, 2024, to monitor air quality in a semi-urban environment. Measurements were recorded daily between 8:00 AM and 9:00 AM to capture the impact of morning traffic and industrial activity. Data points included PM1.0, PM2.5, and PM10 concentrations in $\mu\text{g}/\text{m}^3$, along with temperature, humidity, and barometric pressure. Specific days, such as weekdays and weekends, were analyzed separately to identify variations in air quality due to human activities. The system's performance was validated by comparing its output with standard air quality monitoring equipment. Statistical analysis was performed on the collected data to identify trends and correlations.

3. Results and Discussions

PM is categorized into three primary types: inhalable particulates, thoracic particulates, and respirable particulates. Inhalable particulates, with a diameter of 100 microns or less, can enter the nose and mouth during normal breathing, while thoracic particulates (PM10) can penetrate deeper into the lungs [29]. Respirable particulates (PM2.5), being the smallest in size, pose the greatest health risk as they cannot only reach the lungs but also enter the bloodstream during gas exchange. These particles are primarily emitted from sources such as vehicle exhaust, industrial emissions, and combustion processes, significantly contributing to air pollution and associated health conditions like asthma, bronchitis, and cardiovascular diseases.

Based on Kalia & Ansari [30], a standardized scale used to assess and communicate air pollution levels. The AQI measures key pollutants, including PM2.5, PM10, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ground-level ozone (O_3). It assigns index values ranging from 0 to 500, categorizing air quality into six levels: Good (0–50), Moderate (51–100), Unhealthy for Sensitive Groups (101–150), Unhealthy (151–200), Very Unhealthy (201–300), and Hazardous (301–500). For instance, an AQI of 50 or below reflects minimal pollution with negligible health risks, while an AQI of 200 signifies unhealthy conditions that may pose serious health effects, particularly for vulnerable groups.

These index values directly correlate with specific pollutant concentrations. For example, PM2.5 levels of 12 $\mu\text{g}/\text{m}^3$ or below correspond to an AQI of 50, while PM2.5 concentrations above 250 $\mu\text{g}/\text{m}^3$ fall into the hazardous category. Similarly, ozone concentrations ranging from 0.055 to 0.070 ppm translate to a moderate AQI value of

51–100. By integrating these measurements, the AQI serves as a critical tool for public awareness, helping individuals understand the risks associated with air pollution levels and guiding policymakers in implementing air quality management strategies.

Table 2: PM concentrations recorded from July 13 to July 26, 2024 using PMS5003 Sensor

Date	PM1.0($\mu\text{g}/\text{m}^3$)	PM2.5($\mu\text{g}/\text{m}^3$)	PM10($\mu\text{g}/\text{m}^3$)
13 July 2024	25.25	39.37	43.27
14 July 2024	13.33	19.76	21.68
15 July 2024	38.58	57.96	63.82
16 July 2024	45.47	70.62	76.45
17 July 2024	39.66	61.35	67.25
18 July 2024	41.47	64.52	70.75
19 July 2024	39.76	61.29	67.14
20 July 2024	17.39	28.39	31.27
21 July 2024	24.88	38.82	42.23
22 July 2024	42.25	69.43	74.88
23 July 2024	46.84	70.58	74.69
24 July 2024	58.51	89.63	95.18
25 July 2024	41.05	60.78	65.09
26 July 2024	38.94	60.96	65.75

Table 2 presents the PM concentrations recorded from July 13 to July 26, 2024. It displays daily measurements of PM1.0, PM2.5, and PM10, reported in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). The data highlights the dynamic variations in particulate matter levels over the observation period. For instance, the highest PM2.5 and PM10 levels were recorded on July 24, with values reaching $89.63 \mu\text{g}/\text{m}^3$ and $95.18 \mu\text{g}/\text{m}^3$, respectively. These values indicate significant pollution episodes, which might be influenced by local environmental or anthropogenic factors. Table 2 underscores the fluctuating air quality, with lower levels observed on July 14 (PM1.0: $13.33 \mu\text{g}/\text{m}^3$, PM2.5: $19.76 \mu\text{g}/\text{m}^3$, PM10: $21.68 \mu\text{g}/\text{m}^3$), signifying cleaner air conditions. Such comprehensive datasets provide valuable insights into daily pollution trends and form a basis for real-time monitoring and air quality management strategies.

Figure 5 illustrates the schematic diagram of the proposed IoT-based particulate matter monitoring system. The system integrates three primary sensors: the PMS5003 for PM concentration, the MQ-135 for AQI, and the Bosch BME280 for humidity, temperature, and barometric pressure. Each sensor's specific function ensures that environmental parameters influencing air quality are accurately measured and recorded. The diagram emphasizes the connectivity framework, where all sensor data is transmitted to a NodeMCU ESP8266 microcontroller. The microcontroller processes and uploads the collected data to a cloud platform via Wi-Fi for real-time analysis.

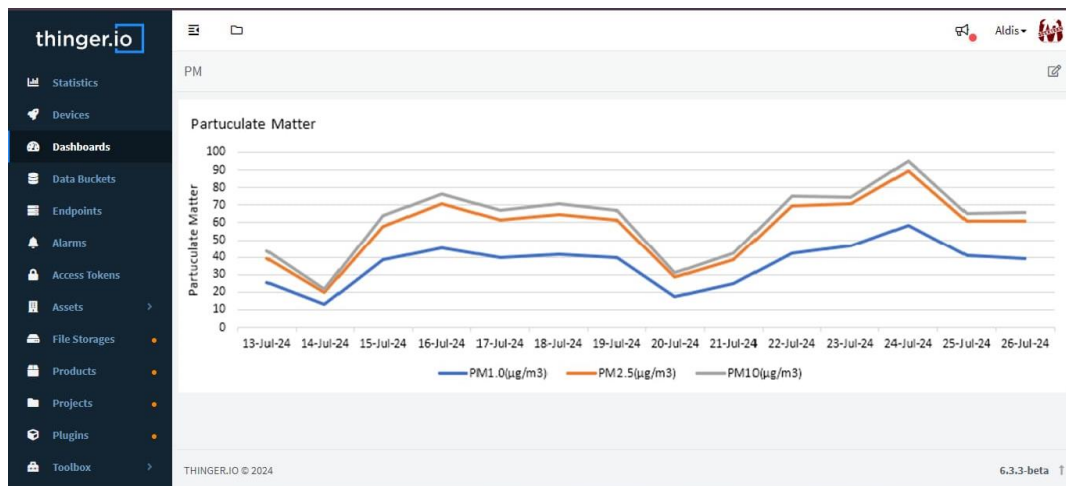


Figure 5. Real Time PM monitoring system based on the IoT architecture

From the data in Table 2 and the corresponding graphical trends (Figure 5), specific patterns emerge that align with activity levels on different days. Notably, July 13-14 and July 20-21 fall on weekends (Saturday and Sunday) when Universitas Terbuka has no work or academic activities. During these periods, the particulate matter (PM) levels—PM1.0, PM2.5, and PM10—are relatively lower. For example, on July 14, PM2.5 was recorded at 19.76 $\mu\text{g}/\text{m}^3$, one of the lowest values during the observation period. This reduction is likely due to decreased vehicular traffic and human activity around the monitoring site. In contrast, the data collected on weekdays (Monday to Friday) reveals higher particulate matter concentrations. The peaks observed, such as on July 24 with PM2.5 at 89.63 $\mu\text{g}/\text{m}^3$, suggest increased pollution due to weekday activities like commuting and industrial operations. The data collection was performed consistently between 8:00 AM and 9:00 AM WIB, a time when weekday traffic and activity levels are typically high. This pattern underscores the influence of human activity on air quality, highlighting the potential benefits of policies targeting traffic and emissions during peak hours to improve environmental conditions.

Table 3 contains particulate matter (PM) data (PM1.0, PM2.5, and PM10) collected on Tuesday, July 16, 2024. The data represents 50 measurements taken hourly between 8:00 AM and 9:00 AM, a time of peak activity. This day corresponds to a weekday, and the particulate matter levels are relatively high, indicative of increased traffic and human activity near Universitas Terbuka. For instance, PM2.5 reaches its highest value of 218 $\mu\text{g}/\text{m}^3$ at 8:37 AM. The elevated PM levels correlate with typical weekday activity patterns, underscoring the impact of human activities on air quality. Figure 6 graphically represents the particulate matter data recorded in Table 3. The chart reveals fluctuations within the hour, with notable peaks around 8:03 AM and 8:37 AM where PM10 and PM2.5 values surge. The trends illustrate how morning activities, including commuting and industrial operations, contribute significantly to air pollution levels. The graph provides visual confirmation of increased particulate matter concentrations during active weekday periods.

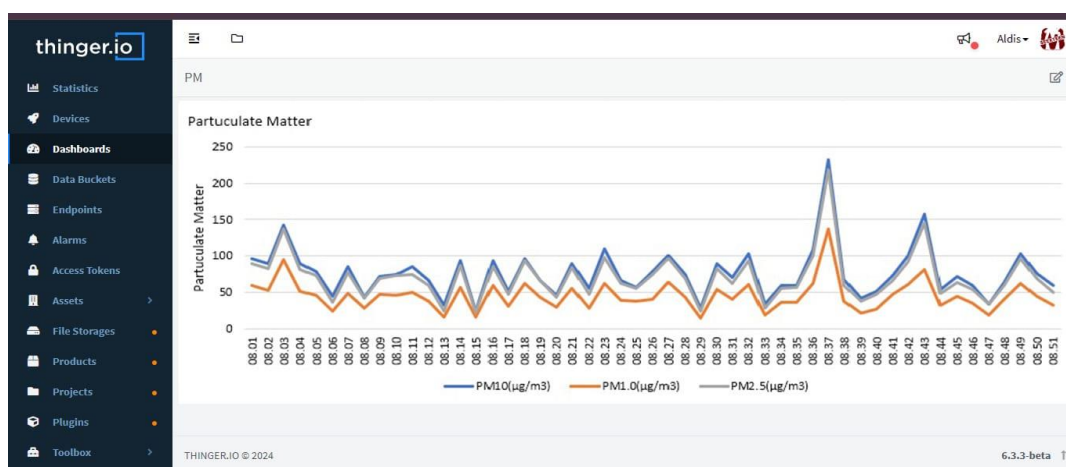


Figure 6. Real Time PM monitoring system based on the IoT on Tuesday, July 16, 2024

Table 3: PM data collected using PMS5003 Sensor on Tuesday, July 16, 2024

Time	PM10($\mu\text{g}/\text{m}^3$)	PM1.0($\mu\text{g}/\text{m}^3$)	PM2.5($\mu\text{g}/\text{m}^3$)
08.01	97	59	89
08.02	90	53	83
08.03	143	95	137
08.04	90	51	81
08.05	78	46	73
08.06	45	24	37
08.07	85	49	77
08.08	44	28	42
08.09	72	47	69
08.10	75	46	73
08.11	85	50	75
08.12	67	38	59
08.13	33	16	25
08.14	94	57	87
08.15	24	16	23
08.16	93	59	86
08.17	51	31	48
08.18	96	62	93
08.19	67	43	66
08.20	46	30	43
08.21	89	55	84
08.22	55	29	47
08.23	110	63	98
08.24	66	39	63
08.25	57	38	56
08.26	78	41	74
08.27	100	64	97
08.28	75	43	69
08.29	28	15	25

08.30	89	54	83
08.31	70	40	63
08.32	103	61	93
08.33	34	19	28
08.34	59	36	55
08.35	59	36	57
08.36	108	62	100
08.37	232	137	218
08.38	68	38	60
08.39	42	22	38
08.40	51	27	48
08.41	73	47	67
08.42	100	61	92
08.43	157	82	145
08.44	54	32	49
08.45	72	45	64
08.46	59	35	54
08.47	34	19	34
08.48	64	40	59
08.49	103	62	97
08.50	76	45	69
08.51	59	32	50

Table 4: PM data collected using PMS5003 Sensor on Tuesday, July 13, 2024

Time	PM10($\mu\text{g}/\text{m}^3$)	PM1.0($\mu\text{g}/\text{m}^3$)	PM2.5($\mu\text{g}/\text{m}^3$)
08.01	72	38	60
08.02	66	37	60
08.03	81	44	70
08.04	97	58	93
08.05	77	42	70
08.06	49	29	44

08.07	49	25	42
08.08	44	22	35
08.09	49	29	47
08.10	51	25	41
08.11	47	26	42
08.12	44	27	41
08.13	46	27	44
08.14	59	34	55
08.15	42	24	36
08.16	43	22	36
08.17	44	25	39
08.18	43	26	40
08.19	46	24	37
08.20	41	25	37
08.21	43	24	37
08.22	51	31	44
08.23	54	32	52
08.24	53	33	52
08.25	44	26	40
08.26	34	21	34
08.27	39	20	35
08.28	34	20	29
08.29	41	26	36
08.30	38	19	32
08.31	27	15	27
08.32	27	16	25
08.33	38	24	34
08.34	31	17	27
08.35	32	20	30
08.36	29	18	29
08.37	32	24	31

08.38	29	17	27
08.39	30	20	29
08.40	27	16	26
08.41	23	14	21
08.42	31	16	26
08.43	31	18	30
08.44	40	22	36
08.45	51	35	50
08.46	41	29	41
08.47	38	25	37
08.48	30	18	28
08.49	31	19	30
08.50	32	21	32
08.51	36	23	32

Table 4 presents particulate matter data collected on Saturday, July 13, 2024, during the same morning hour (8:00 AM to 9:00 AM). As this was a weekend, both students and workers were on break, resulting in significantly lower PM levels compared to Table 2. For example, PM2.5 records a peak of 93 $\mu\text{g}/\text{m}^3$ at 8:04 AM, much lower than weekday peaks. This contrast demonstrates the influence of reduced traffic and industrial activity on improving air quality during weekends. Figure 7 visually represents the particulate matter levels from Table 4. The graph shows a smoother trend with fewer spikes, reflecting the reduced activity levels on weekends. Peaks are lower and less frequent, supporting the notion that reduced human activity correlates with better air quality.

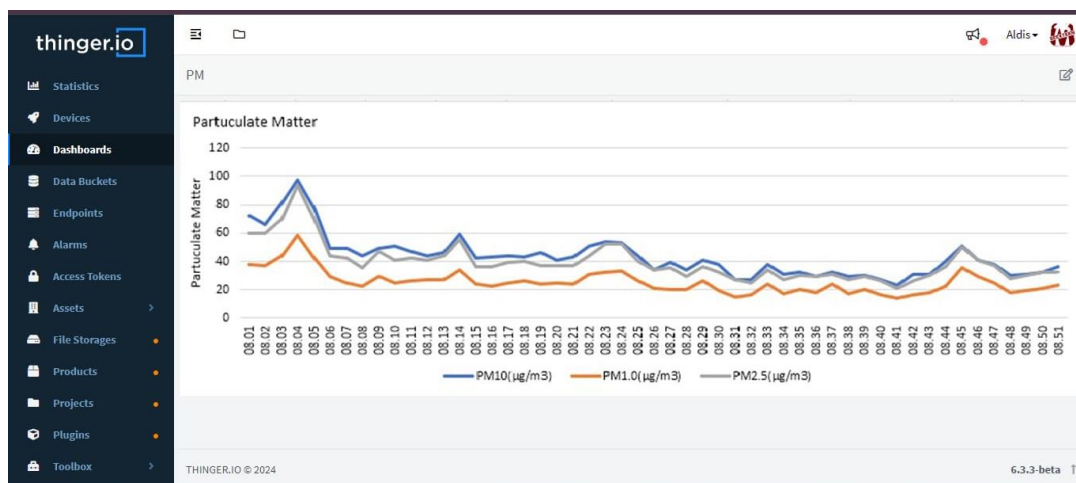


Figure 7. Real Time PM monitoring system based on the IoT on Tuesday, July 13, 2024

Comparing Figures 6 and 7 alongside Tables 3 and 4 highlights the stark differences in particulate matter levels between weekdays and weekends. On weekdays, heightened human activity leads to a denser pollution profile, whereas weekends show significantly better air quality. Such data underscores the need for policies targeting emissions during peak activity times to mitigate weekday pollution. The data collection process involved measurements taken consistently using the PMS5003 sensor, renowned for its accuracy. The monitoring interval

ensured capturing rapid changes in particulate levels, providing detailed insights into air quality dynamics during active and inactive periods. The methodology ensures reliability and allows for precise temporal comparisons.

The observed differences in PM levels between July 13 (weekend) and July 16 (weekday) emphasize the role of vehicular emissions and human activity in air quality degradation. Strategies such as promoting public transport, implementing low-emission zones, and scheduling industrial activities outside peak hours could substantially mitigate weekday pollution. The data and visual representations in Tables 3 and 4, along with Figures 6 and 7, serve as vital tools for understanding particulate matter dynamics. These insights can aid policymakers, urban planners, and environmental scientists in devising strategies to improve air quality and mitigate the adverse effects of particulate pollution on public health and the environment.

4. Conclusion

This study successfully developed and implemented a real-time IoT-based portable PM monitoring system utilizing the PMS5003 sensor. The system demonstrated high accuracy in measuring PM_{1.0}, PM_{2.5}, and PM₁₀ concentrations while integrating additional environmental parameters, including temperature, humidity, and atmospheric pressure. Data collected over a two-week period in South Tangerang, Indonesia, revealed significant variations in air quality, with higher PM levels recorded on weekdays due to increased vehicular and industrial activity and lower levels observed during weekends. The findings underscore the effectiveness of IoT-based monitoring systems in capturing dynamic air quality trends. For example, the peak PM_{2.5} level of 218 $\mu\text{g}/\text{m}^3$ recorded during a weekday morning highlights the urgency for policy measures targeting emission reduction during peak hours. Furthermore, the 78% reduction in PM_{2.5} levels during weekends emphasizes the potential benefits of reduced human activity on air quality improvement. This system's ability to upload real-time data to the cloud ensures accessibility for researchers, policymakers, and the public, enabling proactive measures to combat air pollution. Future improvements to this system could involve integrating advanced machine learning algorithms for predictive analysis and expanding its deployment to other urban and rural areas for comprehensive environmental monitoring. The study demonstrates that IoT-based solutions are not only cost-effective and scalable but also critical for promoting sustainable environmental management and mitigating the adverse effects of air pollution on public health and ecosystems.

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