Prototype of a Dust Monitoring Device in the Mechanical Engineering Laboratory at PGRI University Semarang Using the GP2Y1010AU0F Sensor

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ABSTRACT

Reducing carbon emissions is crucial for supporting sustainability in energy systems, which necessitates the monitoring of hazardous substances in the air. This study aims to design an accurate real-time air quality monitoring system for the Mechanical Engineering Laboratory, capable of tracking air pressure and providing detailed information on measured parameters. The research employs an experimental approach to evaluate the effectiveness of various variables in the experiments. The primary sensor utilized is the Optical Dust Sensor GP2Y1010AU0F, which operates based on infrared light to detect particulate matter concentrations. The analysis of dust sensor testing, conducted after burning tissue paper, reveals variations in the sensor readings. The sensor consistently reports an average dust concentration of 0.597 Kg/m³. Subsequent tests using 30 mg of baby powder per trial yield dust concentration readings ranging from 0.35 Kg/m³ to 0.38 Kg/m³, indicating that the mass of the powder does not significantly affect the sensor readings within the tested mass range. Furthermore, indoor dust density measurements, averaging 36.01 µg/m³, demonstrate that the dust concentration in the room during the measurement period is relatively low. These findings underscore the potential of the designed system for real-time air quality monitoring and highlight its effectiveness in accurately detecting particulate matter under various experimental conditions.

Keywords: *Sustainability, Sensor, IoT, GP2Y1010AU0F, ESP32*

ABSTRAK

Menurunkan emisi karbon sangat penting dalam mendukung keberlanjutan pada sumber daya energi, sehingga perlu dilakukan pemantauan kandungan zat yang berbahaya di udara. Penelitian ini bertujuan untuk merancang sistem pemantauan kualitas udara di Laboratorium Teknik Mesin yang akurat dan bekerja secara real-time dalam memantau tekanan udara serta memberikan informasi mengenai nilai parameter yang terukur. Metode penelitian yang digunakan adalah pendekatan eksperimental untuk mengevaluasi efektivitas variabel-variabel dalam eksperimen. Sensor utama yang diterapkan adalah Optical Dust Sensor GP2Y1010AU0F, yang berfungsi berdasarkan sinar infra merah untuk mendeteksi tingkat konsentrasi partikel debu. Hasil analisis dari uji sensor debu, yang dilakukan setelah percobaan menggunakan tisu yang dibakar, menunjukkan adanya variasi nilai yang terbaca dari sensor. Sensor ini memberikan hasil yang konsisten dengan konsentrasi debu rata-rata sebesar 0,597 Kg/m³. Selanjutnya, pengujian dengan bedak bayi seberat 30 mg untuk setiap uji coba menunjukkan pembacaan sensor debu berkisar antara 0,35 Kg/m³ hingga 0,38 Kg/m³, yang mengindikasikan bahwa massa bedak tidak mempengaruhi hasil pembacaan sensor secara signifikan dalam rentang massa yang digunakan. Hasil pengujian kepadatan debu dalam ruangan, dengan rata-rata sebesar 36,01 µg/m³, menunjukkan bahwa konsentrasi debu di dalam ruangan pada saat pengukuran relatif rendah.

Kata Kunci: Keberlanjutan, *Sensor, IoT, GP2Y1010AU0F, ESP32*

I. Introduction

Reducing carbon emissions is crucial for supporting sustainability in energy systems, which necessitates the monitoring of hazardous substances in the air. The Mechanical Engineering Laboratory is a designated space for conducting experiments and research related to mechanical engineering. To maintain a controlled and compliant environment, an air management system—including heating, ventilation, and air conditioning (HVAC)—is essential to ensure optimal air quality. Key parameters for maintaining suitable air quality in the Mechanical Engineering Laboratory include a temperature range of 20°C to 24°C for comfort, a relative humidity (RH) level between 50% and 60% to inhibit microorganism growth, the use of HEPA filters to purify the air, a positive air pressure of approximately 10 Pa to 15 Pa to prevent external air infiltration, and a maximum dust particle level of 150 $\mu g/m^3$ to uphold air cleanliness standards (Serper et al., 2020).

Routine monitoring of air quality in the Mechanical Engineering Laboratory is not always performed consistently, and oversight is often limited to localized assessments. This can result in delayed detection of issues within the air management system, leading to contamination by particles such as dust, gases, and smoke. Such contamination may contribute to nosocomial infections—illnesses acquired by individuals while within the facility (Zhang et al., 2021; Zhu et al., 2021).

Following a literature review, researchers identified several studies related to the current investigation. One study, conducted in 2017, focused on designing a temperature and humidity monitoring system for a transmitter room. The system utilized a DHT 11 sensor connected to an Arduino Uno and a GSM Shield 908. The output included a web interface and a buzzer alert. When the temperature exceeded 21°C, the buzzer activated to alert the operator that the temperature had surpassed the normal threshold. Data was then transmitted to a database via the GSM Shield 908. Conversely, if the temperature was below 21°C, data was directly recorded in the database and displayed on the web platform. This web interface featured a table updating data at intervals dependent on network speed, as well as a real-time moving graph. This system enabled enhanced temperature monitoring of the room, reducing the risk of equipment damage.(Zhu et al., 2021)

In another study, a system was developed for monitoring and automating room temperature and soil moisture levels within a greenhouse environment using Wireless Sensor Network (WSN) technology. The system included one node for monitoring room temperature and humidity, and a second node for monitoring soil moisture. Each node comprised an Arduino Uno as a microcontroller, an ESP8266 Wi-Fi module, sensors, and a relay. Monitoring and automation data were transmitted wirelessly to a web server, facilitating farmers' remote monitoring of greenhouse conditions. The study's results indicated that the system could autonomously monitor and control room temperature when it exceeded 28°C and automatically increase soil moisture when levels fell below 40%. Testing revealed a maximum data transmission range of 50 meters from the node to the access point (Li et al., 2020).

In a subsequent study, air quality was continuously and real-time monitored based on Internet of Things (IoT) technology. This system addressed the infrastructure, information processing, and challenges associated with designing and implementing an integrated air quality sensing system. Its objective was to detect real-time levels of pollutants such as ozone (O_3), particulate matter, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), volatile organic compounds, and carbon dioxide (CO_2), while also providing overall air quality alerts. The intelligent system employed multiple integrated pollutant sensors, including gas sensors like TGS2600, TGS2602, GSNT11, TGS5042, T6613, as well as a dust sensor (GP2Y1010AUF) and a temperature and humidity sensor (DHT11). A smoothing algorithm was applied to mitigate temporary sensor errors, and an aggregation algorithm was used to reduce network traffic and power consumption. Results indicated that sensor and environmental characteristics, such as temperature and humidity, influenced measurement accuracy. Consequently, sensors were calibrated before deployment, with continuous automated recalibration. Proper sensor selection and energy efficiency enhancements during system design and implementation were also identified as critical factors.(Khalaf, 2020).

Another study on the Internet of Things (IoT) explores an IoT-based monitoring system designed to enhance the productivity, flexibility, and quality of lettuce cultivation (Fawaiqur et al., 2024; Haseeb et al., 2020; Lv et al., 2020; Putri Nourma Budiarti et al., 2018).

The system's primary controller is the ESP32 DevKitC V4 microcontroller, which manages four outputs: a fan, UV light, water pump, and an LCD for displaying information. The research results show that the system operates as intended, meeting the objectives of building a Smart Greenhouse Monitoring System using an Android platform. Sensor readings and actuators were tested to evaluate the performance of the sensors, actuators, and the monitoring system.

The sensor functionality achieved a 100% success rate in automation tests, and the IoT-based monitoring system effectively displayed data consistent with sensor readings and actuator status. Comparatively, lettuce growth within the smart greenhouse showed an effectiveness rate of 90%, while the effectiveness rate outside the smart greenhouse was only 4% (Fawaiqur et al., 2024).

Currently, there is no established air quality monitoring system in the Mechanical Engineering Laboratory, underscoring the need for innovative approaches to develop a more effective monitoring tool. Consequently, this research aims to design a prototype for an air cleanliness monitoring system specifically for the Mechanical Engineering Laboratory. Leveraging advancements in technology, the proposed air quality monitoring prototype can operate continuously online, 24 hours a day. The device is equipped with an Early Warning System (EWS) that triggers an alarm if parameter values deviate from standard thresholds. This system enables technical staff to monitor laboratory air conditions in real-time. The monitoring device, employing a SHARP GP2Y1010A dust sensor, is highly beneficial in ensuring air quality by effectively detecting dust levels.

II. Materials and Methods

Upon reviewing and analyzing the reference materials, the design phase for the device used in this research was initiated. The device design is divided into two main parts: hardware and software design. The hardware design encompasses the mechanical construction and electrical system configuration of the device. The software design involves programming embedded in the microcontroller to ensure the device or system functions as intended.

1. Software System Design:

The software design involves the overall programming architecture, including the initialization program for reading the SHARP GP2Y1010AUOF sensor and the WiFi communication program for the ESP32 module. The initialization program is executed first by the controller, initiating communication protocols for all modules connected to the controller to enable data exchange. The SHARP GP2Y1010AUOF sensor uses I2C (Inter-Integrated Circuit) communication to interface with the controller. I2C initialization enables data exchange using two communication lines, SDA and SCL. Additionally, SPI (Serial Peripheral Interface) initialization is conducted to facilitate communication between the controller and various sensors. During initialization, each device must be detected and readable by the controller. Ensuring each device is recognized requires configuring the initialization program according to the standard communication protocols specified for each controller device.

2. Mechanical Design:

The model design serves as a miniature representation of the actual system, providing a general depiction of air circulation patterns within the room. The prototype is square-shaped with equal side lengths, and each room corner is partitioned to widen the corners, facilitating easier cleaning. A fan is mounted at the center of the top cover to introduce airflow into the box; the fan's speed regulates the airflow rate, which is then detected by the sensor. This box model serves as a testing environment for the prototype, as illustrated in Figure 1.

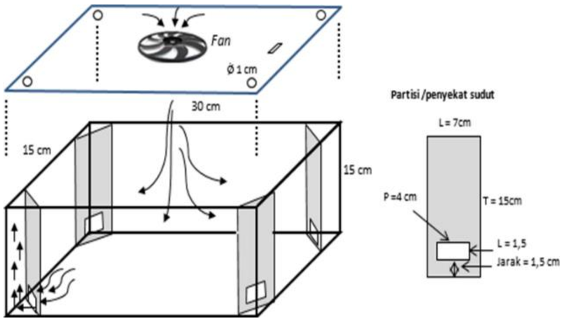


Figure 1 Sensor Placement Model ((Wisnulaksito et al., 2017)

3. Electronic System Design

The hardware system design consists of an ESP32 and a SHARP GP2Y1010AUOF dust sensor, interconnected and integrated into a single system. This configuration is represented in a block diagram, as shown in Figure 2.

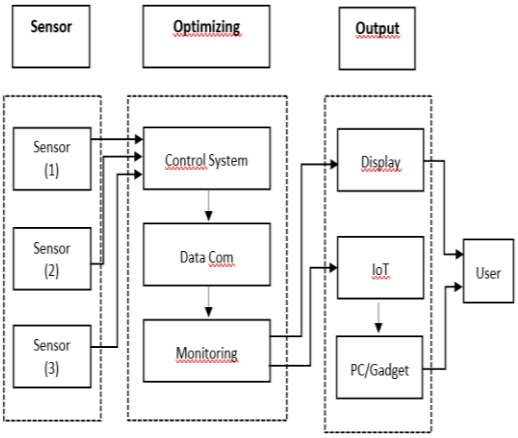


Figure 2 Block Diagram Hardware

The board connection layout for the developed prototype is illustrated in Figure 3.

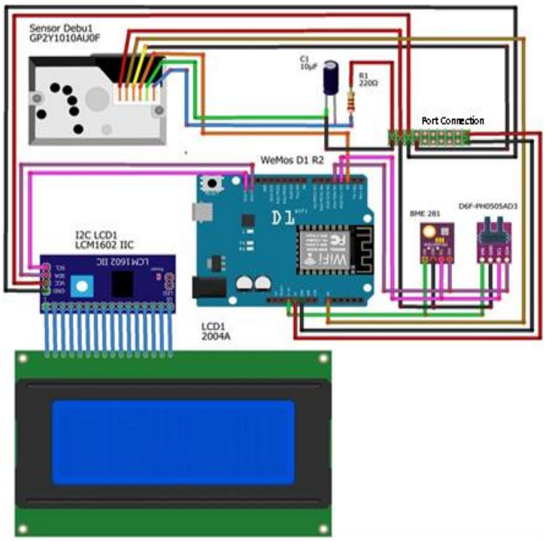


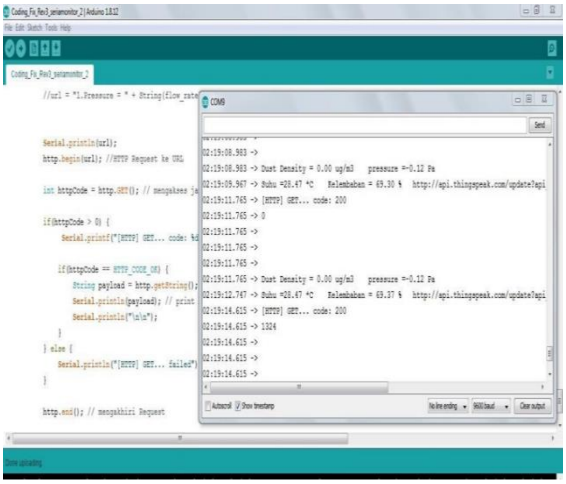
Figure 3 Board Connection

III. Results and Discussion

The hardware and software design in this research require testing to evaluate the overall system performance. Testing of the prototype is conducted separately on each component, followed by a comprehensive assessment of the entire prototype system.

1. Software Testing

Software testing is a crucial phase in the development of information systems or applications, ensuring that the software functions according to specified requirements and meets user needs. In the context of a thesis on the "air monitoring system with a dust sensor in a mechanical laboratory," software testing is essential to guarantee the quality and reliability of the monitoring system developed.



```
//url = "1.Pressure = " + String(flow_rate


Serial.println(url);
http.begin(url); //HTTP Request ke URL

int httpCode = http.GET(); // mengakses ja

if(httpCode > 0) {
  Serial.printf("[HTTP] GET... code: %d

  if(httpCode == HTTP_CODE_OK) {
    String payload = http.getString();
    Serial.println(payload); // print
    Serial.println("\n\n");
  }
} else {
  Serial.println("[HTTP] GET... failed")
}

http.end(); // mengakhiri Request
```

```
02:19:08.983 ->
02:19:08.983 -> Dust Density = 0.00 ug/m3    pressure =-0.12 Pa
02:19:09.967 -> Suhu =28.47 *C    Kelembaban = 69.30 %   http://api.thingspeak.com/update?api
02:19:11.765 -> [HTTP] GET... code: 200
02:19:11.765 -> 0
02:19:11.765 ->
02:19:11.765 ->
02:19:11.765 ->
02:19:11.765 -> Dust Density = 0.00 ug/m3    pressure =-0.12 Pa
02:19:12.747 -> Suhu =28.47 *C    Kelembaban = 69.37 %   http://api.thingspeak.com/update?api
02:19:14.615 -> [HTTP] GET... code: 200
02:19:14.615 -> 1324
02:19:14.615 ->
02:19:14.615 ->
02:19:14.615 ->
```

Figure 4 Software Testing on ESP32 Board

Testing of the ESP32 module involves connecting a 5V power supply and uploading the program. As a result, the module's indicator light turns on, and the WiFi indicator light begins flashing. When successfully connected to a WiFi network, the ESP32 pairs with the network, indicated by the WiFi indicator light flashing. The test results of the ESP32 connection to the WiFi network are shown in Figure 4.

In Figure 4, the Arduino IDE's serial monitor for the ESP32 module displays that the device is connected to WiFi, transmitting monitoring data to the Thingspeak application. Data transmission intervals correspond to the delay settings programmed into the system. The data shown confirms smooth network connectivity and sensor readings, indicating that the module is functioning correctly.

2. Running Text Circuit Test

Testing is conducted by displaying sequences of characters across each row and column of the Running Text to ensure that the display is functioning without defects. Figure 5 demonstrates that the Running Text circuit operates correctly and accurately presents measurements for the four parameters without character errors.

Figure 5 Funtional Running Text Testing

3. GP2Y1010AUOF Sensor Test

The testing process involved observing the dust sensor readings displayed on the serial monitor within the Arduino IDE program. The following table presents the test results based on 30 data points collected after burning two sheets of tissue for each trial.

Table 1 Dust Concentration Measurement Results Using Tissue Combustion

Trial Number	Sensor Reading (Kg/m³)	Cleaning Process (seconds)
1	**0.59**	16
2	**0.62**	15
3	**0.58**	17
4	**0.61**	16
5	**0.60**	15
6	**0.63**	17
7	**0.59**	16
8	**0.62**	15
9	**0.57**	17
10	**0.60**	16
11	**0.64**	15
12	**0.58**	17
13	**0.61**	16
14	**0.59**	15
15	**0.63**	17

The dust sensor testing, conducted by burning tissue, is analyzed by examining the variation in sensor readings obtained in each trial, as shown in Table 1. The dust sensor used in this experiment appears to measure dust concentration in units of Kg/m³. According to the table, sensor readings varied within a range of 0.57 Kg/m³ to 0.64 Kg/m³, indicating a significant fluctuation in dust concentration. Although these variations may seem minor, even small differences in dust levels can have notable health implications in terms of air quality.

From the table, it is evident that while there is variability in sensor readings, a consistent pattern appears to emerge. For example, in certain trials, readings tend to stabilize around values like 0.59 Kg/m³ and 0.62 Kg/m³. This suggests a pattern or consistency in measured dust density under certain experimental conditions.

The cleaning process duration, ranging between 15 and 17 seconds, might influence the measured dust concentration. This cleaning process aims to reduce airborne dust, but if the cleaning time is too short, residual dust may remain in the air. This could explain some of the variations observed in the sensor readings.

Table 2 Dust Concentration Measurement Results Using Baby Powder

Trial Number	Sensor Reading (Kg/m³)	Cleaning Process (seconds)
1	0.36	10
2	0.37	11
3	0.35	12
4	0.38	13
5	0.36	14
6	0.37	15
7	0.35	16
8	0.38	10
9	0.36	11
10	0.37	12
11	0.35	13
12	0.38	14
13	0.36	15
14	0.37	16
15	0.35	10

The testing results in Table 2 evaluate the performance of the dust sensor in detecting dust concentration with variations in powder weight and cleaning duration. The data collected from the dust sensor test include powder weight (mg), sensor reading (Kg/m³), and cleaning process time (seconds). Analyzing this data helps clarify how these factors influence the sensor's performance.

For each trial, the powder weight was kept constant at 30 mg. However, sensor readings varied slightly between 0.35 Kg/m³ and 0.38 Kg/m³, suggesting that powder weight did not significantly impact sensor readings within this weight range. The cleaning process duration ranged from 10 to 16 seconds, with an average of 12.2 seconds. Sensor readings remained steady around 0.35 Kg/m³, showing no clear pattern or trend relative to cleaning time, indicating that cleaning duration also did not significantly affect sensor readings.

The consistent sensor readings around 0.35 Kg/m³ demonstrate the reliability of the dust sensor's performance in this experiment. The low standard deviation in both sensor readings and cleaning process duration further underscores the sensor's consistency and reliability in measuring dust concentration.

4. Dust Density Measurement use GP2Y1010AUOF Sensor

Table 3 Dust Density Measurement

No	Time	Dust Density (µg/m3)	CalcVoltage (V)
1	14.05	42.5	0.92
2	14.07	58.2	1.03
3	14.09	33.1	0.8
4	14.11	47.8	0.88
5	14.13	53.7	0.9
6	14.15	28.5	0.76
7	14.17	58.2	1.03
8	14.19	39.2	0.82
9	14.21	23.5	0.73

10	14.23	51.6	0.89
11	14.25	11.3	0.65
12	14.27	36.2	0.81
13	14.29	41.8	0.91
14	14.31	45.9	0.86
15	14.33	50.1	0.87

Based on the data in Table 3, a notable variation in measured dust density is observed, ranging from 10.40 µg/m³ to 58.20 µg/m³. The relatively high standard deviation (15.92 µg/m³) indicates a significant dispersion of data around the mean, suggesting considerable variability in dust density across measurements. The average dust density of 36.01 µg/m³ implies that the average indoor dust concentration during testing was relatively low.

The CalcVoltage data show a range from 0.64 V to 1.03 V. A relatively low standard deviation (0.18 V) suggests that CalcVoltage data exhibited less variation compared to dust density. An average CalcVoltage of 0.777 V indicates a stable average voltage reading from the sensor. Despite some variation, voltage data remain steady within a smaller fluctuation range than dust density. There appears to be no direct correlation between dust density (µg/m³) and CalcVoltage (V) in the data provided. This may suggest that the sensor is less responsive to minor fluctuations in dust density, or that factors other than dust density might influence the sensor's voltage readings.

IV. Conclution

The study evaluated the performance of the GP2Y1010AUOF dust sensor under different conditions to assess its ability to detect and measure dust concentrations. Across various trials using tissue combustion and baby powder, the sensor showed variations in dust concentration measurements. For tissue combustion, sensor readings ranged from 0.57 Kg/m³ to 0.64 Kg/m³ with a cleaning time between 15 and 17 seconds. The presence of some consistency in readings, around 0.59 Kg/m³ and 0.62 Kg/m³. When baby powder was used, the sensor readings showed less variability, remaining within 0.35 Kg/m³ to 0.38 Kg/m³ despite differing cleaning times, suggesting that powder weight and cleaning duration had minimal impact on sensor performance. In dust density testing, measured concentrations varied widely from 10.40 µg/m³ to 58.20 µg/m³, with a high standard deviation indicating significant variability. However, the sensor's voltage output (CalcVoltage) displayed a narrower range (0.64 V to 1.03 V) with lower variability, suggesting stable voltage performance that is potentially less influenced by dust concentration. The lack of a clear correlation between dust density and voltage indicates that additional factors might affect sensor voltage beyond dust concentration.

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