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IoT-based material height monitoring and temperature-humidity control system with ESP32 on a Dosimat Feeder Hopper at PT. Semen Padang

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ABSTRACT

A hopper is a temporary storage container for rock material before it is fed by a feeder into a crusher. At PT Semen Padang, monitoring of material in the dosimat feeder hopper is still local, limiting supervision flexibility and response time, as well as lacking temperature and humidity control, which can degrade sensitive materials such as gypsum. This study aims to design an integrated system using Internet of Things (IoT) technology to overcome these limitations. The system employs an ESP32 microcontroller as the main processor, using an HC-SR04 ultrasonic sensor to measure material height and two DHT22 sensors to monitor temperature and humidity. Based on sensor readings, the ESP32 controls a DC motor for the filling conveyor and fans for cooling through a relay module. Real-time data visualization is implemented via the Blynk IoT platform for remote monitoring. Testing shows that the HC-SR04 sensor has an accuracy of 95.44%, while the DHT22 sensor achieves 98.62% accuracy. The automatic control system worked correctly according to logical conditions, and the configuration using four fans proved most effective for reducing temperature. Data transmission to Blynk was successful and consistent. In conclusion, the IoT-based monitoring and control system enhances operational efficiency and material quality in industrial settings. It provides a reliable model for implementing remote monitoring and automation, supporting modernization in similar industrial processes through improved supervision, environmental control, and system responsiveness.

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1. INTRODUCTION

The cement industry is one of the strategic sectors in national infrastructure development because it provides key materials such as cement, clinker, and gypsum. In the production process, hoppers play an important role as temporary storage for bulk materials before they are fed into the next processing unit [1]. At PT Semen Padang, hoppers are used in the dosimat feeder system to regulate the supply of materials to the grinding machine [2]. The efficiency and accuracy of material distribution from the hopper are critical to production smoothness and final product quality [3].

At PT Semen Padang, the hopper monitoring system is still locally based. Operators must regularly check the hopper's condition to monitor material levels, and there is no control over temperature or humidity inside [4]-[5]. This local material level monitoring reduces the effectiveness and flexibility of hopper supervision. On the other hand, environmental conditions inside the hopper, such as temperature and humidity, significantly affect material quality, especially for hygroscopic materials sensitive to high humidity

[6][7]. If uncontrolled, these conditions can cause material to clump and obstruct flow within the system, thereby reducing the quality of the final product [8].

With advancements in technology, the Internet of Things (IoT) offers a modern solution to address these challenges [9]-[10]. IoT enables monitoring and control processes to be performed automatically and remotely via an internet connection. This system utilizes microcontroller devices such as the ESP32, which is equipped with Wi-Fi connectivity, enabling it to collect data from sensors and transmit it to monitoring applications like Blynk [11]-[12]. The HC-SR04 ultrasonic sensor is used to measure the material level in the hopper non-contact [13], while the DHT22 sensor continuously monitors the ambient temperature and humidity [14]. Additionally, the system is equipped with actuators such as a mini fan and conveyor motor that can be automatically controlled based on sensor data, enabling real-time response to hopper conditions [15].

Based on these issues, this study aims to design and implement a material level monitoring system and temperature and humidity control for a dosimat feeder hopper using IoT technology with an ESP32. This system is expected to enhance operational efficiency and maintain material quality through automated responses to environmental conditions. The implementation of this system is also expected to provide a solution that can be applied in similar industrial environments that require intelligent and sustainable material monitoring [16].

2. METHOD

The design of this system is divided into three main parts: mechanical design, electrical design, and IoT software design. The system is centered on an ESP32 microcontroller that functions as the main processing unit. The ESP32 receives data from three input sensors, namely one HC-SR04 ultrasonic sensor to measure material height and two DHT22 sensors to monitor temperature and humidity. The received data is then processed to control two output actuators via a relay module, consisting of a DC motor for the filling conveyor and a mini fan as a temperature controller. Simultaneously, all sensor data is sent to the Blynk application platform for remote monitoring functions. The entire system is powered by a 12VDC power source, which is also stepped down to 5VDC by a step-down module to supply power to the ESP32 and sensors. The system block diagram can be seen in Figure 1.

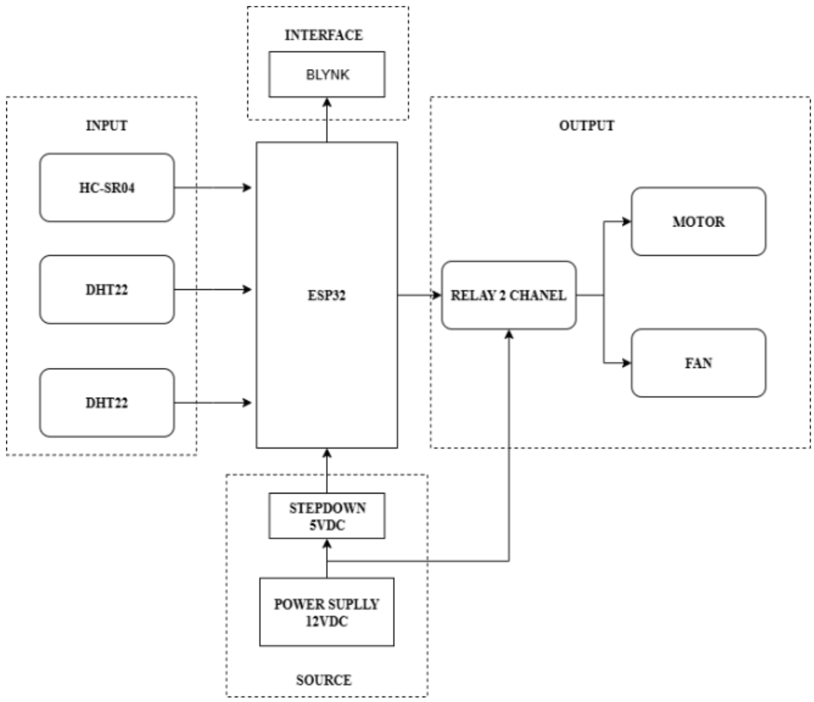

Figure 1. Block diagram

The functions of each component in the system block diagram are : 1) Power Supply 12VDC for provides the main 12V power source for the entire system, 2) Stepdown 5VDC that converts 12V to 5V to power the ESP32 and sensors, 3) ESP32 is the main microcontroller that reads sensor data, controls relays, and sends data to Blynk, 4) Blynk as IoT platform that displays sensor data and system status in real-time over the internet, 5) DHT22 1 to measures temperature and humidity at the top of the hopper, 6) DHT22 2 to measures temperature and humidity at the bottom of the hopper, 7) HC-SR04 as the ultrasonic sensor used to measure the material level inside the hopper, 8) Relay 2 Channel that controls the motor and fan based on ESP32 commands, 9) Motor for drives the conveyor to fill the hopper with material when it's not full, and 10) Fan to reduce the temperature when the DHT22 detects high heat.

The system begins with the initialization of components by the ESP32. The HC-SR04 and DHT22 sensors then begin continuous measurements. Material height data will control the conveyor motor: if the material is below the minimum limit, the conveyor is activated, and if it reaches the maximum limit, the conveyor is deactivated. Meanwhile, temperature and humidity data will control the fan: if it exceeds the set point, the fan activates until conditions return to normal. All sensor data is periodically sent to the Blynk platform for monitoring. The overall system flowchart can be seen in Figure 2.

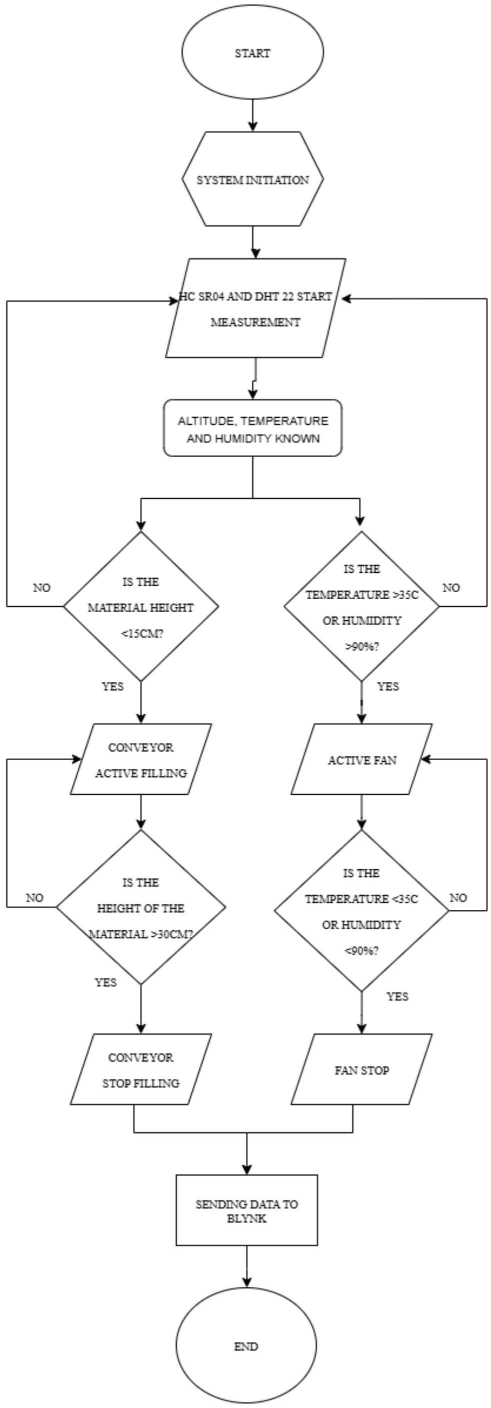

Figure 2. System Flowchart

The electrical system is centered around the ESP32 microcontroller, a System on Chip (SoC) that is integrated with WiFi and Bluetooth features. The main 12VDC power supply is used to power the DC motor and mini fan through a 2-channel relay module. This voltage is stepped down to 5VDC using a step-down module to supply power to the ESP32, HC-SR04 sensor, and DHT22 sensor. The HC-SR04 sensor, which operates by emitting ultrasonic waves, is connected to the ESP32's digital pins for trigger and echo functions. Two DHT22 sensors, which generate calibrated digital signals, are connected to different digital pins to read temperature and humidity data. The output pins of the ESP32 are also connected to the input pins of the relay module to control the motor and fan. The block diagram and electrical circuit schematic are shown in Figures 3 and 4.

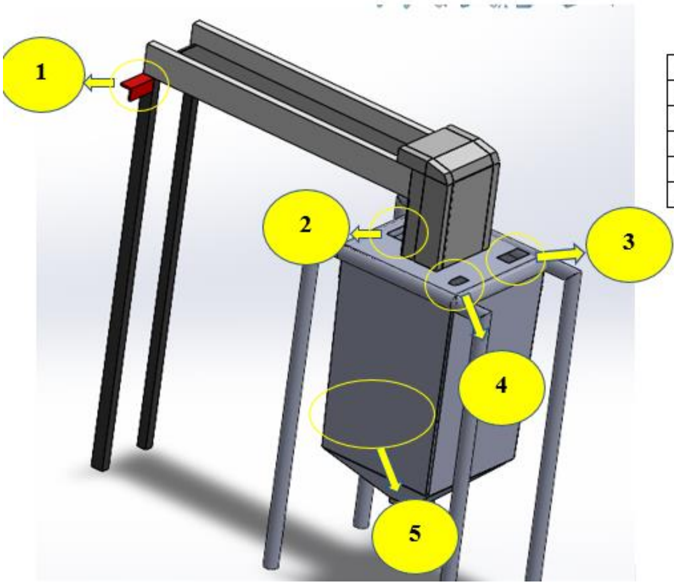

Image Description

No	Name
1	DC Motor
2	Fan
3	Ultrasonic
4	DHT22
5	DHT22 and Fan

Figure 3. Mechanical Design

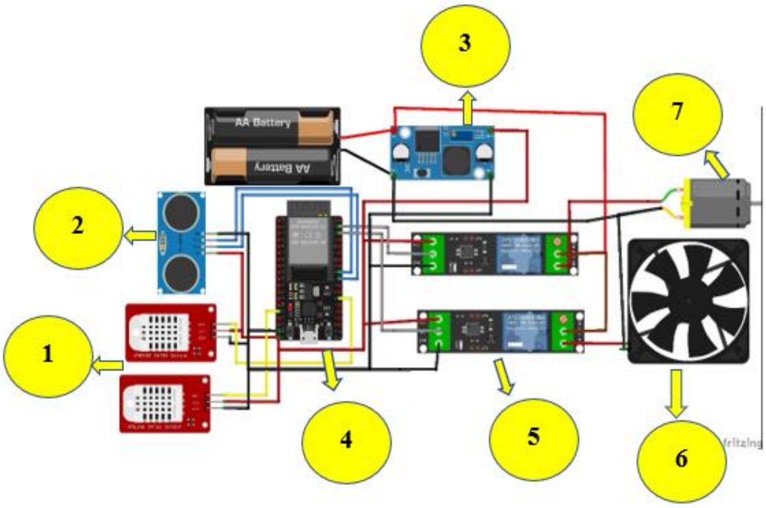

Image Description

No	Name
1	DHT22
2	HC-SR04/Ultrasonic
3	Stepdown
4	ESP32
5	Relay
6	Fan
7	DC Motor

Figure 4. Electrical design

The IoT software was designed using the Blynk platform, a platform that enables the creation of applications to control electronic devices via a smartphone. The interface on the Blynk application is configured to display data in real time. Gauge meter widgets are used to visualize data from sensors: material height (cm), volume percentage (%), temperature (°C), and relative humidity (%) for two points inside the hopper (top and bottom). Data from the ESP32 is sent to the Blynk server via a WiFi connection, enabling users to perform remote monitoring. The IoT software design can be seen in Figure 5.

Figure 5. IoT Software Design

3. RESULTS AND DISCUSSION

This section presents the final results of the tool design process, which includes the realization of the mechanical design and electrical configuration as the basis for the testing stage. The hopper prototype was made using plywood with four wooden support legs. The hopper dimensions are 45 cm in total height (30 cm for the block section and 15 cm for the cone section) with a base area of 25x25 cm, providing a maximum volume of approximately 21,875 cm³. An HC-SR04 sensor, a DHT22 sensor, and a cooling fan are installed on the hopper lid. The filling conveyor uses a rubber belt with a plywood base, driven by a DC motor. The final mechanical design of the device can be seen in Figure 6.

Image Description

No	Name
1	DC Motor
2	Fan
3	Ultrasonic and DHT22
4	Fan and DHT22

Figure 6. Final Results of the Tool

All electrical components of this system are placed in a black multibox. Inside, there is an ESP32 microcontroller installed on an expansion board, as well as a step-down module and relay. This multibox is also equipped with holes as cable paths to the sensors installed on the conveyor and hopper. The final result of the electrical device can be seen in Figure 7.

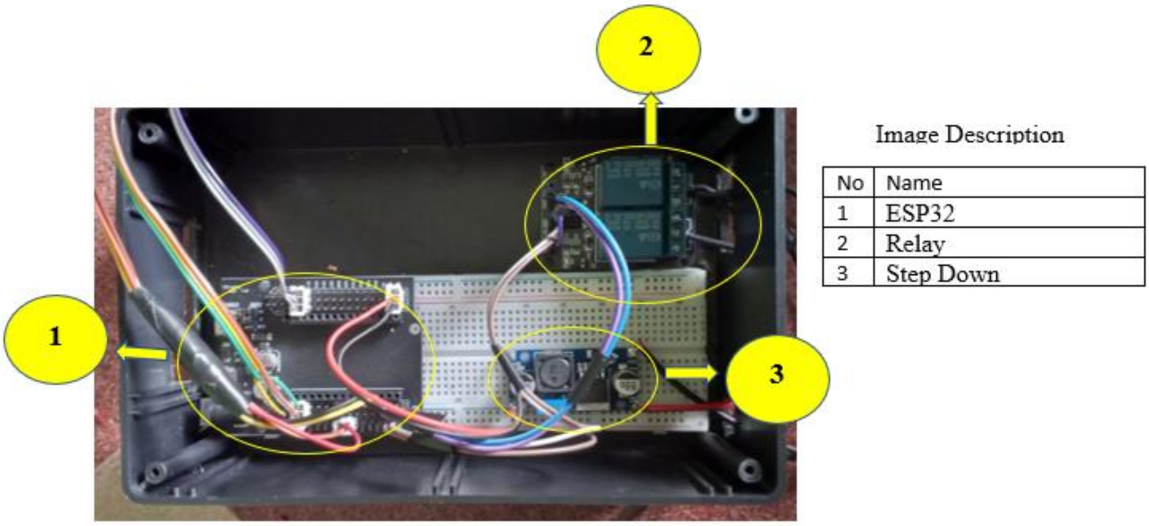

Figure *7*. Final Electric Results

This section presents the results of testing the system that has been designed to evaluate the performance and functionality of the tool in accordance with the research objectives.Accuracy testing of the HC-SR04 ultrasonic sensor shows that the sensor has a higher error rate at short measurement distances (below 10 cm), with an error rate of up to 8.90%. However, at distances between 15 cm and 30 cm, accuracy improves significantly, with the error rate dropping to 0.07%. This indicates that the HC-SR04 sensor is reliable for use within the operational distance range of this hopper monitoring system. The measurement results of the ultrasonic sensor can be seen in Table 1.

Table 1. Ultrasonic Sensor Accuracy Data

No	Original Distance (cm)	Measured Distance (cm)	Difference (cm)	Error (%)
1	5	4.56	0.44	8.80%
2	8	7.4	0.6	7.50%
3	10	9.11	0.89	8.90%
4	15	14.89	0.11	0.73%
5	20	19.7	0.3	1.50%
6	30	30.02	0.02	0.07%

Accuracy testing of the DHT22 sensor compared to a reference measuring device showed good performance. Sensor 1 has a maximum temperature error of 2.19% and a humidity error of 3.06%, while Sensor 2 shows better performance with a maximum temperature error of 0.63% and a humidity error of 1.77%. These low error values confirm that the DHT22 sensor is suitable for use in temperature and humidity monitoring systems in hoppers. The measurement results from the DHT22 sensor can be seen in Table 2, where AH refers to absolute humidity and RH refers to relative humidity.

Table 2. DHT22 Sensor Accuracy Data

Temperature of measuring device	RH Measuring Device (%)	Sensor 1 (°C)	RH1 (%)	Temperature Error 1 (%	RH Error 1 (%)	Sensor 2 (°C)	RH2 (%)	Temperature Error 2 (%)	RH Error 2 (%)
32.0	62	32.7	63.9	2.19%	3.06%	32.2	63.1	0.63%	1.77%
31.5	61	31.8	62.5	0.95%	2.46%	31.6	61.7	0.32%	1.15%
31.8	60	32.0	61.2	0.63%	2.00%	31.7	60.6	0.31%	1.00%
32.3	63	32.9	64.2	1.86%	1.90%	32.5	63.5	0.62%	0.79%
31.7	62	32.1	62.8	1.26%	1.29%	31.8	62.5	0.32%	0.81%

This test aims to observe and record the time required for the hopper to be fully filled. Through this method, data on filling time and system behavior during the process is obtained. Hopper filling data can be seen in Table 3.

Table 3. Hopper Filling Data

No	Test 1				Test 2			
	Time (seconds)	Volume (cm³)	Material Height (cm)	Hopper Fill Percentage	Time (seconds)	Volume (cm³)	Material Height (cm)	Hopper Fill Percentage
1	0	0	0.0	0	0	0.00	0.0	0.00
2	48	3536	15.6	22	48	3762	16	24
3	72	5304	18.4	34	72	5535	19.0	35
4	96	7072	21.3	45	96	7417	21.8	47
5	120	8840	24.1	56	120	9046	24.3	57
6	132	9724	25,5	62	132	9922	25.8	63
7	144	10608	26.9	68	144	10842	27.2	69
8	168	12376	29.8	79	160	12485	29.9	79
9	192	14144	32.6	90	178	14212	32.7	91
10	213	15625	35.5	100	195	15625	35.5	100

Testing was carried out continuously until the fan was no longer able to lower the hopper temperature. Two fans were installed on the 8 cm hopper lid and two on the 4 cm hopper body. The purpose of this process was to observe the effectiveness of the cooling system in controlling the temperature. Temperature and humidity control data can be seen in Table 4, where AH refers to absolute humidity and RH refers to relative humidity.

Table 4. Temperature and Humidity Control Data

Time (Second)	Upper Temperature (°C)	Upper RH (%)	Upper AH (g/m³)	Lower Temperature (°C)	Lower RH (%)	Lower AH (g/m³)
0	33.3	61.7	22.3	33.0	61.9	22.06
100	32.8	60.4	21.5	32.6	60.8	21.49
200	32.6	60.1	21.3	32.4	60.3	21.31
340	32.4	59.7	21.1	32.3	59.9	21.14
443	32.3	59.4	21.0	32.2	59.5	21.02

The Blynk system was tested by comparing the data displayed on the Blynk application with the data read directly through the Serial Monitor on the ESP32 device. The IoT software test data can be seen in Table 5, where RH refers to relative humidity.

Table 5. IoT Software Testing Data.

No.	Data in Serial Motitor	Data in Blynk App	Status
1	Height: 10.52 cm Temperature 1: 28.50°C RH 1: 89.5% Temperature 2: 29.10 °C RH 2: 88.9%	Height: 10.52 cm Temperature 1: 28.50 °C RH 1: 89.5% Temperature 2: 29.10 °C RH 2: 88.9%	Same
2	Height: 25.34 cm Temperature 1: 28.40 °C RH 1: 90.1% Temperature 2: 29.00 °C RH 2: 89.2%	Height: 25.34 cm Temperature 1: 28.40 °C RH 1: 90.1% Temperature 2: 29.00 °C RH 2: 89.2%	Same
3	Height: 35.81 cm Temperature 1: 28.70°C RH 1: 91.5% Temperature 2: 29.30 °C RH 2: 90.8%	Height: 35.81 cm Temperature 1: 28.70 °C RH 1: 91.5% Temperature 2: 29.30 °C RH 2: 90.8%	Same
4	Height: 35.80 cm Temperature 1: 28.80 °C RH 1: 91.8% Temperature 2: 29.40 °C RH 2: 91.1%	Height: 35.80 cm Temperature 1: 28.80 °C RH 1: 91.8% Temperature 2: 29.40 °C RH 2: 91.1%	Same
5	Height: 35.75 cm Temperature 1: 28.90 °C RH 1: 92.0% Temperature 2: 29.50 °C RH 2: 91.3%	Height: 35.75 cm Temperature 1: 28.90 °C RH 1: 92.0% Temperature 2: 29.50 °C RH 2: 91.3%	same
6	Height: 35.30 cm Temperature 1: 29.00 °C RH 1: 92.3% Temperature 2: 29.60 °C RH 2: 91.5%	Height: 35.30 cm Temperature 1: 29.00 °C RH 1: 92.3% Temperature 2: 29.60 °C RH 2: 91.5%	Same

Based on the test results, an analysis was conducted to assess the extent to which the system works effectively, accurately, and responsively to the conditions observed. Testing of the HC-SR04 ultrasonic sensor shows that the accuracy of readings is highly dependent on the distance to the target. At close distances between 5 and 10 cm, the sensor experiences errors between 7.5% and 8.9%. This is likely due to suboptimal reflection of ultrasonic waves caused by the conical shape of the bottom of the hopper, causing the sensor to read the sloped surface or hopper wall instead of the material directly. Conversely, at distances between 15 and 30 cm, accuracy improves significantly, with errors decreasing to 0.07% at 30 cm. This indicates that the sensor performs optimally when used to measure material height after the hopper's lower section is fully filled, and the material surface is in a straight, open reflection zone. Therefore, the HC-SR04 is highly suitable for use in material level monitoring systems in hoppers, especially when installed in a position that minimizes reflection interference. The ultrasonic sensor test graph can be seen in Figure 8.

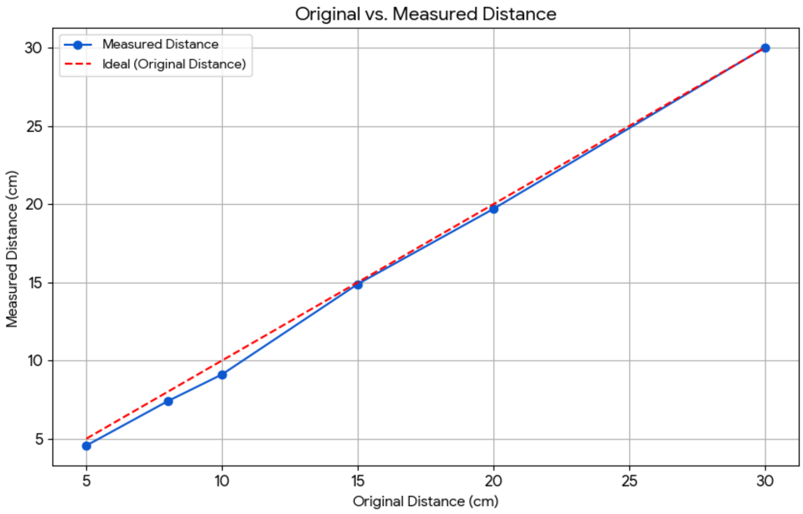

Figure 8. Ultrasonic Sensor Testing Graph

Meanwhile, the DHT22 sensor showed good performance in measuring temperature and humidity. Both sensors tested showed temperature error values <2.2% and humidity <3.1%, with Sensor 2 being slightly more accurate than Sensor 1. These results are still within the sensor specification tolerance limits and show that the DHT22 is suitable for use in environmental monitoring in microcontroller-based systems. The DHT22 sensor test graph can be seen in Figure 9.

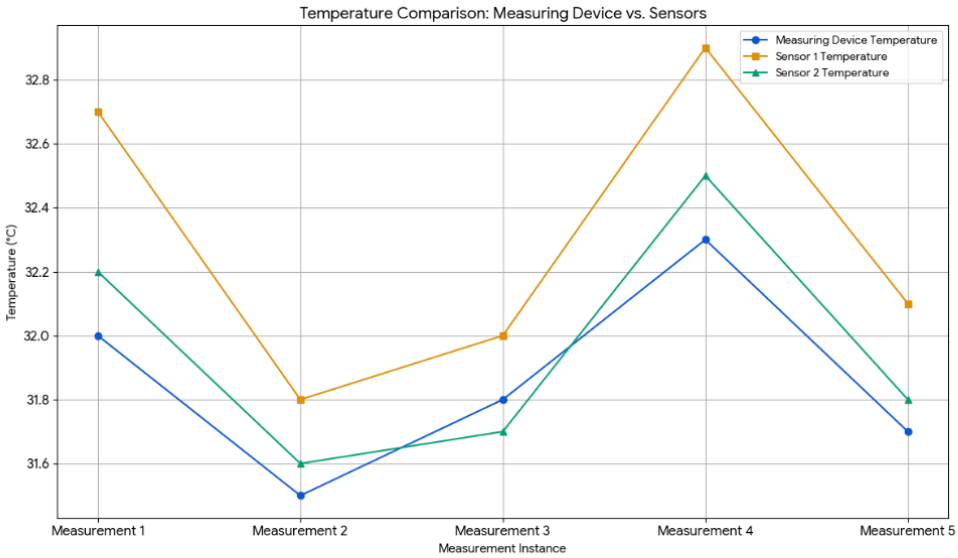

Figure 9. DHT22 Sensor Test Graph

Testing of the hopper filling system showed that the system works automatically and responsively based on sensor data. In the first test, the ultrasonic sensor began to accurately read the material height after the hopper cone was filled, namely at 48 seconds with a height of 15.6 cm. Previously, the reading was still affected by the narrow shape of the hopper at the bottom. Subsequently, the height increase proceeded linearly until reaching 29.8 cm at the 168th second, then began to slow down until reaching the setpoint of 35.5 cm at the 213th second. This slowdown occurred because the material began to spread sideways rather than just piling up. When the material height reached the setpoint, the system automatically shut off the conveyor and reactivated it after the hopper was emptied, proving that the control system worked effectively. In the second test, the filling pattern was almost the same, but the filling time was faster by about 18 seconds. This was due to smoother material flow to the conveyor, as the material supply process when transferred to the conveyor ran more stably. Both tests demonstrated that the system can accurately detect material height and regulate the filling process in a stable and precise manner. The hopper filling test graph can be viewed in Figure 10.

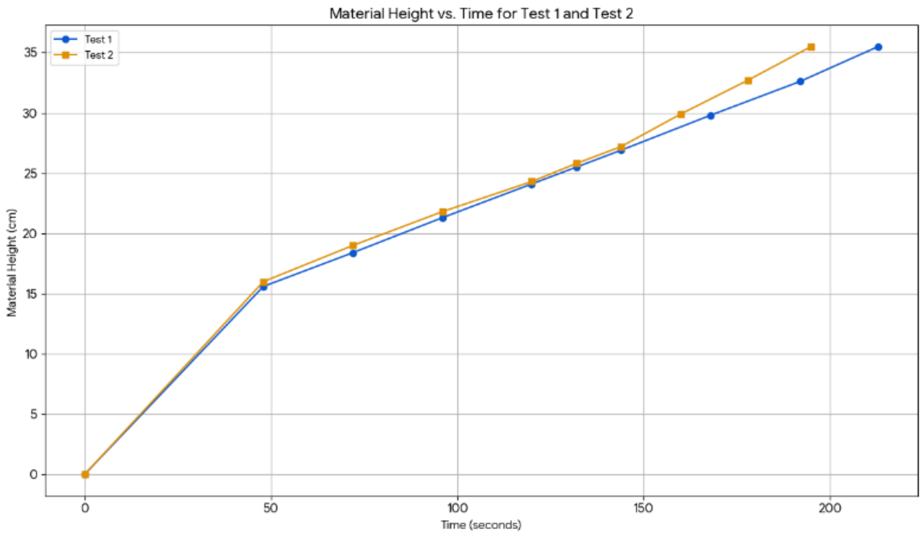

Figure 10. Hopper Filling Test Data

The use of two fans in the lid and two fans in the hopper body provides the most optimal cooling results. The temperature of the upper part of the hopper successfully dropped from 33.3°C to 32.3°C in 443 seconds, while the lower temperature decreased from 33.0°C to 32.2°C. This decrease was also accompanied by a decrease in absolute humidity (AH), from 22.34 g/m³ to 21.05 g/m³ at the top, and from 22.06 g/m³ to 21.02 g/m³ at the bottom. The effectiveness of these four fans is evident in the system's ability to evenly distribute hot air, enabling simultaneous cooling throughout the hopper. However, the fans can only reduce the temperature to near ambient levels, making their use more suitable for maintaining material temperature stability rather than extreme cooling. Temperature and humidity test graphs can be seen in Figures 11 and 12.

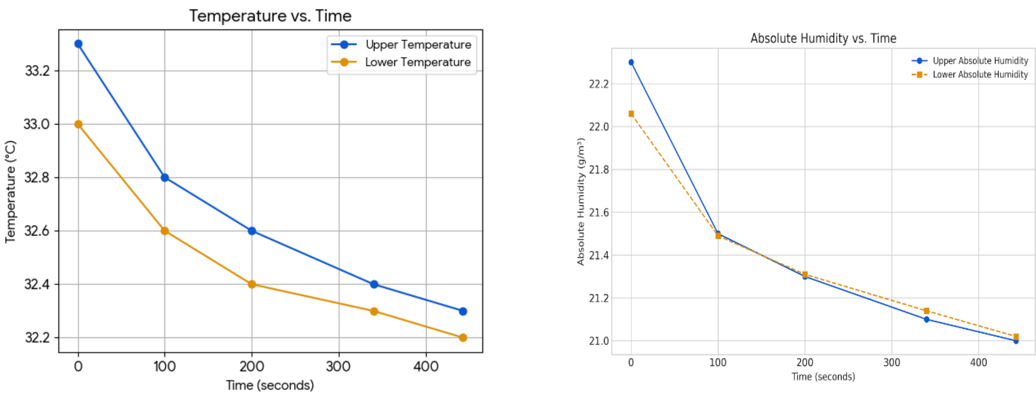

Figure 11. Temperature control test data and absolute humidity control test data

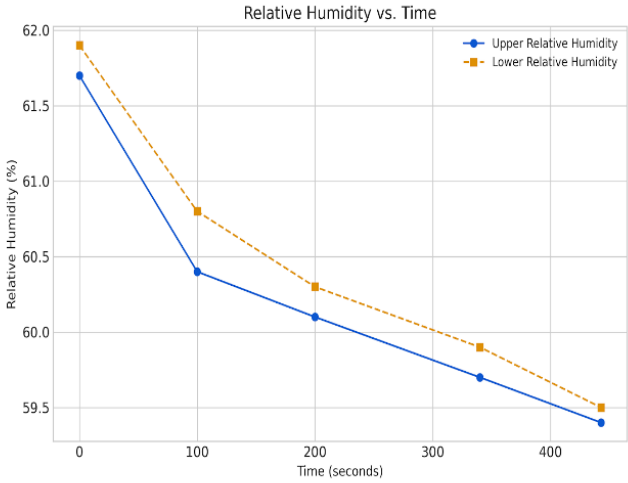

Figure 12. Relative Humidity Test Data

Test results show that the data transmission system from ESP32 to the Blynk application runs accurately and stably. This indicates that cloud-based data communication works well under normal network conditions. The system generally shows reliable real-time performance. To improve reliability in industrial environments, it is recommended to add a retry mechanism, data buffer, and local logging when the connection is interrupted.

4. CONCLUSION

This study successfully designed and implemented a material height monitoring system and temperature and humidity control in an IoT-based dosimat feeder hopper using an ESP32 microcontroller. This system is capable of reading sensor data in real time, automatically activating actuators, and sending information to the Blynk application via the internet. Test results indicate that the HC-SR04 ultrasonic sensor has an average accuracy of 95.44%, with the highest accuracy at a distance of 30 cm (error of only 0.07%) and a decrease in accuracy at closer distances. This sensor has proven reliable for measuring material height in ranges above 10 cm. Meanwhile, the DHT22 sensor shows an average temperature accuracy of 98.6% and humidity accuracy of 97.5%, with Sensor 2 being slightly more stable than Sensor 1. Both sensors remain within the manufacturer's tolerance specifications, making them suitable for use in industrial environmental monitoring systems that are not overly critical. In the hopper filling system test, the system can automatically stop and activate the conveyor according to the material height setpoint. Material filling runs stably, with full filling time achieved in 213 seconds in the first test and 18 seconds faster in the second test due to smoother material flow. This indicates that the system responds effectively to field conditions. Temperature control using four fans (two on the hopper lid and two on the body) proved most effective. The upper temperature dropped from 33.3°C to 32.3°C, and the lower temperature from 33.0°C to 32.2°C within 443 seconds, accompanied by a decrease in absolute humidity. Although it could only lower the temperature to near ambient levels, the fans functioned well in maintaining the stability of material temperature and humidity. In terms of data communication, data transmission accuracy to Blynk reached 90%, with only one out of ten tests experiencing delays due to temporary connection issues. The system generally displays data in real-time and remains stable. To enhance reliability, it is recommended to add features such as retry, local buffer, and offline data logging. Overall, the developed system is deemed effective, accurate, and stable. This system has significant potential for implementation in industrial environments through further development into a system that utilizes these features..

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