

Development of an IoT-Based Broiler Chicken Coop Air Quality Monitoring Prototype

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ABSTRACT

Inadequate air quality in the cage causes broiler chickens to become stressed, resulting in suboptimal weight gain, even death, and crop failure. Adequate broiler chicken cage air quality parameters include: a temperature range of 22 °C to 32 °C (depending on the chicken's age), a humidity range of 45% to 65%, an O₂ level of ≥ 19.6%, an NH₃ level of ≤ 10 ppm, a CO level of ≤ 10 ppm, and a CO₂ level of ≤ 3,000 ppm. Therefore, a technology is needed to monitor the air quality of the chicken coop in near real time. Thus, farmers can provide appropriate and prompt handling to maintain good air quality in the chicken coop. The purpose of this research is to develop a prototype for monitoring the air quality of broiler chicken coops based on IoT. The method used is research and development (R&D) with a prototype manufacturing approach based on the Internet of Things (IoT). The prototype was developed using temperature and humidity sensors (DHT22), NH₃, O₂, CO, and CO₂ sensors. Each sensor is connected to the ESP32, which processes the data and displays it on the liquid crystal display (LCD) and the Thingspeak dashboard. Prototype testing was conducted by comparing the measurement results with those from standard measuring instruments in a closed container. Based on the test results, the prototype measured air quality accurately. This is evidenced by the mean absolute error (MAE) values for each measurement result of the O₂ sensor, CO sensor, CO₂ sensor, DHT22 sensor, and A02YYUW sensor, which are 0.10 % Vol, 4.46 μmol/mol, 24.20 ppm, 0.71 °C, and 0.13 cm, respectively. Thus, this prototype offers an advantage in measuring air quality in near real time using IoT.



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I. INTRODUCTION

The main problem currently faced by broiler chicken farmers is the difficulty of maintaining cage conditions suitable for broiler chickens. One of the factors causing these difficulties is that farmers do not know, in near real time, the values of parameters that affect the condition of chicken coops. So that farmers cannot provide proper, fast handling to re-optimize the cage's condition when its quality decreases. This causes chickens to become stressed, resulting in suboptimal weight gain and potentially leading to death and

crop failure. Important factors that affect the condition of chicken coops and help them remain optimal include sufficient feed and drinking water, as well as adequate air quality [1], [2]. This study focuses only on real-time monitoring of air quality in broiler cages using *the Internet of Things* (IoT) [3]. Adequate air quality for broiler chicken coops is if it has the following parameters, namely temperature between 22 °C – 32 °C (according to the age of the chicken), humidity between 45% – 65%, O₂ gas ≥ 19.6%, NH₃ gas ≤ 10 ppm, CO gas ≤ 10 ppm, and CO₂ gas ≤ 3000 ppm [4], [5]. Based on this, an innovation that can measure

air quality in chicken coops in near real time and with high accuracy is important to further develop. As well as an innovation that can automatically notify farmers when air quality is suboptimal. This innovation is important to develop because currently, some farmers only measure temperature, humidity, and NH_3 levels to assess cage quality. In addition, there has been no research on air quality monitoring within the cage to determine O_2 , CO , and CO_2 levels. Research [6], [7] has resulted in a Fuzzy and IoT-based logic chicken coop temperature and humidity control and monitoring system. Research [8] has led to the development of an IoT-based automated system for monitoring animal feed and cage temperature. Research [9] has led to the development of an IoT-based system for monitoring air quality, temperature, and cage hygiene. However, the measured air quality is only NH_3 . Research [10], [11], [12] has focused only on NH_3 gas monitoring and control. Research [13], [14], [15] has not yet measured O_2 , CO , and CO_2 levels.

The innovation developed aims to provide farmers with real-time air quality data from broiler chicken coops via Android. Based on previous research, this innovation is unique: it not only measures temperature, humidity, and NH_3 gas. However, the innovation also measures O_2 , CO , and CO_2 . This research can completely overcome farmers' problems in monitoring air quality parameters. Thus, the research has also addressed the limitations of previous research on measuring air quality parameters. Previous research has only monitored NH_3 , temperature, and humidity; no one has integrated O_2 , CO , and CO_2 monitoring in a single, accurate, low-cost IoT system. This prototype fills that gap by providing a complete, calibrated five-parameter air-quality solution.

II. METHOD

This study employs the research and development (R&D) method, using an IoT-based prototype development approach. The research flow diagram is shown in the following Figure 1. Problem identification was based on the results of previous research, field surveys, and interviews with broiler chicken farmers. Based on the identification results, the problems farmers often experience and the appropriate cage air quality parameters for broiler chicken farming were determined. Furthermore, a literature study was conducted on various sources, including articles, reference books, and the internet. This is needed to determine a problem-solving approach to developing a prototype to monitor chicken-cage air quality in near real time [16].

Prototype development was carried out by adding the ability to measure O_2 , CO , and CO_2 gases, in addition to the previously measured temperature, humidity, and NH_3 . Figure 2 is a block diagram of the prototype development. Based on the block diagram, schematic, and wiring series have been designed and are shown in Figures 3 and 4, respectively. The prototype is connected to a Wi-Fi network via the *router*.

The prototype developed consists of several sensors: a temperature and humidity sensor (DHT22), an O_2 gas sensor

(SEN0322), an NH_3 gas sensor, a CO gas sensor (SKU: KL2031), and a CO_2 sensor (SEN0159). Each sensor is connected to an ESP32 processor, which processes the data and displays it on an LCD and on the ThingSpeak platform.

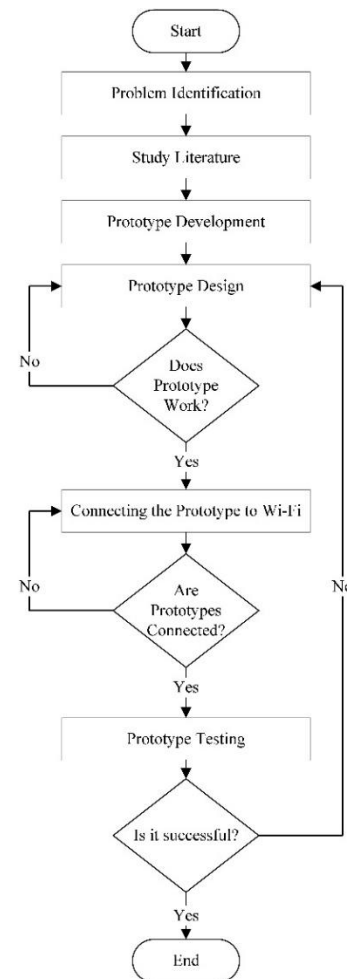


Figure 1. Research Flow Diagram

The ThingSpeak platform is used to display the chicken coop's air quality on Android and on a computer. The prototype test was conducted in a closed container by performing combustion to vary the gas content. Then, the NH_3 gas test was conducted by adding chicken manure to the container to vary the NH_3 gas concentration. The air quality parameter measurements from each sensor were then compared with those from the standard measuring device. Thus, the performance of each sensor can be evaluated using the mean absolute error (MAE) [17], mean absolute percentage error (MAPE) [18], root mean square error (RMSE) [19], and the coefficient of determination (R^2) [20]. The four formulas are calculated using Equation 1, Equation 2, Equation 3, and Equation 4 [21].

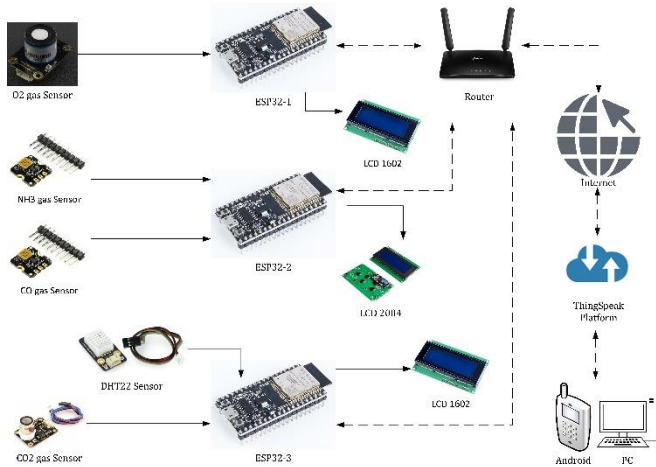


Figure 2. Prototype Block Diagram

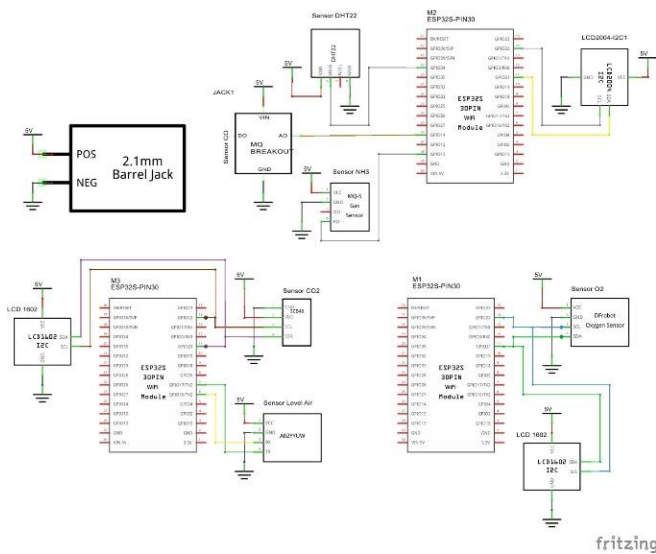


Figure 3. Schematic Diagram of the Prototype

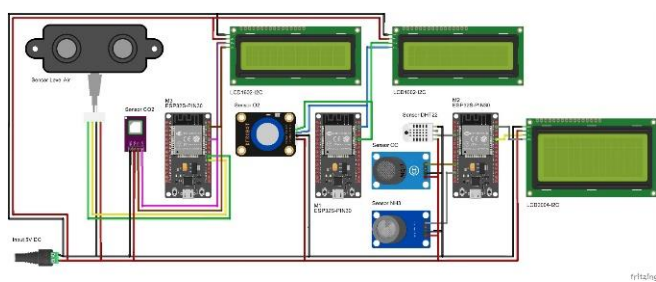


Figure 4. Prototype Wiring Design

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_{meas.} - y_{sensor}| \quad (1)$$

$$MAPE = \frac{100\%}{n} \sum_{i=1}^n \left| \frac{y_{meas.} - y_{sensor}}{y_{sensor}} \right| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_{meas.} - y_{sensor})^2} \quad (3)$$

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_{meas.} - y_{sensor})^2}{\sum_{i=1}^n (y_{meas.} - y_{meas. average})^2} \quad (4)$$

n is the amount of measurement data. $y_{meas.}$ is the result of measuring air quality parameters using standard measuring instruments. y_{sensor} is the result of measuring air-quality parameters with sensors on prototypes. $y_{meas.}$ The average is the mean of the measurement results obtained using standard measuring instruments [22].

The use of ThingSpeak as a monitoring dashboard provides security through unique API keys, TLS encryption for HTTP/MQTT communications, and private channel settings. In terms of capacity, ThingSpeak is free to store data at intervals of at least 15 seconds, up to 3 million messages/year. For 6 parameters with 1-minute intervals, it is still well below the limit. In terms of scalability, the use of Thingspeak allows the system to be extended to multiple enclosures by creating separate channels or using a single channel with multiple fields, and by migrating to a local MQTT server if needed.

III. RESULTS AND DISCUSSION

The exterior view of the developed prototype is shown in Figure 5. Figure 5(a) is the front view of the prototype equipped with a switch selector (ON/OFF) and two indicator lights. In Figure 5(b), you can see the back of the prototype, with a sensor box positioned at the height of a broiler chicken.



Figure 5. Exterior Display of the Prototype

Prototype Testing

Table 1 is the specification of the sensor used to produce the proposed prototype.

TABLE 1.
SPECIFICATIONS OF SENSORS USED

Sensor	Specification
Water Level Sensor (A02YYUW - SEN0311 DFRobot)	<ul style="list-style-type: none"> a. Operating Voltage: 3.3~5V b. standby Current: $\leq 5\text{mA}$ c. Average Current: $\leq 8\text{mA}$ d. Blind Zone Distance: 3cm e. Ranging Distance for Flat Object: 3-450cm f. Output: UART g. Response Time: 100ms h. Probe Center Frequency: $40\text{K}\pm 1.0\text{K}$ i. Operating Temperature: $-15\sim 60^\circ\text{C}$ j. Storage Temperature: $-25\sim 80^\circ\text{C}$ k. Sensing Angle: 60° l. Protection Rate: IP67
Temperature and humidity sensor (DHT22 - SEN0137 DFRobot)	<ul style="list-style-type: none"> a. Supply voltage: 5V b. Output voltage: 0-3.3V c. Temperature range: $-40\sim 80^\circ\text{C}$ resolution 0.1°C error $< \pm 0.5^\circ\text{C}$ d. Humidity range: 0-100%RH resolution 0.1% RH error $\pm 2\%$ RH e. size: 38 x 20mm
O ₂ Sensor Gas (SEN0322 DFRobot)	<ul style="list-style-type: none"> a. Detection of Gas: oxygen / O₂ b. Operating Voltage: 3.3 to 5.5V DC c. Output Signal: I2C output d. Measurement Range: 0~25% Vol e. Maximum Measurement limit: 30% Vol f. Resolution: 0.15% Vol g. Sensitivity: $(0.10\pm 0.05)\text{mA}$ (in the air) h. Stability: $< 2\%$ (Every month) i. Repeatability: $< 2\%$ j. Response Time: ≤ 15 seconds k. Operating Temperature: $-20\sim 50^\circ\text{C}$ l. Operating humidity: 0~99%RH (no condensation) m. Pressure Range: standard atmospheric pressure $\pm 10\%$ n. Lifetime: > 2 years (in the air) o. Dimension (L x W x H): 37 * 27 * 24.5 mm / 1.46 * 1.06 * 0.97 inches p. Weight: 0.037kg
MEMS NH ₃ Sensor Gas (SEN0567 DFRobot)	<ul style="list-style-type: none"> a. Gas detected: NH₃ b. Detection range: 1-300ppm c. Operating voltage: 3.3-5V d. Operating current: $< 20\text{mA}$ e. Output signal: Analog voltage f. Load resistance (RL) : $4.7\text{K}\Omega$ g. Sensitivity: $R_0(\text{in air})/R_s$ (in 50ppm NH₃) ≥ 3 h. Operating temperature: $-10\sim 50^\circ\text{C}$ i. Operating humidity: 15-90%RH (non-condensing) j. Lifespan: ≥ 5 years (in air) k. Dimension $13\times 13 \times 2.5\text{mm}/0.0.51\times 0.51\times 0.1''$
MEMS CO Sensor gas (SEN0564 DFRobot)	<ul style="list-style-type: none"> a. Gas detected: CO b. Detection range: 5-5000ppm c. Operating voltage: 3.3-5V d. Operating current: $< 20\text{mA}$ e. Output signal: Analog voltage f. Load resistance (RL) : $4.7\text{K}\Omega$

Sensor	Specification
	<ul style="list-style-type: none"> g. Sensitivity: $R_0(\text{in air})/R_s$ (in 150ppm CO) ≥ 3 h. Operating temperature: $-10\sim 50^\circ\text{C}$ i. Operating humidity: 15-90%RH (non-condensing) j. Lifespan: ≥ 5 years (in air) k. Dimension : $13\times 13 \times 2.5\text{mm}/0.0.51\times 0.51\times 0.1''$
CO ₂ Sensor Gas (SEN0159 DFRobot)	<ul style="list-style-type: none"> a. Operating voltage: 5V b. Interface: Analog (Gravity Compatible) c. One digital output d. High-quality connector e. Immersion gold surface f. Onboard heating circuit g. Size: $32\times 42\text{mm}$ (1.26x1.65")
ESP-32 DOIT WIFI Bluetooth IOT ESP-32S Development Board	<ul style="list-style-type: none"> a. Operating voltage: 3.3V b. Input voltage: 7-12V (Vin) c. Digital IO Pin (DIO): 25 d. Analog Input Pin (ADC): 6 e. Analog Output Pin (DAC): 2 f. UART: 3 g. SPI: 2 h. I2C: 3 i. Flash Memory 4 MB j. SRAM: 520 KB k. Clock Speed: 240 MHz l. Wi Fi: IEEE 802.11 b/g/n/e/i m. Modes supported: AP, STA, AP+STA n. CP2102 USB controller
LCD 1602 Character Blue Backlight with I2C Serial Interface Module	<ul style="list-style-type: none"> a. 1602-character LCD with I2C module for Arduino b. LCM Type: Character c. Displays 2 lines \times 16 characters. d. Voltage: 5 V DC. e. Module dimensions: 80mm x 35mm x 11mm. f. Area: 64.5mm x 16mm g. Features IIC/I2C 4 cables
LCD 2004 Character Blue Backlight with I2C Serial Interface Module	<ul style="list-style-type: none"> a. 2004 Character LCD with I2C module for Arduino b. LCM Type: Character c. Displays 4 lines X 20 characters. d. Voltage: 5 V DC. e. Features IIC/I2C 4 cables f. Size: 60mm X 99mm
Charger Dual USB	<ul style="list-style-type: none"> a. Input : 100-240V, 300mA b. USB1 Output: DC 5V/2A Max c. USB2 Output: DC 5V/2A Max d. USB1+USB2 Output: DC 5V/2.1A Max e. Micro USB Cable

Table 2 shows the type of sensor and reference measuring instrument used to measure the performance of the proposed prototype.

TABLE 2.
SENSORS AND REFERENCE MEASURING INSTRUMENTS USED

No.	Parameter	Sensor	Reference Tools
1.	Water Level (cm)	A02YYUW – SEN0311 DFRobot	SNDWAY Digital Laser Distance Meter 40
2.	Temperature (°C)	DHT22 – SEN0137 DFRobot	Calibration Thermometer
3.	Humidity (%)	DHT22 – SEN0137 DFRobot	SNDWAY Single CO ₂ Gas Detector Portable SW-723
4.	Oxygen Gas (% Vol)	O ₂ SEN0322 DFRobot	SNDWAY Gas Detector 4 in 1 CO H ₂ S O ₂ Combustible Gas Sensor Air Pump SW 7500A
5.	Ammonia Gas (NH ₃ – ppm)	MEMS NH ₃ SEN0567 DFRobot	Ammonia Gas Detector Smart Sensor AR8500 Tester
6.	Carbon Monoxide Gas (CO – μmol/mol)	CO SEN0564 DFRobot	SNDWAY Gas Detector 4 in 1 CO H ₂ S O ₂ Combustible Gas Sensor Air Pump SW 7500A
7.	Carbon Dioxide Gas (CO ₂ – ppm)	CO ₂ SEN0159 DFRobot	SNDWAY Single CO ₂ Gas Detector Portable SW-723

The prototype test is shown in Figure 6. In Figure 6(a), you can see a closed container that is used as a gas trap to produce variations in gas levels. Variations in gas levels are carried out by burning and feeding chicken manure. Figure 6(b) shows the interior of the test container, which consists of a prototype sensor box, several gas-measuring instruments, and a tripod used to photograph the display on each instrument.

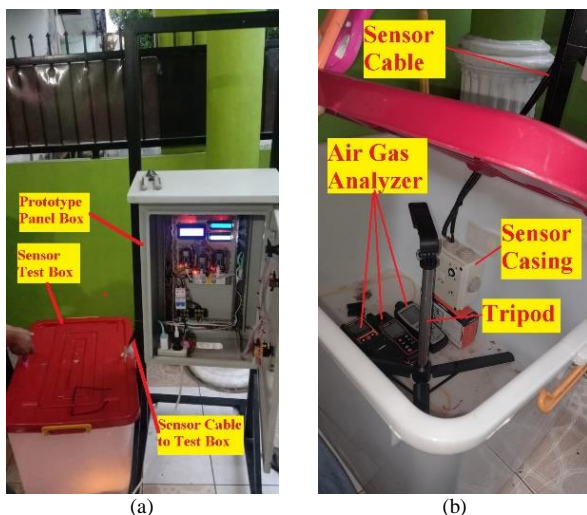


Figure 6. Testing Prototypes on Containers

Figure 7 shows the results of the air quality parameter test. Figure 7(a) is the LCD display of the air quality readings from each prototype sensor. Figure 7(b) is the display of the air quality reading results of each standard measuring instrument used.

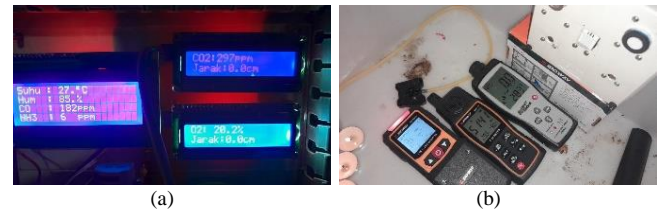


Figure 7. Test Result Display

Testing in a closed container aims to evaluate the sensor's intrinsic accuracy over a controlled concentration range. However, the actual conditions of the cage have air circulation, temperature fluctuations, and dynamic sources of contaminants. Figure 8 is a test of the proposed prototype in a broiler chicken coop with a capacity of 10,000 heads. Each parameter has 100 samples, with data captured every 30 seconds.

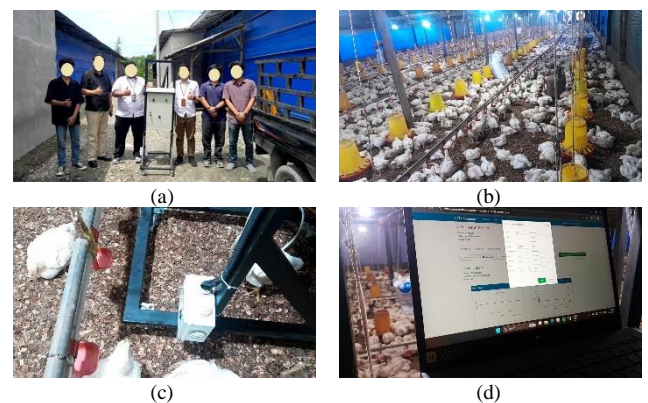


Figure 8. Field Testing of Proposed Prototypes

Figure 8(a) shows the entire testing team of the proposed prototype that has arrived at the closed house-type broiler chicken coop. Figure 8(b) shows the inside of a chicken coop consisting of thousands of chickens partitioned into blocks. Figure 8(c) shows the air quality sensor box section of the proposed prototype, positioned parallel to the chicken's height. Figure 8(d) is a view of the ThingSpeak platform that has been connected to the proposed prototype.

Test Results

Testing of the O₂ gas sensor was carried out on up to 54 samples, and a comparison graph was produced, as shown in Figure 9. Based on Figure 9, the O₂ level decreases as the combustion duration increases in the container. This is due to the combustion process, which requires O₂ gas, while the container is tightly closed. Thus, O₂ gas from outside cannot quickly enter the container. Based on the figure, the curve measured by the standard instrument overlaps with that of the

dominant O₂ gas sensor. Furthermore, by using model evaluation metrics such as Equation 1, Equation 2, Equation 3, and Equation 4, it can be calculated that the MAE values = 0.1 % Vol, MAPE = 0.57 %, RMSE = 0.14, and R² = 0.98 can be calculated.

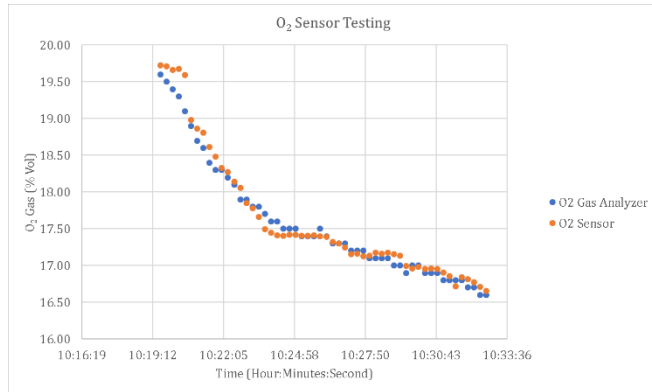


Figure 9. O₂ Gas Measurement Results

Figure 10 shows a comparison of CO gas measurements from the CO sensor on a prototype and a standard measuring instrument, with a sample count of 54. From the image, it appears that the two curves are almost intertwined. Furthermore, using the evaluation metric formula, the values are MAE = 4.46 μmol/mol, MAPE = 2.03%, RMSE = 4.81, and R² = 0.99. Based on the image, the CO gas level in the container also increases with combustion duration. This is caused by combustion in the container, where the limited O₂ leads to incomplete combustion and the production of CO.

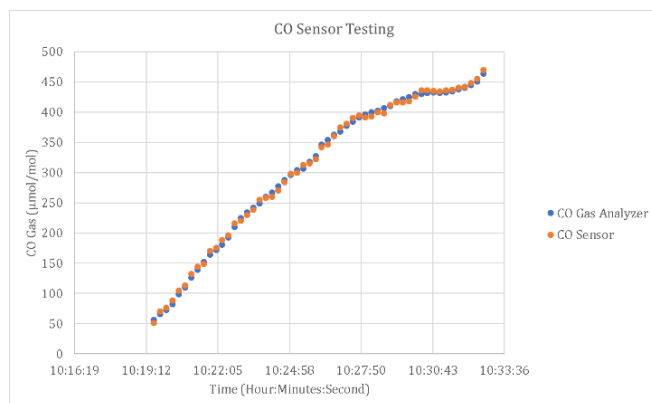


Figure 10. CO Gas Measurement Results

CO₂ gas levels were measured in 15 samples, as shown in Figure 11. The limited number of CO₂ gas measurement samples was due to the combustion process using candles in the container. The combustion process produced CO₂ at a level that was too high, causing the container level to exceed the upper limit of the standard measuring instrument. In addition, the image shows an increase in CO₂ levels resulting from combustion. The CO₂ gas measurement curve from the sensor on the prototype aligns with that of the standard measuring device. Using evaluation metrics, the values are

MAE = 24.20 ppm, MAPE = 0.36%, RMSE = 32.20, and R² = 0.99.

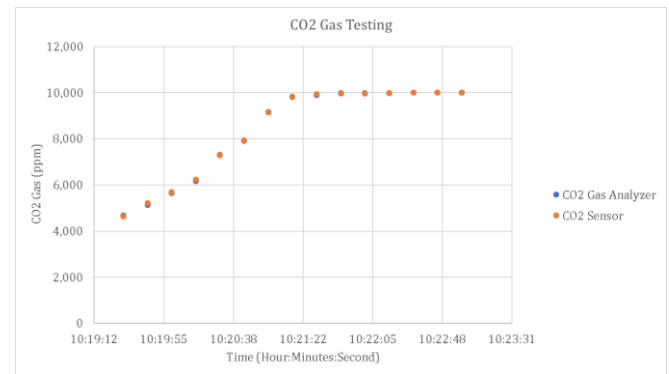


Figure 11. CO₂ Gas Measurement Results

Temperature measurements were carried out by a DHT22 sensor in 54 samples. A comparison of temperature measurements from a standard instrument and the DHT22 sensor is shown in Figure 12. From the image, it is clear that the two curves never overlap. Furthermore, using the metric formula, the evaluation yields MAE = 0.71 °C, MAPE = 2.28 %, RMSE = 0.73 °C, and R² = 0.95. Based on the image, there is also an increase in the air temperature inside the container. This is caused by combustion within the container, which releases heat.

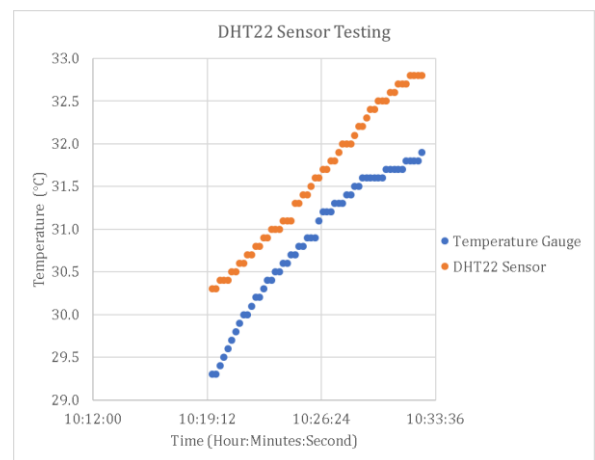


Figure 12. Air Temperature Measurement Results

The results of the IoT performance test on the prototype through the ThingSpeak platform are shown in Figure 13. The ESP32 reads the sensor every 2 seconds, averages the readings over 30 seconds, and then sends the data to ThingSpeak via an HTTP GET request every 30 seconds. If the delivery fails, the data is stored in temporary memory, and the delivery is retried. A 30-second interval was chosen to balance real-time monitoring and the limitations of the ThingSpeak API.

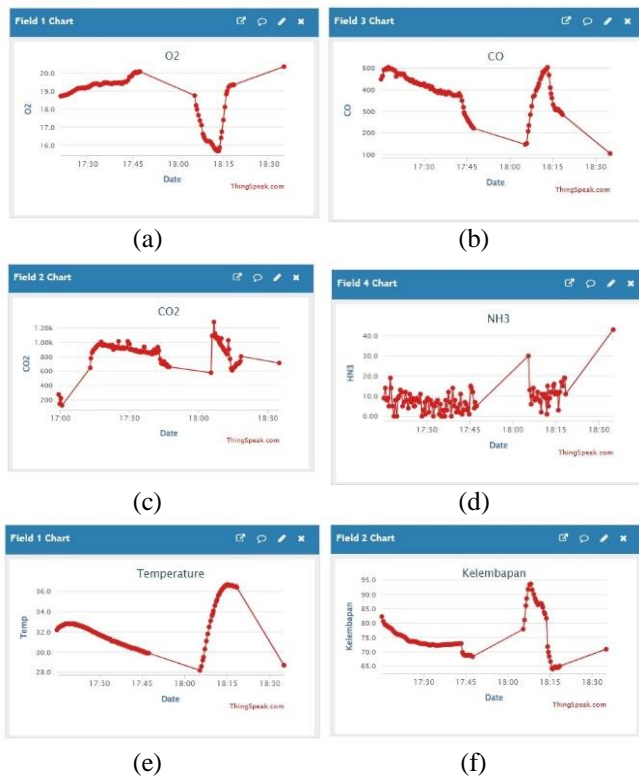


Figure 13. ThingSpeak Platform View

Figure 13(a), Figure 13(b), Figure 13(c), Figure 13(d), Figure 13(e), Figure 13(f) are the curves of the measurement of O₂ gas, CO gas, CO₂ gas, NH₃ gas, temperature and humidity, respectively. The proposed prototype provides information on chicken coop air quality via the internet, enabling near-real-time monitoring. The resistance test to internet interruptions (unstable) is carried out by the ESP32, which temporarily stores data in a buffer or saves it to microSD, then resends it after reconnection.

Discussion

Table 3 presents the evaluation metrics for each prototype sensor. Based on Table 1, the R² values for each sensor exceed 0.9, indicating a strong correlation between each sensor and the standard measuring instrument. This study has developed a more comprehensive prototype for IoT-based monitoring of air quality parameters in chicken coops than previous research.

TABLE 3. RESULTS OF PROTOTYPE EVALUATION METRICS

Sensor	MAE	MAPE	RMSE	R ²
O ₂ (% Vol.)	0,10	0,57	0,14	0,98
CO (μmol/mol)	4,46	2,03	4,81	0,99
CO ₂ (ppm)	24,20	0,36	32,20	0,99
DHT22 (°C)	0,71	2,28	0,73	0,95

Table 4 presents the reference values for the MAE and RMSE evaluation metrics to determine the sensor's accuracy limit. Based on the comparison of the two tables, the MAE

and RMSE values for the O₂, CO, and CO₂ gas sensors remain within the reference range. The MAE and RMSE values for the DHT22 sensor are outside the reference range. Based on this, the O₂, CO, and CO₂ gas sensors provide accurate measurements. Meanwhile, the DHT22 sensor provides quite accurate measurements.

TABLE 4. MAE AND RMSE (ACCURATE SENSOR) REFERENCE

Sensor	MAE and RMSE References
O ₂ (% Vol.)	0,2 – 0,5
CO (μmol/mol)	3 – 10
CO ₂ (ppm)	10 – 50
DHT22 (°C)	0,1 – 0,5

Table 5 presents the average air quality measurements in closed-house broiler chicken coops for each sensor section of the proposed prototype. Based on the table, it can be seen that the average of each parameter, namely temperature of 28.55 °C, humidity of 81.47%, CO gas of 3.2 ppm, NH₃ gas of 3.07 ppm, CO₂ gas of 669.52%, and O₂ gas of 20.19 % Vol. Based on the average measurements, the air quality in the chicken coop meets the adjusted standard values, except for humidity. The humidity in the chicken coop exceeds the maximum limit of 65%. Increased humidity can raise NH₃ gas levels, but this increase can be mitigated with adequate litter and exhaust fans in the enclosure. Table 6 is the result of the calculation of the standard deviation of each sensor part of the prototype.

TABLE 5. AVERAGE MEASUREMENT RESULTS IN THE FIELD

Parameter	Min.	Max.	Ideal Avg.	Avg.
Temperature (°C)	28,10	29,00	(27 – 34)	28,55
Humidity (%)	80,00	82,90	(45 – 65)	81,47
CO (ppm)	2,90	3,50	≤ 10	3,20
NH ₃ (ppm)	0,00	15,00	≤ 10	3,07
CO ₂ (μmol/mol)	623,00	755,00	≤ 3.000	669,52
O ₂ (% Vol)	20,14	20,27	≥ 19,6	20,19

TABLE 6. STANDARD DEVIATION OF FIELD MEASUREMENT RESULTS

Parameter	Ideal Std. Dev.	Std. Dev.
Temperature (°C)	≤ 0,50	0,29
Humidity (%)	≤ 2,00	0,77
CO (ppm)	≤ 5,00	0,17
NH ₃ (ppm)	≤ 5,00	3,88
CO ₂ (μmol/mol)	≤ 50,00	14,27
O ₂ (% Vol)	≤ 0,50	0,03

Based on Table 6, the standard deviation for each sensor meets the ideal standard deviation. This indicates that each sensor has good measurement stability. Low-cost electrochemical sensors (CO SEN0564 DFRobot, MEMS NH₃ SEN0567 DFRobot, and SEN0159 DFRobot (CO₂)) have limitations, including susceptibility to drift over time and sensitivity to temperature/humidity. Mitigation measures

for these deficiencies include calibration before testing, heating the sensor as specified in the datasheet, temperature/humidity compensation (if applicable), and periodic revalidation. The recommended action is to replace the gas sensor every 6–12 months in a corrosive broiler chicken coop environment.

IV. CONCLUSION

Based on the test results, the prototype development yields accurate measurements of air quality parameters, and the model evaluation metrics meet the reference standards. In addition, the prototype has also been integrated with IoT technology through the ThingSpeak platform. This research can be advanced by integrating exhaust fans and lighting in chicken coops. Both devices can work automatically to produce adequate air quality for broiler chicken farming. Further research will integrate a relay module to power an exhaust fan, a heating light, a cooling pad pump, or an automatic notification sender via Telegram/Blynk when parameters exceed their thresholds, so that the system not only monitors but also responds.

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