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Design of Oxygen and Carbon Dioxide Monitoring System in Cocoa Fermentation with Internet of Things and Automatic Stirring System

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ABSTRACT

In some areas in Indonesia, more traditional cocoa farmers have yet to carry out special monitoring of O_2 and CO_2 levels during fermentation because the practices and technologies used by cocoa farmers can vary significantly in different regions and levels of development. The right amount and level of O_2 and CO_2 can regulate the activity of microorganisms and affect the overall fermentation process. The fermentation box is made using a wooden board measuring 50x50 cm and is equipped with a stirring blade inside. The sensors used are the Gravity O_2 I2C Sensor and the CO_2 Sensor MG-118, with a high torque D.C. motor as the stirring blade drive. The results of monitoring and controlling the stirrer are carried out using the Blynk IoT platform or directly on the fermentation box. The tests carried out include testing on an empty fermentation box and testing on the fermentation process of 1kg and 6kg cocoa. After carrying out the testing process, the sensors and IoT systems created can work optimally. The sensor test results in the cocoa fermentation process show a change in CO_2 concentration, initially 400 ppm, increasing to a maximum of 1600 ppm. Meanwhile, the O_2 concentration remains stable at 20-21% vol, and the stirrer can work optimally. The D.C. motor-driven stirrer can operate effectively with a stirrer response time of 2 seconds and a stirring efficiency of 95% at both fermentation loads (1kg and 6kg). The monitoring system integrated with the Blynk IoT platform shows a gas measurement accuracy rate of 98%, making it easier for cocoa farmers to monitor and control the fermentation process more accurately. The effectiveness of this system can improve the quality of cocoa fermentation results by optimizing fermentation conditions through the right O_2 and CO_2 levels.

INTRODUCTION

Fermentation is one of the crucial stages in cocoa bean processing. The fermentation process turns fresh cocoa beans into beans ready to be dried and then processed into chocolate products [1]–[3]. One of the factors that must be considered in the cocoa fermentation process is the levels of oxygen (O_2) and carbondioxide (CO_2). Monitoring O_2 (oxygen) and CO_2 (carbondioxide) during cocoa fermentation is crucial because both produce good-quality cocoa beans. Good fermentation requires the presence of oxygen initially to trigger the growth of microorganisms that carry out fermentation but then produce CO_2 when the microorganisms break down the sugar in the cocoa beans [4], [5].

Fermentation is a crucial stage in determining the quality of cocoa beans, as this process significantly affects the composition and characteristics of the beans. During fermentation, compounds in cocoa beans undergo changes that can affect the texture, color, flavor, water content, aroma, and appearance of the beans. These changes significantly improve the quality of cocoa beans and their selling value. However, it is crucial to carry out the fermentation process correctly; if fermentation is carried out incorrectly or the cocoa beans are not appropriately fermented, the result can be purple or grayish beans with a dense and complex texture. This condition reduces the quality of the cocoa beans and can negatively affect the final product's taste and aroma. Therefore, careful monitoring and proper fermentation techniques are essential to ensure high-quality results. Regular monitoring can help determine the right time to stop the fermentation process and continue the next processing stage. Cocoa beans that are ripe and have optimal fermentation will produce good-quality beans. So, by monitoring O_2 and CO_2 during cocoa fermentation, you can optimize the fermentation process, control the temperature, and ensure the cocoa beans reach the proper maturity. This has a direct impact on the final quality of cocoa beans and the products produced from them [6], [7].

The cocoa bean fermentation process must be carried out carefully because this stage determines the final quality of the cocoa beans [3], [8]. During fermentation, the temperature increases, which is initiated by microbial activity that converts sugar into alcohol through an exothermic reaction. This increase in temperature is also influenced by certain bacteria that produce

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significant amounts of CO_2. In addition, CO_2 produced during the oxidation process utilizes O_2, which contributes to important chemical changes in fermentation. Therefore, proper control during fermentation is essential to optimize the quality of cocoa beans and ensure that the final results meet industry standards.

However, the main challenge in maintaining the cocoa fermentation process is the dynamic changes in O_2 and CO_2 levels that occur during fermentation [9]–[11]. The optimal cocoa fermentation process is highly dependent on the balance of O_2 and CO_2 levels, as well as the homogeneity of the stirring. Without accurate monitoring, farmers often have difficulty controlling fermentation conditions, resulting in the risk of producing cocoa beans with inconsistent quality. High CO_2 levels can inhibit the activity of beneficial microorganisms, while low O_2 levels can slow down the oxidation process, which is essential for effective fermentation [12]–[14]. This challenge is further complicated by the varying fermentation conditions between farmers in different regions and the unavailability of technology that allows real-time monitoring and control.

This study proposes a monitoring system based on O2 (Gravity O2 I2C) and CO2 (MG-118) sensors integrated with the Blynk IoT platform to overcome these challenges. Blynk IoT Platform is a free platform designed to simplify developing and managing Internet of Things (IoT) devices. This system allows real-time monitoring of changes in O_2 and CO_2 levels during fermentation and automatic adjustment of the stirrer to ensure optimal fermentation conditions. By using this technology, changes in O_2 and CO_2 concentrations can be detected. This technology is also equipped with a stirrer system that can operate optimally, increasing the efficiency of the fermentation process and reducing the risk of gas entering which can be detrimental to the quality of cocoa beans.

To stir cocoa beans in the fermentation process, generally, cocoa farmers only stir manually. The process of stirring cocoa beans is still done using human power. Therefore, an automatic stirrer is needed to help farmers in the cocoa bean fermentation process. The automatic stirrer integrated into this system also reduces reliance on manual labor, making the fermentation process more efficient and consistent. By making an automatic stirrer, the automatic stirrer can be equipped with remote operations that utilize the IoT platform. Automatic stirrers using remote applications will add practicality to cocoa farmers in the cocoa fermentation process, such as the efficiency of fermentation time.

Internet of Things (IoT) technology enables remote and real-time monitoring of the observed variables, making it easier to analyze and detect changes in conditions. This system monitors air quality directly using an ESP32 microcontroller connected to an IoT network. With the ability to provide real-time data, IoT technology helps monitor and analyze air quality efficiently, making it easier to detect potential air quality problems early [15]–[17]. Based on the above description of the technical challenges and potential of IoT solutions, an integrated approach is needed that is not only able to monitor fermentation conditions in real-time but is also able to intervene automatically when needed.

Judging from the existing problems, a tool is needed that can monitor O_2 and CO_2 levels and an automatic stirrer in the cocoa fermentation process. Therefore, this study will create a "Design and Construction of O_2 and CO_2 Level Monitoring with a Stirrer in the Cocoa Fermentation Process based on the Internet of Things (IoT)". The creation of O_2 and CO_2 level monitoring using Gravity: I2C Oxygen/O_2 sensor and MG-811 CO_2 sensor with a stirrer that can be turned on or off remotely. The microcontroller used is the NodeMCU E.S.P. 32 Microcontroller. The ESP32 is a microprocessor designed for Internet of Things (IoT) applications, embedded electronics, and smart devices. This study is expected to help cocoa farmers in the cocoa bean fermentation process, especially in the efficiency of fermentation time; cocoa farmers can also save more energy because the fermentation process is more practical even with an increase in production quota and can improve the quality and quality of cocoa beans.

METHODS

In this study, several key variables were selected as objects of observation to ensure that the cocoa bean fermentation process takes place optimally. These variables include oxygen (O_2) and carbon dioxide (CO_2) levels as indicators of microbial activity, as well as a mixer that functions to maintain fermentation homogeneity. Monitoring of O_2 and CO_2 is carried out using special sensors connected to an ESP32-based system, while control of the mixer is automatically regulated through the application interface. By monitoring and controlling these variables, it is hoped that the fermentation process can run more efficiently, resulting in better quality cocoa beans. The variables used as research objects are as follows:

Oxygen (O_2) and Carbon dioxide (CO_2)

Oxygen (O_2) plays an important role in supporting the activity of microorganisms in cocoa fermentation. Therefore, it is expected that oxygen levels can be monitored [18], [19]. The fermentation reaction in cocoa beans produces CO_2 as the main by-product. Microorganisms break down the sugar in cocoa beans into other compounds, including CO_2. So, monitoring CO_2 levels is needed to determine the CO_2 produced during the cocoa bean fermentation process [20], [21].

Mixer

In the cocoa fermentation process, stirring is done to ensure that the fermentation process runs evenly and optimally throughout the pile of cocoa beans. So that the stirrer that can be set on/off remotely can maximize the cocoa fermentation process to produce better-quality cocoa beans [22], [23].

The flow diagram of the O_2 and CO_2 monitoring system illustrated in Figure 1. Figure 1 shows that the O_2 and CO_2 sensors are inputs that send data to the ESP 32 board, then the ESP 32 processes data from the sensor. If the sensor is read and the ESP 32 is connected to the internet, it will send monitoring data to the Application and LCD. Furthermore, when sending a signal from the Application to turn on the stirrer, the ESP 32 will process the signal and turn on the DC motor. If sending another signal from the Application to turn off the stirrer, the ESP 32 will process the signal and turn off the DC motor.

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Figure 2 shows a block diagram of the system on the O_2 and CO_2 monitoring device and the variation of the stirring speed in cocoa fermentation, which uses the O_2 sensor and CO_2 sensor as input to the ESP 32, which then sends the monitoring data to the Application and displays it on the LCD. For the variation of the stirring speed, the Application is used as input to the ESP 32, which then gives output to the motor driver. The motor driver receives input from a 12V DC voltage source, where the Motor Driver controls the on/off of the motor.

From the block diagram that has been designed, continue by making a wiring diagram of the components used. Assembly is the connection of all the device cables used until all components can function according to their respective functions. The design that was done is illustrated in Figure 3.

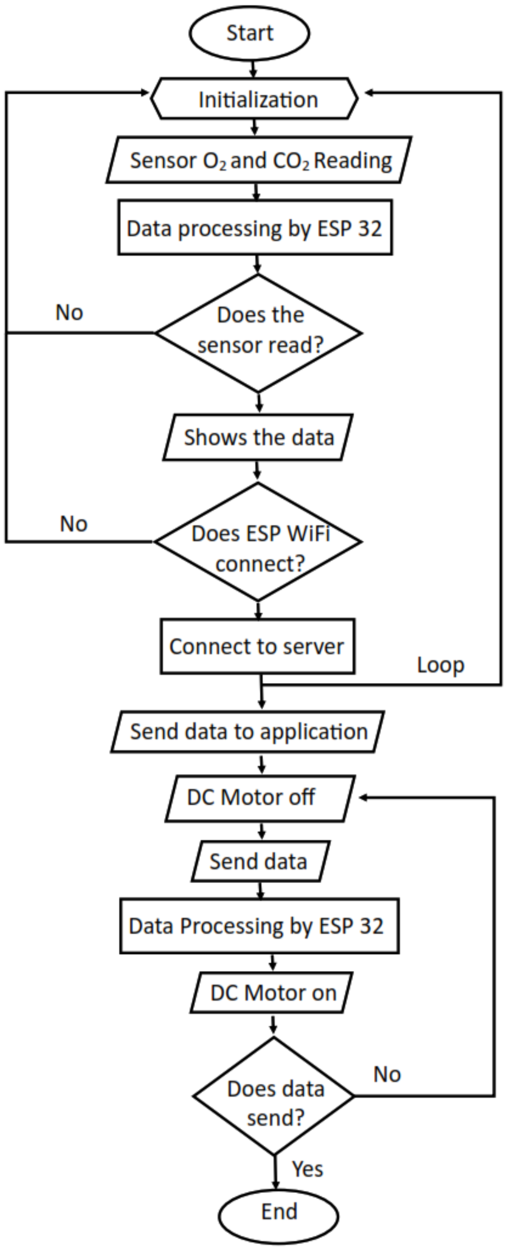

Figure 1. Flowchart of O2 and CO2 Monitoring and Stirring System

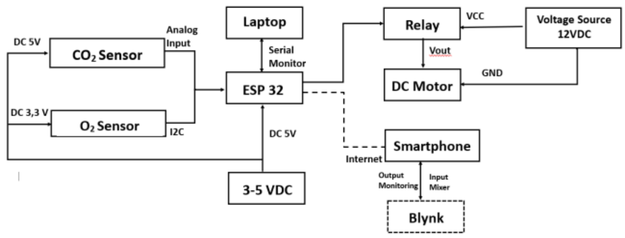

Figure 2. Block Diagram of the O_2/CO_2 Monitoring and Stirring System

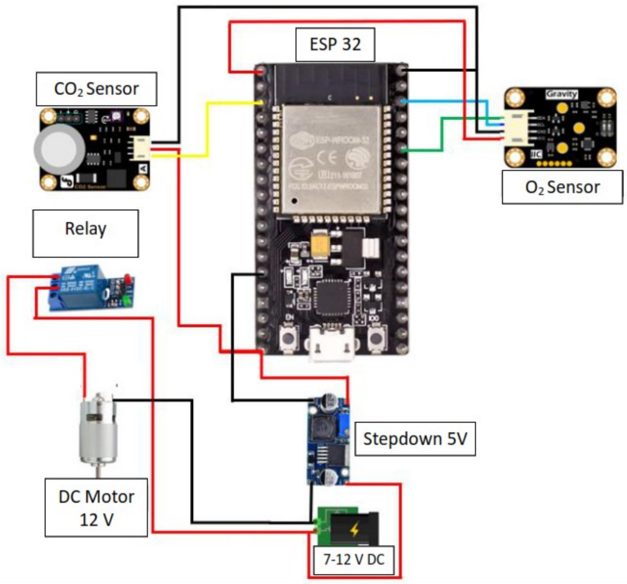

Figure 3. Wiring Diagram

The fermentation box will be designed using basic wood material with a height of 50 cm, a width of 50 cm, and a length of 50 cm, which will be used for cocoa fermentation. The testing procedure is carried out by placing cocoa beans in the fermentation box and monitoring changes in O_2 and CO_2 levels during fermentation. Before the test begins, the data is validated by calibrating the O_2 (Gravity O2 I2C) and CO_2 (MG-118) sensors to ensure measurement accuracy. This calibration is carried out using standard gases with known O_2 and CO_2 concentrations so that the data produced can be trusted and provide accurate information about fermentation conditions.

O_2 and CO_2 sensors calibration

Calibration of O_2 and CO_2 sensors is done to obtain data on O_2 levels and the output voltage of the CO_2 sensor in the environment around the sensor. The test was carried out for 15 minutes, and a sensor warming-up process was completed before the sensor could work optimally. The data shows in Appendices A that the oxygen concentration detected by the O_2 sensor is 20.37-20.50%. The results are not much different from the O_2 concentration value in the atmosphere, which is ±20%vol. Meanwhile, it can be seen that after the sensor is warmed up for 15 minutes, the sensor voltage output is 2.4 V. So if the reference value of CO_2 concentration in the atmosphere is ±400 ppm, it can be concluded that when the CO_2 sensor detects a CO_2 level of 400ppm, it produces a sensor voltage output of 2.4 V.

RESULTS AND DISCUSSION

This tool is made to determine the performance of sensors in the fermentation process of cocoa beans. Testing is divided into several stages, from testing in the fermentation box environment to testing using cocoa bean samples in the fermentation process.

Testing O_2 and CO_2 Sensors on an empty fermentation box

The test results show in Appendix B that in the empty cocoa fermentation box, there is a change in the O_2 content value caused by air circulation. The CO_2 concentration is stable, and there is no increase in CO_2 levels in the empty cocoa fermentation box. The O_2 concentration value read by the sensor is 20.80%—21.02%, so it can be said that there is an increase in O_2 concentration of 1,02% from the O_2 concentration in the atmosphere, which is 20%.

Testing of O_2 and CO_2 sensors in a fermentation box with 1 kg of cocoa beans as the object

The O_2 and CO_2 sensor testing was carried out on a fermentation box with 1 kg of cocoa beans as the object. This test aimed to determine the changes in O_2 and CO_2 concentration levels in the fermentation box during the cocoa bean fermentation process. The sensor test results can be seen in Table 1.

Table 1. O_2 and CO_2 Sensor Test Data on 1kg cocoa fermentation

No	Time /60 minutes	O_2 Read (% vol)	CO_2 Reading (ppm)	Sensor Voltage *Output*
1	60 minutes 1	20.76	922	2.46
2	60 minutes 2	20.75	1159	2.40
3	60 minutes 3	20.77	1646	2.30
4	60 minutes 4	20.72	848	2.49
5	60 minutes 5	20.69	607	2.58
6	60 minutes 6	20.69	526	2.62
7	60 minutes 7	20.64	854	2.48
8	60 minutes 8	20.67	1043	2.43
9	60 minutes 9	20.60	1204	2.39
10	60 minutes 10	20.61	1376	2.35

From the test results, it can be seen that there is no significant change in O_2 concentration in the cocoa bean fermentation process. However, there is a significant change in CO_2 concentration, so it can be said that the cocoa bean fermentation process produces CO_2 gas, which increases CO_2 concentration in the cocoa bean fermentation box. The resulting voltage output decreases when the sensor detects a high CO_2 concentration value. Conversely, when the sensor detects a low CO_2 concentration value, the voltage output increases.

Testing of O_2 and CO_2 sensors in a fermentation box with 6 kg of cocoa beans as the object

O_2 and CO_2 sensor testing was carried out on a fermentation box with 6 kg of cocoa beans as the object on the second and third days of fermentation. Test data was taken in multiples of 15 minutes. The sensor test results can be seen in Table 2 for day five and Table 3 for day 7.

Table 2. O_2 and CO_2 Sensor Test Data on 6kg cocoa fermentation on the 2nd day

No	Time /15 minutes	O_2 Read (% vol)	CO_2 Reading (ppm)	Sensor Voltage *Output*
1	15 minutes to 1	20.97	994	1.74
2	15 minutes 2	20.93	1077	1.72
3	15 minutes 3	20.98	1044	1.73
4	15 minutes to 4	21.00	956	1.75
5	15 minutes to 5	21.06	936	1.76
6	15 minutes to 6	20.99	920	1.77
7	15 minutes to 7	21.03	966	1.75
8	15 minutes to 8	21.00	863	1.78
9	15 minutes to 9	21.05	904	1.77
10	15 minutes to 10	21.01	860	1.78
11	15 minutes 11	20.93	799	1.80
12	15 minutes to 12	21.10	764	1.82
13	15 minutes 13	20.99	834	1.79
14	15 minutes to 14	20.88	850	1.77
15	15 minutes to 15	21.03	895	1.77

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Table 3. O_2 and CO_2 Sensor Test Data on 6kg cocoa fermentation on the 3rd day

No	Time /15 minutes	O_2 (% vol)	CO_2 (ppm)	Sensor *Output Voltage* (Volt)
1	15 minutes to 1	20.83	1180	1.70
2	15 minutes 2	20.81	1557	1.62
3	15 minutes 3	20.75	1442	1.64
4	15 minutes to 4	20.77	1493	1.63
5	15 minutes to 5	20.80	1607	1.61
6	15 minutes to 6	20.78	1624	1.61
7	15 minutes to 7	20.75	1493	1.63
8	15 minutes to 8	20.76	1457	1.64
9	15 minutes to 9	20.72	1525	1.63
10	15 minutes to 10	20.76	1422	1.64
11	15 minutes 11	20.67	1552	1.62
12	15 minutes to 12	20.80	1541	1.62
13	15 minutes 13	20.75	1447	1.63
14	15 minutes to 14	20.68	1457	1.64
15	15 minutes to 15	20.65	1665	1.60

As seen in Table 2 and Table 3, there are differences in O_2 and CO_2 concentrations in the fermentation process on day two and day 3. On day 2 of fermentation, the O_2 concentration value is higher than on day 3. On day 2 of fermentation, the CO_2 concentration is higher than on day 3, while the O_2 concentration decreases from the previous day. The O_2 concentration value in the fermentation process decreased from day 2 to day 3, while the CO_2 concentration value in the fermentation process increased from day 2 to day 3 of fermentation.

Comparison Of Proposed Sensor to The Existing Research

Table 4 is a comparative analysis of this study with existing research. It shows that the results of the carbon dioxide and Oxygen concentrations detected in this study have results within the appropriate range. So, by considering the sensor type and the sensor detection performance, the proposed study provides good performance.

Table 4. Comparison Of The Proposed Research With Existing Research

Reference	Sensor	Detection	Concentrate
[24]	MG-811	Carbon dioxide	400-1900 ppm
[25]	MG-811	Carbon dioxide	328-489 ppm
[26]	DO	Oxygen	4-6 ppm
[27]	Gravity O_2 I2C MG-811	Oxygen and Carbon dioxide	21,2% - 22,0% and 907-1404
This work	Gravity O_2 I2C MG-811	Oxygen and Carbon dioxide	20.80%— 21.02% and 400-1700 ppm

Blynk IoT application testing

In Figure 4, the Blynk application uses 2 Gauge displays as O_2 and CO_2 monitoring indicators, 1 Value display as an indicator of the voltage output from the CO_2 sensor, and 1 button with a switch mode to turn the stirring motor on and off.

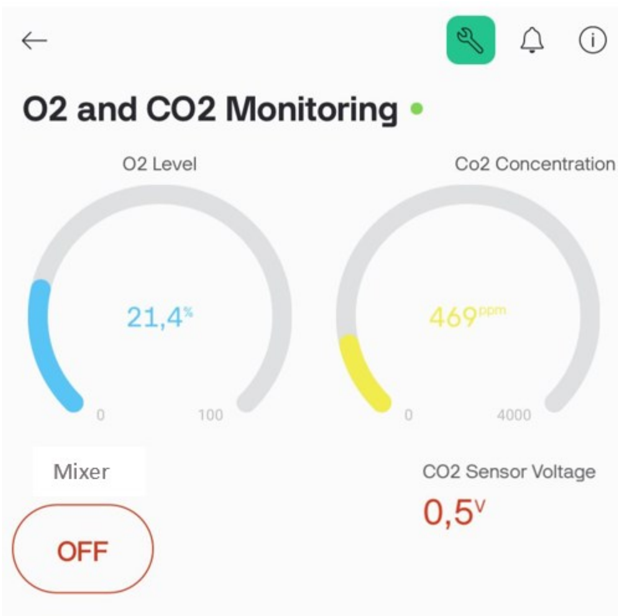

Figure 4. Blynk application display on Smartphone

Mixer System Testing

The stirrer can be operated via the button widget on the Blynk application display. After testing, when the button is pressed, the widget changes condition from off to on, and the stirrer motor works. Furthermore, if the button is pressed again, the widget changes condition from on to off, and the stirrer motor stops working. The change in the condition of the off button widget is illustrated in Figure 4, and the on button widget in Figure 5.

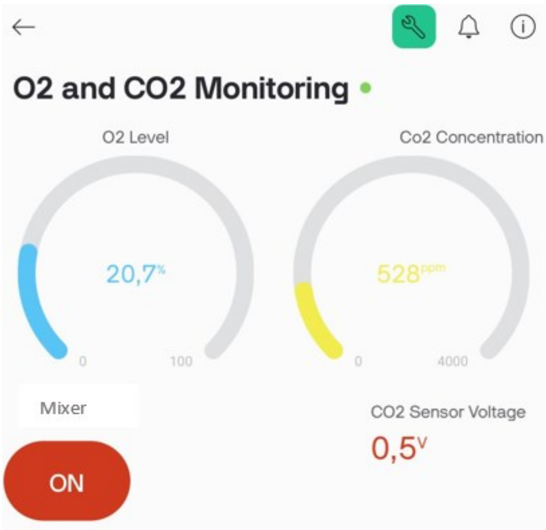

Figure 5. Blynk application display with the button on

CONCLUSIONS

Based on the research that has been conducted, the O_2 and CO_2 monitoring system designed in the cocoa fermentation box has shown success in accurately detecting O_2 and CO_2 concentrations. This system allows real-time data monitoring via the Blynk IoT platform as long as the monitoring device and smartphone are connected to the internet. With this technology, the cocoa fermentation process can be stored more efficiently. In addition, this study provides a practical solution to improve quality control in cocoa fermentation, which impacts improving the quality of the final results. In the cocoa fermentation process, an increase in CO_2 concentration was detected from 400 ppm to 1600 ppm, while the O_2 concentration remained stable at 20% vol. This shows that the fermentation process produces CO_2 gas, which can be effectively monitored using this system. The motor stirrer in the fermentation box can also be operated remotely via the Blynk application, strengthening the system's efficiency and ease of use. However, further research is needed to expand the application of this technology. For example, the development of sensors with higher sensitivity, integrating with automated systems based on artificial intelligence, or evaluating performance in industrial-scale fermentation environments. In addition, challenges such as system resilience under extreme environmental conditions and power consumption optimization also need to be explored.

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APPENDICES

APPENDIX A

The placement of the sensor for calibration in the work environment is illustrated in Figure A1, and the sensors calibration results data can be seen in Table A1 and Table A2.

Figure A1. Sensor Calibration

Table A1. O_2 Sensor Calibration

No	Time/1 minute	O2 (%vol)
1	Minute 1	20,41
2	Minute 2	20,40
3	Minute 3	20,39
4	Minute 4	20,35
5	Minute 5	20,37
6	Minute 6	20,41
7	Minute 7	20,45
8	Minute 8	20,42
9	Minute 9	20,39
10	Minute 10	20,43
11	Minute 11	20,39
12	Minute 12	20,43
13	Minute 13	20,42
14	Minute 14	20,43
15	Minute 15	20,43

Table A2. CO_2 Sensor Calibration

No	Time/1 minute	Sensor Voltage Output CO_2 (V)
1	Minute 1	2,33
2	Minute 2	2,31
3	Minute 3	2,32
4	Minute 4	2,32
5	Minute 5	2,33
6	Minute 6	2,35
7	Minute 7	2,34
8	Minute 8	2,33
9	Minute 9	2,34
10	Minute 10	2,38
11	Minute 11	2,38V
12	Minute 12	2,40V
13	Minute 13	2,42V
14	Minute 14	2,46V
15	Minute 15	2,48V

APPENDIX B

O_2 and CO_2 sensor testing was carried out on the fermentation box, which aimed to determine the concentration of O_2 and CO_2 levels in the fermentation box in an empty box. The data from the O_2 and CO_2 sensor testing results can be seen in Table B2 and illustrated in Figure B2.

Figure B2. Sensor Data Collection Process in an empty fermentation box

Table B2. O_2 and CO_2 Sensor Test Data on an empty box

No	Time /10 minutes	O_2 Read (%vol)	CO_2 Reading (ppm)	Sensor Voltage *Output* (Volts)
1	10 minutes to 1	20.82	<400	2.45
2	10 minutes to 2	20.89	<400	2.51
3	10 minutes to 3	20.87	<400	2.50
4	10 minutes to 4	20.84	<400	2.55
5	10 minutes to 5	21.00	<400	2.57
6	10 minutes to 6	21.00	<400	2.63
7	10 minutes to 7	20.93	<400	2.64
8	10 minutes to 8	20.98	<400	2.65
9	10 minutes to 9	20.99	<400	2.72
10	10 minutes to 10	21.03	<400	2.73
11	10 minutes to 11	21.09	<400	2.78
12	10 minutes to 12	21.08	<400	2.77
13	10 minutes to 13	21.14	<400	2.81

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14	10 minutes to 14	21.04	<400	2.80
15	10 minutes to 15	21.01	<400	2.80