Data Acquisition System on Cocoa Bean Fermenter Using ESP32 Based on MQQT Protocol

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Abstract — The fermentation process of cocoa beans is a critical stage in chocolate production that affects the final quality of the product. To ensure that fermentation takes place optimally, monitoring parameters such as temperature, humidity, and pH is necessary. This research aims to develop and validate an Internet of Things (IoT)-based data acquisition system that uses ESP32 and MQTT protocols to monitor the fermentation process of cocoa beans. The system consists of an ESP32 module connected to DHT22 sensors to measure temperature and humidity, and a pH meter to measure acidity. The data collected by the sensors is sent in real-time via a wireless connection to an MQTT broker, where it can be monitored continuously.

System testing was conducted in a small-scale fermentation environment. Validation results show that the system is capable of providing accurate and consistent data when compared to manual measurements using standardized tools. The difference between the data collected by the system and manual measurements was within acceptable tolerance limits, indicating that the system is reliable enough to be used in small-scale applications. The system also demonstrated fast response to changes in fermentation conditions, and stable data connection with minimal latency via the MQTT protocol.

The developed data acquisition system has successfully acquired data and validated it using standard measuring instruments. The average data error for the pH sensor is 2.78%, temperature sensor 1.41%, and humidity sensor 1.94%. These error values indicate that the performance of the sensors used is good.

Keywords — Cocoa Bean Fermentation, IoT-based Data Acquisition System, ESP32, MQTT Protocol, Real-time Monitoring

I. Introduction

Fermentation of cocoa beans is a critical stage in chocolate production that affects the final quality of the product, including taste, aroma and color [1]. The process involves biochemical changes that are influenced by microorganisms that thrive in the fermentation environment. Temperature and humidity are two key parameters that must be closely controlled to ensure fermentation goes well. When these conditions are not optimally monitored, cocoa beans can undergo uneven fermentation, which negatively affects chocolate quality.

In traditional practice, monitoring of fermentation conditions is often done manually, which is not only time-consuming but also prone to human error[1]. This method is less efficient in providing accurate and real-time data, which is necessary for making quick decisions during the fermentation process. Therefore, there is an urgent need for an automated monitoring system that can provide data in real-time and with high accuracy.

The development of Internet of Things (IoT) technology has opened up new opportunities in the development of automated monitoring systems for various industrial applications, including fermentation. ESP32, a microcontroller module with Wi-Fi connection capability, has become one of the popular platforms for IoT projects due to its flexibility, low cost, and sufficient processing capacity.[2][3]. When combined with the Message Queuing Telemetry Transport (MQTT) communication protocol, the ESP32 can be used to send sensor data in real-time to a larger monitoring system [4][5].

This research aims to develop and validate a data acquisition system based on ESP32 and MQTT protocol to monitor temperature, humidity, and pH in the fermentation process of cocoa beans. The system is designed to be applied on a small scale, with a fermenter capacity of 20 kg, and implemented in a controlled environment without significant external environmental influences. With this system, it is expected that the fermentation process can be monitored more efficiently, thus improving the consistency and final quality of cocoa beans.

II. Research Methods

A. Hardware dan Software

The system uses an ESP32 module as the data processing center, which is connected to two types of sensors: DHT22 to measure temperature and humidity, and a pH meter to measure acidity in the fermentation process. The ESP32 was chosen for its capacity to efficiently manage wireless connections and data processing.

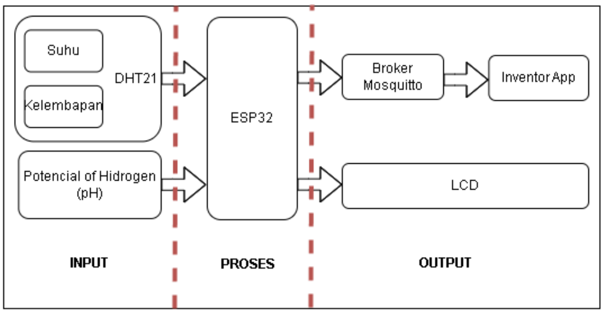

Figure 1. System block diagram

The data collected from the sensors is transmitted wirelessly using the MQTT protocol to the mosquitto broker.

B. System Architecture

The system architecture consists of several main components: DHT22 sensor, pH meter, ESP32 module, Wi-Fi network, and MQTT (Mosquitto) broker. Here is the detailed data transmission flow:

- Data Collection: A DHT22 sensor and a pH meter were placed in the fermenter to monitor temperature, humidity, and pH in real-time. The DHT22 sensor measures temperature and humidity, while the pH meter measures acidity. Each sensor is connected with the ESP32 through a wired connection, where analog data from the pH meter and digital data from the DHT22 are retrieved by the ESP32 module.
- Data Processing: Once the data from the sensors is received by the ESP32, this module processes the data to ensure that the transmitted information is in a suitable format for transmission over the network. This processing involves converting the data from the analog pH sensor into understandable pH values, and adjusting the data from the DHT22 sensor for temperature and humidity.
- Data Transmission via MQTT: The processed data is then sent by the ESP32 using the MQTT protocol over the available Wi-Fi connection. In this protocol, the ESP32 acts as a "publisher" that sends data to specific topics on the Mosquitto broker. For example, temperature data might be sent to the "fermenter/temperature" topic, while humidity and pH data are sent to the "fermenter/humidity" and "fermenter/pH" topics, respectively.
- Mosquitto Broker and Data Distribution: The Mosquitto broker, which serves as an intermediary, receives data from the ESP32 and distributes it to other clients that subscribe to the appropriate topics. These clients can be computers or other devices that monitor fermentation conditions in real-time, display data on a user interface, or store data for further analysis.
- *Real-Time* Monitoring: Data received by the client can be monitored in real-time, allowing users to see fluctuations in temperature, humidity, and pH during the fermentation process. If there are sudden changes in these parameters, the system can trigger alerts or automatic actions to control the fermentation process.

C. Testing Environment

The test was conducted in a laboratory environment with a fermenter capacity of 20 kg. This environment was chosen to minimize external influences that could interfere with the fermentation process, so that the validity of the system could be tested objectively.

D. System Validation

To validate the accuracy of the system, the data collected by the ESP32 system was compared with manual measurements using standard gauges. The consistency and accuracy of the measurements are key indicators in assessing the effectiveness of the system.

III. Result and Discussion

IoT Fermentor Electronic Circuit

The designed system uses several devices as shown in Figure 2. This device is in the form of ESP32 as a data processor, DHT22 and pH sensors as input, namely devices that function as detectors of changes in physical quantities into electrical quantities.[2][6]. DHT22 sensor as a temperature and humidity meter[7] while the pH Sensor as a measure of acidity level[8]. LCD Oled as an output that functions to provide information in the form of text. This device uses a 5V DC adapter as a trade source.

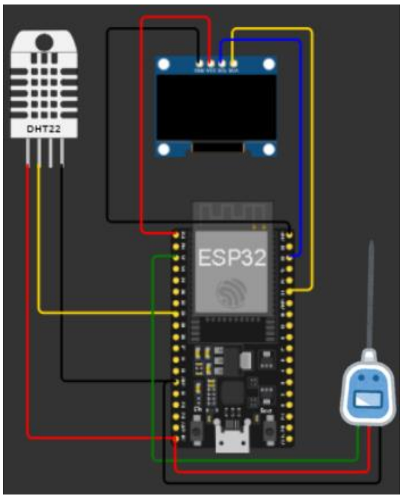

Figure 2. System circuit schematic

Figure 3. IoT electrical circuit

pH Sensor Validation

The observation results of pH value during the fermentation process of cocoa beans can be seen in table 4.

Table 1. Results of pH measurement

Time	pH sensor	pH meter	Error (%)
01.00	4.1	4.15	1.22
02.00	4.5	4.45	1.11
03.00	4.3	4.32	0.47
04.00	4.5	4.55	1.11
05.00	4.8	5.10	6.25
06.00	4.8	4.90	2.08
07.00	4.7	4.51	4.04
08.00	4.5	4.59	2.00
09.00	4.4	4.20	4.55
10.00	4.6	4.85	5.43
11.00	4.9	4.75	3.06
12.00	5.1	4.98	2.35
13.00	5.3	5.50	3.77
14.00	5.3	5.55	4.72
15.00	5.2	5.10	1.92
16.00	4.9	4.80	2.04
17.00	4.8	4.82	0.42
18.00	4.9	5.11	4.29
19.00	5.1	5.35	4.90
20.00	5.2	5.25	0.96
21.00	4.9	5.20	6.12
22.00	5.1	5.15	0.98
23.00	5.2	5.30	1.92
24.00	5.3	5.35	0.94
Average error (%) average			2.78

Table 1 is a comparison table of the pH sensor with the pH meter V05. From the table it can be observed that the comparison between the pH sensor value and the pH meter has an average error of 2.78, which indicates a small deviation in the measurement results. The small deviation in the pH sensor indicates that the difference between the value measured by the sensor and the actual value is relatively small. the sensor is quite accurate and consistent in taking measurements.[9]. Even if there is a small amount of error or inaccuracy, the measurement results remain within an acceptable range and do not significantly affect the final results or decisions made based on the data. This is important in applications where pH measurement accuracy is critical, such as in fermentation processes or quality control.

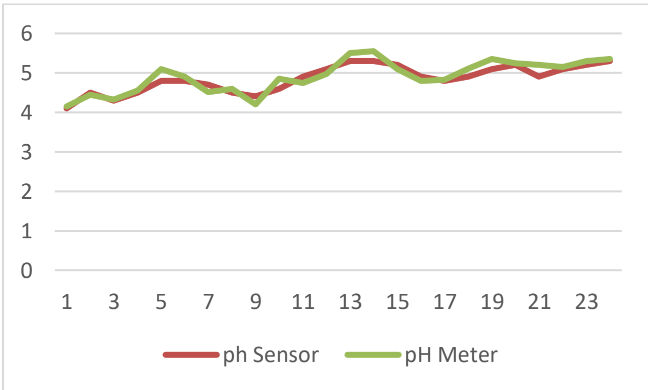

Figure 4. Validation of pH meter sensor

DHT22 Sensor Validation

The observation results of the DHT22 sensor value during the cocoa bean fermentation process can be seen in table 2.

Table 2. Temperature and humidity measurement

Time	Temp (°C)		error (%)	Humidity(%)		error (%)
	DHT22	Therm		DHT22	Hygro	
01.00	25.20	25.51	1.23	50.11	51.33	2.43
02.00	26.10	25.19	3.48	48.06	49.17	2.31
03.00	27.30	26.87	1.58	45.36	45.82	1.03
04.00	28.12	28.08	0.16	45.07	46.18	2.47

05.00	28.72	28.40	1.12	48.80	48.05	1.54
06.00	30.10	29.01	3.62	48.67	48.76	0.17
07.00	30.90	30.54	1.16	44.45	43.49	2.15
08.00	32.30	31.70	1.85	43.47	44.47	2.30
09.00	32.80	32.34	1.41	52.33	51.88	0.87
10.00	33.70	33.14	1.65	50.19	50.62	0.87
11.00	34.80	34.97	0.49	51.38	50.44	1.83
12.00	34.90	34.77	0.36	50.45	50.81	0.70
13.00	35.80	35.54	0.73	51.86	50.63	2.36
14.00	35.90	34.78	3.12	45.67	44.39	2.81
15.00	35.90	36.34	1.22	49.59	50.51	1.86
16.00	36.80	35.51	3.50	51.28	50.32	1.87
17.00	36.80	36.79	0.03	45.44	45.85	0.92
18.00	36.90	36.36	1.48	46.67	47.95	2.76
19.00	37.40	37.08	0.84	42.71	41.61	2.57
20.00	38.30	38.06	0.62	45.95	46.91	2.09
21.00	39.90	39.83	0.18	44.60	46.72	4.76
22.00	40.40	39.47	2.31	45.69	44.71	2.15
23.00	40.70	41.08	0.93	52.47	51.55	1.76
24.00	40.30	40.01	0.73	45.35	46.30	2.08
Average *error* (%)			**1.41**			**1.94**

Table 2 shows measurements using the DHT22 sensor which has two measurement features, namely measuring temperature and humidity compared to the benetech GM320 infrared thermometer as a temperature comparison instrument and hygrometer as a humidity comparison instrument. From the measurement results using the DHT22 sensor, the deviation is relatively small, namely temperature with an *error of* 1.41% and humidity of 1.94%. This indicates that measurements using the sensor used, namely DHT22, have good performance. The deviation of the data that has been taken can be seen from graph 5 below.

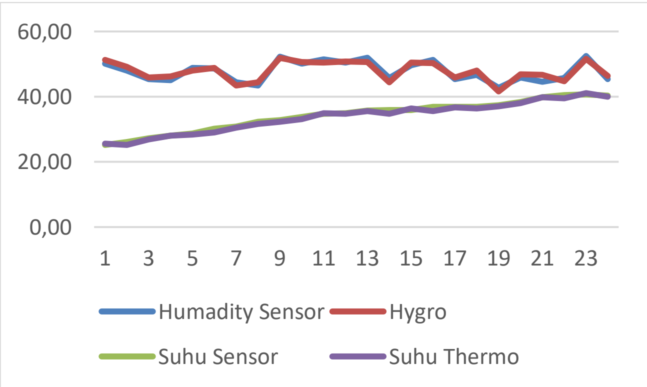

Figure 5. DHT22 sensor validation

Validation of data transmission using the MQTT Protocol

MQTT (Message Queuing Telemetry Transport) is a lightweight and efficient communication protocol, often used in Internet of Things (IoT) applications. It is designed to send messages between devices with low bandwidth and unstable connections. MQTT uses a publish/subscribe model, where a device (publisher) sends messages to a specific topic, and another device (subscriber) receives messages from that topic.

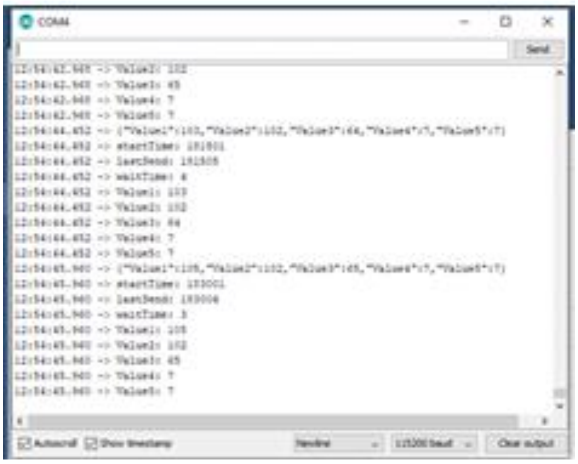

Figure 6 ESP32 data publish result

Figure 7 Result of MQQT submission

To communicate using the MQTT protocol, the *publisher* in this research is the pH, temperature and humidity sensor data is must define two elements to be sent to the MQTT Broker: message and topic. The message is the string data that the publisher wants to share with the subscriber through the MQTT Broker.

IV. Conclusion

The developed system has successfully acquired data by validating it using standard measuring instruments. The average data error for the pH sensor is 2.78%, the temperature sensor with an error of 1.41% and the humidity sensor with an error of 1.94%. The error values of these three sensors indicate that the performance of the sensors used is very good. In this research, the MQQT protocol is used with publisher (ESP32) and publisher (App Inventor) elements that run well. The data sent can arrive at the application validated correctly.

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