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Design of an Internet of Things (IoT) Based Composter Monitoring System Using Arduino Leonardo, ESP-01S, DHT-11, MQ-4 and Blynk

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ABSTRACT

Conventional methods of manually monitoring compost parameters are often inefficient and susceptible to human error. To address this, this study conducted an Internet of Things (IoT) smart composter system designed to track the fermentation process in real-time. The system architecture integrated Arduino Leonardo microcontroller with DHT-11 sensor for temperature and humidity, and MQ-4 sensor to detect the methane concentrations indicative of anaerobic activity. Data were transmitted via ESP-01S Wi-Fi module to the Blynk cloud platform for visualization. A ten-day performance test, with data recorded at six-hour intervals, demonstrated the system's ability to accurately capture the physical fluctuations inherent in decomposition. The results highlighted a temperature rise over five days peaking at 38.7°C, humidity saturation reaching 95.8% RH, and a maximum methane concentration of 218 ppm on the fourth day. Therefore, this system presented a robust technological intervention for agricultural practitioners, facilitating the precise, efficient, and real-time surveillance of compost bins.

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I. INTRODUCTION

Organic fertilizers are increasingly popular in the Industry 4.0 era. These fertilizers are a more environmentally friendly alternative to chemical fertilizers. The manufacturing process generally involves fermenting organic materials. The success of this fermentation process depends heavily on the raw materials, namely organic waste, and the environmental conditions within the reactor or composter tank [1]. Based on the basic concept, composting is divided into two methods : aerobic and anaerobic. The aerobic method is carried out with the help of oxygen available in the air. Aerobic microorganisms (bacteria and fungi) require air to break down organic materials. Meanwhile, the anaerobic method is carried out in conditions without oxygen. Decomposition is carried out by anaerobic microorganisms in a container that is tightly closed from outside air.

The three main physical parameters that are indicators of microorganism activity in the composting process are temperature, humidity, and gas composition as a result of the chemical reaction process. In the aerobic method, the composting process will produce CO_2 gas, while in the anaerobic method the composting process produces digestate (liquid fertilizer) and methane gas (CH_4) [2].

The decomposition process of organic matter is divided into three phases : mesophilic, thermophilic and maturation phase as depicted in Fig. 1.

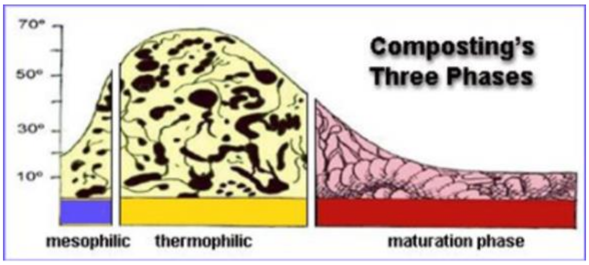

Fig. 1. Three phases of the composter decomposition process (https://ditjenbun.pertanian.go.id [15])

Temperature is a vital indicator of microbial metabolic activity. An ideal fermentation process will go through mesophilic (25-40°C) and thermophilic (40-55°C) phases. Optimal humidity is also necessary to support microbial life. Meanwhile, anaerobic fermentation (without oxygen) produces methane gas. Methane concentration can be an indicator of how active the anaerobic decomposition process is [3].

Based on a comparison of the two composting methods, the anaerobic method proved superior for monitoring and measuring physical parameters. Its primary advantage lies in the tightly sealed reactor tube design, allowing the chemical and physical processes within it to be continuously observed and measured without interruption. Furthermore, compost production monitoring is more stable because there is no external air exchange caused by opening and closing the composter tank. This ensures that measurements are not disrupted by fluctuations or changes in external environmental conditions [3].

Monitoring the fermentation and decomposition processes in composters is traditionally done manually (for example, occasionally measuring the temperature with a thermometer). This has several drawbacks, including: [4], [5], [6] :

a. Discontinuous: Data cannot be obtained continuously,
b. Invasive: Opening the reactor lid to measure can disrupt the fermentation process,
c. Subjective: It is difficult to determine the exact "maturity" of the fertilizer.

Internet of Things (IoT) technology offers a solution for real-time, remote, and non-invasive monitoring [7]. By placing sensors inside the composter tank reactor, data can be automatically sent to the cloud and accessed by users via smartphone or computer [8], [9]. In the IoT architecture system, several hardware and software are required [10]. The hardware used includes a microcontroller, WiFi module, sensors, and power supply module. Meanwhile, the software used is Arduino IDE and the system interface is either web-based or mobile phone-based [11]. By designing an IoT-based smart composter, the compost production process can be monitored more effectively and efficiently [12]. This is made possible by measuring key physical parameters through sensors embedded in the reactor tube, namely temperature and humidity sensors and gas sensors. Data from these sensors are then integrated into an IoT-based monitoring interface system using the Blynk platform [8], [13]. With this system, users can access information in real time via smartphone, both to find out temperature and humidity values and to monitor the concentration of methane gas in the composter tank.

II. METHODOLOGY

A. *Organic Fertilizer Materials*

In this study, the following materials were used to make the compost:

a. Organic waste (fruit and vegetable peels) =± 250 grams
b. Rice waste =±250 grams
c. Bioactivator EM4=10 mL
d. Soil =±250 grams

Fruit and vegetable waste was crushed into small enough pieces. In this study, materials a and b were left in a closed container for five days. This means the materials used were not new waste or had undergone an initial phase of decomposition. Next, all materials a, b, c, and d were mixed evenly in a composter. The total volume of organic material occupied half the volume of the composter [2].

B. *System Architecture Design*

The design of an IoT-based organic waste composting process monitoring system is illustrated in Fig. 2.

Fig. 2. The Design of IoT-based composter monitoring system

The monitoring system consists of several pieces of hardware :

a. Arduino Leonardo microcontroller
b. ESP-01S module
c. Voltage Regulator module
d. DHT-11 temperature and humidity sensor
e. MQ-4 methane gas sensor
f. Jumper cables
g. Power supply adapter

Supporting software used:

a. Arduino IDE
b. Blynk on a smartphone as the IoT system dashboard display

C. *System Algorithm Flowchart*

This system uses a temperature and humidity sensor (DHT-11) and a methane gas sensor (MQ-4) programmed through the Arduino IDE. The program algorithm is written to read the sensor voltage data which is then translated into the form of physical parameters of temperature in ^{0}C, humidity in % RH (Relative Humidity) and relative concentration of methane gas in PPM. The results of the physical parameter readings are then sent via ESP-01S to the cloud and displayed on the Blynk dashboard. The flowchart of the IoT-based smart composter monitoring system design is explained in Fig. 3.

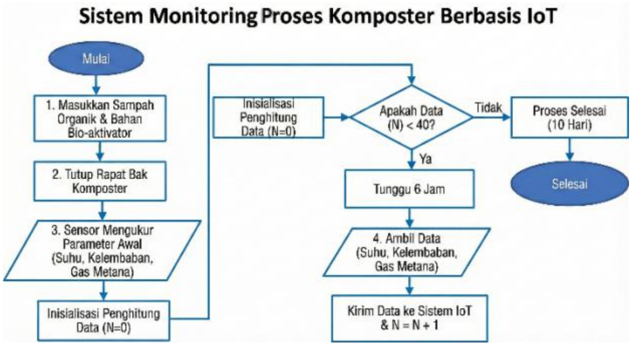

Fig 3. The IoT System Algorithm

D. *Tool Testing and Data Collection Steps*

The biocompost materials are placed inside the smart composter, occupying half the total volume of the tank. Temperature, humidity, and MQ-4 gas sensors are located inside the tank lid, as shown in Fig. 4. The composter tank is then tightly closed for 10 days, and the monitoring system is started. Every 6 hours, sensor measurement data is read and displayed on the Blynk dashboard.

III. RESULT AND DISCUSSION

A. *Prototype of the system design results*

Fig. 4 shows a prototype of the system design. The Arduino Leonardo microcontroller module, ESP-01S module, and voltage regulator module are placed on top of the composter lid. Meanwhile, the DHT11 temperature and humidity sensor and the MQ-4 methane gas sensor are embedded/attached to the inside of the composter lid.

Temperature and humidity measurement data, as well as methane gas concentration, are displayed on a smartphone via the Blynk dashboard, as shown in Fig. 5. In Fig. 5, the temperature measurement value is depicted in the upper left corner and the humidity measurement value in the upper right corner. Meanwhile, the methane gas concentration measurement value is located in the lower right corner of the Blynk dashboard.

Fig. 4. Prototype of Smart Composter

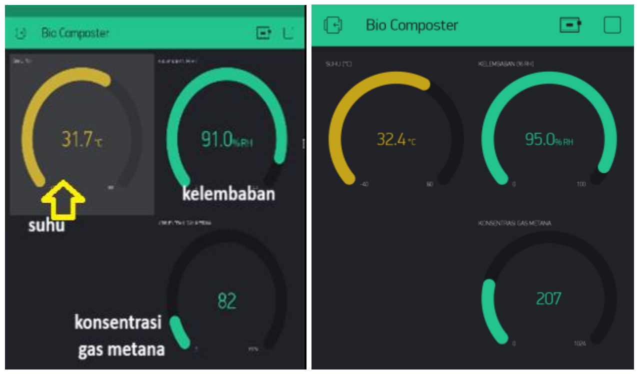

Fig. 5. Blynk smart biocomposter dashboard

B. *Sensor Data Collection*

Every 6 hours, the sensor reading data is displayed on the Blynk dashboard as shown in Fig 5. The complete data on temperature, humidity and methane gas concentration measurements are tabulated as shown in Table I.

TABLE I. DATA ON TEMPERATURE, HUMIDITY AND RELATIVE CONCENTRATION OF METHANE GAS DURING 10 DAYS

No	*Day*	*O'clock*	*Time (in hour)*	*Temperature (^0C)*	*Humidity (%RH)*	*Relative Concentration of Methane Gas (ppm)*
1	1	06.00	0	29.0	60.0	32
2	1	12.00	6	30.4	65.0	50
3	1	18.00	12	31.0	72.0	65
4	1	24.00	**18**	**31.7**	**91.0**	**82**
5	2	06.00	24	32.0	93.7	130
6	2	12.00	30	32.2	94.2	185
7	2	18.00	**36**	**32.4**	**94.8**	**207**
8	2	24.00	42	33.1	95.0	210
9	3	06.00	48	34.2	95.2	213
10	3	12.00	54	35.3	95.6	215
11	3	18.00	60	36.0	95.8	217
12	3	24.00	66	36.5	95.7	218
13	4	06.00	72	36.9	95.9	213
14	4	12.00	78	37.4	95.5	210
15	4	18.00	84	38.0	95.7	205
16	4	24.00	90	38.2	95.8	202
17	5	06.00	96	38.7	95.8	200
18	5	12.00	102	38.7	95.7	199
19	5	18.00	108	38.6	95.8	197
20	5	24.00	114	38.5	95.7	197
…	…	…		…	…	…
40	10	24.00	234	34	90.2	195

C. *Data Analysis Graphs*

Based on Table I, the graph of temperature values is obtained for each six-hour period as shown in Fig. 6. The data obtained shows the dynamics of the anaerobic fermentation process in the composter tank.

Fig. 6 shows the temperature change over time in the composting cycle monitored by the IoT-based Smart Composter system. With data collection intervals of every 6 hours, it is clear that the microbiological activity occurring in the closed composter tank shows a significant increase in temperature. Starting from the first data when the tank lid is closed, the initial temperature is 29^{0}C. The rising and winding curve pattern indicates that the decomposition process of organic material combined with the EM4 bioactivator is running quite well with a smooth exponential curve tendency.

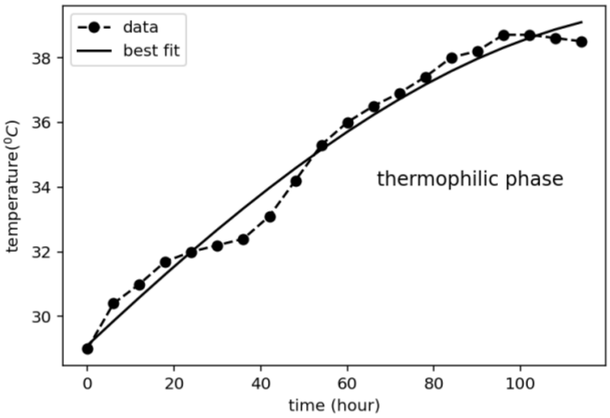

Fig. 6. The Graph of temperature measurement values in the composter tank

Activation Phase and Mesophilic Transition (Data 1 to 7). In the initial stage (data 1 to 8, or the first 42 hours), a gradual increase in temperature is observed from around 29°C to 32.4°C. This phase is called the mesophilic phase. Early decomposing bacteria begin to actively break down simple organic compounds such as sugars and starches [3]. The heat produced at this stage is a byproduct of the bacteria's metabolism, indicating that the bioactivator has worked and the microbes have begun to reproduce well in the humid environment.

Thermophilic Phase and Peak Activity (Data 8th to 18th). Entering the 8th data collection, the graph shows a significant and sharp (exponential) temperature spike. This indicates the start of the thermophilic phase, the most crucial phase in composting. This drastic temperature increase occurs due to the dominance of thermophilic bacteria (heat-resistant and heat-loving bacteria) working hard to break down complex organic materials such as proteins, fats, and cellulose [3]. The process of breaking down these complex chemical bonds releases heat energy. The next phase after the thermophilic phase is the maturation phase, or compost ripening. This phase is characterized by a decrease in temperature.

Overall, based on the observation data of temperature, humidity, and relative concentration of methane gas, experimental data fitting was carried out using the Levenberg-Marquardt (LM) algorithm. This algorithm is used as a numerical optimization algorithm, combining two classical methods: Gradient Descent and Gauss-Newton to solve the "non-linear least squares" problem to obtain the best parameters of a mathematical model that represents the experimental data [14].

Fig. 7 and Fig. 8 show the interpretation of humidity and relative methane gas concentration data from 20 data collection sessions, conducted every 6 hours. Fig.7 shows that the initial humidity in the composter tank immediately after it was closed reached 60% RH. This is because the composter waste had undergone a previous decomposition process. This means that the raw composter material was already moist, so the humidity rose sharply when it entered the composter tank, as shown in data points 2 through 5.

```
// konfigurasi pin pada Leonardo
const int DHT_PIN = 2; // Digital pin  DHT11
const int MQ4_PIN = A0; // Analog pin MQ-4
```

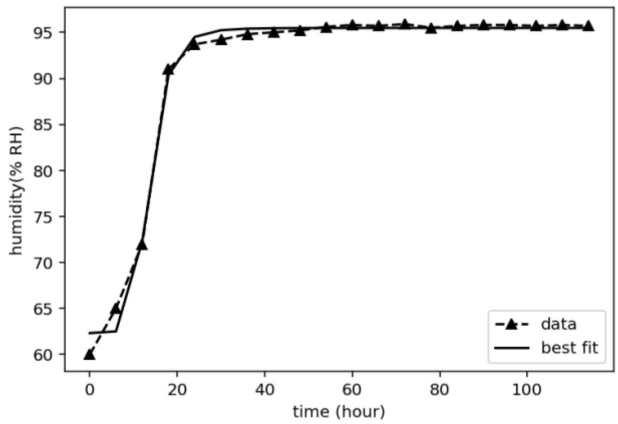

Fig. 7. The Graph of Humidity measurement values

Fig. 8 depicts the relative concentration of methane gas measured by the MQ-4 sensor. Methane concentration, indicating microbiological activity, increased sharply from the fourth to eighth data points, or from the second to third days of observation. Subsequently, the relative concentration of methane gas tended to remain stable. This stability indicates that there was no relative change in gas concentration in the composter tank. The measured gas concentration tended to decrease in subsequent observations. This was due to the loosely fitting composter tank lid, allowing a small amount of gas, approximately 25 ppm, to escape into the environment.

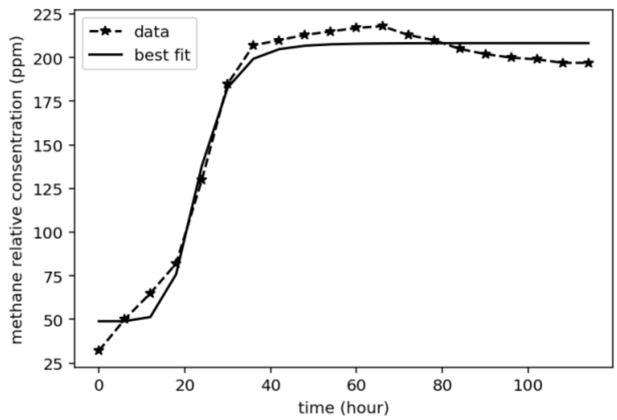

Fig. 8.The Graph of relative concentration measurement values of methane gas

D. Analysis of the Smart Composter IoT System

Fig. 9 depicts the wiring diagram of the DHT11 sensor, MQ-4 sensor and ESP-01S module on the Arduino Leonardo board using the web application web, *https://www.circuito.io/* [16].

Smart Composter System Main Control. The Arduino Leonardo board was chosen as the main controller because this microcontroller is based on the ATmega32u4 and has a different architecture from the Arduino Uno (ATmega328P). The Arduino Leonardo has an onboard USB controller so it can function as a HID (Human Interface Device). In addition, the Arduino Leonardo board has an additional built-in UART so communication with other boards that use UART does not require serial software. The Arduino Leonardo's digital pin D2 is connected directly to the DHT11 temperature and humidity sensor. Meanwhile, the Arduino Leonardo's analog pin A0 is connected to the MQ-4 methane gas sensor which requires a working voltage of 5 volts, as shown in Figure 7. The UART pin (RX/TX on pin 0/1) is connected to the ESP-01S as a WiFi client for the IoT system. The Arduino Leonardo sends sensor reading data to the Blynk cloud via ESP-01S connectivity. When reading the methane gas concentration through the MQ-4 sensor, the sensor reading is calibrated as in Fig. 10.

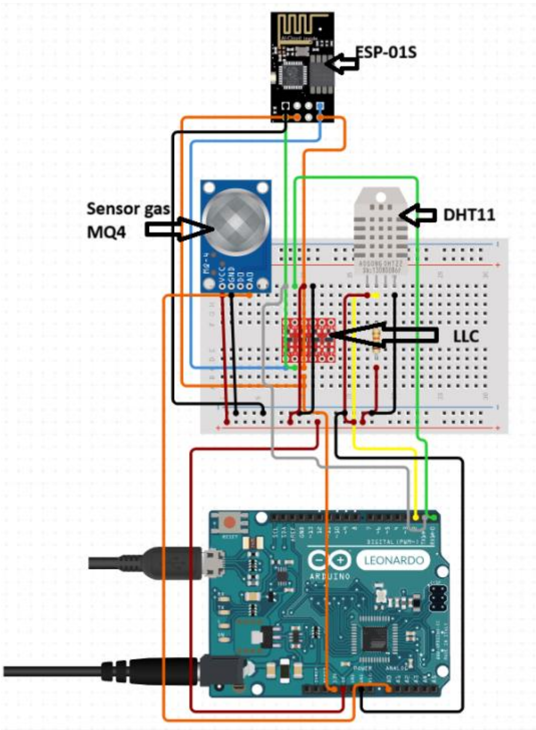

Fig. 9. The IoT system wiring diagram

```
float kalibrasiMQ4(int rawADC) {
  float voltage = rawADC * (5.0 / 1023.0);
  float rs = (5.0 - voltage) / voltage;
  float ratio = rs / 9.8; // Nilai RS/RO di udara bersih
  return ratio;
}
```

Fig. 10. MQ-4 gas sensor reading calibration syntax

WiFi Client-based Internet Communication. The ESP-01S is connected to the Arduino Leonardo board via the UART pins (RX/TX on pins 0/1) as a WiFi client for the IoT system. In order for the ESP-01S to communicate with the Arduino Leonardo at 3.3 V, a logic level converter (LLC) is required, as shown in Fig. 9.

The ESP-01S is a small Wi-Fi module based on the ESP8266 chip, functioning as a "bridge" in IoT architecture. The ESP-01S enables the microcontroller to send sensor reading data to a WiFi network. The ESP-01S connects to a local access point (router) and sends sensor reading data to the cloud. The router then forwards the data via the internet to the Blynk Cloud Server. This creates communication between the microcontroller and the Blynk Cloud Server.

Blynk as an IoT System Interface. In terms of user interface, the Blynk application on smartphones is quite good at displaying the results of sensor data readings connected to the Blynk Cloud Server in real-time. Users can monitor the physical parameters of the composter's condition, namely temperature data, humidity data, and methane gas concentration data directly on the smartphone screen. The Blynk application provides user-friendly features with simply 'drag and drop' to build the interface display. Blynk has a variety of Widgets (such as SuperChart, Gauge, and LCD) that are very effective for displaying sensor data in real-time as depicted in Fig. 11.

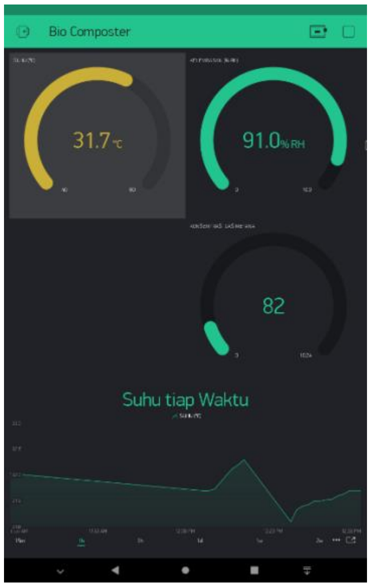

Fig.11. IoT System Interface using Blynk

IV. CONCLUSION

This research successfully designed an IoT-based Smart Composter system that integrates Arduino Leonardo, ESP-01S module, and DHT11 and MQ-4 sensors to monitor the dynamics of organic waste decomposition in real-time through the Blynk application interface. Technically, the system is able to acquire and transmit physical parameter data of the internal environment of the composter tank. The Data analysis of DHT-11 sensor data validated the success of the biological process through the formation of a temperature curve pattern reaching the thermophilic phase with a peak of 38.7°C and a humidity curve pattern reaching the saturated phase at 95.8 %RH. The analysis of MQ-4 sensor data reached a peak relative concentration of methane gas at 218 ppm. The integration between the reliability of Arduino Leonardo hardware, ESP-01S, DHT11 sensors, MQ-4 sensors and the ease of digital data visualization of the Blynk application is able to transform conventional composting methods into a measurable and efficient process, allowing users to monitor the condition of the composter tank remotely without disturbing the dynamics of physical parameters in a closed container.

Further work is needed to conduct repeated experiments to obtain a larger data set. Further research could involve validation of the extended control strategy with control logic using predictive learning-based methods such as fuzzy logic, adaptive thresholds that provide the opportunity to optimize the decision whether the system needs to be stopped after reaching equilibrium of the physical parameters in the composter tank.

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