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AUTOMATED AND EFFICIENT MONITORING SYSTEM FOR ORGANIC WASTE COMPOST PROCESSING BASED ON THE INTERNET OF THINGS (IoT)

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Developed countries have viewed waste as an important part of their waste management and recycling systems, while developing countries, particularly Indonesia, still face various challenges in waste management. Approximately 60% of the total national waste generation comes from household waste, and approximately 39.98% of this has not been optimally managed. Processing organic waste into compost is an environmentally friendly alternative that can reduce waste volume while increasing the utility value of household and agricultural waste. However, conventional composting methods often experience obstacles in maintaining stable temperature and humidity, resulting in suboptimal decomposition. Based on these problems, this study aims to design and implement an Internet of Things (IoT)-based compost processing automation and monitoring system using an action research approach. This method includes the stages of planning, action, testing, evaluation, and reflection, with system testing conducted for 30 days on a small-scale composter. The developed system utilizes an ESP32 microcontroller, a soil moisture sensor for moisture measurement, a DS18B20 temperature sensor for compost temperature monitoring, and an automatically controlled water pump. Sensor reading data is sent in real-time to the Blynk platform as a remote monitoring medium. The novelty of this research lies in the integration of an automatic control system and real-time monitoring in a single composting system that allows the device to maintain process stability autonomously. Test results show that the system is able to maintain humidity in the range of 50–60% and compost temperature in the range of 30–40°C, so that the composting process is more stable and efficient than conventional methods.

Keywords— **Automatic Composting, ESP32-based Control, IoT Monitoring, Temperature and Humidity Control, Organic Waste Compost.**

I. INTRODUCTION

Climate change is one of the greatest challenges facing the world today. This phenomenon is characterized by long-term shifts in weather patterns, and its impacts are not limited to the environment but also affect the long-term sustainability of human life. In recent decades, waste, particularly poorly managed organic waste, has become a significant contributor to greenhouse gases [1][2][3].

According to World Bank data (2016), global waste production reached 2.01 billion tons and is expected to increase to 3.4 billion tons by 2050. In Indonesia, total waste production in 2020 reached 67.8 million tons per year, with approximately 60% coming from poorly managed household waste [4]. The composition of waste by type can be seen in Figure 1.

Figure 1. Waste Composition Based on Waste Type

The problem of organic waste is still a major issue in various regions, especially in urban and agricultural areas. Organic waste that is not managed properly can cause environmental pollution and unpleasant odors [5]. One effective method of managing organic waste is composting [5]. The composting process requires certain environmental conditions, especially temperature and humidity, so that microorganisms can work optimally. The development of Internet of Things (IoT) technology allows the composting process to be monitored and controlled automatically and in real-time [6]. By implementing IoT-based sensors and control systems [7], the composting process can run more efficiently, stably, and reduce dependence on manual supervision [3].

Although several previous studies have applied IoT technology to the composting process, most of this research still focuses on environmental monitoring functions without the integration of a continuously operating automatic control system. Furthermore, system implementation is generally carried out at a laboratory or simulation scale, so direct application in the community environment has not been studied in depth. Therefore,

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there is still a research gap related to the development of an IoT-based compost processing system capable of integrating real-time monitoring and automatic control and being tested for implementation at the household or community scale.

This research proposes the design and implementation of an IoT-based compost processing automation and monitoring system using an ESP32 microcontroller integrated with a DS18B20 temperature sensor to monitor compost temperature, a soil moisture sensor to measure humidity levels [8][9], and actuators consisting of a water pump, a 12V DC motor, and a 12V DC fan that are automatically controlled. This system is designed to maintain the compost temperature and humidity within the optimal range, allowing for a more stable, efficient, and controlled decomposition process. Sensor measurement data is sent in real time to the Blynk platform for remote monitoring.

II. RESEARCH METHOD

This study uses an action research approach consisting of five main stages: Diagnosing, Action Planning, Action Taking, Evaluating, and Reflection. The action research approach was chosen because this study focuses not only on the technical development of the IoT system, but also on the implementation and application of the automated compost processing system in the community environment. This approach allows researchers to iteratively improve the system based on field testing results and user feedback, making it suitable for the context of IoT-based appropriate technology. The following stages of the research flow can be seen in Figure 2 below.

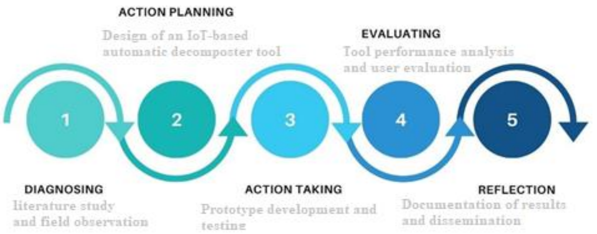

Figure 2. Action research flow

In the Diagnosing stage, literature studies and field observations were conducted to identify problems in household organic waste management, supplemented by interviews with residents and waste managers. The results were a system requirements document and problem analysis. The Action Planning stage included designing an automatic decomposter system, including hardware (IoT sensors: input, output, mechanics, load cells, ESP32) and software in the form of a monitoring dashboard. The results were technical specifications and system design. The Action Taking stage involved prototyping, sensor and actuator installation, and IoT dashboard development. Trials were conducted in laboratories and household environments [10][11]

The principal investigator was responsible for system integration, the technical team developed the tool, and community partners conducted trials and provided feedback. The Evaluating stage included analyzing the tool's performance in terms of decomposition time, temperature, humidity, power consumption, and user satisfaction through direct measurements and questionnaires. The Reflection stage was conducted to draw conclusions and develop development recommendations, as well as produce technical documentation, a tool manual, and a demonstration video for dissemination to the community.

A. System Design

In designing the system, researchers used several main components. The design focused on integration between components to form an IoT-based compost processing automation and monitoring system.

1. ESP32 microcontroller as control center

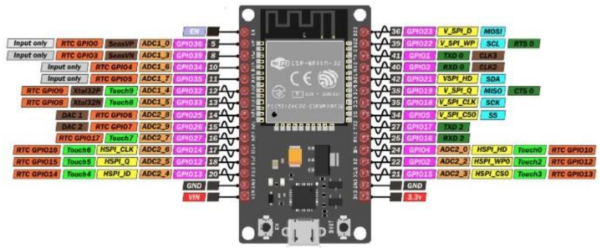

Figure 3. Esp32 microcontroller diagram

In this system, the ESP32 functions as a control center that integrates temperature and humidity sensor data readings, threshold-based decision making, and automatic actuator control.

In addition, the ESP32 is used as a link between the physical composter system and the IoT monitoring platform for real-time data transmission [10]. It can be programmed with various platforms such as Arduino IDE, MicroPython, and PlatformIO, supporting connection with various sensors and other IoT support modules. This architecture allows the ESP32 to perform multiple tasks simultaneously in IoT projects [12][13][14]

2. Soil moisture sensor to measure compost moisture

The soil moisture sensor is used as the primary input to determine the moisture content of the compost media. The system uses the data obtained to automatically control the water pump to maintain optimal humidity levels.[15] [16] The image of the soil moisture sensor in question is shown in Figure 4.

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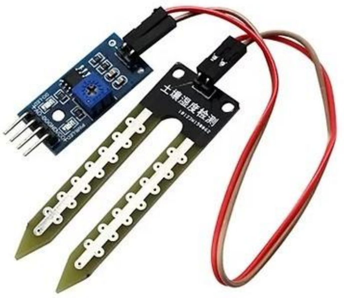

Figure 4 Soil Moisture sensor

3. *DS18B20 temperature sensor for measuring compost temperature*

Figure 5 DS18B20 temperature sensor

The DS18B20 temperature sensor is used to monitor the compost temperature as the main parameter in the composting process. This temperature data is used to automatically control the DC fan when the temperature exceeds the set threshold [17], thus requiring only one data line to communicate with the microcontroller, in addition to the power supply and ground lines. The DS18B20 is capable of measuring temperatures in the range of −55°C to 125°C with a resolution of up to 12-bit and an accuracy level of around ±0.5°C in the temperature range of −10°C to 85°C. In this study, the DS18B20 sensor is used to monitor the temperature in the composting process. The measured temperature value is then sent to the ESP32 microcontroller for processing and forwarded in real-time to the Blynk platform as a remote monitoring medium.

4. *12V DC Fan*

Figure 6 DC12 V Fan

In the developed system, a 12 V DC fan functions as a temperature control actuator that is automatically activated based on temperature sensor data to maintain stable compost conditions. The use of a 12 V DC fan aims to prevent excessive temperature increases due to microbial activity during the organic material decomposition process [18]. In addition to functioning as a temperature controller, the 12 V DC fan also helps improve air circulation within the compost media, which plays an important role in maintaining aerobic conditions.

5. *DC 12 V water pump as humidity control actuator*

Figure 7 12V DC Motor

A A 12 V DC water pump is integrated as an actuator that works automatically to adjust the humidity of the compost media based on soil moisture sensor readings. In this system, the 12 V DC water pump is automatically controlled by an ESP32 microcontroller through a relay module or driver circuit. The pump will activate when the humidity value measured by the soil moisture sensor is below a predetermined threshold, and will stop operating once the humidity reaches the desired value. This mechanism allows humidity control to be carried out efficiently and consistently without manual intervention [7].

6. *IoT System Integration and Monitoring*

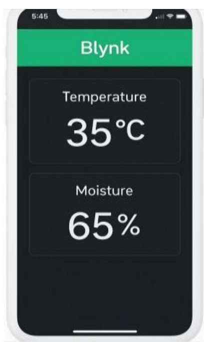

Figure 8 Blynk platform

All sensor and actuator components are integrated by ESP32 and connected to an IoT monitoring platform to display temperature and humidity data in real-time. This integration allows the system to work autonomously while providing remote monitoring facilities for users. [19][20]. Sensor data sent by the ESP32 microcontroller is displayed in an easy-to-understand visual form. In addition, Blynk also provides a manual control feature to activate or deactivate actuators such as water pumps and

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12 V DC fans, so that the system can be managed more flexibly and efficiently [21][22] [23].

a. System Workflow

At this stage several designs are made, such as input-output block diagrams, schematic circuits, and system flow diagrams. The design aims to understand the working principle of the tool and provide an initial description of the prototype that will be developed [19][14][24].

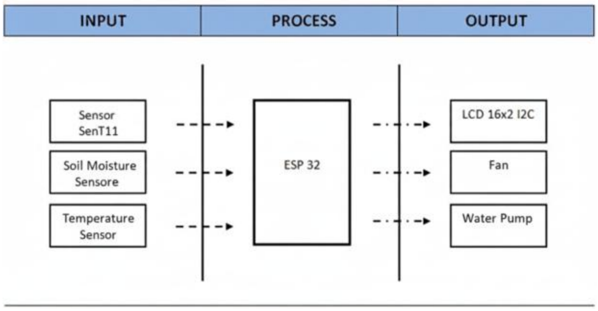

Figure 9 Block diagram of the input output of the composter system

The flow of the composter performance system is depicted in Figure 10.

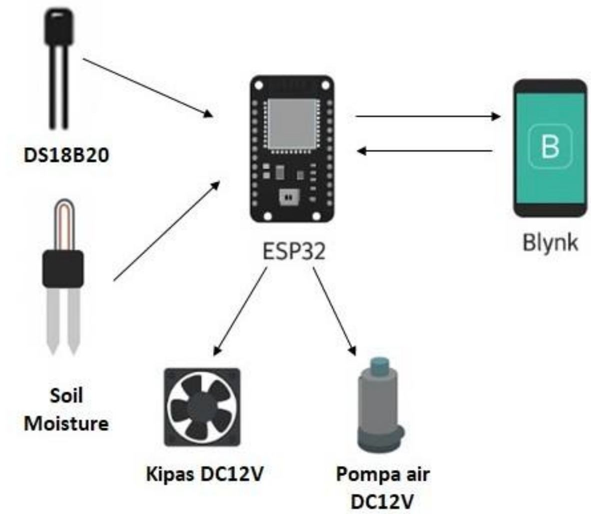

Figure 10 Composter system performance flow

Then the composter system flow diagram is drawn as in Figure 11 below.

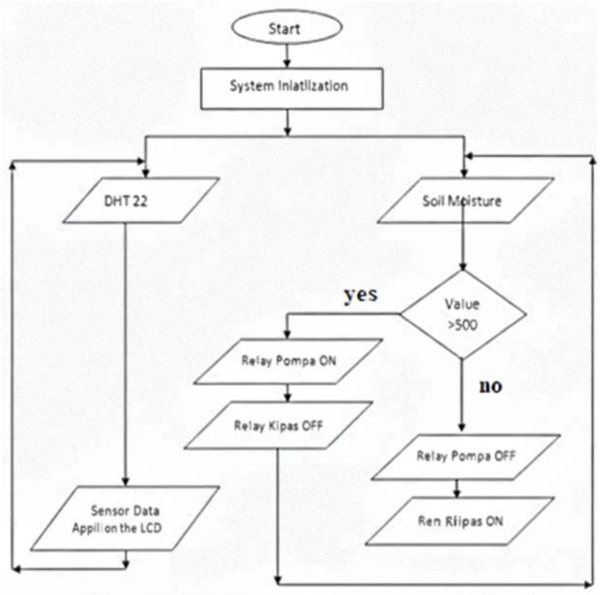

Figure 11 Compost system flow diagram

Figure 12 Composite prototype

III. RESULT AND DISCUSSION

a. Autonomous composter performance testing

In the composter performance test, it was carried out on a small-scale compost medium for 30 days. The monitoring data showed a phase of increasing temperature (thermophilic phase), for humidity fluctuated in the first and second weeks then tended to increase in the third and fourth weeks then stabilized towards the maturation phase. The results of this study are in line with the research of Rahman et al. [22] which showed that the Internet of Things (IoT) based composting system is able to maintain temperature and humidity stability through automatic control, so that the decomposition process takes place more efficiently than

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conventional methods. However, in the research of Rahman et al. [32], increasing the efficiency of the composting process was achieved through the addition of EM4 activator microorganisms as a supporting factor for accelerating decomposition, in addition to the use of an IoT-based monitoring and control system. In contrast to that research, the system developed in this study did not use the addition of microbial activators, but instead relied on automatic control of temperature and humidity as the main factors in maintaining the stability of the composting process. This shows that the stability of environmental conditions controlled in real-time can play a significant role in increasing composting efficiency without dependence on additional materials.

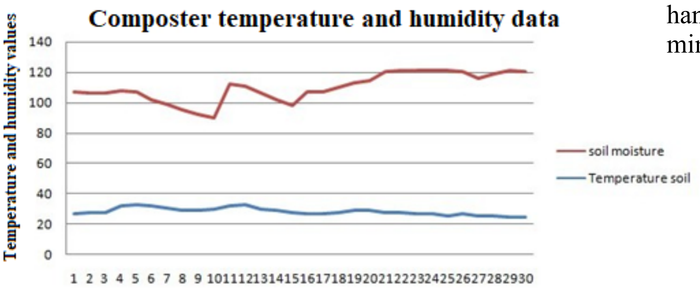

Figure 13 composting graph

The following is a running composting process that, from the initial color of various vegetable waste and kitchen scraps, was entered in the 4th week, which shows the compost media changing color to blackish brown, making the compost ready to be used as a fertilizer medium. The implications of these results indicate that the integration of an automatic control system in the composter can increase the efficiency of the composting process by maintaining the stability of environmental conditions during the thermophilic phase until maturation.

Figure 14 results of composting for 1 month

b. Testing temperature and humidity monitoring with mobile devices

In the test, temperature and humidity data are displayed in the form of interactive graphs on the mobile device dashboard using the Blynk platform. The test results show that the system is capable of real-time and continuous monitoring, so that users can monitor compost conditions quickly and accurately. When compared with previous research [22], the developed system not only functions as a monitoring tool, but is also directly integrated with actuators to maintain temperature and humidity stability automatically. The implications of implementing this real-time monitoring are increased operational efficiency because the need for manual supervision can be reduced and the risk of delays in handling compost environmental conditions can be minimized..

Figure 15 monitoring temperature and humidity via Blynk mobile device

In the context of organic waste management, the application of IoT has been proven to improve production efficiency and quality by utilizing sensors for data acquisition and cloud platforms for remote monitoring [22]. The ESP32 is a microcontroller with Wi-Fi and Bluetooth connectivity that is widely used in IoT system development due to its efficiency in processing sensor data and its ability to integrate with various monitoring platforms. The DHT22 sensor was chosen because of its high accuracy in measuring temperature and humidity, which are important parameters in the composting process [18]. The Blynk platform is a popular solution for building mobile-based IoT dashboards because it supports data visualization, device control, and real-time notification systems.

The implications of this research indicate that integrating an automatic control system into a composter can improve composting process efficiency by maintaining stable environmental conditions during the thermophilic phase through maturation. The novelty of this research lies in the IoT-based composting process control approach that emphasizes autonomous environmental parameter stabilization without the addition of external microbes, making the system simpler, more applicable, and potentially easier to implement at the household and community scale.

IV CONCLUSION

This research resulted in a prototype of an integrated ESP32-based Internet of Things (IoT) device for monitoring and controlling temperature and humidity during the organic composting process. The system was tested on a small-scale composter for 30 days, with monitoring results indicating an initial temperature increase (thermophilic) and a stable condition leading up to the maturation phase. The automatic integration of sensors, actuators, and a microcontroller allows the device to operate autonomously, maintaining the humidity of the compost media and controlling the temperature within an optimal range, thus supporting a stable decomposition process. Furthermore, this research contributes to the implementation of real-time monitoring through visualization of temperature and humidity data in the form of interactive graphs on the Blynk dashboard, accessible anytime and anywhere via mobile devices. Test results indicate that the system can improve the efficiency of the composting process by maintaining the temperature within the range of 30–40°C and humidity at optimal conditions, while also facilitating remote monitoring. Thus, the developed system not only functions as a monitoring tool but also contributes to improving the stability and efficiency of the IoT-based composting process.

V CONCLUSION

Suggestions for further research are that the system developed still relies on a third-party application, namely Blynk, with the disadvantage of being less stable in communicating the monitoring system with the composter device. In the future, composter monitoring can be developed using the MQTT (Message Queuing Telemetry Transport) technique, which is a lightweight communication protocol specifically designed for IoT devices, networks with low bandwidth, high latency, or unstable connections. The composter that has been made cannot yet be able to stir automatically, so that future developments in this research can add a driving mechanism that functions as a mechanical stirrer that can work automatically periodically.

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