

Rational Design of an IoT-Based Automated Mini Maggot Farm for Optimizing Organic Waste Management

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Article History:

Received: 17-08-2024

Revised: 29-09-2024

Accepted: 2-10-2024

Keywords: Mini Maggot Farm, Internet of Things, ESP32, Organic Waste Management, Automated Monitoring, Smart Farming

Abstract: *This The increasing volume of household and market organic waste has become an environmental issue that requires effective and sustainable solutions. Cultivating Black Soldier Fly (BSF) maggots is one method capable of reducing organic waste while producing economically valuable products. However, traditional maggot cultivation still faces challenges in maintaining environmental conditions such as temperature, humidity, air quality, and inconsistent feeding schedules. This study aims to design and implement an Internet of Things (IoT)-based automated mini maggot farm to optimize organic waste management. The research method used is the Waterfall model, which includes planning, analysis, design, implementation, and system testing stages. The system utilizes an ESP32 microcontroller as the main controller, a DHT22 sensor for monitoring temperature and humidity, an MQ-135 sensor for detecting air quality, and an RTC DS3231 module for automated feeding schedule management. Additionally, the system is equipped with actuators such as fans, heaters, and servo motors that operate automatically based on environmental conditions. The system monitoring is conducted in real-time using the Blynk application and local display through an LCD. The testing results indicate that the system operates stably and is capable of monitoring and controlling the mini maggot farm environment automatically. The implementation of this system improves efficiency and consistency in maggot cultivation compared to manual methods. Therefore, the IoT-based automated mini maggot farm can serve as an effective solution for optimizing organic waste management and supporting sustainable smart farming practices.*

How to Cite: Syukri & Anwar (2024). Rational Design of an IoT-Based Automated Mini Maggot Farm for Optimizing Organic Waste Management 2(1). 54-67. <https://doi.org/10.61536/ambidextrous.v2i1.490>



<https://doi.org/10.61536/ambidextrous.v2i1.490>

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Introduction

The rapid growth of population and urban activities in Padang City has significantly increased waste generation each year. Data from the Padang City Environmental Agency indicates that more than 600 tons of waste are produced daily, with approximately 60% consisting of organic waste from households, traditional markets, and the culinary sector. Improper management of this organic waste can lead to environmental pollution, greenhouse gas emissions, and declining public health quality. Therefore, effective and sustainable organic waste management solutions are urgently needed.

One promising solution is the utilization of Black Soldier Fly (BSF) larvae, commonly known as maggots, which can reduce organic waste volume by 50–60% within 7–10 days. In addition to waste reduction, maggots produce high-protein larval biomass suitable for alternative animal feed, while the by-product residue (frass) can be used as organic fertilizer. Maggot cultivation can also be implemented at household and community levels, offering economic benefits and supporting sustainable waste management practices.

However, traditional maggot cultivation still faces several challenges, particularly in maintaining environmental conditions such as temperature, humidity, air quality, and feeding schedules. Inconsistent manual monitoring often results in suboptimal growth and increased risk of larval mortality. Although previous studies have introduced semi-automated systems using microcontrollers and sensors, most implementations remain limited to on-site control and do not fully integrate multiple environmental parameters.

The development of Internet of Things (IoT) technology provides an opportunity to overcome these limitations through real-time monitoring and remote control. This study aims to design and implement an IoT-based automated mini maggot farm using an ESP32 microcontroller, environmental sensors, and automated actuators. The system enables real-time monitoring via mobile applications, improving efficiency, consistency, and sustainability in maggot cultivation while supporting smart farming and environmentally friendly organic waste management.

Research Methods

The research employed the Waterfall development model to design and implement an IoT-based automatic mini maggot farm system. This approach follows a sequential process consisting of planning, analysis, system design, implementation, and testing. In the planning stage, system requirements were identified through literature studies on maggot cultivation and organic waste management. The analysis stage further specified system components, including sensors (DHT22 and MQ-135), actuators (fan, heater, servo motor), and the ESP32 microcontroller. The system design phase involved developing block diagrams, electronic schematics, and defining the overall working principles, followed by implementation through hardware assembly and software programming. Finally, testing was conducted to verify system functionality under various environmental conditions.

The system was designed to automatically monitor and control key environmental parameters required for optimal Black Soldier Fly (BSF) larval growth, including temperature, humidity, and air quality. The ESP32 microcontroller processes data from



sensors and controls actuators such as fans, heaters, and an automatic feeding mechanism based on predefined setpoints (27–32 °C and 60–70% RH). Data is displayed locally via an LCD and transmitted to the Blynk IoT platform for remote monitoring. The hardware system integrates multiple components, supported by a stable power supply design, while the software is developed using Arduino IDE with relevant libraries for sensor reading, communication, and control logic.

System testing and validation were conducted to evaluate the performance and reliability of the prototype. Testing procedures included sensor accuracy verification, actuator response evaluation, IoT monitoring functionality, and system integration under real operating conditions. Additional measurements of voltage and current were performed to ensure compliance with component specifications. The results indicate that all system components functioned as intended, with stable operation, accurate monitoring, and effective automatic control, demonstrating the feasibility of the proposed IoT-based automatic maggot mini farm system.

Result and Discussion

System Implementation and Testing

This chapter discusses the implementation and testing stages of the Internet of Things (IoT)-based automated mini farm maggot system that has been designed in Chapter III. Implementation is carried out by assembling all hardware components and integrating them with the software that has been developed so that the system can function as a whole.

After the implementation process is completed, a series of tests are carried out on each part of the system to determine the success rate of the tool, including sensor testing, environmental control systems, automatic feeding mechanisms, and IoT-based monitoring systems. This test aims to ensure that all components can work according to the design that has been carried out and produce data that can be used to analyze the performance of the system.

The test results obtained are then analyzed to determine the suitability between the system design and the actual performance of the tool, so that conclusions can be drawn about the success rate of the automatic mini farm maggot system that has been developed.

System Implementation

At the implementation stage, all hardware and software components that have been designed in Chapter III are realized into an automatic mini maggot farm system based on the Internet of Things (IoT). The implementation process includes hardware assembly, microcontroller programming, and integration of all system components.

a. Hardware Implementation

The hardware used in this study consists of an ESP32 microcontroller as a control center, a DHT22 sensor for temperature and humidity measurement, an MQ-135 sensor for detecting air quality, an RTC DS3231 module as a timer, a servo motor as an automatic feed feeder drive, a relay as a fan and heater controller, and a 16×2 LCD as a local monitoring medium.



All components are assembled in a maggot mini farm box measuring 25 × 33 × 18 cm, with the placement of the components adjusted so as not to interfere with the larvae activity and maintain the accuracy of sensor readings.

b. Software Implementation

The software implementation is carried out by developing programs on the ESP32 microcontroller using the Arduino IDE with the C/C++ programming language. The program is created to read environmental sensor data, control the actuator based on detected conditions, set an automatic feeding schedule using the RTC module, and send monitoring data to IoT applications.

Here is an example of the main program pieces used in the system.

1. Library Initialization Program and System Configuration

```
// ===== BLYNK CONFIG =====
#define BLYNK_TEMPLATE_ID "TMPL67TtYTovy"
#define BLYNK_TEMPLATE_NAME "maggot iot"
#define BLYNK_AUTH_TOKEN "1p4rpYynTIUP4NepVBSpvjY2zK6fI-mW"

#define BLYNK_PRINT Serial

#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include "RTClib.h"
#include <DHT.h>
#include <ESP32Servo.h>
```

The above programs are used for WiFi communication, Blynk IoT, sensors, RTC, LCD, and servo and ESP32 is the center of the system control

2. Pin and Component Initialization Program

```
// ===== PIN =====
#define DHTPIN 4
#define DHTTYPE DHT22
#define MQ135_PIN 34
#define RELAY_FAN 26
#define RELAY_LAMP 27
#define SERVO_PIN 25
```

The program used for the installation of pins and components to be used



3. System Automatic Control Logic

```
if (suhu > suhu_max) {  
    digitalWrite(RELAY_FAN, LOW);  
    digitalWrite(RELAY_LAMP, HIGH);  
}  
else if (suhu < suhu_min) {  
    digitalWrite(RELAY_LAMP, LOW);  
    digitalWrite(RELAY_FAN, HIGH);  
}  
else {  
    digitalWrite(RELAY_FAN, HIGH);  
    digitalWrite(RELAY_LAMP, HIGH);  
}
```

Program for control logic if Temperature > 32°C → fan ON

Mouth < 27°C → heater ON

Normal → all OFF

4. Gas Detection System

```
if (gas > 800) {  
    digitalWrite(RELAY_FAN, LOW);  
}  
}
```

A program to detect gas if the fan exhaust gas will ignite, which is used to reduce anomalies

5. IoT Notification System (Blynk)

```
if (gas > 800 && !gas_bahaya) {  
    Blynk.logEvent("gas_alert", "Gas tinggi! Cek alat!");  
    gas_bahaya = true;  
}
```

The program used to send notifications to the mobile phone when the gas is low and the notification is only once (anti-spam)

6. Automatic Feeding System (RTC+Servo)

```
if (now.hour() == 8 && now.minute() == 0 && !sudah_pakan_pagi) {  
    bukaPakan();  
    sudah_pakan_pagi = true;  
}  
  
if (now.hour() == 16 && now.minute() == 0 && !sudah_pakan_sore) {  
    bukaPakan();  
    sudah_pakan_sore = true;  
}
```

This program is used to drive the servo feeder to open and close the feed hole according to the automatic feeding schedule.

The program used to organize the feed

7. LCD Monitoring System

```
char waktu[6];  
sprintf(waktu, "%02d:%02d", now.hour(), now.minute());  
lcd.print(waktu);  
lcd.print(" ");  
lcd.print(suhu, 1);
```

Programs used to display time, temperature, humidity, and gas



8. IoT Monitoring System (Blynk)

```
Blynk.virtualWrite(V0, suhu);  
Blynk.virtualWrite(V1, gas);  
Blynk.virtualWrite(V6, hum);
```

The program snippets are used to send sensor data to the Blynk application so that environmental conditions can be monitored in real-time.

Tool Implementation Documentation

The documentation of the implementation of the tool aims to show the results of the physical realization of the IoT-based automated maggot mini farm system that has been designed in Chapter III. This documentation includes an overall view of the appliance, the internal parts of the system, as well as the main components integrated in the system.

a. Overall Tool View



Image 1. Overall Tool View

The IoT-based automatic maggot mini farm tool is designed in the form of a closed box with a size of $25 \times 33 \times 18$ cm. The system consists of a maggot cultivation container, a sensor system, an actuator, and an ESP32-based control module. On the front of the device there is a 16×2 LCD that functions to display temperature, humidity, and system status information in real-time. The design of the tool is made compact and portable so that it is easy to use on a household and research scale.

b. Inside Tool Display



Image 2. Display of the inside of the appliance

The inside of the tool consists of a maggot larval cultivation area as well as the

placement of key components such as sensors and actuators. DHT22 and MQ-135 sensors are placed on the top and sides of the box to obtain representative environmental conditions readings. In addition, there is a DC fan that functions as a ventilation system to maintain air circulation, as well as a heater that is used to maintain the optimal temperature in the range of 27–32 °C.

c. Electronic and Wiring Systems

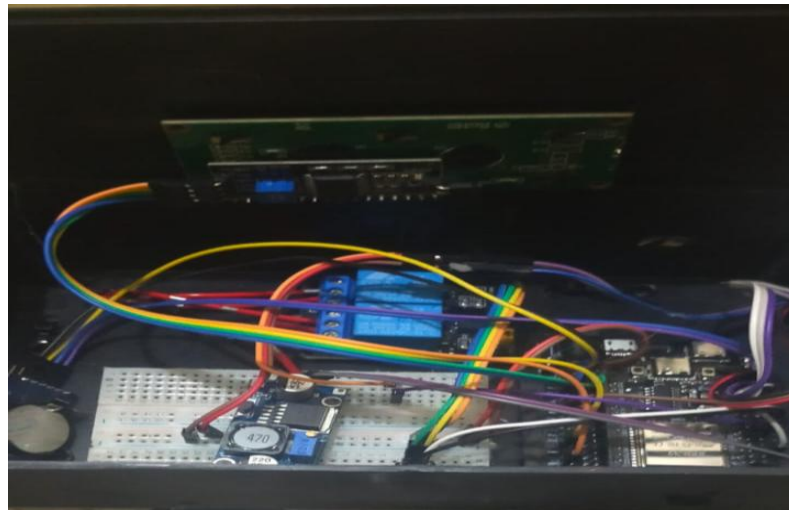


Image 3. Electronic and wiring systems

The electronic array consists of the ESP32 microcontroller as the control center, the DHT22 sensor, the MQ-135 sensor, and the DS3231 RTC module. The system is also equipped with a relay module to control the fan and heater. The power source comes from a 12V adapter which is then lowered to 5V using the LM2596 step-down module. All components are connected in one wiring system with a common ground concept to maintain system stability.

d. IoT Monitoring Display (Blynk)



Image 4. IoT Monitoring Display

The Blynk application is used as a real-time system monitoring and control platform. Temperature, humidity, and air quality data are displayed directly on the app dashboard. In addition, users can control the system manually such as activating the fan, heater, and running the feeder directly through a smartphone.

Based on the implementation documentation of the tool, the IoT-based automatic mini farm maggot system has been successfully realized according to the design. All components work in an integrated manner in monitoring and controlling the conditions of the cultivation environment automatically and remotely.

System Testing

System testing is carried out to determine the performance of each part of the tool and ensure that the system is working according to design.

a. Temperature and Humidity Sensor Testing

Table 1. Temperature and Humidity Sensor Testing

Yes	Time	Temperature (°C)	Humidity (%)	Remarks
1	08:00	29.5	70	Normal
2	10:00	30.2	68	Normal
3	12:00	32.5	65	High temperature
4	14:00	31.0	67	Normal
5	16:00	29.8	72	Normal

Based on the results of the DHT22 sensor test, it was obtained that the sensor is able to read the ambient temperature and humidity fairly stably. The temperature values that are read are in the range of 26–33 °C, while the humidity ranges from 60–70% RH. When the temperature exceeds the maximum limit (32 °C), the system automatically activates the fan as coolant. On the other hand, when the temperature is below the minimum limit (27 °C), the heater will be activated to raise the temperature. This indicates that the temperature control system works according to the logic that has been designed.

b. MQ-135 Gas Sensor Testing

Table 2. MQ-135 Gas Sensor Testing

No	Time	Gas Value	Status	Remarks
1	08:00	650	Normal	Secure
2	10:00	720	Normal	Secure
3	12:00	920	Height	Active fan
4	14:00	780	Normal	Stable
5	16:00	700	Normal	Secure

The test results showed that the MQ-135 sensor was able to detect changes in air



quality in the cultivation box. The reading value increases when there is an increase in gas from the decomposition process of organic waste. When the gas value exceeds the specified threshold (>900), the system automatically activates the fan to improve air circulation. In addition, the system also sends notifications through the Blynk app as a warning to users. This shows that the gas monitoring system functions well in maintaining the air quality of the cultivation environment.

c. Automatic temperature control system testing.

Table 3. Testing of Automatic Temperature Control System

No	Temperature (°C)	System Conditions	Fan	Lampu	Results
1	26	Low temperature	OFF	ON	Conform
2	28	Normal	OFF	OFF	Conform
3	33	High temperature	ON	OFF	Conform
4	31	Normal	OFF	OFF	Conform

Temperature control system testing shows that the system is capable of responding to temperature changes automatically. When the temperature is above the maximum limit, the fan is active to lower the temperature, while when the temperature is below the minimum limit, the heater is active to raise the temperature. The system's response to temperature changes occurs quickly and steadily without significant delays. This proves that the control algorithm applied to the ESP32 is running well..

d. Automated Feeding System Testing

Table 4. Automated Feeder System Testing

No	Time	Servo Angle	Conditions	Results
1	08:00	180°	Open	Successful
2	08:00	0°	Close	Successful
3	16:00	180°	Open	Successful
4	16:00	0°	Close	Successful

The automatic feeding system is tested according to a predetermined schedule using the DS3231 RTC, which is at 08:00 and 16:00. The test results showed that the servo motor was able to work on schedule by opening the feeder valve for ±4–5 seconds. The amount of feed that comes out is in the range of 100–250 grams per cycle, according to the system design. This mechanism shows that the system is capable of delivering feed consistently and on a scheduled basis without manual intervention.

e. IoT Monitoring Testing



Table 5. IoT monitoring test results

No	Parameter	Performing on Blynk	Real-time	Status
1	Temperature	Ya	Ya	Successful
2	Humidity	Ya	Ya	Successful
3	Gas	Ya	Ya	Successful
4	Control Kipas	Ya	Ya	Successful
5	Lighting Control	Ya	Ya	Successful
6	Servo (Feeder)	Ya	Ya	Successful

The test results showed that temperature, humidity, and air quality data was successfully sent and displayed on the Blynk app in real-time. In addition, users can also control systems such as fans, heaters, and feeders through the app. No significant delays in data transmission were found as long as the internet connection was stable. This shows that the IoT system is built to run well and supports remote monitoring

f. Testing the Whole System

Table 6. Testing the Whole System

No	Components	Function	Status
1	ESP32	Primary controls	Works
2	DHT22	Temperature & humidity	Works
3	MQ-135	Gas detection	Works
4	Relay	Fan & light control	Works
5	Servo	Automatic feed	Works
6	PSTN	Timetable	Works
7	LCD	Local view	Works
8	Blynk	Monitoring IoT	Works

Testing the system as a whole shows that all system components, whether sensors, actuators, or IoT systems, can work in an integrated manner. The system is able to automatically monitor and control temperature, humidity, air quality, and feeding according to predetermined conditions. In addition, the system is also able to provide notifications to users if abnormal conditions occur. Thus, the IoT-based automated mini farm maggot system can be said to function successfully according to the design objectives.



Results and Analysis

Based on the results of tests that have been carried out on each system parameter, IoT-based automatic maggot mini farm is able to work according to the design that has been made. The DHT22 and MQ-135 sensors can read environmental conditions well and produce fairly stable data on each test. Based on the test data on the temperature and humidity test table, the temperature control system shows effective performance in keeping the environmental conditions in the predetermined range, which is between 27°C to 32°C. When the temperature exceeds the maximum limit, the fan automatically activates to lower the temperature, whereas when the temperature is below the minimum limit, the lamp serves as a heat source. This shows that the control system works according to the logic that has been designed.

In addition, based on the test results of the feeder system, the automatic feeding mechanism controlled by servo and RTC motors is able to provide feed on a scheduled basis with consistent movement. The servo opening angle of 180° allows the feed to come out optimally, so that the feeding system is considered to run stably. In terms of monitoring, the test results show that Blynk-based IoT systems are able to display temperature, humidity, and gas data in real-time. Users can also control the system remotely without experiencing significant delays as long as the internet connection is stable.

However, this system still has some limitations, namely the gas value displayed is still in the form of an analog value (ADC) and has not been converted to ppm units, so the level of gas measurement accuracy is still limited. In addition, IoT monitoring systems still rely on a stable internet connection. Overall, the system designed has successfully integrated automatic monitoring and control functions in one platform, so that it can help improve efficiency in maggot cultivation management. In addition, the system designed also contributes to the optimization of organic waste management. This is shown by the use of organic waste as maggot feed that is managed in a scheduled and controlled manner. With this automatic system, the waste decomposition process becomes more consistent and efficient than manual methods, so that the volume of waste can be reduced more optimally.

Discussion

Based on the results of the tests that have been carried out, the IoT-based automated mini farm maggot system shows that the integration between hardware and software can run well. The ESP32 microcontroller as a control center is able to process data from various sensors and control the actuator simultaneously without experiencing significant interference. The use of DHT22 and MQ-135 sensors allows the system to monitor environmental conditions in real-time, so that changes in temperature, humidity, and air quality can be detected immediately. This gives it an advantage over manual methods that rely on user observation. The automatic control system implemented is able to maintain environmental conditions at the optimal range. The fan and lamp work based on a predetermined setpoint value, so that the conditions in the cultivation box can be controlled stably without direct intervention from the user.

In addition, RTC-based automated feeding systems provide an advantage in terms of consistency of feed time and quantity. Compared to manual methods, these systems are more efficient and reduce the possibility of delays or irregularities in feeding.



From the IoT side, the use of the Blynk application allows users to monitor and control the system remotely. This increases flexibility in the management of maggot cultivation, especially for users who are not always on site.

However, this system still has several limitations, including the gas value displayed is still in the form of analog values and has not been converted to ppm units, as well as dependence on an internet connection for IoT monitoring features.

Overall, the system designed is able to provide a more effective and efficient solution in monitoring and managing maggot cultivation compared to conventional methods.

Conclusion and Recommendation

The study concludes that the IoT-based automatic mini maggot farm system was successfully designed, implemented, and tested using an ESP32 microcontroller as the main control unit. The system effectively monitors temperature, humidity, and air quality in real time using DHT22 and MQ-135 sensors, with data accessible both locally via an LCD and remotely through the Blynk IoT application. Automated environmental control, including fan and heater operation, maintains optimal conditions, while the RTC-based servo feeding mechanism ensures consistent and efficient feeding schedules. Overall, the integrated hardware and software system operates reliably and enhances efficiency in maggot cultivation and organic waste management compared to manual methods. Future improvements may include cloud-based data storage for historical analysis, integration of load cell sensors for precise feed measurement, and the addition of backup power systems such as batteries or solar panels to ensure continuous and sustainable operation.

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