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# IoT Based Temperature and Humidity Monitoring System for Black Soldier Fly (BSF) Biopond Using ESP32

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**Abstract**

Black Soldier Fly (BSF) maggot cultivation requires stable environmental conditions, particularly temperature and humidity, to ensure optimal growth and productivity. However, many small-scale breeders still rely on manual monitoring, resulting in inefficient environmental control and increased risk of unfavorable cultivation conditions. This study proposes an Internet of Things (IoT)-based monitoring and control system for BSF biopond using an ESP32 microcontroller, DHT22 temperature and humidity sensor, soil moisture sensor, DC exhaust fan, L298N motor driver, and Firebase as a real-time monitoring platform. The system was developed using the Waterfall methodology, including requirements analysis, system design, implementation, testing, and evaluation. Environmental data collected by the sensors are transmitted to Firebase for remote monitoring, while the exhaust fan is automatically activated to stabilize environmental conditions when the measured values exceed predetermined thresholds. Experimental results demonstrate that the proposed system successfully performs real-time monitoring and automatic environmental control with stable communication between hardware and the cloud platform. The integration of IoT technology with automatic temperature regulation improves monitoring efficiency, minimizes manual intervention, and provides a practical solution for household-scale BSF cultivation. The developed system is expected to support sustainable maggot farming by maintaining optimal environmental conditions and improving cultivation productivity.

***Keywords***: *Internet of Things, Black Soldier Fly, ESP32, DHT22, Firebase, Temperature Monitoring.*

## 1. Introduction

The increasing volume of organic waste has encouraged the development of sustainable waste management technologies, one of which is the cultivation of Black Soldier Fly (BSF) (Hermetia illucens) larvae. BSF larvae are capable of converting organic waste into high-protein biomass that can be utilized as an alternative source of animal feed while reducing environmental pollution [1]. The success of BSF cultivation is strongly influenced by environmental conditions, particularly temperature and humidity, because these parameters directly affect larval metabolism, growth rate, and waste decomposition efficiency [2]. Therefore, maintaining a stable environmental condition is an important factor in improving the productivity of BSF cultivation.

In practice, household-scale BSF cultivation generally relies on manual observation to monitor environmental conditions. Farmers periodically check the temperature and humidity inside the biopond and manually operate ventilation equipment whenever environmental conditions become unsuitable. This conventional approach is inefficient because environmental conditions may change rapidly throughout the day, resulting in unstable cultivation conditions that can reduce larval productivity. Consequently, an automatic monitoring system capable of providing real-time environmental information is required to support more effective BSF cultivation [3].

Several researchers have developed Internet of Things (IoT)-based monitoring systems for BSF cultivation. Previous studies successfully implemented ESP32 and DHT22 sensors to monitor temperature and humidity, while Firebase was utilized as a cloud platform for real-time data transmission [4]. Other studies integrated gas sensors and lighting sensors to monitor environmental quality during the cultivation process [5]. Although these systems provide real-time monitoring capabilities, most of them are limited to environmental observation without implementing an automatic control mechanism to maintain optimal cultivation conditions. In addition, several systems rely on water spraying methods to regulate humidity, which increases water consumption and requires additional maintenance [6].

Based on these limitations, this study proposes an IoT-based temperature and humidity monitoring system for Black Soldier Fly (BSF) bioponds using an ESP32 microcontroller, DHT22 sensor, soil moisture sensor, Firebase cloud platform, and a DC exhaust fan as the environmental control actuator. The proposed system continuously measures environmental conditions and transmits sensor data to Firebase, enabling users to monitor the biopond remotely. When the measured temperature or humidity exceeds the predefined threshold, the DC exhaust fan is automatically activated to improve air circulation and restore suitable environmental conditions inside the biopond.

## 2. Research Method

This research employed the Waterfall software development model to design, implement, and evaluate an Internet of Things (IoT)-based monitoring system for a Black Soldier Fly (BSF) biopond. The Waterfall model consists of five sequential stages: requirement analysis, system design, implementation, testing, and maintenance. This approach was selected because it provides a structured development process and facilitates systematic evaluation of both hardware and software components.

### 2.1. System Architecture

The proposed system consists of an ESP32 microcontroller, a DHT22 temperature and humidity sensor, a soil moisture sensor, an L298N motor driver, a DC exhaust fan, and a Firebase cloud database. The DHT22 and soil moisture sensors continuously measure environmental conditions inside the BSF biopond. Sensor readings are processed by the ESP32 and transmitted to Firebase through a Wi-Fi connection, allowing users to monitor environmental conditions remotely using a smartphone or web application.

The ESP32 also functions as the main controller for the automatic ventilation system. When the measured environmental parameters exceed predefined threshold values, the ESP32 activates the DC exhaust fan through the L298N motor driver to improve air circulation inside the biopond. Figure 1 illustrates the overall architecture of the proposed system. As you can see in Figure 1.

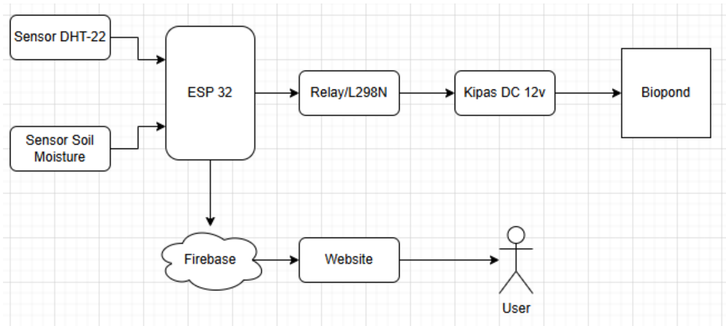


**Figure 1 :** Block Diagram of the proposed system

### 2.2. System Workflow

The operational workflow of the proposed system begins with environmental data acquisition using the DHT22 and soil moisture sensors. The collected data are processed by the ESP32 and subsequently uploaded to Firebase for real-time monitoring. Users can observe temperature and humidity conditions remotely through an internet-connected device.

If the measured environmental conditions exceed the specified threshold, the ESP32 automatically sends a control signal to the L298N motor driver, which activates the DC exhaust fan. The fan continues operating until the environmental conditions return to the desired range. This process is continuously repeated to maintain stable environmental conditions within the BSF biopond. As you can see in Figure 2.

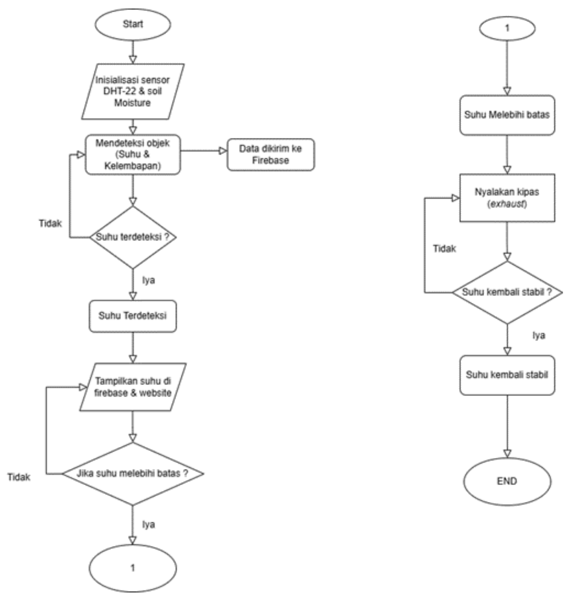


**Figure 2 :** Workflow of the proposed system

## 3. Result and Discussion

### 3.1. Prototype Implementation

The proposed IoT-based BSF biopond monitoring system was successfully developed by integrating an ESP32 microcontroller, DHT22 temperature and humidity sensor, soil moisture sensor, L298N motor driver, 12 V DC exhaust fan, Firebase Realtime Database, and a web-based monitoring application. The ESP32 functions as the main controller responsible for acquiring sensor data, processing environmental parameters, controlling the exhaust fan, and transmitting monitoring data to the cloud platform.

The hardware prototype was assembled using a dedicated enclosure to separate the control module from the sensing environment, thereby improving component protection and system reliability. The DHT22 sensor was positioned inside the biopond to measure temperature and humidity, while the soil moisture sensor was installed in the cultivation media to monitor soil moisture conditions. The developed prototype is shown in Figure 3.

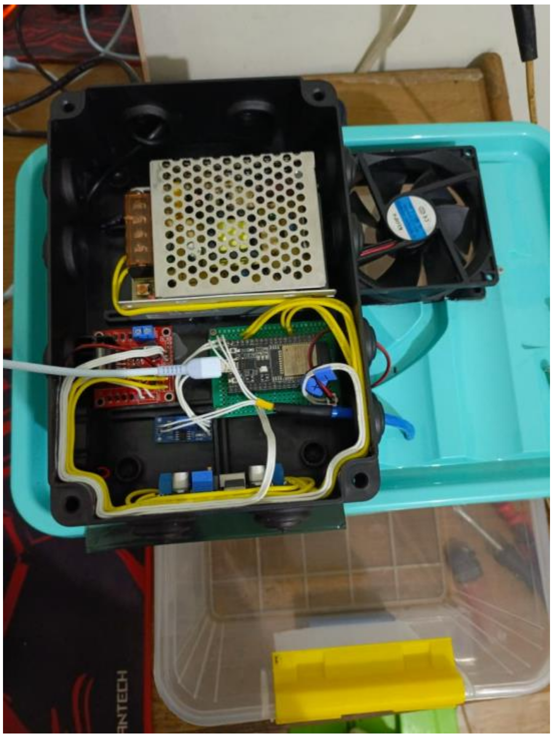

**Figure 3 :** The physical prototype of the Maggot BSF System

Furthermore, a web-based monitoring application named Maggot Watch was developed and integrated with Firebase Realtime Database. The application enables users to observe environmental conditions in real time, including temperature, humidity, soil moisture status, and exhaust fan speed. The successful integration between hardware and software demonstrates the feasibility of implementing an IoT-based monitoring system for household-scale BSF cultivation. As you can see in Figure 4.


**Figure 4 :** The user interface of the MaggotWatch web by Firebase

### 3.2. DHT-22 Sensor Testing

The DHT22 sensor was evaluated to determine its capability in measuring temperature inside the Black Soldier Fly (BSF) biopond. This testing aimed to verify that the sensor could provide stable and accurate environmental data before being integrated into the automatic monitoring and control system. During the experiment, the sensor continuously measured environmental conditions and transmitted the collected data to the ESP32 microcontroller for further processing.

**Table 1 :** DHT-22 Sensor Testing

| No | Measured Temperature (°C) | Sensor Status |
|---|---|---|
| 1 | 29 | Normal |
| 2 | 30 | Normal |
| 3 | 31 | Normal |
| 4 | 32 | Normal |
| 5 | 33 | High |

Based on the results presented in Table 1, the DHT22 sensor successfully measured the environmental temperature and humidity throughout the testing process. The sensor readings remained stable and were consistently received by the ESP32 without communication failure. The measured values indicate that the sensor is capable of monitoring environmental changes inside the BSF biopond under actual operating conditions.

Furthermore, the sensor data were successfully transmitted to the Firebase Realtime Database and displayed on the Maggot Watch monitoring interface. This confirms that the DHT22 sensor can be reliably integrated into the proposed IoT-based monitoring system, providing real-time environmental information required for automatic ventilation control.

### 3.3. Soil Moisture Sensor Testing

The soil moisture sensor was tested to evaluate its ability to detect moisture conditions in the BSF cultivation media. This experiment was conducted by exposing the sensor to different moisture levels to ensure that it could distinguish dry, moist, and wet conditions. The measured data were processed by the ESP32 and utilized as one of the environmental parameters monitored by the proposed system.

**Table 2 :** Soil Moisture Sensor Testing

| No | Sensor Value | Condition |
|---|---|---|
| 1 | 850 | Dry |
| 2 | 700 | Moist |
| 3 | 550 | Wet |
| 4 | 400 | Very Wet |

Based on Table 2, the soil moisture sensor successfully detected variations in moisture conditions during the testing process. The obtained sensor values changed according to the moisture level of the cultivation media, indicating that the sensor responded appropriately to environmental changes.

The successful operation of the soil moisture sensor provides additional environmental information that complements temperature and humidity monitoring. Consequently, the proposed system is capable of delivering more comprehensive monitoring of BSF cultivation conditions.

### 3.4. L298N Driver and DC Fan Testing

The L298N motor driver and DC exhaust fan were tested to evaluate the performance of the automatic ventilation subsystem in the proposed monitoring system. This testing aimed to verify that the L298N motor driver could properly control the DC exhaust fan based on the control signals generated by the ESP32. The experiment was conducted by applying different control conditions corresponding to the predefined environmental thresholds to observe the fan's operational response.

**Table 3 :** L298N Driver & DC Fan Testing

| No | Sensor Value | Condition |
|---|---|---|
| 1 | 850 | Dry |
| 2 | 700 | Moist |
| 3 | 550 | Wet |
| 4 | 400 | Very Wet |

Based on the results presented in Table 3, the L298N motor driver successfully controlled the operation of the DC exhaust fan according to the commands received from the ESP32. The fan responded correctly under each testing condition, operating as expected when the environmental parameters exceeded the predefined threshold values. No communication errors or delays were observed during the control process.

The testing results also indicate that the integration between the ESP32, L298N motor driver, and DC exhaust fan functioned reliably throughout the experiment. The automatic activation of the exhaust fan improved air circulation inside the BSF biopond, contributing to a more stable cultivation environment. Therefore, the proposed automatic ventilation subsystem is suitable for supporting real-time environmental control in household-scale BSF cultivation.

### 3.5. Firebase and Web Monitoring Testing

The Firebase Realtime Database and the Maggot Watch web application were evaluated to verify the communication performance between the ESP32 microcontroller and the cloud platform. This testing was conducted by observing whether the environmental data acquired from the DHT22 and soil moisture sensors could be transmitted successfully and displayed in real time through the web interface. In addition, the synchronization between automatic fan operation and the monitoring application was also examined to ensure that system status updates were accurately presented to users.

**Table 4 :** Firebase & Web Testing

| No | Parameter | Result |
|---|---|---|
| 1 | Temperature | Displayed Successfully |
| 2 | Soil Moisture | Displayed Successfully |
| 3 | Fan Speed | Displayed Successfully |
| 4 | Auto Update | Working |

Based on the results presented in Table 5, all environmental parameters, including temperature, humidity, soil moisture, and fan status, were successfully transmitted from the ESP32 to the Firebase Realtime Database. The transmitted data were displayed correctly on the Maggot Watch web application without data loss or synchronization issues during the testing process.

The monitoring interface provided real-time updates, allowing users to remotely observe the environmental conditions inside the BSF biopond through an internet connection. Furthermore, changes in the fan operating status caused by the automatic control system were immediately reflected in the web application, demonstrating successful synchronization between the hardware and software components.

Overall, the testing results confirm that the integration of ESP32, Firebase Realtime Database, and the Maggot Watch web application provides a reliable cloud-based monitoring system for BSF cultivation. This implementation enables users to supervise environmental conditions remotely, improves monitoring efficiency, and reduces the need for direct observation of the biopond.

## 4. Conclusion

This study successfully developed an Internet of Things (IoT)-based monitoring and automatic environmental control system for Black Soldier Fly (BSF) bioponds using an ESP32 microcontroller, DHT22 sensor, soil moisture sensor, L298N motor driver, DC exhaust fan, Firebase Realtime Database, and the Maggot Watch web application. The experimental results demonstrate that the proposed system is capable of monitoring temperature, humidity, and soil moisture conditions in real time while automatically controlling the exhaust fan to maintain a suitable cultivation environment. Furthermore, the integration between the hardware components, cloud database, and web application operated successfully, enabling users to remotely monitor environmental conditions through an internet connection.

The implementation of the proposed system improves monitoring efficiency and reduces the need for manual observation during BSF cultivation. The automatic ventilation mechanism contributes to maintaining more stable environmental conditions, thereby supporting the growth of BSF larvae. Future research may focus on integrating additional environmental sensors, implementing more advanced intelligent control algorithms, and developing a mobile application to enhance accessibility and improve the overall performance of the monitoring system.

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