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Smart Organic Waste Composter (Automatic Biodegrader)

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ABSTRACT

The increasing generation of organic waste in household setups presents a rather big problem to both the environment and sanitation in terms of landfill overflow, green house emission, and odor. This paper introduces the Smart Organic Waste Composter (Automatic Biodegrader), an IoT-based gadget that is aimed at automating the composting process by mechanically mixing, aerating, drying, and monitoring the environmental conditions in real-time. The sensors for the conduct of moisture, gas, temperature, and humidity monitor the conditions of the compost, and an ESP32 microcontroller modulates the actuators according to the preset limits. The real-time system status and remote monitoring and user feedback are achieved with the help of an LCD screen and the Blynk IoT platform. The system was experimentally tested to be successful in minimizing moisture and odor and improving waste-handling productivity with the environmental correction cycles accomplished in 6-10 minutes. The suggested solution can be described as a low-cost, environmentally-friendly, and user-friendly solution that will provide a sustainable approach to the management of domestic organic wastes.

Keywords: Smart Composting, Organic Waste Management, IoT-Based System, Automated Biodegrader, Sustainable Technology

INTRODUCTION

The rapid growth of urban areas and increase in population have caused a substantial hike in the organic waste generation, with food waste from households being the major contributor. The orthodox methods of waste disposal, such as burying organic substances in landfills, not only cause environmental issues like the release of methane, the production of bad smells, and the depletion of the Earth's resources, but also result in the disposal of the resources in a very unproductive manner. Soil reclamation gives us a greener method by changing the nature and properties of organic wastes to that of a very effective fertilizer; however, the process of going through the traditional composting method comes with inconveniences like being time-consuming, messy, and not easily managed indoors.

The Internet of Things (IoT), along with embedded system technology, has opened up the possibility of developing smart waste management solutions that can automate the monitoring and controlling processes. The suggested Smart Organic Waste Composter (Automatic Biodegrader) is a sensor, actuator set, up with wireless communication software that helps with composting in a eco, friendly and efficient way. The system takes care of the moisture, the odor and mixes the compost mechanically thus not needing a lot of human interference and at the same time speeding up the process of biodegradation. This way, the system can even be used indoors and in semi, indoor places.

REVIEW OF RELATED LITERATURE

A number of studies have shown that the use of smart technologies in waste management and composting systems, especially through automation and sensor-based monitoring, can lead to considerable improvement. The IoT-based smart composting system proposed by Vinothini, C. et al. (2020) comes with environmental sensors that monitor the internal conditions of organic waste bins. The authors of the study were able to prove that real-time data acquisition not only increased composting efficiency but also decreased the need for manual supervision. Moreover, studies involving smart waste systems emphasize that the combination of automation and sensors significantly contribute to the fast and efficient handling of waste, thereby allowing for the adoption of eco-friendly waste management practices. The research findings point to the fact that the combination of technology and automation in waste management would be a major asset in dealing with the ever-increasing problem of organic waste disposal.

Smart Composting

Lew et al. (2021) basically did an experiment on smart composting by refining Bokashi composting with Effective Microorganisms-1. They found out that by adjusting environmental factors like temperature and moisture, the composting process would speed up a lot and the compost quality would be better. Smart composting containers eliminated the necessity for ongoing manual monitoring, thus making the process not only more efficient but also more convenient. This research exhibits that the sensors and automated control-dependent smart composting systems can be considered as good alternatives for organic waste disposal.

IoT-Based Systems

Studies on the use of the Internet of Things for waste management systems have found that smart bins with sensors installed can improve the entire process by monitoring it in real-time and giving feedback to the system. Vinothini, C. et al. (2020) pointed out that IoT connectivity allows the users to monitor the composting conditions from a distance and get the updates at the right time, which makes the system more usable and trustworthy. Though IoT systems have been used extensively in public waste monitoring, their use in household composting systems is still a significant area of development, especially if it is along with automation and environmental sensing.

Organic Waste Management

Organic waste management has been one of the researched topics in depth as a sustainable way to reduce the load on landfills and environmental pollution. Omkar Rajkumar et al. (2022) developed a mechanized organic waste machine that assisted in mechanical mixing and regulated the processing time to speed up the organic waste decomposition process. Their results showed that automation reduces the involvement of human labor and at the same time increases the effectiveness of the decomposition process. This research is in line with the concept that automated systems for organic waste management at the home level can be great instruments to minimize waste and dispose of it in an environmentally friendly manner.

Temperature and Humidity Sensors

Environmental factors like temperature and humidity are very important in the process of composting. Lew et al. (2021) emphasized that holding the right temperature and moisture levels is necessary for the microbes to be active during composting. Also, a vermicomposting research released in 2024 revealed that controlling the humidity is important to keep the conditions not only good for the compost but also efficient in the process of the decomposition. These pieces of research validate that temperature and humidity sensors combined are necessary to sustain composting conditions, and thus the performance of the system can be improved.

Automated Biodegrader Systems

Automated biodegraders are quite advance tech that combine sensors, mechanical parts, and automated control systems for the purpose of allowing organic waste to be broken down naturally, completely, and without human intervention. They basically act as small ecosystems, where various factors such as temperature, humidity and aeration are carefully balanced to create the perfect conditions for the microbes that carry out composting to thrive, which in turn is a faster process, generates less odor, and requires fewer interventions. Research in 2024 on the automation of vermicomposting and biogas production pointed out that uninterrupted sensor, based monitoring together with automated environmental control not only assist in obtaining high, quality compost but also make the process more efficient. Such results demonstrate how automated biodegrader systems have the potential to tie together the practical task of waste disposal with one of resource creation and environmental sustainability.

Table 1. Comparison Matrix of Related Studies and Current Research

Study	Sensors Used	Controller	Main Outputs	Scope	Key Features	Gap Addressed by This Study
GRENZE / GIJET (2025)	Ultrasonic, Camera, Load Cell	ESP32	Web App Dashboard, Collection Routes	Household /Smart City	Image processing for plastic; incentivized rewards.	User Participation: Incentivized public engagement in waste segregation; reward system implementation.
Lew et al. (Bokashi) (2021)	DHT11, Ultrasonic, Soil Moisture	Arduino + ESP8266	Google Sheets data, Bran Sprinkling	Laboratory / Experimental	Chemical optimization; ratio of EM-1 microorganisms.	Standardization: Automated control of Bokashi fermentation ratio; reduces DIY composting inconsistencies.
ICEES / Vermicompost (2024)	DHT11, pH Sensor, Soil Moisture	ATmega328 / ESP32	Automated moisture, Android App	Agricultural Prototype	Environmental control for earthworm survival.	Biological Loss: Minimizes earthworm mortality; reduces errors from manual monitoring.
IJERT / Solar Garbage (2020)	Ultrasonic, Rain Sensor, MQ Gas	Arduino Uno / PIC	SMS Alerts, Cloud Data, Auto-lid	Urban/Public Bin	Solar-powered; weather-adaptive lid.	Energy Autonomy: Enables operation in off-grid locations; supports smart bin deployment in remote areas.
Sibarani et al. (2022)	Temperature sensor	Arduino	Processed compost from organic waste	Automated compost processing	Automatic mechanical stirring for aeration	No moisture and gas monitoring; limited sensor integration
Current Study: Smart Organic Waste Composter (Automatic Biodegrader)	Gas sensor (MQ), Capacitive moisture sensor, Temperature & Humidity sensor (DHT)	ESP32	Exhaust fan, mixer motor, LCD display, Blynk IoT notifications	Small-scale indoor organic waste composting	Real-time compost monitoring; automated odor control; IoT notifications; low-voltage safe operation	Integrated Environmental Monitoring: Monitors gas, moisture, temperature, and humidity with automated odor control and real-time IoT alerts in a single low-cost system.

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METHODOLOGY

The Smart Organic Waste Composter (Automatic Biodegrader) integrates a mechanical system, electronic circuitry, and embedded software management. It operates as an intelligent closed-loop control system, using sensor feedback and actuator responses to maintain optimal composting conditions continuously. The sensors monitor environmental parameters, moisture levels, and odor, while the microcontroller processes this data to manage mixing, aeration, and user notifications. Operating instructions are provided in the user manual (Appendix A, Figure 5), which can be referred to for correct system usage.

System Architecture:

The system operates on a modular hardware architecture centered around the ESP32 microcontroller, selected for its built-in Wi-Fi capability and compatibility with IoT platforms. The ESP32 serves as the main processing unit responsible for sensor data acquisition, decision-making, actuator control, and wireless communication with the mobile monitoring application.

Composting Chamber and Mechanical Design:

The physical structure consists of a semi-sealed composting chamber designed to minimize odor leakage while allowing controlled airflow. A mixing blade or stirring rod is mounted inside the chamber and driven by a DC gear motor. This mechanism prevents waste clumping and accelerates aerobic decomposition. An activated carbon filter is integrated into the ventilation path to absorb odors before air is expelled.

Motor and Actuator Control:

To interface the ESP32 with the DC gear motor, a motor driver module (L298N or equivalent) is used. The driver supplies sufficient current from the power source while allowing the microcontroller to regulate motor operation. The mini exhaust fan is directly controlled to manage airflow, humidity reduction, and odor suppression. Motor and fan activation are triggered based on real-time sensor thresholds.

Sensor Array and Environmental Monitoring:

The system employs multiple sensors to assess compost conditions:

- Moisture Sensor: Continuously measures the dampness of organic waste. When excessive moisture is detected, the system activates drying and aeration mechanisms.
- Gas/Odor Sensor (MQ-type): Detects rising odor or gas concentration inside the chamber, prompting increased ventilation to maintain safe and hygienic operation.
- Temperature and Humidity Sensor: Measures the internal temperature and moisture level inside the composting chamber. These readings are used to assess whether conditions are suitable for decomposition. When abnormal temperature or excessive humidity is detected, the system activates the exhaust fan and mixing mechanism to stabilize the internal environment.
- Sensor Calibration: Before deployment, sensors were calibrated by doing baseline tests at normal indoor conditions. The sensors for moisture and gas were tested their responses in dry, wet, and odor situations to make sure threshold, based activation was consistent. Calibration was mainly focused on ensuring a reliable system operation rather than exact measurement accuracy.

Human–Machine Interface (HMI):

User interaction is achieved through a combination of visual and audible indicators:

- LCD Display: Presents live sensor readings and current system status.

IoT Integration and Remote Monitoring:

Using its built-in Wi-Fi, the ESP32 connects to the Blynk IoT platform, enabling real-time system monitoring via a mobile application. Notifications such as high moisture levels, odor detection, active processing, bin full status, and cycle completion are sent to the user, allowing remote supervision of the composting process.

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Software Implementation

The control logic has been coined in C++ through the Arduino Integrated Development Environment (IDE) and has been assumed to be a non-blocking program and an idea has been the possibility of simultaneous monitoring of sensors and controlling actuators. The program runs on a loop-based architecture where sensor data has been gathered in consistent intervals and then evaluated within pre-determined threshold limits. The operational decision hierarchy is prioritized as follows:

The operational decision hierarchy is prioritized as follows:

1. **Environmental Condition Analysis:**

   The system first evaluates moisture and gas sensor readings.

   - If moisture exceeds the allowable limit, the system activates the exhaust fan and mixing motor to reduce dampness.
   - If odor or gas concentration is detected, ventilation intensity is increased, and the user is notified via the IoT platform.

2. **Automatic Mixing and Aeration Control:**

   At scheduled intervals or when triggered by sensor data, the mixing motor is activated to rotate the composting mechanism. This ensures uniform aeration and prevents waste accumulation.

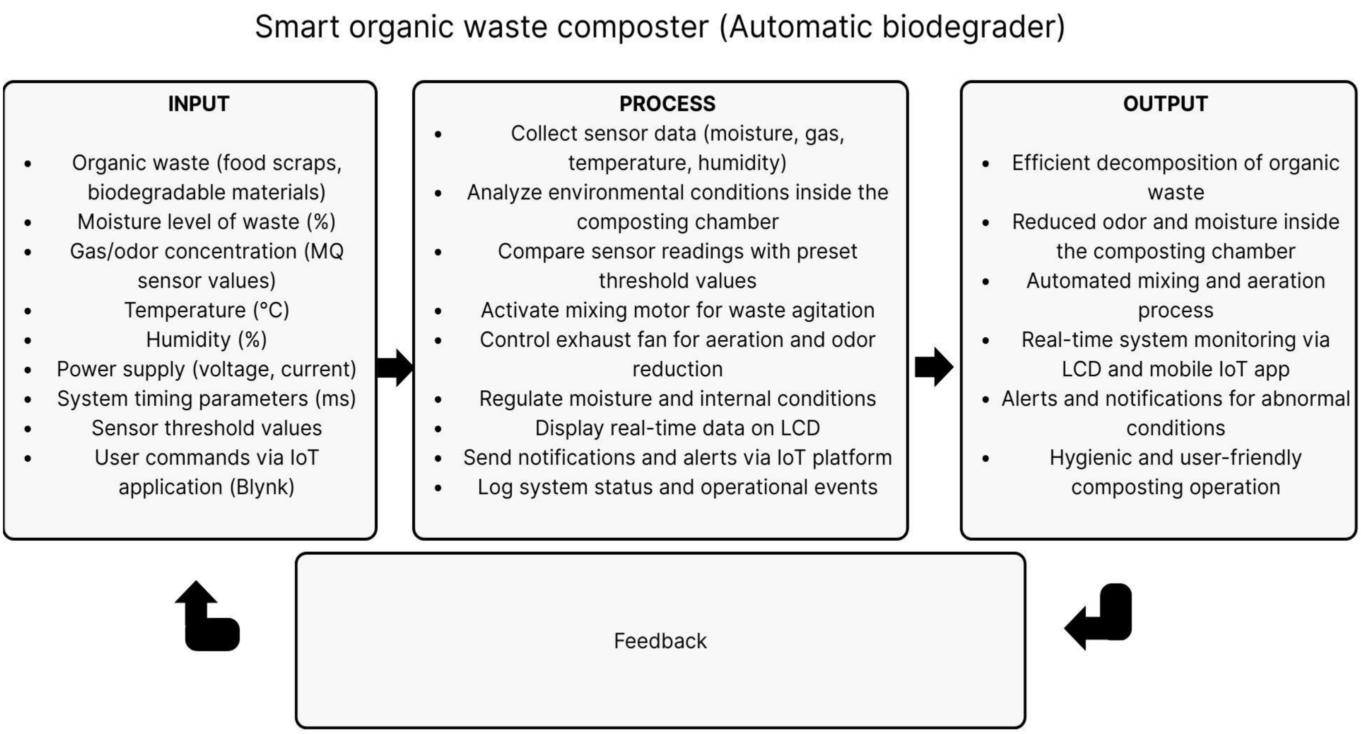
3. **Status Display and Alerts:**

   Sensor readings and operational states are displayed on the LCD alerts provide immediate feedback on system conditions.

4. **Remote Notification and Logging:**

   All critical events and status updates are transmitted to the Blynk application, allowing users to monitor system performance and respond promptly when intervention is required.

Figure 1. Input–Process–Output (IPO) Model



The Smart Organic Waste Composter is developed around the Input-Process-Output (IPO) model, which is depicted in Figure 1. It essentially maps out the orderly movement of information and instructions starting from detecting the internal composting conditions to the execution of automated mechanical actions and the delivery of user feedback.

Various environmental and system parameters necessary for efficient composting are included in the input stage. Organic waste is deposited in the composting chamber, while sensors keep track of the moisture level, gas or odor concentration, temperature, and humidity. To the power supply, predefined sensor threshold values, system timing parameters, and user commands received via the IoT platform are some of the additional inputs. These inputs are continuously updated and thus provide real-time data for the maintenance of optimal conditions for composting and compliance with safety standards.

The process phase is under the control of the ESP32 microcontroller, which acts as the system's central control unit. The readings from the sensors are gathered and interpreted all the time and are then checked against the preset threshold values. In the case where there is too much moisture, the system will turn on the exhaust fan and the mixing motor so that the wastes are aerated and dried. If high levels of gas or odor are detected, the air circulation ventilation is increased to reduce odor buildup and maintain a hygienic environment. Moreover, the system mixes the waste either on a schedule or based on the condition to prevent the formation of clumps and also speed up its decomposition. Through the LCD, the real-time system status and sensor data are made visible to the users, while significant events and alerts are communicated to the mobile IoT app.

The output stage interprets the control decisions of the system into physical actions and user feedback. Such outputs comprise automatic waste mixing, aeration control, odor reduction, and the maintenance of internal composting conditions. Besides that, the LCD screen serves as a visual output aid, whereas the notifications and alerts are transmitted through the IoT platform to keep the user updated about the system status, abnormal conditions, or process completion. Hence, the user gets to enjoy an effective, clean, and convenient composting process when the system is at work.

In order to finalize the operation cycle, the system acts as a closed-loop feedback control. By continuously monitoring the changes in the composting environment due to mixing or aeration through the sensors, the microcontroller is regularly updated. Such real-time feedback enables the system to modulate the actuator's operation constantly, thus ensuring the composting conditions to be steady, the odor to be low, and the system's performance to be consistent with the least amount of human intervention.

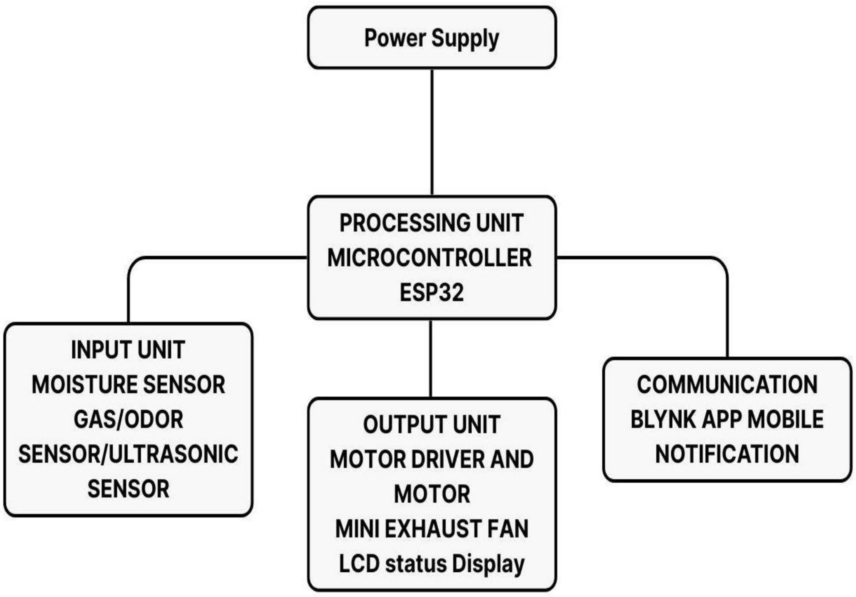


Figure 2. Block Diagram

A system block diagram visually demonstrates how different functional subsystems of the Smart Organic Waste Composter are connected, and it is an effective medium to show the flow of information and energy within the system. The diagram categorizes the system into four main subsystems: the power subsystem, processing

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subsystem, input subsystem, and output subsystem. These subsystems are physically or logically interconnected in such a way as to perform a complete cycle of data acquisition, decision-making, actuation, and user feedback.

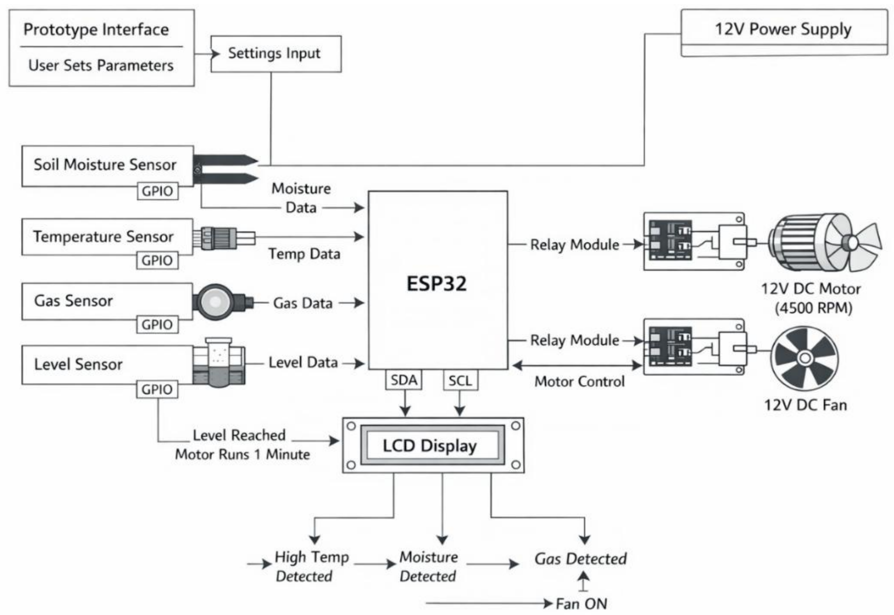
The power subsystem is responsible for providing stable and regulated electrical energy to all the system components. The source of power for the system is a DC power supply that meets the voltage requirements of the ESP32 microcontroller as well as the peripheral devices. This power source produces enough current for the motors and ventilation parts while providing the low-voltage stable power required by the sensors, display, and communication modules.

The ESP32 microcontroller lies at the heart of the system and serves as the central processing unit. The ESP32 obtains sensor data, controls the whole system by running the control logic, and issues system commands. It takes environmental inputs in real time and gives outputs based on threshold values preset in the control routines. Besides, the ESP32 handles wireless communication so that the system can be remotely controlled and notifications sent to the mobile IoT application.

The input subsystem is made up of several sensors that monitor the internal conditions of the composting chamber at all times. For instance, there is a moisture sensor that detects excessive dampness, a gas or odor sensor that measures odor concentration, and a temperature and humidity sensor that determines the environmental conditions favorable for composting. The sensor data thus obtained give a real-time picture of the situation to the microcontroller, which in turn instructs the system to automatically adjust the composting conditions to the optimum level.

The output and actuation subsystem has the function of physically implementing the control decisions made by the microcontroller. This subsystem comprises a motor driver and an agitator motor that are responsible for the stirring of the organic waste, a mini exhaust fan that provides aeration as well as odor control, and an LCD display that shows the system status and sensor readings. In addition, there may also be audio and visual alerts that the user can recognize when the system is under abnormal conditions. These output elements, working in unison, convert the digital control signals into physical actions and user feedback, thus guaranteeing efficient, clean, and automated composting operation.

Figure 3. Schematic Diagram



The complete schematic diagram shows the whole hardware architecture of the ESP32-based monitoring and control system. It also details how each component interacts to provide the functionality of sensing, decision-making, actuation, and user feedback. In the top left corner, a prototype interface is depicted. It shows the user setting the operating parameters through a settings input, which is then sent to the ESP32 as the main controller.

The ESP32 continuously senses the input/output devices connected to its various GPIOs. This is shown at the left side of the diagram, where the Soil Moisture Sensor gives moisture data, the Temperature Sensor gives

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temperature data, the Gas Sensor gives the concentration of gas data, and the Level Sensor gives the status of the monitored system.

Here at the bottom of the schematic, an LCD display is shown communicating with the ESP32 via an I2C bus (SDA and SCL lines). It acts as the system's display panel that shows the real-time readings, the detection states, and the operating status. On the right side, the ESP32 is seen managing two heavy electrical loads through relay modules.

These relays act as electrically isolated switches, allowing the 12V DC motor (4500 RPM) and other 12V output devices to be safely driven by the 12V power supply. The diagram highlights key automatic actions, such as the motor operating for one minute when the level sensor detects the target level. This chart exemplifies the monitoring and control system: the ESP32 microcontroller continuously receives sensor inputs, executes control logic based on user settings and detected conditions, activates the output devices through relays, and provides immediate visual feedback via the LCD display.

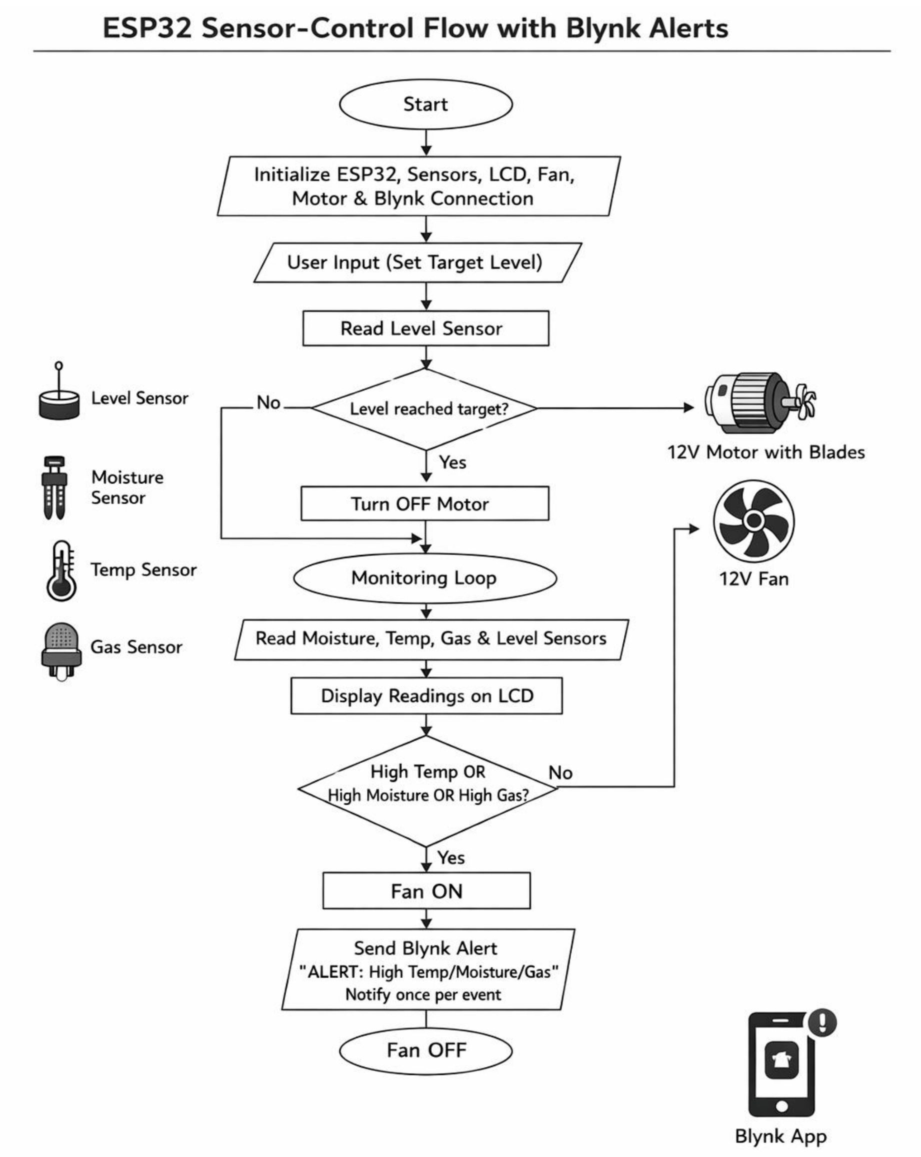

Figure 4. Flow Chart

The flowchart shows in detail the operational logic of the ESP32 sensor and the control system with Blynk alerts. It illustrates how the system initializes, gets sensor data, controls actuators, and sends notifications.

The system is initialized by the ESP32 along with all peripherals such as the level sensor, moisture sensor, temperature sensor, gas sensor, LCD display, 12V fan, 12V motor, and Blynk for mobile alerts. A target level set by the user becomes the basis for the system's control decisions after the initial setup.

Once the target level is set, the ESP32 reads the level sensor and checks if the desired level has been reached. If the target level has not been reached, the system keeps the sensor monitoring task until the condition is satisfied. When the target is reached, the system responds by turning the motor OFF, thus limiting the operation to the level only required.

Afterward, the flow goes down into an infinite monitoring loop, wherein the ESP32 continuously reads the moisture, temperature, gas, and level sensors' values and shows them on the LCD display in real time.

The flowchart further depicts the system's safety and alert features. If the target isn't reached yet, the system keeps checking the situation until the goal is met. Once the target is reached, the system reacts by switching OFF the motor; thus, it won't perform the action more than the required level. From there, the path goes into an endless monitoring loop, where the ESP32 continuously takes readings from the moisture, temperature, gas, and level sensors and shows the live data on the LCD screen.

The flowchart also represents the system's safety and warning operation. When the ESP32 finds high temperature, high moisture, or high gas concentration, it hands the fan to ON immediately to handle the abnormal situation. Meanwhile, the system sends a Blynk alert notification to the user's mobile device together with a warning message (e.g., "ALERT: High Temp/Moisture/Gas"). To prevent the user from being bombarded with messages, the alert is tailored to notify one time per event, and after the condition is fixed, the fan is turned OFF, bringing the system back to the normal monitoring mode.

Thus, the flowchart illustrates a closed-loop embedded system in which sensor data determine the decisions. The ESP32 executes control actions for the motor and fan, the LCD provides on-site feedback, and the Blynk application provides remote alerts for real-time monitoring and safety.

RESULTS AND DISCUSSION

To evaluate the effectiveness of the Smart Organic Waste Composter (Automatic Biodegrader) prototype in automated waste monitoring, moisture control, mechanical mixing, and odor reduction, a series of performance tests was conducted using the ESP32-based control system. The sensors reliably detected internal composting conditions and triggered the actuators as programmed. The mixing motor improved waste homogeneity, while the exhaust fan promoted airflow through the filtration line, reducing moisture and odor levels.

The sensor array controlled fertilization optimally. The level sensor turned on the motor at a 15 cm threshold thus preventing its operation from being wastefully activated, meanwhile, temperature, humidity, and gas sensors are the components which, when detecting unhealthy situations, will immediately start ventilation. Users were able to track the system status and environmental conditions even externally through LCD display and the Blynk IoT platform, thus, real, time monitoring was ensured without interruption of the composting process.

A successful processing cycle work would typically last between six and ten minutes. Despite the consistent performance of the system throughout the preponderance of tests, isolated tests highlighted the need of optimization of sensor calibration and, specifically, the baseline of MQ gas sensor and the depth of the insertion of the moisture sensor. These shortcomings would at times disrupt the accurate timing of the actuator practices but did not affect the operational safety. All in all, the data reveal that the proposed ESP32-based platform can operate independently in the domestic setting, which could mean that the system is a feasible and cost-effective solution to the problem of managing indoor organic waste.

Table 2. Variables and Conditions of Smart Organic Waste Composter (Automatic Biodegrader)

Variable / Component	Type	Parameter Measured / Controlled	Condition or Range	System Response/Action
Level Sensor	Input	Waste height/volume	Reaches 15 cm target	Activates Mixing Motor for 1 minute
Gas/Odor Sensor (MQ)	Input	Gas concentration	Threshold exceeded	Turns ON the exhaust fan and sends Blynk alert

Temperature Sensor	Input	Internal heat	High Temp detected	Turns ON the exhaust fan to stabilize environment
Humidity Sensor	Input	Internal air moisture	High Humidity detected	Turns ON the exhaust fan to reduce dampness
Soil Moisture Sensor	Input	Waste dampness	Excessive moisture detected	Triggers aeration via Fan and mixing
Mixing Motor	Output	Waste agitation	Level = 15 cm	Rotates blades to prevent clumping
Exhaust Fan	Output	Airflow/Odor control	Abnormal Gas/Temp/Hum	Turns ON to reduce odor and moisture

Table 3. Performance Evaluation of Smart Organic Waste Composter (Automatic Biodegrader)

Test #	Input Condition	Observed Output	Expected Output	Pass/ Fail	Remarks/Behavior
1	Waste level reaches 15 cm	The motor runs for 1 minute	Mixing motor activation	Pass	Successfully agitated waste only when volume was sufficient.
2	High Gas detected	The fan turns ON immediately	Exhaust ventilation	Pass	Odor concentration was reduced via the filter path.
3	High Temperature/Humidity	Fan turns ON	Environmental stabilization	Pass	The exhaust fan improved air exchange to cool the chamber.
4	Level below 15 cm	The motor remains OFF	No motor activity	Pass	The system stayed in monitoring loop without unnecessary mixing.
5	All Thresholds Normal	LCD shows "Normal" status	No actuator response	Pass	The system correctly identifies and displays stable composting states

The Smart Organic Waste Composter was tested by using a series of experimental runs, controlled under an indoor environment. These tests evaluated the system with respect to garbage quantity detection, control over the interior gases, and the provision of status information through IoT. Further in the trials, the programmed logic implementation in the system was done with high success rate. The time of success cycles of environmental correction was between six and ten minutes. The composter was able to record a reliable level of waste at 15cm and subsequently, mixing started to prevent anaerobic clumping in all the succeeded compiter runs. The unpleasant odor was countered by switching on the exhaust fan and passing the air through a filter thus effectively countering the odor.

There were some discrepancies in the sensitivity of the gas sensor to changes in ambient air, which sometimes caused the delay in reverting the "Normal" status. These examples are the MQ series sensors' high sensitivity to baseline calibration and humidity levels in the chamber. There is also a possibility that moisture buildup on the sensor surface influenced the accuracy of the readings. These findings strongly indicate that accurate sensor installation and advanced calibration techniques will be necessary to improve the overall dependability of the system.

Even with the calibration issues, the mechanical agitation and IoT notification systems were working perfectly in each experiment. The level sensor correctly detected the height of the waste and triggered the stirring action to make sure the compost was aerated. The LCD display and Blynk interface gave real-time visual feedback, facilitating the user to keep track of the composter's condition without opening the lid. The outcomes of the experiments unequivocally indicate that the ESP32-based system can accomplish indoor composting by itself, and it is a feasible, inexpensive model for sustainable household waste management.

CONCLUSION

The creation and assessment of the Smart Organic Waste Composter (Automatic Biodegrader) suggests that the use of IoT and sensor-based automation greatly improves the productivity and cleanliness of domestic waste management. The outcome of the system proves that it has been able to change a simple storage container to a fully active processing unit by using the ESP32 microcontroller to control the mechanical stirring and the environment. The particular framework, which gives first priority to safety and stability, keeps the mixing motor off until the 15 cm waste level is reached, and the exhaust fan is activated immediately when gas and humidity increase, resulting in a fine-tuned, low-energy operation that is suitable for indoor use.

Integration with the Blynk IoT platform also turned out to be a great decision for automated hardware supervision and user monitoring. By giving real, time data and mobile alerts, the system tackles household composting problems, such as the release of odors and the need for constant manual checking.

Although sensor baseline calibration posed some difficulties, the overall results confirm that the prototype is a robust and expandable solution. The Smart Organic Waste Composter is a tech-enabled approach to the circular economy, enabling households to reduce landfill waste efficiently while maintaining environmental integrity.

Future improvements may include advanced sensor calibration techniques, additional environmental sensors, and extended long-term compost quality evaluation. These enhancements can further improve system accuracy, scalability, and applicability in diverse deployment environments.

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The authors, [1]Mark Jerome A. Delima, [2]John Kenneth R. Añonuevo, [3]Selwyn James S. Jimenez, [4]Emanuel Zack Morabe, and [5]Ian Exequiel B. Santuyo, are currently pursuing their Bachelor of Science degrees in Computer Engineering at the Eulogio "Amang" Rodriguez Institute of Science and Technology (EARIST), Manila, Philippines.

The authors' collective research interests focus on embedded systems, IoT-based automation, and smart environmental technologies, particularly in the development of intelligent waste management systems. This work was conducted in partial fulfillment of the requirements for their academic degree.

APPENDIX A

Figure 5. User Manual

This manual provides operational requirements and safety provisions as well as maintenance measures that should be followed by the users to ensure that the system has been properly utilized. This content is designed for household and educational use.