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Design and Implementation of a Smart Composting System using IoT over 5G-Enabled Network Infrastructure

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***Abstract* - Organic waste management has emerged as a critical environmental challenge due to the rapid increase in biodegradable waste from residential, institutional, and agricultural sources. Traditional composting methods require continuous manual monitoring to maintain optimal moisture and temperature conditions, leading to inefficiencies in compost quality and processing time. This paper presents the design and implementation of a smart composting system using Internet of Things (IoT) technology over 5G-enabled network infrastructure for efficient organic waste management. The proposed system utilizes an Arduino Uno as the central control unit, integrated with moisture and temperature sensors for real-time monitoring of compost conditions. A 16×2 LCD module provides local visualization of sensor data. Automated control is achieved using a servo motor for cutting mechanisms and an L293D motor driver to operate a DC motor and water pump. A DC fan is activated based on temperature thresholds to maintain optimal environmental conditions. An ESP32 enables cloud connectivity by transmitting data to the Adafruit IO platform via available high-speed network infrastructure. Additionally, an ESP32-CAM provides real-time visual monitoring of the composting process. The system significantly reduces manual intervention, enhances process efficiency, and supports sustainable waste management practices. The proposed solution is suitable for small-scale deployment in smart homes, institutions, and agricultural applications.**

Keywords* - *Organic Waste Management, Smart Composting, Internet of Things (IoT), Arduino Uno, ESP32, Cloud Monitoring, Automation, 5G-Enabled Network Infrastructure

I. INTRODUCTION

Rapid urbanization and population growth have significantly increased the generation of organic waste from domestic, agricultural, and commercial sectors. Improper disposal of biodegradable waste leads to serious environmental issues such as land pollution, foul odor, greenhouse gas emissions (especially methane), and ecological imbalance [1]. Effective waste management strategies are therefore essential to ensure environmental sustainability.

Composting is widely recognized as an eco-friendly and sustainable method for converting organic waste into nutrient-rich manure [2]. However, conventional composting techniques are often slow, inefficient, and highly dependent on manual monitoring of key parameters such as moisture content, temperature, and aeration [3]. Inconsistent maintenance of these parameters can adversely affect microbial activity, thereby reducing compost quality and increasing processing time.

To address these challenges, the integration of embedded systems and Internet of Things (IoT) technologies has gained significant attention in recent years [4]. IoT-based smart systems enable real-time monitoring, automation, and remote supervision of environmental conditions. In a smart composting environment, sensors are used to measure critical parameters, microcontrollers process the collected data, and actuators regulate internal conditions to optimize the decomposition process [5].

In this work, a smart composting system is developed using an Arduino Uno as the central control unit, integrated with sensors, actuators, and IoT communication modules. The system continuously monitors moisture and temperature conditions and performs automatic control actions using a motor driver, DC motor, DC pump, servo motor, and DC fan to maintain optimal composting conditions. The sensed data is transmitted to the Adafruit IO cloud platform through an ESP32, utilizing available high-speed communication infrastructure, including 5G-enabled networks, for remote monitoring and analysis. Additionally, an ESP32-CAM is employed to provide real-time visual monitoring of the composting chamber.

The main contributions of this work are summarized as follows:

1. Design and implementation of an automated smart composting system for organic waste management.
2. Real-time monitoring of moisture and temperature parameters using sensor-based integration.
3. Automatic control of water pump, cooling fan, and mechanical system based on predefined threshold conditions.
4. Cloud-based remote monitoring using IoT connectivity via ESP32 and Adafruit IO platform.

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II. LITERATURE REVIEW

These systems utilize sensor networks and cloud platforms to ensure optimal composting conditions and reduce manual intervention. A study in [1] demonstrated that IoT-enabled monitoring significantly enhances process control and improves compost quality through continuous data acquisition.

Recent research has also highlighted the importance of automation in composting systems. In [2], an IoT-based compost monitoring system using sensors and cloud integration was proposed, where alerts were generated when compost parameters exceeded threshold values. The system improved operational efficiency but lacked advanced control mechanisms.

A recent study in [3] emphasized that AI-based models can predict compost maturity and optimize environmental conditions; leading to improved decomposition rates and reduced processing time. Similarly, intelligent waste management systems integrating IoT and AI have shown improved automation, classification accuracy, and real-time decision-making capabilities.

Recent works also focus on energy-efficient and scalable smart composting solutions. In [4], an energy-efficient IoT-based composting system was developed for sustainable food waste management, demonstrating reduced energy consumption and improved system performance. Additionally, modern smart composting approaches incorporate advanced sensors and intelligent control strategies to optimize aeration, moisture balance, and microbial activity.

Furthermore, IoT-based waste management systems have been widely adopted in smart city applications. These systems utilize sensor data and cloud platforms to monitor waste levels and improve resource management. A recent study in [5] proposed an IoT-based waste management system with predictive analytics, enabling efficient waste handling and real-time monitoring of environmental conditions.

III. PROPOSED SYSTEM

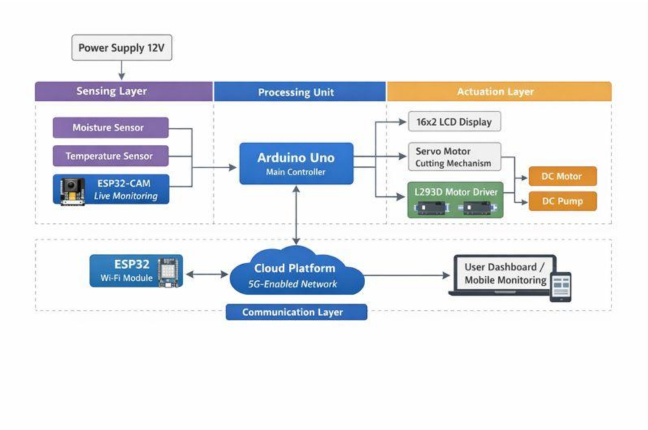

Fig. 1. Proposed Block Diagram

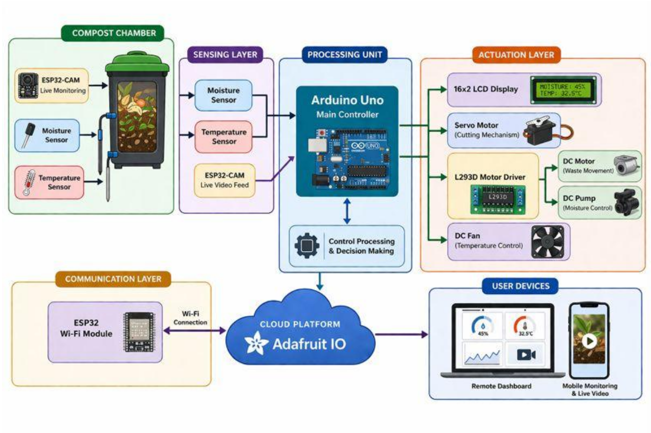

Fig. 2. Proposed System Architecture

The proposed system presents an automated and intelligent composting solution designed to improve the efficiency of organic waste management through real-time monitoring, control, and cloud-based supervision. The system integrates sensing, processing, actuation, and communication modules into a unified architecture.

The overall framework consists of an Arduino Uno as the central control unit, interfaced with environmental sensors, actuators, and IoT communication modules.

The ESP32 communicates via Wi-Fi, while cloud access is supported over 5G-enabled network infrastructure.

A. *System Architecture*

1. Sensing Layer

The sensing layer includes a moisture sensor and a temperature sensor, which are embedded within the composting chamber. These sensors continuously measure the environmental conditions required for effective microbial activity and decomposition.

2) Actuation Layer

The actuation layer consists of mechanical and electrical components controlled by the microcontroller. An L293D motor driver is used to interface and control a DC motor and a DC pump. The DC pump regulates moisture levels, while the DC motor supports mechanical operations such as waste movement. A servo motor is used to control the cutting or storage mechanism of the composting chamber. Additionally, a DC fan is employed to regulate temperature when it exceeds predefined limits.

3) Communication Layer

The communication layer is implemented using an ESP32, which enables wireless data transmission to the Adafruit IO cloud platform. The system leverages available high-speed communication infrastructure, including 5G-enabled networks, to ensure reliable and low-latency data transfer.

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Furthermore, an ESP32-CAM provides live visual monitoring of the composting process.

B. System Operation

The proposed system operates based on continuous monitoring and automatic control of composting conditions. Initially, the sensors measure moisture and temperature levels inside the compost chamber. These values are transmitted to the Arduino Uno for processing.

The controller compares the measured values with predefined threshold limits. If the moisture level falls below the required threshold, the system activates the water pump through the motor driver to restore optimal moisture conditions. Similarly, if the temperature exceeds the permissible range, the DC fan is automatically turned on to cool the composting environment.

The real-time sensor values are displayed locally using a 16×2 LCD module for user awareness. Simultaneously, the ESP32 transmits the data to the Adafruit IO cloud platform, enabling remote monitoring and analysis. The ESP32-CAM provides real-time visual feedback of the composting chamber, enhancing system transparency and supervision.

C. Control Logic

The system follows a threshold-based control mechanism for automation. The decision-making process is governed by the following conditions:

- If moisture level is below the minimum threshold → Water pump is activated
- If temperature exceeds the maximum threshold → Cooling fan is activated
- Otherwise → System remains in monitoring mode

This simple yet effective control strategy ensures stable composting conditions with minimal human intervention.

D. Key Features of the Proposed System

- Real-time monitoring of compost parameters using sensors
- Automated control of moisture and temperature conditions
- Integration of mechanical and electrical actuation systems
- Cloud-based remote monitoring using IoT technology
- Live visual monitoring using camera module
- Compatibility with modern high-speed network infrastructure, including 5G-enabled networks.

IV. METHODOLOGY

The methodology of the proposed smart composting system is based on a structured approach involving sensing, data processing, decision-making, actuation, and cloud communication. The system operates in a continuous loop to ensure optimal composting conditions with minimal human intervention.

A. System Initialization

Initially, all hardware components including the Arduino Uno, sensors, actuators, LCD display, and communication modules are initialized. The predefined threshold values for moisture and temperature are set within the controller program. These threshold values determine the operational conditions for activating the pump and cooling fan.

B. Data Processing and Decision Making

The Arduino Uno processes the acquired sensor data and compares it with predefined threshold values. Based on this comparison, the system determines whether corrective actions are required.

The decision-making logic is defined as:

- If moisture level is below threshold → Activate water pump
- If temperature exceeds threshold → Activate DC fan
- Otherwise → Maintain monitoring state

This threshold-based control ensures that the composting environment remains within optimal conditions for microbial activity.

C. Actuation Mechanism

The actuation process is controlled through an L293D motor driver, which interfaces the controller with mechanical components.

- **DC Pump:** Activated to increase moisture level when required
- **DC Fan:** Activated to reduce excess temperature
- **DC Motor:** Performs mechanical operations such as waste movement
- **Servo Motor:** Controls the cutting or storage mechanism of the compost system

These actuators operate automatically based on control signals generated by the Arduino Uno.

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D. Cloud Communication and Remote Monitoring

The system incorporates an ESP32 for IoT-based communication. Sensor data is transmitted to the Adafruit IO cloud platform through wireless connectivity supported by available high-speed network infrastructure, including 5G-enabled networks.

Remote users can monitor:

- Moisture levels
- Temperature conditions
- System status

Through a web dashboard or mobile device.

E. Continuous Operation Cycle

The entire system operates in a continuous loop:

1. Sensor data acquisition
2. Data processing and threshold comparison
3. Actuator control
4. Data display on LCD
5. Data transmission to cloud
6. Repeat cycle

This cyclic process ensures real-time monitoring and automatic control of composting conditions.

V. IMPLEMENTATION

F. Hardware Implementation

The hardware setup is centered around the Arduino Uno, which acts as the main controller. A 12V power supply is used to provide energy to the entire system, including sensors, actuators, and communication modules.

The moisture sensor and temperature sensor are placed inside the compost chamber to measure real-time environmental conditions. These sensors are interfaced with the Arduino Uno through analog input pins. A 16×2 LCD display is connected to the controller to provide real-time visualization of sensor readings.

For actuation, an L293D motor driver is used to control the DC motor and DC pump. The DC motor is connected to the mechanical system responsible for waste movement, while the DC pump is used for water regulation. A DC fan is connected to control temperature when it exceeds the threshold.

A servo motor is interfaced with the Arduino Uno using PWM pins to control the cutting mechanism inside the compost chamber. Additionally, an ESP32 is connected via serial communication to enable IoT-based data transmission. An ESP32-CAM is mounted on the compost chamber for live monitoring.

G. Software Implementation

The system is programmed using the Arduino IDE. The embedded code is written in C/C++ and includes modules for:

- Sensor data acquisition
- Threshold comparison logic
- Actuator control
- LCD display handling
- Serial communication with ESP32.

H. Composting Mechanism Implementation

The composting mechanism is designed as a controlled environment where organic waste is processed efficiently. The system consists of a **storage tank integrated with a cutting chamber**.

- Organic waste is initially deposited into the storage tank.
- The servo motor controls the cutting mechanism, which helps in breaking down larger waste particles into smaller pieces, accelerating the decomposition process.
- The DC motor assists in internal movement or mixing of compost material, ensuring uniform decomposition.

Moisture and temperature sensors continuously monitor internal conditions:

- When moisture levels drop below the required value, the DC pump supplies water to maintain optimal moisture content.
- When temperature rises beyond the threshold, the DC fan is activated to regulate heat and improve aeration.

This controlled mechanism ensures efficient microbial activity and faster compost formation.

I. IoT and Cloud Integration

The ESP32 enables communication between the hardware system and the cloud platform. Sensor data such as moisture and temperature are transmitted to Adafruit IO using Wi-Fi connectivity supported by available high-speed network infrastructure, including 5G-enabled networks.

Users can monitor:

- Moisture levels
- Temperature conditions
- System status

Through a remote dashboard or mobile interface. The integration of cloud services enhances accessibility and allows real-time decision-making.

J. System Integration

All components are integrated into a single functional system. The Arduino Uno continuously reads sensor data, processes it, and generates control signals for actuators. The ESP32 ensures data transmission, while the ESP32-CAM provides live visual feedback.

The complete system operates synchronously to maintain optimal composting conditions with minimal human intervention.

VI. RESULTS & DISCUSSION

The proposed smart composting system was implemented and tested under controlled conditions to evaluate its performance in monitoring and regulating compost parameters such as moisture and temperature. The system demonstrated reliable operation with real-time sensing, automatic control, and cloud-based monitoring.

K. Experimental Setup

The prototype was tested using organic waste materials in a controlled compost chamber. The moisture sensor and temperature sensor were placed inside the compost to continuously measure environmental conditions. The system was powered using a 12V supply, and all components including the Arduino Uno, actuators, and ESP32 were integrated as per the proposed design.

L. Observed Results

The system successfully monitored and controlled compost conditions. The following observations were recorded:

- When moisture levels dropped below the threshold (≈40%), the DC pump was automatically activated.
- When temperature exceeded the threshold (≈38°C), the DC fan was turned ON to regulate the internal environment.
- The 16×2 LCD displayed real-time sensor values accurately.
- Cloud data transmission via ESP32 was stable and enabled remote monitoring.

M. Sample Experimental Data

TABLE I
SAMPLE EXPERIMENTAL DATA OF SMART COMPOSTING SYSTEM

Time	Moisture (%)	Temperature (°C)	Pump Status	Fan Status
10:00 AM	35	32	ON	OFF
11:00 AM	42	34	OFF	OFF
12:00 PM	45	39	OFF	ON
01:00 PM	48	36	OFF	OFF
02:00 PM	38	33	ON	OFF

The data shows that the system effectively maintained compost parameters within optimal ranges by automatically controlling actuators.

N. Performance Analysis

The proposed system improves composting efficiency by:

- Maintaining optimal moisture levels for microbial activity
- Preventing overheating through automatic ventilation
- Reducing manual intervention through automation
- Providing real-time monitoring through IoT integration

Compared to traditional composting methods, the system ensures better environmental control, leading to faster decomposition and improved compost quality.

O. Discussion

The integration of sensing, processing, and actuation components resulted in a stable and efficient composting system. The use of an ESP32 enabled seamless communication with the cloud platform, allowing remote monitoring through a 5G-enabled network infrastructure.

P. Project Implementation

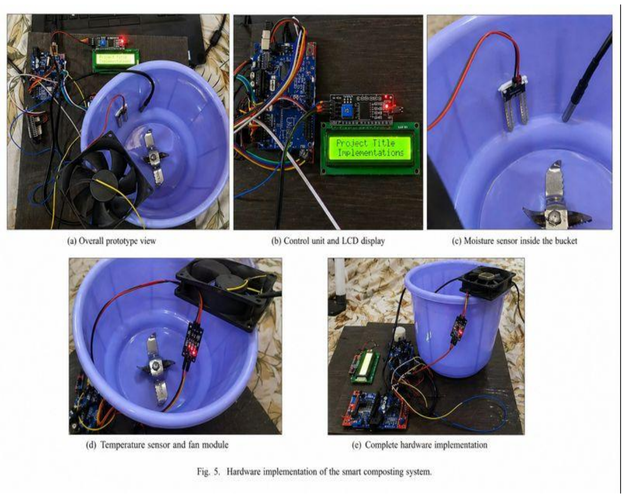

Fig. 3. Hardware Implementation of Smart Composting System

VII. CONCLUSION

This paper presented the design and implementation of a smart composting system using IoT over 5G-enabled network infrastructure for efficient organic waste management. The proposed system integrates sensing, processing, actuation, and cloud communication to automate the composting process and maintain optimal environmental conditions.

The system successfully monitors key parameters such as moisture and temperature using sensor-based inputs and performs automatic control actions through actuators including a DC pump, DC fan, servo motor, and DC motor. The use of an Arduino Uno as the central controller ensures reliable processing and control, while the ESP32 enables real-time data transmission to the Adafruit IO cloud platform. The integration of the ESP32-CAM further enhances the system by providing live visual monitoring of the composting chamber.

Experimental results demonstrate that the system effectively maintains composting conditions within optimal limits, reduces manual intervention, and improves overall process efficiency. The automated control of moisture and temperature contributes to faster decomposition and better compost quality compared to conventional methods.

REFERENCES

[1] M. Folianto, Y. S. Low, and W. L. Yeow, “Smartbin: Smart waste management system,” in *Proc. IEEE TENSYMP*, Kuala Lumpur, Malaysia, 2015, pp. 1–5.

[2] S. A. Abdulrahman, M. H. Isa, and N. A. Rahman, “Monitoring of composting process parameters using sensor technologies,” *International Journal of Environmental Science and Technology*, vol. 15, no. 3, pp. 589–598, 2018.

[3] A. Singh, S. Kumari, and R. Kumar, “A review on traditional composting and its limitations in organic waste management,” *Journal of Environmental Management*, vol. 240, pp. 1–10, 2019.

[4] N. Kumar, V. Kumar, and S. Kumar, “IoT-based smart agriculture monitoring system using wireless sensor networks,” *IEEE Internet of Things Journal*, vol. 6, no. 3, pp. 1–8, 2019.

[5] R. K. Kodali and S. Mandal, “IoT-based smart composting system,” in *Proc. IEEE Region 10 Conference (TENCON)*, Singapore, 2016, pp. 1–5.

[6] L. Da Xu, W. He, and S. Li, “Internet of Things in industries: A survey,” *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, pp. 2233–2243, Nov. 2014.

[7] A. Sharma, P. Gupta, and R. Mishra, “IoT-based waste management system using cloud platform,” *Procedia Computer Science*, vol. 167, pp. 214–223, 2020.

[8] J. A. Alsayaydeh et al., “IoT-Based Smart Waste Management System: A Solution for Urban Sustainability,” Int. J. Safety and Security Eng., 2025.

[9] A. A. Mohamed et al., “Smart Composting Solutions for Organic Waste Management using IoT and Machine Learning,” Proc. ICSES, 2024.

[10] Y. F. S. Mior et al., “Energy-Efficient Smart Composting IoT System for Sustainable Food Waste Management,” Proc. MECON, 2025.

[11] S. Compost Guardian System, “IoT-Based Real-Time Compost Monitoring and Alert System,” IJERT, 2025.