Automated compost monitoring with low-cost RFID, drones, and machine learning for improved control and pathogen safety

Summary

Composting converts organic waste into nutrient-rich material, but maintaining the proper temperature and moisture is critical for eliminating pathogens and ensuring regulatory compliance. Traditional monitoring methods are labor-intensive, costly, and fail to capture temperature and moisture variations across large compost piles. These variations can lead to cold spots, where pathogens survive. Therefore, we proposed to develop an intelligent compost monitoring system using low-cost, battery-free RFID sensors ($3–4 per unit). These sensors will be placed throughout compost piles to measure temperature and moisture. Drones equipped with RFID readers will collect data and record precise locations. Machine learning algorithms will analyze the data, identifying cold spots. Data displayed on a digital dashboard will help operators adjust turning schedules, ensure uniform heating, and automate compliance reporting.
It will improve monitoring accuracy, reduce operational costs, and support data-driven decision-making toward a more sustainable composting process.

Objectives

1. Deploy and refine an adaptable RFID-based sensor network for reliable data recording of key metrics (temperature and moisture) across compost piles.
2. Develop a digital toolbox for data visualization, process classification, and risk hotspot mapping.
3. Conduct experimental validation of the sensor network and digital toolbox in commercial composting facilities to assess accuracy, efficiency, and feasibility in real-world conditions.

Methods

The proposed system comprises two components: modular sensor sticks distributed throughout the compost piles and a robotic platform for automated data collection (**Fig. 1**). The robot operates in a repeating four-step cycle — navigating between windrows, approaching each sensor node, activating it via RFID, and collecting localized temperature and humidity data. Solar energy harvesting and RFID-triggered communication eliminate the need for battery replacement or manual data retrieval.

The sensor stick (5 ft) incorporates distributed sensor nodes at 1.5 ft intervals to capture conditions at multiple depths (**Fig. 2**). The electronics include a solar energy-harvesting subsystem pairing a 5 V, 200 mA solar panel with a 6 V, 5 F supercapacitor stack for energy storage. Characterization tests were conducted using a microcontroller and LED load, recording supercapacitor and solar panel voltage during charging under 80 kLux illuminance — comparable to direct midday sunlight. Post-startup current draw was monitored over one hour to capture both active and sleep-state energy consumption.

Results to Date

Initial testing under simulated conditions characterized the charging performance of energy storage system and the operating power demands of the candidate microcontroller, establishing a baseline for low-power optimization and platform comparison.

- Supercapacitor stack reached the 4.2 V startup threshold in 2.12 min, enabling rapid cold-start of the sensor stick.

Results to Date *(continued)*

- Charging continued to 5.38 V over 6.34 min, storing 72.3 J — approximately 80% of rated energy capacity for a sufficient reserve to operate through periods of low light.
- Duty-cycle testing revealed a deep-sleep current of 1.179 mA and wake-state current spikes up to 38.40 mA, using a flash–sleep–long-flash cycle representative of intermittent sensing operation.
- Ongoing work focuses on evaluating low-power microcontrollers, transitioning to a custom PCB, and integrating temperature, moisture, RFID, and antenna hardware.

Benefits to the Industry

The potential impact of this intelligent compost monitoring system on the produce industry includes improved compost management through automated, remote monitoring enabled by low-cost sensor networks. This project will benefit compost producers, waste management agencies, and produce growers by increasing operational efficiency, reducing labor requirements, minimizing cross-contamination risk, improving compliance with regulatory standards, and enabling automated data collection, storage, and reporting. In the short term, the project will provide a reliable, data-driven compost monitoring system. In the long term, it will enhance the sustainability of waste management operations and reduce contamination risks at the source.

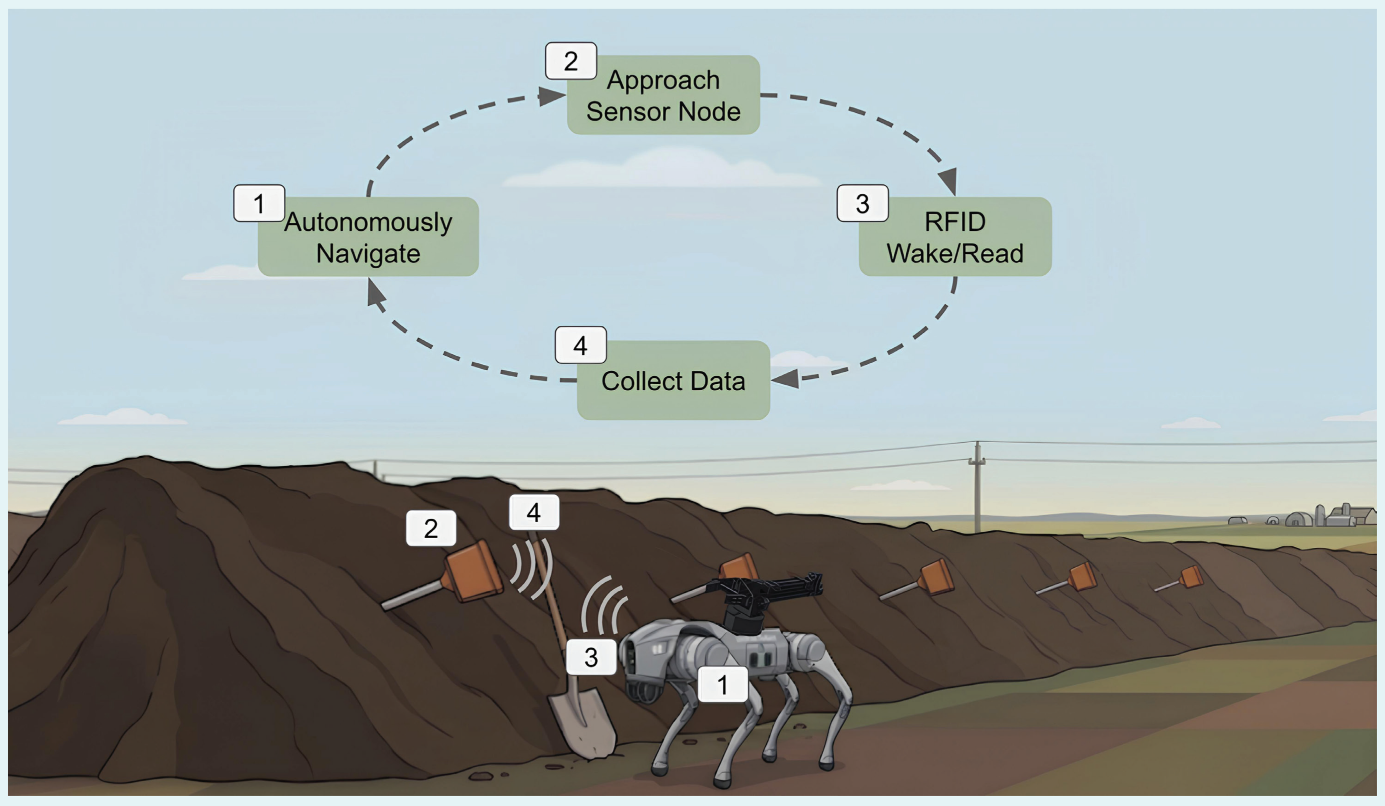

Figure 1: Overview of the intelligent compost process monitoring system.

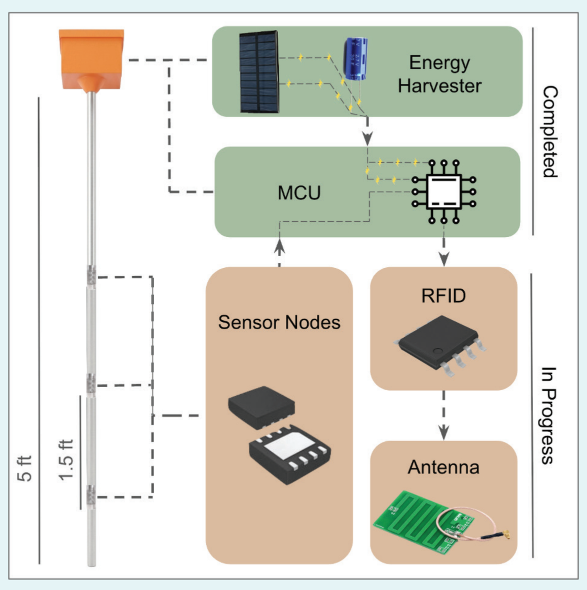

Figure 2: Proposed prototype sensor sticks with working components.

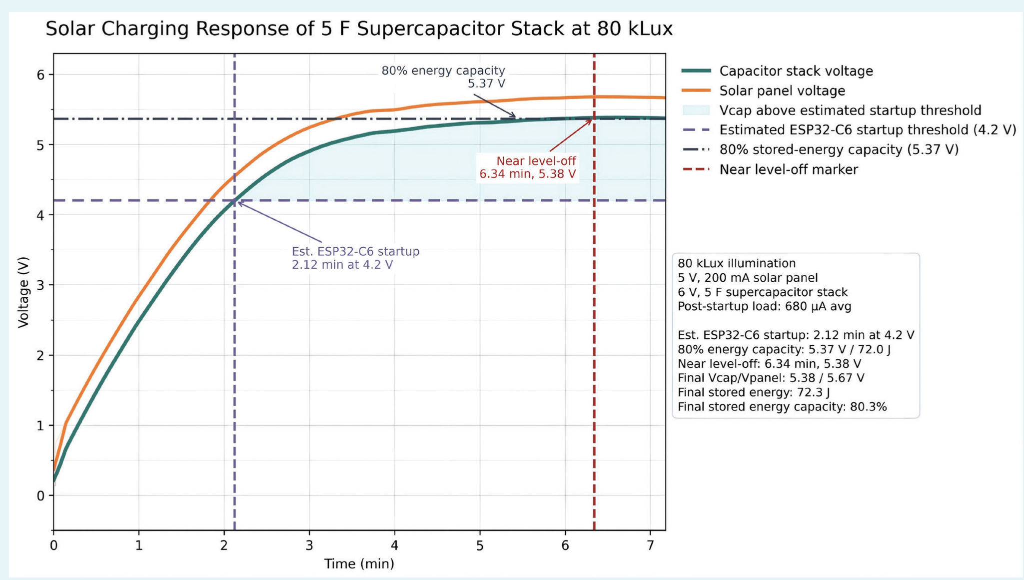

Figure 3: Preliminary results of solar charging response using a supercapacitor system.

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