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SIGNAL CHARACTERIZATION OF SENSORS FOR OPERATIONAL STATUS MONITORING IN SMART VERTICAL FARMS

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ABSTRACT

Vertical farming represents an advanced agricultural practice capable of efficiently producing high-quality crops through precise environmental management, optimal spatial utilization, and consistent production outcomes. Ensuring reliable and accurate performance of environmental sensors is essential for sustaining ideal growth conditions within these advanced agricultural systems. This study aimed to characterize signals from environmental sensors to enhance real-time operational status monitoring and facilitate effective abnormal detection in smart vertical farms. The data collection setup comprised an enclosed, multi-layered vertical farm equipped with integrated sensors measuring temperature, humidity, potential of hydrogen (pH), carbon dioxide (CO_2), electrical conductivity (EC), and light intensity. These sensors were interfaced through a microcontroller-based network employing long-range wide area network (LoRaWAN) technology for continuous and real-time data transmission. Data acquisition and visualization framework systematically processed sensor signals, enabling detailed analysis of sensor stability, sensitivity, drift, and responsiveness under various controlled environmental conditions. The analysis confirmed that sensor signals exhibited consistently high accuracy, minimal noise interference, and negligible signal drift, demonstrating reliable and stable performance under typical vertical farming conditions. Detailed signal examination enabled precise differentiation of operational states and facilitated rapid detection of environmental changes. The system effectively identified and characterized sensor anomalies such as sensor saturation, response delays, and communication failures, allowing for immediate anomaly detection and prompt corrective actions. This research highlights the substantial advantages of comprehensive signal characterization for improving the operational reliability, responsiveness, and automation potential of smart vertical farming systems. By integrating detailed diagnostic features, the system enhances preventive maintenance and accelerates informed decision-making processes, crucial for sensitive and high-value crop production.

Keywords: Smart agriculture, sensor status characterization, LoRa-WAN, fault detection.

INTRODUCTION

Vertical farming is emerged as a sustainable and efficient method for crop cultivation, enabling year-round production, optimized resource utilization, and the growing of high-value foods. The success of such farming depends heavily on the continuous monitoring of key environmental parameters, including temperature, relative humidity, light intensity, pH, electrical conductivity (EC), and carbon dioxide (CO_2) concentration (Tripathy et al., 2021). Accurate sensor data are essential for sustaining optimal growth conditions in vertical farming. However, signals are often compromised by calibration drift, environmental interference, or communication errors. Signal characterization provides a workflow of evaluating data stability, sensitivity, and susceptibility to error. This study aimed to characterize sensor signals within a smart vertical farming system to enhance data reliability and optimize overall operational performance.

MATERIALS AND METHODS

The experimental setup was implemented in an enclosed, multi-layered vertical farming system equipped with temperature and humidity sensors, CO_2 sensors, light intensity sensors, and pH and electrical conductivity (EC) sensors. The environmental sensors were integrated into a microcontroller-based platform. Sensor signals were acquired at 2 s intervals and transmitted to a central server via a LoRaWAN gateway for a period of one week. The raw sensor outputs were processed using a moving average and low-pass filter with a cutoff frequency of 0.5 Hz to remove high-frequency noise. Furthermore, statistical analyses were performed to characterize the signal quality, detect anomalies, and compare performance across sensor types and farm layers.

RESULTS & DISCUSSION

The environmental sensors demonstrated accurate and stable measurements across temperature, humidity, pH, CO_2, EC, and light intensity. Measurements outputs showed minimal noise (<2%) and negligible drift over one week, with response times to environmental changes of less than 3 s. This performance enhances reliability and efficiency of environmental control and monitoring for smart vertical farming systems by enabling timely anomaly detection.

CONCLUSIONS

Sensor signal characterization is essential for maintaining optimal conditions, enabling rapid response to abnormalities, and supporting consistent, sustainable vertical farming practices.

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