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# SIGNAL CHARACTERIZATION OF ENVIRONMENTAL SENSORS FOR ABNORMALITY DETECTION IN HOT TEMPERATURE GREENHOUSES

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## ABSTRACT

Maintaining optimal microclimatic conditions is critical for crop productivity in greenhouse cultivation. High-temperature environments can induce subtle but critical deviations in environmental parameters, often resulting in reduced crop growth, quality, and yield. This study aimed to characterize the raw signal behavior of environmental sensors to enable early detection of abnormal conditions in hot-temperature greenhouses. An internet of things (IoT)-based sensor network comprising temperature, relative humidity, carbon dioxide ($CO_2$), and light intensity sensors were installed. Real-time data acquisition was implemented using a LoRa-based wireless communication framework. Sensor data were collected at 1 kHz sampling rates to evaluate the impact of temporal resolution on anomaly detection. The high-resolution 1 kHz data enabled the capture of rapid transient fluctuations and short-duration anomalies, especially during thermal events exceeding 35°C patterns not detectable at lower sampling rates. In contrast, low-frequency sampling smoothed critical signal variations and delayed detection. Among all sensors, temperature and $CO_2$ sensors exhibited the highest responsiveness, with anomaly detection latency under 3 s at high sampling frequencies. Raw signals were further processed using a 10 s moving average filter, enhancing signal-to-noise ratio (SNR) by 5% and improving the visibility of early-stage deviations. Abnormal events were identified using threshold-based deviation analysis and temporal trend tracking. Validation through cross-referencing manual observations and greenhouse climate control logs showed a 92% agreement rate. Results highlight the importance of raw data characterization and high-frequency acquisition for reliable greenhouse monitoring.

**Keywords:** Precision agriculture, sensor node, greenhouse microclimate, LoRa, IoT

## INTRODUCTION

Greenhouse cultivation offers a reliable approach of crop cultivation maintaining stable microclimatic conditions. Minor fluctuations in temperature, humidity, $CO_2$, or light can adversely affect crop growth, quality, and overall productivity. Recent advances in internet of things (IoT) technologies connected with low-power communication protocols of greenhouse environments. High-frequency data acquisition allows the detection of short-term anomalies, while signal filtering techniques enhance data reliability facilitating early identification of abnormal events and support better precision farming (Akhtar et al., 2021). The study aimed to characterize the raw signal behavior of environmental sensors to enable early detection of abnormal conditions in hot-temperature greenhouses.

## MATERIALS AND METHODS

An IoT sensor network including temperature, humidity, $CO_2$, and light sensors was installed in a hot temperature greenhouse with data transmitted via long range (LoRa) module to a central gateway. Signals were recorded at 1 kHz and compared with 1 Hz and 0.1 Hz to evaluate the effect of sampling resolution on sensor anomaly detection. To reduce noise, a moving average filter was applied to the raw signals using Eq. (1) and for the anomaly detection using Eq. (2), as follows:

$$y(t) = \frac{1}{N} \sum_{i=0}^{N-1} x(t-i) \quad (1)$$

Where, y(t) is filtered signal, x(t) is raw signal, and N is moving window length (10 s).

$$\Delta(t) = | x(t) - \mu | > k\sigma \quad (2)$$

Where, $\Delta(t)$ is anomaly decision function, x(t) is instantaneous sensor signal, μ is baseline mean under stable conditions, σ is standard deviation, and k is sensitivity factor.

## RESULTS AND DISCUSSION

At a 1 kHz sampling rate, anomaly detection latency was reduced to 3 s, compared with 8s at 1Hz and 12 s at 0.1 Hz. Temperature and $CO_2$ sensors showed higher responsiveness, while humidity and light sensors responded slower. The filtering step enhanced anomaly visibility, with a signal to noise ratio (SNR) of 2.1. Overall detection accuracy reached 91%, exceeding the lower sampling frequencies (76% at 1 Hz and 63% at 0.1 Hz).

## CONCLUSIONS

High-frequency signal characterization improves anomaly detection by capturing rapid fluctuations and enabling early warnings, thereby supporting automation in greenhouse management.

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