Development of Temperature and Humidity Sensor Calibration Procedure for Multifunctional Orchid Greenhouse Monitoring System

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Abstract

Bacterial soft rot and bacterial brown spot are primary diseases that threaten orchid cultivation, often resulting in substantial economic losses. To address labor shortages and environmental challenges in recent years, the orchid industry is increasingly adopting intelligent disease management systems that combine sensing technologies and data analytics as part of its transformation strategy. The multifunctional monitoring system was developed as an economical, integrating sensors for temperature, humidity, carbon dioxide concentration, oxygen concentration, wind speed, and light intensity to enable long-term monitoring of various environmental parameters in orchid greenhouses. Due to hardware limitations, focusing on the system's performance of temperature and humidity sensors, this study proposed a calibration procedure in which environmental temperature and humidity conditions were controlled to evaluate the accuracy of four different types of temperature and humidity sensors. Regression analysis and linear fitting techniques were employed to establish sensor calibration models. Experimental results revealed that the temperature and humidity sensors in the system achieved R^2 values of up to 0.99. The calibration procedure developed in this study could be a reference for quality screening and anomaly detection of temperature and humidity sensors in future applications.

Keywords: Orchid diseases, environmental monitoring, temperature and humidity calibration.

INTRODUCTION

Taiwan, renowned as the Orchid Kingdom, sustained a thriving orchid industry characterized by intensive commercial activity and substantial export volumes. However, the sector faced critical production challenges, particularly among younger growers, for whom disease incidence remained the predominant risk factor. Bacterial soft rot and bacterial brown spot were especially concerning due to their rapid propagation in warm and humid greenhouse environments, presenting considerable threats to crop health and economic viability. Diagnostic protocols for these pathogens traditionally relied on the experiential judgment of seasoned cultivators—a process that was labor-intensive and increasingly impractical given persistent labor shortages and the imperative for standardized, proactive disease management

practices.

To address these limitations and mitigate the associated economic losses, this research introduced a localized microclimate monitoring system tailored to orchid cultivation settings. Leveraging real-time environmental sensing at fine spatial resolutions, the proposed solution enabled growers to implement timely adjustments to greenhouse climate-control regimes, thereby optimizing conditions unfavorable to pathogen proliferation (Liao et al., 2017). Since temperature and relative humidity constituted primary determinants of bacterial and fungal activity, the system integrated a rigorous calibration protocol for sensing hardware to maximize consistency and measurement accuracy. Utilizing high-fidelity microclimatic data, the study further sought to develop a predictive early-warning model for heightened disease risk periods. Such a framework was anticipated to facilitate preemptive interventions, reduce labor demands, and minimize sector-wide economic impact.

MATERIALS AND METHODS

Development of an Orchid Greenhouse Environmental Monitoring System

Environmental Monitoring System

This study sampled an orchid greenhouse and focused on six environmental variables critical to orchid cultivation: air temperature, relative humidity, carbon dioxide (CO_2), oxygen (O_2), illuminance, and wind speed. The system was constructed using a NodeMCU controller and integrated sensors corresponding to these six indicators, paired with an LED display panel for real-time readout. Data were transmitted via Wi-Fi and simultaneously written to an SD card as a backup, ensuring uninterrupted data logging even during network outages.

For power management, the system adopted a duty-cycled mode: the sensor module awakened every 5 minutes to measure and log, while the LED display was button-activated; at all other times, the sensors, LED panel, and fan remained off to minimize energy consumption and thermal disturbance, thereby extending device lifetime. To enhance maintainability and measurement stability, a dedicated printed circuit board (PCB) with a modular layout was designed, shortening wiring runs, reducing connector loosening and electrical noise, facilitating rapid sensor replacement, and improving long-term reliability.

For gas measurements, flow stabilization was implemented. Before each reading, a fan flushed the sensing chamber, and sampling was performed after a steady state was reached. Flow-straightening perforations were positioned opposite the fan to promote a uniform flow field within the chamber, thereby reducing stagnant zones and vortices and yielding more representative and reproducible concentrations (Wang et al., 2017).

Taken together, the system balanced low power consumption, data reliability, and field maintainability, providing a foundational platform for long-term small-area monitoring and real-time greenhouse climate-control decisions in orchid production.

Temperature and Humidity Sensor Calibration Procedure

To ensure consistent and accurate temperature and humidity measurements, this study established a standardized calibration procedure. utilizing both the monitoring system under

investigation and commercial reference sensors. All calibrations were performed in a programmable temperature–humidity chamber, taking the chamber setpoints as reference values to conduct variable-specific calibration and derive linear calibration models (González et al., 2017).

For temperature calibration, the monitoring system and three additional temperature sensors (IDs S01–S03) were placed in the chamber. Initial conditions set at 20 °C and 60% RH, with a calibration range of 20–40 °C. After readings stabilized, the setpoint temperature was raised by 2 °C every 30 minutes. At each increment, outputs from all sensors and the chamber setpoint were logged to provide multi-point coverage over the target operating range.

For humidity calibration, the monitoring system and two additional humidity sensors were placed in the chamber. Initially at 25 °C and 50% RH, with a calibration range of 50–90% RH. Under isothermal 25 °C conditions, relative humidity was increased by 2% RH every 30 minutes, and at each step, sensor outputs and the chamber setpoint were recorded to form a multi-point humidity reference dataset.

Measurement datasets were organized in Excel and imported into MATLAB for analysis. Least-squares linear regression was used separately to estimate temperature and humidity calibration models, with calibration lines plotted accordingly. Model performance was evaluated using the coefficient of determination (R^2) and related metrics. The resulting calibration coefficients for each sensor are intended for direct use in subsequent data processing and analysis, ensuring cross-device and cross-period comparability and consistency.

RESULTS & DISCUSSION

As shown in Fig.1, the system employs a NodeMCU-based controller to coordinate a sensor suite that monitors six environmental variables. Using a duty-cycling power-management strategy, it reduced energy demand by approximately 75%. Telemetry was transmitted over Wi-Fi with no observed data loss, and an on-board SD-card logger provided redundant storage. Collectively, the platform enables long-term, small-area monitoring and supports real-time climate-control decision-making in orchid greenhouses.
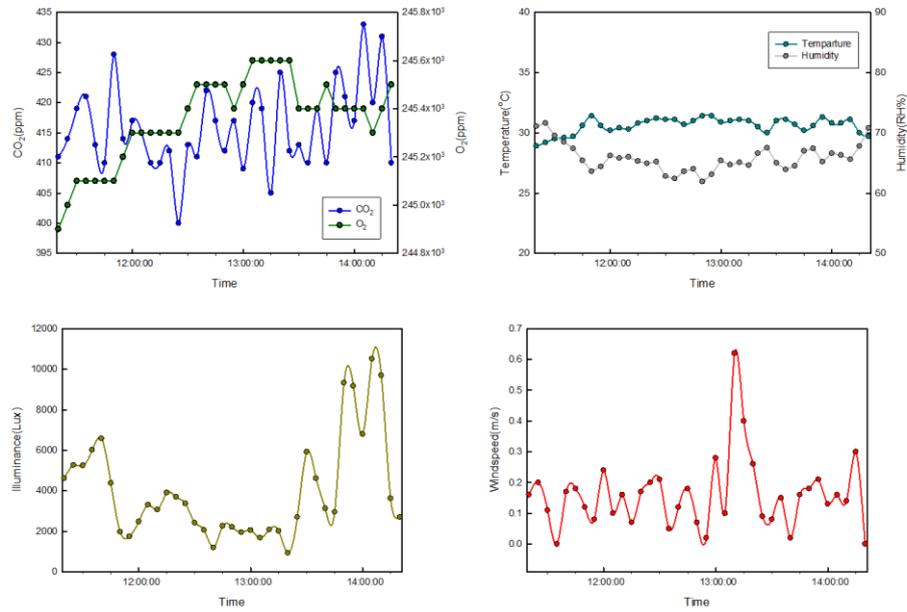
Fig1. Monitoring data from Multifunctional Orchid Greenhouse Monitoring System

For temperature, calibration results for the monitoring system and three additional sensors were shown in Fig. 2; for humidity, results for the monitoring system and two additional sensors were shown in Fig. 3. In these plots, y denotes the raw sensor reading and x the corrected value. Pre-calibration errors were primarily attributable to minor drift and were removable via the fitted calibration lines. Across all calibration lines, the coefficients of determination reached $R^2 \geq 0.99$, indicating that the models effectively correct measured values back to true values, reduce measurement error at medium-to-high relative humidity, and improve the accuracy of climate-control data in orchid greenhouses.
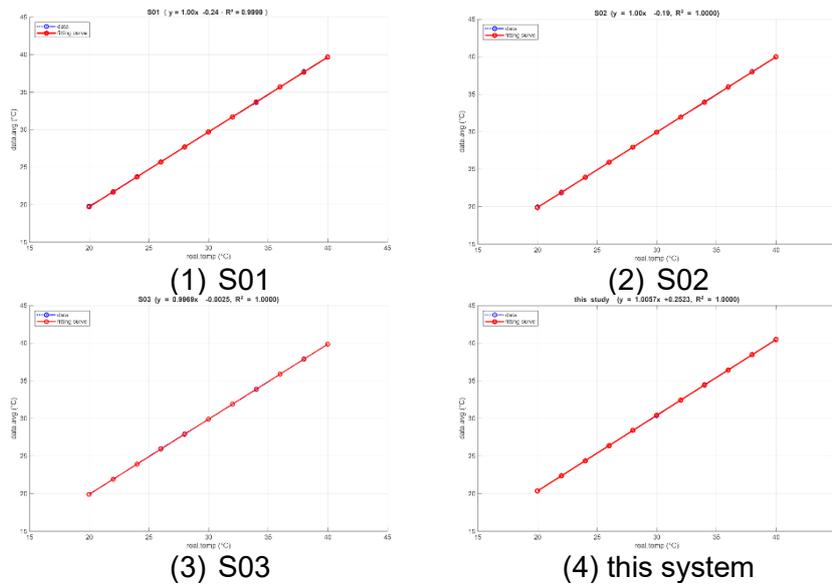

(1) S01

(2) S02

(3) S03

(4) this system

Fig2. Temperature calibration model

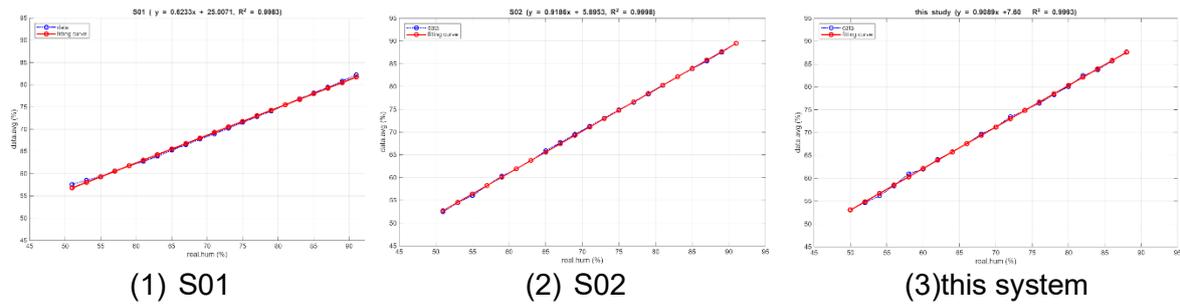|		
(1) S01	(2) S02	(3)this system

Fig.3 Humidity calibration model

CONCLUSIONS

This study successfully developed a NodeMCU-centered, multifunctional monitoring system for orchid greenhouses and proposed a reproducible calibration procedure for temperature and humidity sensors. Experimental results demonstrated that intermittent, duty-cycled sampling reduces energy use by approximately 75%. Data were transmitted wirelessly over Wi-Fi with redundant SD-card logging to meet the requirements for long-term remote monitoring at small spatial scales. Paired with the calibration procedure, the system reduced measurement error, improving the accuracy of orchid-greenhouse environmental monitoring and enhancing inter-sensor consistency and reproducibility. Future work will develop a predictive early-warning model for periods of elevated disease risk in orchids to mitigate economic losses from bacterial diseases and will adapt the platform to other greenhouse crops.

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