



Real-Time Environmental Monitoring and Data Logging System for Smart Polyhouses

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Article Info

Article History:

Published: 05 Oct 2026

Publication Issue:

Volume 03, Issue 10
October 2026

Page Number:

68-71

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Abstract:

Commercial yields in enclosed agrarian infrastructures depend heavily on sustaining microclimatic equilibrium. Left unmonitored, sharp fluctuations in thermal energy and airborne water vapor degrade plant stamina, hamper transpiration mechanisms, and promote destructive spore proliferation. In numerous localized farming facilities, ambient tracking still relies on sporadic site visits and non-recording dial devices, which prevents immediate countermeasures during sudden atmospheric spikes. To resolve this operational constraint, this work designs, constructs, and examines an economical embedded telemetry station customized for sheltered horticultural structures. The sensory hardware incorporates an ESP8266-driven NodeMCU development board fixed to a terminal break-out expansion shield and interfaced with a DHT22 thermohydrometric module. Acquired microclimatic metrics are transferred via local 2.4 GHz wireless pathways to a Google Firebase Realtime Database. A self-contained, browser-based management portal consumes these records through uninterrupted bi-directional WebSocket, driving dynamic analog-style dials and running trend graphs without requiring page refreshes. Empirical benchmarking over a continuous 48-hour testing phase confirmed consistent sub-second communication delays, resilient sensor fidelity, and complete packet retention during prolonged field exposure.

Keywords: smart polyhouse, NodeMCU ESP8266, DHT22 sensor, Firebase Realtime Database, telemetry dashboard, data logging, environmental monitoring

1. Introduction

Protected agricultural enclosures create specialized microenvironments that shield sensitive produce from unseasonal downpours, wind erosion, and predatory biological pests. Nevertheless, trapping thermal radiation within closed polymer structures produces rapid shifts in vapor density and canopy warmth. When moisture levels saturate the enclosed volume, crops quickly fall prey to foliar fungal blights; conversely, acute temperature escalation triggers excessive plant water loss and shuts down carbon fixation pathways.

In typical regional polyhouse installations, environmental observation continues to depend on periodic inspections using uncoupled thermometers or mechanical wall hydrometers. This reliance introduces severe latency into agricultural management, prevents growers from reviewing historical diurnal profiles, and leaves facilities unmonitored during sudden nighttime drops or midday heat surges.

Modern Internet of Things (IoT) technologies provide practical options to automate localized agrarian intelligence. Integrated microcontrollers with onboard radio transceivers enable autonomous data capture straight from crop foliage zones. Deploying a dedicated terminal expansion baseboard isolates the processing platform from physical stress, prevents contact oxidation, and guarantees clean voltage rails within humid polyhouse environments.

This study implements a cohesive telemetry and recordkeeping solution for covered cultivation sites. An ESP8266 processor retrieves thermal and hygrometric measurements from a digital DHT22 transducer, pushes structured

records directly to Google Firebase, and renders the data on an independent client-side dashboard equipped with real-time radial indicators and continuous historical telemetry logs.

2. System Architecture and Methodology

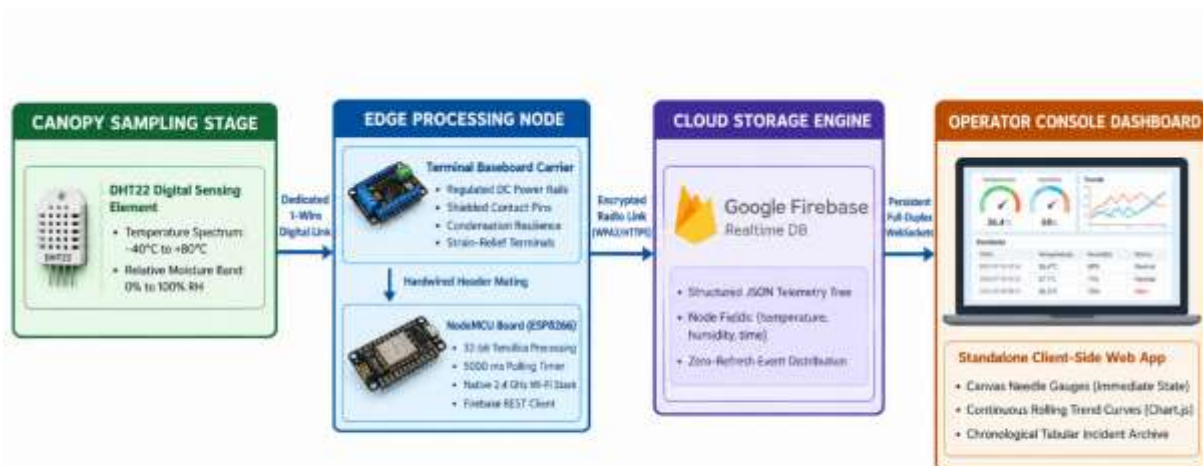
Hardware Integration and Signal Conditioning

The edge-sensing station is built using an integrated microcontroller core combined with specialized field support hardware:

- **Edge Processing Platform (NodeMCU ESP8266):** Powered by an integrated 32-bit Tensilica L106 processing engine operating at 80 MHz with an onboard 802.11 b/g/n wireless transceiver. The chip orchestrates polling intervals, handles temporary buffer arrays, and manages encrypted TCP/IP sessions.
- **Terminal Interface Baseboard:** Equips the core processing unit with industrial screw terminals, ground plane isolation, and dedicated 5V/3.3V power rails, eliminating wiring faults caused by structural vibration and air saturation.
- **DHT22 (AM2302) Transducer:** Captures dry-bulb air temperature across an operational boundary of -40°C to $+80^{\circ}\text{C}$ ($\pm 0.5^{\circ}$ resolution) and relative air humidity from 0% to 100% RH ($\pm 2\%$ error margin) over a single-wire digital interface.

System Architecture Layout

Figure 1



Execution Logic and Cloud Dispatch

The operational firmware was implemented in an embedded C++ framework :

1. **Network Association:** Upon boot sequence completion, the processing node joins the designated wireless local area network using WPA2 protocols.
2. **Transducer Interrogation:** A non-blocking internal timer interrupt triggers the DHT22 sampling sequence every 5,000 milliseconds, validating bit integrity and dropping corrupted frames.
3. **Cloud Transmission:** Clean numeric entries are serialized into lightweight JSON records and committed over TLS-secured connections to designated paths in the cloud database.

Standalone Visualization Portal

The user application operates as an independent web client developed with HTML5, CSS3, and standard JavaScript :

- **Uninterrupted Cloud Connection:** The interface maintains an open WebSocket channel directly to the cloud database path via client libraries.

- **Dynamic Gauge Deflection:** When incoming parameter updates reach the client, custom scripts immediately recalculate needle coordinates on HTML5 canvas gauges, bypassing browser page reloads.
- **Chronological Record Indexing:** Ingested parameter strings are simultaneously mapped onto dynamic multi-axis charts, allowing growers to inspect thermal trends and moisture variations over extended periods.

3. Results & Analysis

The operational reliability, transmission fidelity, and sensor response of the complete monitoring prototype were evaluated across an unbroken 48-hour observation window inside an active polyhouse cultivation sector. Throughout this trial, the sensing assembly captured continuous diurnal microclimate cycles across varying ambient conditions.

Thermal measurements observed at the canopy layer spanned between 21.4°C during early dawn periods and peaked at 38.2°C during high afternoon solar exposure. The acquired thermal readings matched reference benchmarks with a deviation restricted within $\pm 0.4^\circ\text{C}$, confirming high measurement stability. Concurrently, relative moisture levels ranged from 43.1% RH during peak daylight warmth up to 87.8% RH during nighttime condensation cycles, remaining well within the sensor's $\pm 2.0\%$ accuracy margin.

Network throughput and cloud communication delay remained consistent throughout the operational run. The hardware-to-cloud dispatch cycle from the NodeMCU to Google Firebase averaged between 410 ms and 940 ms, sustaining a successful packet reception rate of 99.7% without memory leakages. On the client interface, incoming updates prompted DOM canvas needle deflections within 180 ms via the continuous WebSocket listener, delivering seamless zero-refresh monitoring.

Deploying the terminal expansion baseboard shield prevented unintended electrical interruptions, ground bounces, and contact oxidization that routinely cause system failures in high-humidity cultivation tunnels. Throughout deliberate test disconnections, the firmware automatically restored communication upon Wi-Fi recovery without manual intervention.

4. Conclusion

This work demonstrated a cost-effective, dependable environmental monitoring and data logging system built specifically for protected horticultural polyhouses. Coupling a DHT22 transducer to a NodeMCU ESP8266 controller on an industrial terminal shield ensures stable canopy surveillance. Storing observations in Google Firebase Realtime Database and streaming them to a responsive web dashboard gives growers instant visibility into microclimate fluctuations without relying on expensive proprietary control gear. Subsequent upgrades will evaluate integrating solid-state relay modules to control misting lines and motorized roof vents, alongside dedicated solar charging boards for remote sites.

Funding Details

This project was carried out autonomously by the author team with support from laboratory facilities provided by the Department of Electronics & Telecommunication Engineering, Samarth Polytechnic, Belhe, Pune, Maharashtra, India.

Disclosure Statement

The contributing authors confirm that no financial entanglements, commercial interests, or professional conflicts exist that could have influenced the outcomes reported in this study.

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