FiltSure HVAC Monitor

IoT Mesh-Based HVAC Filtration Health Monitor  
  
Industrial and DIY Installation & Operation Guide  
  
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Prepared for:  
Industrial HVAC Technicians & DIY Installers  
  
Prepared by:  
[Your Name / Your Company Name / Placeholder]

# Table of Contents

1. Project Overview  
2. System Architecture  
3. Hardware Bill of Materials (BOM)  
4. Software & Firmware Structure  
5. Communication Protocol  
6. Installation & Configuration Instructions  
6.3 Safety Notes  
7. Operating Instructions  
8. Troubleshooting Guide  
9. Development Log / Timeline  
10. Full Source Code Appendix / Links  
11. References / Related Documents

# 1. Project Overview

The FiltSure HVAC Monitor is a wireless IoT system designed to monitor HVAC air filtration systems and airflow performance in real time. It provides both industrial service technicians and DIY users with actionable insights into filter condition, airflow efficiency, and overall system health.  
  
FiltSure combines a distributed network of sensor nodes and a central gateway to create an intelligent, mesh-capable HVAC monitoring solution. Data is wirelessly transmitted to the cloud for logging, diagnostics, and long-term performance tracking.

## 1.1 Key Features

- Wireless mesh network using LoRa for long-range, resilient communication  
- ESP32-based Sensor Nodes with multi-sensor data collection  
- Cloud logging to Google Sheets via WiFi-connected Gateway Node  
- OTA (Over-The-Air) firmware updates for easy device maintenance  
- Visual diagnostic LED feedback on each Sensor Node  
- Compatible with both commercial HVAC units and home systems  
- Simple installation for both professionals and DIY users

# 2. System Architecture

Typical System Layout  
  
The FiltSure HVAC Monitor system typically consists of one or more Sensor Nodes installed inside HVAC units, communicating wirelessly with a centrally located Gateway Node. The Gateway connects to the building's WiFi and forwards data to a Google Sheets-based cloud log.  
  
LoRa Range Expectations  
  
- Indoors: typical LoRa range is 50–100 feet indoors, depending on HVAC cabinet construction and building materials.  
- HVAC cabinets may attenuate signal; Gateway should be located within one floor level and with partial line-of-sight to the Sensor Node when possible.  
- Sensor placement tip: avoid mounting Sensor Node inside fully sealed metal compartments unless external antenna used.  
  
Component Roles  
  
Sensor Node: Collects sensor data, transmits via LoRa, responds to diagnostic PINGs, supports OTA.  
Gateway Node: Receives LoRa packets, forwards to Google Sheets, handles OTA distribution, issues PINGs.  
Google Sheets Cloud Log: Stores time-stamped data records from each Sensor Node.  
  
Multi-Node Support  
  
The system supports multiple Sensor Nodes communicating with a single Gateway Node.  
Each Sensor Node must be assigned a unique Device ID (currently manually assigned in firmware).  
Google Sheets will automatically create a separate tab for each node (UNIT\_<DeviceID>).

# 3. Hardware Bill of Materials (BOM)

3.1 Sensor Node (per unit)  
- ESP32-C6 or ESP32-C3 Dev Board  
- BME280 Environmental Sensor  
- MFRC522 RFID Module  
- Brushless Fan Wind Sensor  
- 2x D Cell Batteries  
- Voltage Divider (for Battery ADC)  
- RGB LED  
- Misc passive components  
- Mounting hardware

3.2 Gateway Node  
- ESP32-C3 or ESP32-S3 Dev Board  
- LoRa Module (RFM95 / SX127x)  
- WiFi Antenna (optional)  
- Power Supply

3.3 Optional / Tools  
- USB-Serial Adapter  
- JTAG/SWD Debug Adapter

# 4. Software & Firmware Structure

Startup Sequence Overview  
  
When a Sensor Node is powered on:  
1. Self-test sequence runs.  
2. LED Diagnostic Pulse runs (3-stage).  
3. LoRa link check performed.  
4. OTA PING handled if received.  
5. Enters deep sleep between read cycles.  
  
Deep Sleep vs Active Mode  
  
Deep sleep mode: minimal current draw.  
Active mode: approx. 5–15 sec per cycle.  
Default cycle: every 5 min, configurable.  
  
OTA Process Expectations  
  
When OTA is triggered:  
- LED flashes in OTA sequence.  
- OTA chunks received via LoRa (~32 KB max).  
- Typical OTA takes 1–2 minutes.  
- Sensor Node reboots after successful update.  
- Failure causes fallback to existing firmware.

# 5. Communication Protocol

PING / PONG Practical Use  
  
- Installers should issue PING after installation.  
- Gateway sends PING → Sensor Node replies with PONG.  
- Expect PONG within ~1–2 seconds.  
- No PONG: check LoRa range, battery, placement.  
  
OTA Process Flow (Practical Notes)  
  
- OTA update initiated manually.  
- Sensor Node must be awake.  
- OTA retries automatically if packet loss.  
- Do not move Gateway or Sensor Node during OTA.  
  
LoRa Troubleshooting Tips  
  
- Move Gateway higher or closer.  
- Verify antenna connection.  
- Reduce obstructions.  
- Use PING/PONG and RSSI to evaluate link quality.

# 6. Installation & Configuration Instructions

See detailed Industrial Technician and DIY Installation procedures.  
Section includes:  
- Pre-Installation Checklist  
- Sensor Node Mounting  
- RFID Tag Setup  
- Gateway Setup  
- Initial Testing  
- Detailed Safety Notes provided in Section 6.3.

## 6.3 Safety Notes

Installation Safety Precautions  
  
- Always power down HVAC system.  
- Do not install Sensor Node near high-voltage wiring.  
- Mount securely; avoid obstructing airflow.  
- Route cables properly; no loose wires.  
- Do not install near HVAC logic boards unless shielded.  
- Only qualified technicians should open commercial HVAC units.

# 7. Operating Instructions

Normal Behavior Expectations  
  
- After power-on:  
- LED Diagnostic Pulse runs.  
- First data packet sent within 30 seconds.  
- Data appears in Google Sheet every 5 min.  
- Sheet row includes: Device ID, Boot Count, Battery Voltage, Sensor Status, Temp, Humidity, Pressure, Wind Speed, RFID UID.  
- Gateway retries failed WiFi sends.  
  
RFID Tag Replacement Flow  
  
- Replace HVAC filter and RFID tag.  
- Sensor Node reads RFID at next cycle.  
- New UID appears in Google Sheet automatically.  
- No reboot required.  
  
Battery Replacement Best Practices  
  
- Monitor Battery Level column in Google Sheet.  
- Replace batteries below 40% (Yellow LED pulse).  
- Preventive replacement: 1 year for D Cells.  
- Use fresh matched D Cell pair.

# 8. Troubleshooting Guide

Common Issues & Solutions  
- No data in Google Sheet  
- No LoRa link (PING fails)  
- Sensor Node not powering on  
- RFID Tag not reading  
- Sensor data missing / wrong  
- OTA update fails  
- Diagnostic LED shows persistent Red  
- Battery level stuck at 100% / 0%  
- Wind speed reading 0 consistently

Forcing Diagnostic Mode  
- Connect USB cable  
- Short GPIO2 to GND  
- Send LoRa PING from Gateway

Reset Procedure  
- Press RESET button  
- Node re-reads RFID and performs self-test

# 9. Development Log / Timeline

- April 2025: Initial RF + LoRa hardware testing  
- May 2025: Sensor Node firmware stabilization  
- May 2025: Diagnostic LED codes implemented  
- May 2025: First successful LoRa → Gateway → Google Sheets data flow  
- May 2025: OTA update system tested  
- May 2025: Gateway Node PING → Sensor Node PONG implemented  
- June 2025: Sensor Node deep sleep optimized  
- June 2025: Documentation first draft created  
- Ongoing: Continued improvements  
  
  
Known Limitations / Roadmap  
  
- Mesh auto-routing not implemented.  
- OTA size limited to ~32 KB.  
- LoRa MAC ACK/Retry not fully implemented.  
- Multi-hop LoRa repeater nodes under investigation.  
- Remote configuration planned.  
- Gateway to support MQTT / cloud services.

# 10. Full Source Code Appendix / Links

GitHub / Repository (TBD)  
- Sensor Node Firmware  
- Gateway Node Firmware  
- Google Apps Script  
- Additional Resources  
FiltSure Power Budget Spreadsheet

# 11. References / Related Documents

- FCC Part 15 Compliance Notes  
- Bosch BME280 Datasheet  
- MFRC522 Datasheet  
- SX127x / RFM95 Datasheet  
- ESP32 Hardware Reference  
- Google Apps Script API Documentation  
- FiltSure Power Budget Spreadsheet