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# AUTOMATION IN VALIDATING WASH FORMULAS FOR CHEMO-THERMAL DISINFECTION IN PHARMA CLEANROOM LAUNDRIES

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*Abstract:* The pharmaceutical industry mandates strict hygiene and sterilization practices, particularly in cleanroom laundry environments. Manual processes for validating wash formulas often fall short in ensuring consistency, regulatory compliance, and safety. This paper presents the design and implementation of an IoT-based chemo-thermal disinfection monitoring system for pharmaceutical laundry operations. The system employs industrial-grade pH and temperature sensors connected via RS485 Modbus to an ESP32 microcontroller. Data is processed and transmitted to a cloud server using MQTT, allowing real-time monitoring through the Blynk platform. The system includes a water circulation mechanism to ensure accurate sampling and has been rigorously tested under harsh environmental conditions. Results demonstrate significant improvements in measurement accuracy, process transparency, and operational efficiency. This approach exemplifies the convergence of Industry 4.0 and hygiene-critical operations, providing a scalable model for smart industrial laundry automation

**Keywords:** Pharmaceutical Laundry, Cleanroom Hygiene, Chemo-Thermal, Disinfection, IoT Monitoring System, Industrial IoT (IIoT), RS485 Modbus, Communication, ESP32 Microcontroller, pH and Temperature Monitoring

***Index Terms* - Component, formatting, style, styling, insert.**

## 1. Introduction

Industrial cleanroom laundries are critical for preventing contamination in pharmaceutical manufacturing. Employees must wear specialized garments that are frequently exposed to chemicals, biological agents, and microbes. Ensuring that these garments are effectively disinfected is essential to comply with standards such as Good Manufacturing Practices (GMP), ISO 14644, and FDA guidelines. Current laundry practices rely heavily on manual inspection, which is both labor-intensive and error-prone. Automated systems are needed to ensure repeatability and traceability in wash validation, especially for disinfection-critical parameters like pH and temperature.

### 1.1. Problem Statement

Manual monitoring of laundry parameters results in inconsistent data collection, delayed response to faults, and non-compliance with hygiene protocols. Sensor drift, stagnant water, and lack of real-time feedback further degrade process requirements in pharmaceutical and healthcare facilities.

### 1.2. Need for Automation

Automation is vital for:

- Ensuring consistent disinfection outcomes
- Maintaining traceable digital records
- Minimizing reliance on manual labor
- Enabling real-time alerts and predictive maintenance
- Adapting to Industry 4.0 standards integrity. The absence of reliable data also weakens the ability to conduct audits and maintain documentation—key

## 2. Literature review

### 2.1. Conventional Practices

Traditional systems use manual thermometers and pH test strips, which offer no automation or digital logging. Garment cleanliness is judged based on empirical observations, which do not meet GMP validation requirements.

### 2.2. Sensor-Based Systems

Recent studies, such as those by Raja and Ramathilagam (2021), propose fuzzy logic systems for temperature regulation. However, pH monitoring remains underexplored. The Hydro-Air sensor series provides industrial-grade alternatives capable of real-time pH and temperature tracking, bridging this gap.

- No existing system integrates pH, temperature, Modbus communication, and cloud interfaces for laundry applications.
- Most IoT systems are designed for environmental monitoring, not wet or high-temperature environments.
- Lack of user-facing transparency tools for audit and validation purposes.

## 3. System Architecture and Methodology

### 3.1. Components and Configuration

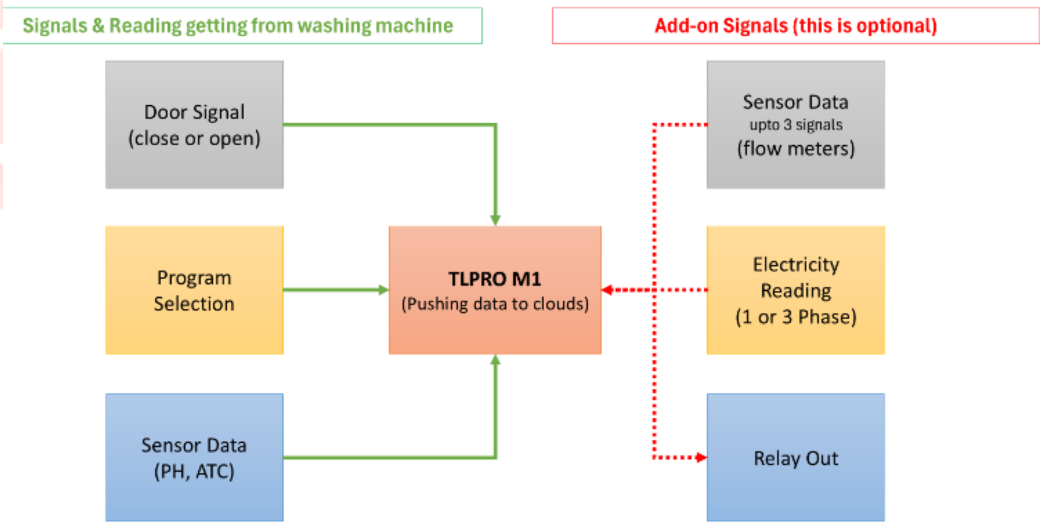


Figure 3.1 Components and configuration

- ESP32 Microcontroller: Dual-core, Wi-Fi/Bluetooth-enabled unit managing sensor polling and MQTT publishing.
- Hydro-Air pH/Temp Sensor: Industrial-grade, RS485 output with built-in PT1000 temperature compensation.
- Water Circulation Pump: Ensures fresh sample flow, avoiding reading inaccuracies due to water stagnation.
- RS485-TTL Converter: Interfaces Modbus sensors with ESP32 via UART.
- Blynk IoT Platform: Provides dashboard

with graphs, notifications, and downloadable logs.

### 3.2. Software Architecture

Written in Arduino IDE using modular functions for:

- Modbus data parsing
- Wi-Fi management
- MQTT client handling
- Blynk API integration
- Real-time sensor values are published in JSON every 5 seconds.
- Alerts are triggered on deviations (e.g., pH out of 6.5–8.5 range, temp below 60°C).

## 4. Implementation and Calibration

### 4.1. Sensor Integration

- Sensors are calibrated using 3-point buffer solution methodology (pH 4, 7, 10).
- Sensor readings are adjusted in firmware based on buffer response curves.
- Temperature calibration uses a certified digital thermometer and IR gun cross-verification.

### 4.2. Flow Optimization


Figure 4.2 One day Graph

Initial trials revealed inaccuracies due to stagnant water near the sensor. A water circulation system was implemented using a T-joint and pump to keep water moving across the probe. This significantly reduced latency and improved response accuracy

## 5. Testing and Validation

### 5.1. Key Performance Metrics

| Parameter | Benchmark | Achieved |
|---|---|---|
| pH Accuracy | ±0.1 | ±0.08 |
| Temp Accuracy | ±0.5°C | ±0.3°C |
| Uptime | 48 hrs | 50+ hrs |
| MQTT Latency | < 1.5 sec | ~0.8 sec |
| Sensor Immersion | 24 hrs | 72+ hrs |

### 5.2. Environmental Testing

- High-temperature tests (90°C) and high-humidity (95% RH) simulations.
- Stability validated under power fluctuations and sensor disconnections.

### 5.3. Dashboard & Alerts

- Mobile and web dashboards displayed realtime data.
- Historical logs stored for regulatory audits.
- Alerts (push + email) for out-of-range values and sensor failures.

## 6. Results and Outcomes

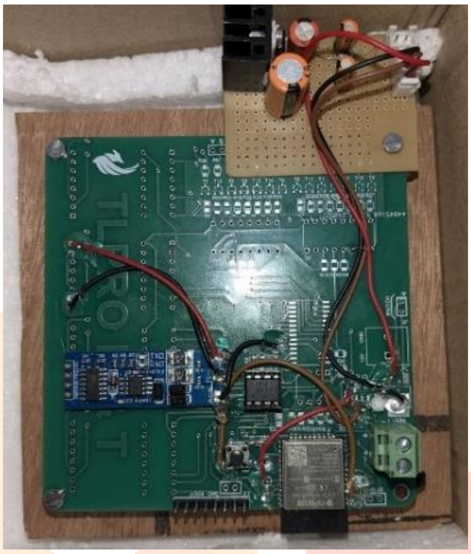

Figure 6 Modified ESP32

### 6.1. Operational Gains

- Reduced manual labor by 80%.
- Improved pH and temperature consistency across batches.
- Transparent logs supported audit readiness for ISO and GMP.

### 6.2. Client and Compliance Impact

- Facilities reported improved confidence in hygiene protocols.
- Blynk app enabled real-time access for supervisors and customers.

## 7. Conclusion and Future Scope

This project successfully demonstrates the viability of an IoT-based chemo-thermal validation system for cleanroom laundries. It ensures regulatory compliance, reduces human error, and provides scalable architecture for industrial adoption. Future enhancements may include:

- AI-based wash cycle optimization
- Microbial count sensors
- Integration with SCADA or ERP systems
- Solar-powered or battery-operated modules for remote installations.

## REFRENCES

### Academic and Conference Publications

1. K. Kostopoulos, D. Triantafyllidis, “Automation of a Washing Machine: An Open-Source Approach,” International Hellenic University – Department of Industrial Engineering & Management, Thessaloniki, Greece.
2. K. Raja and S. Ramathilagam, "Automation on Washing Machine Using Fuzzy Logic Controller Provided with Three Input and Two Output for Setting the Temperature of Water," 2021 5th International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India, IEEE, 2021, pp. 1751–1757. doi: 10.1109/ICOEI51242.2021.9453060.
3. Apoorva R. Naik et al., "RoboWash: A Review on Automated Laundry Collection System," Mangalore

Institute of Technology & Engineering, Karnataka, India.
4. Mark Austin et al., "Automated Laundry rocessing System (ALPS)," ENPM 645, University of Maryland, 2006.
5. D. Minoli, K. Sohraby, and B. Occhiogrosso, "IoT Considerations and Architectures for Smart Buildings: Energy Optimization and Next-Gen Management Systems," IEEE Internet of Things Journal, vol. 4, no. 1, pp. 269–283, Feb. 2017. doi: 10.1109/JIOT.2017.2647881.
6. M. A. A. da Cruz et al., "A Reference Model for Internet of Things Middleware," IEEE Internet of Things Journal, vol. 5, no. 2, pp. 871–883, 2018. doi: 10.1109/JIOT.2018.2796561.
7. S. P. Makhanya et al., "A Smart Switch Control System Using ESP8266 Integrated with an Android App," 2019 IEEE Smart Energy Grid Engineering Conference (SEGE), Ontario, Canada, pp. 125–128. doi: 10.1109/SEGE.2019.8859904.
8. Z. A. M. Almaqtari and Z. Janin, Development of Virtual pH Analyzer," 2013 IEEE ICSIMA, Kuala Lumpur, Malaysia. doi: 10.1109/ICSIMA.2013.6717976.
9. T. Promsawat et al., "Real-Time Monitoring and Alarm System for pH in Wet Scrubbers," ICCAS 2016, Gyeongju, Korea. doi: 10.1109/ICCAS.2016.7832343. Liu Ximin et al., “A Linear Temperature Transmitter Based on Pt100,” Chinese Control Conference 2008, Kunming, China, pp. 215–218. doi: 10.1109/CHICC.2008.4605109s

**Technical and Engineering References**

10. Hydro-Air Instruments, “E-Series Industrial pH/ORP Sensor Datasheet,” Hydro Air Instruments, Malaysia.
11. AMS1117 Voltage Regulator Datasheet, Advanced Monolithic Systems, [Available online from Texas Instruments and Sparkfun]
12. Espressif Systems, “ESP32-WROOM-32 Datasheet,” Version 1.4, 2023,
13. RS485 to TTL Converter Module Datasheet, Waveshare Electronics, 2022.
14. Modbus Protocol Specification, Modbus Organization,

**IoT and Cloud Integration Resources**

15. Blynk Documentation – Official Developer Guide, https://docs.blynk.io
16. Eclipse Foundation, “Mosquitto MQTT Broker – Lightweight IoT Messaging Protocol,”
17. MQTT.org, “MQTT v3.1.1 Standard,” OASIS Open, 2015. https://mqtt.org/specs/
18. Arduino.cc, “Arduino IDE and ESP32 Board Support Package,”
19. Random Nerd Tutorials, Rui Santos, “Getting Started with ESP32 and MQTT,”

**Standards and Industrial Guidelines**

20. World Health Organization (WHO), “Good Manufacturing Practices (GMP) for Pharmaceutical Products,” Annex 2, WHO Technical Report Series.
21. ISO 14644-5: Cleanrooms and Associated Controlled Environments – “Cleanroom Garment Cleaning Protocols,” ISO Standards.
22. US FDA – “Guidance for Industry: Sterile Drug Products Produced by Aseptic Processing,” Center for Drug Evaluation and Research (CDER), 2020.
23. Centers for Disease Control (CDC) – “Guidelines for Environmental Infection Control in Health-Care Facilities,” 2021.
24. Occupational Safety and Health Administration (OSHA), “Chemical and Biological Hazard Handling in Laboratory Environments,” OSHA.gov, 2020.

**Online Technical Blogs and Communities**

25. Hackster.io, “Industrial IoT with ESP32: Monitoring pH in Real-Time,” User Projects.
26. Instructables, “DIY Water Quality Monitoring Using ESP32 + pH Sensor,” Community Tutorials.
27. AllAboutCircuits.com – “Understanding RS485 for Industrial Communication,” 2021.
28. ElectronicsForU – “Smart Laundry Automation Using Embedded Systems,” EFY Labs, 2022.
29. EngineersGarage – “Microcontroller-Based Automation Systems in Industry,” 2023.

**Prototyping Tools and Simulation**

30. Fritzing – PCB Design Software for ESP32-based Layouts,
31. Tinkercad Circuits – Virtual Simulation for IoT and Embedded Systems, Autodesk.
32. Proteus Design Suite – “Modbus + Serial Communication Simulations,” Labcenter Electronics

**Research Articles and Future Trends**

33. S. Misal et al., “Indoor Positioning System Using ESP32, MQTT, and BLE,” IEEE ICCMC 2020.
34. D. Costean & S. Mischie, “BLE IoT Network Sensors,” IEEE ISETC 2022.
35. R. Cayre et al., “ESPwn32: Hacking with ESP32 SoCs,” IEEE Security and Privacy Workshops (SPW), 2023