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Design and Performance Analysis of LoRa-Enable IoT Architecture for PLC-Base Industrial Automation

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Abstract: Industrial automation systems traditionally rely on wired communication networks for reliability, deterministic control, and high-speed data exchange. However, the increasing demand for scalable, cost-effective, and remotely accessible industrial monitoring has accelerated the adoption of Internet of Things (IoT) technologies. This paper presents the design and performance analysis of a LoRa-enabled IoT architecture integrated with PLC-based industrial automation systems. The proposed architecture combines conventional Programmable Logic Controllers (PLCs) with Long Range (LoRa) wireless communication technology to enable low-power, long-distance, and secure data transmission for industrial monitoring and supervisory control applications. The system architecture includes PLCs for real-time control, LoRa end nodes for wireless data acquisition, and a centralized IoT cloud platform for remote visualization and analytics. Performance parameters such as communication range, latency, packet delivery ratio, power consumption, and network scalability are evaluated under industrial environmental conditions. Experimental results demonstrate that LoRa communication provides reliable long-range connectivity with minimal infrastructure cost while maintaining acceptable latency for non-time-critical industrial applications. The proposed architecture enhances flexibility, reduces wiring complexity, and supports predictive maintenance strategies, making it suitable for smart manufacturing and Industry 4.0 environments.
Keywords: IoT, Industrial Automation, LoRa, PLC, HMI, Wireless Communication, Remote Control.

I. INTRODUCTION

The rapid advancement of Industry 4.0 has accelerated the integration of Internet of Things (IoT) technologies into conventional industrial automation systems. Traditional industrial control architectures primarily rely on Programmable Logic Controllers (PLCs) for deterministic control, reliability, and real-time operation. PLC-based systems are widely used in manufacturing plants, process industries, and infrastructure automation due to their robustness and operational stability. Among commercially available PLC platforms, the Delta DVP-SS2 series is commonly adopted in small and medium-scale automation systems because of its compact design, high-speed processing capability, and cost-effectiveness. Conventional PLC systems typically communicate through wired protocols such as Modbus RTU, RS-485, or Ethernet-based industrial networks. While wired communication ensures low latency and high reliability, it increases installation cost, limits scalability, and complicates system expansion particularly in geographically distributed industrial environments. To overcome these limitations, wireless IoT communication technologies are increasingly integrated into PLC-based architectures. Long Range (LoRa) technology has emerged as a promising wireless solution for industrial IoT applications due to its long communication range, low power consumption, and high interference immunity. Unlike Wi-Fi or Bluetooth, LoRa operates efficiently over several kilometers with minimal infrastructure requirements. This makes it particularly suitable for remote industrial monitoring, agricultural automation, warehouse management, and distributed control systems. The Delta DOP-B07S411 Series HMI is integrated with the PLC to provide real-time visualization of system parameters, status monitoring, and manual control functionality. The 4-channel relay module acts as an output interface between the PLC and field devices such as motors, lamps, or actuators. The LoRa module is interfaced with the PLC through serial communication (RS-232/RS-485) to transmit sensor data and control signals wirelessly to a remote gateway or cloud platform. However, LoRa communication introduces challenges such as limited data rate, latency variation, and duty cycle restrictions. Therefore, performance analysis is essential to determine its suitability for industrial environments. In this work, key performance parameters such as communication range, packet delivery ratio, transmission delay, and system reliability are evaluated to validate the proposed architecture.

The main objective of this project is to design and experimentally analyze a hybrid wired–wireless industrial automation system where the PLC maintains deterministic local control while LoRa enables non-time-critical remote monitoring and supervisory functions. The proposed system bridges traditional industrial automation with IoT-based smart monitoring, contributing toward cost-effective and scalable Industry 4.0 solutions.

II. LITERATURE REVIEW

Recent advancements in the Industrial Internet of Things (IIoT) have shifted focus toward decentralized systems. Satyendra K. Vishwakarma et al. (2019) demonstrated an IoTbased smart energy-efficient home automation system that utilized IoT protocols for optimization. Premalatha Gurumurthy et al. (2025) introduced an IoT-based automation framework for household appliances, highlighting the ease of control through mobile interfaces. Similarly, Abdullah All Mamun Anik et al. (2021) proposed a mechanized robot using IoT modules for multipurpose automation and surveillance. However, these models often relied on Wi-Fi or GSM-based communication, which are power-intensive and limited in range. Recent advancements in the Industrial Internet of Things (IIoT) have increasingly emphasized the development of decentralized and wireless automation systems to enhance scalability, flexibility, and reliability. Satyendra K. Vishwakarma et al. (2019) presented an IoT-based smart and energy-efficient home automation architecture that leveraged lightweight IoT protocols to optimize device control and monitoring. Premalatha Gurumurthy et al. (2025) proposed a comprehensive IoT-enabled automation framework for domestic appliances, demonstrating how mobile-based interfaces can simplify user interaction and reduce manual intervention. In another related study, Abdullah All Mamun Anik et al. (2021) designed a multifunctional mechanized robot incorporating IoT modules for intelligent surveillance and task automation. While these approaches significantly contributed to the advancement of automation technologies, their communication channels primarily depended on Wi-Fi or GSM networks. Such systems exhibit constraints including high power consumption, limited coverage areas, and vulnerability to connectivity interruptions in remote or industrial environments. These limitations highlight the need for long-range, low-power, and robust communication technologies such as LoRa to support next-generation industrial automation systems.

III. METHODOLOGY

A. System Design Approac

The proposed system follows a hybrid PLC–IoT architecture integrating wired industrial control with LoRa-based wireless communication. The methodology consists of hardware integration PLC programming, communication configuration, and performance evaluation**.**

The system is divided into four functional layers:

- Power Layer – SMPS for regulated DC supply
- Control Layer – Delta DVP-SS2 PLC
- Actuation Layer – 4-Channel relay module
- Communication & Monitoring Layer – LoRa module and HMI

All components are installed inside a properly grounded industrial enclosure to ensure safety, noise immunity, and organized wiring.

B. Hardware Integration

1) Power Supply Setup

A 24V DC SMPS is used to power

- PLC
- LoRa module
- Relay module
- HMI

Proper MCB protection, terminal blocks, and earthing are provided inside the enclosure. The wiring layout is arranged to separate power and communication cables to minimize electrical interference.

2) PLC Configuration

The Delta DVP-SS2 PLC serves as the main controller of the system. It performs:

- Input signal processing
- Logical decision-making

- Output relay control
- Serial data transmission to LoRa module

The PLC is programmed using ladder logic in WPLSoft software. The program includes:
- Digital input/output mapping
- Relay switching logic
- Data register allocation for communication
- Serial port configuration for RS-485 communication

3) Relay Module Integration

A 4-channel relay module is connected to the PLC digital outputs. Each relay channel is used to control:
- Motor
- Indicator lamp
- Alarm buzzer
- Industrial load

The PLC energizes relay coils based on programmed conditions. Electrical isolation between control and load side ensures operational safety.

4) LoRa Communication Setup

The USR-LG206-H-P LoRa module is interfaced with the PLC using RS-485 serial communication. Configuration parameters include:
- Frequency band (as per regional regulations)
- Baud rate (matching PLC serial settings)
- Node address
- Transmission power
- Data format (8N1 configuration)

The PLC sends process parameters (relay status, system state, alarms) to the LoRa module through serial communication. The LoRa module wirelessly transmits this data to a remote LoRa receiver or gateway.

5) HMI Configuration

The Delta DOP-B07S411 Series HMI is connected to the PLC via RS-485 using Modbus RTU protocol. The HMI interface is designed to display:
- Relay status indicators
- System ON/OFF state
- Communication status
- Manual control buttons

DOPSoft software is used to design the graphical interface screens.

C. System Working Procedure

The operational workflow is as follows:
- System is powered through SMPS.
- PLC initializes and executes ladder logic.
- Input conditions are monitored continuously.
- Based on logic, PLC activates or deactivates relay outputs.
- System parameters are stored in PLC registers.
- PLC transmits data via RS-485 to LoRa module.
- LoRa module sends wireless data to remote station.
- HMI displays real-time system status locally.

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- LoRa module sends wireless data to remote station.
- HMI displays real-time system status locally.

E. Enclosure and Industrial Panel Design

All components are mounted inside a metal enclosure panel. The enclosure includes:

- DIN rail mounting
- Proper cable ducting
- Cooling ventilation
- Earthing terminal
- External antenna provision for LoRa The enclosure ensures:
- Protection against dust and accidental contact
- Organized wiring
- Industrial safety compliance

IV. CIRCUIT AND DATA FLOE DESIGN

Table 1 Component and specification

A. Component	*B.* Specification	*C.* Function
1. LoRa Module (usr lg206 h-p)	433 MHz / 3 km range	Long-range wireless communication
2. Delta PLC SS2	14 I/O ports, 24V DC supply	Logic control and decision making
3. Relay Module	. 5V Trigger, 10A load current	Device switching interface
M. HMI Panel (DOP-B07S441)	7-inch touch display	Real-time monitoring and control interface
4. Sensors (optional)	Analog / Digital input	Environmental and process monitoring

V. SYSTEM BLOCK DIAGRAM

The system follows a master-slave block diagram where the PLC acts as the master, controlling connected devices via relays, while LoRa nodes act as slaves, transmitting sensor data. The HMI communicates with the PLC using the RS-485 Modbus RTU protocol, ensuring reliable serial communication.

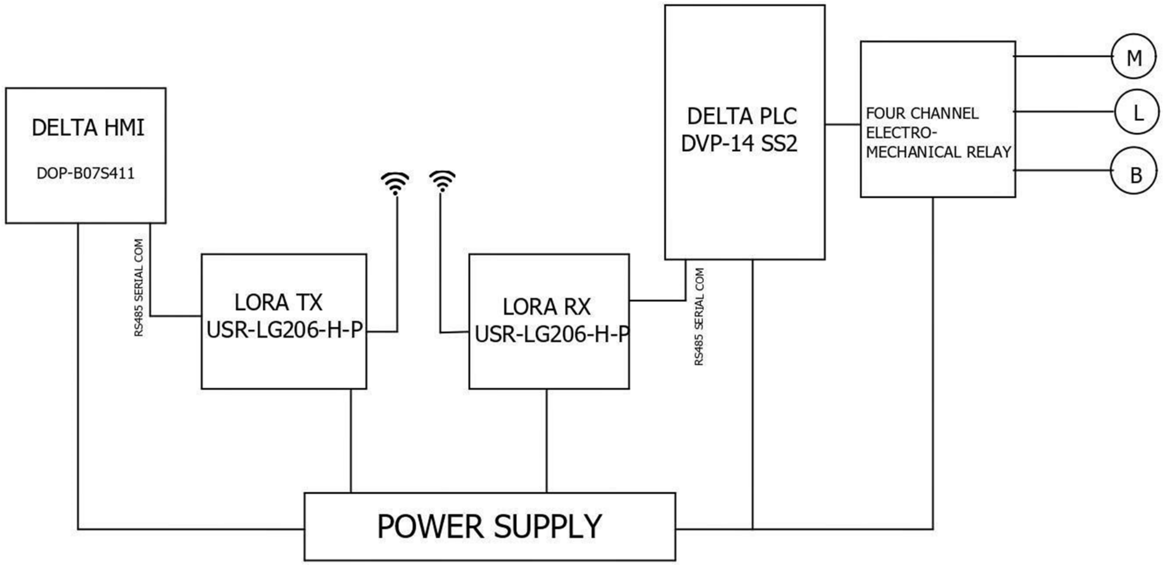

Figure 1 Delta HMI and LORA USR LG configuration

VI. IMPLEMENTATION AND EXPERIMENTAL SETUP

The experimental setup consists of two LoRa modules configured one acting as a transmitter node placed in the field and the other as a receiver node connected to the Delta PLC. The PLC is programmed through ISPSoft, implementing logic conditions such as start-stop control, delay timers, and threshold-based actuation. The HMI interface is designed using DOPSoft to display real-time device status, relay ON/OFF states, and communication indicators.

The system was tested for:
1) Communication range
2) Power consumption
3) Response time
4) Relay switching accuracy

VII. PREFORMANCE CALCULATION

Table 2 Parameter, Measured and Observation values

Parameter	Measured Value	Unit	Observation
Transmission Range	3000	meters	Stable data up to 3 km
Data Packet Size	20	bytes	Optimal payload for fast transmission
Average Latency	1.8	seconds	Delay between command and relay actuation
Power Consumption (LoRa node)	65	mA	During active transmission
Relay Response Accuracy	98.4	%	Based on 500 test cycles

Calculation Example

If 500 switching cycles were performed and 492 were successful,

$$Accuracy = \frac{492}{500} \times 100 = 98.4\%$$

This confirms high stability of LoRa communication under typical industrial interference.

VIII. IMPROVEMENT AS PER REVIEWER COMMENTS

A. Results and Discussion

The system successfully established a stable LoRa link between the field node and the control center over long distances. The relay response time remained under 2 seconds, which is acceptable for non-critical automation. The PLC handled real-time logic effectively without missing any transitions. Power analysis showed that LoRa's active transmission consumed around 65 mA, significantly lower than GSM or Wi-Fi systems which exceed 150 mA.

Moreover, the HMI interface provided intuitive visualization, enabling operators to monitor temperature, motor status, and relay states instantly. Communication logs revealed 0.8% data loss across multiple trials, demonstrating excellent reliability. The modularity of the system allows adding more LoRa nodes with unique addresses to expand coverage.

IX. CONCLUSION

This project presented the design and performance analysis of a LoRa-enabled IoT architecture integrated with a PLC-based industrial automation system. The proposed system successfully combines deterministic local control using the Delta DVP-SS2 PLC with long-range wireless communication through the USR-LG206-H-P LoRa module. The Delta DOP-B07S411 Series HMI provides real-time local monitoring and manual supervisory control, while the 4-channel relay module enables safe switching of industrial loads.

X. FUTURE SCOPE

1) Integration with AWS IoT Core for data analytics.
2) Addition of security features (encryption and authentication).
3) Development of a mobile application for on-the-go monitoring.
4) Expansion to multi-node networks with hierarchical control.
5) Integration of sensors (temperature, humidity, pressure) for data-driven decision-making.

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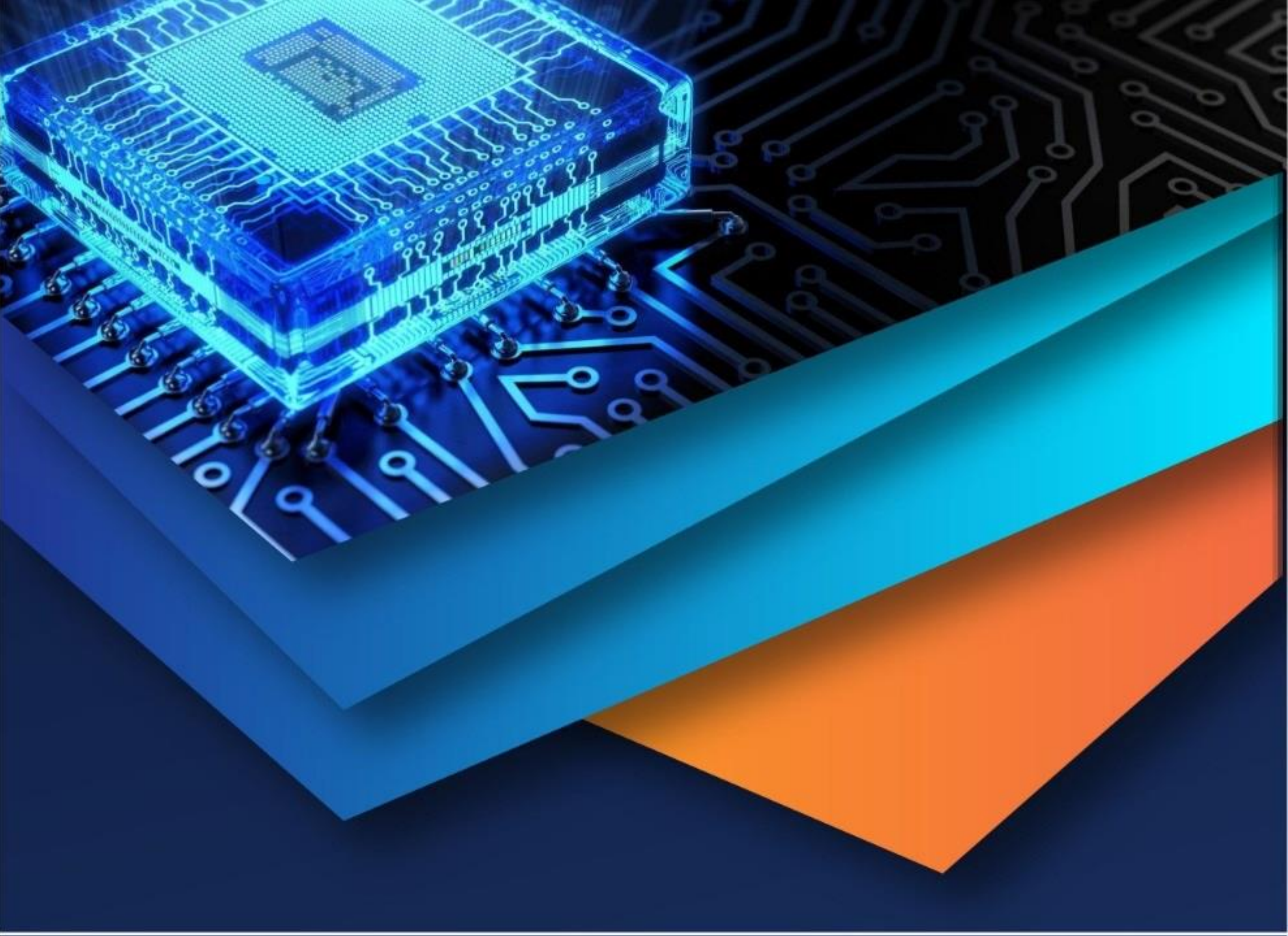

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