A Wireless Soft PLC Architecture for Scalable and Cost-Efficient Intelligent Automation Platform for Precision Agriculture

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Intelligent automation in precision agriculture demands scalable, adaptive, and cost-effective control architectures capable of reliable operation across distributed environments. Conventional Programmable Logic Controllers (PLCs), while deterministic and robust, are limited by high cost, hardware dependency, and poor scalability in geographically dispersed applications. This work proposes a software-defined Soft Programmable Logic Controller (Soft-PLC) architecture that virtualizes traditional PLC functionality while maintaining deterministic execution and hierarchical organization. A unified cyber-physical framework is introduced using a single long-range LoRa communication network to support sensing, closed-loop control, and actuation over distances up to 1 km. Wireless sensor nodes, each powered by a dedicated solar panel with a backup battery pack, measure nitrogen, phosphorus, potassium, pH, temperature, humidity, and electrical conductivity. Data are transmitted to a centralized control hub at intervals ranging from 30 seconds to 5 minutes, depending on agronomic requirements. The unified bidirectional LoRa infrastructure replaces the multiple communication gateways and multi-network infrastructure of conventional PLC-based precision agriculture systems, reducing system complexity and communication hardware by 30–50%. Control logic is executed on a Raspberry Pi-based hub using a deterministic scan-cycle paradigm (input acquisition, logic execution, output update) aligned with IEC 61131-3 standards, achieving local controller scan times of 40–80 ms. End-to-end communication performance is evaluated separately through LoRa network latency and packet loss. The system follows ISA-95 layered design principles to ensure structured interaction between field devices, control processes, and supervisory systems, supporting integration with existing industrial automation frameworks. The key contribution is the integration of Soft-PLC virtualization, unified LoRa communication, and ISA-95 architecture into a scalable, hardware-independent automation platform for precision agriculture. Field validation over 72 hours in an open agriculture field with node–hub distances from 200 m to 1 km demonstrates the feasibility and stable short-term operation of the proposed architecture, with an average communication latency of 180 ms (range: 150–250 ms) and a packet loss rate of 2.3% (below 5% across all nodes). The system achieves a 40–50% cost reduction compared to conventional PLC-based precision agriculture setups while maintaining comparable control performance, providing a scalable automation and communication platform capable of supporting future AI-driven precision agriculture applications.

Keywords: soft PLC, intelligent automation, LoRa network, wireless control, precision agriculture

Acknowledgement: *The authors acknowledge the financial support provided by the University of Peradeniya (Grant No. URG/2024/17/E) and the Department of Electrical and Electronic Engineering, University of Peradeniya, for providing the facilities and support necessary to conduct this research.*