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REVIEW

The Future of Intelligent Industrial Systems: PLC, Node-RED, and IoT/IIoT

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ABSTRACT

Integrating Programmable Logic Controllers (PLCs) with Node-RED and IoT/IIoT has emerged as a transformative technique for developing intelligent industrial systems as industrial automation improves. This narrative review brings together more than 70 research sources on industrial PLC, Node-RED, IoT, and IIoT applications. Case studies, experimental implementations, and industry reports are used to discover trends, challenges, and opportunities. The review focuses on three main topics: PLCs in modern industrial systems and their evolution and integration with IoT/IIoT; Node-RED as a middleware for industrial automation and its ability to connect PLCs to cloud and edge computing; and IIoT and smart manufacturing and how it improves data acquisition, processing, and analytics for optimized operations. This study review elucidates the technical interplay of PLCs, Node-RED, and the Industrial Internet of Things (IIoT) in smart industrial systems. It delineates essential integration trends, emphasizes current problems, and specifies prospective trajectories for the advancement of automation, connection, and system intelligence.

Keywords: PLC, Node-RED, Industrial Internet of Things (IIoT), Internet of Things (IoT)

1. Introduction

The connection of programmable logic controllers (PLCs), Node-RED software programs, and the Industrial Internet of Things (IIoT) technology has played a significant and important role in the development and improvement of industrial automation in Industry 4.0 (I4.0) [1]. This transformation in I4.0 has been supported because of the increasing demand for remote control, real-time monitoring, and predictive maintenance that legacy PLC systems have failed to deliver [2].

For decades, programmable logic controllers (PLCs) have been the cornerstone of industrial automation, providing precise and reliable control over various industrial processes. On the other hand, due to the limited communication and data processing capabilities of traditional PLCs, the rapid development of industrial processes, the volume of information required for each process, and the speed of successive operations, this necessitates the need for additional hardware and advanced configurations to achieve maximum efficiency and continuous improvement of industrial automation processes in I4.0 [3]. Recent developments in PLCs, especially soft PLCs and cloud-enabled PLCs, have optimized connection with IoT/IIoT systems [4]. However, issues such as high prices, proprietary software limitations, and limited interoperability have made more flexible middleware solutions like Node-RED more popular [5].

IBM developed the Node-RED framework, a low-cost software tool that simplifies process management by using data flows and nodes that connect them to achieve immediate automation. Node-RED consists of the flows, nodes, and JavaScript codes needed to perform the operations [6]. Unlike traditional PLC programming languages like Ladder Logic Diagram (LLD) and Function Block Diagram

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Table 1. The main differences between PLC, Node-RED, and IIoT.

PLC	Node-RED	IIoT
Industrial process automation.	Visible programming platform.	Smart Data Communications.
Solid logic structure.	Soft integration and simple updates.	More scalable and flexible.
Ability to networks connection-limited (Modbus/Ethernet).	Ability to networks connection-wide (HTTP/ MQTT).	Ability to networks connection-wide (Edge/Cloud platforms, PLCs, and 5G).
Programming method using traditional programming languages such as (LLD, FBD).	Drag-and-drop visual programming environment.	Depends on Edge/Cloud platforms protocols, and data analysis.
It does not require an Internet connection to work.	Requires an internet connection to work.	Requires an internet connection to work.
Expensive because it is a real industrial device in addition the software needed for programming.	Low cost (open source).	The cost varies depending on the required structure and application.

(FBD), Node-RED offers a graphical interface called Dashboard for building the desired process control, which in turn makes it easier to connect PLCs to cloud and IIoT platforms [7]. Moreover, the integration of PLCs and Node-RED has been effectively applied in many industrial applications, such as water management systems [8], industrial automated production lines [9], and predictive maintenance for equipment [10]. This integration increases operational efficiency by minimizing downtime, enhancing real-time diagnostics, and enabling edge and cloud computing capabilities [11].

The IIoT expands the ability of classic industrial automation through integrating cloud/edge computing, intelligent devices, and large data analyzers into industrial operations [12]. The IIoT also provides remote monitoring of industrial processes, continuous process improvement based on machine learning, and instant decision-making, all of which are necessary for the development of smart factories in I4.0 [1].

While many recent studies and research have focused on the individual capabilities and applications of each of the three elements rather than highlighting the significant benefits that arise in production processes when the three elements are combined, which aims to improve smart industrial automation systems, and despite many developments, changes, and improvements in the work of PLCs, Node-RED, and the IIoT, a scientific and research gap still exists regarding the integration of these three elements together in modern industrial automation processes [13, 14]. This study aims to fill the current research gap by presenting a narrative review article that illustrates the integration of the three components, focusing on the technical and practical benefits, the challenges that hinder this integration, and how to continuously develop and improve industrial processes and applications in the future. A number of basic differences between the three elements can be illustrated in Table 1.

This study compiled information from more than 70 scientific and academic sources, as illustrated in Fig. 1, which illustrates the steps involved in the methodology used. This research can be useful to companies seeking to implement smart industrial automation projects. The results will serve as a systematic path for companies to transition to flexible, interconnected management systems for components and parts, contributing to the ongoing digital revolution in Industry 4.0.

Finally, this narrative research paper recommends the imperative of using a strategy combining PLCs, Node-RED, and the Industrial Internet of Things to ensure the construction of smart industrial automation systems with robust infrastructure, available resources, and the ability to scale in the future.

2. PLC, Node-RED, and IoT/IIoT

To deeply understand how Industry 4.0 (I 4.0) systems developed and expanded, it's necessary to study the core components that make up their infrastructure. Programmable logic controllers (PLCs), the Internet of Things (IoT) / Industrial Internet of Things (IIoT) solutions, and the open-source programming tool Node-RED are all important components of the digital transformation of Industry 4.0. Fig. 2 illustrates the relationship between the components. This study's methodology is based on a review of over 70 recent studies and will examine each of the three components separately, how they have developed over time, what their functions and tasks are, and how they fit with the other components.

2.1. Programmable logic controllers (PLCs)

PLCs operate equipment and processes efficiently and in real time, forming the foundation of industrial automation systems. The PLC units observe inputs, perform actions, and produce outputs to complete industrial operations. Due to the many specifications of PLCs, they are widely used in various fields, including industry, medicine, energy, and many other sectors. (Benjamin, 2025) [15] revealed that PLC and Supervisory Control and Data Acquisition (SCADA) can improve the utilization of available resources in

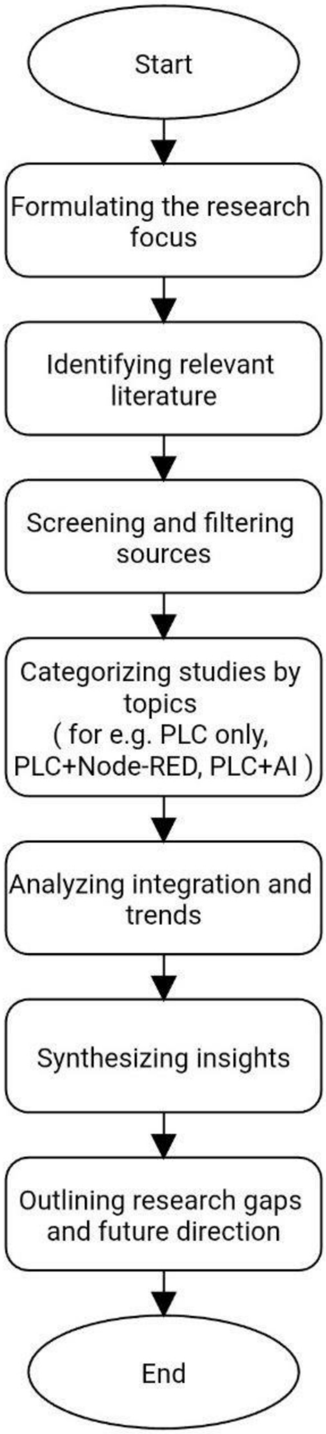


Fig. 1. Workflow of the narrative review methodology.

urban water supply systems, automate operational control, and enable remote monitoring and control. (Desai and Maske, 2024) [16] Developed city water distribution system using a PLC (AB MicroLogix 1100) and other system components, including sensors, control valves, and electric pumps, to monitor and control water flow and generate consumption bills. Results showed that the system controls water consumption in homes and cities and quickly stops leaks by maintaining system pressure and meeting demand during peak times. Similarly, (Abdulwahid et al., 2023) [17] Developed An intelligent model for controlling water level in tanks using a PLC (S7-300) and SCADA system with a graphical interface (HMI) to monitor and control the process. The Modbus/TCP protocol was used to connect the controllers, and a variable frequency drive (VFD) was used to regulate the speed of a three-phase electric motor. The results indicated that the model could automatically control the filling and emptying of tanks with water. (Singh et al., 2021) [18] PLC and SCADA were used to improve water management. The water level monitoring and control system consists of sensors connected to PLC that control electric pumps and control valves. Results showed stable water pressure in the system with minimal human intervention. (Febaide et al., 2020) [19] Using the same concept, the water pumping station in Koroti village was automated using a PLC (AB MicroLogix 1000) to optimize water management. The PLC was programmed in Ladder Logic Diagram (LLD) using RSLogix software. The PLC connected to water level switches, control valves, and electric pumps as analog and digital input/output signals. The results showed that the system can monitor and control pumps and valves based on water levels, and can solve the problems of rural manual labor and water shortage difficulties. Correspondingly, (Umachagi et al., 2020) [4] used a PLC (Siemens S7-200) and SCADA system to automate water distribution to increase efficiency and reduce waste. Also added: water theft tracking and alarm via GSM system. A prototype with an RS-232 interface and Micro WIN CC was used to visually display system status, monitor water levels, and autonomously operate pumps and valves based on sensor data. To detect theft or leakage, a flow sensor was added. The findings show that the system distributes water continuously and equitably while reducing water loss by 75%. In a comparable manner, (Ashok et al., 2019) [20] designed and built a PLC and SCADA based fluid flow and liquid level monitoring system to automate chemical and pharmaceutical systems. A Ladder Logic language PLC controlled the system with a flow and level sensors, electromechanical valves, and pumps for processes and enable safe automated operation with safety commands and alarms. The study found, the automated technology reduces human error, response quickly, and prevents flammable fluid leaks in long-distance oil transportation networks. Along the same lines, (Kadiran K et al., 2024) [21] created a PLC programming simulator using a water-filling machine

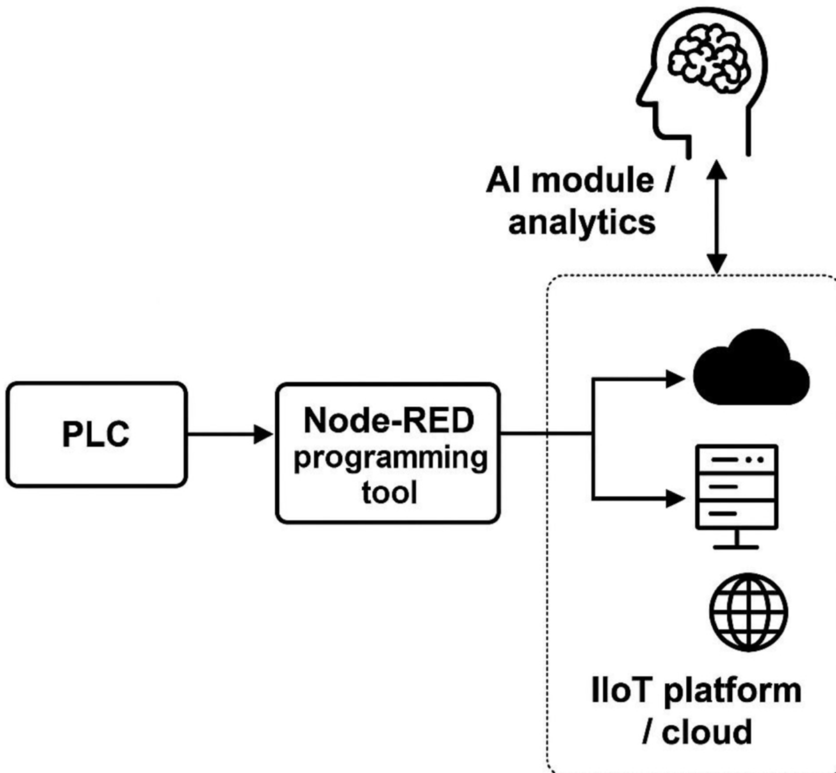


Fig. 2. Modern architecture of intelligent industrial systems integrating PLC, Node-RED, IIoT, and AI.

model based on the (Omron CP1H) module to provide safe and efficient hands-on training at technical and vocational education institutions. Design and development utilizing CX-Programmer and CX-Designer tools produced an interactive interface and an accurate simulation of industrial components, including sensors, motors, and valves. Students' scientific and practical knowledge of PLCs in industrial automation applications was enhanced. Furthermore, (Muralidharan et al., 2021) [22] developed an automated water bottle filling system using a PLC (delta-type) to develop production process and reduce labor costs. The results demonstrated that the system is inexpensive and can be used in small and medium-sized industrial systems. Additionally, (Liton Ahmed et al., 2019) [23] An automated bottle filling system was developed using a PLC to operate the water pump, an infrared sensor to detect the bottles, and a conveyor belt to move the bottles. Results showed that the system filled bottles accurately and efficiently, at a reasonable cost and time. In parallel, (Harahap et al., 2018) [24] A PLC (Allen Bradley Micrologix 1400) was created to automate the water filling process. The system included a simulation model with water level switches, control valves, and electric pumps controlled by RSLogix500 software and connected to an HMI configured with RSView32 software for system monitoring and control. The sensors were replaced with led indicators in the simulation. The results demonstrated the system's independent tracking of water level, and operation of valves and pumps, and also the system has good operational efficiency and can be expanded by adding modules. In other way, (Aye Mar et al., 2019) [25] created an automated fluid mixing and filling system using a PLC (Delta DVP-14SS2) with level sensors to reach maximum accuracy and minimize waste. The method used ladder logic programming via WPL Soft to connect valves, motors, and sensors to the control unit to sequentially control the mixing and filling process using a conveyor belt and cups passing through an optical sensor, which stops the conveyor and activates the filling pump. Filling equal quantities of water and juice combinations was precise, eliminating waste and improving output. The technology reduces human involvement and provides a reliable and efficient industrial filling solution. In addition, (Patel et al., 2014) [26] designed a loop control system using a PLC (Siemens S7-300) to control water level, flow, and pressure in the bottle washer to enhance efficiency and decrease waste. The method used an HMI interface and a PI algorithm to create a ladder logic. The system was then connected to a variable frequency drive (VFD) to adjust pump speed depending on detected data. The system indicated strong control, high precision, and rapid reaction. The PLC-user interface combination provides a smart, versatile, and scalable solution for industrial water-related applications. In the same context, (Chattal M et al., 2019) [27] created a cheap industrial automation system using a PLC (Fatek) and LabVIEW software to control the process of mixing limestone powder with hot water and reduce worker health risks. A model with four sensor-equipped tanks, a mixer, and a heater was built; ladder logic in a PLC controlled pumps and other components, and a LabVIEW control panel monitored and managed activities. Results demonstrated how successfully the gadget-controlled fluid levels and temperature in real time. In other study, (Wei et al., 2024) [28], using a PLC (Mitsubishi FX5U) and it is software (MCGS), to established a liquid level control system for industrial vessels. Simulation software and non-contact sensors were used to develop the system. Touchscreen-controlled technology responded automatically to limited scenarios. When critical levels are exceeded, the system can regulate precisely with automated reaction and visual and audible alerts. Furthermore, (Yahya et al., 2020) [29] designed a training module for controlling liquid level in a tank using a PLC (Omron CP1H) to gain knowledge and enhance students' skills in industrial automation. The training module also included an Arduino microcontroller and ultrasonic level devices. The system was tested under turbulent liquid flow conditions and was found to be stable and operate with high efficiency. As well, (Sahu and Tripathi, 2018) [30] designed an automated system to control the opening and closing of dam gates using a PLC (Siemens S7-300) to control a variety of applications, including controlling water levels and flow in agriculture, electricity generation, and flood protection during the rainy season. The system responded fast and precisely to a number of factors, such as operating length and operation safety. Equally, (Mahfooz et al., 2012) [31] automated a water carry system between two reservoirs using a PLC (Siemens LOGO) to decrease human error and enhance water quantity precision. The strategy used proximity sensors to detect the tank's lower and higher levels, input signals to automatically control the pump and valve, and a ladder diagram to manage the cycle. Results revealed how precisely the system assessed quantities and operated machines without human aid. It was found that this affordable, user-friendly approach works in households and enterprises. Similarly, (Siddiqi et al., 2016) [32] developed and tested a PLC-based teaching approach to teach pneumatic and hydraulic systems at technical institutions. The strategy focused on building a training platform including a water tank, submersible pump, level sensors, motor, Allen Bradley PLC, and electrical components. The program stressed hands-on practice and theoretical integration. Impact was measured using pre- and post-tests. Students understood relevant concepts 90% better, the study found. Combining theoretical knowledge with PLC training increases industrial automation learning in educational and community settings. Much like, (Upadhyaya and Grewal, 2023) [33], in a university course on industrial control techniques, developed an educational laboratory experiment that simulated a system for controlling water levels using a Modicon M580 PLC, an HMI interface, and a VFD module. The study used an integrated simulation with PID programming and Function Block Diagram (FBD) to manage water flow in a hypothetical 100-gallon tank, incorporated random noise to simulate real-world problems, and employed the Trend tool to assess the results. The system met the setpoint with a satisfactory reaction time and 4.7% overshoot. The model helps students understand industrial automation methodologies, including PLC, VFD, and HMI integration, the study found. Moreover, (Hidayat, 2023) [34] focused on creating an automated control system that employs a PLC to start a water pump in intelligent hydroponic farming systems while conserving energy. The inquiry required LDR-based sensor circuits with Omron CP1E PLC interfaces. The technology consumes less power than typical systems since it only runs the pump during the day. Results show that running the system effectively for nine hours a day saves 63.3% of energy. The results suggest that this design might lead to an energy-efficient smart farming system with wireless management and monitoring. Additionally, (Xueqin et al., 2018) [35] designed a Siemens S7-200 PLC-based automated control system for a rotating cage sweet potato washer to regulate motors, pumps, and valves sequentially. An electrical system with a main circuit and a control circuit was built and programmed using a ladder diagram to execute sequential logic (set/reset), start-up, water pump timing, and automatic machine shutdown after a predetermined time. The results revealed the system lowers human errors and operates efficiently. Automating industrial farm cleaning equipment with the approach improves safety and reliability. In a different framework, (Gnana et al., 2024) [36] analyze several industrial control and monitoring system applications to critically review SCADA and PLC in smart buildings and the energy business. The study founded that integrating PLC and SCADA is important for modern control systems to achieve these aims, energy management with efficiency, improve operational capability, decrease operational hazards, and enhance cybersecurity. As well, (Alphonsus and Abdullah, 2016) [37] examined the use of PLCs in industrial control, monitoring, renewable energy, and education, focusing on their capability and integration with modren technologies like artificial intelligence and wireless networks. The study analyzed above 70 case studies and applications from industrial, solar, wind, and water sectors. PLCs are most common because of their lower cost, ease of programming, and robustness. The study concluded that the PLCs primarily connected to modern automation. Another study conducted by (Nasser et al., 2024) [38] focused on the use of wireless ADAM modules to develop and simulate an intelligent remote control and monitoring system for industrial manufacturing lines. The study analyzed sensors, actuators, and controllers, utilizing Modbus and UDP in a simulation environment to provide real-time monitoring and supervision from a central control room. The results detected this path enhanced operating efficiency, speed, and safety in many industrial systems. Also, (DeGuglielmo et al., 2020) [14] created instructional units to teach engineering students to program PLCs using Ladder Logic to increase practical skills and relate them to industrial environments needs. This control units generated by software simulation using a PLC (Mitsubishi FX2N-32mt) module and (GX-Works 2) software to build, and execute tasks without real hardware. In parallel, (Namekar and Yadav, 2020) [3] looked at how PLCs are used in electricity power plants, steam boilers, and fuel or gas furnaces to enhanced automation and lower errors made by operators. The method discussed at how PLC hardware components and software work in real situations, like automating steam boilers by using SCADA system, and boost performance of steel heating furnace, to show that PLCs are reliable, flexible, and easy to program. In addition, (Almtireen et al., 2025) [39] offered a PLC-based on intelligent conveyor system with AI- enhanced for waste separation to minimize human labor and improve accuracy. A PLC and servo-motors controlled conveying and sorting, while a (YOLOv8) deep learning model recognized and classified recyclables in real time. AI- and PLC-based automated control boost waste management.

Lately, the combination of AI with PLCs in industrial automation has become very important. This hybrid integration improves control, predictive maintenance, and command generation, essentially in complex or dynamic systems where classic PLCs alone are not useful. The researchers studied this integration between AI and PLC systems in Industry 4.0 by using some applications. (Alaribi et al., 2021) [40] aimed to automate manual water system in Zintan city, Libya, using a PLC to increase reliability and decrease human labor. This system contains level and pressure sensors, electric valves. Simulations demonstrated that the system is cheap, precise, flexible, and can handle water problems in steep and rugged areas. In a related work, (Ali et al., 2021) [41] used a PLC (Siemens S7-200) and a wireless network were used for remote control and monitoring of water level in the Rajaban city storage tanks, for this reason an intelligent automated control system was built. This method used level and flow sensors, radio frequency waves to transmit on/off signals, and ladder logic to program the PLC. The results showed the system reduced waste, stabilized flow, and needed less effort. Expanding on this concept, (Howimanporn S et al., 2018) [42] created a PLC (Mitsubishi) system for controlling water levels using PID controller tuning by particle swarm optimization (PSO) algorithm to achieve exact and rapid response. The system was linked to SCADA and implemented in real-world applications to monitor performance in real time. The gain scheduling-based system settled quicker and oscillated less than the non-adaptive technique. We found that this strategy provides an accurate and adaptive control system for intelligent industrial control. Similarly, (Campisano and Modica, 2002) [43] examined PID controllers and PLCs in sewage system sluice gate control to regulate water levels in real time and reduce floods. Numerical simulations using the FLUSS hydraulic model evaluated how quickly and accurately the system responded under three different water flow situations. It also examined PLC hydraulic control equations and sensitivity levels. PLCs need proper programming with complex equations to perform similarly, whereas PID controllers, especially when using P control with $Kp = 1.0$, perform efficiently. Both systems can present accurate control, but PLCs are more compatible with the special features of hydraulic systems and don't need to pre-calibration. In like manner, (Ahmad and Prajitno, 2020) [44] to fix the nonlinear control problems in standard PID controllers, the study designed a controller to manage the water flow by using PLC connected with an artificial neural network (ANN). The method based on built a lab system that contain a water tank, a flow sensor, a control valve, and a pump. The neural network was used for control over an OPC link between the PLC unit and MATLAB program after being trained on data coming from a PID controller. After comparing the results of the two methods, the performance of the integration of the PLC with the artificial neural network controller was greater than that of the PID controller alone, starting from reducing errors and reaching the steady-state case faster. In a related work, (Saban et al.,

Table 2. The main differences between Classic PLCs, AI-based PLCs.

Classic PLCs	AI-based PLCs
Making consistent logical decisions according to the programming method.	Making smart decisions based on data analysis and learning from AI models.
Only deals with pre-programmed and known devices connected to it and it is impossible to adapt to unprogrammed changes.	Able to handle, adapt and predict unprogrammed changes with the help of intelligent algorithms.
Any change to the system requires manual reprogramming.	Due to machine learning, any system change often does not require manual reprogramming.
Can not predict faults because it depends only on signals from the devices and sensors connected to it.	Can be predicted errors before they occur using data analysis.
Operational efficiency is constant over time.	Operational efficiency improves over time through continuous learning and improvement.

2023) [45] constructed a smart agricultural system utilizing PLC controllers, cloud-based web server for remote control and monitoring, and LoRa and Lora WAN techniques. Used a distributed sensor network to assemble agricultural environment data. Via the LoRa gateway, this collect data is transmitted to a cloud server for processing and display by a web interface. The results showed success of the system for conservation water and energy in the farm. Another study, (Chaudhary et al., 2020) [46], used a PLC (Mitsubishi) to create and execute an intelligent system for sorting metallic and non-metallic industrial waste to reduce human involvement and boost waste management efficiency. Motors and valves are controlled by a PLC on a conveyor belt equipped with infrared, proximity, and optical sensors to push the waste into container. Timer controls adjusted the conveyor's sorting halt time. The results showed high sorting accuracy and minimal wiring and operation costs. From a different angle, (Guo, 2018) [47] designed a smart campus settlement system using IoT technology and a PLC module to improve university administrative, financial, and logistical operations. The strategy required a multi-layered system with WinCC interfaces, RFID sensors, and a central administration platform for electronic payments, student registration, access control, and library monitoring. The system handled activities well with a response time of 0.06 seconds. The "automatic settlement" technology was shown to be secure, scalable, and successful for data integration and smart campus transition.

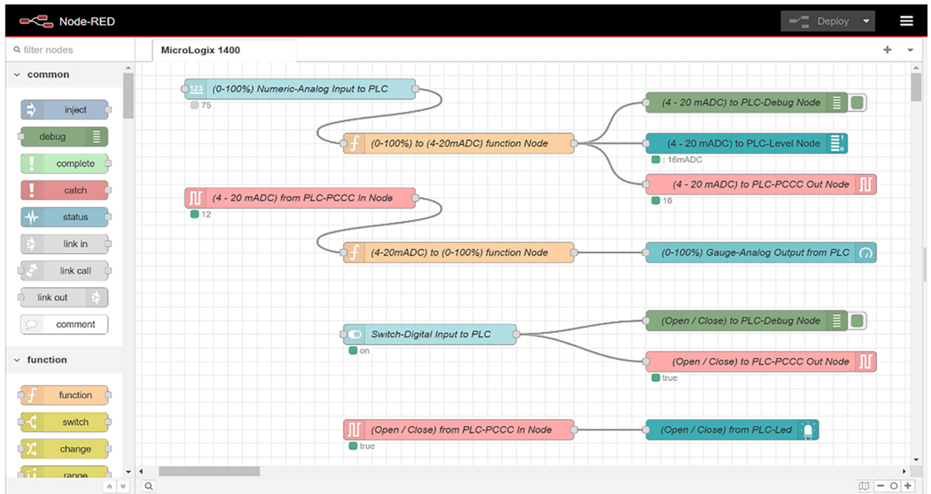
Finally, some differences between Classic PLCs and AI-based PLCs systems can be highlighted, as shown in Table 2.

2.2. Integration of (Node-RED) in industrial systems

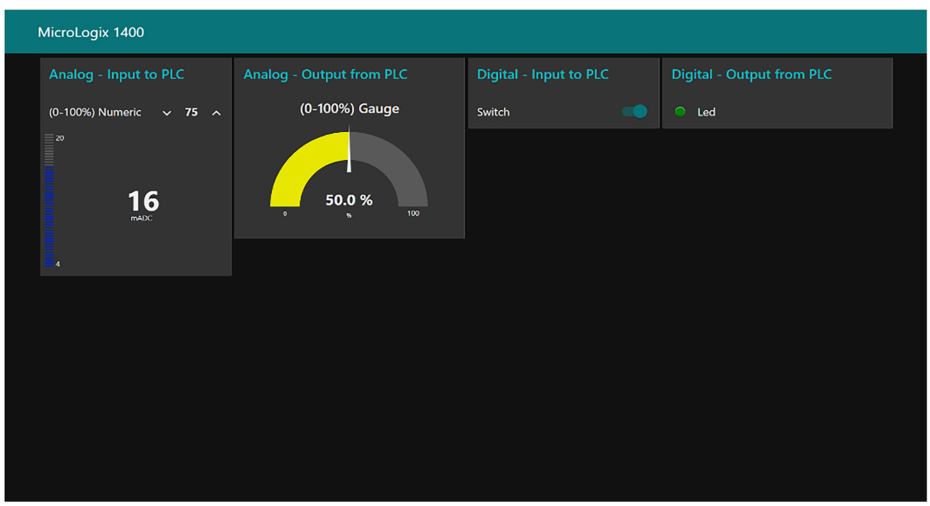
Node-RED is a powerful flow-based programming tool that helps connect and automate internet services, APIs, and devices. It is popular in industrial automation applications because of its visual interface, which is built on JavaScript and the Node.js platform and enables rapid prototyping and straightforward logic design. Fig. 3(a) and (b) shows the programming environment for the Node-RED and Node-RED Dashboard, respectively. Because of its growing importance in IIoT ecosystems, recent research has focused on its applications in cloud-based control systems, smart manufacturing, and real-time monitoring. The studies mentioned give information on how Node-RED is used and adjusted to meet the changing demands of modern industrial contexts. (Avilés et al., 2024) [48] used the Node-RED IoT platform to simulate the water distribution network in Tecate, Mexico. The project aimed to build and implement a proportional-integral (PI) control system to manage reservoir water levels. Mathematical modeling of the hydraulic system, PI controller creation, and prototype deployment utilizing industrial sensors and actuators were the primary steps. MQTT was used in Node-RED to send and analyze data. System results demonstrated that it can correctly modify water level despite measurement noise. The SCADA and IoT-based system are scalable and efficient for real-world applications. In another related work, (Onwuegbuzie et al., 2024) [6] integrated Node-RED with IoT analytics to develop a real-time data processing and presentation platform using a Raspberry Pi, ESP32, and BME280 sensor. The experimental technique entailed constructing an integrated Internet of Things system that takes temperature, humidity, and pressure data and communicates it over MQTT to an interactive Node-RED interface on a computer or phone. Results revealed how adaptably and cost-effectively the system handled real-time data.

2.3. Prospects for the Industrial Internet of Things (IIoT)

The Industrial Internet of Things (IIoT) has become a major player in modern automation due to quick



(a)



(b)

Fig. 3. Node-RED example. (a) Flows and nodes. (b) Dashboard.

progress in industrial technologies. To achieve the best results for modern industrial operations, the IIoT is integrated with other industrial technologies and elements in Industry 4.0. This section of this narrative paper focuses on the significant impact and prominent role that the IIoT plays in modern industrial systems, and how it enables smart and timely decision-making, energy efficiency, and predictive maintenance across various industrial processes. (Keshav Kolla et al., 2022) [49] studied the use of the IIoT to modernize old machinery and equipment by installing sensors on them. They also used a simple method to collect data and then transmit it to a cloud server for monitoring and control. This simplified technology reduces modernization costs in industry, allowing small and medium-sized companies to upgrade their equipment at a lower cost. Another study is presented by (Madhumitha et al., 2020) [50], examined liquid level measurement and control using Internet of Things (IoT)-based, highlighting PID, fuzzy logic, Arduino, GSM, Wi-Fi, and ZigBee for several applications to compare traditional and IoT-based systems. The studies proved that IoT-based solutions enhance application precision and remote control, and these methods decrease water problem mostly for residents of remote and the people with special needs. Corresponding to this idea, (Prasanna Lakshmi et al., 2023) [51] created an intelligent irrigation system using IoT, sensors, and an LSTM model to evaluate agricultural irrigation and water conservation requirements. The system raised irrigation efficiency, enhanced smart agricultural, and reduced water use by half compared to other methods.

With the growing popularity of the (IoT/IIoT), artificial intelligence (AI) has appeared as a basic element for data processing, real-time commands, and predictive maintenance. AI-powered systems (IoT/IIoT) can improve resource usage, find system errors before they occur, and automatically integrate with industrial systems. Recent research has discussed this connection. (Gupta N et al., 2020) [52] designed an IoT-based water level measurement system that automatically controls pumps to improve urban water management and minimize waste. The water level signal is transmitted from an ultrasonic level sensor to a central server. This system can control up to 20 tanks simultaneously. Results showed that this approach is easy to implement and scalable and optimized using machine learning. In a similar vein, (Hadipour et al., 2020) [53] implemented a Multi-Intelligence Control System (MICS) based on the IoT to manage water by operating water pumps, monitoring water levels in tanks, and remotely activating sensors and alarms. The system consists of control circuits, a water tank, electric pump, and sensors. Results demonstrated that this smart system is easy to use, flexible, and suitable for a variety of industrial and agricultural applications. Additionally, (Chinnusamy et al., 2018) [54], designed a water management system that combines IoT and LoRa technologies to monitor water levels in a tank using mounted sensors and remotely control valves. Ultrasonic level sensors and low-power wireless nodes with automatic valves were used. These wireless nodes were connected via LoRa and GSM to a central control unit, and a Grafana dashboard was used to control the system and display data. Testing of the system continued for up to four months without interruption, and the results demonstrated that the system can provide highly efficient monitoring and operation at a low cost. In parallel, (Jadhav S et al., 2018) [55] built a water management system for a dairy company using the IoT. Sensors equipped with wireless controllers transmit signals to a cloud server using an (STM32) microcontroller. Data signal was received via computer and smartphone to generate reports. The results demonstrated the accuracy of measuring water consumption due to wastage or malfunctions. Similarly, (Rahaman et al., 2024) [56] created a smart and secure control and monitoring system for rural farms and fields using AI and the IoT, with a strong focus on security and threat protection. The (AVISPA) tool was used to enhance cybersecurity. The system was characterized by speed, security, resistance to various attacks, and protection of sensitive data. The results indicated that the system is suitable for smart farms. Another study, (Mishra et al., 2024) [12], demonstrated the use of AI and IIoT in metal smelting operations. This technology relies on integrated field study of systems to collect real-time sensor data and analyze it using machine learning algorithms to predict failures and optimize production. Likewise, (Hajjaj et al., 2020) [57] built an autonomous floodgate system to address the problem of dispersion and delay in controlling floodgates in rural areas using the IoT. Results demonstrated the ability of this smart system to quickly control floodgates. In this way, open-source technologies were used to control a critical interactive system.

In this section, we'll discuss how to integrate PLCs with Node-RED tool to achieve a more flexible and scalable infrastructure for automation applications. Some research has discussed this integration. As an example, (Ribeiro de Sousa et al., 2023) [7] designed a PLC (S7-300) system connected to Industry 4.0 networks using Node-RED and OPC-UA. Node-RED flows for controlling and monitoring an industrial processing facility in a PROFIBUS network were created utilizing integrated review and experimental design. Despite the need for further programming in the main PLC, the model's feasibility was shown by real-time data exchange and effective connectivity across many interfaces. Similarly, (Sousa et al., 2024) [58] created and improved a control system that links traditional S7-300 PLCs to IIoT platforms in an educational FMS context using Node-RED and OPC-UA. In addition to an integrated literary and technical review, it employed incremental development to optimize the program structure, minimize nodes, and organize variables via a CSV file to simplify maintenance and setup. The number of nodes dropped 30%, and the project size dropped 37%. The proposed method is scalable and efficient, but it requires technical support and documentation updates for large-scale industrial applications. Moreover, (Toc S et al., 2018) [59] studied an intermediate that links the OPC UA to the Modbus serial protocol using the IoT-2040 platform and Node-RED environment to provide interoperability in industrial water systems. The method required an intermediary architecture with time management, formatting, and data processing. The initial lab testing employed an Arduino, and a Wago PLC managed a wastewater pumping system. The results showed that the system is responsive and efficient, and the solution provides a non-intrusive, inexpensive, and efficient bridge to increase industrial IIoT communication between old and new systems. In a comparable study, (Nicolae A et al., 2018) [8] used the OPC UA protocol and Node-RED platform to construct a cheap, data-driven history system that can be linked to water sector SCADA and PLC systems. To integrate local systems and store data in an SQLite database, a Java application with a configurable graphical user interface, data export and analysis, and Node-RED integration was needed. The system was tested at an 8,000-person water treatment plant. Even with intermittent connection disruptions, the system worked effectively and provided trustworthy data. Future smart data analysis applications may use the model, which worked and scaled in industrial water settings. In alignment with this approach, (Tietz F et al., 2018) [60] aimed to establish an Internet of Things gateway connecting a cloud-based monitoring and control platform to a multi-function industrial station with several PLCs and communication protocols, such as S7 and MODBUS. The method entailed constructing an interactive web control panel, measuring response time, interfacing with PLCs using a Raspberry Pi running open-source Python, and delivering data via MQTT to Node-RED. The interface-PLC read time was 11.2 milliseconds. The technology may be expanded to bigger plants with future security advancements and delivers industrial-grade real-time reaction speeds. From a different perspective, (Khanmohammadi Hazaveh et al., 2024) [61] designed an industrial dishwashing system using Factory I/O software and a Hardware-in-the-Loop (HiL) PLC simulation. It then connects to SCADA systems using MQTT and Node-RED. The integrated development technique included designing a 3D virtual model, programming the PLC using RSLogix5000, creating an HMI with FactoryTalk View, and connecting all the pieces to a remote monitoring and operating system via SCADA. The system worked successfully in a simulated environment without faults or congestion, proving its potential as a means for establishing automated dishwashing systems in big facilities. We found that this instructional model is safe and effective for evaluating future industrial systems.

PLCs and the IoT and IIoT have revolutionized industrial automation. Combining PLCs with IoT/IIoT platforms allows cloud-based decision support, data analytics, predictive maintenance, and remote monitoring. PLCs are reliable in real-time process management. This integration modernizes, scales, and adapts traditional control systems to evolving industrial needs. Recent studies have examined various topologies and usage cases to demonstrate PLC-IoT integration's effectiveness in various sectors. (Fitria Suryatini et al., 2024) [62], examined Ziegler-Nichols and trial-and-error parameter tuning methods to create a dual-tank water level control system using PID based on an Omron PLC and IoT technology. An applied approach was used to build a real-world model of interconnected tanks, connect sensors and actuators to the PLC, and connect the system to Node-RED via Ngrok for remote control and real-time monitoring. Wireshark analyzed system reaction. Trial-and-error has greater steady-state accuracy, whereas ZN-1 has a shorter settling time. It monitors and controls with high precision and low latency, making it suitable for industrial applications. This trend continued with (Syufrijal et al., 2019) [63], who created a control system using PID in a Siemens S7-1200 PLC to maintain constant pressure in water distribution networks. The system would be remotely monitored via the Internet of Things. A prototype model with a three-phase pump, frequency converter, pressure sensors, HMI module, and Raspberry Pi was needed to deliver data to a cloud server using MQTT. System programming utilized JavaScript and TIA Portal. Results revealed that the system could quickly react to demand changes while sustaining 1.2 bar pressure. Integration of PLCs with IoT provides an effective and long-term approach to control and monitor industrial water distribution systems. In a related framework, (Możaryn et al., 2022) [64] developed a PLC-based fault isolation and remote monitoring system using IIoT technology to manage water levels in a three-tank system. Simulink was used to create a simulation environment and connect it to Node-RED via a Siemens IOT2040 gateway via OPC. The Siemens S7-1200 PLC used the Unknown Input Observer (UIO) technique to isolate. The results demonstrated the system success to detecting and isolating faults and enabling online monitoring at real-time. Similarly, (Ali M et al., 2020) [2] compared fuzzy control with standard PID algorithms to build a smart system for controlling and measuring water levels in tank using PLCs and IoT technologies. MQTT and MODBUS protocols were used to build a tiered system including sensors, network, processing, gateway, and cloud. IoT, smart control, and PLCs provide a reliable and effective remote industrial control solution with the opportunity to develop. In addition, (Chen et al., 2022) [65] planned to use a robotic arm and PLC to analyze temperature, pH, dissolved oxygen, and water level to construct an intelligent system for monitoring water quality in fish farms based on the Internet of Things. LoRa sends data to a central server, which uses an integrated design with a microprocessor for automated operation, a programmable controller, and sensors. The arm collects data and cleans the sensor after each usage, alerting for replacement. The results revealed improved management, decreased staff expenses, and accurate measurement. The system supports fish farming's digital transformation and environmental sustainability. A different perspective was presented by (Calderón et al., 2024) [66], who proposed connecting open-source hardware and software with PLCs to design and test an industrial IIoT architecture. It installed a four-layer architecture (sensor, network, middleware, and application) to a hybrid solar-hydrogen microgrid using Node-RED, Python, MariaDB, and Grafana for real-time data monitoring. The results demonstrated that this technique works perfectly in real life. In a related study, (Qin et al., 2022) [10] used IIoT with a mixed slow feature analysis (MSFA) algorithm to create a monitoring system for an integrated thermal pump system that can detect quickly faults and errors without the need for pre-integrated sensors. This built model was more flexible than traditional methods for early failures detection, practical, cheap, and more successful in monitoring legacy industrial system using IIoT techniques. In similar research, (Rai P et al., 2021) [67] examined the usage, advantages, and challenges of PLC and SCADA systems in thermal power plants, focusing on security in light of IIoT and Industry 4.0. It also examined network connectivity risks and examined prior research and application models that showed how big data analytics, cloud computing, and artificial intelligence have improved efficiency, security, and real-time monitoring. Despite technological advances, SCADA is still vulnerable to hackers, according to the report. It concluded that greater cybersecurity, standardized protocols, and automation-IT collaboration are needed for its future use. Another survey by (Chen et al., 2022) [68] proposed a smart, programmable intelligent IoT controller that used the Theory of Constraints (TOC) for wireless communication and PLC control to assist smart manufacturing. The method used an embedded controller using SunCre Flow Language, a simplified programming language, and RS-232 and Wi-Fi. On an oil and water mixing device, the system was tested for remote control, real-time alerting, and monitoring. The system supports smart alerts and real-time monitoring with little human input. This program proved effective in helping SMEs with Industry 4.0 applications. Expanding on this concept, (Mellado et al., 2022) [13] aimed to create an Industry 4.0-oriented programmable controller (IoT-PLC) using a containerized architecture for wireless communications, edge processing, and effortless cloud integration. The method included building a Raspberry Pi prototype with containers for control, filtering, HMI, and CoAP/OPC-UA communication. Performance assessment under container failure and movement scenarios and hands-on testing on a four-tank system with PID and MPC controllers followed. The results revealed that the system provides precise control and fast reaction times for industrial control. IoT-PLC is a possible platform for smart businesses since containers are flexible and reliable without compromising performance. (Gutierrez-Guerrero et al., 2019) [69] attempted to automate OPC UA server installation in industrial IIoT environments by automatically recognizing and connecting PLC modules without human intervention The technique included TCP/IP device identification, configuration meta-information exchange, OPC UA information model creation, and Modbus protocol connection to PLC parameters. The system was lab-tested using M-DUINO and Arduino One modules. The results demonstrated that the strategy might reduce human configuration errors and time. The recommended method enhances smart industrial system adaptability and scalability and is a solid first step in implementing the “Plug and Produce” concept in Industry 4.0.

Node-RED, a low-code, flow-based programming environment that integrates hardware, APIs, and internet services, is essential for IoT and IIoT. Its easy integration with MQTT, Modbus, and OPC-UA makes it perfect for industrial situations. Node-RED simplifies IoT/IIoT remote device management, automation orchestration, and real-time data collection. This synergy makes Node-RED essential to Industry 4.0 designs, enabling the rapid deployment of intelligent industrial solutions like dynamic system visualization and predictive maintenance. As an example of predictive maintenance, (Nugraha et al., 2023) [70] connected temperature sensors to the Internet of Things using the Node-RED platform to periodically measure the temperature of the transformers. Four K-type thermocouples were connected to the transformer windings, and a computer running the Node-RED platform read the data from the temperature sensors and displayed the actual winding temperature using the Node-RED dashboard. To enable preventative and predictive maintenance, a 90°C cooling mechanism was used to protect the transformer windings from damage when temperatures rise. The results demonstrated that the system operated efficiently, resulting in improved transformer maintenance and infrastructure improvements. Following a similar approach, (Bahri et al., 2024) [11] used the Node-RED platform to control the speed of induction motors. Using a PLC (S7-1200) and a variable speed drive (VSD) (Sinamic G120), a remote-control system was designed via a computer server, human-machine interface (HMI), and smartphone interfaces. The devices were connected via Ethernet. The significant advantages of this system are the control of the motor speed and direction of rotation, and its low cost. (Chen et al., 2024) [71] presented a similar concept in Built an IoT-based home lighting control system using Node-RED and the MQTT, Modbus protocols running on Linux. The research results showed that the web-based Node-RED platform transformed the old system into a new one with greater efficiency and lower costs.

3. Conclusion

This narrative paper examines more than 70 recent studies, exploring the advantages and disadvantages of various technologies. Significant progress has been made in the field of industrial automation by combining PLC units, Node-RED tools, and IIoT technology to develop real-time control, predictive equipment maintenance, and optimized energy utilization, representing significant advances.

Finally, this integration of the three elements in industrial automation processes leads to the creation of scalable, expandable, and intelligent frameworks that will greatly serve the factories of the future. Continued progress in various fields of industrial automation, artificial intelligence, 5G networks, and cybersecurity, despite current challenges, will lead to the development of industrial control systems in Industry 4.0 and beyond.

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