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IOT ENABLED REAL TIME LOAD HEIGHT MONITORING AND CONTROL SYSTEM USING PLC AND HMI FOR SMART INDUSTRIAL

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ABSTRACT
This study develops a laboratory-scale prototype of an IoT-enabled, real-time load height monitoring and control system that integrates Programmable Logic Controllers (PLCs), Human–Machine Interfaces (HMIs), and cloud-based MQTT communication. Developed and validated under controlled conditions, the prototype consistently demonstrates sub-2-second latency (0.66–1.58 seconds) across varying network speeds, confirming its technical feasibility for future industrial applications. Proximity sensors and PLCs enable precise load height measurement, while the Haiwell C7S HMI provides real-time visualization and multi-platform control via web and mobile interfaces. Experimental results highlight the prototype's robustness, scalability, and alignment with Industry 4.0 frameworks, offering a foundational architecture for subsequent industrial deployment. This work bridges the gap between theoretical Cyber-Physical Systems (CPS) principles and practical implementation, emphasizing adaptability and low-latency performance for smart manufacturing ecosystems.
Keywords: *Internet of Things, Real Time Monitoring, Load Height Control, Programmable Logic Controller, Industrial Automation*.

1. Introduction

In modern industrial environments, automation and precise control systems are essential for maintaining operational efficiency and ensuring compliance with safety standards (Sharma, 2024; Wan et al., 2019). Among various processes, real-time monitoring and control of load height is a critical task, particularly in industries such as warehousing, manufacturing, and logistics (Lyu, 2024; Prunet et al., 2024b, 2024a; Raza et al., 2024). An IoT-enabled system capable of continuously tracking and adjusting load height is crucial to prevent overloading, ensure transportation safety, and maintain uninterrupted production workflows (Dionova et al., 2023; Hendrawati et al., 2025; Presciuttini et al., 2024). Traditional load monitoring methods, which rely on manual measurements and adjustments, are often time-consuming, prone to human error, and inadequate to meet the dynamic demands of contemporary industry (Molka-Danielsen et al., 2018). Consequently, industries are increasingly adopting smart solutions that emphasize real-time automated monitoring, integrating Internet of Things (IoT) and Human–Machine Interface (HMI) technologies.

Programmable Logic Controllers (PLCs) have long been central to industrial automation due to their robustness and reliability in managing complex processes (Bakshi et al., 2019; Mellado & Núñez, 2022). They offer flexible programming capabilities and support diverse input/output (I/O) configurations, making them well-suited for monitoring and control applications. Recent technological developments have enhanced PLC systems by integrating them with IoT platforms, enabling real-time data transmission, remote monitoring, and wireless control-capabilities that are essential for supporting Industry 4.0 applications (Folgado et al., 2024; P. Senna et al., 2023).

Conventional systems typically limit control to localized HMI panels. In contrast, the architecture proposed in this study utilizes interoperability between PLC, IoT, and HMI systems to unify supervision across web, HMI, and mobile interfaces. This accessibility across multiple platforms ensures that data can be synchronized and accessed by decision-makers regardless of their location, including on-site technicians, remote supervisors, or supply chain managers. Each of these roles can interact with the system and initiate timely corrective actions based on the same real-time data.

Additionally, HMI technology enhances the usability of the overall system. Solutions such as the Haiwell C7S HMI allow operators to visualize information, interact directly with control processes, and make adjustments as needed in real time (Siddique, 2020). Together, these technologies support operational flexibility, reduce reliance on manual intervention, and improve the quality of decision-making.

Despite these advances, a significant research gap remains. Many legacy systems, such as the Mitsubishi FX series and Siemens S7-200 PLCs, struggle to integrate IoT functionality effectively. This difficulty arises from limited network capabilities, reliance on proprietary protocols, and high latency in data transmission-often exceeding five seconds. These limitations hinder real-time remote monitoring, reduce accessibility across platforms, and obstruct seamless interoperability with enterprise-level systems such as Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) (Alice, 2025; Caiza & Sanz, 2024; Syreyshchikova et al., 2020; Tabim et al., 2024).

This research contributes by developing a robust load height monitoring system that operates in real time and achieves transmission speeds of less than two seconds, surpassing conventional industrial monitoring systems (Bakshi et al., 2019; Farahani & Monsefi, 2023). For instance, one study reported an average latency of approximately five seconds for the integration of PLC and IoT in industrial monitoring applications (Hirman et al., 2020). In contrast, the system introduced in this paper demonstrates an average latency of 1.8 seconds, representing a reduction of more than 60 percent. This improvement validates the proposed architecture as effective in meeting the real-time demands of industrial environments.

The system also supports centralized and remote operations through access from personal computers, smartphones, and web portals. Furthermore, it offers strong scalability and integration capabilities with industrial enterprise platforms, aligning with the strategic goals of Industry 4.0 (Barton et al., 2024; Mardonova & Choi, 2018; Mutua, 2024). In comparison with prior research, which often addressed only partial aspects such as basic sensor integration or simple HMI deployment, this study introduces a comprehensive architecture tailored for smart industrial environments. The proposed system integrates PLC, IoT, and HMI technologies to address challenges of latency, interoperability, and enterprise-level integration, establishing a new reference framework for industrial load monitoring solutions compatible with Industry 4.0.

The remainder of this paper is structured as follows: Section 2 discusses recent developments and challenges in PLC, IoT, and HMI integration. Section 3 outlines the research methodology, including system architecture and development stages. Section 4 presents experimental results and performance evaluations. Finally, Section 5 concludes the study and outlines directions for future research.

2. Literature Review

Accurate load monitoring and control are critical components of modern industrial automation systems. Traditional approaches, which heavily rely on manual measurement and adjustment, often fail to meet the demands for responsiveness and precision required in contemporary industrial environments (Chen et al., 2024; Farahani et al., 2018; Presciuttini & Portioli-Staudacher, 2024). As a result, recent studies have increasingly focused on integrating Programmable Logic Controllers (PLCs) with Internet of Things (IoT) frameworks to improve data accessibility, enable real-time decision making, and support remote control capabilities. PLC systems, known for their robustness and reliability, are now evolving toward greater interoperability with IoT technologies, allowing for real-time control and remote access (Hirman et al., 2020; Presciuttini et al., 2024; Yordanova et al., 2020).

IoT-based solutions enable data to be transmitted to cloud platforms in real time, allowing operators to access and analyze information remotely. This reduces operational downtime and enhances decision-making efficiency. Complementing these technologies, Human–Machine Interface (HMI) systems offer intuitive interfaces for data visualization and interaction. Several studies have highlighted the effectiveness of HMIs such as the Haiwell C7S in simplifying operations and enabling centralized control. Furthermore, recent advancements have demonstrated that cloud-based SCADA and HMI systems can improve monitoring and control by providing low-latency data transmission and access across platforms, thus addressing the limitations of traditional architectures (Babayigit & Abubaker, 2024; Dai et al., 2016) .

Despite these advancements, existing research often remains narrowly focused. For instance, one study proposed a basic PLC and IoT integration model with approximately five-second latency but did not ensure integration across multiple platforms, particularly smartphones and enterprise systems like ERP (Hirman et al., 2020). Similarly, another study demonstrated a wired PLC and IoT configuration that inherently restricted system scalability and operational flexibility (Bakshi et al., 2019). Such limitations are not uncommon. Transmission delays in legacy systems often range from four to six seconds-considerably slower than the sub-two-second benchmark required for high-performance industrial applications. Older PLC systems also typically lack the flexibility to integrate with enterprise-level platforms such as ERP and MES, limiting digital transformation at the organizational level (Syreyshchikova et al., 2020).

In addition, most existing solutions are built on isolated or proprietary platforms such as standalone HMIs, closed mobile applications, or private cloud systems. These fragmented architectures lack interoperability and centralized control across web, HMI, and mobile interfaces. As a result, industrial stakeholders are unable to access synchronized operational data or initiate supervisory actions across devices or from remote locations (Dhingra et al., 2019; Islam et al., 2018; Mahbub & Shubair, 2023). This fragmentation limits operational flexibility and prevents the realization of IoT’s full potential to support centralized monitoring and rapid response to process deviations.

To address these gaps, Table 1 compares previous research with the proposed system in terms of methods used, latency performance, and scalability attributes. Emerging technologies such as MQTT have demonstrated efficient transmission performance in real time. One study successfully applied MQTT in environmental monitoring, citing its low-latency benefits (Kodali & Mahesh, 2016a). However, their application remained limited to environmental parameters, highlighting an opportunity to adapt such protocols to more complex industrial scenarios.

The role of HMI systems has also expanded significantly. One study explored fuzzy logic control implemented via HMI, reporting usability benefits but lacking integration with cloud-based platforms necessary for realizing smart manufacturing goals (Yordanova et al., 2020). Similar limitations were noted in another study (Presciuttini & Portioli-Staudacher, 2024). Recent research also reveals contradictions in performance across varied conditions. For instance, one experiment demonstrated that MQTT-based monitoring systems achieved latency below two seconds in laboratory environments but experienced significant delays and data packet loss under unstable network conditions (Chen et al., 2024; Kodali & Mahesh, 2016a, 2016b). This shows that while IoT-based systems can perform well under controlled settings, their reliability may diminish under real-world constraints such as fluctuating networks and harsh environments. Therefore, robust system design is essential to ensure consistent performance in practical deployments.

Theoretically, the integration of PLC, IoT, and HMI technologies aligns with Cyber–Physical Systems (CPS) principles, where digital and physical domains are interconnected to enable real-time optimization and autonomous control (Matana et al., 2023). In this study, PLCs, IoT communication, and HMI interfaces form a closed-loop system that continuously processes and acts on sensor data. This design supports autonomous feedback, decentralized decision making, and real-time synchronization across devices. Furthermore, the system’s compatibility with ERP and MES platforms demonstrates its alignment with the Industry 4.0 vision of intelligent, interconnected manufacturing.

Despite the strong conceptual foundation, practical implementation continues to face challenges including outdated communication protocols, hardware rigidity, and a lack of modularity. At a strategic level, achieving digital maturity requires integrated IoT devices, scalable cloud infrastructure, and ERP/MES compatibility (P. Senna et al., 2023). However, many PLC-based monitoring systems still fall short, leading to siloed data and underutilized decision support.

In summary, while considerable advancements have been made in integrating PLC, IoT, and HMI systems for industrial automation, several technical gaps and inconsistencies remain. Persistent issues include high latency, lack of multi-platform interoperability, ERP/MES integration difficulties, and limited adaptation of lightweight communication protocols in complex scenarios.

To address these gaps, this study proposes a scalable load height monitoring and control system with real-time responsiveness. By adopting MQTT-based cloud communication and integrating PLC, IoT, and HMI technologies, the system bridges local operations with enterprise-level platforms. The proposed framework is based on CPS, enabling tight integration of sensing, communication, and control functions. It operationalizes CPS concepts through autonomous feedback loops, decentralized decision making, and real-time interactions. Its compatibility with ERP and MES systems reinforces the Industry 4.0 vision of intelligent, interconnected manufacturing.

Table 1 - Comparison of Prior Works and the Proposed System in Terms of Methods, Latency, and Scalability

Study	Methods	Latency	Scalability
(Hirman et al., 2020)	PLC-IoT integration	~5 seconds	Limited multi-device support
(Bakshi et al., 2019)	Basic PLC with wired connections	~6 seconds	Limited integration with mobile platforms
(Shukla et al., 2017)	Traditional PLC (without IoT)	>5 seconds	Poor ERP/MES integration
(Mellado & Núñez, 2022)	IoT-PLC with containerization, MQTT messaging	~2-3 seconds	Good for cloud-edge hybrid systems
(Wang et al., 2024)	Cloud-based intelligent monitoring using MQTT/Modbus	<2 seconds	High scalability (PC, smartphone, ERP)
(Caiza & Sanz, 2024)	Digital Twin with real-time MQTT data for MES	~1–2 seconds	Full integration with MES and ERP platforms
(Di Capaci & Scali, 2021)	Cloud centralized monitoring using MQTT	~1.8 seconds	Scalable to various industrial plants
(Langmann & Stiller, 2019)	Smart PLC services in Industry 4.0	~3-4 seconds	Moderate scalability with smart device interface
This Study (Dwiana et al.)	PLC, IoT, and HMI system integration with MQTT and HaiwellCloud	0.66–1.58 seconds	High scalability (PC, smartphone, ERP/MES compatible)

As shown in Table 1, the proposed system offers better latency and scalability than earlier approaches. Some studies reported delays of five to six seconds and limited multi-device support (Bakshi et al., 2019; Hirman et al., 2020). In contrast, the system in this study maintains latency under two seconds and integrates easily with PCs, smartphones, and enterprise platforms. While a direct comparison with PLC brands like Siemens S7-1200 or Mitsubishi Q Series was not performed, literature indicates these platforms often require additional modules or proprietary tools for similar functionality (Shukla et al., 2017; Syreyshchikova et al., 2020) This underscores the practical advantage of the proposed system in both performance and integration ease for smart industry use.

3. Research Methods

This study develops a laboratory-scale, IoT-enabled real-time load height monitoring and control system, in which a Programmable Logic Controller (PLC) continuously acquires height data from proximity sensors mounted on a conveyor. The PLC dynamically adjusts operational parameters based on real-time measurements, while the Human–Machine Interface (HMI) allows operators to visualize and manage load height remotely. The methodology follows the System Development Life Cycle (SDLC) model, ensuring a structured, efficient, and scalable development process (Olusanya et al., 2024). The system incorporates IoT technologies, including the MQTT protocol and cloud platforms such as HaiwellCloud, to enable synchronized data transmission across personal computers and smartphones, thereby enhancing operational flexibility and multi-platform accessibility. Key features include a communication adapter (RS232 to RS422), lightweight protocols for fast and reliable data transmission, and automated functions such as threshold alarms and remote counter resets to minimize manual intervention. Designed with scalability in mind, the system supports integration with Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES), promoting comprehensive operational digitization and facilitating industrial IoT adoption.

This research employs an applied research and development (R&D) methodology, supported by a design-based research (DBR) framework. The study emphasizes the design, development, and laboratory-based validation of a prototype IoT-enabled real-time load height monitoring and control system. It is guided by two key research questions: (1) How can a PLC, IoT, and HMI system be designed to achieve real-time monitoring with latency below two seconds? (2) How scalable and user-friendly is the system when integrated across multiple platforms, such as PCs, smartphones, and ERP/MES systems?

To address these questions, two hypotheses are proposed. The first hypothesis (H1) posits that integrating MQTT-based communication with PLC and HMI technologies will result in transmission latency under two seconds. The second hypothesis (H2) suggests that the system interfaces-including HMI and mobile applications-will demonstrate high usability based on user evaluations.

The research follows the SDLC methodology to systematically organize the development process. In the planning phase, the core problem was identified: the lack of scalable and real-time remote monitoring systems in traditional industrial settings. Objectives were defined to ensure multi-platform accessibility, low-latency communication, and integration with enterprise-level platforms. During the analysis phase, a comprehensive literature review was conducted to assess existing approaches and identify gaps. This informed the definition of functional and non-functional requirements, with an emphasis on interoperability, reliability, and scalability for industrial environments.

In the design phase, system architectures were developed, including communication flow diagrams, HMI designs using the Haiwell C7S-W, and hardware configurations with the Mitsubishi FX1N-24MR PLC. Lightweight protocols such as MQTT were selected for their efficiency and compatibility with IoT environments.

The implementation phase involved building the system using HaiwellScada for the HMI and GX-Works2 for PLC programming. Hardware components were integrated according to the design specifications. Laboratory-scale testing involved functional validation and performance evaluation. Data transmission latency was tested across 50 trials under varying internet conditions. Object detection through proximity sensors and system responsiveness were also measured. The maintenance phase monitored long-term system reliability, focusing on communication stability and identifying minor improvements for future scalability.

The SDLC approach incorporated iterative development cycles. After each round of testing, user and system feedback were analyzed, leading to refinements in communication reliability and HMI responsiveness. To evaluate usability, a small-scale user test was conducted with five technicians experienced in industrial monitoring. Participants performed representative tasks using the web, HMI, and mobile interfaces. Following these sessions, participants provided open-ended feedback regarding the system’s intuitiveness, responsiveness, and overall user experience. The results validated the system's ease of use and cross-platform operability.

Through this iterative development, laboratory-scale testing, and validation process, the proposed PLC, IoT, and HMI system demonstrates technical robustness, user-centered design, and practical relevance for smart industrial applications.

3.1 System Architecture and Communication Flow

The system architecture and communication flow are illustrated in Figure 1, which depicts the communication protocol layout. The communication link between the Programmable Logic Controller (PLC) and the Human–Machine Interface (HMI) is established using a serial adapter that converts RS232 signals to RS422, ensuring stable and reliable data exchange within the system.

To support connectivity across multiple platforms, including personal computers and smartphones, the system employs the MQTT protocol. MQTT was selected for its lightweight structure, transmission efficiency, and capability to enable real-time data exchange, making it ideal for Internet of Things (IoT) applications. In this system, the MQTT broker is hosted on the HaiwellCloud platform, which handles message distribution between connected devices, ensuring low-latency communication for both desktop and mobile users.

The system offers flexible access options tailored to various user platforms. Smartphone users can interact with the system via the HaiwellCloud mobile application, which provides remote monitoring and control functionality. Meanwhile, users on personal computers can access the system through the HaiwellCloud web portal. This cross-platform accessibility delivers a consistent and user-friendly interface that supports efficient remote operations regardless of device.

HaiwellCloud was chosen over other cloud platforms, such as AWS IoT, due to its native compatibility with Haiwell PLC and HMI devices, lower operational costs, and simplified setup process optimized for industrial applications.

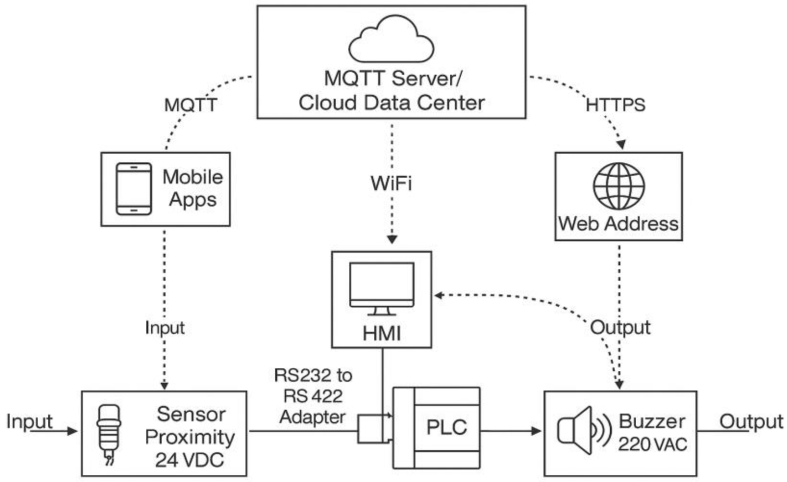

Fig. 1. Communication Protocol Layout

3.2 Operational Workflow and Real-Time Monitoring

The operational workflow of the system, illustrated in Figure 2, outlines the core functionality and steps required for real-time monitoring and control in industrial environments. The process begins with input signal acquisition, where proximity sensors mounted on a conveyor continuously measure the height of each passing load. The PLC processes this data in real time to evaluate whether each load complies with predefined safety and operational thresholds. If deviations are detected, the system enables immediate corrective action.

The processed data is then transmitted to the Human–Machine Interface (HMI), where it is displayed visually, allowing local operators to monitor system status. Simultaneously, the HMI uploads the data to a cloud platform, providing remote access through smartphones and personal computers. This dual access via web and mobile platforms enhances operational flexibility, enabling both supervisors and operators to monitor and manage the system from any location.

The workflow incorporates a threshold-based alert and reset mechanism. When a predefined item count is reached, the PLC activates a buzzer alarm to notify the operator. For example, in a simulated warehouse scenario, this feature prevents bottlenecks on the conveyor. If the accumulation of bottles or containers exceeds the designated threshold, an alert is triggered, prompting the operator to remove excess items. This intervention prevents jams, spillage, or production halts, thereby ensuring smooth and continuous packaging operations.

Once the alert is addressed, the system requires a counter reset. This action can be performed remotely using the HMI, smartphone, or PC. This end-to-end workflow ensures efficient operation, enables real-time monitoring, and supports remote control, thereby addressing key challenges in industrial automation.

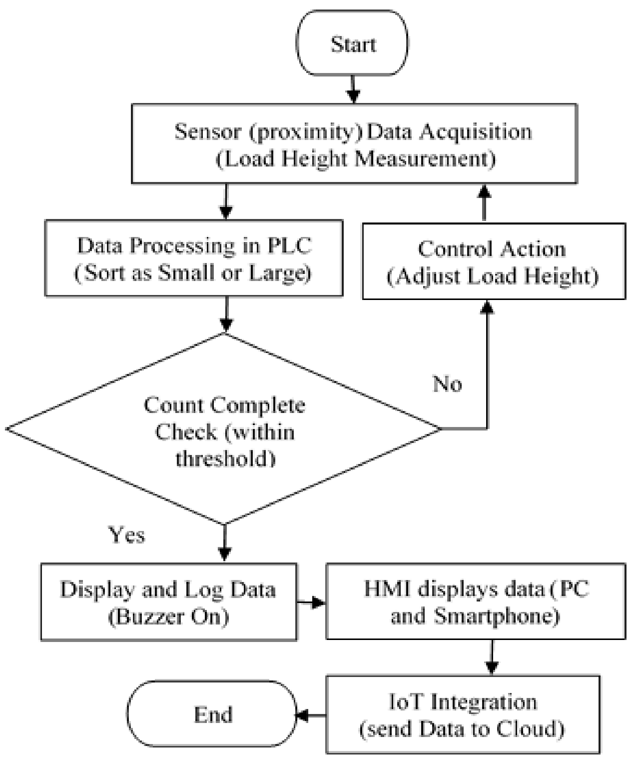

Fig. 2. Operational Workflow for Real Time Monitoring and Control

3.3 Development Stages Using the SDLC Methodology

This research applies the System Development Life Cycle (SDLC) model to guide the structured development and prototype implementation of the proposed system, evaluated within a laboratory environment. This approach ensures a systematic, iterative process that encourages collaboration among developers, designers, and analysts.

The methodology begins with the planning phase, which identifies the core challenge: enabling remote monitoring and control of industrial processes in real time without requiring physical presence near machinery. Specific goals include achieving multi-platform accessibility, enhancing system reliability, and integrating IoT technologies.

During the analysis phase, an extensive literature review was conducted to evaluate existing solutions and identify areas for innovation. The findings revealed that legacy systems often suffer from limited scalability and poor integration with enterprise platforms. These insights informed the inclusion of compatibility with Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) in the proposed design. In addition, recurring limitations in remote data access capabilities among traditional PLC systems led to the adoption of the MQTT protocol for its lightweight and flexible communication structure. Functional and non-functional requirements were defined to meet industrial needs, focusing on strengths, weaknesses, and areas for improvement.

In the design phase, a prototype was developed using carefully selected hardware and software. The Human–Machine Interface (HMI) was created using HaiwellScada to offer an intuitive user experience. Programmable Logic Controller (PLC) programming was completed using GX-Works2 to ensure seamless communication across system components. Hardware integration included the assembly of the Haiwell C7S-W IoT Cloud HMI and compatible PLC. Simulations were performed to validate functionality, ensuring system reliability prior to real-world deployment.

The implementation and testing phase involved deploying the prototype in a simulated industrial environment within laboratory conditions. This stage evaluated system functionality and adaptability under varying operational conditions. Key performance indicators such as data transmission speed, response time (targeted under 1.5 seconds), and operational accuracy were measured. Fifty trials were conducted across different internet speed tiers to ensure consistent and reliable results. These real-time tests validated the MQTT communication framework and confirmed the effectiveness of cloud-based remote access. The results demonstrated that the system successfully met core operational requirements.

3.4 System Components and Features

This research employs the Haiwell C7S-W IoT Cloud HMI with a 7-inch display as a core component of the proposed system. The HMI provides advanced functionalities suited to industrial applications, including support for remote access and control through a dedicated smartphone application. This enables users to monitor operations and interact with the system in real time. Additionally, the HMI offers real-time alarm notifications via the mobile application, allowing prompt user intervention in the event of critical system conditions.

The device integrates seamlessly with databases and enterprise platforms such as Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES), ensuring comprehensive system connectivity with broader industrial infrastructure. Its support for various third-party protocols enhances compatibility with a range of industrial equipment, including Programmable Logic Controllers (PLCs), inverters, and auxiliary instrumentation. These features align the system with modern industrial standards and allow for future scalability and enhancements.

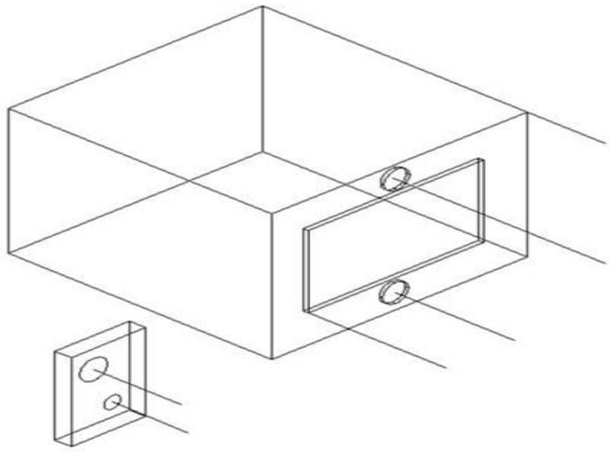

Fig. 3. Design of the Equipment

Figure 3 illustrates the equipment design, showing the system's primary physical components: (1) Electrical Panel Box, (2) Power Lamp, (3) Buzzer Alarm, (4) Haiwell HMI, (5) Large Proximity Sensor, and (6) Small Proximity Sensor.

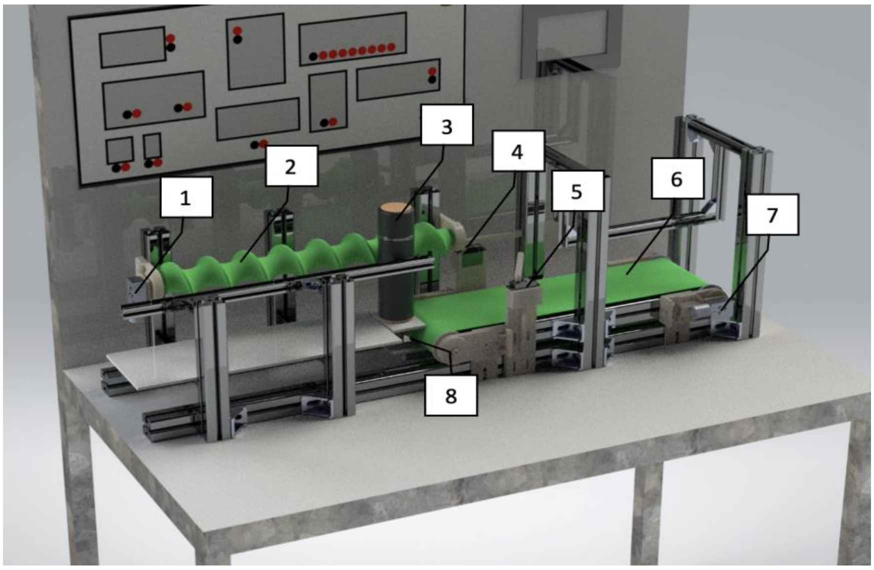

Fig. 4. Schematic Layout of the Laboratory Scale Prototype System.

To provide a clearer understanding of the laboratory-scale prototype configuration, Figure 4 presents the schematic layout diagram. This design highlights the integration of essential mechanical and sensing components in a controlled laboratory environment to simulate industrial material handling processes. The scaled-down prototype includes: (1) DC Motor 1, (2) Screw Conveyor, (3) Object (Workpiece), (4) Left Servo Motor, (5) Right Servo Motor, (6) Belt Conveyor, (7) DC Motor 2, and (8) Load Cell (Scale). Each component replicates industrial-grade functionality while operating under laboratory testing conditions.

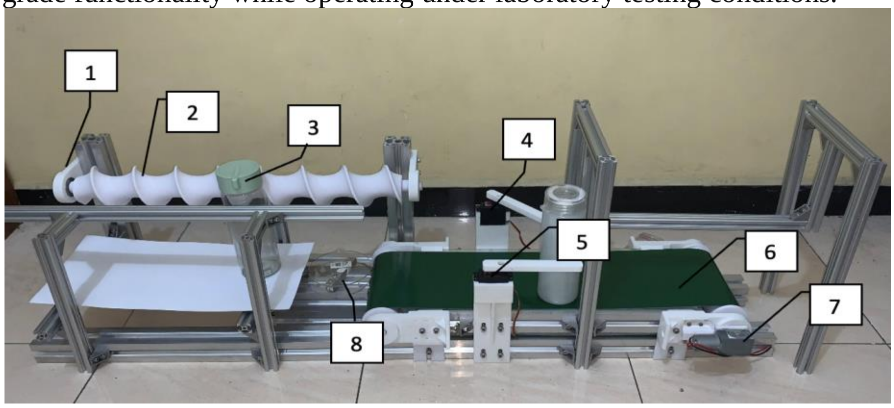

Fig. 5. Laboratory Implementation of the Prototype System for Controlled Testing.

4. Results and Discussions

The prototype was assembled and tested exclusively in a laboratory environment to validate its functionality under controlled conditions. Figure 5 illustrates the integration of control, actuation, and sensing components within a simulated industrial setup, including the PLC, HMI, conveyor mechanisms, and proximity sensors. This configuration enabled systematic evaluation of real-time data transmission, latency, and sensor accuracy without requiring full-scale industrial deployment. Testing was conducted under controlled conditions to isolate variables such as network latency and sensor accuracy, ensuring the reproducibility of results without interference from external industrial factors.

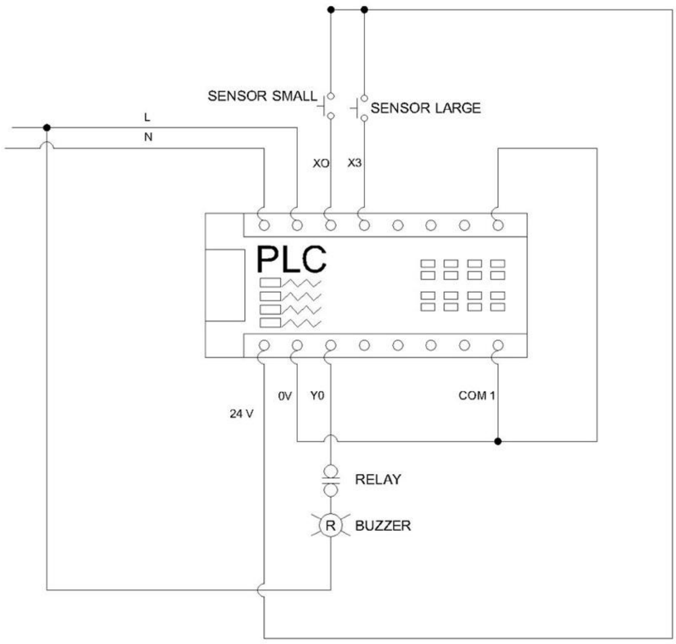

Fig. 6. PLC Wiring Diagram Of Sensors And Alarm System

The installed components correspond directly to those outlined in the schematic layout, confirming the successful realization of the prototype's mechanical and control architecture. This test setup provided the foundation for subsequent validation stages, including wiring, connectivity checks, and real-time data transmission trials. The image highlights the coordinated operation of the PLC, Human–Machine Interface (HMI), conveyor mechanisms, servos, and sensors under laboratory test conditions.

Table 2 - I/O Addressing Integration of Sensors and Alarm System

No.	Address	Function	No.	Address	Function
1	X0	Sensor Proximity Small	12	D14	Balance Large
2	X3	Sensor Proximity Large	13	D20	Realtime Large
3	D100	Target Small	14	D2	Time Product
4	D102	Actual Small	15	D22	Actual Percentage Large
5	D104	Balance Large	16	D24	Balance Percentage Large
6	D110	Realtime Small	17	M800	Always On
7	D112	Time Product Small	18	M0	Reset Target Small
8	D122	Actual Percentage Small	19	M8103	1 Sec Clock Pulse (flicker)
9	D124	Balance Percentage Small	20	M10	Reset Large
10	D10	Target Large	21	Y0	Buzzer
11	D12	Actual Large			

A Mitsubishi FX1N-24MR compact PLC was used and programmed via GX-Works2 software to develop the IoT-enabled prototype. The wiring diagram (Figure 6) and Table 2 illustrate the connections between the PLC and peripheral components such as proximity sensors and the buzzer alarm. The prototype's operational flow begins with the configuration of target load height thresholds. As loads pass along the conveyor, proximity sensors measure their height and transmit the data to the PLC. If the height falls outside the designated range, the system activates alerts and may simulate adjustments to conveyance behavior. Small items trigger the small sensor, while larger items activate both sensors.

Figure 7 shows the assembled prototype layout, which features a compact and accessible design. It integrates essential hardware including the electrical panel box, power lamp, buzzer alarm, Haiwell HMI, and proximity sensors, offering efficient space utilization and simplified maintenance access.

Fig. 7. Device Overview - Compact and Functional Design

The interface design for both HMI and web access (shown in Figure 8) emphasizes usability through clear menus, target settings, real-time data visualization, and remote control features. The IoT Cloud HMI Haiwell C7S-W with a 7-inch display was developed using Haiwell Cloud SCADA Designer software. While the hardware setup demonstrates technical integration, its greater significance lies in validating that the prototype supports real-time, cross-platform access-critical for flexible industrial control strategies.

The interface consists of three screens: an initial screen displaying the system title and navigation options; a settings screen for configuring targets, displaying actual values, and resetting counters; and a performance screen with pie charts visualizing operational metrics for small and large items.

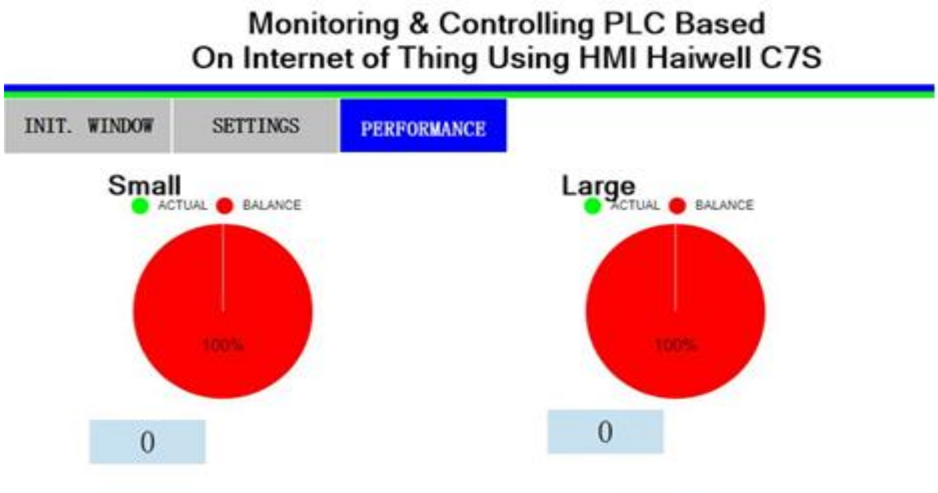

Fig. 7. Performance Display on HMI and Web Visualizing Operational Metrics with Pie Charts

An adjustable timer enables control over the frequency of pie chart updates, ensuring intuitive real-time feedback. Compared with systems reported in earlier studies that exhibited transmission delays of 2 to 3 seconds (Farahani & Monsefi, 2023), the prototype developed in this study consistently achieves transmission speeds below 1.6 seconds, reflecting an average latency improvement of approximately 30 percent.

The system uses an Omron E2E-X2F1 inductive proximity sensor for detecting metallic objects within a range of 2 mm. Experiments were conducted at internet speeds of 2.58 Mbps, 6.56 Mbps, and 5.56 Mbps (see Table 3). Results indicate that the prototype achieves data transmission delays between 0.66 and 1.58 seconds across different conditions. These findings comply with ISO 50001 guidelines, which recommend response times below 2 seconds for monitoring and control systems. The prototype's stable performance under varying network conditions confirms its technical viability for further development.

Table 3 - The Data Transmission Speed from HMI to Mobile /Web Platforms

No.	Internet Speeds of 2.58 Mbps	Internet Speeds of 6.56 Mbps	Internet Speeds of 5.56

					Mbps	
	Transmission Speed to Mobile Apps (sec)	Transmission Speed to web platform (sec)	Transmission Speed to Mobile Apps (sec)	Transmission Speed to web platform (sec)	Transmission Speed to Mobile Apps (sec)	Transmission Speed to web platform (sec)
1	1,13	1,13	1,12	1,12	1,06	1,06
2	1,58	1,58	0,86	0,86	1,06	1,06
3	1,00	1,00	1,06	1,06	1,18	1,18
4	0,66	0,66	0,66	0,66	1,58	1,58
5	1,58	1,58	0,98	0,98	1,45	1,45
6	0,66	0,66	0,86	0,86	0,66	0,66
7	0,94	0,94	1,05	1,05	0,73	0,73
8	1,19	1,19	0,92	0,92	0,92	0,92
9	1,13	1,13	0,73	0,73	0,99	0,99
10	0,86	0,86	0,80	0,80	0,80	0,80

The architecture of this prototype aligns with the principles of Cyber–Physical Systems (CPS), integrating physical sensors, PLC logic, and networked communication to enable autonomous feedback loops. Real-time height monitoring is embedded in a closed-loop control strategy that embodies CPS theory, where sensor data influences PLC action, and IoT connectivity enables remote decision-making. The MQTT protocol ensures low-latency communication (<2 s), addressing the CPS need for synchronized coordination under fluctuating conditions (Oks et al., 2022). Moreover, the system's multi-platform compatibility supports Industry 4.0 objectives by connecting localized control with enterprise-level analytics.

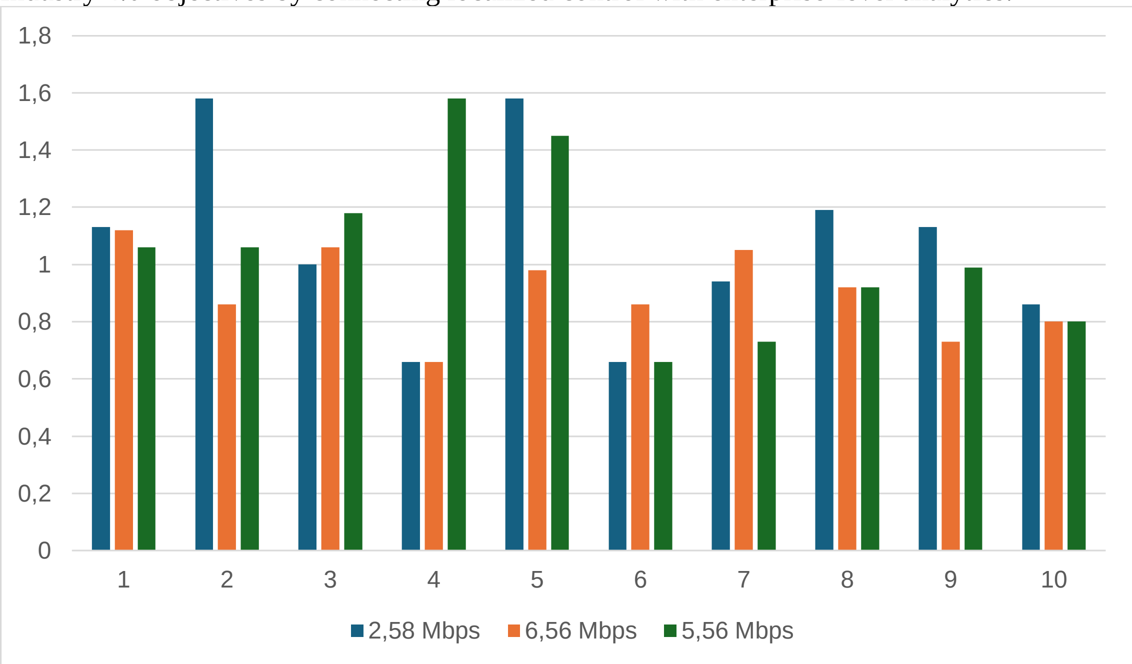

Fig. 8. Evaluation of Data Transmission Speed under Varying Internet Conditions

The correlation between internet speed and system latency is illustrated in Figure 9. Increasing bandwidth to 6.56 Mbps reduced average latency by about 30 percent compared to 2.58 Mbps, demonstrating the prototype's efficiency in leveraging available network resources.

The proximity sensor consistently detected objects within the expected range. Object trials confirmed the sensor's ability to differentiate item sizes based on height, with detection accuracy up to 2 mm (see Table 4). While this precision is ideal for strict height control, it may limit flexibility in detecting non-metallic or oversized items. Future improvements may include broader-range sensors or hybrid detection technologies to increase adaptability.

Table 4 - Object Classification Based on Heights Detected by Sensors

No.	Object Height (cm)	Small	Large
1	6	Detected	-
2	8	Detected	-
3	9	Detected	-

4	13	-	Detected
5	15	-	Detected

While the current configuration supports high-accuracy industrial needs, ongoing research may integrate Digital Twin (DT) technology for predictive analytics, optimization, and enhanced synchronization between physical assets and their virtual counterparts (Ionescu et al., 2025). Incorporating DT could expand system capability toward proactive maintenance and smarter manufacturing processes. Moreover, enhancing detection flexibility through multi-material sensing technologies would further increase the prototype's industrial relevance.

Data integration across HMI, mobile, and PC platforms was seamless, confirming the system's interoperability. This aligns with the research goal of enabling flexible monitoring and control across devices-a key element of scalable smart manufacturing. Accurate detection of object heights ranging from 6 cm to 15 cm further confirms the prototype's utility in scenarios demanding strict load management.

User evaluation was conducted in a controlled laboratory setting with five participants familiar with industrial monitoring systems. Through structured tasks and open-ended feedback, these evaluators consistently noted the prototype's intuitive interface, clear visualization, and ease of remote access. While the evaluation does not reflect deployment in a full-scale industrial environment, it provides meaningful insights into the prototype's usability and practical potential for future implementation. Although no quantitative metrics were gathered, these findings suggest that the prototype meets expectations for usability and workflow improvement in test settings.

In summary, the developed prototype achieved its objectives: enabling real-time remote monitoring and control, supporting cross-platform access, and validating technical scalability aligned with Industry 4.0 standards.

5. Conclusion

This research successfully developed and validated a laboratory-scale, IoT-enabled prototype for real-time load height monitoring and control. The system consistently achieved low-latency performance (0.66–1.58 seconds) under controlled network conditions, demonstrating its technical feasibility for future industrial applications. The prototype's multi-platform interoperability and CPS-aligned architecture address key requirements of Industry 4.0. However, further validation in actual industrial environments is necessary to assess scalability, operational resilience, and long-term reliability. Future work will focus on industrial-scale testing, sensor fusion for non-metallic object detection, and AI integration for predictive maintenance. These advancements are expected to transition the prototype into a robust, deployable solution for smart manufacturing, effectively bridging the gap between laboratory innovation and real-world industrial adoption.

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