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PLC and HMI Based Control and Monitoring System of the Xeno Drinking Water Factory

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Abstract

The automation of small-scale production facilities using affordable technology is critical for enhancing operational efficiency in developing regions. Previously, the Xeno Drinking Water Factory, located in Savannakhet Province, Lao PDR, faced significant challenges, including inaccurate manual bottle counting, inefficient water tank level monitoring, and the absence of reliable production data. This study presents the design and implementation of an automated bottling system based on a Programmable Logic Controller (PLC) and a Human-Machine Interface (HMI) for 20-liter drinking water bottles. The developed system integrates a Mitsubishi FX1N-40MR PLC, a SAMKOON HMI, and a proximity sensor to automate bottle counting and system status display. Comprehensive testing demonstrated that the system achieved 100% accuracy in bottle counting, provided real-time alerts, and supported both manual and automatic operation modes. As a result, labor requirements were reduced from three workers to two, and the average bottling time per bottle decreased from 40.2 seconds to 36.5 seconds. Moreover, the reliability of production data improved from a previously high manual error rate to 0%, enabling more effective management and decision-making. This low-cost, scalable automation solution offers a practical model for similar small and medium-sized manufacturing enterprises in developing regions seeking to improve efficiency and data accuracy.

Keywords: Programmable Logic Controller, Human Machine Interface, drinking water bottling, process monitoring, Mitsubishi FX1N, SAMKOON

1. Introduction

In today's global push toward industrial automation, even small and medium-sized enterprises (SMEs) are increasingly adopting intelligent control systems to enhance productivity, quality control, and real-time process monitoring. Among the most widely used automation technologies are Programmable Logic Controllers (PLCs) and Human Machine Interfaces (HMIs), known for their flexibility, scalability, and cost-effectiveness (Bolton, 2015; Zhang & Wu, 2019; Pradhan & Mishra, 2020).

In developing countries like Lao PDR, small factories often operate using semi-manual methods, which are labor-intensive and prone to errors. These limitations not only affect operational efficiency but also impact decision-making due to the lack of accurate and timely data (Mishra et al., 2020). For instance, studies have shown that local SMEs that adopt PLC-based systems significantly reduce human error and achieve more consistent outputs (Nguyen & Pham, 2019; Singh & Prakash, 2021).

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The Xeno Drinking Water Factory, Branch 2, located in Chalernsouk Village, Outhoumphone District, Savannakhet Province (shown in Figure 1), is a typical small enterprise bottling drinking water in 250 ml, 650 ml, and 20L. The factory previously faced significant operational challenges due to its reliance on manual supervision. Operators had to check the water tank levels visually, count the output bottles by hand, and document daily production through written logs. These manual procedures made the factory highly susceptible to inefficiencies and inaccuracies, particularly when production volume fluctuated, often resulting in counting errors and delayed responses to low water levels (Parmanee, 2024). Before this implementation, the bottling process required 3 operators, and the average time to bottle one 20L container was approximately 40.2 seconds.

To address these challenges, this study aims to design and implement a low-cost PLC and HMI-based monitoring and control system to automate key operations such as bottle counting and water tank level monitoring. The system improves data accuracy, reduces reliance on manual labor, and enables better visibility of the entire production process in real time (Phimmasone & Inthavong, 2021). Similar automation efforts in Southeast Asia have shown promising results, indicating that such systems can be replicated across small-scale manufacturing sectors in the region (Lao & Kim, 2021; Dinh & Tran, 2021). This study contributes to that trend by demonstrating a practical application tailored to local technical and economic conditions.

Therefore, based on the aforementioned importance and challenges, to improve operations through the use of control systems and various devices, the goal is to develop a system that can: Record production volume data, Control production process initiation, Monitor real-time production statuses, Display the operational status of the water filling machine during bottling, Provide alerts when the water storage tank is nearly empty. For this purpose, the study aims to design and test a system capable of: Accurately recording and verifying production volume, controlling the production startup process, Monitoring and tracking drinking water bottling using PLC and HMI.

2. Materials and Methods

2.1 Experimental System

The system consists of the following hardware: Mitsubishi FX1N-40MR PLC (Mitsubishi Electric Corporation, 2019) – main control unit, SAMKOON HMI (Samkoon Tech, 2020) – interface for monitoring and user commands, Proximity sensor – detects bottles passing on the conveyor, Float switch – detects water tank level, Selector switches, relays, contactors – for manual and auto modes are shown in Figure 2.

The control system integrates Programmable Logic Controller (PLC) and Human Machine Interface (HMI) devices to work together for production counting, initiating production commands, and stopping production operations (Figure 3). The system connects control devices' input signals to the PLC's input modules, including: Sensors, Push buttons, Signal lamps (indicator lights), and other input devices. Simultaneously, the HMI connects to the PLC via an RS232 communication cable, enabling operational control through the PLC. This setup allows for: Production quantity monitoring, start/stop command execution, and Real-time system control through the HMI-PLC interface. The RS232 communication provides a reliable serial connection between the HMI and PLC for seamless command transmission and system monitoring.

The experimental setup and testing were conducted at the Xeno Drinking Water Factory, Branch 2, in Savannakhet Province, Lao PDR, during the period from March 15th to March 30th, 2025. All components were assembled and integrated on-site to simulate actual operating conditions. The development process involved several key steps: initial system requirement analysis based on the factory's needs, hardware and software architectural design, PLC and HMI programming, and subsequent on-site integration, testing, and fine-tuning.

2.2 Software Tools

- GX-Developer – used to program the PLC logic.
- SKTool – used to configure the HMI screen layout and tag mapping.

2.3 Control Logic Design

A counter function in the PLC increments for every 20L bottle detected by the sensor. The HMI displays the current count and tank status. The float switch triggers a warning on the HMI and stops the pump when water is low. Manual mode allows the operator to control start/stop using physical buttons; automatic mode handles this based on logic conditions (Figure 4). Table 1 shows the physical I/O mapping between field devices and PLC addresses, with some internal memory references (M1, M3 and M5) used for control logic. The HMI would typically interface with these addresses for monitoring and control purposes. The ladder diagram (LAD) for your PLC system based on the I/O table, with standard IEC symbols, are shown in Figure 5.

2.4 Experimental Procedure and Data Collection

The control cabinet was assembled and wired with all components before testing. The system was then rigorously tested using five main scenarios to verify its functionality and performance:

– Power Startup Test: Verifies correct initialization of indicators and devices upon power-up. Data collected: Visual confirmation of lamp illumination and device readiness.

– Automatic Mode Test: Validates sensor-triggered operation and logic-based pump control. Data collected: Observation of system behavior (start/stop) in response to programmed logic, and HMI display updates.

– Manual Mode Test: Confirms switch-based control by operators. Data collected: Recording of system responses (start/stop) to manual button presses, and HMI display feedback.

– Tank Level Detection Test: Ensures the float switch accurately detects low water conditions. Data collected: Observation of the float switch triggering, activation of the red signal light on the HMI, and pump cutoff.

– Bottle Counting Test: Checks real-time accuracy of the proximity sensor and counter logic. Data collected: Manual counting of bottles passing the sensor compared against the counter value displayed on the HMI.

Each of these five components underwent five separate test iterations to verify consistency and reliability. Data collection primarily involved direct observation of system functionality, confirmation of HMI readouts, and comparison of automated counts against manual verification. The "Test Result (Pass/Fail)" for each iteration was recorded, indicating whether the system performed as expected according to the defined operational criteria.

3. Results

The data analysis for this implementation study was primarily based on a verification methodology, focusing on the system's functional accuracy and reliability under designed operational conditions. For each of the five test components, five independent trials were conducted. The outcome of each trial was classified as "Pass" (✓) or "Fail" based on predefined criteria (e.g., correct light illumination, proper start/stop sequence, accurate count matching manual verification, correct alarm activation).

The test results, demonstrating the system's performance across the five defined components, are summarized in Table 2. As shown in Table 2, all 25 test iterations (5 components x 5 trials each) resulted in a "Pass" outcome, indicating a 100% efficiency and reliability rate for the implemented system across all tested functionalities. This high success rate confirms that:

– Power Startup Function: The system consistently initializes correctly, with the circuit breaker (CB) status light illuminating as expected upon power-up.

– Automatic Mode Operation: The automated bottling sequence initiates and halts precisely as programmed, responding accurately to control logic and commands.

– Manual Mode Operation: The system functions flawlessly under direct operator control via physical buttons, demonstrating robust manual override capabilities.

– Float Switch Accuracy: The water level detection mechanism operates perfectly, triggering the circuit cutoff and activating the red signal light whenever the tank reaches full or empty states, thus preventing overflow or dry running.

– Sensor and Counting Precision: The proximity sensor accurately detects each 20L bottle, and the PLC's counter registers the count with complete precision, reflected by the activation of the orange signal light and the correct display on the HMI.

These results directly translate into significant, measurable improvements in daily operations at the Xeno factory. The system's 100% accuracy in bottle counting has eliminated the manual counting errors that previously impacted production data reliability, leading to a 0% error rate in reported production volume. Furthermore, the reliable water level detection prevents dry running of pumps and ensures continuous operation, which was previously a point of inefficiency. From an operational efficiency standpoint, the implementation of this system successfully reduced the number of personnel required for the bottling process from 3 operators to 2, optimizing labor allocation. Moreover, the average bottling time per 20L bottle was improved from 40.2 seconds (manual process) to 36.5 seconds with the automated system, demonstrating a measurable increase in production speed. The system's ability to operate in both manual and automatic modes provides operational flexibility and reduces the need for constant human supervision in routine counting and monitoring tasks. This level of accuracy and efficiency is crucial for small-scale production facilities seeking to minimize manual errors and improve data reliability, directly addressing the key challenges identified in the introduction. The simplicity and deterministic nature of PLC logic, coupled with careful system integration, allowed for this high level of verifiable performance.

4. Discussion

This research demonstrated how appropriate automation can significantly improve operational efficiency in small-scale manufacturing, specifically within the context of a drinking water bottling plant in Lao PDR. The developed PLC and HMI-based system directly addressed critical pain points faced by the Xeno factory, namely labor inefficiency, production tracking errors, and delayed responses to water shortages.

One of the key successes of this project was the effective utilization of low-cost hardware (Mitsubishi FX1N-40MR PLC, SAMKOON HMI) combined with manufacturer-provided software (GX-Developer, SKTool). This approach contrasts with more complex and expensive Supervisory Control and Data Acquisition (SCADA) systems often employed in larger industries (Arumugam & Shanmugasundaram, 2018; Lin & Li, 2020), making the solution particularly affordable and scalable for SMEs in developing regions. The approximate cost for one complete system set, including the PLC, HMI, sensors, and associated electrical components, is estimated to be around USD 750. This cost is significantly lower than typical SCADA systems, making it a viable investment for small enterprises with limited budgets. While previous studies have highlighted the general benefits of PLC and HMI in automation (Bolton, 2015; Zhang & Wu, 2019), this work specifically tailors a solution to the unique economic and technical constraints prevalent in local small-scale industries. For instance, Mishra et al. (2020) emphasized the need for low-cost PLC systems in small industries, and our implementation provides a concrete example that achieved 100% accuracy, a critical metric for production reliability.

The system's modular design also allows for future integration with more advanced cloud-based SCADA platforms or wireless alert systems, as suggested by trends in smart monitoring (Kittisak & Suksawat, 2022). Regarding potential future improvements for the Xeno factory, the highest priority is considered to be the implementation of remote monitoring capabilities, particularly via mobile access. This would allow factory managers to track real-time production status and receive alerts even when they are not on-site, enabling faster decision-making and improved oversight. However, several challenges might impact the implementation of these further improvements, including:

– Budget Constraints: While the current system is low-cost, integrating cloud-based platforms or advanced wireless communication might require additional investment that could be challenging for a small enterprise.

– Technical Expertise: The factory may need to train existing staff or hire new personnel with specialized knowledge in network communication, cloud computing, and advanced automation to manage more complex systems.

– Infrastructure Limitations: The stability and availability of internet connectivity in the remote location of the factory could pose a challenge for reliable cloud-based or mobile remote monitoring solutions.

The visual interface provided by the HMI significantly reduced training time for operators and improved system transparency. This user-friendly aspect aligns with principles of effective human-machine interface design (Zhang & Wu, 2019) and directly contributes to faster, data-driven decisions for factory managers, a stark improvement over previous manual logging methods (Parmanee, 2024). Compared to traditional manual methods, the automated system demonstrated robust and consistent performance, achieving 100% accuracy in bottle counting and reliable water level monitoring. This finding is consistent with other studies that have shown significant reductions in human error and more consistent outputs through PLC-based systems (Nguyen & Pham, 2019; Singh & Prakash, 2021). The distinct contribution of this research lies in its practical validation of an accessible and reliable automation solution specifically for the water bottling industry in a developing country context, building upon general automation concepts and adapting them to local technical and economic conditions (Lao & Kim, 2021; Dinh & Tran, 2021). The direct implementation and rigorous testing confirm the viability of such systems for improving real-time data reliability and reducing manual labor in similar small and medium-sized manufacturing units across the region.

5. Conclusion

A low-cost Programmable Logic Controller (PLC) and Human Machine Interface (HMI) based monitoring and control system was successfully designed, implemented, and rigorously tested at the Xeno Drinking Water Factory. The system demonstrably improved production visibility, significantly reduced reliance on manual labor by optimizing staffing from 3 to 2 operators, and ensured 100% accurate tracking of 20L bottle output with an improved average bottling time from 40.2 seconds to 36.5 seconds per bottle. The comprehensive testing across five key operational scenarios confirmed the system's robustness, reliability, and consistent performance in both automatic and manual modes, and for critical functions like water level detection and accurate product counting.

This practical and effective model is highly suitable for replication and adaptation in other small to medium-sized water factories within the Lao PDR and similar developing regions. Its ease of replication stems from several factors: the use of readily available and affordable off-the-shelf PLC and HMI hardware, the utilization of free manufacturer-provided programming software (GX-Developer and SKTool), and its modular design which focuses on essential automation functions. This straightforward approach minimizes complex technical requirements and high initial investment, making it an accessible solution for enterprises with limited budgets and technical expertise. The system can be easily adapted to different bottle sizes or production line configurations by simply modifying PLC counter values and HMI screen layouts. Future work may focus on extending the system with mobile access for remote monitoring, integrating energy efficiency monitoring features, and developing remote diagnostic capabilities to further enhance its utility and applicability.

6. Conflict of Interest

This research demonstrates how cost-effective automation can enhance operational efficiency in small-scale manufacturing, providing a practical solution for industries in developing economies. The authors declare no conflict of interest regarding the publication of this paper.

7. Acknowledgments

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Table 1. PLC and HMI I/O assignments

Address	Input Device	Address	Output Device
X000	Selector Switch (M1)	Y000	Selector Switch Lamp
X001	Start Push Button	Y001	Start Indicator
X002	Sensor	Y002	Float Switch Lamp
X003	Stop Push Button (M3)	C0	Counter (D0)
X004	Float Switch		
X005	Reset Counter (M5)		

X series: Input terminals, Y series: Output terminals, C0/D0: Counter register, M tags: Internal memory bits/auxiliary relays

Table 2. Summary of test results, confirming 100% reliability

No.	Test Component	Test Result (Pass/Fail)					%Eff.	Meaning
		1	2	3	4	5		
1	CB Function Test	✓	✓	✓	✓	✓	100%	System operates normally every time.
2	Auto Mode Test	✓	✓	✓	✓	✓	100%	System runs automatically and stops correctly on command.

3	Manual Mode Test	✓	✓	✓	✓	✓	100%	System operates correctly under manual control.
4	Float Switch Test	✓	✓	✓	✓	✓	100%	Circuit cuts off when tank is full/empty, and red light activates.
5	Sensor Test	✓	✓	✓	✓	✓	100%	Product counting works, and orange light activates.

Figure 1. Location of the Xeno Drinking Water Factory (Map for 16°40'55.2"N 105°01'13.2"E)

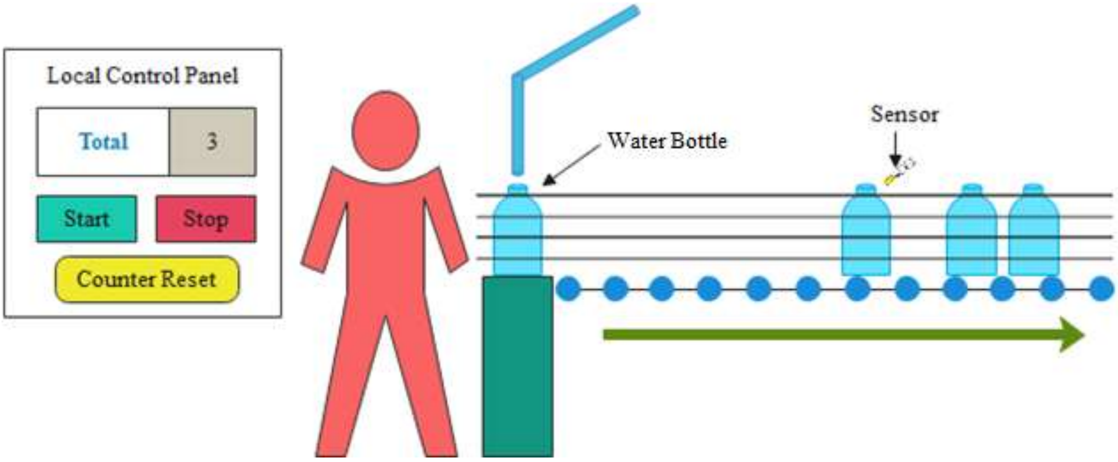

Figure 2. System architecture diagram

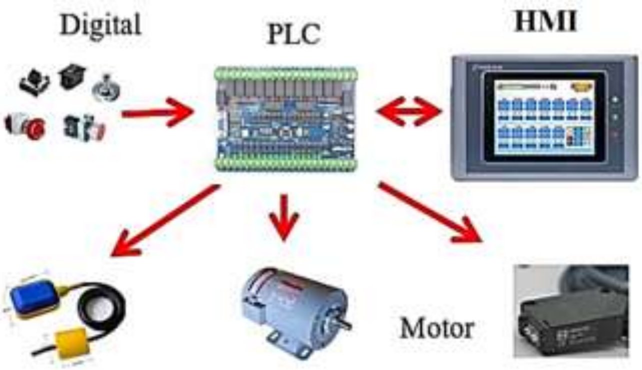

Figure 3. System workflow diagram

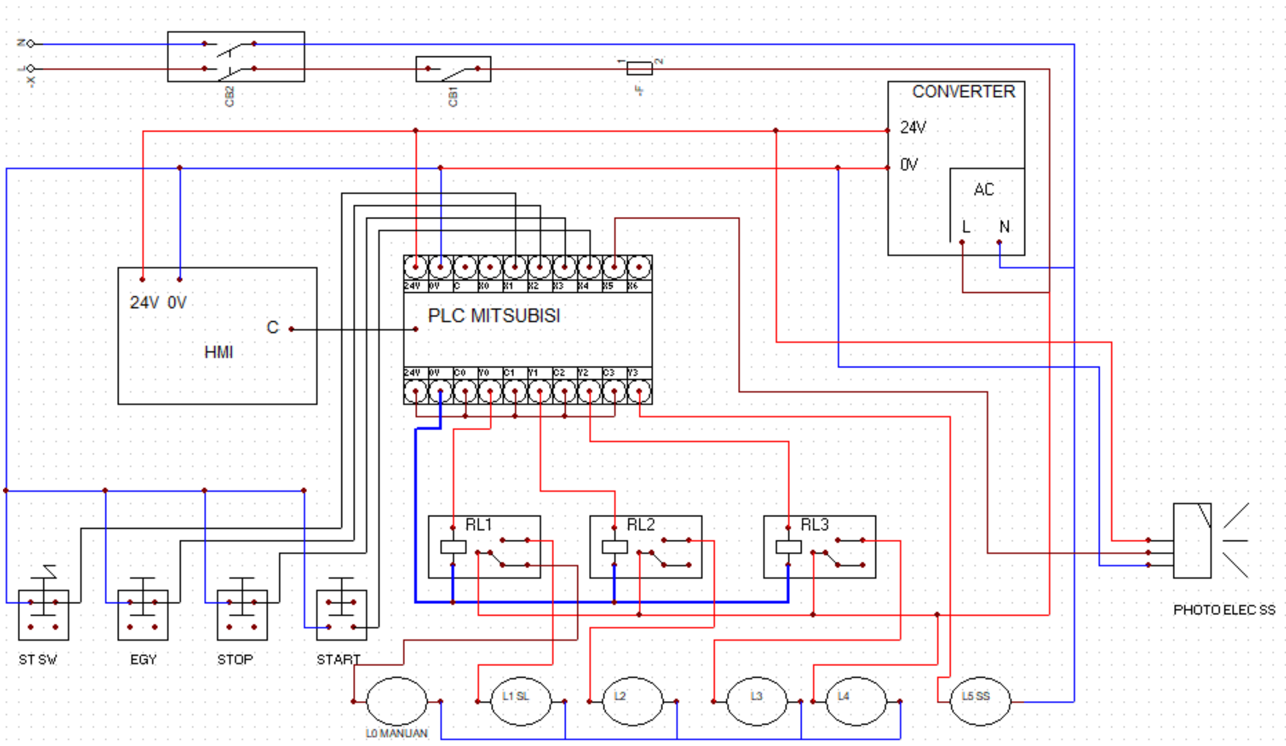

Figure 4. Electrical wiring diagrams

```
Network 1: Mode Selection
|-------[ ]-------[MOV K1 D100]-------|  (Auto Mode)
|   X000   |
|-------[\]-------[MOV K0 D100]-------|  (Manual Mode)
|   X000   |
Network 2: Start/Stop Control
|-------[ ]-------[ ]-------(S)-------|
|   X001   |   M1    |   Y001   |   (Start in Auto Mode)
|-------[ ]-------[ ]-------(R)-------|
|   X003   |   M1    |   Y001   |   (Stop in Auto Mode)
|-------[ ]-------[\]-------(S)-------|
|   X001   |   M1    |   Y001   |   (Start in Manual Mode)
Network 3: Counter Logic
|-------[ ]-------[CNT C0 K500]-------|
|   X002   |                    |   (Count sensor pulses)
|-------[ ]-------(RST C0)-------------|
|   X005   |                    |   (Reset counter)
Network 4: Float Switch Indicator
|-------[ ]-------( )-------|
|   X004   |   Y002   |   (Float switch status lamp)
Network 5: Selector Switch Lamp
|-------[ ]-------( )-------|
|   X000   |   Y000   |   (Selector switch indicator)
```

Figure 5. Ladder diagram for PLC control logic