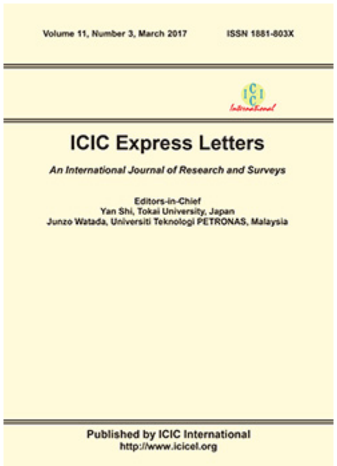

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Contact Information

ICIC-EL Office

Tokai University, Kumamoto Campus
9-1-1, Toroku, Kumamoto 862-8652, Japan
Phone: +81-96-386-2666
Email: office@icicel.org

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SCADA-BASED PLC CONTROLLER FOR LEAK DETECTION IN BOTTLES USING AN ANALOG PRESSURE SENSOR

Th Prima Ari Setiyani, Victor Dragon Kristiawan and Octries Eurico Atpen

Department of Electrical Engineering
Sanata Dharma University
Jalan Affandi, Mrican, Yogyakarta 55281, Indonesia
ariprima@usd.ac.id; { 225114055; 225114012 }@student.usd.ac.id

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Abstract. *This study aims to develop an intelligent SCADA-based leak detection system for plastic bottles to enhance quality control in packaging lines. The paper presents a SCADA-based system for detecting leaks in bottle packaging using a Programmable Logic Controller (PLC) and an analog pressure sensor. The proposed system is capable of identifying leaks in bottles of different sizes (200 ml and 240 ml) by injecting pressurized air into the bottle and measuring the internal pressure. The system is controlled via a Schneider TM221CE24R PLC, and the pressure sensor used is a WISNER WPT-83G-E4G4. Bottles with leaks, indicated by measured pressure falling below a user-defined threshold, are rejected, while intact bottles proceed to the filling station. The system demonstrated high accuracy and reliability in leak detection, achieving an overall success rate of 99.75%.*
Keywords: PLC, SCADA, Liquid filling, Bottle leak, Detecting leak

1. **Introduction.** The use of plastic materials for packaging has become a preferred choice in the packaging industry due to their cost-effectiveness and durability. Plastic bottles, in particular, are widely used for storing beverages and other liquids. However, despite stringent quality control processes, manufacturing defects such as small leaks can still occur [1, 2]. These micro-defects are often invisible to the naked eye, making manual inspection methods ineffective and unreliable.

To address this challenge, automated leak detection systems are increasingly being adopted in the packaging sector. A particularly promising approach involves integrating Supervisory Control and Data Acquisition (SCADA) systems with Programmable Logic Controllers (PLCs) [3, 4]. PLCs offer a reliable and programmable platform for automating machine-level operations and are capable of interfacing with a variety of sensors and actuators for quality control tasks [5].

Several prior studies have proposed bottle leak detection mechanisms using PLCs [6, 7], but these systems often suffer from significant limitations. For example, they typically support only a single bottle size and do not include a Human-Machine Interface (HMI), thus limiting flexibility and user interaction. This research addresses those gaps by proposing a SCADA-based bottle leak detection system that supports multiple bottle sizes (200 ml and 240 ml), incorporates analog pressure sensors for precise measurements, and includes an HMI interface developed using Wonderware InTouch [8]. The system leverages the Schneider TM221CE40R PLC, offering enhanced flexibility and user configurability.

While previous works have demonstrated basic PLC-controlled leak detection, they often lack adaptability for varied packaging formats and user interfaces for dynamic control [9, 10]. This study fills that gap by providing a comprehensive, real-time SCADA solution

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with user-defined setpoints, dual bottle compatibility, and improved feedback mechanisms [11].

This research aims to design and implement an intelligent SCADA-based leak detection system that automates the inspection process for bottles of varying sizes. The academic contribution lies in the integration methodology for SCADA, PLC, and real-time sensor feedback. The practical contribution is a flexible and robust solution that reduces human error and improves operational efficiency in packaging lines.

This paper is organized as follows. Section 2 discusses the system design, including the architecture and components used. Section 3 explains the implementation of the prototype system, including the hardware setup, control algorithms, and user interface. Section 4 presents the experimental results and performance analysis. Section 5 concludes the study and suggests directions for future research.

2. System Architecture and Methodology.

The architecture of the system combines hardware and software components to achieve accurate and automated leak detection. The main controller, Schneider TM221CE24R PLC, is responsible for executing the control logic and coordinating all operations between sensors and actuators. The analog pressure sensor (WISNER WPT-83G-E4G4) captures real-time internal pressure data from the bottles during testing. A proximity sensor ensures that each bottle is positioned correctly before testing, while pneumatic actuators are used to inject pressurized air and reject leaky bottles. These components are connected and synchronized through a digital I/O network defined in the PLC memory map.

The system methodology follows a closed-loop detection process. Upon detecting the presence of a bottle, the system halts the conveyor and initiates pressurization. The internal pressure is sampled by the analog sensor and compared against a user-defined threshold. This threshold is configurable via a Human-Machine Interface (HMI), developed using Wonderware InTouch. The HMI allows operators to select the bottle type, set the acceptable pressure range, and monitor system status. All process steps – from conveyor motion to leak decision – are encoded using ladder diagram logic in the PLC programming environment, ensuring reliable real-time control and seamless operator interaction.

The bottle leak detection system consists of a Schneider TM221CE24R PLC [10], a conveyor system, proximity sensors, pneumatic components, and an analog pressure sensor. The process involves transporting bottles through a pressure station, where air is injected into the bottle, and the pressure is measured. Bottles with insufficient pressure are rejected.

3. Prototype Implementation.

3.1. System overview.

The system is designed to detect leaks in two types of bottles, each with different heights and volumes. The components used in this project include a conveyor, a 24 Volt DC motor, an analog pressure sensor [12], a proximity sensor, a single-acting cylinder, a 5/2 solenoid valve, and a Schneider PLC TM221CE40R. The overall prototype design is shown in Figure 1.

The input and output circuits are connected to the PLC TM221CE40R, which acts as the main controller for the system. This leak detection system operates by using a conveyor to move the bottles to the pressure station. When the proximity sensor detects that the bottle has reached the pressure station, the cylinder stopper is activated to stop the movement of the bottle, and the conveyor halts. Subsequently, the cylinder head pressure is activated, pressing the bottle and injecting compressed air (at 3 bar) for 2 seconds. The pressure inside the bottle is then measured by the analog pressure sensor. If the bottle pressure is below the pre-set threshold value (X kPa), the reject cylinder will expel the leaky bottle, while bottles with a pressure above the threshold will continue to

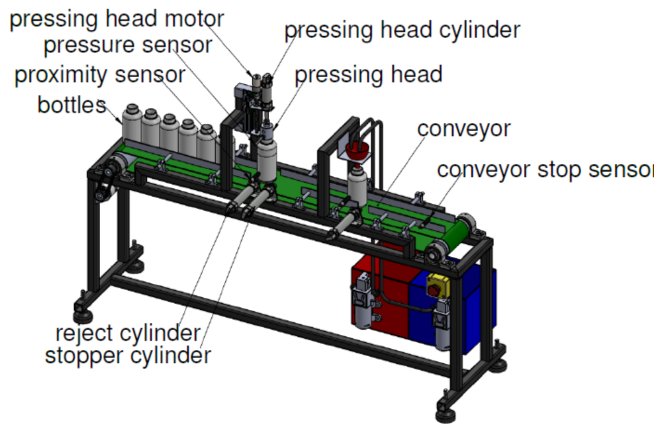

Figure 1. Illustration of the leak detection system prototype

the filling process. The threshold value X can be adjusted by the user before proceeding to the filling station, as further explained by another researcher.

3.2. **Design of controller.** The SCADA system uses a Schneider PLC to control the testing process. The PLC handles sensor data, manages actuators, and communicates with the Human-Machine Interface (HMI) for user input. The control logic is implemented using ladder logic diagrams in the PLC programming environment.

The block diagram shown in Figure 2 represents the controller block diagram in the SCADA system for leak detection in bottles based on a PLC using an analog pressure sensor. This system consists of a Schneider PLC as the controller, sensors as inputs, and output devices.

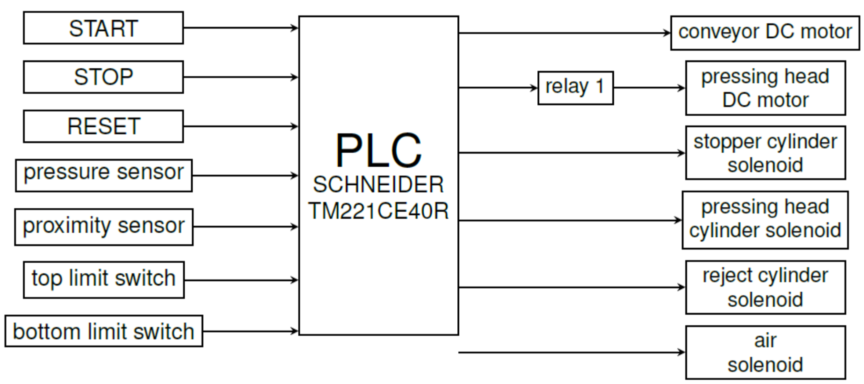

Figure 2. Controller block diagram in leak detection system

The prototype operates when the user provides input on the HMI (Human-Machine Interface), including the choice of bottle type, composition, and the setpoint value, which defines the maximum acceptable pressure for the bottle. After the user enters the input and presses the start button, the system will execute the commands step-by-step according to the pre-configured program.

Initially, after the start button is pressed, the system activates the Pressing Head DC motor to position the pressure head at the height determined based on the selected bottle type. The Pressing Head DC motor will stop once it reaches the limit switch. Next, the conveyor will move the bottle to the pressure station. When the proximity sensor detects that the bottle has reached the pressure station, the cylinder stopper is activated to stop the movement of the bottle, and the conveyor halts.

In the next step, the Head Pressing Head Cylinder will be activated and apply pressure to the bottle for leak testing. If the sensor reading reaches the setpoint value, the bottle is considered good. Conversely, if the sensor reading does not meet the setpoint, the bottle will be rejected and discarded using the reject cylinder. Bottles that pass the pressure test will proceed to the filling process, as explained further by another researcher.

Table 1 contains the description of the I/O (Input/Output) devices, Table 2(a) provides the addressing for external inputs, and Table 2(b) contains the addressing for external outputs.

Table 1. Device functions for leak detection system

Device	Function
START Push Button	Starts the system and begins operation.
STOP Push Button	Stops the system and halts all operations.
RESET Push Button	Resets the system to its initial state.
Pressure Sensor	Detects the pressure inside the bottle.
Proximity Sensor	Detects the readiness of the bottle.
Upper Limit Switch	Limits the DC motor's rotation to set the high position of the pressure head.
Lower Limit Switch	Limits the DC motor's rotation to set the low position of the pressure head.
Conveyor DC 12V Motor	Powers the conveyor to move bottles to the pressure testing station.
Pressing Head DC 12V Motor	Moves the pressure head to the appropriate height (high or low) for testing.
Stopper Cylinder	Holds the bottle in place at the test area during the test.
Pressing Head Cylinder	Applies pressure to the bottle during the leak testing process.
Reject Cylinder	Removes rejected bottles from the conveyor after they fail the test.

Table 2. Memory address

(a) For external inputs

No	Device	Input address	Memory address
1	Start button	%I0.0	%M0
2	Stop button	%I0.1	%M1
3	Reset button	%I0.2	%M2
4	Pressure sensor	%IW0.0	%MW0
5	Proximity sensor A	%I0.4	%M4
6	Upper limit switch	%I0.7	%M7
7	Lower limit switch	%I0.8	%M8

(b) For external outputs

No	Device	Output address	Memory address
1	Conveyor DC motor	%Q0.0	%M15
2	Stopper cylinder	%Q0.1	%M16
3	SOL 2 (Cylinder head pressure)	%Q0.2	%M17
4	SOL 3 (Cylinder reject)	%Q0.3	%M18
5	SOL 4 (Air)	%Q0.4	%M19
6	DC motor head pressure CW	%Q0.10	%M20
7	DC motor head pressure CCW	%Q0.11	%M21

3.3. **Hardware components.** The hardware components of the system are Schneider PLC TM221CE40R, Pressure Sensor (WISNER WPT-83G-E4G4), Conveyor System, Proximity Sensors, and Pneumatic Actuators.

- **Schneider PLC TM221CE40R**: This is the primary controller.
- **Pressure Sensor (WISNER WPT-83G-E4G4)**: Used to measure the internal pressure of the bottle.
- **Conveyor System**: Moves bottles to the pressure station.
- **Proximity Sensors**: Detect the presence of bottles at the testing station.
- **Pneumatic Actuators**: Control the pressure injection and rejection of defective bottles.

The design of the detection system mechanism will allow the pressing head to move up and down, enabling it to adjust the height according to the bottle size. This mechanism will operate once the user provides input for the bottle type, composition, and set point value as the maximum allowable pressure for the bottle. When the start button is pressed, the system will activate the pressing head DC motor to position the head at the predetermined height, and the motor will stop when it reaches the limit switch.

The system includes two limit switches: one for detecting bottle A at the upper position and the other for detecting bottle B at the lower position. Once properly positioned, the bottle undergoes a pressure test where 3 bar of compressed air is applied for 2 seconds. If the pressure inside the bottle meets the set point, the bottle is considered acceptable (i.e., not leaking). However, if the internal pressure fails to reach the set point within 2 seconds, the bottle is classified as defective or leaking.

The design of the detection system is shown in Figure 3. When the system detects bottle A, the head pressure will rise until it touches the upper limit switch, as shown in Figure 3(b). When the system detects bottle B, the head pressure will descend until it reaches the lower limit switch, as shown in Figure 3(c).

(a) (b) (c)

Figure 3. Pressing head for detecting and testing a bottle: (a) Pressing head mechanism; (b) pressing head up; (c) pressing head down

3.4. **Software components.** The main algorithm is shown in Algorithm 1. This algorithm is designed to continuously run two processes in a loop: RunConveyor and LeakDetection. The algorithm starts a loop that will run indefinitely or until a certain condition is met. The loop ensures that the processes of running the conveyor and detecting leaks are continuously executed.

Algorithm 1 Continuous conveyor and leak detection process

```
loop
    call RunConveyor
    call LeakDetection
end loop
```

Within each iteration of the loop, the RunConveyor function is called. This function likely handles the movement of bottles along the conveyor belt, including detecting bottles and possibly stopping them for testing.

After running the conveyor, the LeakDetection function is called. This function tests each bottle on the conveyor for leaks, possibly by measuring pressure and comparing it to a setpoint, as described in the previous algorithm.

Once both functions (RunConveyor and LeakDetection) are executed in a single iteration of the loop, the loop restarts, ensuring continuous operation of both processes.

Algorithm 2 is an algorithm to control conveyor motor. It starts by turning on the conveyor motor, then it continuously checks for the presence of a bottle on the conveyor. Once a bottle is detected, it moves the stopper cylinder forward to stop the bottle's movement and then turns off the conveyor motor.

Algorithm 2 Run conveyor algorithm

```
procedure RunConveyor
    turn on conveyor motor
    repeat
        detect bottle
    until bottle exists
    move stopper cylinder forward
    turn off conveyor motor
end procedure
```

Algorithm 3 is designed to perform leak detection in bottles by checking the internal pressure of the bottle and deciding whether it is faulty (leaking) or not based on a predefined set point. It involves using sensors, motors, and solenoids to apply pressure to the bottle and monitor the results.

Algorithm 3 Bottle leak detection algorithm

```
procedure LeakDetection
    get bottle type as BT
    get set point as SP
    if BT is A then
        move pressing head DC motor up to upper limit switch
    else
        move pressing head DC motor down to lower limit switch
    end if
    move pressing head cylinder down
    turn on air solenoid
    repeat
        read air pressure as P
    until P = SP
    pause 2 seconds
    read air pressure as P
    move pressing head cylinder up
    if P < SP then
        move reject cylinder forward
        move reject cylinder backward
    end if
    move stopper cylinder backward
end procedure
```

Bottle Type (BT) affects the positioning of the pressing head. Set Point (SP) determines the acceptable pressure for a bottle. The algorithm ensures that only bottles that meet the pressure requirement are considered good. Bottles with insufficient pressure are rejected by moving a reject cylinder.

4. **Implementation and Results.** The system was tested with two types of bottles (200 ml and 240 ml), both with and without leaks. The system successfully identified leaks, with bottles demonstrating pressure values lower than the setpoint being rejected. The average test times for bottles without leaks were 14 seconds for the 200 ml bottle and 14 seconds for the 240 ml bottle, while bottles with leaks took longer, with an average of 17 seconds for the 200 ml and 19 seconds for the 240 ml bottle.

4.1. **System testing.** Table 3 presents pressure sensor readings for bottles with various leak conditions, including two sizes (200 ml and 240 ml) and different types of leaks such as slits and varying diameters.

TABLE 3. Pressure sensor readings for leaky bottles

No	Bottle	Condition	Setpoint	PLC readings
1	200 ml	Leak, 0.5 mm slit	66	66.0, 67.0, 68.0, 69.0
2	200 ml	Leak, 1.5 mm diameter	66	57.2, 57.7, 58.2, 59.2
3	200 ml	Leak, 4 mm diameter	66	50.8, 51.3, 51.8, 52.8
4	200 ml	Leak, 9 mm slit	66	52.0, 52.5, 53.0, 54.0
5	240 ml	Leak, 0.5 mm slit	70	70.0, 71.0, 72.0, 73.0
6	240 ml	Leak, 1.5 mm diameter	70	64.2, 64.7, 65.2, 66.2
7	240 ml	Leak, 5 mm diameter	70	58.7, 59.2, 59.7, 60.7
8	240 ml	Leak, 9 mm slit	70	64.1, 64.6, 65.1, 66.1

For 200 ml bottles with a 0.5 mm slit, the sensor readings remained consistent with the set point values (66 to 69). This indicates that there was minimal deviation in pressure, suggesting that the bottle did not exhibit any significant leaks.

Bottles with a 1.5 mm diameter leak showed a decrease in pressure, with sensor readings ranging from 57.2 to 59.2. These values were lower than the set point, indicating that the internal pressure decreased as the leak diameter increased.

For the 4 mm diameter leak, the sensor readings ranged from 50.8 to 52.8, confirming that larger leaks cause a more significant pressure drop compared to smaller leaks, further validating the correlation between leak size and pressure loss.

The bottles with a 9 mm slit showed slightly higher readings (52 to 54) compared to the 4 mm diameter leaks. However, these readings were still notably below the set point, suggesting that while the bottle's pressure dropped, the decrease was less severe than with the larger diameter leaks.

For the 240 ml bottles with a 0.5 mm slit, the sensor readings were identical to the set point (70 to 73), indicating no leakage or only a minimal pressure drop, similar to the 200 ml bottles with a 0.5 mm slit.

Bottles with a 1.5 mm diameter leak in the 240 ml size showed readings consistently lower than the set point, ranging from 64.2 to 66.2, suggesting that a similar leak in a larger bottle causes a significant decrease in internal pressure.

For the 5 mm diameter leak (sensor readings between 58.7 and 60.7) and the 9 mm slit leak (readings between 64.1 and 66.1), both leaks showed a notable pressure drop, but the 9 mm slit had higher readings than the 5 mm diameter. This indicates that slit width might have a different effect on pressure retention than leak diameter, at least for larger bottles.

4.2. **Performance evaluation.** The system demonstrated a high level of accuracy in detecting leaks, with an overall success rate of 99.75%. The pressure sensor readings were consistent, and the system's response time was within acceptable limits for both bottle sizes.

Compared to previous systems that lack flexibility and multi-size support [6, 7], our method provides adaptability through dual-bottle support, HMI integration, and higher detection accuracy (99.75%). Other approaches do not offer dynamic threshold setting or SCADA interface as implemented in this system.

5. **Conclusion.** This study successfully developed a SCADA-based PLC controller for detecting leaks in bottle packaging. The system demonstrated high accuracy in detecting leaks in bottles with sizes of 200 ml and 240 ml, with a failure rate of only 0.25%. The research contributes to improving the quality control process in packaging industries by automating leak detection. In future work, the system can be extended to support more bottle sizes and integrated with machine learning algorithms to dynamically adjust threshold values based on historical pressure data. Additionally, remote monitoring via cloud-based SCADA platforms can improve scalability and operational diagnostics.

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