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A NOVEL DESIGN OF AN AUTOMATED SORTING SYSTEM FOR EFFICIENT SEGREGATION OF UNPICK RETURNABLE BOTTLES AFTER UNCASER IN A BEVERAGE PACKAGING PLANT

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Graphical abstract

Abstract

In the context of modern industrial facilities, automation of production processes has become essential, offering cost reduction, operational efficiency, and minimized human involvement. A specific challenge arises from the conventional method of sorting unpicked bottles post-uncasing, leading to a high incidence of broken returnable bottles. To address this, we present the "Automated Sorting System of Cases with Unpicked Bottles," aimed at minimizing bottle breakage during manufacturing. Our objective is to enhance bottle preservation while achieving substantial cost savings and profitability. At the core of this system is its seamless integration into the conveyor network, enabling real-time bottle sorting as cases move towards the packer. Utilizing the Programmable Logic Controller working in conjunction with various sensors, including retro reflective and diffuse sensors, the system ensures responsive and precise operation. These sensors provide immediate feedback to a linked pneumatic cylinder, enabling it to respond according to preset settings and circumstances. Importantly, through extensive simulation and testing, we have achieved a remarkable reduction in bottle breakage rates. Our results indicate a reduction in breakage by up to 3800 bottles per day, attributed to the system's efficient and precise sorting capabilities. This innovative approach not only significantly improves process efficiency but also results in tangible cost savings, making it a highly cost-effective solution for the industry.

Keywords: Unpick bottle sorting, Automated Sorting System, Bottle breakage reduction, Programmable Logic Controller (PLC)

1.0 INTRODUCTION

Industrial automation has become known as an evolving trend in the industrial sector, leading to an innovative period of efficiency and production by leveraging innovative technologies. This transition from manual labor to automated systems offers a few advantages, optimizing operations across various branches of industry. The field of automation has seen significant advancements, incorporating modern technologies such as sensors, Programmable Logic Controllers (PLCs), pneumatics, mechanics, hydraulics, and electronics to tailor specialized systems to the unique needs of various industries.

A very important field where automation is becoming more popular is in how we deal with bottles that can be used again in the beverage industry. These bottles, which are returned to the bottling plant after consumer use, undergo various processes and are refilled for reuse, making it essential to maintain them throughout the handling process to prevent breakage. A significant problem arises after the uncaser machine, where certain bottles may remain unpicked and fall onto a loop conveyor, leading to breakage and subsequent cost inefficiencies.

To address this issue, leading companies, including industry like Coca-Cola (2023), are actively involved in designing returnable glass bottles with a focus on minimizing waste and maximizing their value during use, promoting reuse, and encouraging recycling to prevent them from becoming waste.

Currently, the primary solution employed in handling returnable bottles involves a case tumbler through which cases with unpicked bottles pass. However, this solution exhibits inefficiencies, as the bottles often fall off the cases during the tumbling process, resulting in breakage. Preserving returnable bottles are not just a matter of reducing waste; they are significantly tied to the efficiency of companies operating in the beverage industry.

Our proposed solution involves the execution of an automated sorting setup that effectively segregates cases with unpicked bottles, diverting them to a separate conveyor. This strategic automation mitigates the issue of bottle breakage and addresses the inefficiencies of the current process. By reducing the contribution of broken bottles to the entire production cycle, our solution aligns with the demands of modern industry and exemplifies the transformative potential of automation.

In line with the fourth industrial revolution, the significance of information and automation technologies cannot be overstated. Research by Fernandes et al. (2021) sheds light on the important role of collaborative automation in achieving increased productivity and efficiency in production processes. In accordance with the principles of Industry 4.0, the research emphasizes the development of service-based monitoring and automation systems through the utilization of a Microservices-Driven Architecture.

In the study of Wahyudi, et al (2022) it aims to automate and improve efficiency in the industrial sector, particularly in the context of a Stamping Machine. The main objective is to use the PLC Omron CP1E - E20 as the controller for the Stamping Machine, integrating Reed Switch sensors and solenoid valves with Single Acting Cylinders to enable automatic stamping processes. The system is optimized with specific operating parameters, a 3-second stamping duration, and a 2-second standby time. Realtime measurements show an average stamping time of 5.044 seconds. The research highlights the benefits of PLC technology in achieving automation and efficiency in industrial applications.

While Putri and Mowaviq (2021) produced an instructional example of a PLC-based automated conveyor machine. This system will enhance students' understanding of industrial automation and provide hands-on experience in applying PLC programming to real-world scenarios. The prototype uses the FX3U Mitsubishi PLC for control and includes conveyor speed adjustment and automation features using an infrared sensor.

Still another study, Thabet, et al (2013) objectives are to automate a food production process using a programmable logic controller (PLC) and to address two specific problems. The first objective is to properly regulate the speed and volume of dough poured into production molds on a conveyor belt. The second task is to keep an eye on the conveyor belt's speed, spot any discrepancies, and alert the operator. Simulation model is designed using the PLC LOGO! V7.0 controller, which offers advanced specifications and rapid responses to signals from sensors such as ultrasonic distance sensors and inductive sensors placed along the production line. The aim is to increase automation in the food industry and contribute to Iraq's development by adopting modern control methods and technology.

Researchers in the field have explored innovative solutions to enhance sorting and recognition processes in diverse industries. C.J. Rao et al. (2022) propose a single conveyor belt combined with a PLC module and sensor module for efficient sorting of objects of various colors, catering to industries like food processing and pharmaceuticals. Safavi et al. (2010) investigated the manufacturing of spiral bevel gears utilizing a three axis CNC milling equipment integrated with a PLC module, offering a cost- effective and time-efficient alternative to traditional SBG machining methods.

Automation extends its impact to diverse sectors, including power plants, educational training, and the packaging industry. For instance, Sasidhar et al. (2017) develops an electromagnetic sorting technique using a PLC-connected LCA system for separating ferromagnetic materials from coal. Jinyu Li (2020) designs an automatic material sorting control system for students in the electromechanical profession, emphasizing the enhancement of practical abilities, adaptability to work, design skills, and teaching levels.

In the pursuit of efficient and productive automation, a modular approach gains prominence in enhancing the performance of robotic mechanisms (Zhang et al., 2017). The researchers advocate dividing control functions into distinct modules based on specific functions, allowing for easier implementation and adaptation to varying mechanism requirements.

Addressing challenges within automated systems is crucial for ensuring desired outputs. Lalegani et al. (2022) develop an intelligent and automated conveyor system for handling circular items in the packaging industry, focusing on mitigating issues arising from defective rollers and misaligned conveyors that may lead to misplaced objects, inaccurate sorting, and false color identification. The advent of PLC-based automation has proven effective in optimizing various industrial processes. Rahmawati et al. (2022) propose a PLC-Based Pneumatic Brushing Machine that streamlines the production process, enhancing productivity by reducing manual labor while delivering superior wood cleaning results.

Kumar et al. (2020) developed and simulated a prototype for a SCADA and PLC system in the beverage industry with the primary objective of automating the filling process for a variety of containers containing different liquid mixtures. This initiative aimed to enhance productivity, reduce errors, and improve product consistency. The paper focuses on replacing manual operations with automated and reconfigurable processes, taking advantage of advanced technologies like Industry 4.0 to achieve efficient bottle sorting, filling, capping, labeling, and batch counting. The use of sensors such as Proximity Sensor and Retro Reflective type sensors is incorporated to detect different types of bottles at various parts of the filling process. The overall aim is to increase production rates and ensure a higher level of quality and accuracy in the beverage industry.

This research specifically addresses the presence of broken bottles arising from inefficiencies in the uncaser stage of returnable bottle handling. We propose an automated process that integrates sensors, PLC programming, and pneumatic cylinders to detect and segregate bottles left in the case. We want to improve total effectiveness, reduce breakage, and improve the process to achieve greater production and cost-effectiveness. In the following sections of this work, we explore the complexities of our proposed system, outlining the experimental setup and the results obtained. Our findings offer invaluable insights to professional engineers seeking to elevate automation practices in the manufacturing industry, differentiating our study in the pursuit of innovative solutions.

2.0 METHODOLOGY

To implement the automated sorting system, a robust PLC programming approach is essential. This section discusses the key components and tools involved in programming the system.

2.1 Allen Bradley CompactLogix 5380 Series PLC

The program of the automated sorting system lies in the Programmable Logic Controller (PLC), which serves as the central control unit. For this application, the Allen Bradley CompactLogix 5380 Series is the preferred PLC model. This PLC offers several advantages and capabilities, making it well-suited for the task at hand.

The CompactLogix 5380 Series, shown in Figure 1, offers flexibility, allowing for future expansion and modifications as needed. Its extensive connectivity facilitates seamless integration with various devices and systems, promoting interoperability. Moreover, the PLC's enhanced performance ensures efficient and reliable automation, even when managing complex logic. Notably, the CompactLogix 5380 Series supports high-speed I/O modules, enabling precise control over fast input and output processing. This feature is crucial for maintaining accuracy and efficiency in the sorting process.

Figure 1 Allen Bradley PLC (Allen Bradley CompactLogix 5380 Controllers, 2022).

2.2 PicoSoft 6 PLC Simulator Software

Before deploying the PLC program to the physical hardware, simulation is an essential step in validating and optimizing the logic. PicoSoft is purpose-built to facilitate the simulation of PLCs and ladder logic programming.

PicoSoft serves as a robust digital training and testing environment for ladder logic programming and industrial control concepts. Its user-friendly interface offers an intuitive experience to programming in real-world PLCs. Researchers can create and virtually simulate ladder logic programs, allowing for extensive testing and fine-tuning.

The simulation capabilities of PicoSoft empower users to refine the logic, identify and resolve potential issues, and ensure the optimal performance of the automated system before transferring the program to the physical PLC. This seamless transition from simulation to implementation streamlines the automation process, enhancing its efficiency and reliability through the utilization of the PicoSoft simulator.

2.3 Sourcing and Sinking Logic Circuits

In PLCs, sourcing and sinking logic circuits are considered when configuring digital input and output signals. These circuits dictate the direction of current flow and are integral to proper PLC operation.
In Figure 2a. current travels from the control interface to field input device through a sourcing input module of PLC. The module is internally wired to connect to a voltage source, enabling it to supply a positive voltage to an external logic DC circuit. In contrast, a sinking input component connects to the ground internally while receiving current into its control terminal. As a result, the module shows the required ground connection for the external logic circuit, completing the circuit with a positive voltage.

In Figure 2b. PLC output modules are categorized into sinking and sourcing modules. A sourcing module enables current to flow out of its control terminal and into the associated load, whereas a sinking module allows current to flow from the load that is connected into its control terminal. This differentiation is essential in configuring PLCs for various industrial applications, as it determines the direction of current flow and how it interfaces with the connected loads.

By selecting and configuring the proper input and output modules, the PLC can effectively control and interact with the components of the automated sorting system.

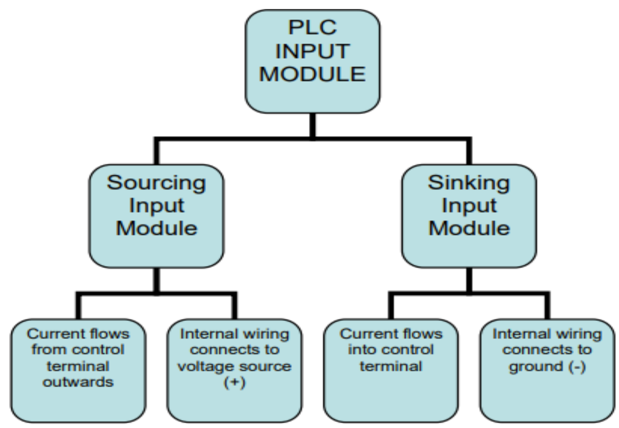

Figure 2a. PLC input module flow chart

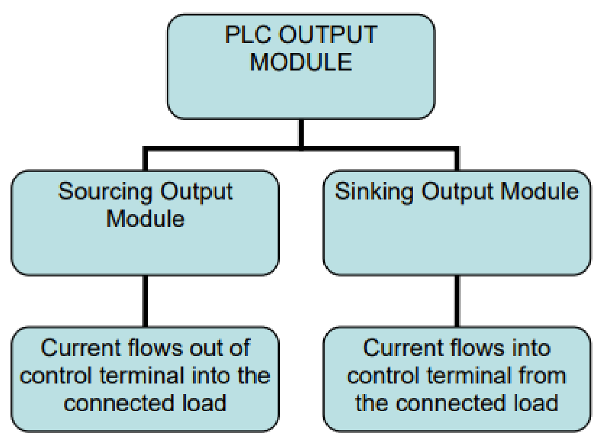

Figure 2b. PLC output module flow chart

2.4 Logic Ladder for the Automated Sorting System

The development and implementation of conceptual ideas in real hardware can be complex and time-consuming. To address these challenges, simulation software solutions, such as the Picosoft 6, are invaluable.

Utilizing the Picosoft simulator, researchers and engineers can effectively simulate the PLC program and logic for the automatic sorting system. This simulator offers the advantage of easy adjustment and troubleshooting, enabling users to rectify errors and fine-tune the logic during the simulation phase. Consequently, this development process ensures a successful integration of the automation solution into the actual PLC system. The Picosoft simulator proves to be a perfect tool in the development process and ensures the seamless performance of the automated sorting system.

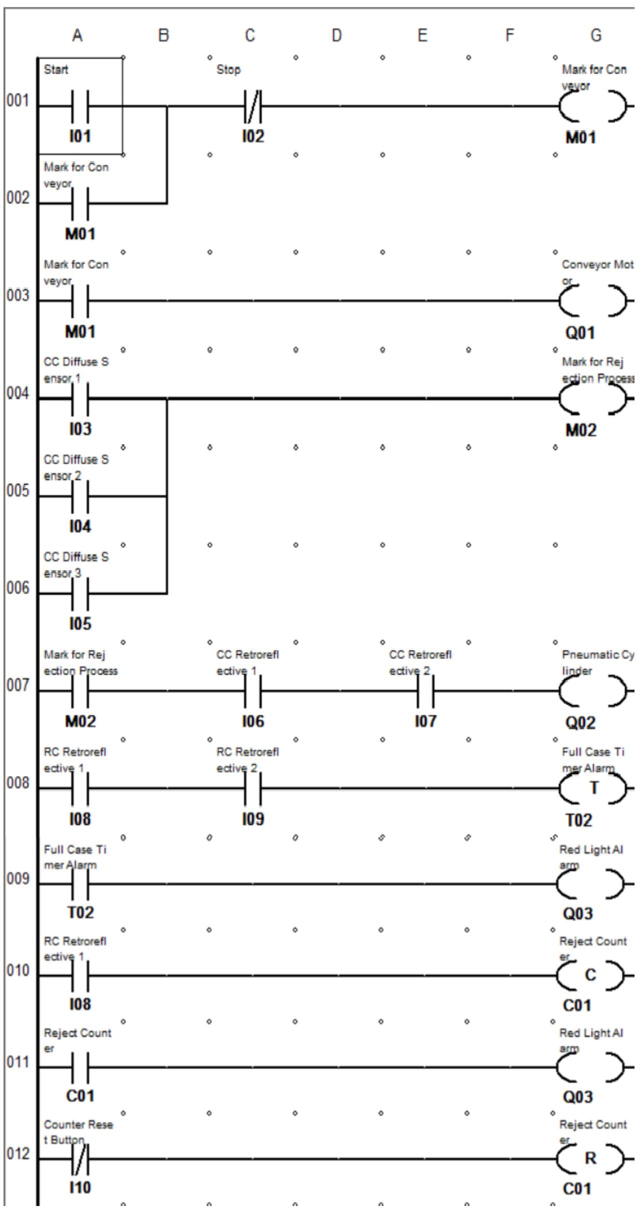

Figure 3 Ladder Logic of the Automated System in Picosoft 6

The components' list is displayed in the PLC simulation (Figure 3). The components include 1. Start, Stop, Reject Counter, Full Case Timer, Counter Reset Button (I01, I02, C01, T02, I10), 2. Diffuse Type Sensors (I03, I04, I05), 3. Retroreflective Sensors (I06, I07, I08, I09), 4. Conveyor Motor (Q01), 5. Pneumatic Cylinder (Q02), 6. Red Light Alarm (Q03), and 7. Marks for Conveyor and Rejection Process (M01, M02).

2.5 Diffuse And Retroreflective Sensor

In this study, a key component of the automation system is a diffuse photoelectric sensor, which operates on the principle of reflection to detect objects within its range. It consists of a light source and receiver within a single unit. The sensor emits light toward objects, and the objects themselves act as reflectors, bouncing the light back to the sensor. We employ Omron sensors (Figure4) for these tasks, specifically the "Omron E3 Series" for photoelectric sensing, offering a versatile selection for diffuse and retroreflective applications. For close-range diffuse sensing, we opt for the "Omron E3T Series," known for its reliability. Notably, diffuse sensors don't require external reflectors, simplifying installation, but have a limited range, while retroreflective sensors, also used, offer broader material detection but necessitate specific reflectors. Both types feature straightforward wiring and mounting, as well as calibration, aligning perfectly with our automation system requirements.

Figure 4 Retroreflective and Diffuse Sensors (E3T-C and E3S-CL, 2017)

2.6 Pneumatic System and components

Kumar, et al (2022) states the significance of pneumatics in the field of industrial automation and robotics. Educational programs equip students with foundational expertise in essential domains such as basic sensors, pneumatics, and programmable logic controllers, accentuating the pivotal role of pneumatics as a fundamental element in industrial automation.

In this research, the pneumatic cylinder is one of the key components, a device that efficiently converts compressed air energy into linear motion by extending or retracting its rod in response to the supplied air. Specifically, the pneumatic component chosen for this study is the DNC-50-100-PPVC-A, shown in Figure 5. This single-acting cylinder is equipped with a spring in the negative chamber, capable of generating both pushing and pulling forces. The selection of the cylinder's size is crucial, as it plays a pivotal role in automating the transfer process of objects. Under predefined conditions, this single-acting cylinder rapidly extends its arm, featuring a custom attachment at the end of the rod. This sudden force effectively propels the object onto another conveyor system.To regulate and control the precise movement of the pneumatic cylinder, a 3/2-way valve with two positions and three ports is skillfully employed. This valve operates electrically via a solenoid valve that interfaces with a PLC. The PLC serves as the brain of the system, executing programmed logic to signal the pneumatic cylinder when to extend or retract, ensuring the seamless execution of the intended tasks.

Figure5 Pneumatic Cylinder DNC-50-100-PPV-A (Festo, n.d.)

2.7 Compressor

An air compressor, specifically a belt-driven three-phase unit, harnesses energy to convert it into potential energy by pressurizing air. It accomplishes this by elevating the air pressure within a storage tank, automatically shutting off once the tank reaches its maximum pressure, effectively storing the compressed air for future use. As the tank releases air, its kinetic energy can be utilized across various applications. The compression cycle continues by the air compressor, which is powered by three-phase power and driven by a belt once the tank pressure reaches its lowest level. It's critical to understand the differences between an air compressor and a pump because the first is made for gases and the second is designed for liquids.

2.8 Conveyor System

According to (Khaing, 2023), conveyors play an important role in the automatic sorting system, which has been recognized as a complex process. By utilizing a Programmable Logic Controller (PLC), conveyor, pneumatic cylinders, and solenoids, gains precise and efficient operation and control.

In the specific case of the conveyor automation system, as shown in Figure 6, the selection of the right tabletop chain is of utmost importance. The chosen tabletop chain, Rexnord 815 SSA815-7.5, is a straight-running Mat Top chain constructed from Austenitic Stainless Steel. With a width of 7.5 inches, this chain is perfectly sized to effectively accommodate the cases used in the process. Its solid stop feature is particularly advantageous, preventing slippage by ensuring sufficient friction between the tabletop chain and the cases, thereby enhancing overall system reliability.

To drive the conveyor, a 5-inch diameter and 6-inch width plastic sprocket with 25 teeth will be used, connected to a 2.5-inch diameter solid shaft that is powered by a 2.5 kW induction motor. The power will be controlled using a Variable Frequency Drive, which allows for greater flexibility in adjusting the system's parameters. With the Variable Frequency Drive, operators can control the motor's speed according to specific requirements, ensuring optimal performance and adaptability to varying conditions.

Adoption of induction motors in conveyor systems offers multiple benefits, including their capability to oversee heavy loads, energy efficiency, low maintenance requirements, and ease of speed control. The case study presented here demonstrates the successful integration of a suitable tabletop chain and induction motor setup in an automated material handling process, showcasing the practical advantages of this approach for similar applications in various industries.

Figure 6. Conveyor System (Tabletop Conveyor, n.d.)

3.0 RESULT AND DISCUSSION

The presentation reveals the arrangement and construction of the system, including the identification of its components.

3.1 Automated System Model and PLC Program

Before we insert the program into the Programmable Logic Controller (PLC) using Picosoft 6, we need to run a simulation and check it (shown in Figure 3.). PLCs are widely used in various industries to automate processes. A PLC is a sophisticated device that controls logic using solid-state technology. It can be customized through a user-friendly programming language, and users can modify its memory. The best part is that this PLC is designed to handle complex operations on an industrial scale while remaining user-friendly and easy to understand for input conditions to the machine or process

Figure 7 shows the current resolving the issue of unpicked bottles in cases due to the inefficient operation of the uncaser. This device, referred to as the "case tumbler," involves the use of two tumbler conveyors to flip the case upside down, allowing the bottles to be removed and fall out through it. Unfortunately, this process is inefficient and results in reduced profitability due to an increased rate of bottle breakage during each production cycle.

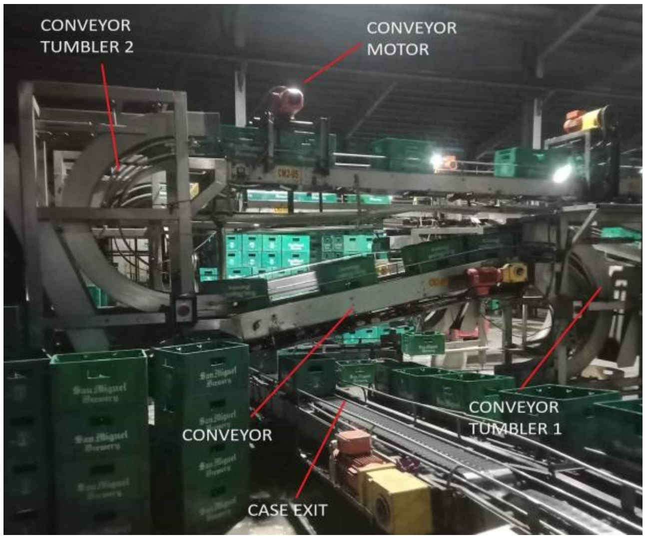

Figure 7 Case Tumbler

In connection with this, Figure 8 presents a model of an upcoming automation system designed to segregate cases with unpicked bottles and eliminate the presence of broken bottles, which can cause production stoppages. In this industrial automation setup, a network of sensors and actuators handles seamless operation. The system utilizes a combination of sensors, including diffuse sensors, retroreflective sensors, and safety interlocks. The diffuse sensors, specifically three of them in a 3x4 configuration, play a pivotal role in detecting the presence of bottles within cases as they pass by.

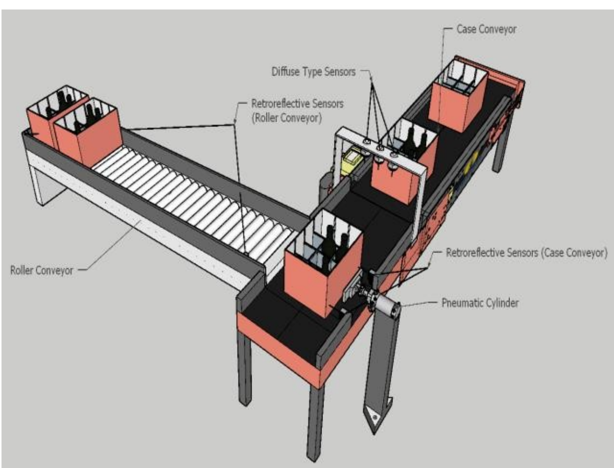

Figure 8. Developed Model of Automated Sorting System to segregate cases with unpick bottles.

When one of these sensors senses the presence of bottles, it initiates a sequence of actions. This includes signaling two retroreflective sensors and a pneumatic cylinder, which is used for case rejection. The pneumatic cylinder extends forcefully to execute the rejection process when both retroreflective sensors confirm proper case alignment. Importantly, the system incorporates timers and counters to precisely control and monitor various stages of the process. The conveyor's occupancy is tracked using a counter, and timers ensure the duration of critical processes is adhered to. A safety interlock, such as a light curtain, ensures operator safety by halting operations when necessary. Altogether, this combination of sensors and actuators, alongside careful logic control, ensures a streamlined and efficient industrial automation process, enhancing productivity and product quality.

3.2 PLC Simulation and Operating Procedure

Operational procedure guarantees a smooth automation process for our sorting system, specifically engineered for efficient handling of cases containing unpicked bottles. Additionally, a PLC logic ladder simulation is presented below to illustrate the system's functionality in detail.

3.2.1 Start and stop

- Figure 9 illustrates the start and stop functions of the system.
- Pressing the I01 button activates the conveyor motor and all the sensors integrated into the automation system.
- When the I02 button is pressed, both the conveyor motor and the sensors will come to a halt.

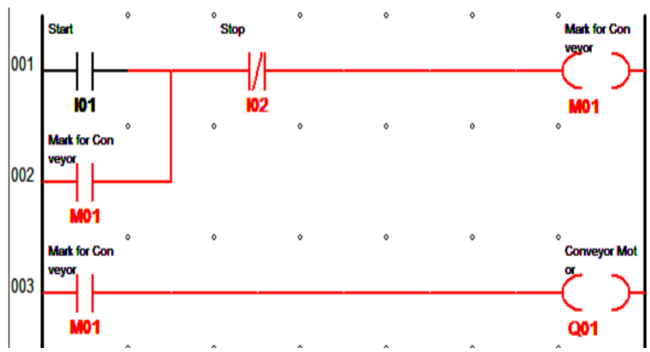

Figure 9 Start and Stop

3.2.2 Detection of Unpick Bottles

- Figure 10 shows how the diffuse type of sensor functions in this automation system.
- In the initial phase of this automation process, cases will pass through three diffuse-type sensors, specifically labeled as I03, I04, and I05, tasked with identifying the presence of unpicked bottles as they exit the uncaser.
- Within this program, a specific condition has been configured: if any of these sensors detects the presence of an unpicked bottle, it triggers the marking process.
- This marking (M02) step holds significant importance as it functions as a signal to the subsequent series of sensors. It informs them that the diffuse sensors have indeed detected the presence of bottles, thus preventing any unnecessary reactions by the following set of sensors.
- Subsequent procedures are only permitted to proceed if the marking signal is received, confirming the initial detection by the diffuse-type sensors.

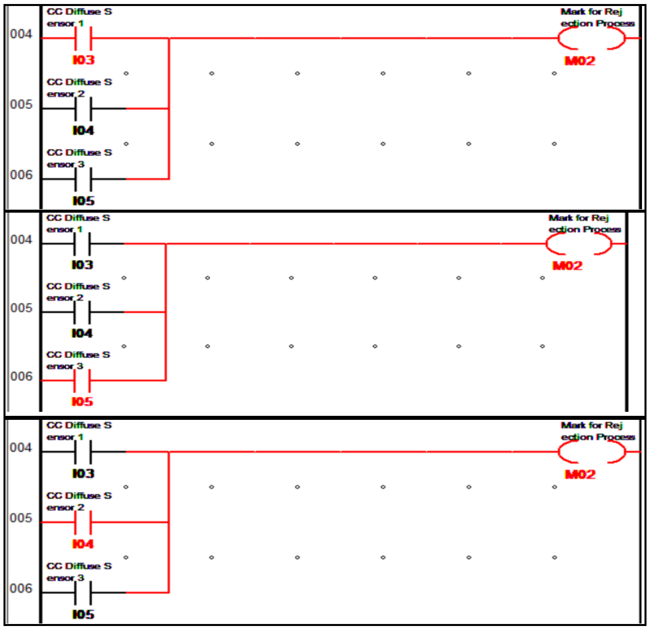

Figure 10 Diffuse Type Sensors

3.2.3 Case Rejection

- In Figure 11, I05 detected a bottle, and this action turned on M02, which acts like a signal allowing the next group of sensors to start working. These sensors are the two retroreflective ones.
- In this part of the automation, the Q02 output, which controls the pneumatic cylinder, will only turn on if both sensor I06 and I07 are blocked at the same time. This situation indicates that the case is positioned right in front of the pneumatic cylinder, situated between these two sensors.

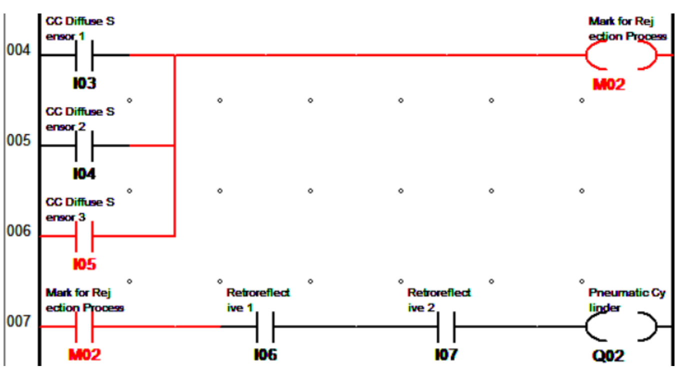

Figure 11. Case Conveyor Retroreflective Sensors

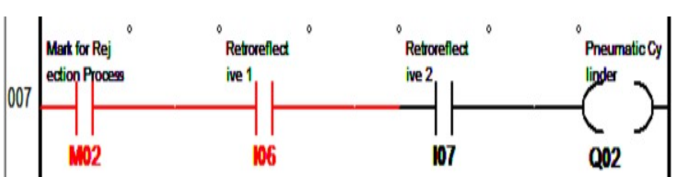

Figure 12 First Rejection Scenario

- In the first scenario in Figure 12., we notice that M02 is active, and sensor I06 is blocked. However, it's worth noting that the Q02 output, which controls the Pneumatic Cylinder, has not been activated yet.

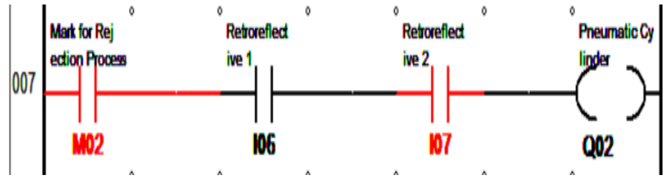

Figure 13 Second Rejection Scenario

- Similarly, in Figure 13., only I07 has detected an object, indicating that the case is not in the correct position. As a result, the output will remain inactivated.
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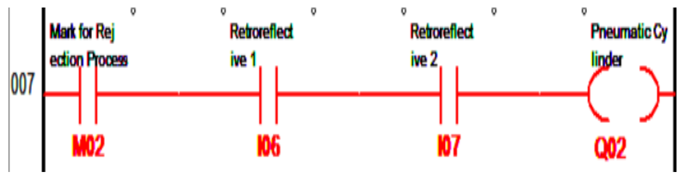

Figure 14 Third Rejection Scenario

In the third scenario (Figure 14), the pneumatic cylinder output is finally activated because all the required conditions have been met. The M02 marking is active, and both the I06 and I07 sensors have detected the presence of the case, confirming that it is in the correct position. This signifies that the pneumatic cylinder is now prepared for the rejection process.

3.2.4 Reject Conveyor Safety and Alarm Features

In this automation, safety features have been added to ensure that the production process will be continuous regardless of different conditions and controls set to the different sensors.

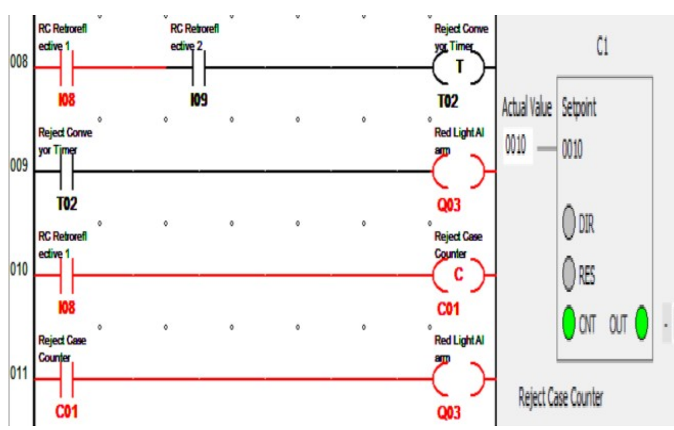

Figure 15 Counter

- Figure 15 shows the automated system for counting the rejection of bottles.
- To assess the occupancy of the roller conveyor, a counter is integrated with one retroreflective sensor (I08) through which reject cases initially pass.
- The counter keeps track of the number of times it detects reject cases.
- When the counter (C01) reaches a count of 10, it signifies that the roller conveyor is full, triggering the red-light alarm (Q03) to alert operators and remove the cases.

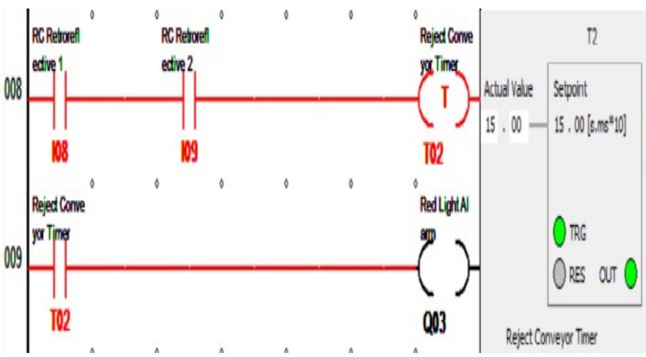

Figure 16 Timer

- In Figure 16, A timer feature has been embedded within the system to monitor the occupancy of the reject conveyor.
- When both retroreflective sensors (I08 and I09) on the roller conveyor are blocked simultaneously, this indicates that the reject conveyor is full.
- If the conveyor remains full for 15 seconds, a red-light alarm activates, promptly signaling the need for intervention.

Figure 17 Reset

- Figure 17 shows that a Counter Reset button is provided for use by human workers.
- When all cases in the reject roller conveyor have been cleared by the operator, pressing the Counter Reset button resets the counter.
- The red-light alarm turns off upon successful reset, indicating readiness to resume normal operations.

4.0 CONCLUSION

The objective of this research is to reduce the number of broken bottles during production. Currently, a significant loss of bottles occurs due to the inefficient performance of the uncaser. To provide a context, the uncaser processes 35 cases per minute, each containing 12 bottles. Upon observation, it reveals an alarming unpick rate of 3 bottles per minute, amounting to 180 per hour and approximately 4,000 per day. Consequently, the precise count of broken bottles directly correlates with the unpicked bottles.

To address this urgent situation, we suggest integrating an automated system that is controlled by predetermined parameters into the conveyor system. This complex system, which consists of sensors, pneumatics, and a PLC, works together to automatically separate cases containing bottles. The main goal goes beyond merely reducing bottle breakage; it also includes a broader mission to improve overall plant efficiency and streamline the manufacturing process.

The separation of cases with bottles will be attained with the utilization of a sensor that detects the presence of a bottle in the case. This program will be implemented by configuring the PLC with specific input and output modules. To ensure the accuracy of the automation, the entire program logic ladder will be simulated using the Picosoft simulator, specifically designed for Allen Bradley PLCs. This simulation is necessary to verify the effectiveness of the program before importing it into the PLC. Initially, this program automation will be employed by small scale industries facing similar issues, with the expectation of achieving positive results and improving production efficiency.

Our initial target for the implementation of this automated program is small-scale industries grappling with similar bottle breakage challenges. We anticipate favorable outcomes, foreseeing notable improvements in production efficiency and a substantial reduction in bottle breakage across diverse industrial contexts. This research not only addresses a critical industry challenge but also presents a scalable, industry-ready solution poised to make a significant impact on manufacturing efficiency and product quality.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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