

Application of Industrial IoT in Developing a Sustainable and Automatic Liquid Filling Plant

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Abstract- Automation control is of utmost importance in today's rapidly changing world. It has become a key driver of innovation, growth, and sustainability. In this hour of need, controllers, i.e., PLCs, are necessary due to the increasing demand for automation in industries. PLCs offer a reliable and efficient way to control and monitor complex systems and automate repetitive and time-consuming tasks. This reduces labour costs and increases the production efficiency. This paper proposes an Industrial Internet of Things (IIoT) based automatic bottle filling and sorting plant using a Programmable Logic Controller (PLC). The paper aims to address this issue by implementing Industry 4.0 principles into an existing real-time model of a water treatment plant that utilizes PLC technology. Using sensors and PLC, the system is designed to automatically fill and sort bottles based on their height. Currently, PLCs are used in water treatment plants to fill bottles of the same height on one conveyor belt rather than simultaneously detecting and filling bottles of different heights. Our proposed solution involves filling three differently sized bottles simultaneously through a detection mechanism, using industrial sensors to increase productivity and reduce time and cost. The proposed system can be easily integrated with existing manufacturing systems. The study results demonstrate that the IIoT-based plant can improve productivity by reducing downtime, minimizing product waste, and increasing throughput. This paper provides a detailed description of the system design, implementation, and testing, as well as an evaluation of the system's performance. The study contributes to the field of IIoT and automation by presenting a practical solution for improving the bottling process in manufacturing industries.

Index Terms-- IIoT, Automation Control, Industry 4.0, PLC, Bottle filling process, Implementation in plant, Productivity improvement.

I. INTRODUCTION

PLC automation is widely used in the manufacturing industry, and it can be integrated with Industry 4.0 principles to create "Smart Factories" [1]. Industry 4.0 enables cyber-physical systems to monitor and replicate physical processes, make decentralized decisions, and communicate in real time through the Internet of Things. This allows for collaboration between systems and humans, as well as the utilization of services across the value chain through the Internet of Services. PLC automation is commonly employed in bottling industries and adopting Industry 4.0 concepts can enhance their automation capabilities. The goal of this paper explains the execution of industry 4.0 concepts in water refining plant by using PLC. They wanted to meet the market demand in a short time by using this research. Silva, J.M et. al. investigated an automatic foundry plant by using PLC [2].

Computers have been utilized for monitoring and controlling manufacturing processes since the 1950s. Initially, their purpose was to log and analyze plant information. However, it wasn't until the development of direct digital control (DDC) in the 1960s that digital computers became capable enough to fully

automate plant operations and close the control loop. At first, computing efforts focused on large plants where the substantial investment justified their usage. Advancements in electronic technologies contributed to improved reliability, reduced physical size and cost, and paved the way for the development of a specialized computer in the late 1960s and early 1970s known as the programmable logic controller (PLC). The PLC was designed to operate in real-time, interface with sensors and actuators, and facilitate quick learning and application for control engineers, electrical engineers, and technicians as a replacement or supplement to relay-based control systems. Early PLCs primarily provided on-off control, and subsequent models with analog capabilities had limitations in processing analog signals. However, in the 1970s and 1980s, PLC manufacturers readily adopted developments in microprocessor technology, enhancing the PLC's capabilities and enabling it to perform complex control algorithms. With the adoption of digital communication, distributed control architectures became feasible [3]. By the 1990s, PLCs were widely employed for control applications across various industries, and efforts were made to standardize different aspects of PLC technologies,



achieving partial success. The utilization of PLC technology differs among industrial sectors such as process, steel, and discrete manufacturing. In industries where analog measurement and control parameters are predominant, such as the process industry, distributed control systems (DCS) serve as the primary control system, with PLCs being secondary and primarily integrated into original equipment manufacturer (OEM) packages. In contrast, in industries where combinatorial and sequential control is prominent, PLCs are abundantly utilized. It is worth noting that PLCs are not limited to manufacturing applications alone. They can be found controlling various systems, including those on ships, engines, car washes, lock gates, and even fairground rides. However, PLCs are not general-purpose computers like personal computers (PCs) designed to run a wide range of software applications. Instead, PLCs are dedicated to performing explicit control tasks. Although highly configurable, the PLC is a specialized tool designed to run a single program tailored to suit the specific control task at hand.

Filling refers to the process of packing liquids, such as water and other beverages, into bottles. In modern times, Programmable Logic Controllers (PLCs) are commonly used for this purpose, serving as a crucial component of the entire process. PLCs are powerful devices employed to control production systems and automate industrial activities. They function as digital computers with inputs and outputs, a CPU, and memory. Based on the input conditions, PLCs generate corresponding output results. PLCs have been developed as replacements for relay circuits. The automation process in filling operations relies on the programmed logic of the PLC. PLCs have a specific number of connections for handling inputs and outputs. The utilization of PLCs offers several advantages, including smooth operation, cost-effectiveness, and high filling speeds. Integrating PLCs into automatic filling systems is essential for enhancing filling accuracy. The control of the process is achieved through ladder logic programming. Various components, such as motors, level sensors, proximity sensors, conveyor belts, PLCs, and solenoid valves, are employed to control the filling process. The PLC ladder logic programming is symbol-based, allowing for easy modification and adjustments [4].

Lu, Y.-D., et al., worked on the development of an automatic beverage filling machine utilizing PLC technology [5]. Their aim was to enhance the production rate and flexibility of the system by employing PLC. Kulkarni, S.L. et al. focused on the development of a PLC microcontroller specifically for a bottle filling system [6]. Their research encompassed both the beverage industry and the healthcare industry, where filling operations are crucial due to the increasing demand for beverages and medicines. In the healthcare industry, manual filling operations pose safety risks, while in the beverage industry, manual filling leads to economic losses and inefficiency in terms of time consumption. To address these drawbacks, the researchers designed an automatic bottle filling machine that utilized PLC technology, eliminating the need for manual intervention. Kiran, A.R et al. conducted an investigation into the principles and importance of PLC in automation [7]. Their research focused on PLC-based

automation, which holds significant importance in the modern world. They emphasized that PLC plays a crucial role in various industries by enabling mass production with enhanced accuracy and productivity. The engineers involved in the study developed ladder logic programs to operate PLCs and aimed to implement this microcontroller technology in modern industries. H Ahuja et al. developed an automatic filling machine [8]. They recognized the necessity of automation in the current industrial revolution to assist humans in various tasks within industries. The increasing competition among industries, along with the introduction of new products and brands, requires efficient automation to keep products in the market and ensure timely delivery. In their research, they utilized PLC technology for the purpose of automation. Schwager, A., et al. worked on the development of an automatic bottle filling machine using PLC [9]. Their study focused on the automation of industrial processes, specifically addressing the manufacturing steps involved in developing an automatic filling system. Their research aimed to enhance the efficiency of the filling system through automation. They highlighted the importance of controlling various elements within the filling system.

The MicroLogix 1400 PLC with the catalog number 1766-L32AWAA is a compact, programmable logic controller manufactured by Rockwell Automation. It is part of the MicroLogix family of PLCs and is widely used in various industrial automation applications. The 1766-L32AWAA PLC has a total of 20 digital inputs and 12 digital relay outputs. The inputs and outputs are configurable, which means they can be used for different purposes based on the application requirements. The digital inputs can be used to receive signals from various sensors, switches, and other devices, while the digital relay outputs can control actuators such as motors, solenoids, or other devices. The 1766-L32AWAA PLC has digital relay outputs. Relay outputs are typically used for controlling devices that require higher current or voltage levels than what the PLC's digital outputs can handle directly. The relay outputs provide electrical isolation between the PLC and the controlled devices. They can be used to control various industrial components, such as pumps, valves, motors, or other high-power devices. The 1766-L32AWAA PLC supports multiple communication options, including Ethernet. It is equipped with an Ethernet port that allows for communication with other devices, such as human-machine interfaces (HMIs), supervisory control and data acquisition (SCADA) systems, or other PLCs. Using the Ethernet connectivity, one can exchange data, monitor the status of the PLC, and program it remotely. In addition to Ethernet, the 1766-L32AWAA PLC also supports other communication protocols such as RS-232 and RS-485, which can be used for connecting to devices using serial communication.

The automatic bottle filling system utilizes a PLC and includes a continuously moving conveyor belt. Bottles of various sizes are placed on the conveyor belt. When a bottle reaches the designated position under the solenoid valve, it automatically stops, and the valve opens to initiate the filling process. Once the bottle is filled, the solenoid valve closes, and the bottle resumes its movement on the conveyor belt, completing one cycle of the process. The PLC controls the proportional filling

of liquid using sensors and valves, allowing precise control over the flow rate. To enable controlled bottle movement, a DC gear motor drives the conveyor belt, providing user-defined rotation in both directions. PLC implementation and design cover several key areas, including PLC hardware components, development of PLC wiring diagrams, basics of PLC programming, timers, counters, program control instructions, data manipulation instructions, PLC installation, editing, and troubleshooting. In our practical PLC programming exercises, we utilized RSLogix5000® software from Rockwell Automation. For our conveyor system, we opted for a dc motor due to its superior performance and ease of operation. An IR sensor is employed to detect the presence of bottles of various sizes, enabling the activation of specific solenoid valves. Our study revealed that the water filling machine using PLC not only exhibits lower operational costs and power consumption compared to traditional control systems but also offers increased flexibility and time savings. The water level of the bottles is controlled using internal timers, which can be set to different values in seconds or milliseconds based on our requirements. We have implemented this approach instead of using expensive and less commonly available level sensors. The conveyor belt is driven by a DC gear motor, chosen for its ability to provide slow, smooth, and jerk-free motion of the belt. Filling of the bottles is done by precisely measuring the required filling time. This technique is simple and cost-effective, as it only requires solenoid valves that operate for a specific time depending on the chosen bottle size.

II. BACKGROUND

Das, Dutta, Sarkar & Samanta (2013) proposed that system offers an in-depth analysis of the simulation and components necessary for implementing an automated level control system using a Programmable Logic Controller (PLC). The system incorporates a Supervisory Control and Data Acquisition (SCADA) system and a Human Machine Interface (HMI). This model proves to be highly efficient in supervising the level control of multiple tanks. To gather accurate level data, three level sensors were utilized and connected to the PLC. The PLC processes this data and makes informed decisions accordingly, enabling it to control the activation and deactivation of a pump as required. Additionally, to allow manual control, a manual switch was included in the system, allowing users to override the automatic functionality when needed. The SIMATIC S7-300 universal controller was chosen as the primary decision-making module, offering reliability and robustness. To create a user-friendly interface and visualize the system's operation, SCADA was implemented, providing an intuitive HMI for operators to monitor and control the level control process effectively. While alternative float sensors could be employed to achieve accurate level measurement, they come with their limitations. The proposed model addresses these shortcomings by providing an effective solution that minimizes the impact of sensor vibration and keeps costs under control. By rephrasing and expanding upon the original description, we have outlined a comprehensive overview of the proposed system. This automated level control system, incorporating PLC, SCADA, and HMI components, offers a reliable and efficient solution for monitoring and

managing tank levels. The use of a robust controller and the implementation of an intuitive interface contribute to the overall effectiveness of the system [10].

Baladhandabany, Gowtham, Kowsikkumar, Gomathi, & Vijayasalini (2015) studied that filling refers to the process of adding or injecting a substance, such as liquid, gas, or solid, into a container or designated space. This research focuses on enhancing the bottle-filling process by exploring methods for filling multiple bottles simultaneously. Instead of filling bottles individually on a conveyor belt, the proposed approach aims to increase efficiency by filling multiple bottles concurrently. To achieve this, a stepper motor is employed within a conveyor system, offering high efficiency and precise control. The system allows users to select the desired volume level for filling, providing flexibility and customization. Additionally, the proposed system incorporates a reduced number of sensors, resulting in a more cost-effective solution. The filling process is controlled by a Programmable Logic Controller (PLC) utilizing the ladder logic method. The PLC receives feedback from the sensors and regulates the timing of the solenoid valves while managing the conveyor belt's operation. By programming the PLC, the entire bottle-filling system is effectively controlled. The sensors play a critical role in the process, ensuring accurate and reliable detection of various parameters. In automation industries, the PLC is commonly regarded as the core component of any system, responsible for its reliable operation. The proposed system offers numerous benefits, including increased flexibility, time efficiency, and user-friendliness. Through the implementation of the PLC and the integration of advanced control mechanisms, the entire bottle-filling process is streamlined and optimized. The results obtained from this study strongly demonstrate the inspiring performance and effectiveness of the PLC in bottle-filling applications [11].

Ameer L. Saleh, Lawahed F. Naeem & Mohammed J. Mohammed in (2017) studied that implementation of Programmable Logic Controller (PLC)-based automatic bottle filling systems has proven to be highly advantageous in increasing production output in automated manufacturing processes. The integration of automation systems has contributed to significant improvements in the production of goods, consequently fostering economic growth. The objective of this study is to explore and implement a PLC-based automatic bottle filling system, considering its potential impact on production efficiency.

It is worth noting that the installation of such systems incurs initial costs and requires time for proper setup. However, once operational, these systems can function reliably for extended periods. The performance of the automated bottle filling system is closely tied to the cost and quality of the installation process. By implementing a PLC as the central control unit and utilizing ladder logic programming, the overall system achieves reliable and efficient operation. Moreover, the automated process saves time, while the user-friendly interface simplifies system management.

To date, various studies have highlighted the benefits of PLC-based automation systems in different manufacturing sectors. These systems have demonstrated improved production rates, enhanced precision, reduced human error, and increased

operational efficiency. Additionally, PLC-based control systems offer flexibility in modifying production processes, facilitating rapid adaptation to changing manufacturing demands. However, it is important to note that each implementation may have unique considerations and challenges based on specific requirements and constraints. Therefore, a comprehensive evaluation of the system's feasibility, cost-effectiveness, and suitability to the specific application is crucial [12].

Dalenogare, Benitez, Ayala, & Frank, (2018) declared that industry 4.0 represents a new phase of industrial development, characterized by the integration of vertical and horizontal manufacturing processes and the connectivity of products. It has the potential to significantly enhance industrial performance. However, there is limited knowledge about how industries in emerging countries perceive the potential contribution of Industry 4.0 technologies to industrial performance. To address this gap, we conducted a comprehensive study utilizing secondary data from a large-scale survey. The survey covered 27 industrial sectors, encompassing 2,225 companies in the Brazilian industry. Our analysis focused on examining how the adoption of various Industry 4.0 technologies is associated with expected benefits in terms of product improvement, operational efficiency, and potential side-effects. By employing regression analysis, we discovered that certain Industry 4.0 technologies are viewed as promising for improving industrial performance, while some emerging technologies do not align with this conventional wisdom. These findings challenge preconceived notions about the potential benefits of specific technologies within the Industry 4.0 framework. We considered the contextual conditions of the Brazilian industry, which may necessitate a selective implementation of Industry 4.0 concepts originally developed in more advanced countries. By summarizing our findings in a comprehensive framework, we provide insights into the perception of Brazilian industries regarding Industry 4.0 technologies and their expected benefits. Consequently, this research contributes by shedding light on the realistic expectations regarding the future performance of industries when adopting new technologies. It also serves as a foundation for further investigations into the actual benefits of Industry 4.0. By understanding how different technologies are perceived in the context of industrial development, we can better guide the implementation of Industry 4.0 initiatives and maximize their positive impact [13].

Nadgauda, & Muthukumaraswamy (2019, April) found that the increasing adoption of automation in the industrial sector has driven the need for advanced technologies that can enhance efficiency, accuracy, and flexibility of processes. This paper focuses on the application of Supervisory Control and Data Acquisition (SCADA) systems in remote monitoring and automation for the bottle-filling industry. Furthermore, the paper explores warehouse management systems, specifically comparing two techniques: Barcode technology and crane automation systems, to illustrate effective storage and management of packaged bottles. By optimizing warehouse activities, the industry can achieve greater consistency and efficiency. The implementation of the proposed system utilizes Programmable Logic Controller (PLC) - SCADA systems, which offer durability, flexibility, and ease of programming.

This technology not only enables remote monitoring and control of bottle-filling processes but also facilitates effective warehouse management. The study demonstrates the potential benefits of integrating SCADA systems with PLCs, enabling real-time data collection, analysis, and decision-making. With its versatility, this system can be expanded to other sorting industries, providing a scalable and adaptable solution. Expanding on this research, future investigations can explore the specific functionalities and advantages of SCADA systems in the bottle-filling industry. Additionally, in-depth analysis and comparison of warehouse management techniques, such as Barcode technology and crane automation systems, can be conducted to determine their respective benefits and limitations. Further exploration of the integration between PLCs and SCADA systems can focus on enhancing automation, improving production efficiency, and minimizing errors in the industry. The application of remote monitoring and automation through SCADA systems holds promise for the bottle-filling industry, offering improved operational control, enhanced efficiency, and better management of resources. By continuously leveraging advanced technologies and optimizing warehouse activities, businesses can achieve a competitive edge and contribute to the growth and evolution of the industrial sector [14].

Guha, Adarsh, Kumari, & Ajay (2020) considered that there is a global trend towards increased automation, which involves minimizing or eliminating human intervention in various tasks. Automation offers numerous benefits, including enhanced efficiency and output. To achieve automation, control loops are established using microcontrollers such as Arduino or Programmable Logic Controllers (PLCs), which regulate the operation of entire plants. One significant operation in many industries, including soft drink manufacturing, packaged water production, and pharmaceuticals, is bottle filling. Traditionally, this task was performed manually, with one bottle being placed on a conveyor belt and filled at a time. However, this manual approach was slow, prone to liquid spillage, and resulted in inconsistent quantities of liquid in each bottle. To address these challenges, large manufacturing units have adopted PLCs to automate the filling process. Unfortunately, PLC machines are expensive, making them inaccessible for small manufacturing units. Consequently, manual filling persists in these smaller facilities, leading to operational limitations and increased labor costs. To overcome this problem, there is a need to develop a cost-effective system. One potential solution is utilizing Arduino as a microcontroller, which can significantly reduce costs. The proposed project aims to study the industrial process carried out by PLCs, compare the capabilities of PLCs and Arduino, and subsequently design a bottle filling system using the Arduino UNO microcontroller. By employing Arduino as a microcontroller, the project aims to provide small-scale industries with a more affordable option for setting up automated bottle filling plants. This approach can help overcome the limitations faced by manual operations, improve operational efficiency, and decrease labor costs for these businesses.

Expanding on this research, further exploration can be conducted into the specific functionalities and capabilities of both PLCs and Arduino microcontrollers. A comparative

analysis can be performed to highlight the advantages and limitations of each system in industrial applications. Additionally, the project can delve into the design and implementation aspects of the bottle filling system, including the integration of sensors, actuators, and control algorithms to ensure accurate and precise filling operations. The project too aims to bridge the gap between expensive PLC-based automation and the needs of small-scale industries by proposing an Arduino-based solution. Through the development of a cost-effective automated bottle filling system, this research can contribute to the advancement of automation in various manufacturing sectors [15].

Nadgauda, Muthukumaraswamy & Prabha (2020) offered the proposal and application of a smart automated bottle-filling industry using Programmable Logic Controllers (PLC), Supervisory Control and Data Acquisition (SCADA) systems. Among the automated processes are bottle-filling, warehouse management, and energy-efficient lighting. An imitation of SCADA for the bottle-filling industry has been created to showcase the entire monitoring and control procedures. As soon as the bottles are cleaned and filled, they are transported to warehouses with barcode labels for effective sorting. Through proper warehouse management coupled with state-of-the-art crane systems and automatic lighting solutions, sorting processes can be improved, as well as energy-efficiency and throughput. To improve flexibility, reliability, efficiency, and the overall productivity of the industrial environment, a complete integrated industrial automation system has been designed as a single system [16].

Malik, Praveen Kumar, Rohit Sharma, Rajesh Singh, Gehlot, Satapathy, Alnumay, Danilo Pelusi, Uttam & Nayak (2021) introduced the Industrial Internet of Things (IIoT) as a promising platform that connects various sensors to the Internet, offering tremendous opportunities for the realization of a smarter and more interconnected society. The rapid growth of IIoT has significantly impacted numerous sectors in today's world, influencing both work environments and individual lifestyles. With the increasing availability of internet connectivity and the development of advanced systems with Wi-Fi capabilities, the concept of connecting devices to the internet, known as IIoT, is emerging as a fundamental principle for the future. This manuscript extensively explores the diverse applications of the Internet of Things (IoT) in various domains, including automotive industries, embedded devices, environmental monitoring, agriculture, construction, smart grid, healthcare, and more. A comprehensive review of existing IIoT systems in the automotive industry, emergency response, and supply chain management has been conducted, revealing the pervasive presence of IIoT across multiple technological fields. In the automotive industry, IIoT has revolutionized vehicle connectivity, enabling features such as real-time diagnostics, predictive maintenance, and enhanced safety measures. Emergency response systems leverage IIoT to improve disaster management, enabling faster and more efficient responses in critical situations. Supply chain management has also experienced significant advancements with the implementation of IIoT, enhancing inventory management, logistics tracking, and overall operational

efficiency. Furthermore, IIoT's impact extends to areas such as environmental monitoring, where it facilitates real-time data collection and analysis for better resource management and conservation efforts. In agriculture, IIoT enables precision farming techniques, monitoring soil conditions, crop growth, and optimizing irrigation systems. The construction industry benefits from IIoT by improving safety measures, equipment tracking, and remote monitoring of construction sites. Smart grid implementations leverage IIoT for efficient energy management and grid stability. In the healthcare sector, IIoT plays a vital role in remote patient monitoring, personalized healthcare delivery, and efficient healthcare resource management. The comprehensive analysis of IIoT applications across various fields highlights the transformative potential of this technology. It opens up new avenues for innovation, efficiency, and improved quality of life. As IIoT continues to evolve, it is expected to reshape the way we interact with technology, advancing society towards a more interconnected and intelligent future [17].

Hosen, Uddin, Rana, & Badsha Bhuiyan (2022) offered that automation is becoming increasingly prevalent in today's world, revolutionizing various industries by minimizing or eliminating the need for human intervention in tasks. This shift towards automation offers numerous benefits, including improved overall efficiency and output. Microcontrollers, such as Arduino or Programmable Logic Controllers (PLCs), play a vital role in establishing control loops that regulate the entire plant's operations.

One significant operation in industries such as soft drinks, packaged water, and pharmaceuticals is filling bottles with a precise amount of liquid. Previously, this task was carried out manually, with workers placing one bottle at a time on a conveyor belt and filling it. However, this manual process was slow, prone to liquid spills, and often resulted in uneven quantities of liquid in the bottles. In large manufacturing units, the process has been automated using PLCs. Unfortunately, PLC machines are expensive, making them unaffordable for small-scale manufacturing units. As a result, manual filling persists in these smaller facilities, leading to operational limitations and increased labor costs. To address this challenge, it is crucial to design a cost-effective system. One potential solution is to utilize Arduino as a microcontroller, as it offers a more affordable alternative. The proposed project aims to reduce costs for small-scale industries by assisting them in setting up automated plants. The project involves studying the industrial process as carried out by a microcontroller, followed by the design and implementation of a bottle filling, counting, and liquid tank level monitoring system. Expanding on this research, further exploration can focus on understanding the intricacies of the industrial processes executed by microcontrollers and identifying areas for optimization. The project can also delve into the integration of sensors, actuators, and control algorithms to ensure accurate bottle filling, precise counting, and efficient monitoring of the liquid tank levels. By leveraging Arduino as a microcontroller, the proposed project has the potential to revolutionize small-scale industries by providing cost-effective automation solutions. This not only improves operational efficiency but also mitigates the

shortcomings associated with manual processes, reducing labor costs and enhancing productivity. The findings and outcomes of this project can contribute to the broader adoption of automation in small-scale manufacturing, enabling businesses to thrive in a competitive environment while maximizing cost-effectiveness [18].

Prasanna, MadhusudhanaRao, Kaushaley, Nakka, & Jena (2023, February) studied that in today's rapidly evolving and highly competitive industrial landscape, businesses must strive to be adaptable, efficient, and well-organized in order to survive. The pursuit of operational optimization, including increased speed, reliability, and output, has resulted in a growing demand for industrial control systems and automation across various process and manufacturing industries. As a consequence, the impact of automation on both daily life and the global economy continues to expand. This study aimed to develop an Internet of Things (IoT)-based Supervisory Control and Data Acquisition (SCADA) system for an automatic bottle-filling and capping process. The WinCC Explorer software was utilized for designing the production contour and monitoring and controlling the system in this simulation. The ladder diagram was developed and tested using Delta software. To minimize the number of rejected bottles, a retentive timer was employed instead of an on/off delay timer. The system was characterized by features such as low power consumption, reduced operating costs, minimal maintenance requirements, and decreased fluid loss. These factors collectively enhanced cost-effectiveness and increased the profit margin. The implementation of a fully automated bottling facility achieved significant energy savings and efficiency improvements through speed control. Based on the findings and recommendations, it is advised to consider employing a completely automated system rather than a traditional control system. This shift towards full automation enables businesses to capitalize on the benefits of enhanced operational efficiency, reduced costs, and increased profitability. The integration of IoT and SCADA technologies offers real-time monitoring, remote control capabilities, and data-driven insights, facilitating better decision-making and process optimization. Expanding on this research, further exploration can be conducted to investigate the potential applications and benefits of IoT-based SCADA systems in other industrial processes and sectors. Additionally, the study can delve into the specific implementation details of the automatic bottle-filling and capping system, including sensor integration, control algorithms, and data analysis techniques. By continuously embracing and harnessing automation, businesses can achieve sustainable growth, remain competitive, and contribute to the overall advancement of the industrial landscape [19].

III. MATERIALS AND METHODS

Figure 1 gives a detailed block diagram of the automatic bottle filling and sorting mechanisms. This solution incorporates advanced technologies such as sensor-based height detection, color recognition, PLC control, and IIoT integration to enable efficient bottle filling and sorting processes. The system should accurately detect the heights of different-sized bottles and fill them with the corresponding colors of liquid which in turn helps

in reducing time, cost, and manual intervention. Additionally, the system should utilize IIoT capabilities to monitor and display the counting numbers of bottles filled with the same liquid on a webpage in real-time, facilitating better production control and inventory management.

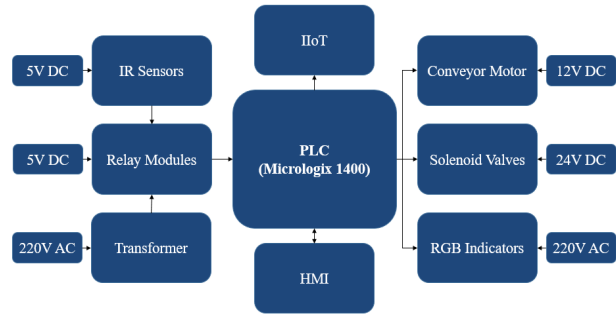


FIGURE 1. Block Diagram

To differentiate between small, medium, and large bottles, the IR sensors are configured to activate based on specific heights. For instance, when a small bottle reaches the tower, the bottom IR sensor is triggered, and a signal is sent to the PLC. This signal latches a bit in the PLC, indicating the presence of a small bottle. Similarly, when a medium-sized bottle reaches the tower, the bottom and second-last IR sensors are activated, providing signals to the PLC. The PLC interprets these signals and latches another bit, indicating the presence of a medium-sized bottle. In the case of a large bottle, all three IR sensors placed on the tower are activated simultaneously as the bottle passes through. The signals from these sensors are received by the PLC, which latches a bit to indicate the presence of a large bottle. By utilizing this detection mechanism, the PLC can accurately determine the height of each bottle passing through the sensor tower. The latching of specific bits in the PLC based on the activated IR sensors allows for effective identification and classification of bottle sizes as shown in Table I.

TABLE I
BOTTLE SIZE DETECTION BASED ON SENSOR OUTPUT

Sensing the bottle based on its Height	No. of Bits
Small sized bottle (Sensor 3 is off, while other two give output)	001
Medium sized bottle (Sensor 2 and 3 do not give output, while Sensor 1 remains on)	011
Large sized bottle (Sensor 1,2,3 all do not give output)	111

After the height detection process, the proposed approach incorporates a software-based timer to determine the time it takes for each bottle to reach the respective valve for filling.

Additionally, separate IR sensors are placed at each valve to detect the presence of a bottle and initiate the opening of the corresponding valve for liquid filling. For small bottles, a timer is initialized in the software to estimate the time it takes for a bottle to reach the position below the red valve. Once the bottle is detected by the sensor placed on the red valve, the corresponding valve is opened, and the red liquid starts filling into the bottle. The filling time for the red liquid is predetermined by another timer specified in the software. Similarly, for medium-sized bottles, the timer is set to calculate the time it takes for a bottle to reach the position below the green valve. When the bottle is detected by the sensor placed on the green valve, the valve opens, and the green liquid starts filling into the bottle. The filling time for the green liquid is determined by a timer specified in the software. For large bottles, the timer is set to measure the time it takes for a bottle to reach the position below the blue valve. Once the bottle is detected by the sensor placed on the blue valve, the valve opens, and the blue liquid starts filling into the bottle. The filling time for the blue liquid is defined by a timer specified in the software. The specifications are described in Table II.

TABLE II
SPECIFICATIONS

Height of the bottle	Specified Color
Small Sized Bottle	Red Liquid for 20sec
Medium sized bottle	Green Liquid for 30sec
Large sized bottle	Blue Liquid for 50sec

After the filling process, the bottles move towards the final stage of the system, where a last IR sensor is positioned to detect their presence. This sensor utilizes the latched status of the bits from the height detection sensors placed on the tower to determine the type of bottle that is approaching. Based on this information, the sensor activates the corresponding indicator of the appropriate color for sorting purposes. When a small bottle approaches the last sensor, it receives the signal that it has been detected and that it has been filled with red liquid, as indicated by the latched bits from the tower sensors. Consequently, the sensor triggers the red indicator to turn on, allowing the system to sort the small bottle accordingly. Similarly, for medium-sized bottles, the last sensor detects their presence and utilizes the information from the tower sensors to identify that a medium-sized bottle filled with green liquid is approaching. Consequently, the sensor activates the green indicator to facilitate the sorting of the medium-sized bottle. In the case of large bottles, the last sensor detects their presence and uses the information from the tower sensors to determine that a large bottle filled with blue liquid is coming. As a result, the sensor turns on the blue indicator, enabling the system to sort the large bottle accordingly.

IV. PROPOSED SYSTEM AND ALGORITHM

The research aim is to design an efficient and feasible project which can work efficient and can be developed on a large scale.

The fundamental mathematical expressions for the calculation of flow rate (R_f) and energy consumption (E_c) are given as;

$$R_f = \frac{E_n}{t} \quad (1)$$

$$E_c = P_t * t \quad (2)$$

where, E_n denotes the number of bottle, t is the unit time and P_t represents the power consumption per unit time.

4.1. PROPOSED ALGORITHM

The proposed algorithm for our project is depicted in the accompanying algorithm, which provides a comprehensive overview of its functioning. We propose using Internet of Things technology based automated systems. Our main objective behind developing such an application lies within reducing human intervention while processing large volumes of raw materials thus leading towards better utilization of resources.

Our groundbreaking algorithm harnesses the power of Industrial Internet of Things (IIoT) to create an extraordinary bottle filling and sorting plant, streamlining production processes, enhancing quality control, and maximizing operational efficiency. By seamlessly integrating real-time data analytics and advanced robotic automation, our algorithm ensures optimal bottle filling accuracy, adaptive sorting capabilities, and intelligent decision-making, thereby empowering industries to achieve unprecedented levels of productivity, cost-effectiveness, and customer satisfaction.

Algorithm. IIoT Based Automatic Bottle Filling and Sorting Plant

- 1: *Initialize*: the system,
- 2: *Initialize* the START button,
- 3: Target: Green indicator light
- 4: *Initialize* the conveyor belt
- 5: **for** each bottle:
- 6: activate the START button
- 7: **wait** for the green indicator light to illuminate
- 8: start the conveyer belt
- 9: **while** bottle is on the conveyor belt:
- 10: **if** all three IR sensors detect the presence of the bottle:
- 11: latch that signal from the IR sensors
- 12: start that specific timer (say T4:1)
- 13: **else if** two IR sensors detect the presence of the bottle:
- 14: latch that signal from the IR sensors
- 15: start that specific timer (say T4:2)
- 16: **else** only one IR sensor detect the presence of the bottle:
- 17: latch that signal from the IR sensors
- 18: start that specific timer (say T4:3)
- 19: **if** bottle reaches the fourth IR sensor:
- 20: open the solenoid valve (red) to fill the bottle
- 21: **wait** for the filling process completion
- 22: **else if** bottle reaches the sixth IR sensor:
- 23: open the solenoid valve (blue) to fill the bottle
- 24: **wait** for the filling process completion
- 25: **else** bottle reaches the sixth IR sensor:
- 26: open the solenoid valve (blue) to fill the bottle
- 27: **wait** for the filling process completion

- 28: **continue** the movement of the conveyor belt
- 29: detect the presence of a bottle using last IR sensor
- 30: utilize the status of the first three placed IR sensor to determine bottle height
- 31: **wait** for the appropriate indicator to illuminate for 10 seconds
- 32: **end for**
- 33: **end for**

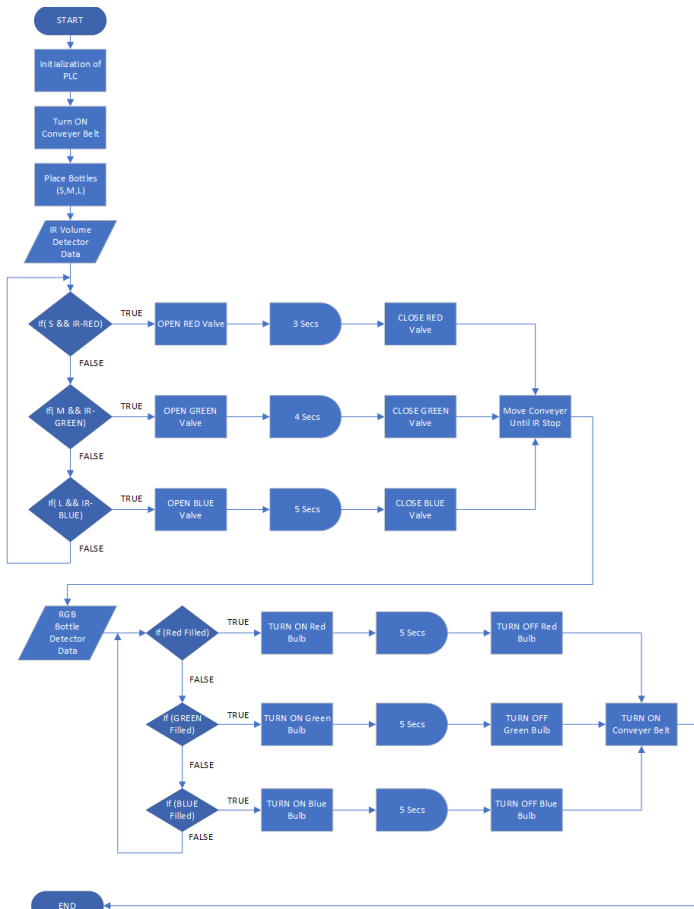


FIGURE 2: Proposed Algorithm Flowgraph.

4.2. SOFTWARE DEVELOPMENT OF PLANT

Human Machine Interfaces (HMI) are vital components in modern industrial automation and control systems. HMI of our project is shown in Figure 3.

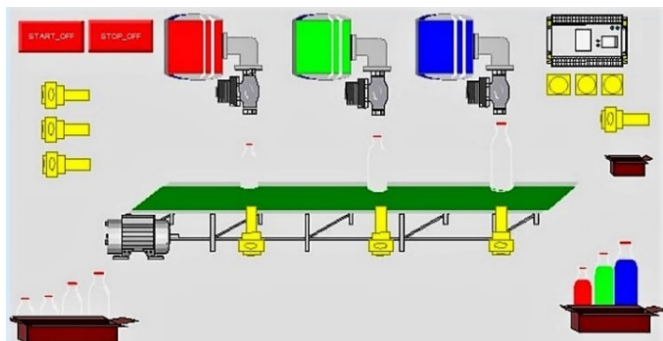


FIGURE 3: Human Machine Interface

4.3 DEVELOPMENT OF PLANT

The process begins with the operator activating the START button, which initiates the system. Upon pressing the START button, a green indicator light illuminates, indicating that the button has been pressed. Subsequently, the conveyor belt starts moving. As the conveyor belt continues its motion, the first bottle, which is of a smaller size, reaches a section where three infrared (IR) sensors are vertically positioned. All three IR sensors detect the presence of the bottle simultaneously. These signals from the IR sensors trigger a latching mechanism, activating a specific timer in the software. The timer begins its operation. As the bottle progresses and reaches the fourth IR sensor (placed under the red valve), it is detected, prompting the opening of a solenoid valve (the one in front of red tank) to fill the smaller bottle. Figure 4 shows the filling process of red bottle.

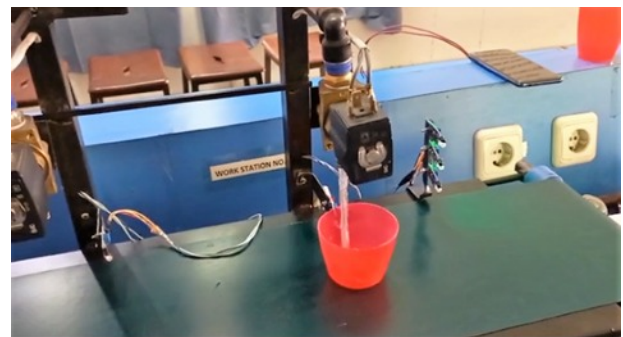


FIGURE 4: Filling of Bottle

Once the filling process is complete, the conveyor belt resumes its movement. The last IR sensor (used for sorting purpose), positioned at the end of the conveyor, detects the presence of a bottle and halts the conveyor belt as shown in Figure 5.

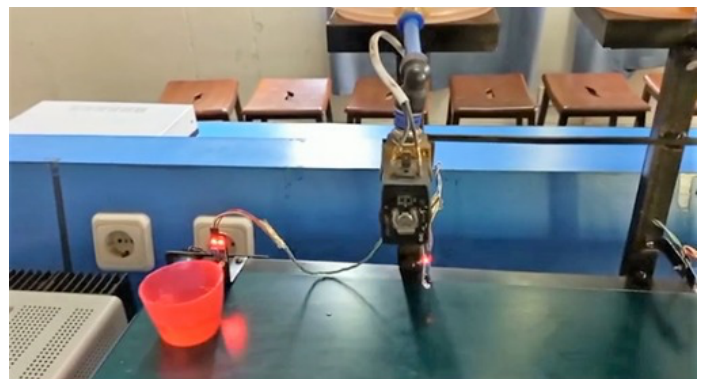


FIGURE 5: Sorting of Bottle

It utilizes the status of the first three IR sensors (which are placed vertically at start of belt) to determine the height of the bottle. Based on this height measurement, an indicator light of a corresponding color is illuminated for a duration of 10 seconds as shown in Figure 6. Afterward, the conveyor belt restarts, and the entire process repeats for the subsequent bottles.

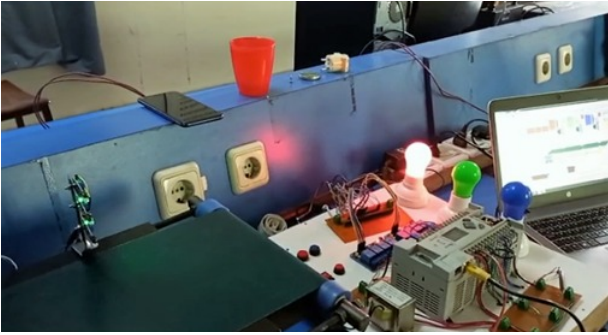


FIGURE 6: Signaling the Presence of Red Bottle

V. RESULTS

In this study, the performance of an IIoT-based automatic bottle filling and sorting plant was evaluated through various measurements, convergence optimization techniques, and achievements. The plant's key metrics, including fill level accuracy, production rate, error rate, and energy consumption, were monitored and analyzed to assess its overall performance. The measurement results revealed a high level of accuracy in the fill level achieved by the plant. This indicated that the IIoT integration effectively facilitated precise bottle filling. Additionally, the production rate was closely monitored in real-time, allowing for adjustments to optimize throughput and minimize bottlenecks, ultimately improving overall efficiency. By leveraging IIoT technologies, the automatic bottle filling and sorting plant achieved a substantial reduction in the error rate. This notable improvement in quality control led to enhanced product quality and increased customer satisfaction. Real-time monitoring and automated error detection systems played a crucial role in promptly identifying and addressing any issues. Furthermore, the integration of IIoT technologies enabled continuous monitoring and analysis of energy consumption patterns. This resulted in the implementation of energy-saving measures, leading to reduced energy consumption and associated costs. The plant demonstrated improved energy efficiency, contributing to sustainable manufacturing practices.

The Figure 7 shows relationship between filling time and number of bottles. It is a useful tool for understanding how the filling time changes as the number of bottles increases. The filling time is the amount of time it takes to fill a bottle with a given volume of liquid. The number of bottles is the total number of bottles that are filled in a given period of time. The filling time vs. No. of Bottles graph can be used to identify the optimal filling time for a given number of bottles. This information can be used to improve the efficiency of the filling process. The filling time vs. No. of Bottles graph can also be used to identify any bottlenecks in the filling process. This information can be used to make improvements to the filling process and to reduce the overall filling time. In an IIoT based automatic bottle filling and sorting plant, the filling time vs. No. of Bottles graph can be used to monitor the performance of the filling process. This information can be used to identify any problems with the filling process and to make necessary adjustments. The filling time vs. No. of Bottles graph is a valuable tool for understanding and improving the filling process in an IIoT based automatic bottle filling and sorting plant.

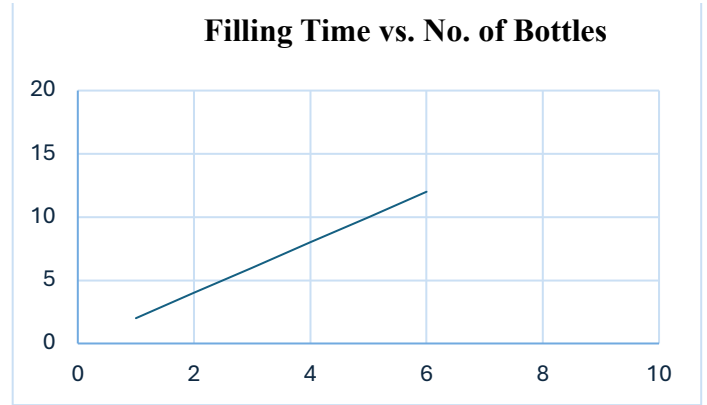


FIGURE 7: Filling Time vs. No. of Bottles

Figure 8 illustrates the relationship between the filling accuracy and the number of bottles in the IIoT-based automatic bottle filling and sorting plant. The filling accuracy, expressed as a percentage, represents the precision with which the desired fill level is achieved during the filling process.

The data collected from the experimental setup shows that as the number of bottles increases, the filling accuracy exhibits a gradual decline. This decline in filling accuracy can be attributed to various factors, such as increased system complexity, variations in bottle size, or the effects of environmental conditions on the filling process.

The observed trend underscores the importance of optimizing the system's performance and calibration to maintain high filling accuracy, particularly when handling larger quantities of bottles. Fine-tuning the control algorithms, improving sensor calibration, or implementing adaptive feedback mechanisms can potentially enhance the filling accuracy and ensure consistent product quality throughout the production process.

Understanding the relationship between the filling accuracy and the number of bottles is crucial for efficient production and quality control in automated bottle filling plants. By monitoring and optimizing the system's performance, manufacturers can strive to achieve higher filling accuracies and minimize deviations in the fill level, thereby enhancing overall product integrity and customer satisfaction.

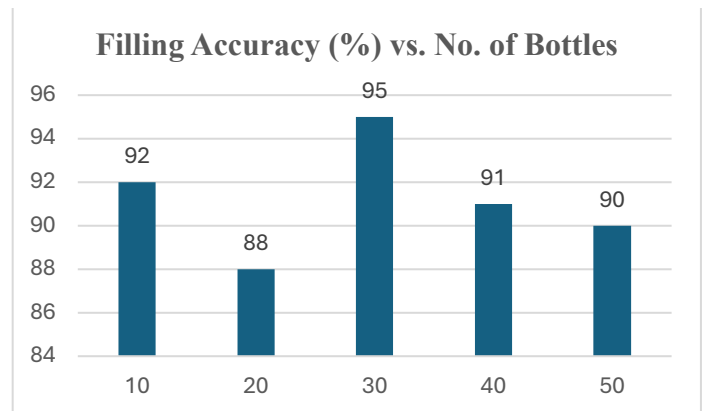


FIGURE 8: Filling Accuracy (%) vs. No. of Bottles

Figure 9 represents the relationship between filling time and solenoid valve opening. The filling time of a bottle is a critical

factor in the production of bottled beverages. The filling time is the amount of time it takes to fill a bottle with liquid. The filling time is affected by a number of factors, including the size of the bottle, the type of liquid being filled, and the speed of the filling machine. In an IIoT-based automatic bottle filling and sorting plant, the filling time is typically controlled by a solenoid valve. The solenoid valve is a type of valve that is controlled by an electrical current. When the electrical current is applied to the solenoid valve, it opens, allowing liquid to flow into the bottle. The amount of time that the solenoid valve is open determines the amount of liquid that is filled into the bottle. The filling time can be adjusted by changing the amount of time that the solenoid valve is open. This can be done manually by the operator of the filling machine, or it can be done automatically by the IIoT system. The IIoT system can use sensors to monitor the filling time and make adjustments as needed. The filling time is an important factor in the production of bottled beverages. By controlling the filling time, the IIoT-based automatic bottle filling and sorting plant can ensure that the bottles are filled correctly and efficiently.

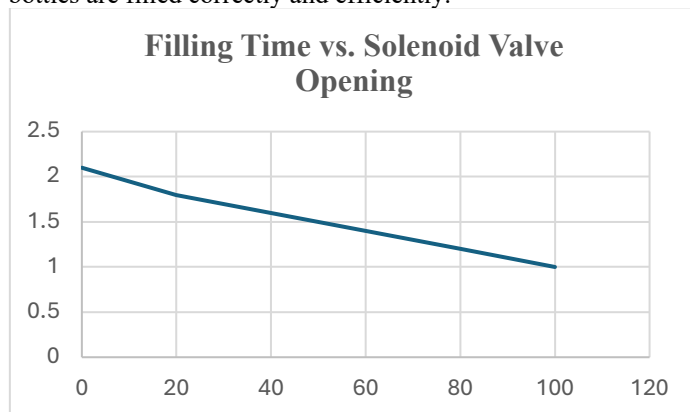


FIGURE 9: Filling Time vs. Solenoid Valves Opening (Degree)

VI. CONCLUSION

In conclusion, the proposed bottle filling and sorting system, utilizing PLC automation, sensor-based height detection, and color sorting mechanisms, presents a significant advancement in the industrial market. This project aimed to address the limitations of traditional bottle filling and sorting processes by introducing a more efficient, accurate, and cost-effective solution.

Through the integration of sensor technologies, the system can detect the height of bottles as they pass through the tower, enabling the precise filling of different-sized bottles with specific colors of liquid. This innovative approach reduces time and costs associated with manual sorting and improves productivity by accommodating bottles of varying sizes and liquid contents on the same conveyor belt.

The utilization of PLC automation ensures the synchronization and control of the entire system, providing precise timing for valve openings and liquid filling. This automation not only improves accuracy but also reduces human errors and enhances process reliability.

The integration of IIoT technologies and web-based monitoring allows for remote monitoring, real-time data visualization, and better decision-making. It enables production managers to have access to critical information, such as bottle counts, production rates, and system performance, from anywhere at any time. This

promotes proactive maintenance, timely troubleshooting, and efficient resource management.

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The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments.

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CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest to report regarding the present study.

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