International Journal of Manufacturing Economics and Management
ISSN 2784-1278 ISSN-L 2784-1278, Vol. IV, No. 2 / 2024
https://doi.org/10.54684/ijmem.2024.4.2.25

A NOVEL BOTTLING MACHINE DESIGN FOR ENHANCED EFFICIENCY AND SCALABILITY IN SMEs

Angélica Quito, Faruk Abedrabbo, Jhoan Narváez, Marcelo Moya

Faculty of Technical Sciences, International University of Ecuador UIDE, Quito
170411, Ecuador

Corresponding author: Angélica Quito, anquitoca@uide.edu.ec

Abstract: This research presents the design, testing, and val- idation steps of a novel bottling machine that can potentially revolutionize the bottling process for small and medium-sized companies. The machine was equipped with a detection system to identify dirty bottles before the bottling process began, ensuring that only clean bottles were used and achieving safety control. The test conducted for the validation showed an accuracy rate of 98.95% in filling the nominal volume and an 87.5% accuracy rate in detecting dirty or clean bottles. The findings demonstrate the potential of the bottling machine design to improve the efficiency and safety of the bottling process, particularly for smaller companies. By identifying dirty bottles before the bottling process, the system prevents product contamination and ensures consumers' safety. The research presents a promising solution for small and medium-sized companies seeking to improve their bottling process while ensuring safety and quality control without investing in big machines or complex industrial systems.

Key words: filling system, automatizing, dirty bottles, Industry 4.0.

1. INTRODUCTION

Design The current industrial landscape is experiencing a significant shift towards digital transformation (Gigova, Valeva, & Nikolova-Alexieva, 2019), where technological innovation is driving unprecedented levels of efficiency and productivity (Charles, 2014). In this context, the Modbus TCP/IP com- munication protocol has emerged as a foundational tool for interconnecting devices in control systems (Wang, Wang, Zhu, & Wang, 2021). Its continuous evolution has unlocked new possibilities for industrial automation by facilitating the inte- gration of key elements (Dai, Dubinin, Christensen, Vyatkin, & Guan, 2017), such as the programmable logic controller (PLC), ESP32 microcontroller, and human-machine interface (HMI), which work in tandem to deliver more precise and efficient control (Sa˘ra˘cin, Deaconu, & Chirila˘, 2019).
It is noteworthy that small and medium-sized enterprises (SMEs) have been gaining strength in recent times and play a pivotal role in the development of local economies worldwide (Pedraza & The Micro, 2021). In this sense, it's interesting to see how automation and Industry 4.0 are gaining momentum in Ecuador (Aguilar et al., 2021), especially with the entry of multinational companies and the increasing industrialization of traditionally manual industries such as metallurgy, food, and pharmaceuticals (Ghobakhloo & Fathi, 2020). The Automation of manual processes and system integration has significantly contributed to the modernization of SMEs (Casalino, Borin, Pizzolo, & Cavallini, 2019). This modernization has enabled them to comply with accreditation and quality regulations for their products, which is paramount for their growth and success (Magd & Arabia, 2010).
Considering that automation has been gaining strength in recent years and with improvements in its implementation in a user-friendly way (Yusupbekov, Adilov, & Ergashev, 2017), it has been a vital ally for the modernization of manual industrial processes (Sutopo, Setiadi, & Hanzla, 2020). With the help of automation, these industries can greatly improve their efficiency and productivity, leading to a more competitive and successful business landscape. For these reasons, the aim of this project is to promote the creation of a solution for small and medium-sized businesses (SMEs) by integrating user-friendly technology with industrial technology. This so- lution will help to reduce repetitive work, minimize waste, and decrease bottling operation times during the bottling process. Additionally, it will allow SMEs to diversify their product portfolio by introducing new products (Quin˜a-Mera, Saransig-Perugachi, Trejo-Espan˜a, Naranjo-Toro, & Guevara- Vega, 2019).

1.1. Related works

Table 1 shows a detailed description of the state of the art related to automation in bottling systems, its main results, advantages, and disadvantages. Based on the information in this table, several aspects need to be highlighted. For example, it can be observed that (Prastiwi et al., 2023) showed the integration of PLC Siemens S7-1200, ESP32, and HMI using Modbus TCP/IP communication protocol, allowing seamless communication and data exchange between different system components. The authors of work (Opz & Ariah, 2024) demonstrated how lights-out factories transform production processes by operating autonomously 24/7, leading to improved time-to-market. Furthermore, in (Hansen, Christiansen, & Lassen, 2024), the article emphasizes that technology alone is insufficient for digitization and that a comprehensive approach involving competence development, knowledge acquisition, and strategic planning is essential for successfully implementing Industry 4.0 initiatives.

The authors of reference (Khairuddin et al., 2022) have contributed to the field of knowledge regarding SCADA systems, PID (Proportional-Integral-Derivative) control, and in- dustrial automation. Their work provides valuable insights for researchers, practitioners, and students. In addition, (Ughade et al., 2018) highlights that automation through PLC leads to cost and time savings as it reduces the need for manual intervention, saving time and costs associated with labor.

In (Sehr et al., 2021) by discussing PLCs in the context of Industry 4.0, the article emphasizes the importance of this technology in the era of intelligent manufacturing, digitaliza- tion, and interconnected systems, showcasing its continued relevance and potential for future advancements and in (Ulm et al., 2018) introduces the PLC Factory tool, which automates repetitive tasks associated with PLC programming.

The work of (Cousineau et al., 2019) mentions a program development for ladder configuration, while (Rajkumar et al., 2021) discusses the practical implementation of PLC technology in converting conventional machines to automated systems. This implementation can be a valuable resource for engineers and industrial practitioners looking for similar automation projects. Furthermore, the authors of (Shaikat et al., 2020) present a development of a prototype system for spray coating in glass bottle manufacturing using a PLC and SCADA along with a PID control system.

Up to this point, it is possible to provide evidence of the importance of applying automation and Industry 4.0 in recent years. However, by focusing on SMEs, the authors of (Ghobakhloo & Fathi, 2020) developed a strategic guideline to help manufacturing SMEs achieve higher digital transforma- tion success under Industry 4.0. More specifically, the authors of (Perpin˜a´n Reyes, 2020) presented a descriptive approach that allows characterizing the bottle filling phenomena, its mechanical and physical processes, and the electronic characteristics necessary for the automation of the process. However, these authors did not implement the system.

The released works provide valuable insights into the benefits and practical applications of automation and digitalization in the industrial landscape. Integrating different components, such as PLCs, ESP32 microcontrollers, and HMIs, through the Modbus TCP/IP communication protocol can facilitate seam- less communication and data exchange, improving efficiency and productivity. Additionally, the automation of repetitive tasks through PLC programming not only saves time but also reduces human errors.

Moreover, developing strategic guidelines can help SMEs achieve a higher degree of digital transformation success under Industry 4.0. Overall, automation and digitalization represent significant contributions to Industry 4.0 and can offer advantages for small and medium-sized companies looking to stay competitive in the ever-evolving technological landscape.

Table 1. Related work

Author(s)	Advantage	Disadvantage
(Prastiwi et al., 2023)	Enhanced functionality: Each device can leverage the strengths of others, like the HMI's visualization capa- bilities or the ESP32's wireless connectivity.	Malfunctions: Incompatible software might crash or be- have unexpectedly, impacting the system's overall func- tionality.
(Opz & Ariah, 2024)	Autonomous operation: Everything runs without human intervention, meaning production continues 24 hours a day, 7 days a week, leading to significant increases in productivity and efficiency.	Advancements might be overlooked: You might miss out on the latest tools, techniques, and best practices if relying on old information.
(Hansen et al., 2024)	Technology is not enough: While tools and infrastruc-	Lack of diversity: The sample might not represent the

	ture are crucial, they’re just one piece of the puzzle.	full range of challenges faced by SMEs globally.
(Khairuddin et al., 2022), 2022	Benefits and advances the field by offering valuable insights to various stakeholders interested in SCADA, PID control, and industrial automation.	Only have a control with de DC motor
(Ughade et al., 2018)	Cost and Time Savings: Automation through PLC reduces manual intervention, saving time and costs associated with labor	They are not present the results of the implementation of the system.
(Sehr et al., 2021)	Importance in Industry 4.0: PLCs serve as the brains and backbone of many Industry 4.0 applications, con- trolling processes, collecting data, and enabling com- munication between devices.	Limited practicality: The article focuses on theoretical advancements or proposed improvements, lacking real- world examples or case studies.
(Ughade et al., 2018)	Reduced errors: Automation minimizes the possibility of human error in repetitive tasks, leading to more reliable and robust PLC software.	Maintenance is ongoing: To ensure the tool works effec- tively with evolving PLC standards and hardware con- figurations, you’ll need to invest in regular maintenance and updates. This requires ongoing effort and resources.
(Cousineau, Mentre´, & In- oue, 2019)	Program development for ladder configuration	They do not present the implementation and proobs of the program
(Rajkumar, Thejaswini, & Yuvashri, 2021)	Industrial practitioners: They can learn from real-world examples and practical tips to apply in their own automation projects, potentially improving efficiency, productivity, and safety in their facilities.	Only use a PLC
(Shaikat et al., 2020)	Improved product quality: Precise control over coating parameters ensures consistent and high-quality results.	Do not use an integration and comunication with a low cost microcontroller like as ESP32 and doesnt have test for the precisio´n of their system.
(Ghobakhloo & Iranmanesh, n.d.)	This guideline aims to be a comprehensive toolkit for SMEs	NA
(Perpin˜a´n Reyes, 2020)	Electronic characteristics necessary for automation: Identifying the sensors, actuators, and control systems needed to automate the process based on the mechanical and physical understanding	They do not present implementation results or control tables to establish the precision of the machine.

1.2. Automation and Industry 4.0

Industry 4.0, also known as the fourth industrial revolution, refers to integrating advanced technologies, such as artificial intelligence, the Internet of Things (IoT), and cloud com- puting, into the manufacturing industry (see Figure 1). This concept emphasizes the use of smart, connected systems that can communicate with each other, analyze data, and make autonomous decisions. With Industry 4.0, manufacturers can achieve higher efficiency, productivity, and quality levels while reducing costs and waste. It is considered a game changer in the manufacturing industry, enabling a new level of automation and interconnectivity between machines, products, and people. As shown in Figure 2, automation is represented as a pyramid, going from the lowest level concerning field sensors, in which the idea is to implement sensors and obtain data of the process to the top being the conceptualization of industry 4.0, in which several technologies are integrated to achieve the communication between machines, operators, and cloud.

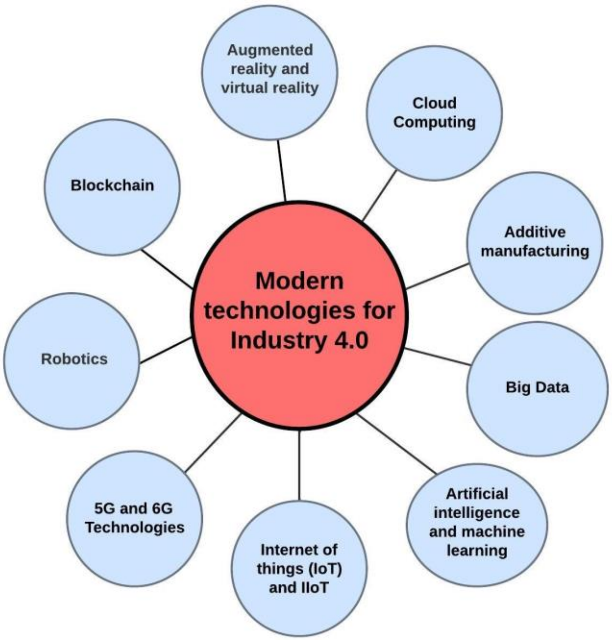


Fig. 1. Modern technologies for Industry 4.0. Adapted from (Javaid et al., 2023)

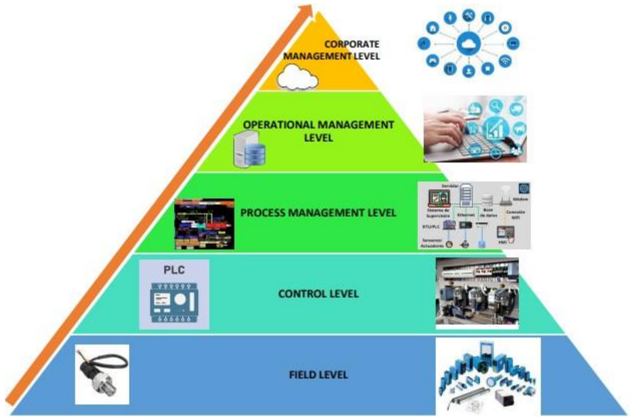


Fig. 2. Automation Pyramid for Industry 4.0

1.3. Main Contribution

The aim of this research is to bring about a revolution in the manufacturing of bottle-filling and transportation systems. Advanced technologies such as PLCs, sensors, and algorithms are being utilized to enhance efficiency and sustainability. By optimizing electronic and mechanical systems, the research aims to reduce waste, improve precision, and optimize re- source use. Moreover, this research aims to contribute to indus- try guidelines and best practices with a focus on prioritizing safety for industry workers and production processes.

1.4. Outline

This work has been organized as follows: Section I presents the introduction and the state of the art. Next, Section II presents the methodology design used to develop the research. Then, Section III shows all the design steps and how the bottle- filling system was developed. Then, Section IV is presented, describing the assembly and validation of the bottle-filling system. Finally, Section V highlights the main conclusions of this work.

2. METHODOLOGY

During the design requirements phase, a thorough exami- nation of the design criteria was conducted, considering the document titled ”VDI Guideline 2206:2004” (Graessler & Hentze, 2020), which provides a design methodology for mechatronic systems. The primary focus of the guideline is a revised and improved V-Model for Mechatronic and Cyber- Physical Systems. The underlying concern logic of the V- Model embodies the systematic order of tasks. The main benefit of this methodology is its ability to remain autonomous regardless of the selected project structure. The V-Model can be implemented in both traditionally managed projects and agile initiatives.

The previous examination encompassed factors such as manufacturing capacity, belt options, filling valves, PLC or microcontroller features, filling accuracy, and prerequisites for bottle cleanliness detection. The process encompassed the research and comparison of several techniques for bottle filling, considering energy efficiency and ease of maintenance. Then, with the filling system technique selected, an advanced CAD (Cˇ ok, Vlah, & Povh, 2022) software was used to create a 3D model. This model facilitated a comprehensive visual- ization of the system, enabling the consideration of factors such as material selection based on strength, durability, and compatibility with industry standards. Additionally, structural calculations were performed to guarantee the integrity of the design.

In terms of electronic design, a resilient solution was built that incorporates high-accuracy level sensors, actuators, and controllers, following the recommendations of the standard VDI-2206 and the Industry 5.0 Framework (Massaro, 2023) for automated systems. The programming was conducted using high-level languages like Python and C++ to guarantee effortless maintainability and adaptability for forthcoming improvements. The system integration entailed coordinating mechanical and electronic components using standardized interfaces, ensuring smooth and effective functioning.

A closed-loop control system incorporating sensors and actuators was chosen to guarantee optimal motor operation based on the size of the mechanical and electrical components. In addition, a microcontroller algorithm was implemented to detect clean bottles effectively. Additionally, presence sensors were used to detect the location of the bottles on the filling line. The control method, reliant on data gathered from the upper tank, ensures the machine's accurate functioning uti- lizing a predetermined PLC magnitude. In addition, the HMI display was directly connected to the PLC to offer system control and visualization. This HMI was enhanced by physical buttons that provide operational redundancy. Furthermore, the screen was selected after selecting the Programmable Logic Controller (PLC) to guarantee compatibility.

Once all the components had been designed, the entire sys- tem was assembled and implemented. Then, the bottle-filling system was tested using water to ensure the functionality of all the components. To measure the system's performance, the precision of filling and the cleanness detection were tested. For the accuracy of filling, the weight of each bottle was quantified, and the volume of each bottle was estimated. This volume was compared to the nominal volume of 685 ml. Using all data extracted in the test, control charts to follow system behavior were developed.

The cleaner system detection was also evaluated during the test step, and the color-recognized error was calculated. All these evaluations enabled precise changes and optimizations to fulfill the quality criteria set by the VDI-2206 (Jahangirkhani et al., 2023), thereby ensuring the efficiency and dependability of the bottle-filling system.

3. PROJECT DEVELOPMENT

3.1. Mechanical Design

Mechanical Design: CAD software was used to create a three-dimensional model, which was the first step in the mechanical design process. Figure 3 shows the 3D models with all components of the bottle-filling system. This model was the basis for studying the system requirements.

A series of theoretical calculations were carried out to ensure the machine worked properly. The goal was to meet the design requirements for bottling water in containers weighing up to 2.5 kilograms (685 ml of water per bottle). To achieve this objective, a speed of 3 m/s and a torque of 0.17 N was selected for the conveyor motor. Additionally, 720 N of force was required for the pneumatic bottling piston, and the force needed to hold the filling nozzle was 9600 N. Furthermore, it was verified that the structure supported the weight of the bottles, the belt with all actuators and sensors, the structure of the filling nozzle, and the water tank.

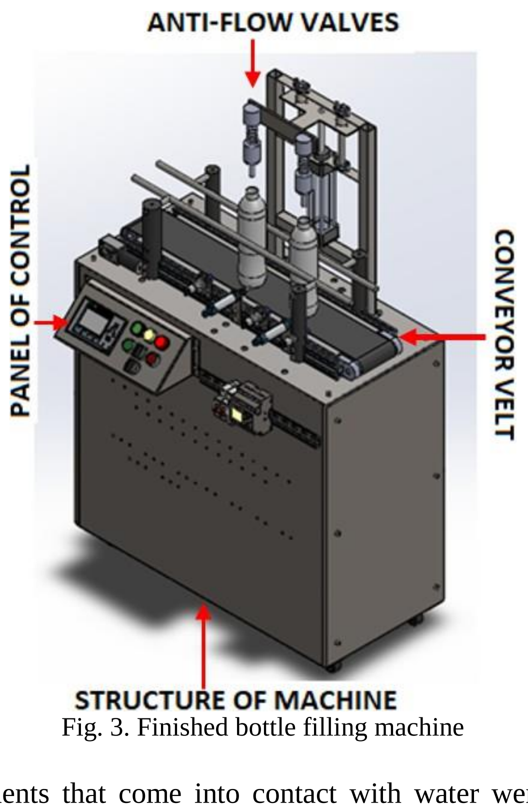


Fig. 3. Finished bottle filling machine

Materials Selection: All components that come into contact with water were constructed using long-lasting materials such as corrosion-resistant stainless steel and fortified Tungsten Inert Gas (TIG) welding. In addition, The AISI 1018 carbon steel was selected for the structural composition due to its combination of strength and cost-effectiveness (Ramadan & Boghdadi, 2020).

Polyamide 6, Also known as nylon 6 (Bernal, Cuevas, Rubio, Perez, & Rodriguez, 2021), was selected for the filling nozzle beam. It is a thermoplastic polymer made from petrochemicals. It has a somewhat crystalline structure and is widely used due to its easy manufacture. This material demonstrates resistance against greases, hydrocarbons, and lubricating oils. In addition, it has elasticity and the ability to absorb vibrations, fatigue, shocks, and low temperatures.

PVC Conveyor Belt Integration: The PVC conveyor belt, essential for transporting bottles, was meticulously chosen to ensure optimal performance. The conveyor belt was con- structed with polyester fibers in the longitudinal direction and polyamide 6 in the transverse direction. For this belt, low-friction bearings were selected to ensure smooth belt movement.

3.2. Electrical Components and Wiring

PLC-based Control System: A programmable logic con- troller (PLC) was selected. The PLC was responsible for interpreting the signals from the sensors and components to activate, deactivate, and coordinate the system's operations according to the programmed logical sequence.

DC Motor Control with Encoder Feedback: The proportional-integral and derivative (PID) control was selected, and the DC motor was located directly on the conveyor. This motor was fitted with an encoder to ensure accurate feedback (Chitsaz, LaValle, Balkcom, & Mason, 2009). The performance of the motor was guaranteed to be smooth and accurate, regardless of the load or speed variations.

H-Bridge Motor Driver (L293D): To ensure that the bottle conveying process was successful in both forward and reverse directions, the L293D H-bridge motor controller was selected as it allows precise bi-directional control of the DC motor.

Color Sensor Integration: The ESP32 microcontroller was selected because it interacts with a color sensor to detect bottle cleanliness, using advanced algorithms for evaluation.

Control Panel Interface: A control panel interface was selected to manage the system. This control panel is integrated into the PLC programming. Additionally, the control panel shows the start, stop, and emergency operation buttons.

Human Machine Interface: In the Human Machine In- terface (HMI) the person who operates the machine sets the parameters for the speed and selects the container of the machine. Additionally, the operator can view the alarms for the system.

Integration and Wiring: Figure 4 summarizes the connec- tions of the PLC. In this figure, it is possible to see the inputs and outputs of the PLC to integrate all electronic components. The wiring layout required for this integration was developed according to industrial standards to create a well-assembled electrical set. This wiring layout and cable management help reduce interference and greatly simplify maintenance.

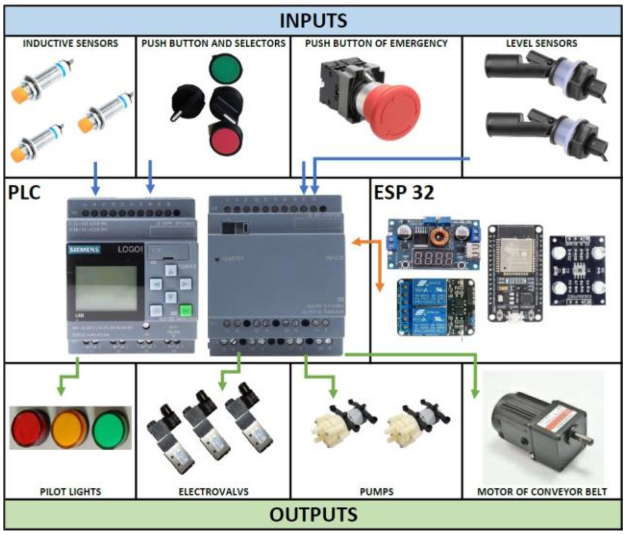


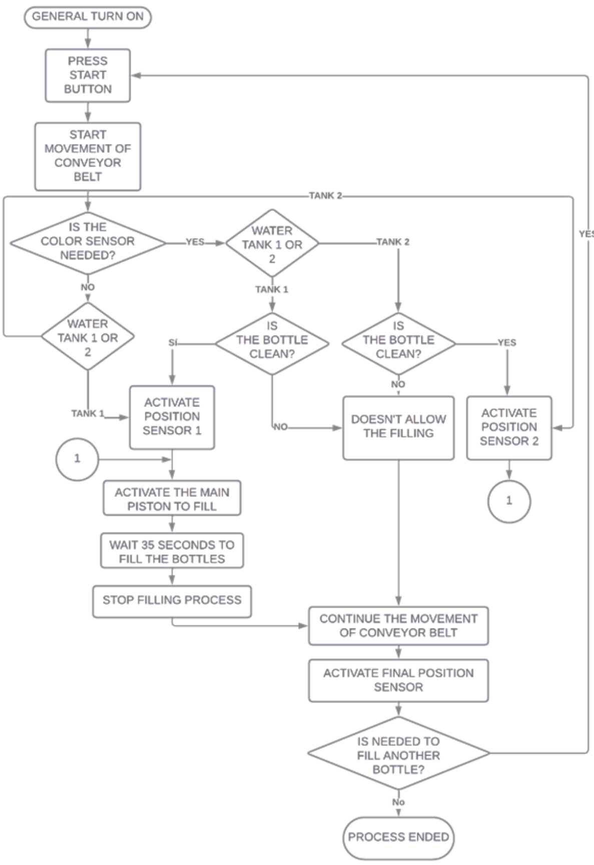
Fig. 4. Electronic Diagram of machine.

3.3. Electronic Design

The electrical system used a closed-loop PLC controller that receives information from the bottle presence sensor. This method negatively prevents tape overload and provides information on the state of the liquid and the cleanliness of the bottle. The HMI panel allowed users to manipulate filling variables, monitor tracking, color coding of filled bottles, and manage notifications about system failures and operations. In addition, an emergency stops and digital stop system was incorporated to avoid accidents with bottles during a new process, without the need to remove the previous bottle.

The cumulative energy consumption of the components was 2.54 A, while operating at their maximum workload. Therefore, a power source with a voltage of 12 V and a current of 5 A was chosen. The list of the components of the 12 V system was: 2 water pumps, 1 ESP32 microcontroller, 1 DC motor equipped with an encoder, and 1 TCS 3200 color sensor. The 24 V and 10 A component of the bottle-filling system consisted of 1 PLC Logo 12/24RCE, 1 module LOGO DC16 24R, 1 LOGO TDE Display, 3 Capacitive Sensor NPN 18mm, and 3 Solenoid Valves.

The flow chart shown in Figure 5 presents the process of the bottle filling system, which comprises a system that transports a bottle to a detection zone, where a color detection sensor is used. If the watercolor is absent, the conveyor belt proceeds to the first presence sensor. In contrast, the conveyor belt proceeds to the last presence sensor if color is recognized. The user chooses the watercolor using a selector. When the bottle reaches the corresponding presence sensor, one piston stops moving, and another piston begins to fill the bottle. A valve stops at a user-defined time, allowing the conveyor to advance to the final presence sensor.



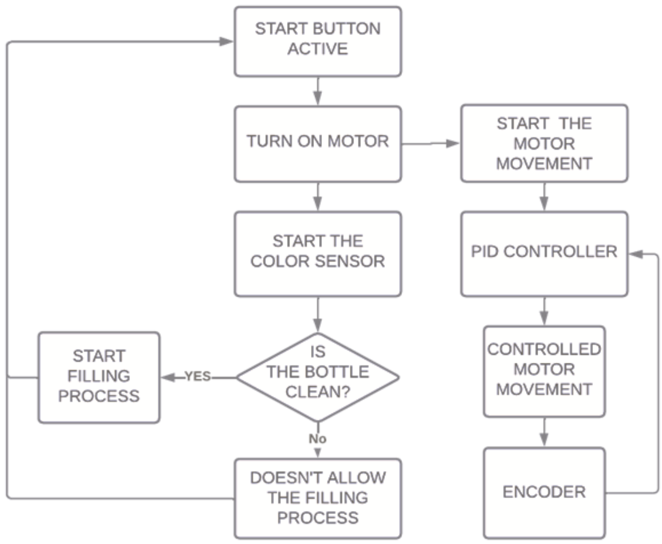


Fig.5. Working principle of the filling system

Fig. 6. Working principle inside of ESP32

The diagram shown in Figure 6 illustrates the operating principle and the communication between the ESP32 and the PLC Logo 8. The PID controller calculates an error signal, the difference between the setpoint and the measured value (Salem, 2013). This signal adjusts the conveyor belt motor's speed. The three PID terms are: Proportional: with a quick response to error changes. Integral: corrects the steady-state error by integrating the error signal over time, and Derivative: prevents overshoot and oscillation by considering the rate of change of the error signal.

The PID values optimized for the process are the following:

- P: 0.7902
- I: 0.1723
- D: 0.1666

4. MACHINE ASSEMBLY AND VALIDATION

After completing all design steps, the team purchased the electronic components and manufactured the mechanical com- ponents in-house. Upon combining all of these components, the machine was assembled. The final product, as shown in Figure 7, resembles the CAD design depicted in Figure 3. To ensure user-friendliness and adherence to safety standards, the control panel's interface and emergency shutdown procedures underwent extensive testing. In fact, both the interface and energy button performed flawlessly in all 10 tests conducted. Although all machine components appeared to function efficiently, a production batch was necessary to guarantee that the bottle system met industrial specifications. During this phase, the machine, its components, and the efficiency and quality of the bottling-filling system were examined.

Experimental tests were carried out to evaluate the system's performance. In these tests, 40 bottles were filled with water, and the volume was measured to find the error between the volume set in the machine and the real filled volume. To measure the volume filled in each bottle, the mass of the fluid was estimated using a digital balance, subtracting the weight of the empty bottle. Then, the real volume of each filled bottle was determined using the density of the water and the weight obtained. For this purpose, a digital laboratory balance PCE- BT 2000 was utilized.

Fig. 7. Finished bottle filling machine

Table 2 shows the data obtained, the success rate of filling the bottles, and the filling error percentage. According to all tests developed for the 2 filling nozzles, the machine shows an accuracy in the filling volume of 98.95%. Therefore, the filling error is around 1.05%. Additionally, Table II also presents the performance of the color sensor to validate whether a bottle is clean. By meaning the values of the table, the machines achieve an accuracy in detecting clean bottles at around 87.5%. To enhance the analysis, the performance of the filling nozzle was estimated independently. The accuracy of tank 1's nozzle was found to be 98.78%, while tank 2's nozzle demonstrated a value of 99.13%. The difference in filling error amounted to around 0.35%, which can be deemed negligible for the application, thereby confirming the correct operation of the equipment. Although the accuracy parameter holds significance as a global metric of the system, in this type of process, the variation of the filling volume between the bottles is a crucial characteristic. Hence, statistical control charts were implemented to observe the behavior of each bottle passing
through the system.

Table 2. General error table with a 690ml bottle

Bottle number	Tank number	Color recognized?	Weight	Filling Error
1	1	1	684	0.87
2	1	1	682	1.16
3	1	1	671	2.75
4	1	1	670	2.90
5	1	0	683	1.01
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
36	2	1	686	0.58
37	2	0	687	0.43
38	2	1	684	0.87
39	2	1	685	1.01
40	2	1	683	0.72

As per the control chart presented in Fig. 8, it can be inferred that the average volume filled by nozzle 1 is 681.7 ml. The chart limit was formulated using 3 standard deviations around this mean value, which amounts to 687.6 ml for the upper limit and 675.6 for the lower limit. Upon evaluating the plot, it is evident that certain data points are below the lower limit. Although these points do not meet the statistical precision of ±3 standard deviations, the values below the limit are deemed acceptable in the soft drink industry of Ecuador. This is in accordance with the Ecuadorian technical standard RTE INEN 284 (”Quantity of product in prepackaged”), which specifies that the permissible variation for bottles is approximately 15 ml with respect to the nominal volume of 685 ml.

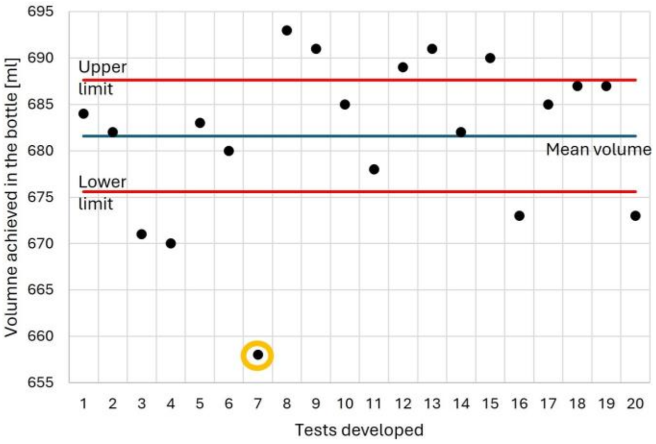


Fig. 8. Control chart mean-standard deviation of the volume filled in the bottles by nozzle 1

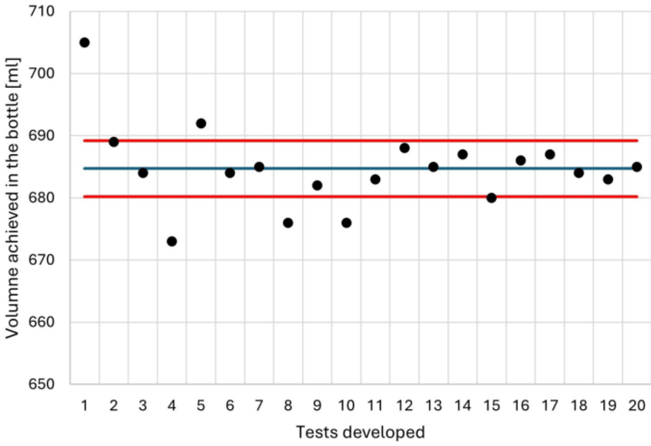


Fig. 9. Control chart mean-standard deviation of the volume filled in the bottles by nozzle 2

Only the bottle marked in orange in Fig. 8 is outside the measurement range estimated by the technical standard. However, it is important to note that this particular bottle is considered an outlier. Further analysis revealed that during the filling process, the presence of air particles in the filling hoses caused a variation of more than 30 ml in the bottle. This issue was thoroughly investigated and served as a validation process to ensure the machine was ready for production. Thanks to this issue, we recommend that prior to using the machine to extract any internal air bubbles, it is necessary to check that none of the fluid hoses have air. To achieve this, we strongly advise draining at least 2000 ml of fluid into the system.

Nozzle 2 has exhibited better behavior than the previous tests. The chart control plot for nozzle 2 is depicted in Figure 9. In this plot, the mean filling volume is around 684.7 ml, and the upper and lower limits are 689.2 ml and 680.2 ml, respectively. Figure 9 shows that only three bottles are under the lower limit of ±3 standard deviations. Nonetheless, it is worth noting that they all fall within the maximum variation range allowed by the technical standard RTE INEN 284.

In addition, the control charts displayed in Figure 8 and Figure 9 provide insights into the repetitiveness of the filling process. These charts indicate the maximum variations in the fill levels of the bottles produced by the machine. Although the process is not within statistical control of ±3 standard deviations, it still complies with the current technical standard of Ecuador as it falls within a range of ±6 standard deviations.

5. CONCLUSIONS

This research aimed to design a novel filling bottle sys- tem for SMEs to enhance efficiency and scalability. From the results of this work, the following conclusions can be highlighted:

•The application of the standard VDI-2221 allowed the complete integration of the electronic, mechanical, and programming systems to ensure the machine’s function- ality for filling bottles;

•The correct selection of the material and mechanical components allowed the bottles to be filled safely without contamination or spills within the system. Likewise, the correct selection and programming of the PLC helped the correct control of valves and conveyor belt control. At the same time, the ESP32 allowed the proper operation of the color sensor to detect bottle cleanliness and control the system’s speed;

•The developed machine was tested for a production batch, showing 98.95% accuracy in filling the nominal volume and 87.5%;

•Despite a slight difference in the behavior of the two filling nozzles. The control chart showed that both nozzles in the machine achieved the minimum standard required in the Ecuadorian technical standard RTE INEN 284 for packing drinks. The findings of this study have significant implications for SMEs in the beverage industry, as the developed system could increase their productivity and profitability.

Funding: This paper has received no external funding.
Conflicts of Interest: There is no conflict of interest.

REFERENCES

1. Artieda, C. H., Chala, P. (2021). *Relationship between social culture, industry 4.0, and organizational performance in the context of emerging economies*, Journal of Industrial Engineering and Management, 14(4), 750-770.
2. Bernal, J. F. P., Cuevas, J. J., Rubio, R. R., Perez, R. R., Rodriguez, L. E. (2021). *Desarrollo de sistema con plc logo 8 siemens, raspberry pi4 y esp8266-12e*, Difu100ci@, Revista de difusion cientifica, ingenieria y tecnologias, 15(3), 17-25.
3. Casalino, N., Borin, B., Pizzolo, G., Cavallini, S. (2019). *Automation, technology transfer and managerial prac- tices for organizational growth of smes. a smart curricu- lum for competitiveness*, 2019 IEEE Global Engineer- ing Education Conference (EDUCON), Dubai, United Arab Emirates, pp.1534-1541.
4. Tolulope Charles Adeyeye, (2014). *The impact of technology on organizational performance*, Industrial Engineering Letters, 4(3), 97-101, available at:
https://www.researchgate.net/publication/338046184_The_Impact_of_Technological_Innovation_on_Organizational_Performance
5. Chitsaz, H., LaValle, S. M., Balkcom, D. J., Mason, M. T. (2009). *Minimum wheel-rotation paths for differential- drive mobile robots*, The International Journal of Robotics Research, 28(1), 66-80.
6Č ok, V., Vlah, D., & Povh, J. (2022). *Methodology for mapping form design elements with user preferences using kansei engineering and vdi*, *Journal of Engineering Design*, 33(2), 144-170.
7. Cousineau, D., Mentre´, D., Inoue, H. (2019). *Automated deductive verification for ladder programming*, arXiv preprint arXiv:1912.10629, 7-12. doi: 10.4204/EPTCS.310.2.
8. Dai, W., Dubinin, V. N., Christensen, J. H., Vyatkin, V., Guan, X. (2017). *Toward self- manageable and adaptive industrial cyber-physical sys- tems with knowledge-driven autonomic service man- agement*, IEEE Transactions on Industrial Informatics, 13(2), 725-736.
9. Ghobakhloo, M., Fathi, M. (2020). *Corporate survival in industry 4.0 era: the enabling role of lean-digitized manufacturing*, Journal of Manufacturing Technology Management, 31(1), 1-30.
10. Ghobakhloo, M., Iranmanesh, M. (n.d.). *Digital trans- formation success under industry 4.0: a strategic guide- line for manufacturing smes.* Journal of Manufacturing Technology Management, 8(32), 1533-1556.
11. Gigova, T., Valeva, K., Nikolova-Alexieva, V. (2019). *Digital transformation opportunity for industrial growth*, In 2019 international conference on creative business for smart and sustainable growth (crebus) (pp. 1-4). Bulgaria. doi: 10.1109/CREBUS.2019.8840065.
12. Graessler, I., Hentze, J. (2020). *The new v-model of vdi 2206 and its validation*, at-Automatisierungstechnik, 68(5), 312-324.
13. Hansen, A. K., Christiansen, L., Lassen, A. H. (2024). *Technology isn't enough for industry 4.0: on smes and hindrances to digital transformation*, Int. J. Prod. Res., pp. 1-23.
14. Jahangirkhani, T., et al. (2023). *Introduction of an approach for the identification of interfaces between the factory planning process and quality management for an opti- mized planning result,* In Ifip international conference on advances in production management systems, pp. 832- 843.
15. Javaid, M., Khan, S., Haleem, A., Rab, S. (2023). *Adoption of modern technologies for imple- menting Industry 4.0: an integrated mcdm approach*, Benchmarking: An International Journal, 30(10), 3753–3790.
16. Khairuddin, M., Budi, E. S., Amalia, Z., Puspitasari, A. D., Rahmadani, A. A., Prasetyo, F. B. (2022). *Implementasi sistem scada dengan metode kontrol pid pada motor dc penggerak conveyor belt*, J. ELTEK, 20(2), 41-49.
17. Magd, H., Arabia, S. (2010). *Quality management standards (qms) implementation in egypt: Iso 9000 perspectives*, Global Business and Management Research: An International Journal, 2, 57.
18. Massaro, A. (2023). *Advanced electronic and optoelectronic sensors, applications, modelling and industry 5.0 perspectives*, Applied Sciences, 13(7), 4582.
19. Opz, F., Ariah, S. (2024). *Exploring the evolution and impact of software automation: From manual tasks to autonomous systems*, (IEEE), available at:

https://www.researchgate.net/publication/377925613_Exploring_the_Evolution_and_Impact_of_Software_Automation_From_Manual_Tasks_to_Autonomous_Systems#fullTextFileContent
20. Pedraza, J. M., The Micro, S. (2021). *The micro, small, and medium sized enterprises and its role in the economic development of a country*, Business and Management Research, Sciedu Press, 10(1), 33.
21. Perpin˜a´n Reyes, A. (2020). *Sistema automatizado para el llenado de botellas en presentacio´n de 5 litros de agua mineral: Automated system for the filling of bottles in presentation of 5 liters of mineral water*, REDIELUZ, 10(2), 136-147. Available at: https://produccioncientificaluz.org/index.php/redieluz/article/view/35527.
22. Prastiwi, A. S., et al. (2023). *Integrasi sistem komunikasi modbus tcp/ip pada plc siemens s7-1200, esp32, dan hmi*, J. Elkolind, 10(2), doi: 10.33795/elkolind.v10i2.3254.
23. Quin˜a-Mera, J. A., Saransig-Perugachi, E. R., Trejo-Espan˜a, J., Naranjo-Toro, M. E., Guevara-Vega, C. P. (2019). *Automation of the barter exchange management in ecuador applying google v3 api for geolocation*. In Information technology and systems: Proceedings of icits 2019 (p. 210-219). Springer.
24. Rajkumar, K., Thejaswini, K., Yuvashri, P. (2021). *Automation of sustainable industrial machine using plc*, In Proceedings of the international conference on recent trends in computing (icrtce-2021). Journal of Physics: Conference Series, 1979(1), IOP Publishing, pp. 012049.
25. Ramadan, N., Boghdadi, A. (2020). *Parametric optimization of tig welding influence on tensile strength of dissimilar metals ss-304 and low carbon steel by using taguchi approach*, Am. J. Eng. Res, 9(9), 7-14.
26. Salem, F. (2013). *Dynamic and kinematic models and control for differential drive mobile robots*, International Journal of Current Engineering and Technology, 3(2), 253-263.
27. Saracin, C. G., Deaconu, I. D., Chirila, A. I. (2019). *Educational platform dedicated to the study of programmable logic controllers and the human-machine interface*, In 11th international symposium on advanced topics in electrical engineering (atee), pp. 1-4.
28. Sehr, M. A., et al. (2021, May). *Programmable logic con- trollers in the context of industry 4.0*, IEEE Transactions on Industrial Informatics, 17(5), 3523-3533.
29. Shaikat, A. S., Imam, H., Tasnim, R., Rocky, S. A., Khan, M., Alam, M. (2020). *Development of plc and scada based spray coating system for application in glass bottle manufacturing industries of Bangladesh*, In Proceedings of the ieee conference on robotics and automation, Bangladesh, Dhaka, pp. 1-7.
30. Sutopo, S., Setiadi, B. R., Hanzla, M. (2020). *Upgrading manual turning machine towards iot-based manufacturing*. Jurnal Pendidikan Teknologi dan Kejuruan, 26, 155-161.
31. Ughade, S., et al. (2018). *Plc based bottle filling using conveyor belt*, International Journal of Engineering and Creative Science, 1(2), 4-6.
32. Ulm, G., Bellorini, F., Brodrick, D., Fernandes, R., Levchenko, N., Fernandez, D. P. (2018). *Plc factory: Automating routine tasks in large-scale plc software development*. In J. Publishing (Ed.), 16th int. conf. on accelerator and large experimental control systems icalepcs2017, Barcelona, Spain, pp. 495-500.
33. Wang, Y., Wang, Y., Zhu, Z., Wang, Q. (2021). *Modbus tcp protocol in industrial control system research on anomaly detection method*, In Ieee international conference on electrical engineering and mechatronics technology, Qingdao, China, pp. 391-395.
34. Yusupbekov, N., Adilov, F., Ergashev, F. (2017). *Development and improvement of systems of automation and management of technological processes and manufactures*, Journal of Automation, Mobile Robotics and Intelligent Systems, 11(3), 53-57.

Received: August 20, 2024 / Received in the revised form: October 30, 2024 / Accepted: December 15, 2024 / Paper available online: December 20, 2024 © International Journal of Manufacturing Economics and Management.