Polo del Conocimiento
Pol. Con. (Edición núm. 92) Vol. 9, No 7
Julio 2024, pp. 735-750
ISSN: 2550 - 682X
DOI: https://doi.org/10.23857/pc.v9i7.7530

Un novedoso sistema de seguridad alimentaria se centra en el embotellado para microempresas

A novel food safety system focusses on bottling for micro enterprises

Um novo sistema de segurança alimentar centra-se no engarrafamento para microempresas

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Ciencias Técnicas y Aplicadas
Artículo de Investigación

*** Recibido:** 27 de mayo de 2024 ***Aceptado:** 05 de junio de 2024 *** Publicado:** 09 de julio de 2024

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Resumen

Este artículo profundiza en el papel fundamental del aprendizaje experiencial en el avance de la industria alimentaria, abordando en particular los complejos desafíos inherentes a los procesos de producción de alimentos. En respuesta a estos desafíos, el estudio presenta un proyecto innovador centrado en la creación de un módulo de capacitación diseñado para simular el proceso de limpieza de botellas Dasani de 600 ml. El desarrollo de esta máquina implicó una exploración exhaustiva de las complejidades del diseño y las especificaciones dimensionales, basándose en principios del campo interdisciplinario de la mecatrónica.

Palabras clave: Industria alimentaria; Limpieza de botellas; Automatización industrial.

Abstract

This article delves into the critical role of experiential learning in advancing the food industry, particularly addressing the complex challenges inherent in food production processes. In response to these challenges, the studio presents an innovative project focused on the creation of a training module designed to simulate the cleaning process of 600 ml Dasani bottles. The development of this machine involved an exhaustive exploration of the complexities of the design and dimensional specifications, drawing on principles from the interdisciplinary field of mechatronics.

Keywords: Food industry; Bottle cleaning; Industrial automation.

Resumo

Este artigo investiga o papel crítico da aprendizagem experiencial no avanço da indústria alimentar, abordando particularmente os complexos desafios inerentes aos processos de produção alimentar. Como resposta a estes desafios, o estúdio apresenta um projeto inovador focado na criação de um módulo de formação concebido para simular o processo de limpeza de garrafas Dasani de 600 ml. O desenvolvimento desta máquina envolveu uma exploração exaustiva das complexidades do projeto e das especificações dimensionais, baseando-se em princípios do campo interdisciplinar da mecatrónica.

Palavras-chave: Indústria alimentar; Limpeza de garrafas; Automatização industrial.

Introduction

Food safety is the absence of harmful elements in food, ensuring safe consumption by humans (Burlingame et al, 2007) Managers of SMEs need more understanding of HACCP, education on risk control, and food handlers' safety practices need improvement (Cape et al, 2007). Furthermore, the challenges faced by small food and catering operators in ensuring microbiologically safe products include developing a construct to enhance safety (Mossel et al, 1999) Additionally, Food hygiene standards in premises with documented or undocumented hazard analysis systems highlight better standards during preparation and cooking in documented systems and emphasize issues with temperature monitoring and cleaning practices (Walker et al, 2002). Therefore, It is crucial to prioritize safe food handling in ready-to-eat establishments. Management should value the staff's good food safety knowledge, and environmental health officers must guide and assist owners and staff in improving food handling standards (Thio et al, 2010).

In bottling plants, when dealing with liquids for human consumption, it is essential to take care of cleanliness in the bottling process (Kramer et al, 2004). In line with, implementing a Food Safety Management System (FSMS) is crucial to ensure the safety of drinking water. Adapting ISO 22000:2005 Food Safety Management Standards for a bottling company can be challenging, but it outlines requirements such as management responsibilities, hazard analysis, and coverage of FSMS for all manufacturing operation (Sarter et al, 2012).

Importantly, the legal requirement for tracing the route of a food product in the food chain is a case study that analyzes and evaluates traceability testing in the context of food safety management, specifically focusing on the packing of soybean oil (Charalambous et al, 2018). Furthermore, the safety of food products must be ensured at all stages of manufacturing to protect human health and the environment (Popyrina et al, 2023) However, the critical issues of food safety and quality, focusing on milk and milk products, emphasizing the importance of preventing food-borne illnesses and the need for a systematic approach to ensure the quality and safety of milk (Ahmedsham et al, 2018).

Currently, there are different disinfection methods in bottling plants (Humayun et al, 2023), whether disinfection for dairy (Chin et al, 2012), juice (Harikumar et al, 2013) or water (Ashbolt et al, 2015) bottling plants. Consequently, in (Runia et al, 1998) present the design and preliminary results of an installation for disinfection of rainwater using heat treatments at high temperatures for short periods, focusing on controlling pathogens in soil less cultures.

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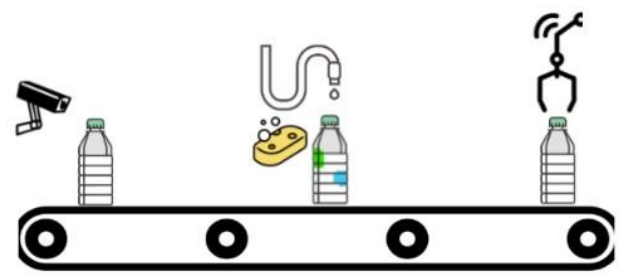
In other hand, in (Zewde et al, 2019) discusses the challenges in meeting clean water demand, the potential of UV technology in advancing water and wastewater treatment, the growth of the UV light disinfection industry, the importance of disinfection for wastewater reuse, and the advantages of UV technology in providing high-log reductions of microorganisms without creating disinfection by-products. In this case, (Ahmad et al, 2019) present developing a semi-automated 3-in-1 machine led to improved productivity and reduced production costs, as well as the successful operation of the new machine with an ergonomic design to minimize physical discomfort to the staff.

Methodology

Mechanical Design

Several ideas were generated and the best ones were selected. Within these, the decision was made to carry out three stages: identification, cleaning and emptying stage (see Fig.1). In addition, conditions are included to identify whether the bottle is clean or dirty, and how it will be treated accordingly.

Fig. 1: *Diagram showing the logical process of the project*



To carry out the full 180° rotation of the gripper at emptying stage, a system consisting of 4 pillars and the servomotor has been implemented. This system provides structural support for the gripper, including the weight of the water bottle. In order to avoid overloading the motor, bearings have been installed in the 4 pillars, thus facilitating rotation and stabilizing the base to prevent deformation. The composition of this system is illustrated in Fig.2. It details the arrangement of the bearings, specifically the 608zz bearings, which come into contact with the caliper pillars, allowing friction-less rotation. In addition, it can be seen that the servomotor is positioned in the central part of the base.

Fig. 2: *Swivel base system that allows the clamp to be rotated 180°*

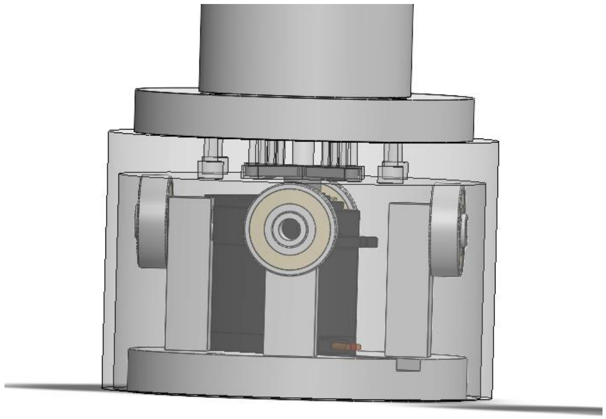
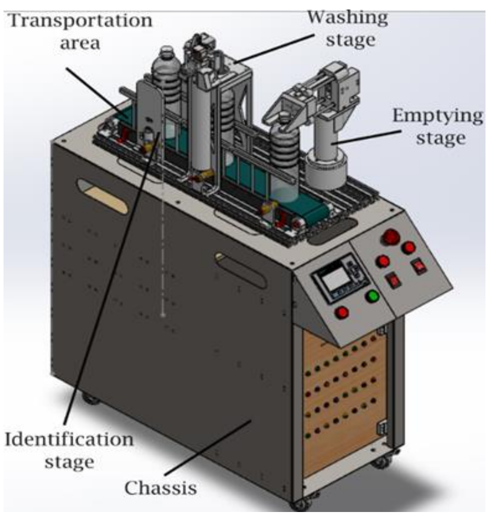


Fig.3. is the 3D model of the prototype with the main mechanical components in order to transport the bottle it includes a conveyor belt? As seen in Fig.3. the bottle is located by the operator in the left position and then the machine starts the process.

Fig. 3: *3D model of bottle washing machine*

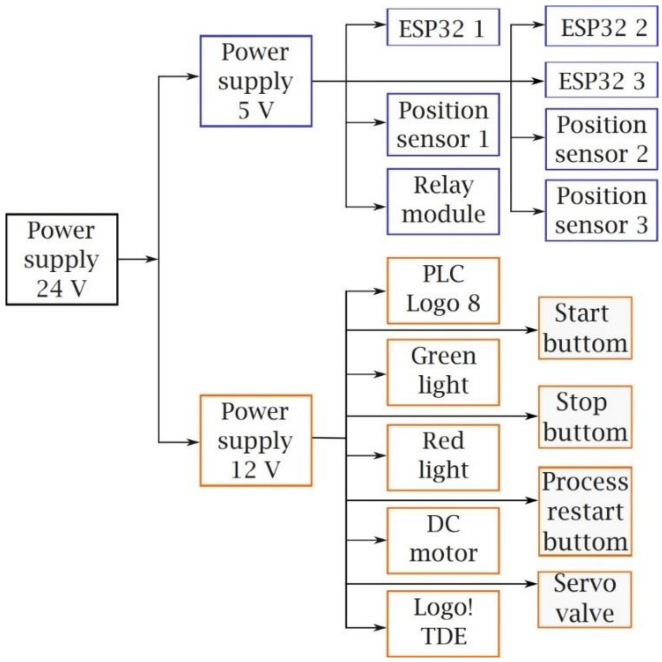


Electronic Design

The project will be controlled by a PLC Logo! 8, which controls the drives of the different electronic elements. In addition to the PLC, microcontrollers, specifically ESP32 microcontrollers, will be incorporated, contributing to generating previously mentioned routines controlled by the PLC. There will also be a Logo TDE display that will enable the process to be visualized using text messages. In addition, the project will have a 24 V power supply that will allow the power supply to be distributed among all the elements.

A 24 V power supply has been used to power the project, distributing its voltage in two primary levels: 12 V and 5 V. This configuration will make it possible to supply the various project elements adequately. Fig.4. shows the distribution of voltages to the different electronic components.

Fig. 4: *Block diagram of how the voltage connections of the elements are made.*



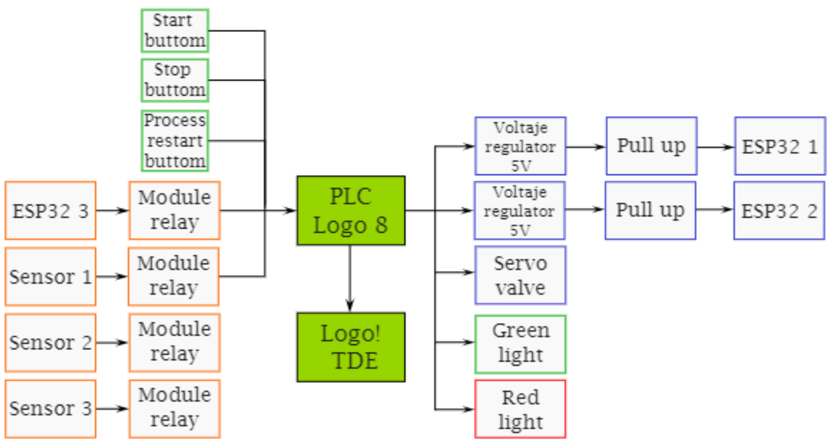
The diagram presented below showcases the main schematic and its connection to the Programmable Logic Controller (PLC). The PLC sends instructions to the ESP32s, which are responsible for executing the required tasks. The diagram also shows the connections to position sensors, LED lights, and a display that provides information about the process status.

In Fig.5, the project's work is detailed in a block diagram format. It highlights the main component, the PLC, along with its inputs and outputs. While three of the seven inputs are directly connected to the PLC, the other inputs require intermediate communication devices. Relay modules play a crucial role in this context, with the ESP32 and the position sensors being connected to them. They send digital values to the PLC for communication.

Regarding the outputs, four of them are noteworthy. The first two outputs have a voltage regulator and a pull-up at the start. This is because when one of the PLC outputs is active, it does not emit 12V, and the microcontrollers used only accept 5V at their inputs. The pull-up regulates the pulse of the voltage regulators.

Furthermore, the third output allows the servo valve to be activated and deactivated while the last output is connected to the pilots, visual indicators of motor action and sensor activation. The PLC and LOGO TDE are connected via its Ethernet input, as shown in the center of the diagram.

Fig. 5: *Block diagram of how the connections between the electronic elements.*



Logo 8 PLC operates at 12 V, so it is necessary to ensure that the elements connected to it also operate at this voltage. However, some elements do not operate at 12 V. To facilitate communication between these elements and the PLC, relays were used, which allow 12 V pulses to be supplied to the PLC. Fig.6. shows an image that exemplifies the materialization of this idea.

Fig. 6: *Connection between ESP32 to PLC*

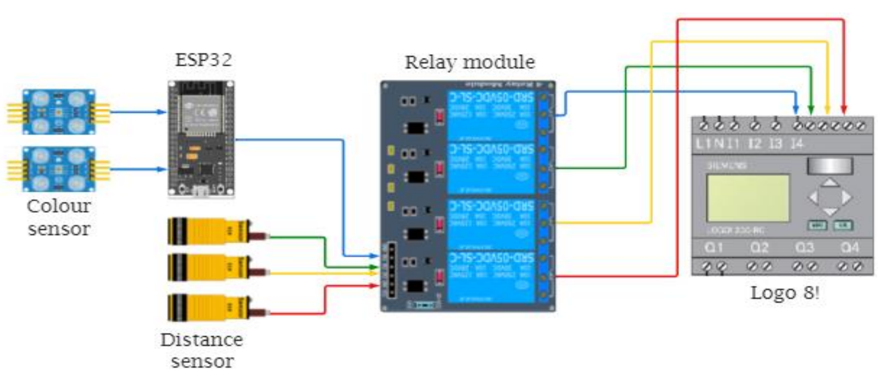


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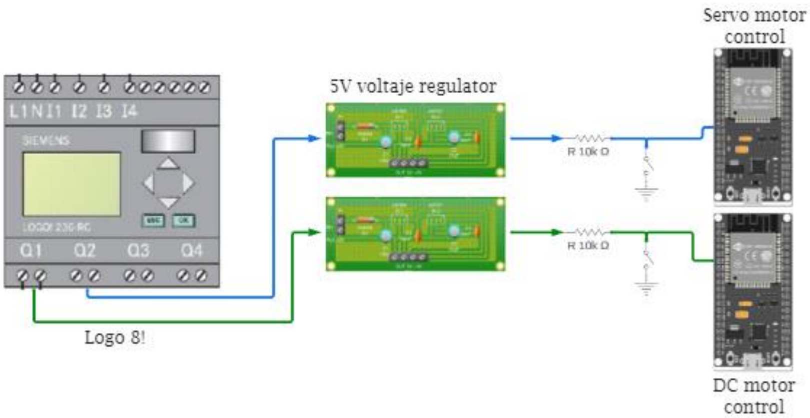
Fig. 7: *Connection between PLC to ESP32.*



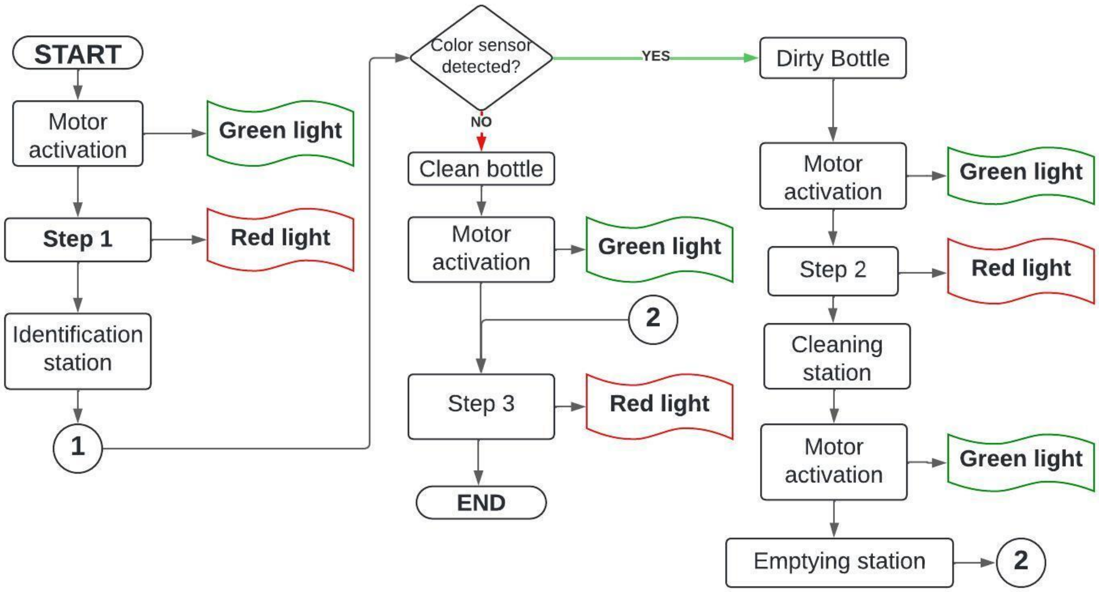
It is important to highlight that special attention has been paid to the selection of power sources and the planning of the distribution of electrical energy to ensure optimal performance and system safety at all times.

Assuming that all elements are running at the same time and at their maximum power consumption, we have a power consumption of 6212 mA. We know that our 10 A supply will have no problem with the power.

Programming

The diagram shown in Fig.8. depicts the process of a machine that starts with the activation of the motor through a start button. This machine has two programming languages, LADDER and C/C++, to program the Logo and ESP32 respectively. The Logo Soft Comfort v8.3 software is used to program the PLC Logo, while the Arduino development environment with the ESP32 Dev library is used for ESP32 programming. The communication between these two programming languages is done through digital inputs and outputs provided by relays. Additionally, Logo Soft Comfort v8.3 enables the programming of the LOGO TDE display. The machine's main flow chart includes a condition that determines whether the bottle is clean or dirty, allowing or preventing the process from being carried out.

Fig. 8: *General equipment control flowchart*



The diagram presented in Fig.8. illustrates a process that begins with the start button that activates the motor to move an empty bottle to Station 1 for identification. If any stains such as blue or green colors are detected, the bottle moves to step 2 for cleaning, where a servo control positions a valve at the mouth of the bottle and performs cleaning. Then, the bottle moves to the emptying stage where a robotic gripper removes the liquid from the bottle, ending the process. A green light indicates belt motion, a red light indicates the bottle's position, and a display shows the activity and stage of the project. This process is efficient and effective in cleaning bottles. The machine prototype was assembled after designing, selecting and manufacturing all the components (refer to Fig.9.)

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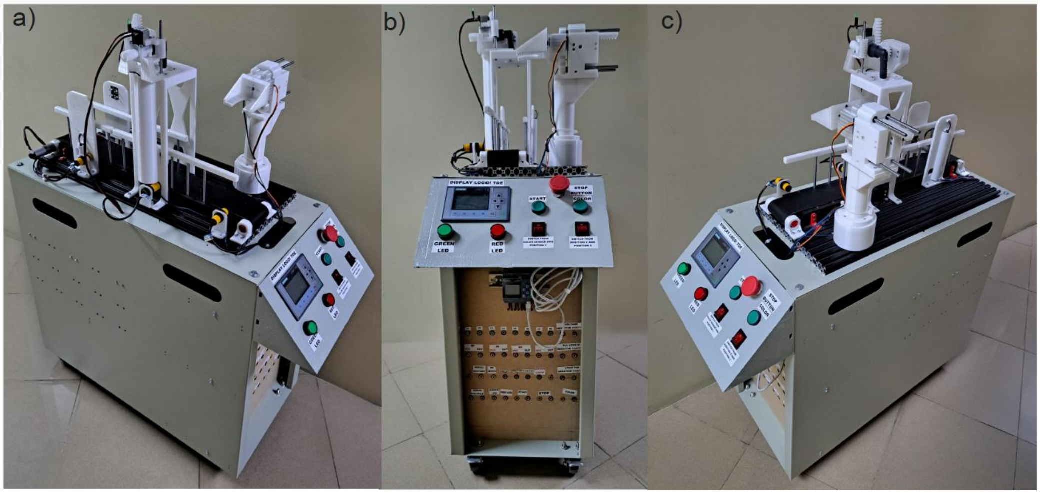
Fig. 9: *Final machine prototype a) left view, b) front view and c) right view*



Experiments and Results

To validate the operation of the prototype, different tests were carried out, including the process with bottles with blue stains, the process with bottles with green stains and the process with bottles without stains. These tests aim to validate the decision-making process of the module, as there are conditions that, when the bottle is dirty, it performs the entire process; otherwise, it sends the bottle to the end of the process.

In addition, these tests have three stations. The first is color identification, which is one of the points of study. The second is the cleaning stage, where the servo valve nozzle must be positioned on the bottle, and it is analyzed if it is correctly positioned. Finally, the third and last station is the emptying station, where the liquid is emptied by means of a clamp; at this station it is validated whether the bottle is correctly positioned.

To perform the tests, the table has the following parameters:

- **Color:** In the first station, it represents whether the color sensor performed proper color identification, which indicates whether the bottle is dirty or not.
- **Valve:** In the second station, it represents whether the valve position has been correctly positioned to perform the cleaning.

It should be noted that a weighting of 0 for non-compliance, 1 for correct compliance and 0.5 in situations where the action was partially carried out was applied to the observation of whether an action was carried out correctly or incorrectly.

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Process with bottles with blue stains

To carry out the validation of the tests, 20 tests were performed with a blue bottle, which are looking in the Table 1. In addition, the time in each test was considered to evaluate the efficiency of the machine in each of its processes.

Table 1: *Table of test with blue stains.*

TEST	COLOUR	VALVE	TIME (s)
1	Blue	Positive	125
2	Blue	Negative	130
3	Blue	Positive	128
4	Blue	Positive	133
5	Blue	Negative	139
6	Blue	Positive	125
7	Blue	Positive	127
8	Blue	Positive	129
9	Blue	Positive	140
10	Blue	Positive	160
11	Blue	Positive	130
12	Blue	Negative	145
13	Blue	Positive	128
14	Blue	Positive	126
15	Blue	Negative	138
16	Blue	Positive	140
17	Blue	Positive	129
18	Blue	Negative	135
19	Blue	Negative	149
20	Blue	Positive	130

Table 2., shows the results of the 20 tests carried out. In the case of the color sensor, it performed correctly in all 20 tests, thus obtaining an efficiency of 100 %. As for the valve, it complied in 16 of the 20 tests, resulting in an efficiency percentage of 80 %. In the case of the claw, it performed

17.5 out of 20 tests, achieving an efficiency of 87.5 %. In addition, all these tests took around 44 min and 46 s to perform.

Table 2: *Table of Result of test 1 to 20 with blue stain*

	TOTAL	% TEST	POSITIVE	TIME (s)
Color	20	100%		
Detection in total	16	80%		
Time (s)	2686	0		44:46

Process with bottles with green stains

To carry out the validation of the tests, 20 tests were performed with a green bottle, as can see in the Table 3. In this presents the tests from 1 to 20. In addition, the time in each test was considered to evaluate the efficiency of the machine in each of its processes.

Table 3: *Table of Result of test 1 to 20 with green stain*

TEST	COLOUR	VALVE	TIME (s)
1	No detected	Positive	165
2	Green	Positive	128
3	Green	Positive	130
4	No detected	Negative	167
5	Green	Positive	135
6	Green	Positive	129
7	No detected	Positive	170
8	Green	Positive	133
9	No detected	Positive	166

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10	Green	Positive	127
11	No detected	Positive	155
12	Green	Positive	134
13	No detected	Positive	156
14	Green	Positive	129
15	Green	Positive	137
16	No detected	Positive	163
17	Green	Negative	127
18	Green	Positive	128
19	Green	Positive	133
20	Green	Negative	137

Table 4 shows the results of the 20 tests performed. In the case of the color sensor, an efficiency of 65 % was obtained by correctly fulfilling 13 of the 20 tests. As for the valve, it complied in 18 of the 20 tests, resulting in an efficiency percentage of 90 %. In the case of the claw, it was successful in 17.5 of the 20 tests, achieving an efficiency of 87.5 %. In addition, performing all these tests took about 47 min and 29 s. In this test, it took longer because the color sensor did not correctly identify the green color. For this reason, a button was included which, in the event that a certain time elapses without identification, allows intervention and continuation of the corresponding process.

Table 4: *Table of Result of test 1 to 20 with green stain*

	TOTAL	**% TEST**	**POSITIVE**	**TIME (s)**
Color	13	65%		
Detection in total	18	90%		
Time (s)	2849	0		47:29

Conclusions

A machine prototype was designed and implemented to cater to the cleaning needs of plastic bottles. The work highlights the following key aspects:

- The test results indicate that blue is identified more accurately than green, with an identification rate of 100 \% for blue and only 65 \% for green, attributing this difference to the higher salience and detection of blue compared to green, as shown in the graphic generated.
- Considering the average time required for each bottle of different colors, it was observed that the blue bottles have an average time of 134 s, while the green bottles have an average time of 142 s. Therefore, in processes where greater speed is required, the blue bottles will be used instead of the green bottles.
- The use of a display to visualize the project process allows us to know what stage the bottle is at. Likewise, it allows us to verify whether each of its stations is working correctly, as well as to supervise the sensors and actuators used in the prototype.

Conflict of Interests

The authors declare that there are no conflicts of interest.

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