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FACULTAD DE INGENIERÍA

Escuela Académico Profesional de Ingeniería Mecatrónica

Tesis

Automatic Sorting System Based on Sensors for The Extrusion of Filament Used in 3d Printers Based on Recycled Pet Plastic Bottles

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Para optar el Título Profesional de
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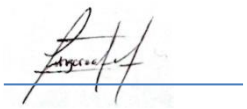

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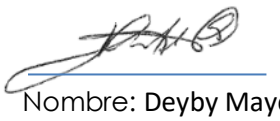

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Automatic sorting system based on sensors for the extrusion of filament used in 3D printers based on recycled PET plastic bottles

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***Abstract*—The problem of the century is environmental pollution, which has a great relationship with plastics that do not reach a proper reuse cycle, from problems such as clogging of sewers in cities to a large increase in the melting of Antarctica, the excess of waste accumulated by plastics has led to seek innovative solutions. Therefore, this article focuses on the design and simulation of a sorting machine and extruder of PET bottles for the manufacture of filament, which will serve as base material for the 3D printer, this means boosting the economy within the regional context, the goal is to implement a new recycling technique to support the environment and improve the quality of life of people. The methodology that develops the study is mainly based on the VDI2221 standard, on the other hand, the type of research is correlational, non-experimental design. Then, the objective of the study focuses on the reuse of plastic bottles from supermarkets in the city of Huancayo. The result obtained is the manufacture of PET filament, which is given by cutting into strips the bottle previously selected by the system, and then, passing to the extrusion phase, obtaining a diameter of 1.7 mm. In conclusion, the prototype was able to manufacture a filament compatible with 3D printers, which is not harmful to people's health, since PET plastic does not emit toxic gases; in addition, it contributes to the care of the environment, by reusing plastic containers.**

Keywords—Plastic contamination, Filament, 3D Printer

I. INTRODUCTION

Currently, environmental pollution caused by plastic is a problem that has brought many ecosystems to a critical state, and people's livelihoods are being decimated by the adverse effects of climate change. This pollutant is located in the least imagined places, either in the atmosphere, where the fibers found are mostly polyethylene terephthalate (PET), nylon and polypropylene [1]. Due to their physical and mechanical characteristics, they impede proper handling, generating a great burden on the marine environment [2].

The advancement of technology and globalization could be catalysts of plastic pollution. Therefore, the project proposed the automatic sorting system based on sensors for the extrusion of filament used in 3D printers based on recycled PET plastic bottles, whose main objective is to implement a new recycling technique to support the environment and improve the quality of life of people. In addition, an alternative solution is the manufacture of polymeric filament for 3D printers through an extrusion process from PET bottles [3].

Among the various systems of filament production is the use of sensors such as infrared, which will be used in this research to detect the presence of PET bottles using a long-range laser to then analyze and make decisions [4], or by using the ultrasonic sensor, which consists of detecting objects with millimeter precision [5].

On the other hand, when performing the analysis in other research, it was observed that the filament first proceeds to shredding, which denotes a longer time [6], in comparison, our machinery has a PET bottle selector system to then perform the cutting of the plastic and proceeds to the extrusion of the filament. On the other hand, it is observed that other authors use Polypropylene (PP) material to manufacture the filament, however, short basalt fibers must be adhered to this material to improve its tensile strength [7].

For the implementation of this project, color, infrared and ultrasonic sensors will be used for the selection of PET bottles. For this, all the information analyzed from the sensors will pass through a RP2040 programmed in Python. In this way, the system will proceed to perform the cutting process and the extrusion of the plastic strips to obtain the PET filament.

II. MATERIALS AND METHODS

To have a better delimitation on the subject, methods consisting of data collection were used, this includes the process of defining the subject, providing ideas, the problematic situation and information searches for the planning of the project of a filament manufacturing machine for 3D printer with selection of recycled PET bottles from supermarkets in the city of Huancayo.

Lotus diagram: It is a tool that generates brainstorming and at the same time is presented in an organized manner, which is presented visually in relation to the chosen topic [8]. In addition, the use of the Lotus diagram provides a connection

between the main idea and the possible solutions to the problem, whose main function is to improve the ability of creative thinking and analytical skills [9].

Therefore, a number of points were investigated: The use of sensor types, actuators, microcontrollers, advantages and, disadvantages of the filament fabrication machine and programming language. From the information gathered and validated in relation to our research topic we have the Lotus diagram as shown in Fig. 1.

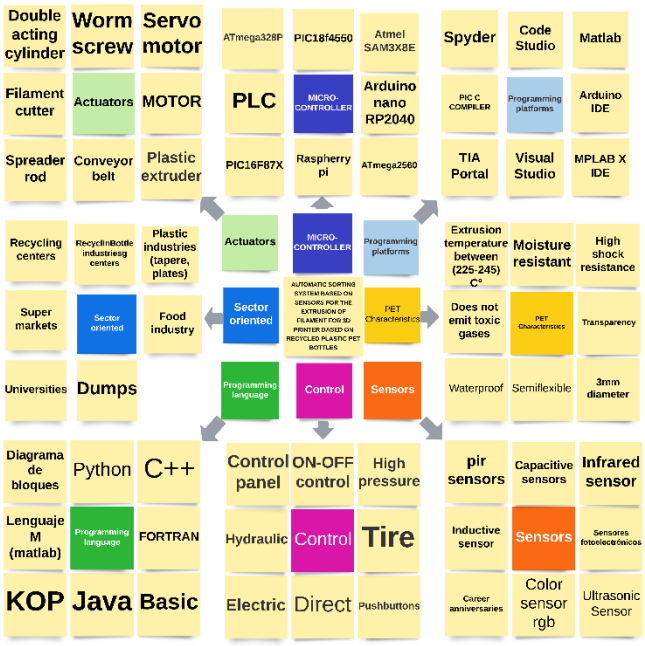

Fig. 1. lotus diagram

To approach the design of the sensor-based automatic sorting system for filament extrusion, we applied the VDI 2221 methodology, this methodology was developed in Germany by "The Society of Professional Engineers" (Verein Deutscher Ingenieure), taking into consideration a systematic approach to the problem.

The design process, as presented in the VDI 2221 standard, is based on 7 stages, of which, the most important to consider are the second, where we propose the functions and their structure, then, in the third, we look for a morphological matrix with all the possible solutions, followed by the electrical and mechanical designs, thus having a more complete structure [10], as shown in Fig. 2.

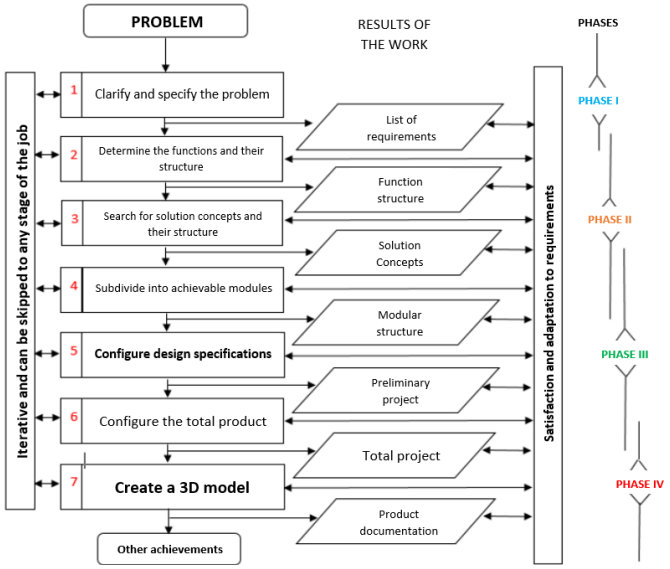

Fig. 2. Methodology VDI 2221

A. *Black Box*

Black box testing, functional testing or behavioral testing, is a type of direct software testing that aims to analyze the interoperability of the interfaces of each software component. This allows a final review of the specifications and coding of the program. A test is considered acceptable if it is performed with a high probability of finding faults, and satisfactory if it does. Therefore, the aim is to perform the minimum number of tests while maintaining their efficiency, i.e. to find as many errors as possible. This is achieved by a complete selection of valid and invalid input and output conditions covering all system functions [11].

Using the black box, the analysis of the main function of the system is presented, which involves the PET bottle classification process, this system has the input of various types of bottles, which vary according to their color, when passing through the classification system, the output will result in PET type plastic bottles, however, the bottles that are not PET type will be removed from the process, this can be seen in Fig. 3.

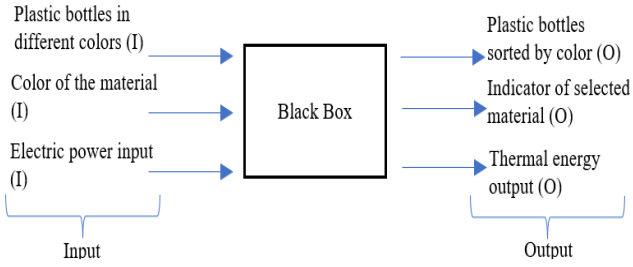

Fig. 3. Black Box

B. *Morphology Matrix*

The morphological matrix is one of the most valuable techniques for generating a large number of ideas in a short period of time, which from its features or attributes is built a matrix that will allow us to multiply the relationships between such parts, was developed in the technological work of

astrophysics and space research carried out in the forties, as a result of the work of astronomer Fritz Zwicky. [12].

For the elaboration of the morphological matrix we must first define very clearly the problem we want to work on in order to decompose it into its basic elements, we have to detect those parameters that are fundamental in the structure of the problem. Once the parameters have been established we will have to identify the variations corresponding to each one [13].

Once we have all these requirements we proceed to combine the possible solutions, we proceed to evaluate the possibilities that we consider most viable from a technical, cost and market point of view [13].

Demonstrating this, a Morphological Matrix of the possible solutions found for the operation of the automatic sorting system based on sensors for the extrusion of the filament used in 3D printers based on recycled PET plastic bottles was proposed , this is shown in table number 1.

TABLE I. MATRIZ MORFOLOGICA

Dimensions	Functions		1	2	3
SELECTION	Controller	Microcontroller	ATmega328P	PLC1214C	RP2040
		Programming platform	Arduino IDE	Python	KOP
		Programming language	Tia Portal	C++	Spyder
	Object recognition	Input device	Vision sensor	Camera	Color sensor
	Actuators	Pneumatic cylinders	Simple effect	Double effect	
CUT	Sensor	Sensor type		Ultrasonic	Infrared
	Cutting system	Object fixation	Worm screw	Snap fasteners	Gripping tongs
		Cutting drive	Food blades	Multi-cutters	Knives for weaving
EXTRUSION	Extruder	Model	MK8	Titan	Bondtech BMG
	Measures	Diameter	1.7 mm	2.5 mm	3 mm
	Temperature measurement	Sensor	LM35	Infrared	PT1000

By applying the combinations, three possible solutions were identified.

TABLE II. COMBINATIONS BY COLOR

COLOR	SOLUTION
Red	S1
Green	S2
Yellow	S3

C. Electric Design

To understand the electronic design used in this project, we have to understand the stages and operation of the machine, we are using an ATmega328p microcontroller, together with the Arduino one development board, we use a proximity sensor, this so that the belt is activated only if material is detected, then to make the selection of PET and non-PET plastic bottles we use a color sensor, To continue the process with the PET bottles we use an ultrasonic sensor, which when detecting the bottle will activate a clamping system that jointly activates two motors with blades that will be in charge of cutting the bottle into strips that will pass to an extruder to obtain the filament, all this electronic process can be seen in Fig. 4.

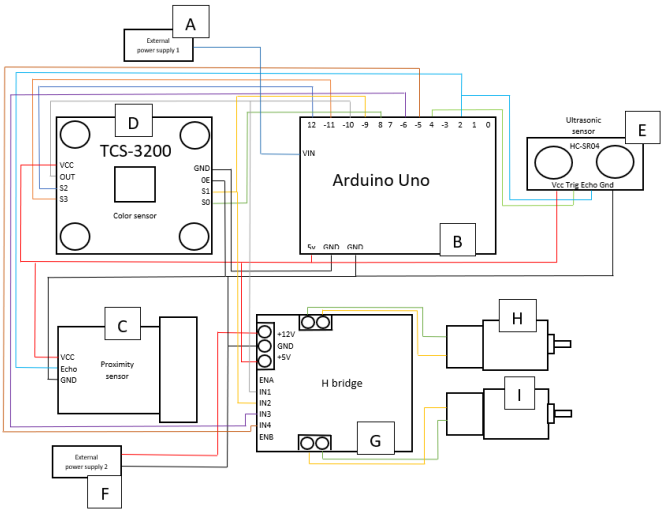

Fig. 4. Electric Design

TABLE III. COMPONENTS

Nomination	Component
A	External power supply (1)
B	Arduino Uno
C	Proximity sensor
D	Color sensor
E	Ultrasonic sensor
F	External power supply (2)
G	H bridge
H	Motor (1)
I	Motor (2)

In order to better understand how each component works within the system, we show the characteristics of each one of them.

TABLE IV. CHARACTERISTICS OF COMPONENTS

Components	Characteristics
External power supply	Because the Arduino's 5-volt output does not supply some components, it is necessary to use an external voltage source.
Arduino Uno	We use the Arduino Uno development board because it includes the ATmega328p microcontroller, where we will connect the sensors already mentioned.
Proximity sensor	This sensor will help us to activate the girdle when material is detected.

Color sensor	With this sensor we will make the selection of bottles, depending on the color of the bottle it will be recognized if it is PET or not PET.
Ultrasonic sensor	The ultrasonic sensor will help us to activate two things, first when it detects a bottle, which in this case is the PET bottle, it will activate a clamping so that then the motors with blades are activated to perform the cut.
H bridge	The H-bridge is a complement that helps us to control the motors and vary their rotation.
Motor	We are using two motors that together have blades at the top, this helps us to cut the bottle into strips.

D. Mechanical Design

To carry out the mechanical design, the system had to be sectioned into three stages. First, the selection system, which consists of a belt and a double-acting cylinder, as main components, these will be driven by programming that will be given with the color sensor. Secondly, we have the cutting stage, which consists of two motors with blades which will cut the bottle into strips. Finally, we have the extrusion stage where the cut filament will be molded with the required diameter , this system can be seen in Fig. 5.

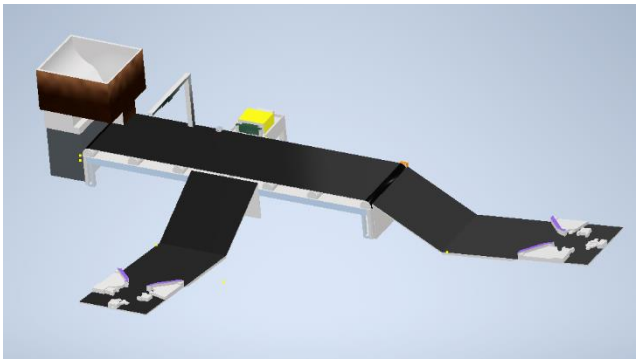

Fig. 5. Mechanical design assembled

To better understand this system, each component of the machine will be explained in a clear and concise manner, explaining the usefulness of each one of them.

The first part of our system is the collection of plastic bottles, this funnel, as shown in Fig. 6, will help to organize the material, so that the process is not disordered and thus does not generate conflict with the other components.

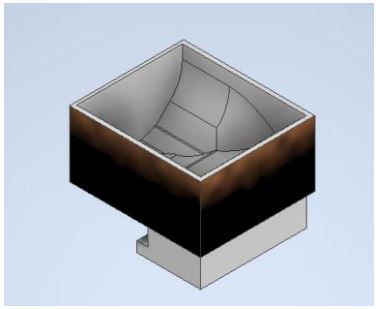

Fig. 6. bottle container

The second part consists of the activation of the conveyor belt thanks to the proximity sensor that, by capturing the entry of material, is activated to pass the bottles and reach the selection stage, this can be seen in Fig. 7.

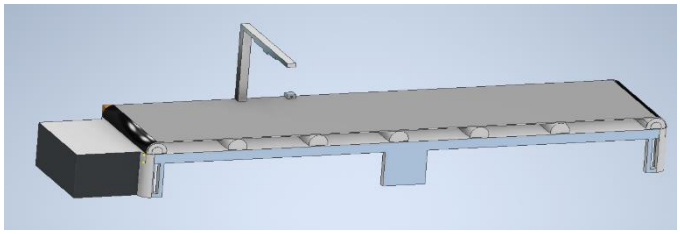

Fig. 7. Bottle conveyor belt

The third part consists of the selection by color of the plastic bottles, PET type plastic bottles are separated from ordinary bottles by using the color sensor, this can be seen in Fig. 8, if the captured material is PET it will continue with the system process, but if it is rejected by the sensor the conveyor belt will stop and the single acting cylinder will be activated for the separation process as shown in Fig. 9. and Fig. 10.

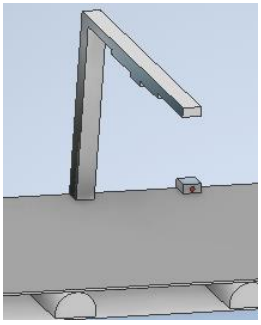

Fig. 8. Color sensor in system

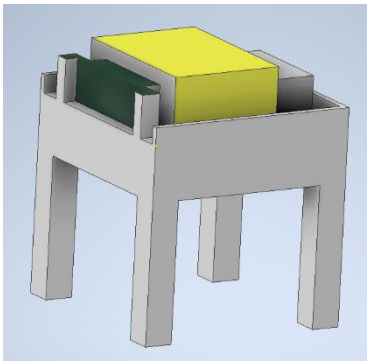

Fig. 9. Bottle sorter

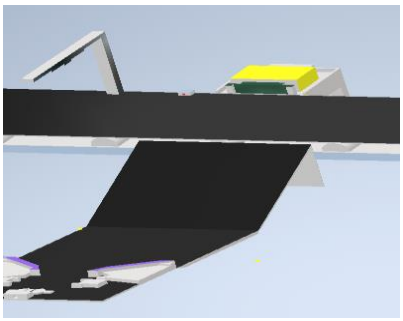

Fig. 10. Non-PET bottle band

TABLE V. Components and description

Components	Characteristics
Plastic bottle container	These are sea containers that store goods and then transport them by trucks, trains, and ships, enabling multimodal transport.
Conveyor belt	The conveyor belt allows the advancement of plastic bottles in the focused material selection process.
Single acting cylinder	The single-acting cylinder used the separation of non-PET plastic bottles by color sensor analysis.
Non-PET plastic bottle container	When the non-PET plastic bottles are separated with the single-acting cylinder, they pass in free fall into the reject storage container.
Worm screw	The auger is actuated downward for bottle gripping as long as the ultrasonic sensor detects the approach of the PET bottle.
Cutting blades	When it is attached to the bottle next to the auger, it immediately actuates the strip cutting blades.
Extruder	When the plastic strips are obtained, they are then passed to the extruder to be melted at a temperature of 150 °C.

III. RESULTS

This section shows a simulation performed on the Tia portal and the Factory IO program. The simulation shows the selection by color, in this case the blue color represents the PET bottle that continues to the next stage of cutting and extrusion and the green color shows the bottle that is not PET, as shown in Fig.11.

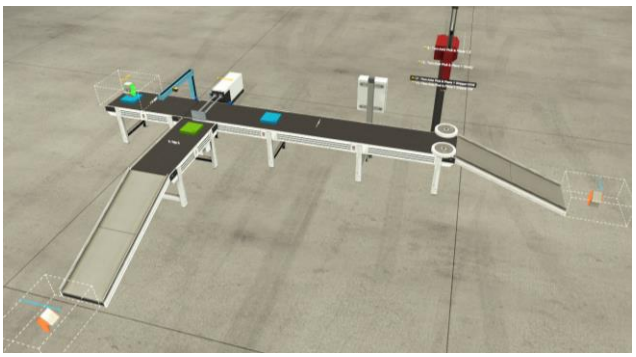

Fig. 11. Factory IO simulation

First, the process is given by pressing the start button, which activates the first belt sedating the passage to the bottles, then the number one, in the figure is given by the color sensor, which recognizes the bottles, in the simulation these colors are represented by two, the blue color represents PET bottles and the green represents non PET bottles. Secondly, number two and three represent the infrared sensor, where they are used to drive the second and third belt that will give way to PET and non PET bottles, the selection is done with the help of a single acting cylinder, which is represented by the number four and is responsible for separating the non PET bottles from the process to the third belt to have another type of treatment, as shown in Figure 12.

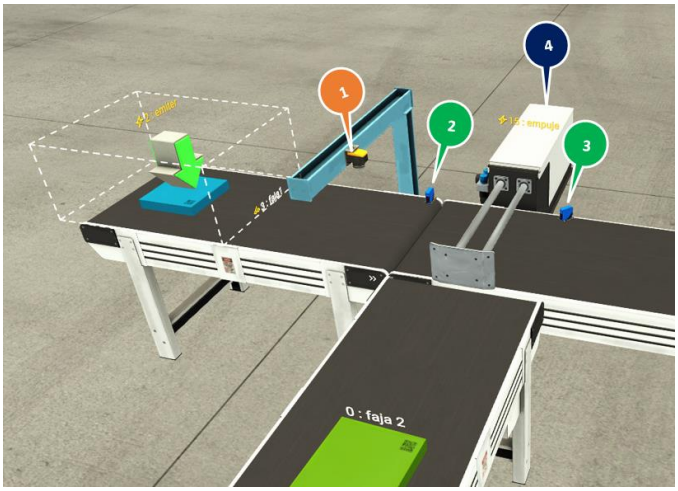

Fig. 12. Selection System

Once the PET bottles are selected, they go to the cutting stage as shown in Fig. 13, this process is carried out using a worm screw, which holds the bottles so that the blades can cut them into strips.

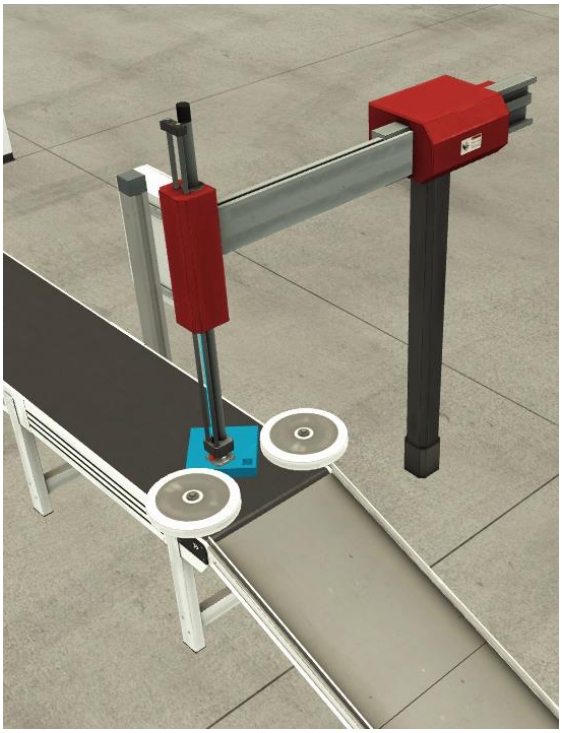

Fig. 13. Cutting System

The The code is shown in Tia Portal in Fig. 14, with it we control the selection by colors and separates according to the configuration, the code also helps us to control the worm drive, which helps to clamp the bottles so that the blades can perform precise machining.

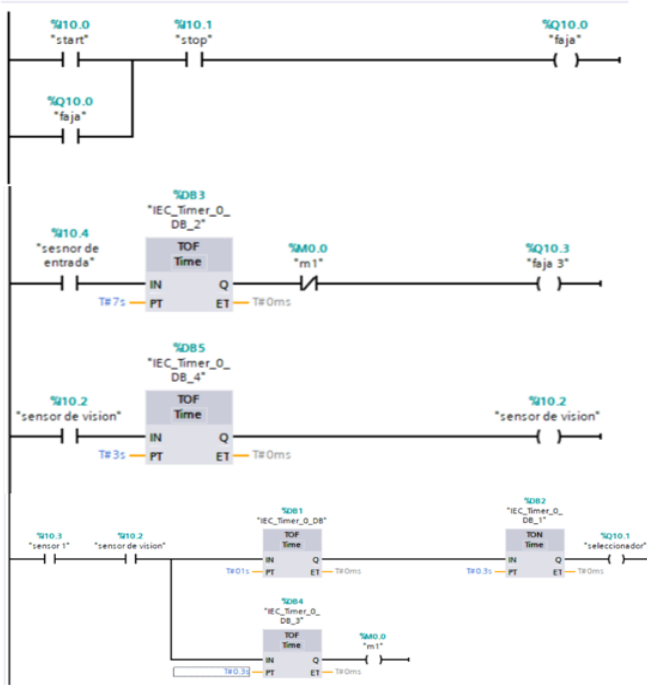

Fig. 14. Code 1

IV. Conclusion and Future Works

In this study, it was proposed to design a sorter to improve the separation of PET bottles, the operation consists of detecting and classifying the bottles by color by activating a cylinder that receives a signal by means of sensors routed through ducts, which allows the non-PET bottles to fall by gravity to the containers to be stored and not to harm the processing of the filament.

- Implement weight sensors for accurate measurement of PET
- Control of different sizes of plastic bottles entering the system.
- Implement HMI screen for real time visualization of the sorting process.

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