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# Prototype for an Automated Home-use Coffee Roaster

Elvin Saúl Díaz Bonilla
*Universidad Tecnólogica Centroamericana (UNITEC)*
Tegucigalpa, Honduras
elvindiaz@unitec.edu

***Abstract*—The current research project aims to deliver an appealing proposal for an emerging market, such as household or micro-business use. It focuses on developing a coffee toaster prototype, with special attention to aspects like maximum automation integration, energy efficiency, cost production optimization, proper user interface development, efficient dimensions and weight, and predictable coffee roasting. Likewise, the research concentrates on control variables that provide better results in determining when the system has completed the toasting process. The project stems from the growing interest in adopting new methods to address coffee industry needs, considering various implications in an increasingly specialized and personalized manner for stakeholder groups. In the case of coffee roasting, this research draws inspiration from previous studies conducted in the Mexican sector with similar items, such as domestic coffee roasting, efficient process development, automation integration, and cost-effective manufacturing. The current document is built on a mixed methodology, where independent or control variables yield quantitative results that can be parameterized based on desired outcomes. In correlation with quantitative data from independent variables, there are qualitative aspects such as the color, smell, and texture of roasted coffee beans as a result of the prototype process. Research variables include temperature, revolutions per minute, relative humidity, timer, fuel supply opening angle, coffee color, and aroma. A prototype was successfully built with optimal dimensions and geometries for data collection. Similarly, the structure's shape addresses the needs of aromatic bean roasting and mixing.**

***Index Terms*— Coffee Roast, Automatization, Control, Temperature, Interface**

## I. Introduction

Honduras is renowned for its outstanding coffee production, with 6.2 million quintals of coffee being marketed during the 2021-2022 period, representing 30 percent of the country's agricultural GDP [1]. In response to the need for economic diversification in the coffee industry, a research project is proposed, focusing on the development of an innovative coffee roaster.

The project addresses key aspects such as the level of process automation and its associated costs, the implementation of efficient control variables, the design of an intuitive user interface, and the integration of safety systems. Additionally, research will be conducted on the relative humidity in the roasting chamber as an indicator of the degree of roasting.

This approach aims to enhance the quality, efficiency, and competitiveness of the Honduran coffee industry, particularly, in domestic and microenterprise settings. The goal is to bridge the gap between limited domestic roasters and expensive industrial ones, offering an appealing prototype to the market. The implementation of these measures seeks to meet the needs of both microenterprises and consumers interested in significant quantities of roasted and ground coffee.

The research will delve into the technical details of the prototype, the project development methodology, and analyze the results and impacts of the proposed solution.

### *A. Objectives*

Design a coffee roaster prototype with partial automation that is fully functional in the roasting process and evaluate the cost-effective feasibility of the finished product for the domestic market.

- Design a control system for temperature, humidity, and revolutions per minute involved in the coffee roasting process.
- Determine the variables that indicate a proper conclusion of the coffee roasting process.
- Determine the machine's capacity for use.

## II. State of the Art

This section presents different projects and research with foundations like the topics corresponding to the current investigation of a coffee roasting prototype with a degree of automation.

### *A. Home Coffee Roasting Machine*

A mechanical engineer [2], focused on the design and development of a home coffee roaster in his professional field, omitting other aspects such as electrical components and implementations of automation and software. Specifically, he focused on the following aspects: Roasting cycle operation, Types of coffee roasting machines, Most common types of coffee beans, Roasting levels, Geometric dimensions calculations of the system, Roasting temperature calculations, Burner design, Electric motor workload calculations, Hopper design, Cost analysis. The studies conducted highlight the author's particular emphasis on the roasting chamber, defining its volume based on the desired quantity of coffee cups to be obtained from a single roasting process. A second emphasis was placed on the geometry of the burners to provide the most efficient heat distribution to the system.

*B. Optimization of a Process for Obtaining Roasted and Ground Coffee*

Made in Hidalgo, Mexico, in 2016, a process involving a coffee pulper, roaster, and grinder was inefficient. It was automated, focusing on high production and labor reduction, improving an initial production of 38 kg of ground coffee to a target production of 114 kg of coffee. The project scope is broader as it considers a process before roasting and the subsequent grinding. Regarding roasting, it integrates automation using PLC technologies and industrial- grade transducers for rugged use, resulting in a proposed system approach that is high-cost and suitable for medium to large-scale production [3].

## III. METHODOLOGY

This research project adopts a mixed-method approach, where independent variables such as temperature, relative humidity, revolutions per minute, timer, and gas opening angle are quantitatively analyzed. These variables subsequently converge into the final system parameterization. In a second stage, dependent variables, such as coffee color and aroma, are qualitatively analyzed. All mentioned variables are considered for research.

The most notable development occurred in:

*A. Desing and Structural Construction*

The designs considered are mentioned, along with their technical attributes, such as welding combined with the materials' resistance to casting [4]. On the other hand, the interaction of the geometries considered in relation to heat transfer is analyzed [5]. Finally, the previously mentioned considerations regarding expected roasting parameters are linked, such as the initial internal grain moisture between 11 and 12 percent [6], roasting temperature between 170 and 260 degrees Celsius [7], and the roasting range between light, medium, and dark [8].

*a) First Prototype Proposal:* The process begins with design characterization, including geometric dimensions and material specifications. For the latter part, the recommendations of specialized technicians in the electric arc welding process are considered, who recommend using a sheet with a thickness of 3/16" for the roasting chamber and a 1" shaft for the mixer. The recommended dimensions by the technicians aim to prevent material deformations due to excess temperature.

*b) Second Prototype Proposal:* The first design was focused on the maximum mixing of coffee beans due to the way the roasting chamber worked with complete revolutions. For this second design, which was ultimately selected, it was oriented towards a structure that would favor data capture by sensors, simultaneously solving the issue of homogeneous mixing with the help of a mixing shaft.

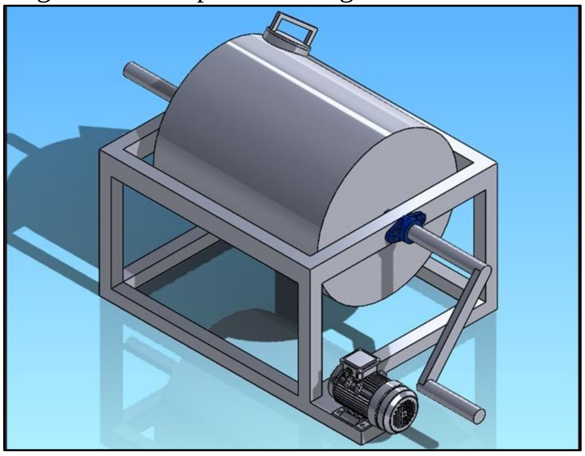

*Fig. 1 First Prototype*

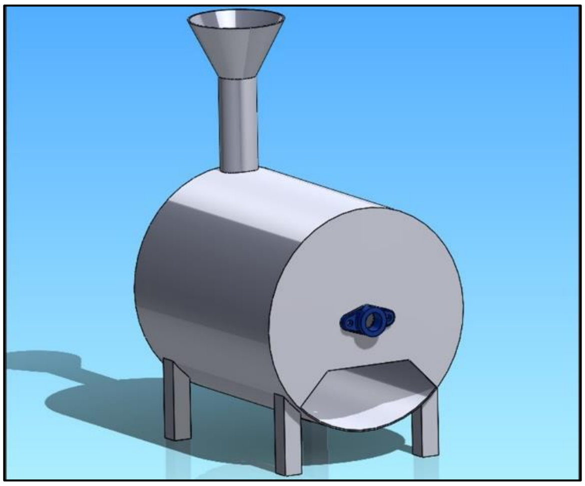

*Fig. 2 Second Prototype*

*B. Mechanical System*

An electromechanical gas valve opening system was designed, which underwent a redesign in the following two stages:

*a) Parallel-Action Solenoid Valve:* This system aimed to use a coupled gear ratio [9] to employ a low-power servomotor and compensate for the power deficiency through this coupling. This would help reduce the overall cost of the mechanism.

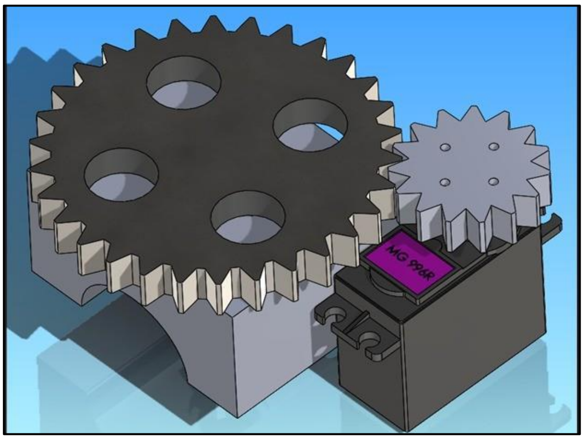

*Fig. 3 Parallel-action solenoid valve*

*b) Concentric-Action Solenoid Valve:* By involving fewer moving parts, it facilitates the design of the assembly, necessitating a higher-power servomotor, specifically 40 kg of force. This is the final design employed in the roaster.

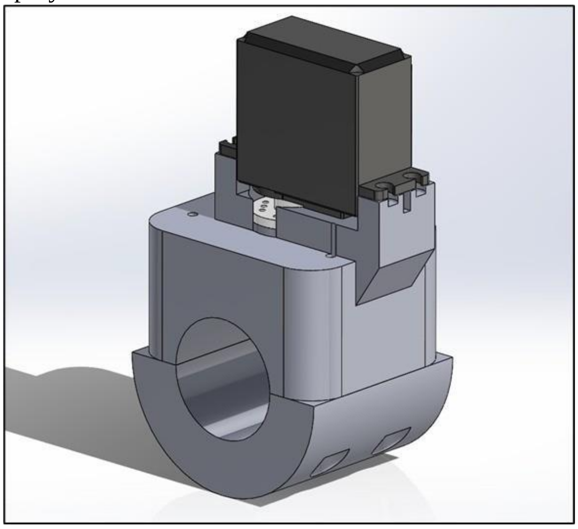

*Fig. 4 Concentric-action solenoid valve*

### *C. Software Development*

The software development begins with the validation of functional code segments for each electronic component of the system. Software development is understood as the code written for the operation of the entire system, taking into consideration the constraints and conditions of interest that the system should consider.

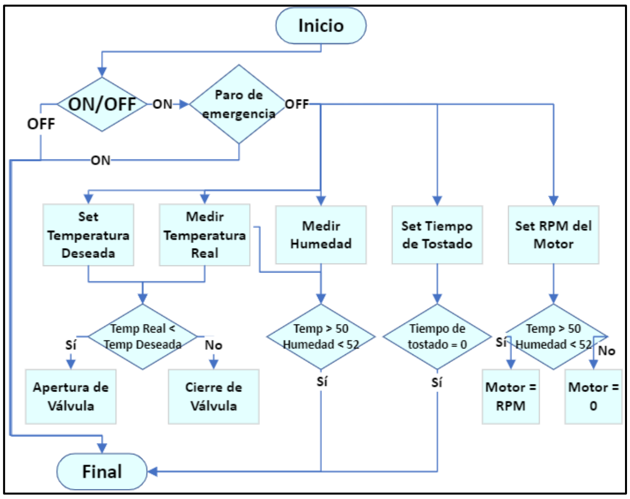


*Fig. 5 Control Flow Diagram*

### *D. Electrical System*

For the construction of the electrical system, it is necessary to consider each of the consumptions that will exist in the system and their nature, i.e., how many watts each element will consume and the total sum of them. Additionally, the units of amperes and voltage in each element that consumes electrical energy must be considered. The system operates with a mix of alternating current segments, such as the AC-DC power supply and the single-phase motor for the mixer, and direct current elements, such as the microcontroller, HMI screen, transducers, etc. The sum of all these characteristics results in the type of power source selected for use and the gauges of conductor wires employed. There is a single originating source from which the remaining sources will be deployed with power supply converters that change the characteristics at the output. Finally, it should be mentioned that in direct current sources, more than one voltage will be used, such as 12, 8, and 5 volts.

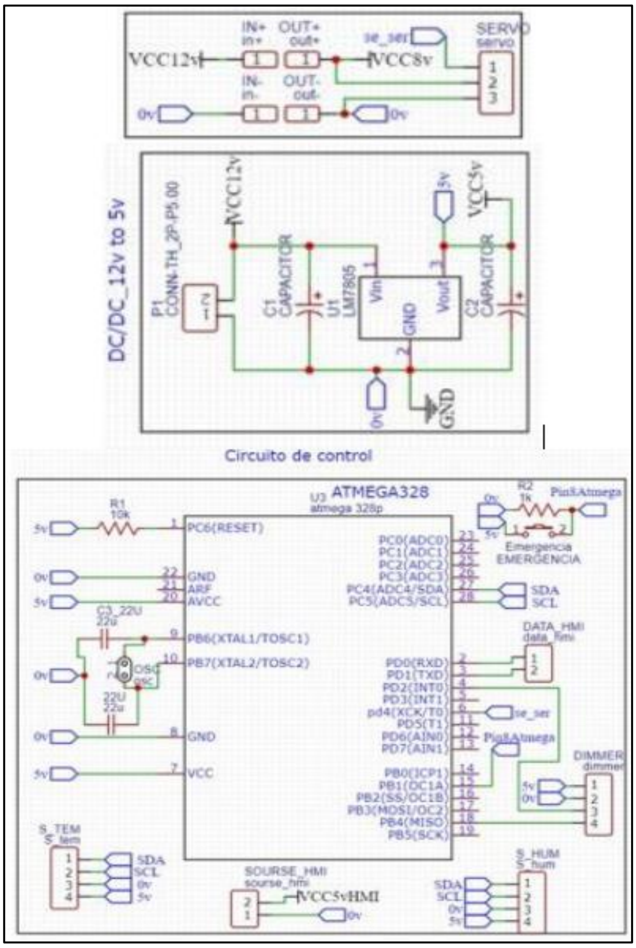


*Fig. 6 Control Electrical Diagram*

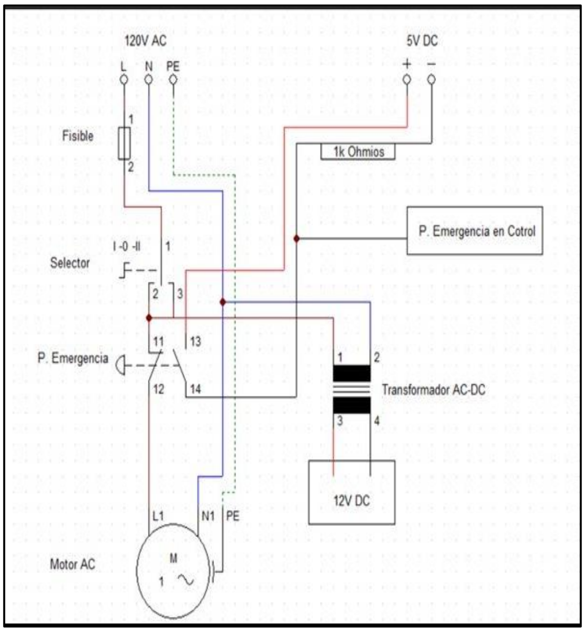


*Fig. 7 Power Control Diagram*

## IV. Results

The results are presented in the main sections developed in the research:

### A. *Prototype Construction*

The different sections of the prototype, such as the electrical, mechanical, structural, and software systems, were constructed, encountering technical aspects that are important to consider. For example, the thicknesses or gauges of the metal profiles used to adjust the final weight of the product as much as possible, as well as the proper consideration of the type of motor used for mechanical work. In "Fig. 8", the structural and mechanical components are presented.

*Fig. 8 Structural and Mechanical Components*

All subsystems work as expected, including the software- controlled fuel addition mechanical system, the mixing system with blades, the electrical power scheme at different voltages, the user interface, the motor control for shaft rotation, and the data acquisition sensors. In "Fig 9", can be seen the electrical system, and in "Fig. 10", the final prototype is shown.

*Fig. 9 Electrical system*

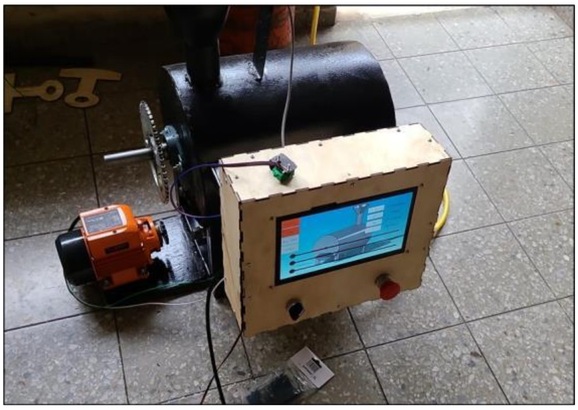

*Fig. 10 Final prototype*

The mixing system, "Fig. 11", was built with a scheme of opposing blades to achieve the mentioned mixing in a much more homogeneous way. They were constructed with iron sheet and machined with the help of laser cutting and SolidWorks. Slight difficulties were encountered in the proper coupling between the surface of the roasting cylinder and the geometry of the blades, regarding the contact tolerances between both pieces.

*Fig. 11 Mixing shaft and roasting chamber.*

In addition to the fuel system, there is the gas burner, which was made with HG-designated pipe, provided with the necessary geometry for proper operation. Subsequent combustion tests were carried out, validating the correct functioning of the system, as seen in "Fig. 12".

*Fig. 12 Combustion Test in burner*

The control system is mainly supported by the processing of the ATmega328 controller. However, it is not entirely, as there are subsystems that operate from the HMI screen controller. Finally, the correct functioning of this duality is achieved thanks to the permanent communication between the screen and the ATmega processor through UART communication. “Fig 13” shows the printed circuit board for the processor and the interconnection of all electronic systems.

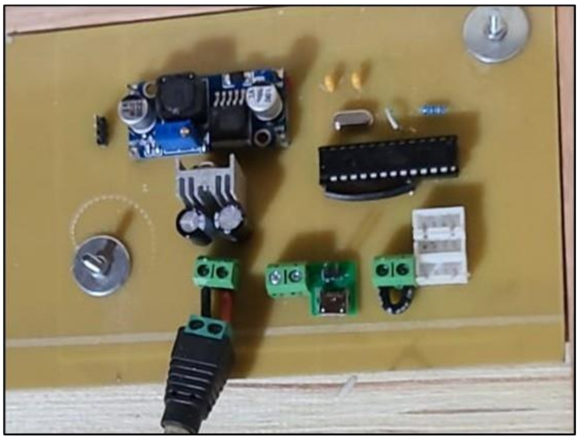

*Fig. 13 Printed circuit board.*

### B. User Interface

The user interface is conceived and designed for proper segmentation, making it more intuitive for the user, as well as safer for the operator and, similarly, for the integrity of the prototype itself.

Its distribution was endowed with additional features to make it even more user-friendly, such as being able to obtain time and date in a configurable way, different screens to have more detailed information and actions that can be taken, internal security mechanisms to avoid operational bugs, a preheating system for the roasting chamber, and independent control of the mixer shaft rotation speed to achieve greater user control.


*Fig. 14 User interface home screen*

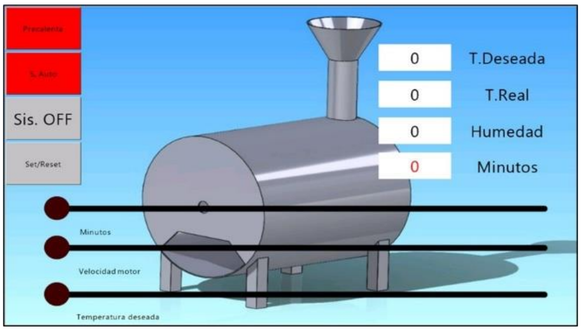


*Fig. 15 Operation screen*


*Fig. 16 Emergency stop screen.*

### C. Budget

The budget for this project is broken down into its most general sections, according to the degree of relevance or cost of each involved section, such as the structural part, combustion system, mixing shaft, labor, and general electrical sections, see Table 1.

*Table 1 Prototype cost estimate*

| ARTICLE/WORK | Money (L) |
|---|---|
| Humidity Sensor | 248 |
| Temperature Sensor | 112 |
| Material for metal structure | 2,000 |
| Labor (Welding) | 1,500 |
| Gas and Combustion System | 850 |
| Traction Kit | 315 |
| Bearings | 520 |
| Used Motor | 600 |
| Mixing Shaft | 1,500 |
| Panel | 200 |
| Screen HMI | 2,500 |
| Power Supplies | 300 |
| Control Circuit | 1300 |
| Servo motor | 600 |
| Screws and Fasteners | 100 |
| wiring | 150 |
| Total | 12, 795 |

### D. Roasting Generated

The quality of coffee roasting achievable with the prototype proposed in this research is remarkable, due to several key factors. First, an adequate heat distribution is achieved thanks to the geometry of the gas burner. In addition, the type of mixing, achieved by the configuration of a central axis with vanes, contributes to this quality by producing a homogeneous roasting. The presence of a roasting chamber is essential for the operation of the shaft, generating an ideal geometry that facilitates data acquisition by sensors that help to have constant and repeatable roasting results. All these technical aspects converge in a precise control by parameterizing the type and degree of roasting.

## V. CONCLUSIONS

A coffee roaster prototype was built with functional partial automation for the realization of the roasting process, contemplating a budget or acceptable manufacturing cost of LPS. 12,795 in relation to the roasting scopes presented by the prototype; it was determined as a profitable project. Additionally, the following conclusions were reached:

- A scheme of independent variables was designed to control the whole system of the prototype and allow to obtain the correct control and manipulation of the process. Regarding these variables, we can mention the temperature, humidity, gas valve opening for the system heat, and AC RMS voltage of the motor to control the RPM of the mixing shaft.
- It was found that the most reliable way to finish the correct roasting of coffee will be based on the user's experience and relying on the roasting time, which is why an HMI screen was developed for this type of implementation in the prototype from the user interface. Likewise, the humidity percentage control was functional to determine when the process is finished.
- The use of the prototype for heavy and/or extended use is entirely feasible by making the appropriate configurations. In the current construction, it presents a compromised integrity due to the construction materials of the electrical and electronic system panel. By upgrading the panel with models built with IP certifications (CEI 60529 Degrees of Protection), the rugged capability grows extensively.

## VI. FUTURE WORK

- The integration of a thermal insulation scheme is proposed, together with a design that favors heat retention in the roasting chamber, minimizing heat loss to the outside as much as possible.
- The research of raw materials and electrical/electronic components that contribute to optimize manufacturing costs, always keeping in mind the premise of not compromising the quality of the product and the results obtained.
- It is suggested to approach the construction process not only as the manufacture of a specific number of units, but rather with the idea of finding an efficient method of large-scale construction for mass production. This would allow for more competitive overall costs.
- It is also proposed to contemplate the different working environments that these machines could face, either in semi-industrial or domestic processes. To this end, we seek to develop designs that are sufficiently robust to effectively withstand the demands of the roasting process.

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