ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.1613

Mechatronic design to improve bakery product packaging tailored for small-sized businesses

Melyssa Garzón, Eng.[1], Faruk Abedrabbo, PhD. [1], Angélica Quito, M.Sc.[1], and Marcelo Moya, M.Sc.[1]
[1] Faculty of Technical Sciences, International University of Ecuador UIDE, Quito 170411, Ecuador, kagarzonzu@uide.edu.ec, anabedrabboha@uide.edu.ec, anquitoca@uide.edu.ec, mmoya@uide.edu.ec.

Abstract*– This paper presents the mechatronic design and implementation of a semiautomatic system for transporting and packaging bakery products focused on small-sized businesses. For the mechatronic design, the standard VDI2206 was followed, in which the mechanical and electronic design is detailed, followed by the programming of the microcontroller. Additionally, a simulation was developed to optimize the model. To validate the machine's functionality, several tests were carried out. These tests also include comparing the semiautomatic system with the manual production of an operator. The main result of this work is an improvement in production of around 64% thanks to the implementation of the machine, which packages four bags in 1.52 minutes. The developed machine costs $ 1,088.52, a realistic investment for small or family businesses.

Keywords*– Packaging, bakery products, conveyor belt, impulse sealing.

I. Introduction

The global pandemic, which began in 2020 [1], sparked significant shifts in business dynamics. Due to economic uncertainty and stringent regulations, various sectors witnessed a surge in innovative endeavors. However, small bakeries and pastry shops often grappled with a common challenge: a lack of automation in their processes [2]. While automation thrives in the food industry on an industrial scale [3], smaller establishments still need to work on embracing it. Automated machinery, tailored for enhanced production efficiency, has predominantly served larger enterprises, leaving artisanal bakeries and pastry shops at a disadvantage. These artisanal family-owned or small-scale businesses grapple with labor-intensive manual processes, encompassing ingredient mixing to product distribution and packaging.

The scarcity of automated technology in small enterprises poses significant hurdles, as automation enhances the final product's production efficiency and quality control. However, the absence of tailored solutions for these ventures leaves a pressing void that requires prompt attention. In this scenario, there is a pressing demand to innovate and create accessible technologies tailored for smaller bakeries and pastry shops. Finding solutions to automate crucial processes like product distribution and packaging becomes fundamental. Developing affordable and efficient systems that can integrate into artisanal settings is essential for enhancing operational efficiency and competitiveness in these emerging ventures [4].

Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
DO NOT REMOVE

For example, conveyor belts are pivotal in the food industry, particularly in bakeries and pastry shops, known for their versatility and efficiency in optimizing production processes. In emerging endeavors, they serve as a valuable solution to automation challenges, adept at handling variable loads and ensuring gentle product handling. Their flexibility allows integration across various stages, from ingredient transfer to product distribution and packaging, maintaining product integrity. Automating these phases with conveyor belts speeds up processes and enhances consistency and product quality while minimizing contamination risks [5]. In today's efficiency-driven era, conveyor belts are essential for modernizing bakery operations and increasing competitiveness. Their adaptability to diverse environments makes them attractive for businesses aiming to optimize processes and embrace automation.

Proper product sealing is crucial alongside conveyor belts to maintain freshness and quality. The impulse sealer, equipped with a nickel strip, swiftly seals bags with precise heat control, preserving product freshness during storage and transportation [6]. The nickel strip's heat-resistant properties ensure proper bag sealing without compromising product quality, ultimately extending the shelf life of baked goods. The combination of conveyor belts for efficient product handling and nickel-strip pulse sealer for bag sealing creates a comprehensive workflow in the packaging and distribution process. This strategic integration of technologies enhances production efficiency and ensures optimal preservation of product quality, maintaining freshness and presentation for final consumers. With the industry's growing demand for plastic sleeves and efficient material transportation on production lines, significant advances in specialized machinery design and construction have emerged, driven by innovative studies and developments, revealing notable trends and approaches [7-9, 10, 14].

References [7] and [8] have developed automated systems for sealing plastic covers using electrical elements, PLC, and synchronized mechanisms to increase efficiency in production. The approach focuses on designing semi-automatic machines with high stamping capacity per minute. They use sealing technologies like bar sealers based on electrical resistance for effectiveness and accessibility. Similarly, references [9] and [10] concentrate on building conveyor belts for efficient dough and material handling on production lines. They employ mechatronic and electromechanical concepts to optimize transportation and reduce costs. These collective efforts contribute to continuous advancements in automation and efficiency in the bakery and pastry industry. Also, references

[11] and [12] discuss the significance of accurately measuring the length of products in motion on a conveyor belt and propose a method for length estimation. Precise length measurements are essential in the bakery and pastry industry to ensure accurate product packaging.

Authors of references [13] and [14] illustrate the effective management of packaging processes on a conveyor belt through various sensors. Building upon this approach, [15] employed an Arduino system to control the conveyor belt, facilitating operator control via a human-machine interface for seamless automation. In reference [16], the automation of a restaurant, which was achieved through the integration of a conveyor belt and Arduino technology, is discussed. Sensors were employed to accurately track the food's position and deliver it to the designated destination. This automation minimized human intervention during food delivery, ensuring a hygienic and efficient food service system.

Similarly, work [17] discusses the significance of automation in the food industry and the integration of robots in food-related processes. In addition, the research developed in [18] highlights the necessity of maintaining quality standards when employing robots in food processing systems. Building upon this, project [19] investigated how the intervention of robots can improve hygiene and productivity in the sector. Finally, project [20] extends this discussion by examining the importance of quality in packaging products, aiming to minimize damage and ensure product integrity.

Regarding packaging food, ensuring proper sealing is fundamental to safeguarding the product's integrity. Research [21] discusses various methods for optimal sealing to prevent contamination and uphold quality standards. Research [22] takes a deeper dive into this topic by examining the overall integrity of food packaging seals and conducting thorough data analysis. Moreover, project [23] validated the efficacy of heat-sealing packaging processes as a reliable method for food packaging. Advancing further, research [24] inspects heat-sealing packaging processes concerning bag packaging within the food industry. All these works developed seek to ensure safety and quality assurance in packaging practices.

Packaging processes must meticulously select the appropriate packaging based on the specific product requirements. Research [25] delved into this aspect by thoroughly analyzing data to identify the most effective packaging methods tailored to different food varieties. This study aimed to develop an innovative packaging system that meets the specific needs of bakery and pastry businesses. This system ensured consistent packaging times, even over extended periods, unlike manual packaging methods prone to slowdowns due to worker fatigue.

As discussed in this work, it has already been proved that automation processes help improve productivity, transportation, packaging, safety, and quality of bakery and pastry products. However, based on the studies cited, there is no evidence of the automation of processes focused on the specific needs of small or artisanal businesses. Despite some studies seeking the best way to transport or package bakery and pastry products, the design and implementation of automated systems for these processes focused on the necessities of small-size businesses have not yet been exploited. For this reason and to cover this niche, this work presents the design and implementation of a semi-automatic system for transporting and packaging bakery products focused on the needs of small companies. In this way, with automation, efficiency remains stable, and human labor may focus on other productive tasks, increasing production capacity and providing significant benefits to bakery and pastry businesses.

II. DESIGN METHODOLOGY

For the design of the semiautomatic system for transport and packing bakery and pastry products, the mechatronic methodology developed by [26] was implemented. This methodology is based on an interdisciplinary approach that combines mechanical, electrical, and computer engineering to design, develop, and control advanced systems (see Fig. 1). It involves the integration of sensors, actuators, controllers, and software to create intelligent machines that can sense, analyze, and respond to their environment. The mechatronic methodology emphasizes the importance of modeling, simulation, and testing to optimize system performance and reliability. This approach has revolutionized the design of complex systems and has led to significant advancements in various fields, including robotics, automation, automotive, aerospace, and biomedical engineering.

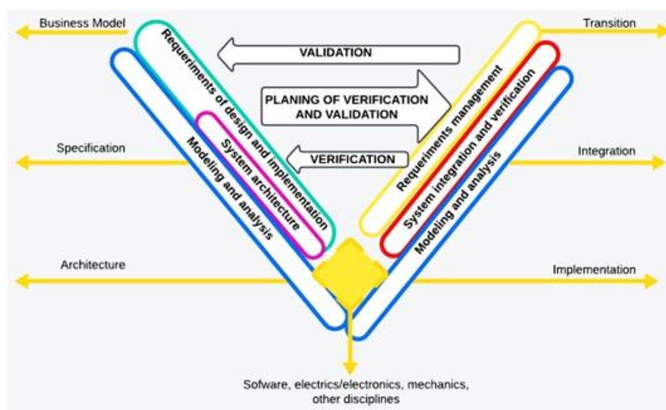

Fig. 1. V-shape mechatronic design methodology used in the transport and packing of bakery products machine [26].

The design process involved choosing materials for the conveyor belt and considering factors like durability and food safety. Additionally, materials for supporting structures and electronic components were analyzed to ensure resilience and compatibility. The critical aspects considered in the system design include:

a. *Materials*: The mechanical components of the machine were manufactured in stainless steel, MDF, PVB, PLA, and PETG materials, ensuring durability and resistance in the production environment. The conveyor belt material chosen was food-grade polyurethane.

b. *Dimensions*: The automatic transport system and sealed bakery product size measures were set in 800x1030x250 mm, offering sufficient space for cookie distribution and packaging processes.

c. *Bakery product mass*: Bakery products like cookies, candies, and small breads are around 5 to 11 grams. For the proposed machine design, a mean value of mass of 8 grams was selected. This mass covers the majority of cookies and candies that are required to be packaged in plastic bags. This mass estimation directly impacts the engineering of the mechanical components.

Following the mechatronic methodology, mechanical design was developed first. A CAD model was created using SolidWorks. Then, using the CAD design, the required mechanical calculations were developed to estimate the stresses at the most critical points of the system. These stresses were estimated to verify that the different mechanical components can support the loads required to operate the machine. In the same way, the calculation of the length of the band and the selection of bearings was carried out. Finally, to verify the rest of the structural components of the machine, a finite element simulation was carried out, where the design of the machine was optimized.

The electronic design started with the mechanical design results. The motors were selected using the weights of the mechanical components and the product mass (necessary forces and torques). Infrared sensors, a load cell, and limit switches were implemented to measure items' weight and the position of the motors to create an efficient system for weighing, moving, and packaging bakery products. It is crucial to keep in mind that accurate product weighing relies on both the analog signals of the load cell and the digital signals from limit switches and infrared sensors. These signals must be processed and sent to the controller without disrupting the programming sequence. Based on the signals received, the necessary interface, and the required actuators, the most suitable controller was selected for the specific application.

The programming for the weighing and packaging machine was developed in both Python and MicroPython. This was done to make it user-friendly and easily modifiable according to the specific requirements of the bakery business. The machine's actuators were programmed to carry out different actions based on signals received from the sensors. This was done at optimal times to ensure the lowest probability of failure during weighing and packaging activities. An intuitive graphical interface was also included, allowing the operator to initiate the process and track the number of packages delivered and their weight.

When all design steps were complete, the manufacture and ensemble of the components were developed to complete the machine. First, the structural and mechanical components were ensemble. Next, all electronic devices were implemented in the machine. After all electronic and mechanical components were working, the controller's programming was developed to ensure the system's functionality.

Since this work is focused on small-sized businesses, the cost related to the machine is a crucial aspect to be considered. For this reason, the final decision was focused on a low-cost machine for the SMEs. This analysis involves all the components of the machine and the specialized labor involved in the machine's manufacturing, assembly, and programming. Finally, to validate the correct functionality of the transport and packing system, the machine was tested through 20 trials to measure the time required for packaging four packages of cookies of 20 grams each (5 grams per cookie). In these packages, the accuracy of the weighting system was also evaluated. Finally, to analyze the performance and test the behavior of the system, the time to package 80 bags of cookies was compared with the time produced by an experimented bakery operator.

III. MECHATRONIC DESIGN

A. *Mechanical design*

Fig. 2 shows the CAD design of the machine. As seen in the image, the bakery products are positioned on the belt. The belt moves and transports the product to the weighing area. Then, when the machine identifies the correct weight, an actuator puts the product into the plastic bags, which should be located in the square holes of the bags tray. When the four bags are filled, they are moved to the sealing area to close them. Using the CAD design, the stresses of the mechanical components were estimated to ensure the resistance required for each component.

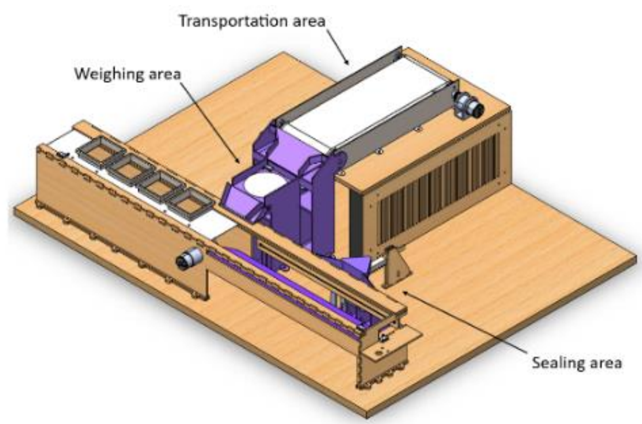

Fig. 2. CAD prototype of transport and packaging bakery products machine.

For the conveyor belt, the contact angles between the driving and driven roller with the belt were determined by accurately applying Eq 1, as specified in reference [28]. In the equation, θd refers to the contact angle on the driven or driven roller in degrees. d_r refers to the trailed or driven roller diameter in mm, D_r refers to the drive roller diameter in mm, and L refers to the distance between roller centers in mm. Due to both rollers having the same diameter, θd is equal to π. This 90º angle facilitates uniform and efficient cookie movement along the conveyor belt, streamlining operations and ensuring compliance with safety and efficiency standards for the cookie production process.

$$\theta d = \pi \mp 2sen^{-1}\left(\frac{D_r - d_r}{2L}\right) \quad (1)$$

After determining the necessary angles for the rollers, estimating the required length of the conveyor belt becomes essential. The band length considers various factors, such as the distance it needs to cover for cookie transportation and the system's specific configuration. The calculation of band length (L_b) was determined using Eq. 2 from Ref. [28]. Considering the diameters of the driven (d_r), the drive rollers (D_r), and the distance between roller centers (L).

$$L_b = 2L + 1.57(D_r + d_r) - \left(\frac{(D_r - d_r)^2}{4L}\right) \quad (2)$$

The L_b calculated was 87.8 cm. This dimension covers the total span required for the conveyor from one side of the machine to the other. This length was critical for ensuring the belt adequately covered the required distance and maintained sufficient tension for optimal system performance. Proper belt length guarantees smooth and efficient bakery product transportation along the belt.

Following the mechatronic design, a simulation was developed to analyze the forces and loads of the bakery products over the structure of the machine. Since the machine structure was designed in MDF, Table I shows the main properties of the material. The mean values of these properties were inserted into SolidWorks to run a correct simulation.

TABLE I

MDF PROPERTIES [29]

PROPERTY	VALUE
Density	600 to 800 kg/m^3
Modulus of Elasticity	2500 to 4000 MPa
Elastic Strength	Approximately 20 MPa
Flexural Strength	20 to 35 MPa
Tensile Strength	About 1.5 MPa
Compression Strength	20 to 50 MPa

Assuming that in the maximum condition of the machine, around 100 bakery products can be in the belt simultaneously. The maximum load applied over the machine is around 80 N (100*8 grams). By applying this load in the simulation, the stress and displacements were obtained. Fig. 3 shows the Von Mises stress in the structural supports of the machine.

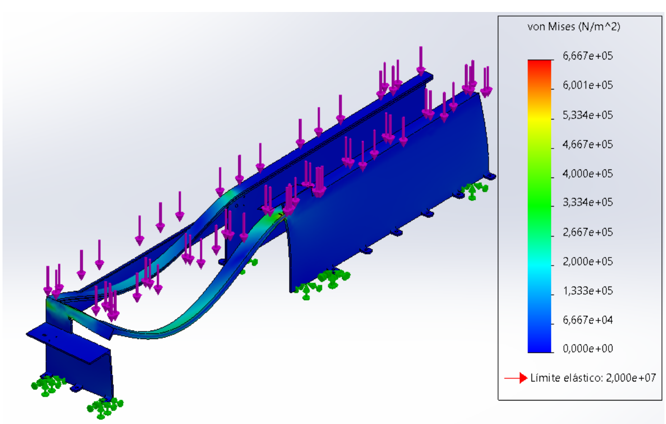

Fig. 3. Von Misses stress in the simulation with 8N.

As seen in this image, the maximum Von Misses stress occurs in the sealing area with a value of 6.7x10^5 N/m2 (0.67 MPa). Comparing the Von Misses stress with the tensile stress of the material (Table I), the safety factor is around 2.24.

The same analysis was developed to find the displacements of the structure. Fig. 4 shows the maximum displacement of the structure in the sealing area with a value of 0.45 mm. This value This deformation remains minimal concerning the structural characteristics. In practical application, achieving such a high multiplication of weight is unlikely. The results confirm that even when applying a higher load to the system, the observed deformation does not reach critical levels or compromise the part's structural integrity.

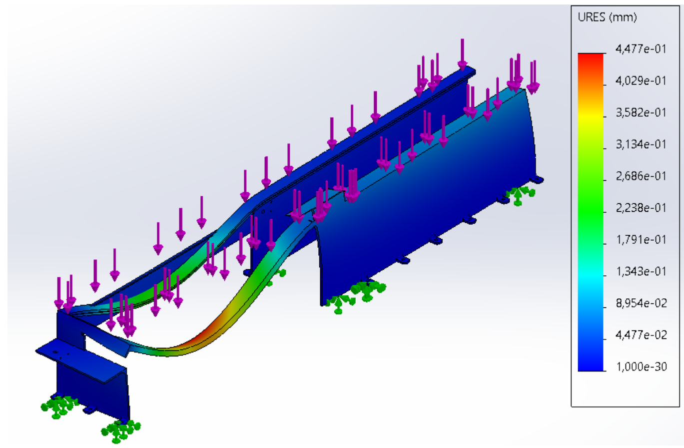

Fig. 4. Displacement simulation with 8N.

Once the final mechanical design was clearly defined, the electronic components were selected according to Table II. All these components were connected following the electric scheme of Fig. 5. After that, the process sequence was analyzed, creating the sequence system diagram of Fig. 6. Using this diagram, the programming of the microcontroller was developed.

TABLE II

COMPONENTS LIST

COMPONENT	DETAILS
Hx711 module	Load Cell Amplifier 1kg, 5kg, 10kg, 20kg
Load cell	1kg Load Cell
Infrared sensor	Operating voltage: 3.3 Vdc - 5 Vdc - Detection distance: 2 - 30cm (adjustable with potentiometer) - Detection angle: 35º
Limit switches	PCB card size: 40x16mm Cable length: 60cm Uses a 22AWG cable that supports up to 2A 300V. Heat resistant housing up to 80ºC
Arduino UNO	Microcontroller: Atmega328 Operating voltage: 5V Supply voltage: 5-20V Digital pins: 14 Analog pins: 6 Clock speed: 16Mhz
Display MIUZEI LCD1602	i2c connector for easy connections 16 characters x 2 lines 5x8 point characters. Character size: 5.23 x 3 mm
L298N	Terminal driver part of the supply area VMS: +5V ~ +35V

	Drive part of the peak current Io: 2A / Bridge Logical part of the terminal power supply range Vss :4.5-5 .5V Logical part of the operating current range: 0 ~ 36mA The control signal input voltage range: 4.5-5.5V low 0V high Maximum power consumption: 20W
Motors 12v	12V 150 RPM S330012
Reduced motor	6-12V Biaxial
Relay	12V 10A

The system starts by activating in reverse direction motor 2 (actuator to move the product from the weighing zone to the plastic bags) and motor 3 (actuator to move bags tray) to initialize the system via limit switches. After the machine modules are initially positioned, motor 1 starts moving the conveyor belt with the product. The product falls to the weighing zone until the load cell detects the weight required (this weight can be fixed; for example, for cookies, the packages are commonly around 20 grams). When the required weight is detected, motor 1 stops and motor 3 moves the product to fill one bag. Next, the system waits for the infrared sensor, indicating that the bag is full of products. At this point, motor 2 is activated to move the bags tray to the next position, and the system continues the process to weigh and move more product to fill other packages. This process is repeated until the infrared sensor detects the 4 packages filled.

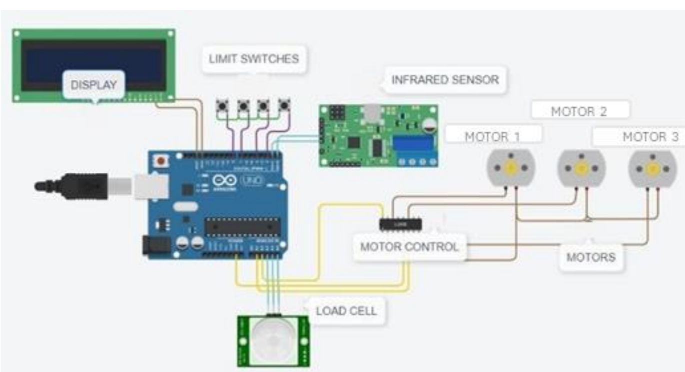

Fig. 5. Electronic Diagram of bakery transport and packaging products.

When the 4 packages are filled, motor 3 moves the bags tray to the end-of-rails limit switch, positioning the bags in the sealing area. When the system is in the sealing area, the limit switch triggers the heating of the nickel plates for 3 seconds. Then, Motor 4 presses the nickel plates together with the product packets in between, thus sealing the bags in a period of 5 seconds. After that, motor 4 returns to its initial position. Finally, motor 3 moves reversely to return the tray to its starting point, and the process repeats until the operator stops the machine by pushing the option in the display.

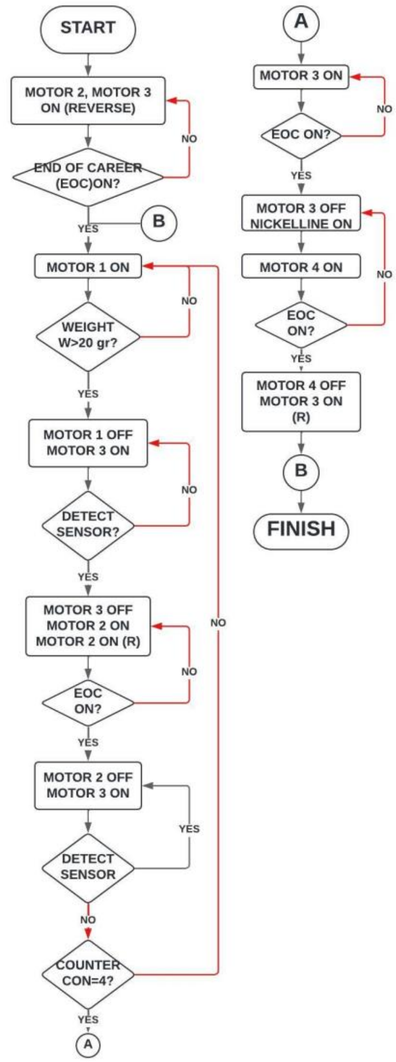

Fig. 6. Flow diagram of the system for transport and packing bakery products.

IV. FINAL PROTOTYPE OF THE SYSTEM

The manufacture of each component and the ensemble of the machine was developed in-house. Fig. 7a shows the top view, while Fig. 7b shows the lateral view. In these images, the three main operating areas of the system are visible. Each segment serves a specific purpose to ensure the accurate packaging of bakery products. The transportation segment facilitates the movement of bakery products without any damage from one location to the weighing area. The weighing segment divides the product into packages, ensuring that all packages have similar mass, while the sealing segment seals the package to prevent deterioration or ageing of bakery products. To see the complete functionality of the transport and packing system, the following link shows a descriptive video in which the machine is testing using cookies as an example to create several packages of 20 grams: https://youtu.be/Zei7ACUoWOk.

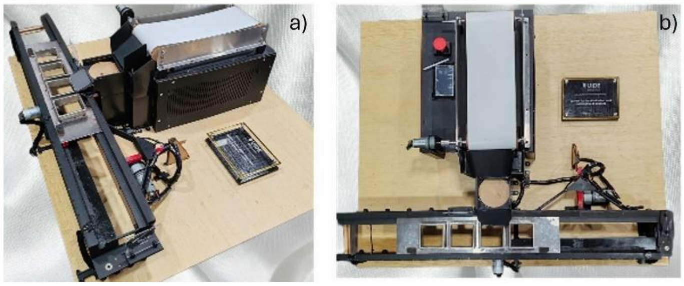

Fig 7. Final prototype.

V. COST OF THE SYSTEM

Table III outlines the costs of executing the system for transporting and packaging bakery products for small-sized businesses. This comprehensive compilation encompasses all financial aspects and resources essential for each phase of the design and construction process. According to Table III, the final cost of the system is around $ 1,089.

TABLE III
COST RELATED TO MANUFACTURING AND ENSEMBLE OF THE MACHINE

ASPECT	COST ($)
Stainless steel parts	$ 122.00
PLA	$ 21.00
PVB	$ 28.00
PETG	$ 24.00
MDF parts	$ 25.50
Polyurethane band	$ 80.64
Electric components	$ 224.78
PCB	$ 12.60
Human Resource	$ 550.00
TOTAL	$ 1,088.52

In a small bakery setting, where budgets are tight, and every expense needs careful consideration, a $ 1,089 dollars machine presents an attractive option. Unlike larger, more complex equipment that can cost thousands of dollars and must be imported [30]. The machine developed offers essential functionality at a fraction of the price. While it may not have all the bells and whistles of its more expensive counterparts, its affordability allows small bakeries to invest in equipment vital for their operations without breaking the bank. Additionally, its simplicity may translate to easier maintenance and lower operating costs over time, making it a practical choice for businesses aiming to maximize value within their limited resources.

VI. EXPERIMENTAL VALIDATION

Twenty tests were carried out with the machine packaging cookies in order to determine how long it took to package four sleeves and how effective the procedure was. Table IV provides a summary of the results, showing that the machine has a mean transport and packing time of 1.52±0.07 minutes. Additionally, Table IV shows that the machine has an accuracy of ±5 grams. There is roughly a 1 cookie difference in the weight of the bundles. The reason for the disparity in the package weights is because, once the machine reaches its weighing limit, there is no barrier that stops more cookies from falling out. When compared to small cookies, larger bakery products might not exhibit this variance. This inaccuracy, nonetheless, falls within the market's permitted 5% tolerance for baked goods. This difference arises from the machine's absence of a gate that stops further cookies from falling in after it has reached the weight limit. It is important to remember that larger bakery goods than cookies might not experience this variance. This inaccuracy, meanwhile, falls within the market tolerance for small products in the bakery industry.

TABLE IV
PACKAGING TESTS

TEST NUMBER	TIME (min)	PACKAGE WEIGHT (Grams)
1	1.4	20
2	1.5	20
3	1.5	25
4	1.6	20
5	1.5	25
6	1.4	25
7	1.5	20
8	1.6	20
9	1.6	20
10	1.5	20
11	1.5	25
12	1.6	20
13	1.5	25
14	1.6	25
15	1.5	20
16	1.6	25
17	1.5	25
18	1.4	20
19	1.5	20
20	1.6	20

Table V compares the result of the previous tests developed by the machine with a test carried out by an expert bakery operator, in which the packaging of the cookies is developed manually. The operator's manual process includes the time of weighing the product, taking the products, taking the bag, putting the products in the bag, and closing the bag with a hot sealer. According to Table V, the operator completed all these steps in around 45 seconds. However, the operator packages one bag in 45 seconds, while the machine produces four bags in a mean of 1.52 minutes.

Additionally, the operator must prepare all the materials before packing the products. He also needs active breaks after making several packages since the task is repetitive and produces operator fatigue. As seen in Table V, after every 6 or 7 packages, the operator loses 5 minutes of productivity. Time in which the machine continues working. Therefore, these operator downtimes directly affect the bakery's production.

For example, to make 80 packages, the machine takes approximately 30.5 minutes. In the same way, the operator completed the work in around 84.6 minutes, which led to a 64% increase in production thanks to the implementation of the machine with 2.7 times of reduction in packaging time.

TABLE V
HUMAN VS MACHINE TESTS

<table>
<tr><th rowspan="2">WORK CYCLE</th><th colspan="2">MACHINE WORK</th><th colspan="2">HUMAN WORK</th></tr>
<tr><th>Packages</th><th>Time (min)</th><td colspan="2">Activities estimated for the cycle of work:
Weigh product: 15 s
Take the products: 5 s
Take the bag: 5 s
Put the products in the bag: 10 s
Close the bag with hot sealer: 10 s
Total time per bag: 45 s</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">4</td><td rowspan="2">1.4</td><th>Time (s)</th><th>Packages</th></tr>
<tr><td rowspan="4">Preparation time for packaging materials 2 min.</td><td rowspan="4">0</td></tr>
<tr><td>2</td><td>4</td><td>1.5</td></tr>
<tr><td>3</td><td>4</td><td>1.5</td></tr>
<tr><td>4</td><td>4</td><td>1.6</td></tr>
<tr><td>5</td><td>4</td><td>1.5</td><td>45</td><td>1</td></tr>
<tr><td>6</td><td>4</td><td>1.4</td><td>45</td><td>1</td></tr>
<tr><td>7</td><td>4</td><td>1.5</td><td>45</td><td>1</td></tr>
<tr><td>8</td><td>4</td><td>1.6</td><td>45</td><td>1</td></tr>
<tr><td>9</td><td>4</td><td>1.6</td><td>45</td><td>1</td></tr>
<tr><td>10</td><td>4</td><td>1.5</td><td>45</td><td>1</td></tr>
<tr><td>11</td><td>4</td><td>1.5</td><td>45</td><td>1</td></tr>
<tr><td>12</td><td>4</td><td>1.6</td><td rowspan="3">Active break for repetitive work 2 minutes.</td><td rowspan="3">0</td></tr>
<tr><td>13</td><td>4</td><td>1.5</td></tr>
<tr><td>14</td><td>4</td><td>1.6</td></tr>
<tr><td>15</td><td>4</td><td>1.6</td><td>45</td><td>1</td></tr>
<tr><td>16</td><td>4</td><td>1.6</td><td>45</td><td>1</td></tr>
<tr><td>17</td><td>4</td><td>1.5</td><td>45</td><td>1</td></tr>
<tr><td>18</td><td>4</td><td>1.4</td><td>45</td><td>1</td></tr>
<tr><td>19</td><td>4</td><td>1.5</td><td>45</td><td>1</td></tr>
<tr><td>20</td><td>4</td><td>1.6</td><td>45</td><td>1</td></tr>
</table>

VII. CONCLUSIONS

The work developed in this study included designing and implementing a semiautomatic system for transporting and packaging bakery products focused on the needs of small companies. Based on the work done, the following key aspects are highlighted:

- The bakery transporting and packaging system developed includes a sealer, conveyor belt, weighing system, and capacity to pack 4 bags simultaneously, with automated repetition of the packaging process. The machine demonstrated notable efficiency in packaging processes and offered the added advantage of freeing up human resources for other bakery tasks.

- Mechatronic design has proven advantageous in implementing the machine because this methodology was crucial to integrating mechanical components design with the electronic components and the programming steps.

- The system's average completion time is 1.52 minutes for packaging four bags, surpassing the efficiency of manual production by around 64%. In addition, the automated packaging system demonstrates excellent performance by packing 80 bags of cookies within a consistent time frame of 30.5 minutes with zero defects.

- The semiautomatic machine implemented in this work cost $1,088.52. This machine is specifically designed for small bakeries and pastry shops. Therefore, its cost is no higher than commercial industrial machines.

REFERENCES

[1] ONU, "Coronavirus disease (COVID-19) outbreak", [Online]. Available: https://www.who.int/es/emergencies/diseases/novel-coronavirus-2019

[2] N.A., "Business process automation – challenges & remedies", Process Discover, [Online]. Available: https://www.processdiscover.com/business-process-automation- challenges-solutions/

[3] Finn A., "The power of automation in the modern food industry", [Online]. Available: https://www.linkedin.com/pulse/power-automation- modern-food-industry-appleton-finn-usune/

[4] N.A., "Technology and production equipment in the bakery industry", BBM, 16-May-2023 [Online]. Available: https://magazinebbm.com/blog/technology-and-production-equipment-in-the-bakery-industry-2796

[5] G. Meulensteen, Marvu, [Online]. Available: https://www.marvu.nl/en/

[6] A. Cooper, "Sealing coffee bags: What are impulse sealers?", MTPAK COFFEE, 01-Feb-2023 [Online]. Available: https://mtpak.coffee/2023/02/impulse-sealers-used-for-sealing-coffee-bags/

[7] V. Yanchaguano, "Automation of a case sealing machine type l plastics for the Eduplastic company.", Escuela Politécnica Del Ejército, 2013.

[8] I. Bedoya and D. Quisirumbay, "Design and construction of a semiautomatic plastic cover sealing machine with a capacity of thirty seals per minute.", Escuela Politénica Nacional, 2007.

[9] D. Pastor, "Design and construction of a conveyor belt for transporting bread dough.", Universidad Politécnica de Valencia, 2019.

[10] H. Torres, L. Medina and J. Garrido, "Prototype design of a conveyor belt", 2017 11. H. Rodriguez, "Design of conveyors belt", Ingemecanica, [Online]. Available: https://ingemecanica.com/tutorialsemanal/tutorialn84.html

[11] T Yamazaki et al., "Development of mass and length measurement system on conveyor belt", The Journal of JASME, pp. 513-514, 2006.

[12] A. Watanabe, T. Yamazaki, H. Ohnishi, M. Kobayashi, and S. Kurosu, 'Length measurement for moving products on conveyor belt', in SICE Annual Conference 2007, 2007, pp. 373–377.

[13] Y. M. Abueejela, A. A. Algitta, S. Mustafa, F. Ibrahim and N. Abdalruof, "Automated packaging machine using PLC", International Journal of Innovative Science Engineering & Technology IJISET, vol. 2, pp. 282-288, 2015.

[14] J. M. M. Baroro, M. Alipio, M. L. T. Huang and T. M. Ricamara, "Automation of packaging and material handling using programmable logic controller", International Journal of Scientific Engineering and Technology, vol. 3, pp. 767-770, 2014.

[15] R. B. Mofidul, M. S. H. Sabbir, A. K. Podder, and M. Shaifur Rahman, 'Design and Implementation of Remote Controlling and Monitoring System for Automatic PLC Based Packaging Industry', in 2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT), 2019, pp. 1–5.

[16] M. J. Islam Jubaid et al., 'Design and Construction of a Smart Restaurant Service Using Conveyor Belt', in 2023 International Conference on Advances in Electronics, Communication, Computing and Intelligent Information Systems (ICAECIS), 2023, pp. 265–270.

[17] B. D. Meshram, S. Adil and S. Ranvir, "Robotics: An emerging technology in dairy and food industry", IJCS, vol. 6, no. 2, pp. 440-449, 2018.

[18] W. Grobbelaar, A. Verma and V. K. Shukla, "Analyzing human robotic interaction in the food industry" in Journal of Physics: Conference Series, IOP Publishing, vol. 1714, no. 1, pp. 012032, 2021.

[19] R. R, R. R. P, S. C and S. K. B, "Role of Robotics and Automation in Food Industries: An Overview," 2023 2nd International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA), Coimbatore, India, 2023, pp. 1-5.

[20] B. Muhammedali, M. Z. Abdullah and M. N. Mohd Azemi, "Food handling and packaging using computer vision and robot," Proceedings. International Conference on Computer Graphics, Imaging and Visualization, 2004. CGIV 2004., Penang, Malaysia, 2004, pp. 177-182.

[21] H. K. S. V. Mohan, C. H. Toh and A. A. Malcolm, "Non-destructive Evaluation of Flexible Sachet Seal Integrity Using a Capacitive Proximity Sensor," 2021 IEEE Industrial Electronics and Applications Conference (IEACon), Penang, Malaysia, 2021, pp. 169-174.

[22] Z. Shuangyang, "Fast Inspection of Food Packing Seals Using Machine Vision," 2010 International Conference on Digital Manufacturing & Automation, Changcha, China, 2010, pp. 724-726.

[23] L. Wanqing, Z. Qinghua and Z. Xiaowei, "Deep Learning Based Heat-

Sealing Quality Inspection," 2021 9th International Symposium on Next Generation Electronics (ISNE), Changsha, China, 2021, pp. 1-4.
[24] D. Chen and M. Wang, "Soft Variable Structure Control for Sealing Temperature of Bag Making Machine," 2007 IEEE International Conference on Control and Automation, Guangzhou, China, 2007, pp. 720-723.
[25] T. Wei and S. Xiangbo, "Selection of Optimal Packaging Methods for Different Food Based on Big Data Analysis," 2020 IEEE International Conference on Power, Intelligent Computing and Systems (ICPICS), Shenyang, China, 2020, pp. 558-561
[26] J. Gausemeier, S. Moehringer, VDI 2206- A New Guideline for the Design of Mechatronic Systems, IFAC Proceedings Volumes, Volume 35, Issue 2, 2002, Pages 785-790, ISSN 1474-6670, https://doi.org/10.1016/S1474-6670(17)34035-1.
[27] Davidson, I. (2018). Biscuit, cookie and cracker production: process, production and packaging equipment. Academic Press, 2018.
[28] Nuttall, A. J. G. (2007). Design aspects of multiple driven belt conveyors (No. Trail Thesis Series T2007/12). Delft, The Netherlands: TRAIL Research School.
[29 American National Standar, "Medium Density Fiberboard (MDF) For Interior Applications. ANSI A208.2", [Online]. Available: https://www.txsmartbuy.com/ShopFlow/Documents/Contract%20Attachments/ANSIA208.2-2002MDF.pdf
[30]AliExpress [Online]. Available: https://es.aliexpress.com/item/1005005954709565.html?spm=a2g0o.productlist.main.21.