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ING. MECATRÓNICA

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DESIGN AND CONSTRUCTION OF A MIXING AND DOSING MEAT MACHINE FOR BURGERS THAT IMPLEMENTS AN ARTIFICIAL VISION SYSTEM FOR QUALITY CONTROL

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CERTIFICATE OF AUTHORSHIP

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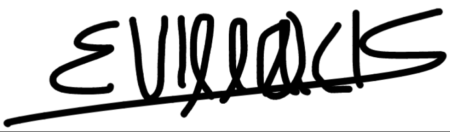

Eduardo Miguel Villacís Santamaría

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I would like to acknowledge my parents, Henry and Maria, for guiding and motivate me throughout this journey, but above all, for teaching me that in life anything is possible with hard work.

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1. General Information of the Project

1.1. Title

DESIGN AND CONSTRUCTION OF A MIXER AND DOSING MACHINE FOR MEAT FOR HAMBURGERS THAT IMPLEMENTS AN ARTIFICIAL VISION SYSTEM FOR QUALITY CONTROL.

1.2. Technical requirements of the project

The proposed mixing and dosing machine integrates the characteristics of already existing machines for mixing and dosing. Is good to mention that there is not a machine for both activities.
The requirements that the company Hambus Grill presents are:

- Generate a homogeneous mixture between the meat and spices and dose the meat in equal portions in the shape of a hamburger.
- Make a modular machine, this meanse, that is capable of being disassembled. Facilitating the cleaning process of the machine.
- Generate a machine that has a lower cost between the machines that are already in the market (around $6000 - 12000\mathrm{USD}$ for Dosing machines and $600 - 1600\mathrm{USD}$ for mixing machines).
- Generate a machine that implement a manual and a semi-automatic mode for operation.
- Implement an artificial intelligence algorithm for measure de area of the dosed meats as a quality control algorithm.

2. Analysis of Alternatives

As there is a wide diversity of alternatives to meet the same objective, this analysis is carried out, which allows visualizing the most convenient options for the project.

2.1. Dosage Mechanisms

For the analysis of the design of the machine, the following alternatives of Hamburger meat dispensers machines/mechanisms already existing in the market are considered.

Pneumatic hamburger meat dispenser

The dispenser that can be seen in Figure 1, requires a compressor along with an electric motor to work. On the one hand, the electric motor is in charge of moving the conveyor belt and on the other hand, pneumatic pistons are used to expel each hamburger meat out of the mold and then proceed to pack them. This machine/mechanism only doses meat, its production is twenty two hamburgers per minute, it is not compact due to its dimensions $(144 \cdot 60 \cdot 140\mathrm{cm})$ and its price is around $7000\mathrm{USD}$.

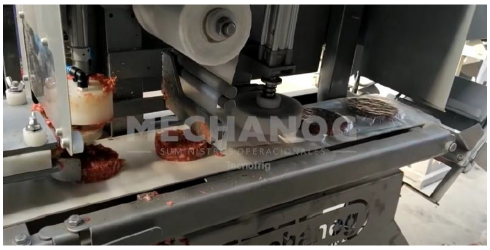

Figure 1. Pneumatic meat dispenser for hamburger meat [1]

Gesame brand hamburger meat dispenser

The dispenser that can be seen in Figure 2, requires an electric motor to work. This electric motor is responsible for stuffing the meat mixture into the molds to be later expelled by its rollers. This machine/mechanism only doses meat, its production is thirty hamburgers per minute, it is compact due to its dimensions $(150 \cdot 50 \cdot 65\mathrm{cm})$ and its price is around $7500\mathrm{USD}$.

Wedderburn automatic meat dispenser

The dispenser that can be seen in Figure 3, requires an electric motor to work. In this case, the blades that this design has are responsible for stuffing the meat into the mold and then it falls onto the conveyor belt. This machine/mechanism only doses meat, its production is thirty hamburgers per minute, it is compact due to its dimensions

Figure 2. Gruen brand hamburger meat dispenser [2]

$(62 \cdot 52 \cdot 59\text{cm})$ and its price is around 7000USD. In Table 1 the weighted criteria matrix is shown.

Figure 3. Wedderburn automatic meat dispenser [3]

Table 1. Weighted criteria matrix

Characteristic	Value
Very bad	1
Bad	2
Normal	3
Good	4
Very good	5

Table 2. Weighted criteria matrix of mecanisms

Criteria					
Simplicity	**Efficiency**	**Speed**	**Cost**	**Score**	**Mechanism**
2	3	3	2	**10**	1
2	3	4	2	**11**	2
3	4	4	3	**14**	3

After analyzing the Table 2, which shows the criteria matrix of Machines/Mechanisms, it can be clearly seen that the Wedderburn automatic meat dispenser is the alternative with the highest score, so this design is the one that will be implemented.

2.2. Mixture systems

Since the machine needs to mix, the following alternatives are considered.

Mobile Mixers

As shown in Figure 4, it consists of a casing of different geometries, whether cylindrical, cubic or conical. The casing is mounted on an axis that when rotated on it the mixing is generated. In the upper part of the casing there is a gate that serves for the entry of raw materials and by the action of overturning and gravity, the finished product goes out to the containers for its dosage.

Figure 4. Cilindric Mixer [4]

Helical ribbon mixer

They have a central cylindrical structure, inside which there is a belt agitator, generally they have two helical belts in the opposite direction that are mounted on an axis that will give them movement as shown in Figure 5. The outer belt produces an axial movement, and the second generates a radial movement. When these movements are generated, turbulence is produced that leads to the mixing of the raw materials.

Figure 5. Helical ribbon mixer [5]

Paddle mixer

It is a high homogeneity mixer and is probably the longest-lived mixer consisting of one or more horizontal, vertical, or inclined paddles attached to a horizontal, vertical, or inclined shaft that rotates axially within the bowl. In this way the material to be mixed is pushed or pulled around the container following a circular path.

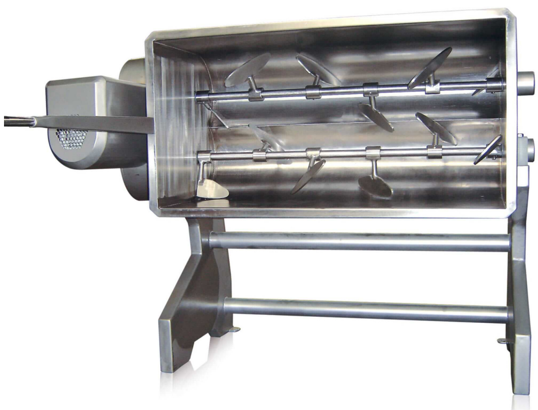

Figure 6. Paddle mixer [6]

Table 3. Weighted criteria matrix of Mixture systems

Criteria					
Simplicity	**Efficiency**	**Speed**	**Cost**	**Score**	**Mechanism**
2	3	3	2	**10**	1
2	3	4	2	**11**	2
5	4	4	3	**16**	3

After analyzing the Table 3, which shows the criteria matrix of Mixture systems, it can be clearly seen that the Paddle mixer is the alternative with the highest score, so this design is the one that will be implemented.

3. Mechatronic Design

A 3D design of the mixing and dosing machine is made taking into consideration the project requirements. This can be seen in Figure 7 and Table 4 details its main components.

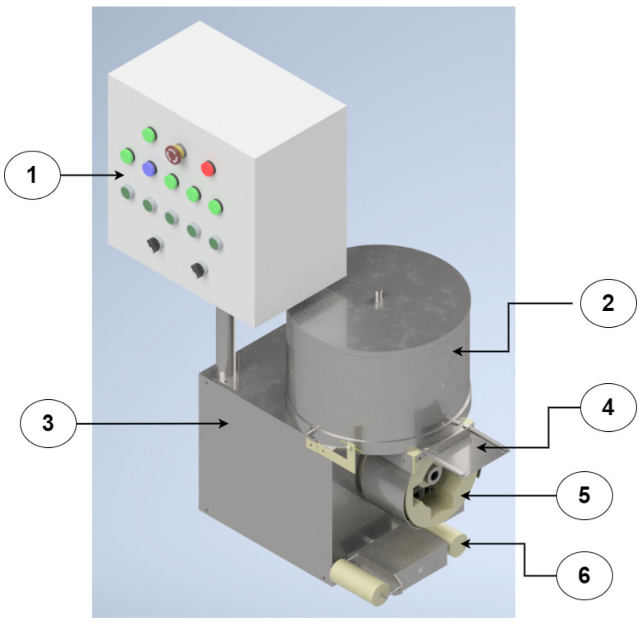

Figure 7. Mixing and dosing machine

Table 4. Main components of the mixer and Dosage machine

Number	Description
1	Electronic cabinet
2	Mixing cylinder
3	Structure
4	Gate system
5	Dosing cylinder
6	Conveyor belt

3.1. Mechanical Design

Material Selection

The key goal in the food industry is hygiene, as good grooming and hygiene practices prevent cross-contamination and prevent the spread of viruses and other foodborne illnesses.
That is why the European Union, through Regulation 21935/2004/EC, establishes the basic requirements for the handling of materials and objects that are in contact with food [7] and due to its characteristics, stainless steel meets all the necessary requirements to ensure compliance with food safety standards.

In [8] it is mentioned that in the food industry stainless steel has become an essential material. The benefits that stainless steel brings to food processes are:

- Highly corrosion resistant material.
- Its surface is slightly rough and compact.
- High resistance to thermal variations.
- Highly resistant to shock and mechanical stress.
- It can be cleaned without altering the material, facilitating its disinfection.
- It is not covered by any protector that degrades easily.

Depending on the environment and characteristics of the product to be made is how the steel is chosen. Taking into account the aforementioned, the following alternatives are presented:

AISI 304

Stainless steel is characterized by having an extra amount of chromium unlike other steels that commonly only have iron and carbon materials as their composition. In this case, 304 steel is characterized by having small amounts of manganese and carbon, between twenty four and sixteen percent of chromium, and a maximum of thirty-six percent of nickel. In Figure 8 the properties of the previously mentioned material are presented.

Property	Value
ρ Density [kg.m^{-3}]	7896
ν Poisson's ratio	0,25
E Elastic Modulus [MPa]	193
T_m Melting Temperature [K]	1811
T_0 Test Temperature [K]	300
Johnson-Cook parameters:	
A [MPa]	350
B [MPa]	275
C	0.022
N	0.36
M	1
$\dot{\varepsilon}_0$ [s^{-1}]	1

Figure 8. Mechanical properties of AISI 304 [9]

AISI 430

In this case, the 430 ferritic steel contains a small composition of carbon, demonstrating resistance to corrosion at high temperatures. In Figure 9 the properties of the previously mentioned material are presented.

Material	*Ultimate Tensile Strength (UTS), MPa*	*Yield Strength (YS), MPa*	*Percentage of elongation, (% El)*	*Impact Toughness, J*	*Fusion zone hardness, Hv*
Base material (AISI 430 ferritic stainless steel)	424	318	13	22	220

Figure 9. Mechanical properties of AISI 430 [10]

AISI 316

In this case, 316 steel contains a composition similar to 304 with the difference that quantities of two to three percent of molybdenum are added, generating greater resistance to chlorides. In Figure 10 the properties of the previously mentioned material are presented.

AISI 316 Stainless Steel		
Yield Strength	205	Mpa
Ultimate Tensile	515	Mpa
Density	8000	Kg/m^3
Elastic Modulus	193	Gpa

Figure 10. Mechanical properties of AISI 316 [11]

Grilon

In this case, the grilón polyamide is obtained by mixing polyamide 6 and polyamide 66. This material is capable of resisting chemicals, chlorides and has good resistance to electricity. In Figure 11 the properties of the previously mentioned material are presented.

Property	**Value**
Density g/cm^3	1.14
Tensile modulus of elasticity MPa	3200
Tensile strength at break by elongation %	70
Fusion Temperature C	220

Figure 11. Mechanical properties of Grilon [12]

This time 304 stainless steel was chosen due to its excellent corrosion resistance, value and availability in the market. This can resist corrosion from the most oxidizing acids, its durability makes it easy to disinfect and ideal for the food industry.

On the other hand, the grilon was used for the pieces that do not support large mechanical loads and because in [13] it mentions that it has the following characteristics:

- High strength and stiffness.
- High impact strength.
- Good abrasion and surface slip (friction) properties.
- Resistance to many chemicals.

- Good electrical properties.
- Economic processin.

Mixing and Dosing motor selection

The sizing of the motor is important for the project since it transforms electrical energy into mechanical energy, that is, it will move the axis where the blades are located with the purpose of mixing and dosing. The presence or absence of turbulence in an agitated fluid can be related to the Reynolds number and its expression for the case of agitators is the one presented in (1) [14].

$$nRe = p * N * \frac{D^2}{u} \tag{1}$$

Where:

nRe : Number of Reynolds, dimensionless.

p : Density of meat, in $\frac{\mathrm{kg}}{\mathrm{m}^3}$.

N : Paddle speed, in $\frac{\mathrm{rev}}{\mathrm{s}}$.

D : Paddle diameter, in m.

u : Substance viscosity of meat, in $\frac{\mathrm{kg}}{\mathrm{m*s}}$.

$$nRe = 1000 * 0.27 * \frac{0.35^2}{20}$$

$$nRe = 1.65$$

As the Reynolds number is less than three hundred, is a laminar transient fluid and to obtain the power it is determined by (2) [14]. Using the table of constants KL or KT depending on the impeller [14] the value of KL can be obtained depending on the type of vanes used.

$$P = KL * N^2 * D^3 * u \tag{2}$$

Where:

P : Power of the mixing and dosing motor, in HP.

KL : Constant of the impeller, dimensionless.

$$P = 36.5 * 0.27^2 * 0.35^3 * 20$$

$$P = 2.28\text{W} = 0.003057\text{HP}$$

Taking into account the previously mentioned, the motor needs to follow this requirements:

- Speed of 1700rpm.
- Power of 0.003057HP.
- Low cost.

The following alternatives are presented:

Alternative 1

It is a WEG brand electric motor with three phases, it has a power of $1/4\text{HP}$, 1700RPM, works with $110/220\text{VAC}$ and has a cost of 150USD. [15].

Alternative 2

It is a WEG brand electric motor with three phases, it has a power of $1/2\text{HP}$, 1800RPM, works with $220/440\text{VAC}$ and has a cost of 175USD. [15].

Alternative 3

It is a Hercules brand electric motor with three phases, it has a power of 1HP, 1755RPM, works with $220/440\text{VAC}$ and has a cost of 210USD. [15].

As there are no 0.003057HP motors, low cost, matching speed and the local availability. The motor selected was the first alternative and is also shown in Figure 12.

Conveyor Belt motor selection

As the name suggests, conveyor belts help transport products from one stage of the production process to another. In the project, the conveyor belt helps transport the already dosed meat to a container or an operator who stores it.

Figure 12. WEG Motor selected [15]

Mass of the conveyor belt

To know the weight of the conveyor belt, (3) is used.

$$m_c = L * W * T * p_c \tag{3}$$

where:

m_c : Mass of the conveyor belt, in kg.

L : Length of the conveyor belt, in m.

W : Width of the conveyor belt, in m.

T : Thick of the conveyor belt, in m.

p_c : Density of the conveyor belt, in $\frac{\mathrm{kg}}{\mathrm{m}^3}$.

$$m_c = (0.35 + 0.05 * 2) * 0.12 * 0.0014 * 1746$$

$$m_c = 0.132\mathrm{kg}$$

Mass on the conveyor belt

The maximum dosage of the machine is seventeen meats per minute, that is to say that two is the maximum number of meats that can be on the belt at the same time. Taking into account the aforementioned, (4) is used to get the maximum weight that will exist on the band.

$$m_b = N_m * m_m \tag{4}$$

where:

m_b : Mass on the Belt, in kg.

N_m : Number of meats, dimensionless.

m_m : Mass of the meat, in kg.

$$m_b = 2 * 0.1\mathrm{kg}$$

$$m_b = 0.2\mathrm{kg}$$

Linear Velocity of the conveyor belt

As the maximum dosage of the machine is seventeen meats per minute, the linear speed is required to be at least $2.06\frac{\mathrm{m}}{\mathrm{min}}$, so that two meats do not collide at the time of dosing. Using the linear velocity of (5) [16], the motor rpm is obtained.

$$V_1 = w_1 * \pi * D_1 \tag{5}$$

where:

V_1 : Linear Velocity of the conveyor belt, in $\frac{m}{s}$.

w_1 : Angular velocity of the conveyor belt, in $\frac{\mathrm{rev}}{\mathrm{min}}$.

D_1 : Diameter of the roller, in m.

$$2.06 = w_1 * \pi * 0.05$$

$$w_1 = 14\frac{\mathrm{rev}}{\mathrm{min}}$$

Required Pull

To calculate the required torque, the coefficient of friction of the band is used [17], which must be multiplied by the sum of the weight of the band together with that of the material it is going to carry as (6) shows.

$$P_r = \sum m * u_b \tag{6}$$

where:

P_r : Require pull, in kg.

$\sum m$: Mass of the conveyor belt plus the Mass on the conveyor belt, in kg.

u_b : Coeficcient of friction of the band, dimensionless.

$$P_r = (0.132 + 0.2) * 0.5$$

$$P_r = 0.166\mathrm{kg}$$

In order to finally obtain the power of the motor, (7) is used.

$$P_2 = P_r * w_1 \tag{7}$$

where:

P_2 : Require power, in $\frac{\mathrm{m*kg}}{\mathrm{min}}$.

$$P_2 = 0.166 * 5.4$$

$$P_2 = 0.9\frac{\mathrm{m*kg}}{\mathrm{min}}$$

Taking into account the previously mentioned, the component needs to follow this requirements:

- Power of $0.9\frac{\mathrm{m*kg}}{\mathrm{min}}$.
- Speed of $14\mathrm{rpm}$.
- Operating voltage of $5\mathrm{VDC}$ or $12\mathrm{VDC}$.
- Low cost.

Taking into account the aforementioned, the following alternatives are presented:

Alternative 1

It is a Greartisan gearbox electric motor with an output eccentric shaft, it has a power of $0.5\frac{\mathrm{m*kg}}{\mathrm{min}}$, a velocity of $50\mathrm{rpm}$, works with $12\mathrm{VDC}$ and has a cost of $20\mathrm{USD}$ [18].

Alternative 2

It is a Greartisan gearbox electric motor with an output eccentric shaft, it has a power of $2\frac{\mathrm{m*kg}}{\mathrm{min}}$, a velocity of $10\mathrm{rpm}$, works with $12\mathrm{VDC}$ and has a cost of $22\mathrm{USD}$ [18].

Alternative 3

It is a Greartisan gearbox electric motor with an output eccentric shaft, it has a power of $1.5\frac{\mathrm{m*kg}}{\mathrm{min}}$, a velocity of $30rpm$, works with $12\mathrm{VDC}$ and has a cost of $18\mathrm{USD}$ [18].

Due to availability and price, the alternative 3 was chosen since it has $30rpm$ and $1.5\frac{\mathrm{m*kg}}{\mathrm{min}}$ of power and is also shown in Figure 13.

Figure 13. Greartisan Motor selected [18]

Shaft safty factor

In order to obtain the safety factor of the axis that transmits movement to the blades and to the dosing cylinder, the value of the torque produced by the meat on the blades must be obtained with (8).

$$T_{\mathrm{Meat}} = m_{\mathrm{met}} * a * d \quad (8)$$

where:

T_{Meat} : Torque produced by meat, in $\mathrm{N*m}$.

m_{meat} : Mass of the meat, in kg.

a : Gravitational acceleration, in $\frac{m}{s^2}$.

d : Length of the palettes from the radius, in m.

$$T_{meat} = 5 * 9.81 * 0.1735$$

$$T_{meat} = 8.51\mathrm{N*m}$$

Then the torque of the motor that mix and dosage is obtained in (9).

$$T_{\mathrm{Motor}} = \frac{P_{\mathrm{Motor}}}{V_{\mathrm{motor}}} \quad (9)$$

where:

T_{Motor} : Torque of the motor that mix and dosage, in $\mathrm{N*m}$.

P_{Motor} : Power of the motor that mix and dosage, in W.

V_{motor} : Velocity of the motor that mix and dosage, in $\frac{\mathrm{rad}}{\mathrm{s}}$.

$$T_{motor} = \frac{186.5}{1.78}$$

$$T_{motor} = 104.78\mathrm{N*m}$$

The torque of the motor will be considered as the maximum since the torque of the motor is bigger than the torque produce by meat. To get the the maximum shear stress (10) is used.

$$\tau_{max} = \frac{16 * T_{max}}{\pi * d_s^3} \tag{10}$$

where:

τ_{max} : Maximum shear stress, in Pa.

d_s : Diameter of the shaftn, in m.

$$\tau_{max} = \frac{16 * 104.78}{\pi * 0.02^3}$$

$$\tau_{max} = 5.76 * 10^7\mathrm{Pa}$$

To get the safty factor (11) is used.

$$FS = \frac{Syt}{\tau_{max}} \tag{11}$$

where:

$FS =$: Safty factor of the shaft, dimensionless.

Syt : Yield point of AISI 304, in MPa.

$$\mathrm{FS} = \frac{2.35 * 10^8}{5.76 * 10^7}$$

$$\mathrm{FS} = 4.08$$

Analysis of material of the gears for bending strength

To know if the material of the gears is suitable from the bending strength point, the process is the following. All the information of the gears presented in Figure 14.

Parameter	Value
d=pitch diamter	45mm
P= diametral pitch	666.66 teeth/m
N= number of tooth	30
Pitch angle	45
Kf= fatigue stress concentration factor	1.5
b= Face Width	10 mm
r avg= pitch radius	22.5 mm
Pressure angle	20

Figure 14. Gear parameters [19]

To get the force in the gear, the torque of the motor is needed as shown in (12).

$$T_M = \frac{P_M}{N_{\mathrm{M2}}} \tag{12}$$

where:

T_M : Torque of the motor, in $\mathrm{N} * \mathrm{m}$.

P_M : Power of the mixing and dosing motor, in W.

N_{M2} : Speed of the mixing and dosing motor, in $\frac{\mathrm{rad}}{\mathrm{s}}$.

$$T_M = \frac{\frac{1}{4} * \frac{745.7}{1}}{17 * \frac{2*\pi}{1} * \frac{1}{60}}$$

$$T_M = 104.71\mathrm{Nm}$$

In [20], says that the transmitted tangential load could be express as in (13).

$$F_T = \frac{T_M}{r_{\mathrm{avg}}} \tag{13}$$

where:

F_T : Tangential load, in N.

r_{avg} : Pitch radius average, in m.

$$F_T = \frac{104.71\ \mathrm{Nm}}{0.0225\mathrm{m}}$$

$$F_T = 4653.77\mathrm{N}$$

To get the axial and radial reactions of the force is necessary to use (14) and (15).

where:

F_a : Axial force, in N.

F_r : Radial force, in N.

ϕ : Pressure angle, in degrees.

α : Pitch angle, in degrees.

$$F_a = F_T * \tan(\phi) * \sin(\alpha) \tag{14}$$

$$F_a = 4653.77 * \tan(20) * \sin(45)$$

$$F_a = 1197.72\mathrm{N}$$

$$F_r = F_T * \tan(\phi) * \cos(\alpha) \tag{15}$$

$$F_r = 4653.77 * \tan(20) * \cos(45)$$

$$F_r = 1197.72\mathrm{N}$$

To discuss the suitability of the chosen material from the bending strength point of view (16) is needed.

$$F_b = \frac{\sigma_o * b * Y}{k_f * P} \tag{16}$$

where:

F_b : Allowable bending load, in N.

σ_o : Allowable static bending stresses for Lewis equation, in MPa.

k_f : Fatigue stress concentration factor, adimentional.

Y : Lewis factor for a gear of 30 tooth, adimentional.

b : Face width of the gear, in m.

P : Diametral pitch of the gear, in $\frac{\mathrm{tooth}}{\mathrm{m}}$.

$$F_b = \frac{221 * 10^6 * 0.1 * 0.358}{1.5 * 666.66}$$

$$F_b = 7911.87\mathrm{N}$$

To get the dynamic load (17) is used.

$$F_d = \frac{600 + 0.16}{600} * F_T \tag{17}$$

where:

F_d : Dynamic load, in N.

$$F_d = 4655.07\text{N}$$

Since $F_b \geq F_d$ the chosen material is suitable from the bending strength point of view.

3.2. Electronic Design

The electronic design covers the selection and sizing of the various electronic components that are going to be used in the machine. The architecture of the electronic component of the machine is presented in the Figure 15.

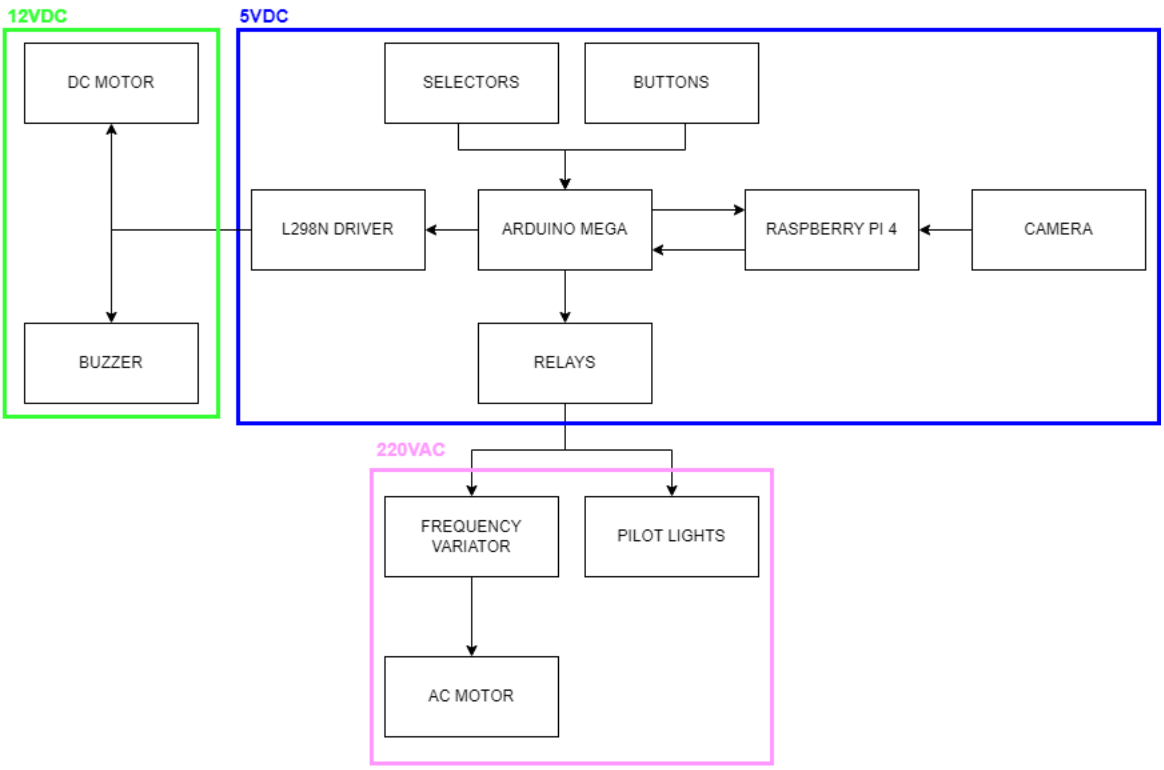

Figure 15. The architecture of the electronic components

Selection of Frequency Variator

A frequency inverter is a precision electrical element which seeks the rotation and speed of motors of one or three phases with alternate current, seeking not to affect the torque, speed, consumption, etc. of the motor. A frequency inverter is needed with the following requirements:

- Ability to control a three-phase motor.
- Ability to control motor spin.
- Ability to set two constant speeds.
- Motor power is $1/4\mathrm{HP}$.
- Motor current consumption is $1\mathrm{A}$.
- The motor works at $60\mathrm{Hz}$.

Taking into account the previously mentioned requirements, the following alternatives are taken into account.

Alternative 1

The WEG Cfw100 model is a variable frequency drive for $2\mathrm{HP}$, three-phase motor, spin control, load capacity of $3\mathrm{A}$, maximum frequency of $50-70\mathrm{Hz}$, three speed selection, and price of $380\mathrm{USD}$ [21].

Alternative 2

The Siemens 6SL3210-5BB17-5BV1 model is a variable frequency drive for three-phase motor up to $1\mathrm{HP}$, spin control, load capacity of $1\mathrm{A}$, maximum frequency of $47-63\mathrm{Hz}$, two speed selection and a price of $750\mathrm{USD}$ [21].

Alternative 3

The ABB ACS150 model is a variable frequency drive for three-phase motor up to $1\mathrm{HP}$, spin control, load capacity of $2\mathrm{A}$, maximum frequency of $30-60\mathrm{Hz}$, two speed selection and a price of $340\mathrm{USD}$ [21].

The ACS150 drive is shown in Figure 16 and was selected because is compact, available, easy to control and is compatible with the threephase motor selected and has an easy connection.

Figure 16. Frequency Variator [22]

Selection of Pilot lights

Pilot lights are a commonly used device in the industry since they are used to signal any type of process. For the machine 7 lights are needed, 1 indicates power on, 1 indicates emergency, 2 indicates operation mode and 3 to indicate which part of the process it is in. Taking into account the previously mentioned, pilot lights are needed that meet the following requirements:

- Operating voltage 220VAC.
- Suitable size for industrial use.
- Low current consumption.

Alternative 1

CAMSCO brand pilot light of 10mm in diameter that works at $110\text{VAC} - 220\text{VAC}$, consumes 0.12mA an its price is 1.40USD [23].

Alternative 2

CAMSCO brand pilot light of 22mm diameter that works at $110\text{VAC} - 220\text{VAC}$, consumes 0.098mA an its price is 1.70USD [23].

Taking into account the previously mentioned, alternative 2 is chosen since it is bigger, the difference in price is small, fulfill the requirements and is shown in Figure 17.

Selection of Relay Module

A relay is an electromagnetic component that by using a small signal helps to close or open a circuit with greater power. It is used because the five 24VDC digital inputs of the

Figure 17. Pilot light [23]

frequency inverter are used to start/stop, rotate clockwise or counterclockwise, select between speed 1 or speed 2, control acceleration and also because its needed to turn on the pilot lights. The pilot lights, unlike the inputs of the frequency inverter, work with 220VAC. Taking into account the previously mentioned, the component needs to follow this requirements:

- Operating voltage of 5VDC.
- Voltages capacity of 24VDC or 220VAC.
- 4 Operation channels and 6 operation channels.

The following relay alternatives are proposed:

Alternative 1

4 Channel Relay Module,it has an operating voltage of 5VDC, a maximum capacity of $10\text{A}/30\text{VDC}$ and have a maximum current of 10A (NO), 5A (NC) [24].

Alternative 2

6 Channel Relay Module,it has an operating voltage of 5VDC, a maximum capacity of 10A/250VAC and have a maximum current of 10A (NO), 5A (NC) [24].

Taking into account the above, both alternatives are chosen since the 4-channel relay module is used to control the frequency inverter and the 6-channel relay module for turning on and off the pilot lights that work at 220VAC and is presented in Figure 18.

Selection of Microcontrollers

To control the machine, a controller or a micro-controller is required, which has inputs and outputs that help execute commands stored in its memory. Taking into account the previously mentioned, the component needs to follow this requirements:

- 8 Digital inputs.

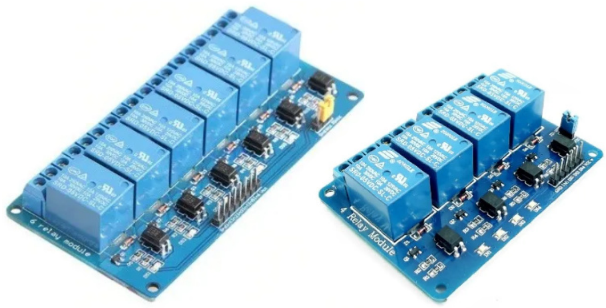

Figure 18. Relay of 4 channels at the right and Relay of 6 channels at the left [24]

- 10 Digital outputs.
- 2 Analog output.
- Open cv library compatibility.
- Operating voltage of $5\mathrm{VDC}$ or $12\mathrm{VDC}$.

Taking this into account, the following alternatives are presented:

Alternative 1

Arduino Mega has 54 digital and analog input and output pins, is small, it has a USB-B port for serial communication, works with $12\mathrm{VDC}$, is open source and has a low cost of $26\mathrm{USD}$ [25].

Alternative 2

A Raspberry PI 4 is a small computer, has $1\mathrm{Gb}$ of RAM ideal for compute vision, works with $5\mathrm{VDC}$, serial communication can be achieved, allows to install operating systems and connect peripheral devices such as cameras [25].

After analyzing the alternatives, both microcontrollers were chosen since Arduino MEGA, helps to control the machine by implementing the manual and semi-automatic process of mixing and dosing, and the Raspberry pi4 since all the mentioned qualities make the the best microcontroller to handle computer vision with a low cost (80 USD). In Figure 19 Raspberry pi 4 at the left and Arduino Mega at the Right are presented.

Selection of Breaker

A prevention for not harm people and to protect the electronic components of the circuit in the machine is the circuit breaker. This electric device acts without human supervi-

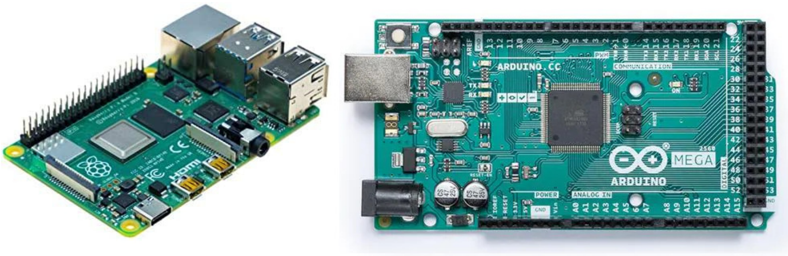

Figure 19. From left to Rigth, Raspberry Pi4 and Arduino MEGA [25]

sion and removes the current over the circuit. To be able to choose this component, the Table 5 must be carried out, in which the voltage and current consumption of each component are reflected.

Table 5. AC Voltage and AC current consumption

Component	Quantity	Voltage	Current	Total Current
Pilot Light	7	220VAC	0.014 A	0.098
Frequency Variator	1	220VAC	4.7 A	2.7
Power Supply	1	220VAC	10 A	10
Three-phase motor	1	220VAC	1 A	1
TOTAL				13.8 A

Taking into account the aforementioned, the component must meet these requirements:

- Pole numbers of 2.
- Rated current of $14.8\mathrm{A}$.
- Operating voltage of $220\mathrm{VAC}$.
- Industrial line.
- Din rail mount.

The following alternatives are proposed:

Alternative 1

SIEMENS breaker of SENTRON line, model 5SL3 201-7, 2 pole, $1\mathrm{A}$, for DIN rail, with type C trip curve and $400\mathrm{VAC}$ working voltage [26].

Alternative 2

Siemens breaker of SENTRON line, model 5SL3232-7MB, 2 pole, $32\mathrm{A}$, trip curve C and $220\mathrm{VAC}$ working voltage [26].

Alternative 3

Schneider breaker model SCH-EASY9216, 2 pole $16\mathrm{A}$, for DIN rail, trip curve C and $220\mathrm{VAC}$ working voltage [26].

After analyzing the alternatives, it is concluded that alternative 3 is the best since it is closer to the maximum total current of the machine, fulfills the requirements and is shown in Figure 20.

Figure 20. Circuit Breaker [26]

Selection of Power Supply

The power source is responsible for transforming alternate current to direct and at the same time decreasing the voltage, commonly to $5\mathrm{VDC}$ or $12\mathrm{VDC}$. To be able to choose this component, the Table 6 must be carried out, in which the voltage and current consumption of each component are reflected. Taking into account the aforementioned,

Table 6. DC Voltage and DC current consumption

Component	Quantity	Voltage	Current	Total Current
DC Motor 26101200	1	12VDC	0.1 A	0.1 A
Arduino Mega	1	12VDC	0.08 A	0.08 A
L298N	1	12VDC	0.036 A	0.036 A
Buzzer	1	12VDC	0.02 A	0.02 A
Camera	1	5VDC	0.015 A	0.015 A
Raspberry Pi4	1	5VDC	3 A	3 A
Stepdown	1	5VDC	0.02 A	0.02 A
Relay Module 4CH	1	5VDC	0.06 A	0.06 A
Relay Module 6CH	1	5VDC	0.08 A	0.08 A
Selectors	2	5VDC	0.01 A	0.02 A
Buttons	5	5VDC	0.01 A	0.05 A
TOTAL				3.5A

the component must meet these requirements:

- Input voltage of $220\mathrm{VAC}$.
- Output voltage of $12\mathrm{VDC}$.
- Supplied current of $3.5\mathrm{A}$.

The following alternatives are proposed:

Alternative 1

Speedmind power supply has an input voltage of $110\mathrm{VAC}$, an output of $12\mathrm{VDC}$, provides a maximum of $28\mathrm{A}$ and costs $20\mathrm{USD}$ [27].

Alternative 2

Power source for CCTV has an output of $12\mathrm{VDC}$, input voltage of $110\mathrm{VAC}$, provides a maximum of $5\mathrm{A}$ and costs $15\mathrm{USD}$ [27].

Alternative 3

Metallic power source for Cctv has an output of $12\mathrm{VDC}$, provides a maximum of $10\mathrm{A}$, input voltage of $220\mathrm{VAC}$ and costs $8\mathrm{USD}$ [27].

Taking into account the previously mentioned, alternative 3 is chosen since it is the one with the lowest cost and provides the required voltage and current and is presented in Figure 21.

Figure 21. 12VDC 10A selected power supply [27]

Selection of Buttons

A button is a device that seeks to generate an electrical signal when pressed or depressed. This signal is interpreted by the micro-controller of the project and helps to control the machine. In this case, 2 buttons are needed for manual mode and 3 for automatic mode.Taking into account the aforementioned, the component must meet these requirements:

- Operating voltage of $5\mathrm{VDC}$.
- Suitable size for industrial use.
- Normally open.

The following alternatives are presented:

Alternative 1

Industrial push button of $11\mathrm{mm}$ of diameter, operating voltage up to $300\mathrm{V}$, normally open and has a cost of $2.50\mathrm{USD}$ [27].

Alternative 2

Industrial push button of $20\mathrm{mm}$ of diameter, normally open, operating voltage up to $300\mathrm{V}$ and has a cost of $1.50\mathrm{USD}$ [27].

Taking into account the previously mentioned, alternative 2 is chosen since it is for industrial use, is normally open, meets the required voltage and is presented in Figure 22.

Figure 22. Button selected [27]

Selection of control elements

If there is the need of keeping a digital input stable, selectors are the best option. These have 2 or more positions that can be kept stable and in the case of wanting to change position, the component just need to be rotated. As it is required to be able to select between on/off and between the manual and semi-automatic modes. Taking into account the aforementioned, the component must meet these requirements:

- Operating voltage of 5VDC.
- Suitable size for industrial use.
- Ensure interlock activation.

The following alternatives are proposed:

Alternative 1

Schneider selector with 2 positions, operating voltage up to 300V, 22mm diameter, normally open and cost of 1.4USD [28].

Alternative 2

Schneider selector with 3 positions, operating voltage up to 300V, 22mm diameter, normally open and cost of 1.6USD [28].

Taking into account the previously mentioned, both alternatives are chosen since one selector is need for ON/OFF (selector of two positions) and another is needed for the manual and semi-automatic mode (selector of three positions and one position is used as rest position) and is presented in Figure 23.

Figure 23. Selector [28]

Selection of Electric cabinet

The electrical cabinet is in charge of storing all the electronic components, connection, signaling, protection and help the electrical installation work in the best way. To size the electrical cabinet, each element previously described must be measured and arranged in such a way that space is optimized, in this way it was decided that a board with dimensions $40 \cdot 40 \cdot 20\text{cm}$ was needed. Taking into account the aforementioned, the component must meet these requirements:

- Dimensions of $40 \cdot 40 \cdot 20\text{cm}$.

- Capacity to put Din mounts.
- Interior use.

The following alternatives are presented:

Alternative 1

Metal cabinet of $40 \cdot 30 \cdot 20\mathrm{cm}$, for interior use, din mount capability, made of carbon steel and costs $45\mathrm{USD}$ [29].

Alternative 2

Metal cabinet of $40 \cdot 40 \cdot 20\mathrm{cm}$ for interior use, din mount capability, made of carbon steel and costs $50\mathrm{USD}$ [29].

Taking into account the previously mentioned, the second option is chosen since it adapts to our needs and the difference in costs is not high. The electrical cabinet selected is presented in Figure 24.

Figure 24. Electrical cabinet selected [29]

3.3. Software Development

Operating modes

The machine has manual and automatic as operating modes and the algorithm that the machine use to work is presented in Figure 25.

Manual: The operator decides whether to mix or dose for as long as he wishes, also in the event of an emergency he can crush the emergency stop and thus the machine would stop at that moment.

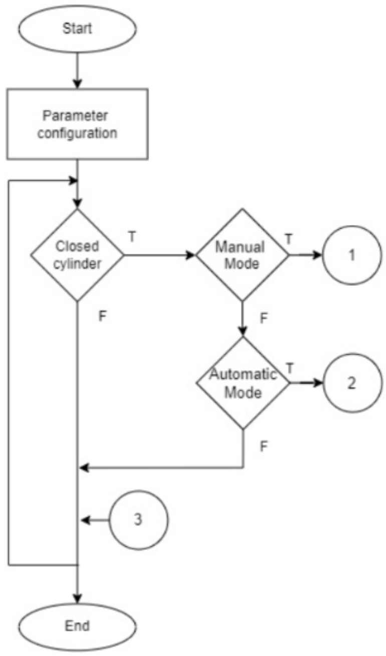

Figure 25. Architecture of the machine algorithm

Automatic: The operator only has to take care of adding the ground meat and spices in the mixing cylinder, the rest is taken care of by the machine by pressing the start button. When the previously mentioned button is pressed, the machine begins to mix for a certain time, when it is finished, a buzzer is turned on and the gate pilot light comes on, which indicates that the gate must be pulled and the respective button pressed. When pressed, the pilot light and the buzzer go off and the dosing process begins and hamburger meats begin to be produced with a width of $10\mathrm{cm}$ and a weight regulated by the operator. As with the previous mode, in the event of an emergency, you can crush the emergency stop and thus the machine would stop at that moment.

Quality control

For quality control, the computer vision algorithm uses the architecture of Figure 26 in which reference points are obtained in virtual reality by using well-known markers with the name of aruco, in the following application the mentioned markers define distance patterns between an object and the camera with which one seeks to measure objects. At the moment of carrying out the aforementioned, a problem occurs and that is that the distance between a camera and the object to be measured is not known, causing the objects closest to the camera to be larger than the objects furthest from the camera.

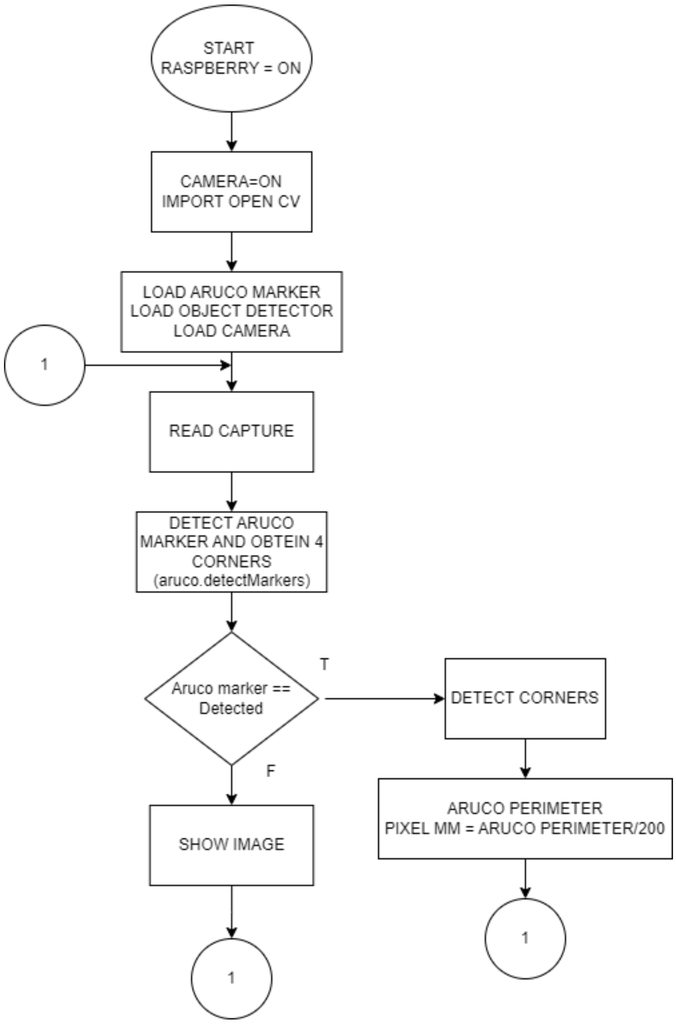

Figure 26. Architecture of the computer vision algorithm

For the implementation of the algorithm, the Python library "Open-cv" will be used, which helps to carry out computer vision exercises in real time, besides being very famous, it is very easy to use. The NumPy library will also be used, which helps the user to handle large vectors or multi-dimensional matrices with high-level mathematical operations.

The program used begins by loading a program for the detection of objects, in which a binary mask is created that differentiates the homogeneous background of the objects to be measured. In this case the background is white due to the color of the conveyor belt and whatever has a different color will be detected as an object. Contours are defined and a list is created, so that with a loop you can go through each of these contours that were found to measure the area of the object. Then the parameters of the aruco detector and a dictionary are loaded to detect the aruco that we are using, in this case it is a 5x5 aruco detector like the one shown in Figure 27.

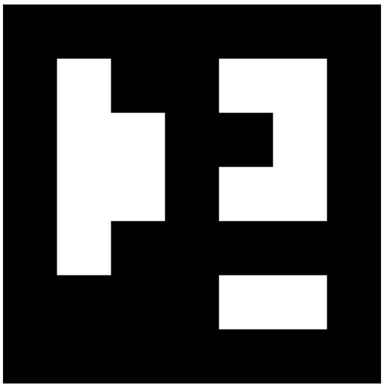

Figure 27. Aruco marker used [30]

There are several examples of arucos markers such as those presented in the Figure 28. The pattern represented by the combination of black and white is called ”ID”, while

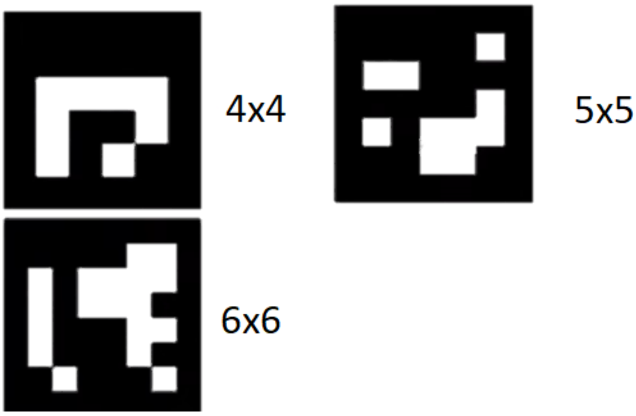

Figure 28. Aruco marker examples [30]

the dimension of the marker is given by the number of cubes in height and width. The aruco used has dimensions $5 \cdot 5$ and each side measures $4\mathrm{cm}$.

Continue with capturing the video, the marker is detected and using the detectMarkers function the corners are obtained and proceed to draw the outline of the marker. With this, the perimeter of the marker is obtained when using the arcLength function and the ratio of pixels per centimeters is obtained. When this proportion is already obtained, the objects are detected, the contours are extracted and a rectangle inscribed in the figure is drawn and the initial coordinate, the width and the length are extracted. Then the width and length are passed to cm using the relationship between cm and pixels previously obtained (because they were in pixels). When doing the aforementioned, it can be seen in Figure 29 how the values of the aruco marker are obtained and in

Figure 30 the length and width are obtained with various objects.

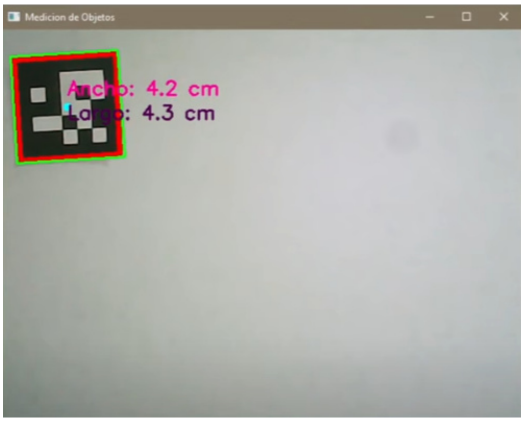

Figure 29. Aruco marker length and width

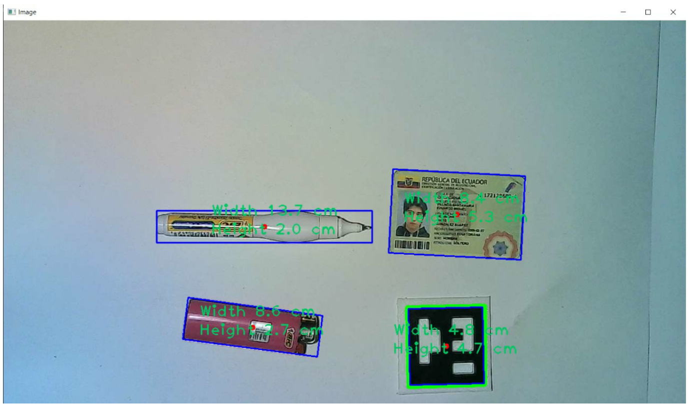

Figure 30. Aruco marker and different objects dimensions

When obtaining the values of width and length, multiply these two to obtain the area. If the area is less than 70cm^2, the system enters safe mode turning off the machine denoting that there has been an error in quality control, that is to say that the measurements of the hamburgers are no longer acceptable. Is good to mention that quality control is carried out when the dosing process is carried out.

4. Expenses table

In order to show the total cost of the machine, the Table 7 is created, in which the products, quantity and price are presented. The values denoted as extras refer to mobilization costs, tolls, etc.

Table 7. Expenses table

Item	Quantity	Price
Ortogonal Gearbox 1:100	1	110
Three-phase motor	1	150
Variable frequency	1	340
Human labor + Materials		2800
Buzzer	1	2
Pilot Lights	7	12
220V plug	1	8
Cable 4x14 AWG 600V 10m	1	10
Flexible Cable #18 16m	1	13
Buttons	6	10.2
Selector 2-Pos	1	1.4
Selector 3-Pos	1	1.4
Electronic Gabinet 40x40x20	1	40
Terminal block	40	15
Breaker 2p 16AMP	1	7
Libretin	1	14
STEPDOWN	1	3.75
Molex	6	3.36
Arduino Mega	1	25
Raspberry PI4 1 Gb RAM	1	80
Camera	1	10
PCB	1	12.25
Flexible aluminum motor coupling	1	4
Heatsinks Raspberry	3	3
Fan Raspberry	1	2
Case Raspberry	1	1
DC Motor	1	18
Conveyor Belt	1	23.8
Power supply 220VAC-12VDC 10 A	1	20
L298N	1	5
Relay Module 6 CH	1	10
Relay Module 4 CH	1	6
Extras		60
TOTAL		3821.16

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