

PROTOTYPE OF LINE FOLLOWER ROBOT APLIED TO INDUSTRIAL CUTTING OF TWO AXIS

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Submitted at 15/12/2017 and accepted at 15/01/2017

ABSTRACT

Currently, the geometric trajectory control of the most updated industrial machinery usually uses computer numerical control to perform complex cuts in two axis, demanding qualified operators in G and M programming language, which is characteristic of CNC equipment. The above features demand a hard economic investment and training. On the other hand, the semi-manual equipment is highly dependent on the operator and specialized

tooling, restricting portability and field complex activities. This paper shows part of methodology applied to the design of a prototype robot, which is based on infrared tracking of lines; a technique that has not been exploited in two dimensional production process. However, which counteracts issues such as low portability, limited intuition operating, high operation time and hard economic investment.

KEYWORD: Following line robot, Two axis cutting, Industrial cutting, Methodology of design

1. INTRODUCTION

In the current estate of the art to achieve pieces with complex flat geometry, according to the compilation of some patents and industrial designs (SANDOVAL ROCHA E. et al, 2016; PLASCENCIA MORA H. et al, 2016; NUMERIK S.R.L., 2016; TECNOIMPORTADORA DE MAQUINARIA S.A. DE C.V., 2015), the commercial machinery usually employs computerized systems of motion to cut several materials such as metals, polymeric foams, solid ceramics, woods, among others. These require a high investment for acquisition and specialized training in G and M language programming, adding a careful handling of the computational system. During the operation of equipment, the most remarkable feature is the immobility of the machine structure, were it keeps motionless while a tool moves to make the cut, Figures 1 and 2 show some examples. This gives a low flexibility and no portability to perform outside activities. As well as, the restrictive disadvantage in processing large dimensions of material.

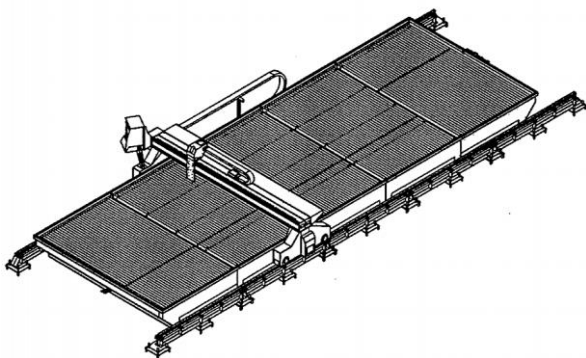


Figure 1: CNC industrial pantograph for cutting plates by oxyfuel, (SANDOVAL ROCHA E. et al, 2016) .

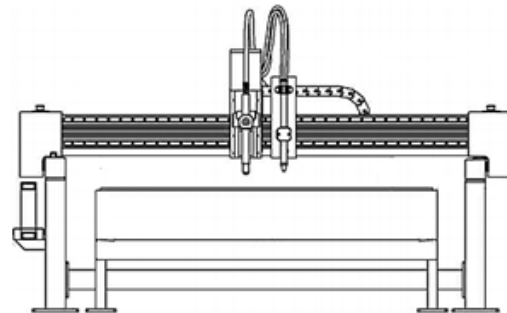


Figure 2: CNC industrial pantograph for cutting plates by plasma, (PLASCENCIA MORA H. et al, 2016).

On the other hand, the industrialized portable devices are manual or semiautomatic, were tasks are highly dependent on operator skills and specialized tooling, according to some industrial products (KOIKE ARONSON INC, 2017; FRANCO F., 1929). That consumes considerable preparation time, limiting to make only simple works. The figures 3, 4 and 5 show some of the most requested semiautomatic industrial cutting devices.

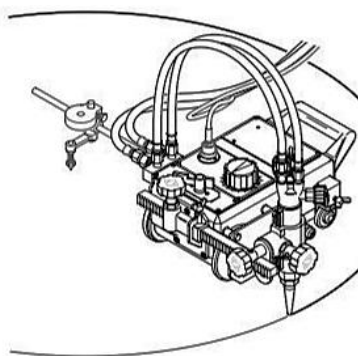


Figure 3: Semiautomatic cutting carriage on a guide for circular pieces, (KOIKE ARONSON INC., 2016).

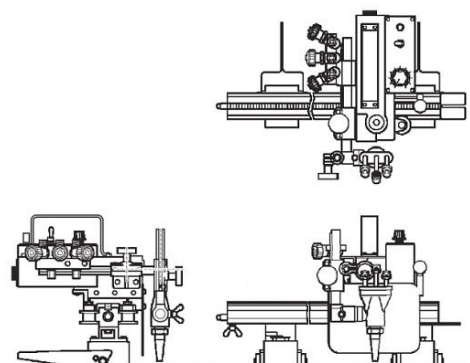


Figure 4: Semiautomatic carriage for straight cuts guided by rails, (KOIKE ARONSON INC., 2016)

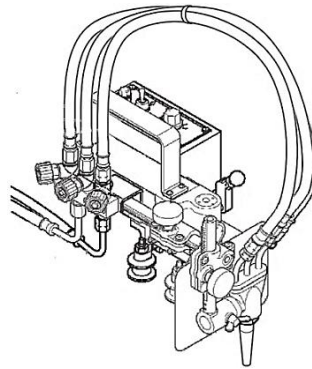


Figure 5: Carriage guided by rails and rollers for straight cuts, (KOIKE ARONSON INC., 2016).

1.1 Nomenclature

Symbol	Units	Description	Symbol	Units	Description
ΔQ	kJ	Heat energy variation.	Δt	s	Time variation.
ΔU	kJ	Internal energy variation.	dt	s	Time differential.
ΔW	kJ	Thermal work variation.	t_1	s	Initial time.
Q_E	kJ	Input heat energy.	t_2	s	Final time.
Q_s	kJ	Output heat energy.	ρ	kg/m ³	Density.
ΔH	kJ	Enthalpy variation.	v	m ³	Volume.
C_p	kJ /kg-K	Specific heat capacity at constant pressure.	D	m	Diameter.
m	Kg	Mass.	L	m	Length.
ΔT	K	Temperature variation.	W_{Elec}	kW	Electrical power.
dT	K	Temperature differential.	V	V	Voltage
T_1	K	Initial Temperature.	I	A	Electrical current intensity.
T_2	K	Final Temperature.	R	Ω	Electrical resistance.
Q_E	kW	Thermal Power.			

1.2 Problem statement

The previous areas of opportunity motivated to develop a portable system able to make cuts on solid surfaces. Below, it is shown part of methodology for portable device design, that initially was focused on the straight and square cutting of expanded polystyrene sheets; moving autonomously through flat surfaces (two axis) and following a physical trajectory (black line). Thus, covering features as portability, management intuition, preparation time, dependence on tooling and economic investment.

2. MATERIAL AND METHODS

Nowadays, line follower robots have not been highly exploited at industrial level, being restricted almost exclusively to academic competitions. However, it is a convenient option as a principle of operation to cut complex trajectories, due to simplicity of construction and low acquisition cost. The line follower robots are equipped with infrared sensors, which vary their nominal voltage when going from reflecting to non-reflective surfaces, Figure 6. This variation is interpreted by an electronic controller, which governs the movement of the robot.

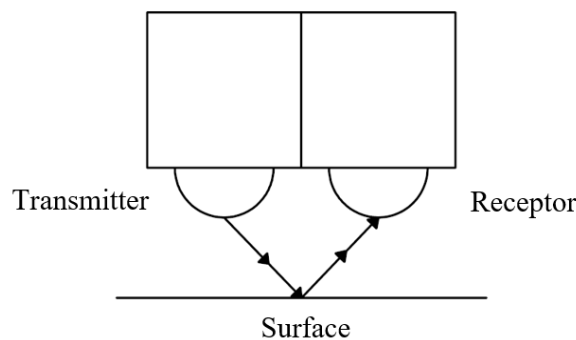


Figure 6: Reflective sensor or infrared sensor.

Base on this principle, the conception of the device follows the next design methodology (ULRICH K. T. et al, 2011):

- Define problem statement.
- Review state of the art.
- Build diagram of functions.
- Solve technical structures.
- Draw sketch design.
- Calculate designs.
- Select particularities.
- Detail design prototype.

2.1 Function diagram

Considering the operation and structure of some similar products, the function diagram for the prototype is elaborated, Figure 7.

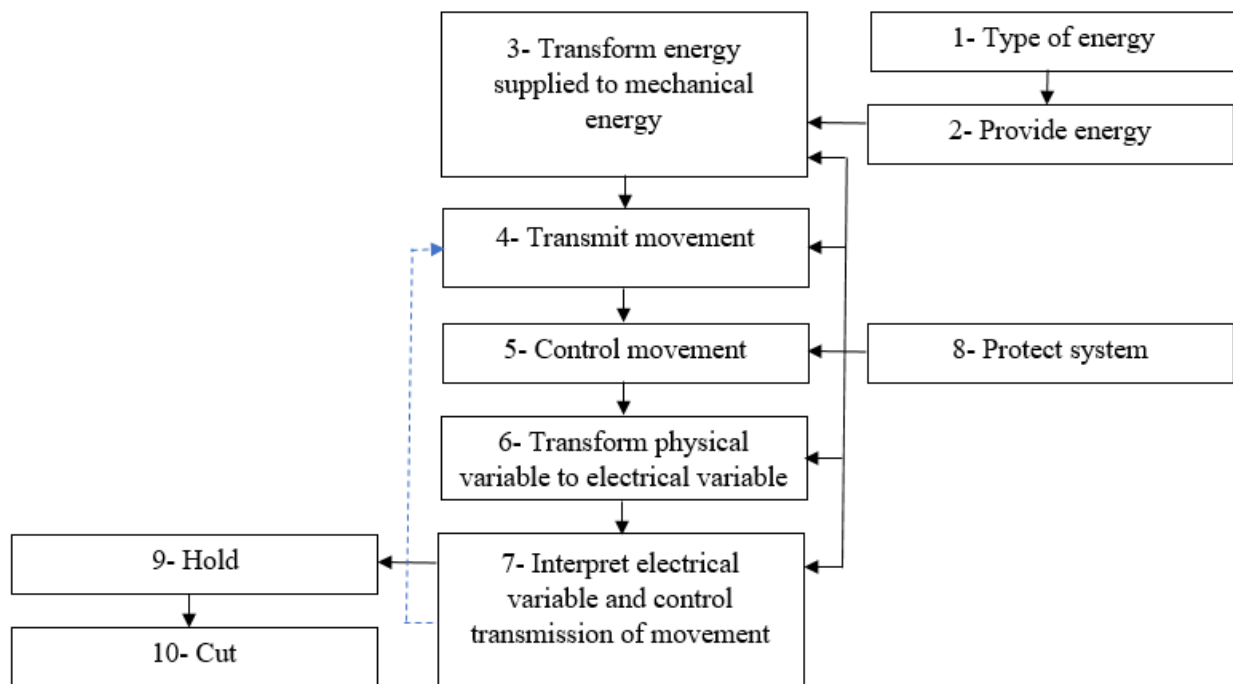


Figure 7: Function diagram for polymeric foams cutting.

2.2 Solution of function diagram

The function diagram, Figure 7, is composed by partial functions, which are necessary to achieve the main objective of the device. Each partial function is solved by capable technical structures to carry out the activities. Accordingly, several alternatives are proposed and evaluated to satisfy individual activities. To illustrate this section, the partial function 4 is taken, which transmits movement and displacement. The alternatives are: conventional wheels, omnidirectional wheels and mecanum wheels, Figures 8, 9 and 10, respectively.

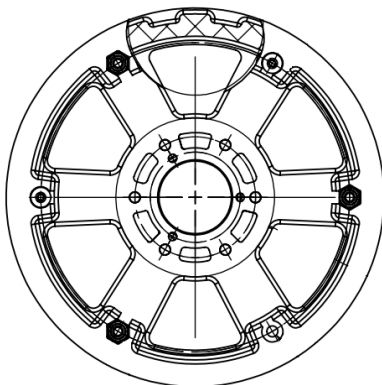


Figure 8: Alternative A - Conventional wheel, main and side views.

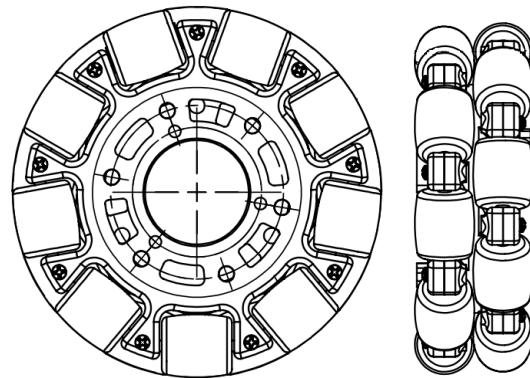


Figure 9: Alternative B - Omnidirectional wheel, main and side views.

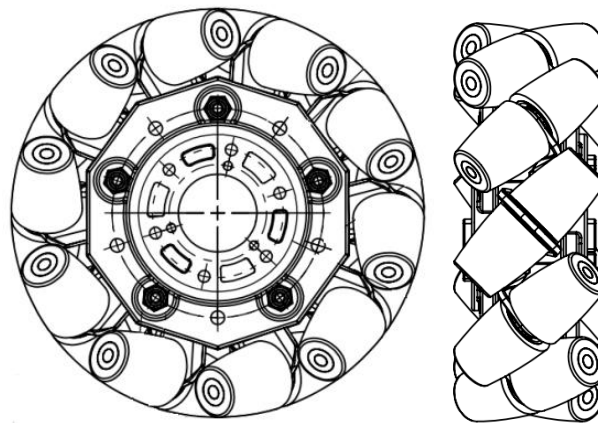


Figure 10: Alternative C - Mecanum wheel, main and side views.

To select technical structures from alternatives, it used an evaluation matrix. However, previously the possible solutions are examined with advantages and disadvantages, Table 1.

Table 1: Advantages and disadvantages of alternatives, partial function 4.

Alternatives	Advantages	Disadvantages
A	Low acquisition cost.	Many adaptive elements for operation. Expensive adaptive elements. Low flexibility for new future functions. Complicated maintenance due to many adaptive elements.
B	Moderate flexibility for new future functions.	High acquisition cost. Low flexibility for new future functions. Complicated maintenance due to many adaptive elements.
C	Flexibility for new future functions. Few adaptive elements for operation.	High acquisition cost.

According to Table 1, the evaluation matrix is constructed, Table 2.

Table 2: Evaluation matrix of alternatives, partial function 4.

Evaluation criteria / Alternative	A	B	C
Low acquisition cost.	3	2	1
Few adaptive elements for operation.	1	2	3
Low cost adaptive elements.	1	2	3
Easy maintenance.	2	2	3
High flexibility for new future functions.	1	2	3
Total:	8	10	13

The score is assigned according Table 3.

Table 3: References for evaluation.

Complies	Moderately complies	Does not comply
3	2	1

The best alternative is C. Following the same procedure, the rest of the partial functions are solved, resulting the next diagram, Figure 11.

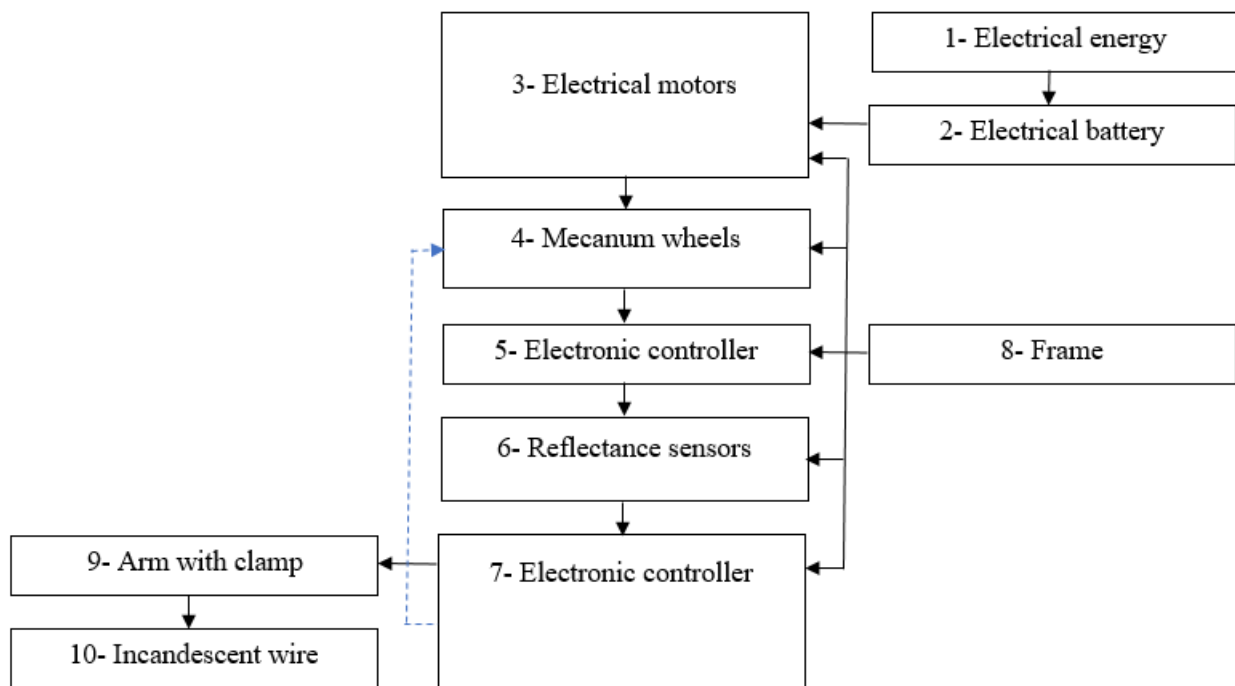


Figure 11: Function diagram with technical structures.

3. RESULTS

The sketch shown in Figures 12 and 13 is constructed from the diagram in Figure 11.

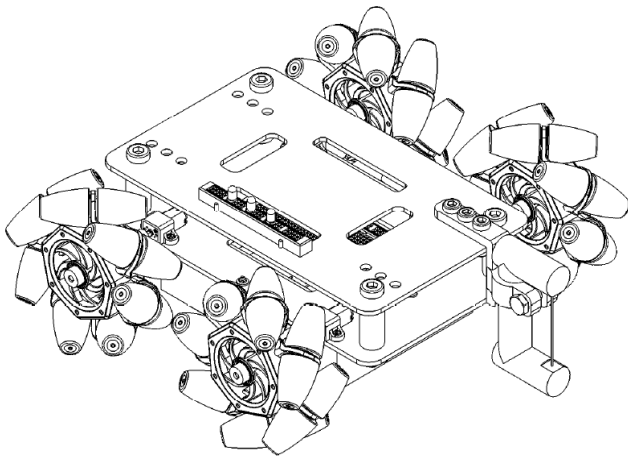


Figure 12: Conceptual sketch of portable system for polymeric foams cutting.

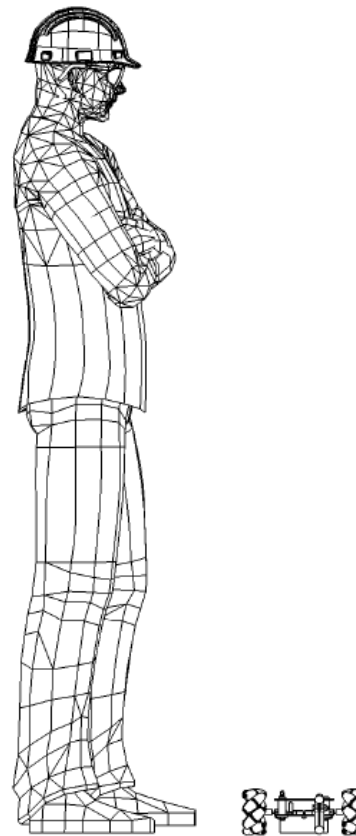


Figure 13: Conceptual sketch of portable system for polymeric foams cutting, with scale reference.

3.1 Selection of particularities and design calculations

Below, there are some selections and calculations made during the methodological design procedure. It is worth mentioning that they are not the only ones. However, the most significant of the development are exposed.

3.1.1 Calculation of electrical potential for incandescent filament

Expanded polystyrene is a thermoplastic polymer, which its viscoelastic behavior depends on temperature (KALPAKJIAN S. et al, 2014; GROOVER M. P., 2010). Accordingly, the separation of material by metallic filaments at temperatures over the melting range is possible. Table 4 contains some thermomechanical and thermochemical polystyrene properties.

Table 4: Thermomechanical and thermochemical properties of expanded polystyrene, (KALPAKJIAN S. et al, 2014; GROOVER M. P., 2010).

Melting range	Inflammation temperature
100°C- 135°C	400°C – 500°C

It is proposed to supply direct current from an electric battery so that the filament reaches the right temperature, Figure 14.

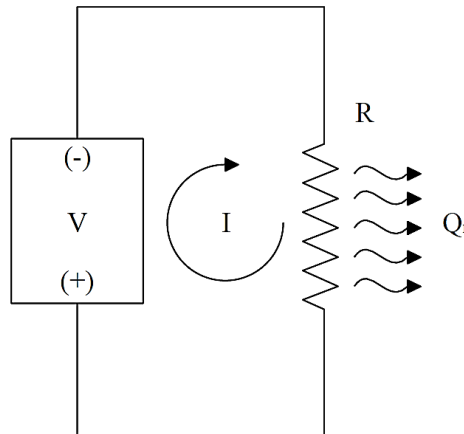


Figure 14: Electrical circuit for the incandescent filament.

Nichrome wire is selected for the filament; a nickel-chrome alloy commonly used in manual cutters to process extruded and expanded polystyrene. Table 5 shows some of the physical and thermomechanical properties of nichrome, 80% nickel 20% chromium.

Table 5: Physical and thermomechanical properties of the 80-20 nichrome wire, (ALLOW WIRE INTERNATIONAL, 2017)

Physical and thermomechanical properties	Numerical value
Density at 20 ° C	8300 kg /m ³
Melting temperature	1400°C
Maximum operating temperature	1200°C
Specific heat at constant pressure and 20 ° C	0.45 kJ/kg-K

In order to know the adequate electrical power to supply the battery, it begins with an energy balance adding the first law of thermodynamics, eq. (1) y (2).

$$\Delta Q = \Delta U + \Delta W \quad (1)$$

$$\Delta Q = Q_E - Q_s = \Delta H \quad (2)$$

Where the enthalpy, as a general definition is equal to the product between specific heat at constant pressure, mass and temperature variation, eq. (3):

$$Q_R - Q_s = \Delta H = C_p m \Delta T \quad (3)$$

If 50% of input heat energy is lost as output heat energy due to thermal contact of the wire with the environment, it obtains eq. (4) and (5):

$$Q_s = \frac{1}{2} Q_E \quad (4)$$

$$Q_E - \frac{1}{2} Q_E = \frac{1}{2} Q_E = C_p m \Delta T \quad (5)$$

The eq. (5) can be rewritten and solved from an initial state 1 to a final state 2, eq. (6):

$$Q_E = 2 C_p m \int_1^2 dT = C_p m (T_2 - T_1) \quad (6)$$

On the other hand, thermal power is defined as the quantity of heat energy transferred per unit time. Therefore, the thermal rate of the incandescent wire is:

$$\dot{Q}_E = \frac{Q_E}{\Delta t} \quad (7)$$

Eq. (8) is obtained by isolating and rewriting heat energy from eq. (7). Now, solving eq. (8) from an initial state 1 to a final state 2 it is obtained eq. (9).

$$Q_E = \dot{Q}_E \Delta t = \dot{Q}_E \int_1^2 dt \quad (8)$$

$$Q_E = \dot{Q}_E (t_2 - t_1) \quad (9)$$

The density is described by eq. (11). Therefore, the mass is equal to eq. (12):

$$\rho = \frac{m}{v} \quad (11)$$

$$m = \rho v \quad (12)$$

Where the wire volume can be calculated by eq. (13):

$$v = \frac{\pi D^2}{4} L \quad (13)$$

With eqs. (12) and (13) is obtained eq. (14).

$$m = \rho \frac{\pi D^2}{4} L \quad (14)$$

According to the principle of energy conservation, the following eq. can be established:

$$\dot{Q}_E = \dot{W}_{Elec} \quad (15)$$

Where the electrical power is equal to the product between the current intensity and the circuit voltage:

$$\dot{W}_{Elec} = V I \quad (16)$$

With eqs. (10), (13) and (15) is obtained eq. (17):

$$\dot{W}_{Elec} = V I = \frac{\rho C_p \pi D^2 L (T_2 - T_1)}{2 (t_2 - t_1)} \quad (17)$$

Considering $L = 50 \text{ mm} = 0.05 \text{ m}$, $D = 0.5 \text{ mm} = 0.0005 \text{ m}$, $t_1 = 0 \text{ s}$, $t_2 = 12 \text{ s}$, $T_1 = 20 \text{ °C} = 293.15 \text{ °K}$, y $T_2 = 160 \text{ °C} = 433.15 \text{ °K}$ (technical characteristics):

$$\dot{W}_{Elec} = \frac{(8300)(450)\pi(0.0005)^2(0.05)(433.15 - 293.15)}{2 (12 - 0)} = 0.85W$$

Accordingly, direct current by cell phone charger (5 V and 180 mA output) is sufficient.

$$\dot{W}_{Elec} = (5)(0.18) = 0.9W \approx 0.85W$$

3.1.2 Logic of reflective sensors

The geometric arrangement proposal for reflective sensors (numbered from 1 to 12) is shown in Figure 15.

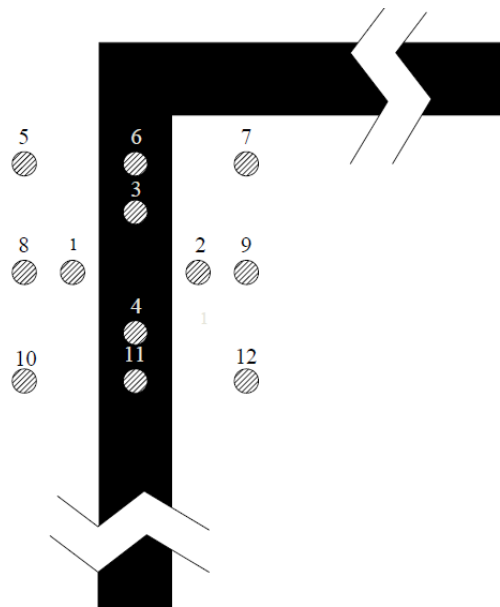


Figure 15: Arrangement of 12 reflective sensors for black line tracking.

Part of programming logic is explained below:

- If 1 and 2 are in white surface: continue moving in 90° direction (\uparrow); keep activated 5 and 7; keep deactivated 3, 4, 6, 8, 9, 10, 11 and 12.
- If 1 is in white surface and 2 is in black surface: move in 45° direction ($\uparrow + \rightarrow$); keep activated 5 and 7; keep deactivated 3, 4, 6, 8, 9, 10, 11 and 12.
- If 1 is in black surface and 2 is in white surface: move in 135° direction ($\uparrow + \leftarrow$); keep activated 5 and 7; keep deactivated 3, 4, 6, 8, 9, 10, 11 and 12.
- If 7 detects black surface: continue moving in 90° direction (\uparrow); activate 9; keep activated 1, 2, and 5; keep deactivated 3, 4, 6, 8, 10, 11 and 12.
- If 9 detects black surface; change movement in 0° direction (\rightarrow); activate 3, 4 and 12; deactivate 1, 2, 5, 9; keep activated 7; keep deactivated 6, 8, 10 and 11.

4. CONCLUSIONS

Starting from the design methodology, the objective selection of various alternatives was reached. Based on the above, a conceptual sketch was obtained. Subsequently, calculations were made to obtain the detailed design, Figure 16.

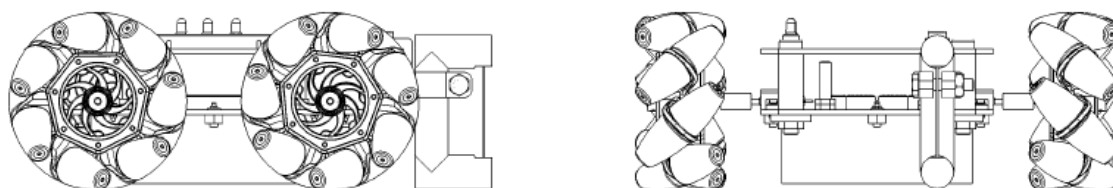


Figure 16: Detailed design of portable system for expanded polystyrene cutting, main view and side view.

Currently, several tests based on factorial experiments have been carried out to evaluate the performance of the prototype. In the same way, the patent registration of the device and its derivatives has been initiated to protect intellectual property. The above is not limited to the polymeric foams cutting, the development includes the ability to cut in other materials by oxyfuel, plasma and laser. However, they are in experimental stages.

Acknowledgments

The authors acknowledge their families, friends and Instituto Tecnológico de San Luis Potosí. In the same way, it is made a special recognition to the following students: Juan Carlos González Esquivel, Miguel Ángel Villaseñor López, Paola Razo Castañeda and Carlos Uriel Reyes Almendariz.

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