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Conceptual Design of a Semi-Autonomous Pole Cleaning Machine with Movement by Wheels, Clamping Using Adjustment and Steel Brush

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Abstract. Visual pollution is a visual problem, which damages the individual's ability to enjoy a view due to posters, billboards that are generated by the large supply and demand for goods and services; it is also due to the accelerated and disorderly urban growth that generates environmental deterioration in cities and urban areas. This problem is specifically found in the energy and telephone poles in urban areas and, therefore, the objective of this research is to carry out the conceptual design of a semi-autonomous pole cleaning machine focused on resolving this specific problem. For the realization of the conceptual design, it was used the VDI 2206 methodology that allows the modeling, analysis and design of a product, allowing to demonstrate all the requirements. In addition, an analysis of the displacement, cleaning and electronic systems, programming and that in turn will serve as a reference in future research was made.

Keywords: cleaning machine; semi-autonomous; conceptual design; VDI 2206; visual pollution.

1. Introduction

Some researchers focused on the development of facade and floor cleaning robots [1], with the characteristic of overcoming obstacles. However, none focused on the development of a robot capable of cleaning vertical cylindrical surfaces, specifically lighting poles. Therefore, this research develops the proof of concept of a robot for cleaning poles since they contribute to the problem of visual pollution.

According to a study in the International Scholarly Research Journals, visual pollution is a problem that damages the individual's ability to "enjoy" their environment [2], especially in the pandemic where this research was conducted. Visual pollution is a worldwide problem that is due to the growth of industrial development, high demand for goods and services, also, accelerated and chaotic urban growth that generates environmental deterioration in cities [3]. Also, according to United Nations data, urban areas are those that generate greater concern in Latin America with 79.43% and 50.46 for the world [4], one of these demonstrations, is observed in the impact on the population of the district of El Tambo, through the presence of visual pollution in light and telephone poles in the city of Huancayo, Junín - Peru.

Some designs, such as the patent by researcher W. Matechuk, detail a drywall sander, commonly called Drywall, which features an electric motor and a rotating sanding head mounted on opposite ends of an arm [5]. Another design, such as J. Due's patent, develops the concrete roughing machine, this device has a handheld concrete grinder that is removable in a right-to-left orientation [6]. Some of these proposals, such as Xiao-Peng Li's, model and control a four-duct fan-driven facade cleaning robot that has the ability of balance, the feature of low weight and the flexibility of overcoming obstacles in window frames [6].

Sahana H.P. and et al. who developed a floor cleaning robot controlled by an Android phone via Bluetooth HC-05, which works with an Arduino UNO microcontroller, an ultrasonic sensor and an L293D controller which activates a DC motor with brushes for cleaning [7]. On the other hand, the proposal by J. Lee and et al. presents a robot that facilitates the cleaning process and saves labor, as it can help physically disabled and elderly people. [8] It achieves its goal thanks to multiple sensors that allow it to avoid obstacles and zigzag [9], managing to access all corners of the house by means of two front brushes, achieving an effective cleaning [10].

The objective of this research is to carry out the conceptual design of a semi-autonomous cleaning machine for poles containing advertising in the district of El Tambo in the city of Huancayo, because this problem contributes to generate visual pollution.

In section 2 of this research, the methodology used to obtain the requirements of the robot, the system design, the operation diagram, the morphological matrix and the technical and economic analysis are detailed. In the third section, the physical design, the electronic design and the programming are carried out. Finally, the fourth section describes the conclusions and possible future work.

2. Methodology

The VDI 2206 methodology [11] was used to perform the conceptual design as it allows to go back and verify as many times as necessary to certain stages of the project such as requirements, technological information and mechanical and electronic design.

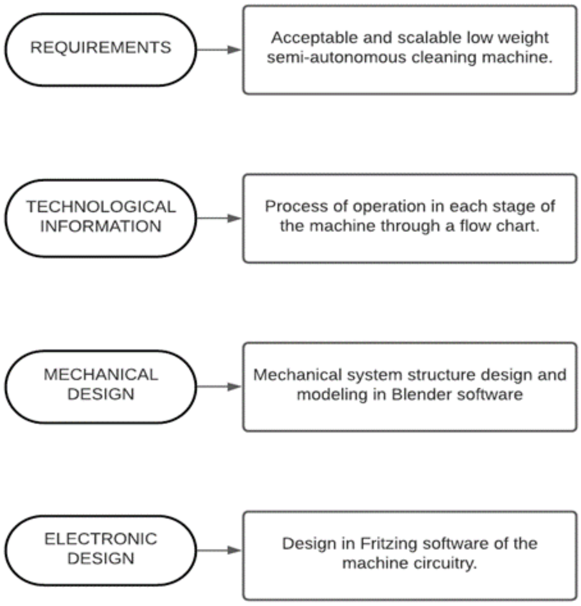


Fig. 1. VDI 2206 Methodology

As can be seen in Fig. 1, the project was broken down in terms of the requirements, the purpose of the concept and the verification of the project, maintaining the integration of the components that allow evidence that the objective of the conceptual design was met.

2.1. Morphological Analysis

The semi-autonomous pole cleaning machine requires specific criteria for its design. The design criteria were obtained through the morphological analysis of the research presented below.

First, the morphological analysis of the designs of the fastening and movement systems on the vertical surface, by means of wheels and different types of fastening is detailed in Table I.

Table I. Morphological analysis of grasping and movement

Morphological Analysis	Fastening	
Movement	Vacuum	Magnet
Wheels	[12], [13], [14], [15]	[13], [16]

The morphological analysis of the designs of the different cleaning methods and types of fastening to the vertical surface is detailed in Table II.

Table II. Morphological analysis of the holding vs. cleaning

Morphological Analysis	Fastening		
Cleaning	Vacuum	Magnet	Legs
Brushes	[12], [14], [15]		
Vacuum cleaner	[13]	[13]	[17]
Fabric accessory		[18]	

After carrying out the morphological analysis of the cleaning and comparing the different cleaning methods, it was decided to use brushes for cleaning. Finally, the morphological analysis of the designs of the different cleaning methods and movement on the vertical surface using wheels is detailed in Table III.

Table III. Morphological analysis of movement vs cleanliness

Morphological Analysis	Movement
Cleaning	Wheels
Brushes	[12], [14], [15]
Vacuum cleaner	[13], [1]
Pump and manifold	[18]
Fabric accessory	[16]

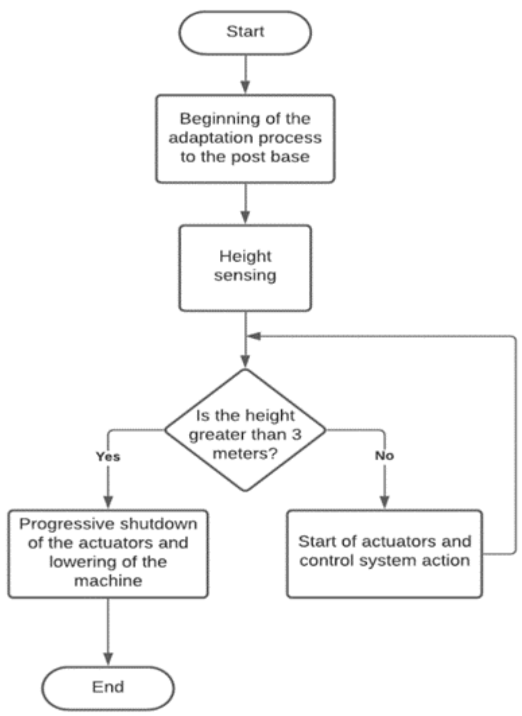


Fig. 2. Diagram of operation

The carried out morphological analysis had a purpose to obtain the proof of concept to work under certain criteria of design in which exist investigations in this respect and in which not. The conceptual design to be carried out will have a movement on the vertical surface by means of wheels, fastening to the vertical surface by means of an adjustment system and a cleaning method using a steel brush.

2.2. Operating Diagram

To obtain the processes to be executed and in the required sequence, the operation diagram was used. In Fig. 2, it specifies the processes that the machine will have from start to finish and its purpose is to sequence the processes to be carried out by the machine to clean the poles containing advertising.

2.3. Morphological Matrix

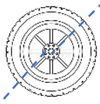
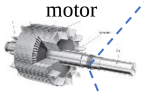
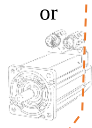
For the selection of components, the VDI 2221 methodology was used, which is a systematic approach to the development and design of technical systems and products [19]. It was used a variety of possibilities, however, there are only three proposed solutions that were obtained from the next Table IV.

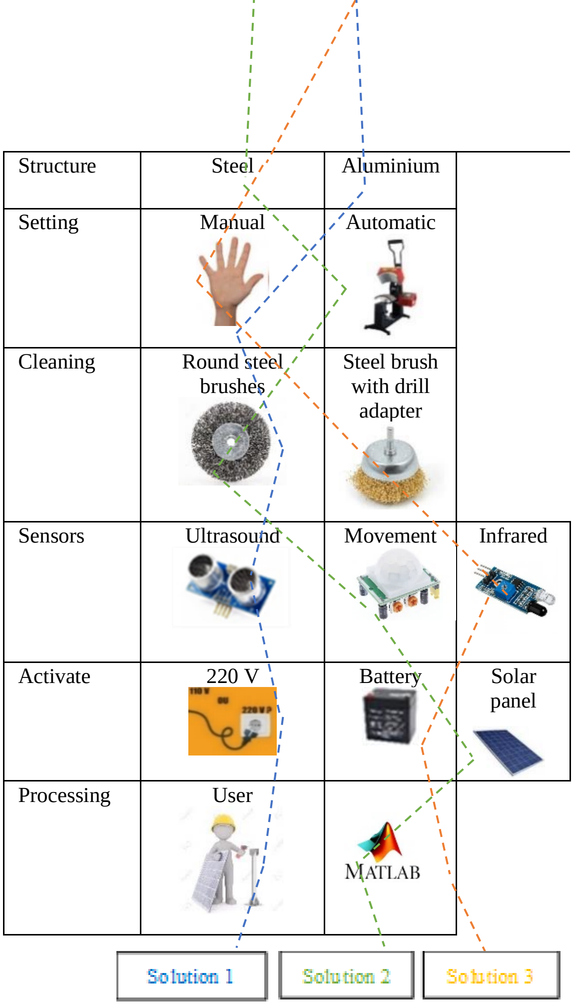
a) Solution 1: In solution 1, the process control is performed by the Atmega microcontroller, the vertical movement is performed by the rubber wheels which in turn obtain the necessary torque for their movement from the squirrel cage motor. These components are contained in a structure of steel material, this structure has the possibility of being able to be adjusted manually to leave the round steel brushes at the distance from the post that the user considers pertinent. The vertical movement of the machine is equipped with an ultrasonic sensor that will measure the height at which the machine is located, and this measurement will be sent to the Atmega microcontroller for processing and making the decision to operate the machine. The power to be used will be 220V and the initial processing of the machine will be done by the user.

b) Solution 2: In solution 2, the process control is done by a microcontroller and a PLC. The vertical movement of the machine is done with caterpillar wheels, these wheels get the torque to climb from the AC 220v motor, these components are inside the aluminum structure and this structure will be automatically adjusted to leave the round steel brushes at the same time. distance from the post that the user considers pertinent. The vertical movement of the machine and the height at which it is located will be censored by the motion sensor and this measurement will be sent to the Atmega microcontroller for processing and making the decision to operate the machine. The energy will be obtained by means of a solar panel and its initial processing will be given by the MATLAB software.

c) Solution 3: In solution 3, the process control is done by a Raspberry Pi4 controller. The vertical movement of the machine is done with polyurethane wheels, these wheels get the torque from the servomotors, these components are inside the steel structure and also this structure will be manually adjustable to leave the steel brushes with drill adapter at the distance from the post that the user considers relevant. The vertical movement of the machine and the height at which it is located will be measured by an infrared sensor and this measurement will be sent to the Atmega microcontroller for processing and making the decision to operate the machine. The energy that will be used will be that of a battery and the initial processing will be given by the MATLAB software.

Table IV. Morphological matrix

MAIN FUNCTIONS	FUNCTION CARRIERS			
Control processes	Microcontroller 	Raspberry Pi4 	PLC 	Atmega 328 
Movement	Caterpillar wheels 	Rubber wheels 	Polyurethane wheel 	
Engines	Squirrel cage motor 	AC motor 220v 	Servomotor 	



2.4. Technical-Economic Evaluation of the Solution Concept

Next, in Table V and Table VI, a technical evaluation by the mechanical project evaluation method will be carried out.

Table V. Technical Evaluation

MECHANICAL DESIGN - EVALUATION OF PROJECTS **Technical value (X_i)**									Area of Design	
p: Score from 0 to 4 (Value scale according to VDI 2225) 0= Not Satisfactory 1= Fairly Acceptable 2= Sufficient 3=Good 4= Very Good (ideal) **g**: is the weighted weight and is given according to the importance of the evaluation criteria.										
Concept / project variants			S1		S2		S3		Ideal Solution	
N °	Evaluation Criteria	g	p	gp	p	gp	p	gp	p	gp
1	Function	1	3	3	3	3	3	3	4	4
2	Geometry	0.4	3	1.2	2	0.8	2	0.8	4	1,6
3	Kinematic	0.6	2	1.2	2	1.2	2	1.2	4	2,4
4	Kinetics	0.7	2	1.4	2	1.4	2	1.4	4	2,8
5	Force	0.6	3	1.8	2	1.2	2	1.2	4	2,4
6	Energy	0.6	3	1.8	3	1.8	2	1.2	4	2,4
7	Matter	0.6	3	1.8	2	1.2	2	1.2	4	2,4
8	Signals	0.4	2	0.8	2	0.8	3	1.2	4	1,6
9	Security	0.4	3	1.2	3	1.2	2	0.8	4	1,6
10	Ergonomic	0.6	2	1.2	2	1.2	2	1.2	4	2,4
11	Fabrication	0.9	3	2.7	2	1.8	3	2.7	4	3,6
12	Assembly	0.6	3	1.8	3	1.8	2	1.2	4	2,4
13	Transport	0.4	3	1.2	3	1.2	2	0.8	4	1,6
14	Maintenance	0.7	2	1.4	2	1.4	2	1.4	4	2,8
Maximum Score ∑p or ∑gp		**8.5**	**37**	**22.5**	**33**	**20**	**31**	**19.3**	**56**	**34**
Technical value X_i				**0.88**		**0.78**		**0.75**		**1**

Table VI. Economic Evaluation

MECHANICAL DESIGN - EVALUATION OF PROJECTS **Economic Value (Y_i)**			Area of Design
p: Score from 0 to 4 (Value scale according to VDI 2225) 0= Not Satisfactory 1= Fairly Acceptable 2= Sufficient 3=Good 4= Very Good (ideal) **g**: is the weighted weight and is given according to the importance of the evaluation criteria.			
Concept / project variants	S1	S2	S3

N °	Evaluation Criteria	g	p	gp	p	gp	P	gp
1	Material cost	1	3	3	3	3	2	2
2	Manufacturing cost	0.75	2	1.5	2	1.5	1	0.75
3	Assembly cost	0.5	3	1.5	2	1	1	0.5
4	Maintenance cost	0.25	2	0.5	2	0.5	2	0.5
Maximum Score ∑p or ∑gp		**2.5**	**10**	**6.5**	**9**	**6**	**6**	**3.75**
Economic Value AND $_i$				**0.87**		**0.8**		**0.75**

2.5. Optimum System Selection

Solution 1 is shown in the Fig. 3, it is closest to the vertex (1.1) and is therefore the optimal solution.

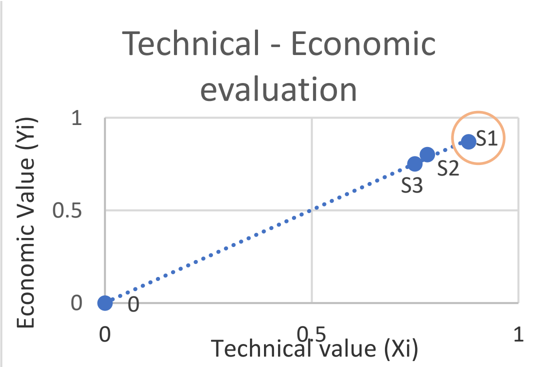


Fig. 3. Technical-Economic Evaluation Graph

3. Physical Design, Electronics and Programming

3.1. Physical Design

The physical design consists of parts such as the wheels that will be used for adjustment and vertical movement, the motors and brushes that will be used to perform the cleaning, as well as the respective gears and the frame that is more convenient. Parts such as the wheels to be used will be 3D printed, the other components will be manufactured with the exception of the motors as these will be purchased. Next, the simulation of the proof of concept is shown in the free design software Blender in Fig. 4. The components used in the conceptual design are described in the Table VII.

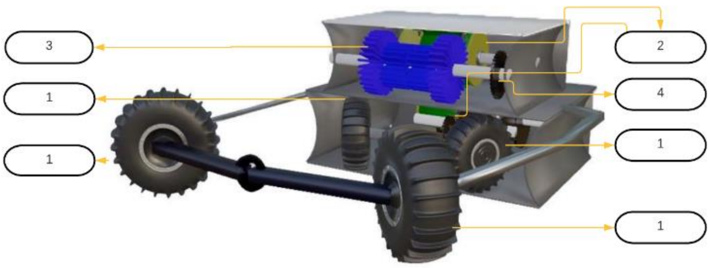


Fig. 4. Simulation in Blender software

Table VII. Table of Design Elements

N°	Quantity	Elements
1	4	Wheels
2	2	Engine
3	2	Large Brush
4	6	Gears

3.2. Electronic Design

A suitable model for the internal circuitry was designed. We worked initially with the ATMEGA 328 to create a new board that allows to enter the programming. The control of the system is given internally in the pic, this will control the activation of the relays. These in turn will activate and deactivate the wheels to either go up or down. To prevent the current from returning to the system, safety diodes were placed. Fig. 5 shows the design of the electronic circuit. The detailed components used for the electronic circuit design are described in Table VIII as well.

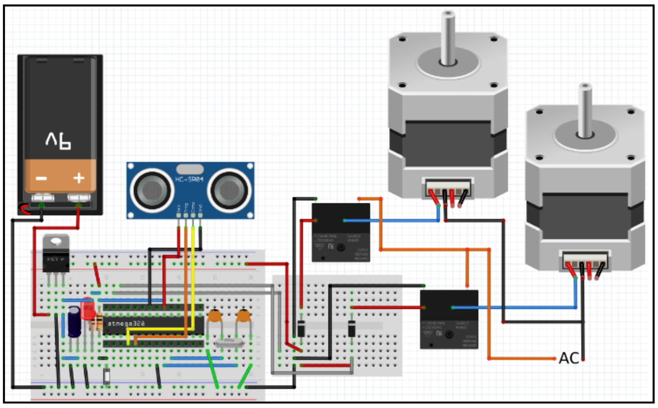


Fig. 5. Electronic circuit design

Table VIII. Electronic components

COMPONENTS	APPLICATION	FEATURES
Atmega328	Controlling the system	Signal processor
Ultrasound	Convert energy	Measures between 2cm to 400cm
Relays	Activate/deactivate	9v
Battery	Feeds the circuit	5 V and 2400mAh
Engines	Scrolling	3Hp

3.3. Weight

Likewise, once the conceptual design was carried out, the quantitative data of the weight of the design concept was obtained. Table IX shows the average total weight of the design, which is 27 kg, thus specifying the components used as part of the design concept.

Table IX. Components weight

TA **Components**	**Q**	**Weight** (kg)	**Weight** (kg)*Q
Atmega328 [21]	1	0.02	0.02
Vacuum rubber wheels 8"	4	0.816466	3.265864
Squirrel cage motor (3 HP)	2	6	12
Aluminum structure (3 m2)	3	3	9
Wheel brush 8"	2	1	2
Wheel brush 4.5"	2	0.2	0.4
Ultrasonic sensor	1	0.03	0.03
Relay	1	0.35	0.35
Total (kg) Σ(Weight ∗ Q)	27		

4. Programming

The programming was done in the C language, this is a language for programmers in the sense that it provides a great flexibility of programming and a very low error checking, so that the language leaves under the responsibility of the programmer actions that other languages perform by themselves. The C program is based on ANSI-C standard, following the ANSI C standard it will be easily portable from one computer model to another computer model, and likewise from one compiler model to another [20], as described in Fig. 6.

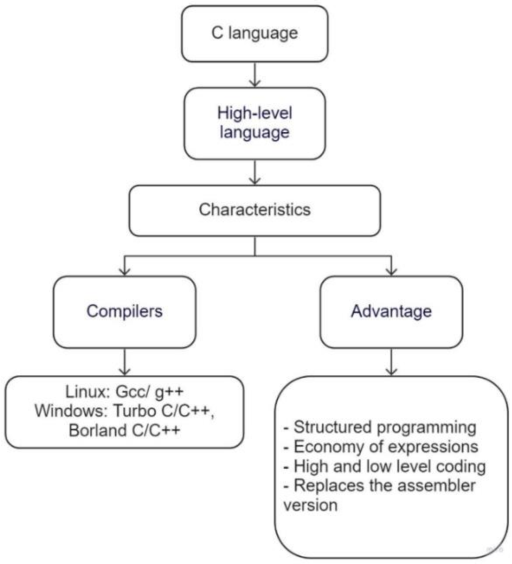


Fig. 6. Optimal programming language.

5. Conclusion

The conceptual design of a semi-autonomous pole cleaning machine containing advertising in the district of El Tambo in the city of Huancayo was achieved. To establish the design requirements, a morphological matrix was used, this methodology allowed comparing similar studies, where investigations that use brushes for cleaning were found. Rubber tires were also used because a gap was found in the investigations. In addition, the clamping and displacement mechanism were designed using the VDI 2221 methodology.

To achieve this, a semi-autonomous cleaning machine was designed, using Blender 3D modeling software and Fritzing software was used for the electronic circuit. The components to use the design were selected by means of a technical and economic evaluation, in which in future investigations the construction of a prototype and the validation of its correct operation are sought.

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