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Original Article

Design of an Electromechanical Lifting System Using Linear Actuators in a Wheelchair for People With Lower Limb Disabilities

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Abstract - *Accessibility is an important aspect of the inclusion of people since the impact on them disinhibits a natural development in society. This article develops a design for a wheelchair with electromechanical elevation so that people can have a primary assistance vehicle and thus achieve independence when moving around. A chair design was proposed that is efficient when elevating and thus keeps the patient at a height where they want to be most comfortable; it complies with technical standards for safety and user protection, and it can extend the useful life of the chair, the designed structure shows ergonomics for the person, it can support the weight of the patient and the accessories that they may carry with them. Outstanding and positive results were observed and analyzed in this study.*

Keywords - *Disinhibits, Electromechanical, Lifting, Ergonomics, Efficiency, Inclusion.*

1. Introduction

It is well known that mobility is important for social participation and quality of life. For people living with locomotor disabilities, mobility aid devices such as manual wheelchairs, electric wheelchairs, scooters and other motorized vehicles can be facilitators of mobility for people [1]. According to the INEI in Peru, 5.2% of the population, that is, 1 million 575 thousand people, have some type of disability. It also stated that 932 thousands people have permanent limitations to move or walk and/or use their arms and legs. People with disabilities do not have adequate treatment and/or rehabilitation therapy [2]. 60% of people with disabilities face difficulties moving through the streets, entering establishments, traveling by bus or even going to a park due to the lack of accessibility that these chairs can generate, according to the Department of Protection of Citizens' Rights of Peru. This fact causes people to be unable to freely exercise their citizenship and their rights to access decent work, education, socialization, health, and information, among others [3]. Nowadays, electric wheelchairs are usually not practical or very useful for people with disabilities since their designs are not practical; current models can be very large and very expensive, making acquiring these vehicles impossible for people with not so high resources, further complicating their daily lives. Due to the progress of medical development in recent years, it was reported that according to population estimates and projections, in Peru, there are 4 million 140 thousand adults over 60 years old, representing 12.7% of the total population in 2020. Therefore, the demand for medical care for the elderly is much higher [4]. Bach proposes in his thesis entitled "Wheelchair with the change of position to upright to assist motor disability of lower limbs in adults" where he presents a chair made of affordable materials with the adaptation of a vertical mechanical lifting system [5]. Hector, in his research entitled "Design of an electric traction system with electronic control for a wheelchair for people with motor disabilities." He presented the idea of making an electric traction system with an electronic control for a wheelchair so that they can move autonomously; the methodology they want to propose is to apply a Joystick so that it can define the position of the wheelchair [6]. The demand for automated vehicles will increase in the future, which is why this electromechanical wheelchair design can improve the quality of people's lives with an innovative elevation design using linear actuators. The objective of the research was to study and design a type of elevation model for an electromechanical wheelchair for people with disabilities in the lower limbs, and they will be practical elements so that it is easy to use by anyone, making them move more fluidly and autonomously. The results were positive since it will be demonstrated that a person can use it since it is easy and comfortable to use. The freedom of movement achieved was that an adult with mobility problems could benefit from the steering and lifting system of the wheelchair. It is an efficient operation and offers independence in the person's movement when it comes to moving without the need for another person to push them, all thanks to the electromechanical design.

2. Materials and Methods

Through this research, a wheelchair with an electromechanical lifting system was designed for the movement of people with disabilities in the lower limbs between 18 and 60 years old for practical and comfortable mobility; for this, a state of technology analysis was made, then the list of medical requirements was identified, and subsequently, the black box and the white box were developed to finally propose components for a sub-function in the morphological matrix which a technical and economic evaluation will filter. As a result, the design proposal is obtained and validated through the analysis of mathematical models and optimization through modelling and simulation. The present research work will follow an adaptation to the VDI 2221 methodologies in which the following activities will be carried out, as shown in Figure 1.

2.1. List of Requirements

The following table details the necessary description required by each function for the electromechanical chair project, whose requirements are designed to focus on desires or demands and a small description focused on the category, which can be seen in Table 1.

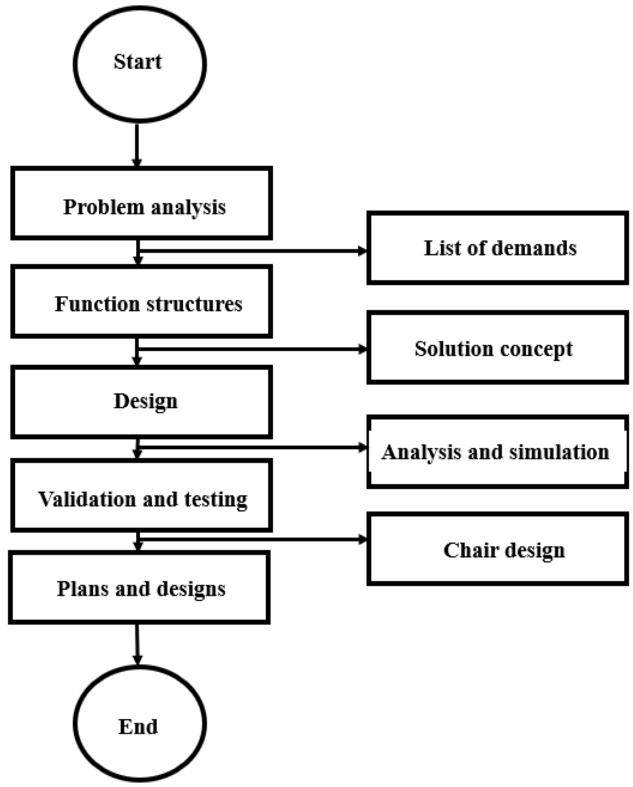

Fig. 1 Methodology adapted for the research project

Table 1. List of requirements

Category	Request	Description
Function	D	Performing an upward movement from a position for the person using it.
Geometric	C	Users with a maximum height of 1.90 also respect the construction measurements respectively.
Force	D	The chair must support a maximum weight of 100 kg and perform upward and downward movements.
Energy	D	Battery life of 2 days and should be able to be charged in a house with a 220V electrical connection.
Material	D	The structure must be made of AISI 1020 steel and comfortable foam.
Signs	D	System indicators are for on, off, up, and down.
Communication	D	Wired connection system.
Security	C	Coatings of electrical components and chair lift support against environmental factors.
Ergonomics	C	Easy to get in and out of the chair and comfortable getting in and out with the column system.
Manufacturing	D	Feasible to be able to do it in workshops in the country.
Mounting	D	Carried out by electrical component specialists.
Maintenance	D	Maintenance twice a year.

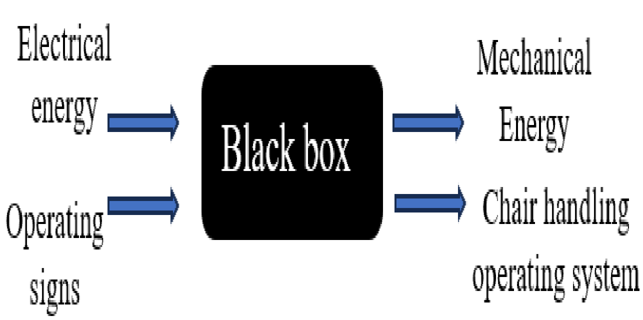

Fig. 2 Black box

Legend:

- D (designer)
- C (client)

2.2. Job Description

Positioning of the human body in the ergonomic chair for its eventual movement. The energy input through batteries is used to operate the chair's ignition. Transformation of electrical energy into mechanical energy for the movement and displacement of the chair. The input of operating signals to indicate electrical movement, as well as the raising and lowering of the chair.

2.3. Function Structure

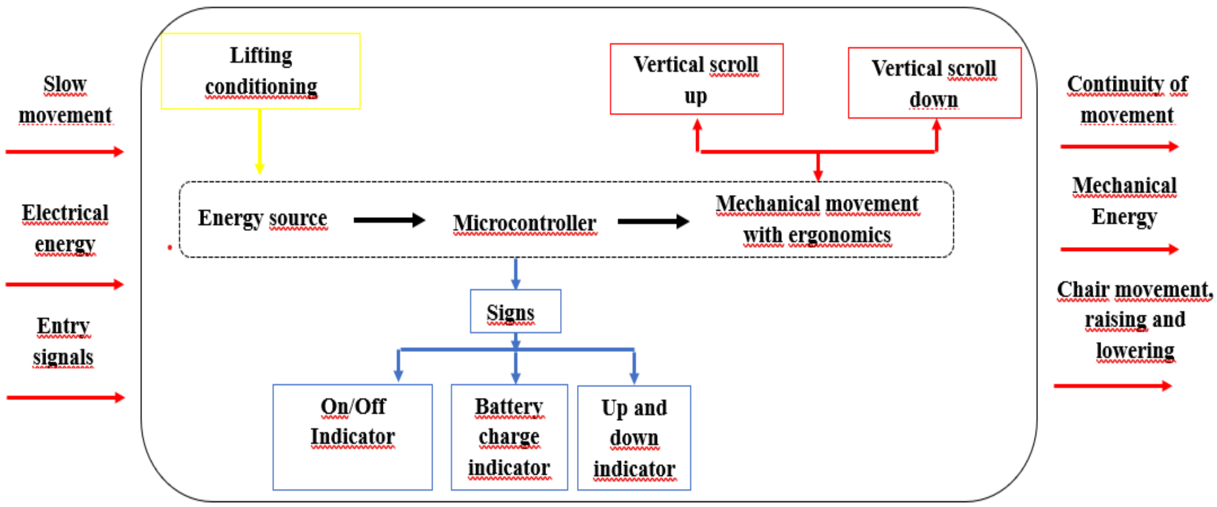

Fig. 3 Function structure

2.4. Morphological Matrix

The alternatives proposed for this design fulfill basic and necessary functions for the proper functioning of the electromechanical chair, and these can be seen in Table 2.

Table 2. Morphological matrix

Functions	Alternative 1	Alternative 2	Alternative 3
Structure of the chair	Square profile	Hollow tube	Solid tube
Chair and backrest	Plastic material	Rubber material	Foam material
Dashboard	Joystick with a control panel	Button system	Cell phone remote control
Energy source	Lithium battery	Battery Set	Gasoline engine
Armrest	Aluminum material	Plastic material	Rubber Material
Lifting systems	Lifting columns bl1	Pneumatic system	Hydraulic system
Solution concept	S1	S2	S3

2.5. Solution Concepts

2.5.1. Solution Concept 1

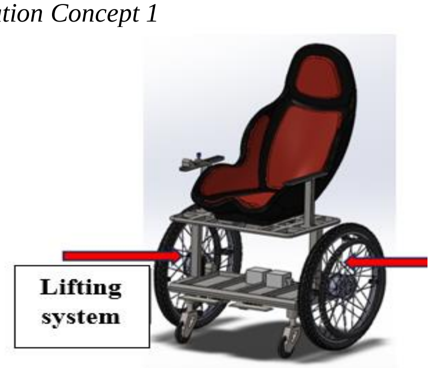

Fig. 4 Solution concept 1

In Figure 4, you can see a structure of rectangular tubes with a hollow interior that will help to provide resistance to support the patient's weight; the chair and the backrest have to be made of a comfortable and soft material since it is a piece that will be in contact with the skin, for the movement of the chair a Joystick was used and for the lifting system that will be fixed to the chair, the power source will be a lithium battery that will store energy appropriately, the armrests will be made of aluminum to support the weight of the arms, the lifting system will be made up of two DHLA 1300 linear actuators that will be able to withstand the force necessary for the chair to rise.

2.5.2. Solution Concept 2

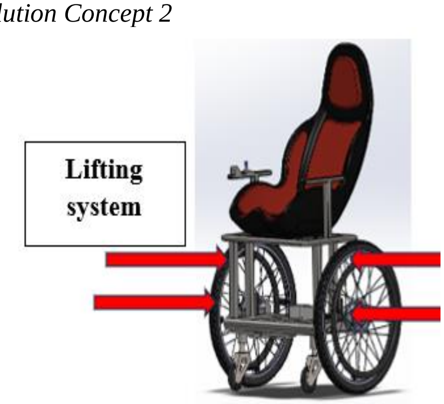

Fig. 5 Solution concept 2

Figure 5 shows a square profile structure that will support the required weight; the chair and the backrest will be made of plastic material, resistant material for the user; the control panel will be a system of buttons that will be for raising the chair, the power source will be a set of rechargeable batteries, the armrests will be made of hard plastic so that they last and are comfortable, the lifting system will be hydraulic so that the lifting is quieter.

2.5.3. Solution Concept 3

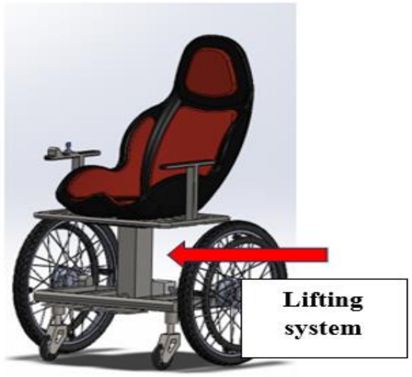

Fig. 6 Solution concept 3

Figure 6 shows a solid tube structure that will be fixed to support the chair to provide high resistance. The chair and backrest will be made of soft rubber for a more comfortable experience; the control panel will be a remote control directed by a cell phone for the chair's elevation. A gasoline engine will be used for a longer duration, and the armrests will be made of rubber for a softer feeling throughout the day that the arm is on the chair. The lifting system will be pneumatic, which will help the elevation faster.

2.6. Optimal Solution Concept

For this optimal solution concept, points from 0 to 4 will be analyzed and considered, where 4 is the maximum or ideal score seen in Table 3.

Table 3. Optimal solution concept

Technical evaluation	Solution concept			Ideal solution
	S1	S2	S3	
Function	3	2	3	4
Design	3	2	3	4
Security	2	3	1	4
Ergonomics	2	2	2	4
Mounting	2	1	1	4
Transport	3	3	3	4
Manufacturing	2	3	2	4
Spare parts	2	2	2	4
Total	19	18	17	32

Once the evaluation is done, the chosen solution concept will be number 1 since it meets the necessary parameters for the chair design.

2.7. Technical and Economic Evaluation

2.7.1. Technical Evaluation

Table 4. Technical evaluation

Technical criteria		**Preliminary project**							
		PP1		**PP2**		**PP3**		**Ideal**	
Description	**g**	**p**	**pg**	**p**	**pg**	**p**	**pg**	**p**	**pg**
Function	4	3	12	3	12	3	12	4	16
Geometric	4	2	8	1	4	2	8	4	16
Force	2	3	6	2	4	2	4	4	8
Energy	2	3	6	2	4	3	6	4	8
Material	2	3	6	3	6	2	4	4	8
Signs	1	2	2	1	1	1	1	4	4
Communication	1	1	1	2	2	2	2	4	4
Security	3	2	6	2	6	1	3	4	12
Ergonomics	3	3	9	1	3	2	6	4	12
Manufacturing	1	2	2	2	2	1	1	4	4
Mounting	1	2	2	1	1	3	1	4	4
Maintenance	1	2	2	1	1	2	2	4	4
Total		**62**		**46**		**50**		**100**	
Rt		**0.62**		**0.46**		**0.5**		**1.00**	

Table 4 on technical evaluation shows that within the technical criteria, a score was given for each preliminary project, giving us a result of 0.62 higher than solution 1.

2.7.2. Economic Evaluation

Table 5. Economic evaluation

Economic criteria		**Preliminary project**							
		PP1		**PP2**		**PP3**		**Ideal**	
Description	**g**	**p**	**pg**	**p**	**pg**	**p**	**pg**	**p**	**pg**
Design cost	4	3	12	3	12	3	12	4	16
Manufacturing cost	4	3	12	2	8	2	8	4	16
Workshop cost	3	3	9	3	9	2	6	4	12
Assembly cost	4	2	8	2	8	3	12	4	16
Maintenance cost	3	2	6	2	6	3	9	4	12
Cost of spare parts	3	3	9	3	9	2	6	4	12
Number of pieces	4	2	8	2	8	2	8	4	16
Total		**64**		**60**		**61**		**100**	
Rt		**0.64**		**0.6**		**0.61**		**1.00**	

In Table 5 on economic evaluation, after analyzing the economic criteria, it can be stated that preliminary project number 1 is the most optimal for an evaluation.

2.7.3. Table of Results in the Technical and Economic Evaluation

Table 6. Technical and economic evaluation

	Solution 1	**Solution 2**	**Solution 3**	**Ideal**
Technical Evaluation	0.62	0.46	0.5	1
Economic Evaluation	0.64	0.6	0.61	1

After a comparative analysis in Table 6, among the three preliminary proposals, it can be confirmed that project number 1 is the best to develop since it complies with a technical and economic evaluation for the study of this project.

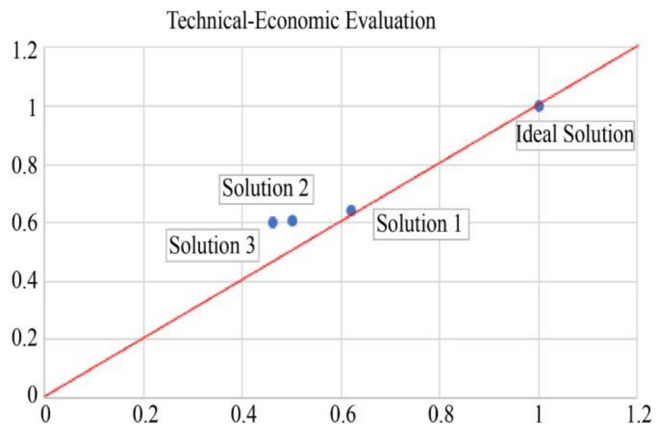

Fig. 7 Scatter plot of the technical and economic evaluation

When observing Figure 7, it can be seen that solutions 2 and 3 are far from the ideal solution line. However, solution 1 is chosen because it is closer to the ideal line for this research project.

2.7.4. Optimal Solution Concept

Based on the technical and economic result, solution 1 will be the correct one to choose since it shows performance in terms of the manufacturing of the project since it will have a design and selection of components in the electrical system and ideal operating signals for the people who require it and this is demonstrated in figure 8.

Fig. 8 Optimal solution concept

3. Calculations

3.1. Optimal Ergonomic Adjustment of the Chair

The electric wheelchair is a good alternative for people with mobility problems; a chair is crucial to have an ergonomic fit for better comfort and thus avoid injuries that further complicate the patient. That is why the chair has adequate dimensions, armrests, footrests and personalized adjustments so that a patient can stay the hours recommended for daily use. [7].

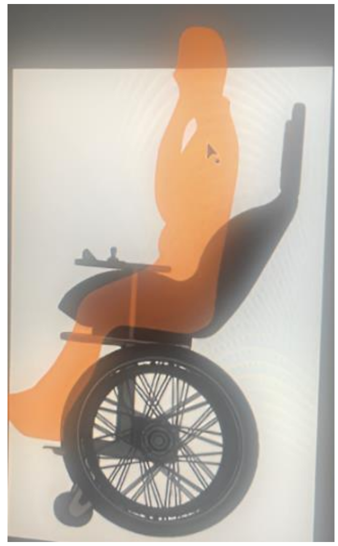

Fig. 9 Ergonomic chair

3.2. Chair Weight

In this section, data was taken from the structure weight, the lifting system, and the weight of the electric batteries. Lithium batteries are the lightest, weighing just 2 or 3 kg. [8]. The electric wheelchair weight is 18 kg without counting the batteries, and the linear actuator weight that will be used to lift the chair is 2.5 kg each; in this chair, a pair will be used for its operation. This gives an electric wheelchair weight of 26 kg, but adding the accessories weight that can be installed in the chair, an additional 12% weight is estimated for the chair.

The result of the electric wheelchair weight would be 29 kg. This calculation can also consider external factors to the electric wheelchair, such as backpacks, bags, food or any external factors the passenger wants to carry. With this, a total weight of 30 kg is calculated for the electric wheelchair. The project for this chair is designed for adults over 18 years old, and the maximum weight supported by the chair will be 90 kg. The person's weight, adding the chair weight, would give us a total of 120 kg.

3.3. Pending for the Chair Power

In the streets, there are different angles of elevation, and this electric wheelchair must respond to the obstacles so that the user can move normally; being able to move within the city with different angles of inclination will benefit this chair.

The design conditions according to the angle of inclination for a ramp must have a level difference of 0.26 to 0.75 and must not exceed 10% of inclination for a slope according to regulations set by the regulations for disabled people and older adults. [9]. The slope on a ramp is measured as the result of the height to be saved and the distance of the section in the horizontal plane multiplied by 100. [10].

$$Pendiente\ (\%) = \frac{H}{D} X100 \tag{1}$$

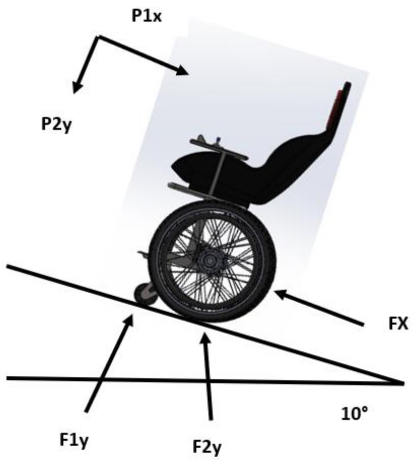

Fig. 10 Chair on a slope

Diagram of a slope for an elevation angle of 10° as shown in Figure 10.

3.4. Study for the Chair Power

Power is measured in Joules per second. For a power calculation for the acceleration of the motors that will move the chair, the formula can be used.

$$P = \frac{W}{T} \tag{2}$$

P= Power (Watts)

W= Work (Joule)

T= Time (seconds)

$$P = F * V \tag{3}$$

P= Power (J/s)

F= Force (N)

V= Speed (m/s)

In practical terms, voltage is categorized in Volts (V) and intensity in Amps (A), but for electrical power, the unit of measurement is the Watt, which is included in the international system. For a better calculation, horsepower (HP) will be used.

$$1\,Hp = 745.7\,W \tag{4}$$

The kilowatt-hour is used as a unit of measurement used to record electricity consumption over a period of time. For the calculation of power, a 10% slope was studied. The wheel of the electric wheelchair will be made of rubber, and its physical characteristics in static friction coefficient is 0.72 [11]. A maximum speed of 6 k/h on a flat surface will be taken as a reference, and this data is taken since it is the average speed of a common electric wheelchair.

3.5. Power Development for a 10% Slope

The maximum power with the weight that will have to be moved by the chair will be found using the following formula:

$$W = m * g \tag{5}$$

$$W = 1177.2\,N$$

This electric wheelchair will consist of 2 electric linear actuators of model DHLA1300; the energy consumption will be given by 12V consumption actuators that will be powered by the 2 batteries that will be adapted to the wheelchair; it must give us 478.45W to be able to achieve this fluid movement that the chair will need to be able to move.

$$F = ma + Frr \tag{6}$$

$$F = 1563.984\,N = 159.4819\,Kgf$$

3.5.1. Power Calculation

$$P = V * F \tag{7}$$

$$P = 956.8914W$$

$$P = 956.8914W * \frac{1Hp}{745.7} = 1.3\,Hp$$

The speed obtained for 6 K/h of the chosen motor will have to be able to supply electricity at 956.891W or 1.3 Hp. The project for this electric wheelchair includes 2 rear wheels in charge of moving the chair.

3.6. Lifting System Specifications

Table 7. Linear actuator datasheet

Product description and features	
The DHLA1300 linear actuator is an electrical device that converts the motor's rotary motion into a push rod movement, and it has many applications within the industrial world due to its easy use and installation.	
Lead screw type	Trapezoidal thread
Input voltage	12V
Maximum load	130 kg
Maximum race	1000 mm
Level of protection	IP54

Table 7 explains the specifications of the lifting system with the DHLA1300 linear actuator for the chair's operation.

3.7. Installation Diagram of the Chair for Movement

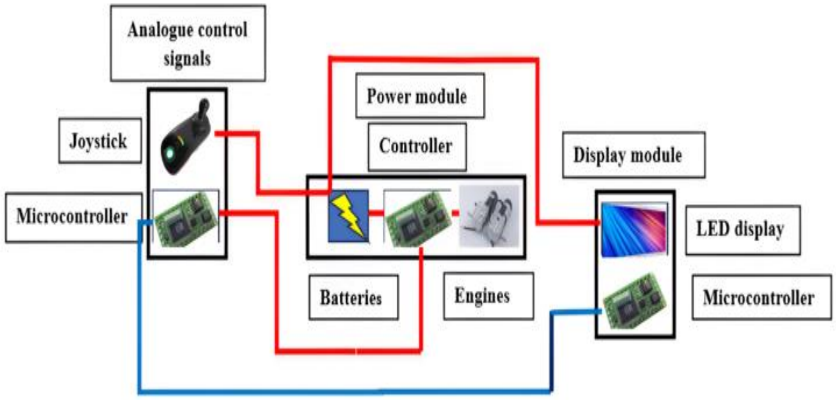

Fig. 11 Motion installation diagram

- Analogue Control Signals
  - Joystick
  - Microcontroller
- Power Module
  - Controller
  - Batteries
  - Engines
- Display Module
  - LED display
  - Microcontroller

3.8. Lifting System Installation Diagram

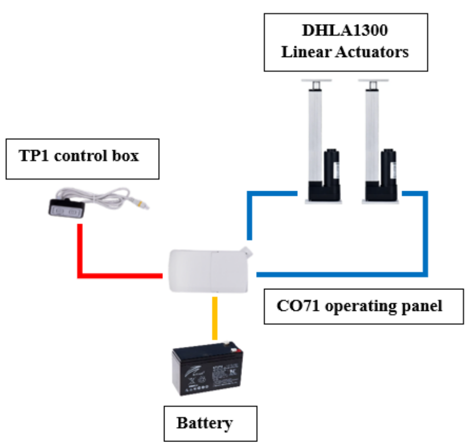

Fig. 12 Lifting system installation diagram

- DHLA1300 Linear Actuators
- Batteries
- CO71 operating panel
- TP1 control box

4. Results

Table 8. Table of results obtained from the chair

Description	Result	Equation
Maximum power with weight for chair movement with a 10° ramp.	1177.2 N	(5)
Power consumption of 2 batteries suitable for the chair motors.	478.45 W	(7)
The average speed of the wheelchair.	6 K/h	(4)
DHLA1300 Linear Actuator (Electric device responsible for chair lifting)	- 12V voltage. - Maximum load 130 Kg. - Maximum stroke 1000 mm.	
Electric power for the desired speed.	1.3 Hp	(7)
Maximum load of the chair.	90 g	

4.1. Strength of the Structure by Simulations

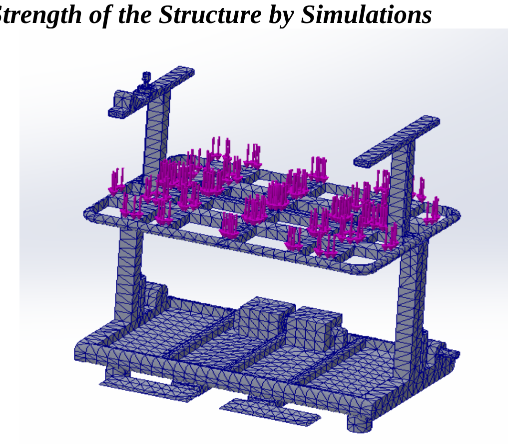

Fig. 13 Simulation applying a mesh

Figure 13 shows a simulation of applying restraints and weight around the entire contour of the chair and then covering it with a standard mesh for static analysis.

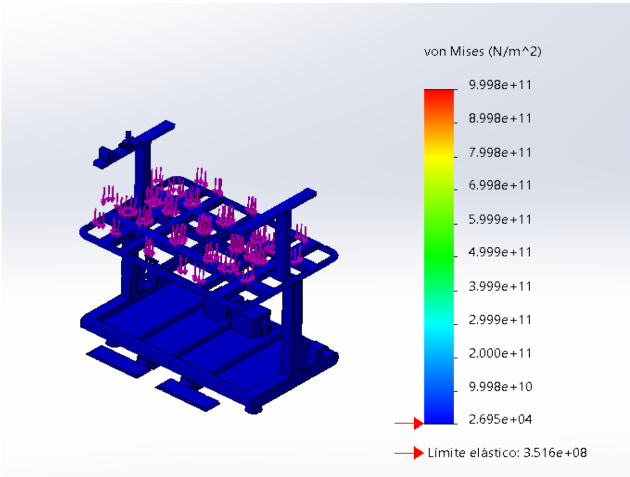

Fig. 14 Lifting system load diagram

Figure 14 shows a simulation accepted by the SolidWorks program where it can be seen that the structure's weight is acceptable, demonstrating once again that the structure's resistance complies with all safety regulations. A tensile strength test in the simulation was carried out in SolidWorks, where it can be seen that applying 588.60 N to the upper base part of the chair where the person will be sitting shows a minimum load, indicating that it can support the weight.

5. Conclusion

The design of this wheelchair with an electromechanical lift system for people with lower limb disabilities contributes to their independence when moving around and performing daily activities. This system allows people with lower limb disabilities to easily access their beds, as the armrests can be folded horizontally. The footrest can also be adjusted to the height of the feet, allowing for unobstructed access if necessary. This wheelchair design allows users to access their beds more economically, as they are inexpensive to manufacture and easy to maintain, allowing them to perform it themselves. Finally, the ergonomic seat supports the patient without discomfort or fatigue. The proposed design for the structure of this electromechanical lift chair is designed to support maximum loads of 90 kg, which was validated by the SolidWord program. The DHLA1300 lift system was chosen for its efficiency, as it can elevate and support the person throughout the day. During the design and calculations for the electromechanical lift chair, the power of the selected motor is estimated to be 1.3 HP. The maximum power found for 10° slopes is 1177.2 N, and the power consumption for the two motors used to move the chair will be 478.45 W.

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