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Tesis

Design of a Therapeutic Crane with Rehabilitation Monitoring for Patients with Reduced Mobility

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Design of a Therapeutic Crane with Rehabilitation Monitoring for Patients with Reduced Mobility

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Abstract— The present investigation has designed a therapeutic crane that helps patients who have lower body problems. As an alternative to the lack of equipment for physical rehabilitation, which leads to the reincorporation of people with reduced mobility to their activities of daily life, the objective proposed to solve the problem is the design and construction of a therapeutic crane with a system to monitor the rehabilitation process. The design and the solution were carried out based on the needs presented by the clinical areas in the implementation of rehabilitation technology that facilitates and promotes a better therapeutic process for patients. In addition, this therapeutic crane has functional duality, it is used for gait training with the support of the bodyweight that allows walking upright; as well as helping patients with cognitive impairment in the standing process; also, it has two vertical curved rails that help support the feet with hand restraints and offers a safe and functional environment, lifting a maximum weight of 180 kg of mass and a height of up to 1.95 m. The solution focuses on the construction of a square tube structure that forms an arch, has a handrail for holding the patient offering firmness and stability; providing the security of a device of reliability and easy handling; since it only requires an operator to monitor the process and an accessible environment for commissioning.

Keywords— Physical Rehabilitation, Reduced Mobility, Therapeutic Device, Therapeutic Control System, Robotized Gait Training.

I. INTRODUCTION

Walking is one of the fundamental actions of the human being, that is the reason for developing tools for ongoing rehabilitation, to help a partially immobile person who has difficulties when walking without assistance. Immobilization generates different internal changes which affect the muscle and bone masses, especially the lower extremities. Therefore patients, and especially the elderly, are likely to be at increased risk for injury after wondering [1].

In certain rehabilitation centers, the relevant equipment is not available to reincorporate people with reduced mobility to their activities of daily life as a result of a disability. In Peru, there are around 3 351 919 disabled people, which is equivalent to 10.3% of the population and 31.2% resides in Lima, according to age groups, the highest percentage 59.4% falls on older adults with mobility disabilities, who have difficulties to walk or use arms and legs [2]. Currently, a patient with a disability of this type requires rehabilitation to help the patient get going with partial weight support.

Difficulties in walking have a great impact on people with a low quality of life and self-independence, being a burden for their health units and their families. That is why it is necessary to recover their lower extremities almost 100%, in recent years several devices have been proposed with gait rehabilitation approaches, through training systems, being necessary the interactions of the environment, function, and adaptation for a recovery of the march [3].

However, in the Peruvian environment, it is not available a device that allows a quantitative and qualitative evaluation of the rehabilitation process. There are methods of rehabilitation for lower limbs where you want to improve your gait and assist those who suffer from it [4].

In this sense, the opportunity to develop this project is presented. This project has the aim to design and build a therapeutic device with a wired control system for the physical rehabilitation of patients with reduced mobility. It is an alternative to help physiotherapists in rehabilitation activities, which shows the modeling and simulation of a therapeutic system for the rehabilitation of lower limbs. That is why, in recent years, various devices have been proposed to participate in rehabilitation.

Therefore, this study uses the methodology created by the Association of German Engineers VDI (Verein Deutscher Ingenieure) 2222, applied to the design of innovative technology by considering the requirements, process functions, optimization, economic evaluation, selection of prototypes, and development of the device through simulation and/or execution of the prototype. Also, this study will be responsible for implementing the technology and automation required to control the device, thus replacing human effort with mechanical effort and improving the quality of life of the patient.

II. STATE OF THE ART

A. Rehabilitation

Rehabilitation encompasses a set of interventions that are necessary when a person experiences or is likely to experience limitations in their daily life because of aging or a health problem, such as a chronic disease or disorder, injury, or trauma. It can be limitations such as having difficulty thinking, seeing, hearing, communicating, moving around, relating to others, or keeping a job. it is an essential component of universal health coverage, along with the promotion, prevention, treatment, and palliative care [5].

Also, rehabilitation is a set of interventions designed to optimize functioning and reduce disability in individuals with health conditions in interaction with their environment. Health conditions refer to illnesses (acute or chronic), disorders, injuries, or trauma. A health condition can also include other circumstances such as pregnancy, aging, stress, a birth defect, or genetic predisposition. Rehabilitation is one of the essential services defined in Universal Coverage [6].

Rehabilitation engineering can be defined as: "The application of technological solutions to the different problems that people with disabilities may face in their daily lives." At present, because of the accelerated advance in technologies for rehabilitation applied in therapies, a diversity of concepts focused on new technologies in rehabilitation can be proposed [7].

Physical Rehabilitation is one of the fundamental tools in the rehabilitation of patients with sequelae of neurological disorders. Physical therapy sessions are based on stimulation exercises that aim to activate and reactivate certain behaviors, movements, or actions of a patient with deficiencies, limitations, or disabilities. Rehabilitation has used the concept of virtual reality to improve alternatives and options for new treatments, which stimulate the results of physical therapies, thus enabling the person to have a better experience in the physical activity carried out within their treatment, and in the case of motor rehabilitation patients, to achieve the attention, concentration, and fun of the patient in the tasks to be performed [7].

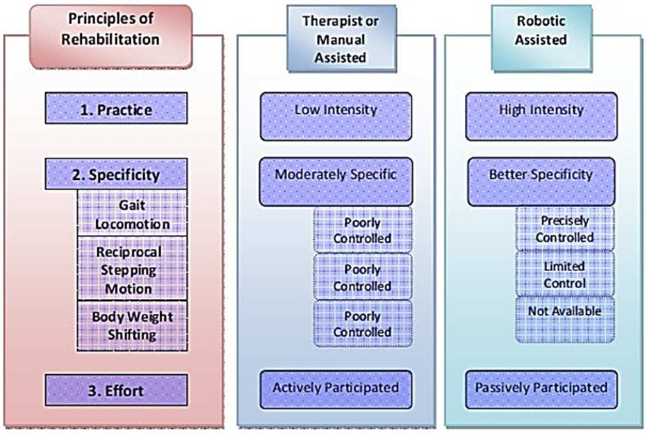


Fig. 1 Principles of rehabilitation. Source: Huat K, Recent Development and Trends of Clinical-Based Gait Rehabilitation Robots, [2015].

B. Reduced mobility

It is the restriction to move that some people have due to a disability or without being disabled, present some type of limitation in their ability to relate to the environment by having to access or move within a space, save unevenness, reach objects located at normal heights [8].

Disability conditions are becoming more frequent in the population. For this reason, the design and implementation of functional rehabilitation systems in automated virtual environments and biomedical technologies are evolving, which can be added by the centers that offer health services, every day there are new incorporations of technological advances that are being used in rehabilitation, which proves to be treatment alternatives to help improve the health condition of patients [7].

Likewise, gait disabilities are frequently observed in people suffering from Parkinson's disease (PD) where follow-up is difficult for a doctor since they are limited to observational information that turns out to be routine and subjective, where evaluations are usually be limited [9,10]. Because of the continuous analysis of these gait parameters when monitoring it during the disease, it could allow a biomarker of the stage of the disease, allowing the adoption of personalized treatments [9,10,11,12,13].

C. Therapeutic Device

A therapeutic device is defined as an instrument, apparatus, or machine that is used for the prevention or treatment of diseases, thereby optimizing the motor functions of the patient. The World Health Organization and its Member States have recognized this in several World Health Assembly resolutions that highlight the importance of health technologies, and in particular medical devices (see Figure 2), to prevent, diagnose and treat ailments, diseases and disabilities and improve health and quality of life [14].

Fig. 2 Rehabilitation device with handrail. Source: Munera M., et al., Lokomat therapy in Colombia: Current state and cognitive aspects, [2017].

Various devices and tools can be found to assist in the recovery process to lessen the risks of fall trauma. Some of these devices help the patient to walk (see Figure 3), designed with a certain number of degrees of freedom, in such a way that they do not impede the kinematics of the walking movements and can be coordinated employing an automated control to improve movements in the patient (see Figure 3), this equipment is expensive and have limited availability in rehabilitation centers [15].

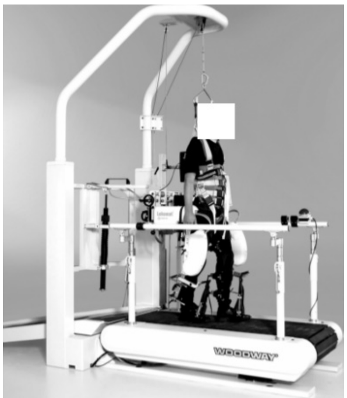


Fig. 3 Device that helps the patient to walk. Source: Lunenburger L., Colombo G., Riener R., and Dietz V., Biofeedback in gait training with the robotic orthosis Lokomat, [2004].

It should be noted that within these technological proposals the use of programs that allow the creation of dynamic applications to rehabilitate functions has been implemented; the great advantage of this implement is that they are available to therapists and can be configured according to the patient's needs [16].

D. Therapeutic control system

Rehabilitation systems have a human-machine interface (HMI), usually on a personal computer, allowing the user to see the patient's interaction with the exoskeleton and the evolution throughout the therapy [16].

III. MATERIAL Y METHOD

A. Tools and material

This research used material for the construction of the structure and for the electronic support of the therapeutic device, which is specified in Table I:

TABLE I. MATERIALS USED FOR THE CONSTRUCTION OF THE THERAPEUTIC DEVICE

Device parts	Materials	Measure	Size	Use
Structure	Nylon	1.5 "x45	65 cm	
	Round tube	2 mm	2 m	Railing
	Iron	1/8 "	1.2x2.4 m	Covering
	Wheels	4x2 "	Unit	-
	Slide DN150	-	Box of 2 units	-
	Rail tube	2 x 2"	6 m	-
	Square tube	4x2 "	6 m	Structure
	Hex Bolt	3/8 "	-	-
	Dipstick	1/2 "	1 m	Interns
Electronic	Electric piston	-	-	Elevation
	Diode bridge	-	-	Rectification
	Transformers	-	-	Electrical power supply
	Arduino Mega	-	-	Controller
	Keypads	-	-	-
	Bluetooth module	-	-	Communication with control Sensor piston height
	Sharp sensor	-	-	-

B. Research site

The research was carried out at the Zarate clinic, a Rehabilitation Center. This work was carried out in 6 months, from November 2020 to April 2021.

C. Investigation Procedure

This research was carried out taking into account the four stages of the VDI 2222 method. The planning stage was to design and build a therapeutic crane with a system to monitor the patient's rehabilitation process. In the conception stage, the operation of the therapeutic device is devised, which has two main functions, the first is that it will help the patient in the process of walking with minor disabilities and the second will serve for the process of standing in delicate patients of health that cannot stand up, it is a device that adjusts to the requirements of the patient.

The purpose of the design stage is to make the sketch that allows visualizing on a plane the different pieces that will be assembled for the elaboration of the device. In the design development stage, the net profit points are found as part development, device shapes are taken to simulation tests to have the desired control and obtain an efficient and feasible technology; likewise, the verification of costs, through the determination of the requirements of construction material, tools used and labor, proceeds to the construction of the structure and integrate the electronic components, this phase culminates with the functional test of the device.

1. Customer Requirements

With the help of a rehabilitation graduate, the need for a rehabilitation device that supports body weight and that can differentiate the point of support of both the left and right legs is manifested. These requirements are shown in Tables II and III.

TABLE II. SPECIFIC REQUIREMENTS

N°	Requirements of the Client
1	Independent control of each arm
2	Mobile Machine
3	Low cost
4	Easy Use System
5	Allow wheelchair entry
6	Allow the entry of treadmill

TABLE III. CHARACTERISTICS OF REQUIREMENTS

N°	Characteristics of requirements
1	Crane dimension
2	Feeding system
3	External Sensors
4	Internal Sensors
5	Wired Control
6	Security Protocol
7	User friendly interface
8	Item Cost

2. List of Requirements

After reviewing the client's and user's requirements, they are classified into two groups: Desires (D) and Demands (E). Table IV shows this classification.

TABLE IV. CHARACTERISTICS OF REQUIREMENTS

N°	W/R	Characteristics	Values
1	R	Length	-
2	R	Width	-
3	R	High	-
4	R	Source feed	220CA
5	W	Operation Time	4 hours
6	R	Cost	< S/ 6 000
7	R	Good aspect	-
8	R	Easy Repair	-
9	W	Low Environmental Impact	-
10	R	Safe	-
11	R	Manual control	-

3. Black Box

An alternative is the generation of the concept is present in the division of functions. With a global scheme of inputs, processes, and outputs, also known as the black box of processes, the internal functions of the process are further disarticulated [17]. The input signals shown below are the power, which is composed of voltage and amperage, the control direction composed of the actuators of the system, and the activation composed of electronic components. The output signals identify the displacement of the pistons and the standing of the person.

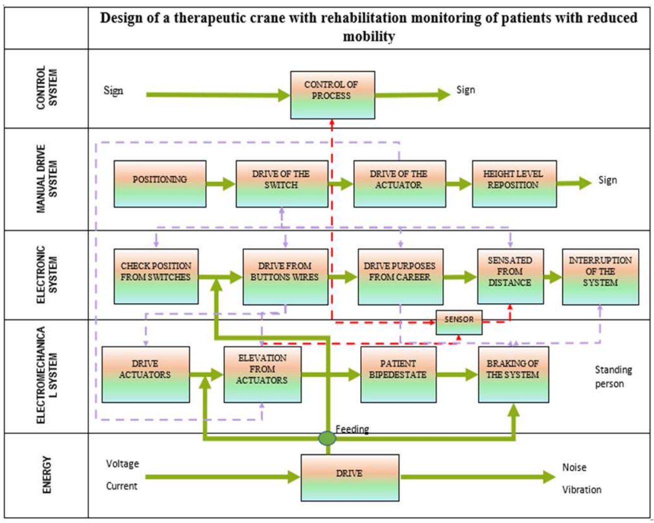
Fig. 4 Black Box

4. Structure of Functions

In the disarticulation of the concept, different functions and sub-functions are presented to which different alternative solutions must be sought [17].

Five fundamental elements were identified for the device: Control System, Manual Drive System, Electronic System, Electromechanical System, and Energy.

TABLE V. DESIGN STRUCTURE OF THERAPEUTIC CRANES



5. Morphological Matrix

Based on the solution alternatives, a matrix will be created to select the possible routes and solutions to the project problem [17]. For the design of the machine, we take into account different parts, separated by the operation. In each solution, the different combinations of these parts will be observed, to reach the best option in our final design.

TABLE VI. MORPHOLOGICAL FACTORS

6. Analysis of the possible alternatives to find an optimal solution that satisfies the system requirements

According to the analysis shown in Table VII and considering the weights assigned to the importance of each criterion for users, the concept of solution 2 is the most appropriate because it achieves the highest possible score compared to the other 3 concepts of the solution, so this will be the one chosen to carry out the Rehabilitation Crane.

TABLE VII. WEIGHT TABLE

QUALIFICATION	WEIGHT
BAD	1
WELL	2
VERY GOOD	3
EXCELLENT	4

TABLE VIII. ANALYSIS OF VIABLE SYSTEM SOLUTIONS

TECHNICAL AND ECONOMIC CRITERIA	PROJECTS										
	FACTOR*	SOLUTION 1		SOLUTION 2		SOLUTION 3		SOLUTION 4		IDEAL SOLUTION	
		WEIGHT	TOTAL	WEIGHT	TOTAL	WEIGHT	TOTAL	WEIGHT	TOTAL	WEIGHT	TOTAL
FUNCTION	3	4	12	4	12	2	6	4	12	4	12
RELIABILITY	2	4	8	4	8	1	2	4	8	4	8
DESIGN	3	1	3	3	9	4	12	4	12	4	12
STABILITY	1	4	4	2	2	4	4	2	2	4	4
MANUFACTURING	1	1	1	2	2	2	2	1	1	4	4
SECURITY	4	4	16	3	12	4	16	2	8	4	16
IMPLEMENTATION COSTS	4	1	4	3	12	1	4	1	4	4	16
OPERATING COSTS	3	1	3	2	6	1	3	1	3	4	12
MAINTENANCE	1	2	2	2	2	1	1	2	2	4	4
ERGONOMICS	1	3	3	3	3	4	4	4	4	4	4
IMPLEMENTATION	2	1	2	3	6	3	6	2	4	4	8
TOTAL			58		74		60		60	44	100

* The Factor goes from 0 to 4, in ascending order. Mark the importance for the project.

D. Design of the Therapeutic Device

The main objective of this research was to design and build a therapeutic device with a control system to constantly monitor the progress of the rehabilitation process of patients with reduced mobility. The development of the device began with a prior evaluation of the commercial teams and then the Solidworks software was used to design the structure of the device (see Figure 5) and parts of the device.

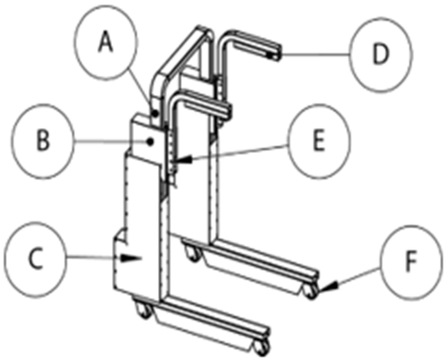
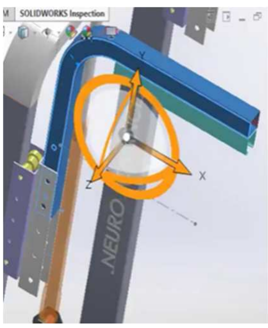


Fig. 5 Parts of the design

TABLE IX. SPECIFICATIONS

DEFINITION	
A	Metallic Structure
B	Mobile platform
C	Metallic Coating
D	The track
E	Height Levels
F	Wheels



(a) (b)

Fig. 6 (a) Height adjustment system and (b) representation of the adjustment system in an angle of inclination.

The design is related to the patient's requirements, among the most important aspects is considered. The equilibrium relations, considering the forces acting on the mechanism, the stresses to which it is subjected, and the constitutive relations of the material to be used. The simulation in 3D Software (SOLIDWORKS), allows us to corroborate the veracity of the analytically calculated data.

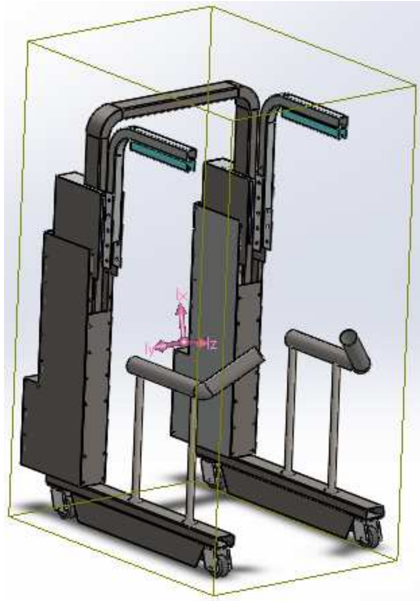
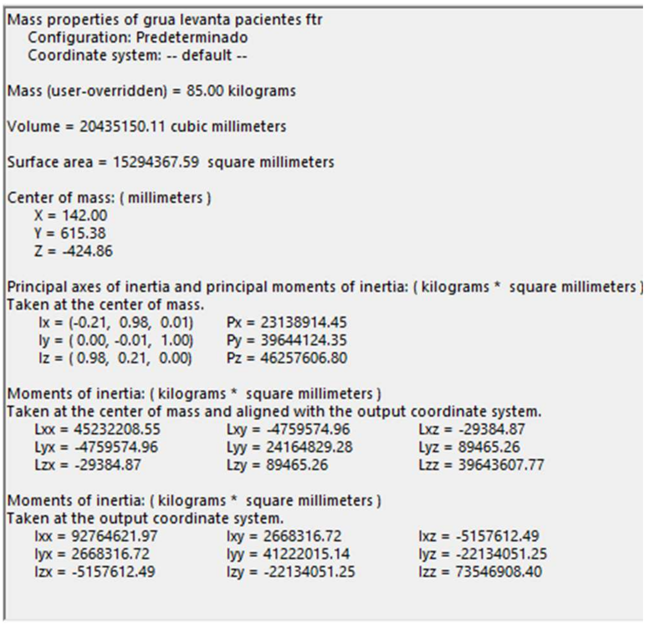


Fig. 7 Representation of the design and the technical data analyzed in SOLIDWORKS.


Mass properties of grua levanta pacientes ftr
Configuration: Predeterminado
Coordinate system: -- default --

Mass (user-overridden) = 85.00 kilograms

Volume = 20435150.11 cubic millimeters

Surface area = 15294367.59 square millimeters

Center of mass: (millimeters)
X = 142.00
Y = 615.38
Z = -424.86

Principal axes of inertia and principal moments of inertia: (kilograms * square millimeters)
Taken at the center of mass.
Ix = (-0.21, 0.98, 0.01) Px = 23138914.45
Iy = (0.00, -0.01, 1.00) Py = 39644124.35
Iz = (0.98, 0.21, 0.00) Pz = 46257606.80

Moments of inertia: (kilograms * square millimeters)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 45232208.55 Lxy = -4759574.96 Lxz = -29384.87
Lyx = -4759574.96 Lyy = 24164829.28 Lyz = 89465.26
Lzx = -29384.87 Lzy = 89465.26 Lzz = 39643607.77

Moments of inertia: (kilograms * square millimeters)
Taken at the output coordinate system.
Ixx = 92764621.97 Ixy = 2668316.72 Ixz = -5157612.49
Iyx = 2668316.72 Iyy = 41222015.14 Iyz = -22134051.25
Izx = -5157612.49 Izy = -22134051.25 Izz = 73546908.40

Fig. 8 Technical data analyzed in SOLIDWORKS.

The data of the longitudinal restrictions of the crane and the maximum weight of the person is used for the monitoring chart as well as for the simulation.

The height regulation system (see figure 6), taking into account the different heights of patients in rehabilitation.

TABLE X. DIFFERENT PISTON MAGNITUDES

PISTON POSITION DIMENSIONS		
HIGH POSITION	Minimum Lift Height (2% Tolerance)	166 cm
	Maximum Lift Height (2% Tolerance)	195 cm
HIGH MIDDLE POSITION	Minimum Lift Height (2% Tolerance)	160 cm
	Maximum Lift Height (2% Tolerance)	189 cm
LOW MIDDLE POSITION	Minimum Lift Height (2% Tolerance)	154 cm
	Maximum Lift Height (2% Tolerance)	183 cm
LOW POSITION	Minimum Lift Height (2% Tolerance)	148 cm
	Maximum Lift Height (2% Tolerance)	177 cm

IV. RESULTS AND DISCUSSION

A. Prototype of the therapeutic evice

The therapeutic device (as shown in Figure 7) is made up of a metallic structure as a support piece for the electronic components, which was made with a square tube.

(a) (b)

Fig. 9 View of the prototype of the therapeutic device. (a) Side view of the prototype and (b) View of the prototype with a user.

B. Results of the performance test

After assembling the therapeutic device, the next stage is the functional and performance test. A bump test is carried out to ensure that the device can function properly. This work is done to test all parts and ensure that all components can function as expected. Once the device works correctly, performance tests are carried out, for which the path developed by the pistons is determined according to the weight and height of the patient, as indicated in Table X.

TABLE XI. DEVICE OPERATION TEST RESULTS

PATIENTS	Date	Session No.	Weight	Size	Piston Status	
					For Minimum Weight (mm)	For Maximum Weight (mm)
A	Mar-22	1	70	1.64	20	18
B	Mar-23	2	65	1.7	24	22
C	Mar-24	3	90	1.8	27	24
D	Mar-25	4	56	1.5	16	12
E	Mar-26	5	70	1.6	18	16
F	Mar-27	6	80	1.8	27.36593878	25.71276445
G	Mar-28	7	75	1.7	22.71985314	20.24114754
H	Mar-29	8	65	1.67	21.48642048	18.83913848
I	Mar-30	9	60	1.62	19.57769935	16.71491676
J	Mar-31	10	58	1.5	15.66014782	12.54318562

Trial and Error Heights (A–E); Heights Proposed by the Software (F–J)

C. INDICATIONS AND CONTRAINDICATIONS

For the indications and contraindications, the ergonomics of the patient and the different positions reached by the piston are considered (see Table X).

Indications

- Low position, recommended for patients from 1m to 1.30m.
- Low medium position, recommended for patients from 1.20m to 1.50m.
- Medium-high position, recommended for patients 1.40m to 1.70m.
- High position, recommended for 1.60m to 1.85m patients.

Contraindications

- Patients weigh more than 140kg.
- The patient has joint pain.
- Patients with heights greater than 1.90m.
- Pregnant women.

V. CONCLUSIONS

A standing machine has been manufactured, which allows continuous, repetitive, and safe mobility during the patient's rehabilitation process. The standing machine has a total weight of 80 kg with all its mechanisms and components, and its maximum dimensions are 130 cm high in the upright position, 110 cm long in the normal position, and 70 cm wide in all its positions. It can bear a maximum weight of 150 kg.

The calculations were consistent for the manufacture of the standing machine, these data obtained were validated with the use of the SOLIDWORKS computational tool under critical operating conditions.

After subjecting the standing machine to tests, it was concluded that it meets the basic needs that a patient with a disability in the lower limbs needs for their rehabilitation process, without causing any difficulty due to its intuitive, effective, and easy-to-use control system. handle.

It was concluded that it is necessary to take the anthropometric measurements of the patient, weight and make an evaluation of the patient's condition, to achieve a personalized treatment.

The current system carries an open-loop control. In future work, it is recommended to add the closed control loop, since the distance sensor and the linear pistons can carry this type of control. This would lead to being able to compensate the height of the pistons concerning the height of the patient automatically.

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