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Development of a Semi-Automatic Patient Lift Vehicle for Bedridden or Wheelchair-Bound Persons With Reduced Mobility

José Alonso Dena-Aguilar[1], Enrique Javier Martínez-Delgado[1], Víctor Manuel Velasco-Gallardo[1], Edgar Zacarías-Moreno[1], Ludovico Hernández-Aguilar[2], and Ruth Elizabeth Martínez-Escobedo[1]

[1]Tecnológico Nacional de México Campus Instituto Tecnológico de Pabellón de Arteaga, Pabellón de Arteaga, AGS 20670, Mexico
[2]Tecnológico Nacional de México Campus Instituto Tecnológico de Reynosa, Reynosa, TAMPS 88730, Mexico

ABSTRACT

Users with motor disabilities who are bedridden or in wheelchairs depend on the assistance of third parties to perform routine mobility movements through transport and/or transfer actions. This generates physical wear and tear on the assistant and the risk of injury or lumbar disease that may even lead him/her to stop assisting the patient. This article presents the development of a low-cost semi-automatic patient lift vehicle for bedridden or wheelchair-bound people with reduced mobility. The equipment was designed and built using specialized manufacturing techniques and mechatronic methodologies to provide operational stability and mechanical control of the equipment's linear travel and lifting movements. The designs of the equipment were obtained using Solidworks®. The semi-automatic patient lift vehicle support structure was manufactured based on dimensions declared on ISO 10535 standard and using readily available materials of proven resistance, considering a mobile structure composed of a wheeled base, a mast and an ergonomic pendant were attached to several stability points. A mechatronic remote-control system was developed using an Arduino® UNO electronic board with its respective programming platform. The remote-control interface was developed using the App Inventor® application and by means of a mobile device the up and down control of the patients in the proposed prototype was achieved. Design and prototype construction allows and adequate lifting and transport of patients with no difference on age, height, weight and gender due to the statistical analysis applied determined that design of semi-automatic patient lift vehicle is adequate to accomplish the purpose of patient lifting indistinctly of weight, height and route type. Nevertheless, improvements must be done as a future work in order to have a better prototype considering the handling of the caregiver person for the operation. The semi-automatic patient lift vehicle was put into operation directly in public social assistance centers (DIF Municipal and Centro de Atención Múltiple VIII) located in Pabellón de Arteaga City, Aguascalientes, Mexico.

Keywords: Patient lift vehicle, Disable people, Automation

INTRODUCTION

Motor disability is generally manifested as a limitation in moving, climbing or descending that includes a total or partial decrease in mobility characterized by a total or partial difficulty of motor skills of the body (Peñaloza-Gómez *et al.*, 2022). In Mexico, in 2010, 5.1% of the national population had some type of disability, mainly on people of 85 years old or older, where 58.3% of them had a motor disability (Bonilla-Muñoz and Torices-Rodarte, 2019). In this context, at America, the population of adults over 60 years of age is growing at an annual rate of 3% to 5%, having in this population age range a higher probability of developing chronic diseases that are one of the causes for motor disability (Dueñas *et al.*, 2006). In this scenario, adults over 50 years of age with motor disabilities acquired in different stages of their lives, need a series of attentions and care associated with dependence of people or caregivers, in order to be able to deal with their conditions and daily life activities (Venturiello, 2014). A caregiver is a person who assists a patient with a disability by providing informal and unpaid cares, in 80% of the cases, it is a family member or close friend of the affected person, being mainly women who assume first role of caregiver (Argimon *et al.*, 2003; Mboungou-Hechevarría *et al.*, 2018). Caregiver attends physical and emotional needs of the person with motor disabilities, both at home and outside home, nevertheless, this role leads to stress situations and burdens that increase the risk of suffering physical, social, emotional and other problems as well (Moreno *et al.*, 2004; Marco *et al.*, 2010; Navarrete-Llamuca and Taipe-Berronez, 2023). That's why has been used to develop assistive devices that allow people with disabilities to perform their daily activities with greater independence. In this context, a patient lift vehicle (with a weight between 110 kg and 160 kg) is the ideal system (although high cost) to move or sit with minor effort patients with disabilities, due to the system bases its function on up and down patient in a controlled manner, because this equipment have a steel chassis that have wheels, hangers and fastening chains, and have also a lift system that could be manual or electrical (Sánchez-Zaplana and Buj-Fernández, 1991). Although there are several options on market, several brands and types of lifting systems for people like, MediCare Mexico, OrtoWeb Medical, Hergom Medical, among others, their availability and cost make these don't be an accessible option for must of people with the need of one of these systems. It is therefore, that have been presented various studies, designs and construction of patient lift vehicle for patient move or elevation with the purpose of have more options, improve functionality or reduce costs of these devices. Just for mention some of them, Astudillo-Flores (2019) reports an academic work of design and construction of a mobile crane to transport patient, being this of easy maintenance, ergonomic, and easy assembly and disassembly, although costs were similar to market prices. Avilez-Arévalo and Fajardo-Sigua (2019) develop an academic project of design and construction of a mobile crane to transport people where they integrate an electromechanical lifting device to up and down the patients, having cost similar to market prices. Cox-Lozada (2021) describes an academic study of design and construction of a lifting system geriatric crane type for move people under REBA method for evaluate ergonomic risk, he also includes a semi-automatic lift system. Morales-Pérez *et al.* (2022) present several proposals for mechanical lifting devices, which are a lower cost alternative but comply with the ISO 10535 standard. Chung-Luna (2021) shows an academic project on a proposal for the design of a mobile crane for transferring patients with motor disabilities with a control system based on electronic cards and with costs similar to those of the market. Martínez-Delgado *et al.* (2022) describe the design of a device for transferring patients with motor disabilities based on a patient lift vehicle model. where its cost is relatively lower tan market prices for be based on a manual operation with winch system for lifting. This paper presents the design and construction of a semi-automatic patient lift vehicle (PLV) for bedridden or wheelchair-bound people with motor disabilities, manufactured under a conventional PLV design for use as an assistive device capable of helping to reduce physical risks on caregivers during the attention, specially for loading the patients for moving them for daily care. The semi-automatic PLV has the novelty of being remotely operated by means of a mobile device to up and down the patient.

3D MECHANICAL DESIGN

For the development of 3D CAD mechanical designs of a semi-automatic PLV, SolidWorks® software was used in order to define the dimensions, material and operation. Prototype design was defined under a conventional PLV architecture consisting of a support structure (chassis) with (1) a wheeled base with dimensions 1000 × 500 x 100 millimeters (mm) to be able to enter under a bed or resting chair, also through any conventional door, as well as to serve for supporting base for the power motor of the semi-automatic lifting system, (2) prototype has a main vertical mast of 1800 mm long with an 90° attached arm of 850 mm long and 2 reinforced beams 940 mm long to help support the load (weight of a disabled person) to which the prototype will be subjected. Additionally, the mast has a support plate for the mechatronic control system of the semi-automatic hoisting system, and (3) an ergonomic pendant with stability points to hold the lifting harness. Figure 1 shows the isometric design of prototype chassis without the ergonomic pendant harness. Design shows the basic structure of the semi-automatic PLV.

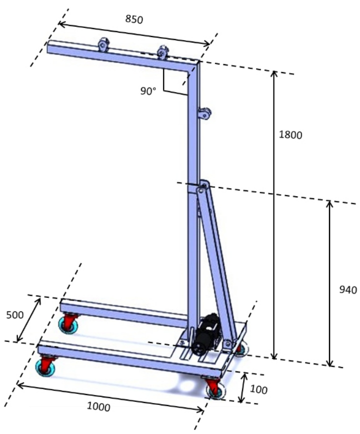

Figure 1: Isometric design of the PLV chassis (source: own).

MATERIALS AND MANUFACTURING TECHNIQUES USED

For the construction of the PLV, advanced manufacturing techniques of cutting, welding, turning, drilling, painting, among others, were applied, as well as the use of specialized of CNC machinery such as LINCOLN ELECTRIC 4400 plasma cutter, DMTG CKE 6150Z CNC lathe, horizontal band saw, LICOLN ELECTRIC micro-wire welding machine and bench drill. Table 1 describes materials used for the various sections of the prototype. For the lifting system, a set of safety guides composed of 2 double wheel pulley and 3 pulleys with bearings were installed on the mast and arm of the PLV to guide the winch cable and distribute the weight of the patient during its mobility. Additionally, the design and manufacturing of prototype allows it to be set into operation through semi-automatic via remote control through the mobile application created for this study.

Table 1. Description of prototype manufacturing materials (source: own).

Section	Description	Remarks
Base, mast, arm and beam reinforcement	Supporting structure made of 2" ASTM A500 structural steel profile	MIG welding was used for joining the parts
Linear scroll wheels	4" red polyurethane slice	4 swivel casters with a load capacity of 40 kg each
Ergonomic pendant	Support structure made of 1" ASTM A500 structural steel profile with 4 stability points	H Model
Harness	Blue raincoat with rigid tape reinforcement at edges and safety straps	One-piece one-size-fits-all seating position practical for caregivers
Semi-automatic lifting system	Winch type, consisting of a DC electric motor with a hook and cable clamp, driven by a safety guide system based on double pulleys with bearings	Weston model 00990 electric winch with 900 kg capacity at 12V, 2 double wheel pulley and 3 pulleys with bearings, LTH model CTX4L-BS motorcycle gel battery
Semi-automatic control box	Rectangular structure made of standard steel sheet	Mechatronic remote control system housing

SEMI-AUTOMATIC CONTROL SYSTEM

In order to facilitate the operation of the PLV, a semi-automatic lifting system was designed and constructed using a Weston model 00990 12V electric winch with 900 kg load capacity hook and cable, which is powered by an LTH model CTX4L-BS motorcycle gel battery. The on/off control of the winch was set for automatic operation. In automatic mode, using the free App Inventor®, a Bluetooth remote interface was designed with an easy interface for user, to up, down, and stop the ergonomic pendant. As safety measures, there is a manual safety button (stop) and lever limit switch with 10t85 roller to stops the winch from turning on when moving up or down. Mechatronic control system was built using an Arduino® UNO board connected to a EB0048720 3-36V 15A PWM DC motor drive provided with heat dissipator and a Bluetooth HC-06 module. Figure 2 shows the constructed mechatronic arrangement. The control algorithm (not presented) was designed in the Arduino® board with the remote application designed in App Inventor®, the operation of the PLV was enabled with the means of a mobile device in a simple way. Figure 3 shows the proposed remote interface where 3 buttons can be observed to up, down and stop the lifting of patient with this prototype.

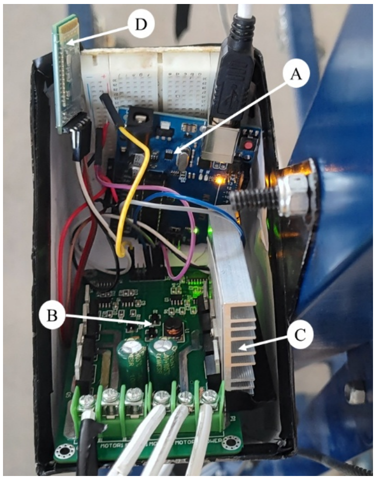

Figure 2: Mechatronic system (source: own). A) Arduino® UNO electronic board, B) EB0048720 driver, C) heat dissipator, D) HC-06 Bluetooth module.

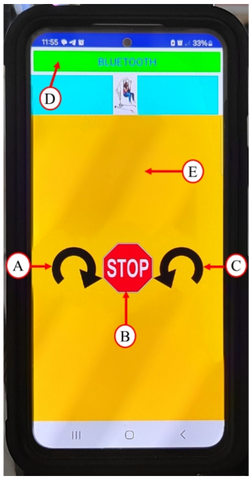

Figure 3: Remote interface of prototype control (source: own). A) Button for moving up, B) stop button, C) button for moving down, D) bluetooth signal activated, E) remote interface IDE design.

MANUFACTURE AND OPERATION

Figure 4 shows the completed semi-automatic PLV manufactured. Figure 5 shows a close-up of the electric winch area.

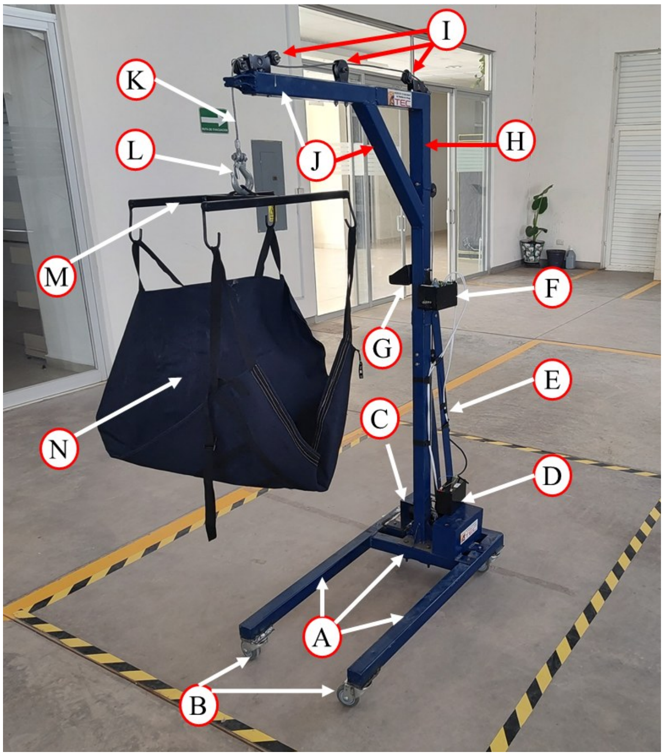

Figure 4: Completed PLV (source: own). A) Base, B) wheel, C) electric Winch, D) battery, E) reinforced beam, F) mechatronic semi-automatic control box, G) cell phone holder box, H) mast, I) double wheel pulley and pulleys with bearings, J) arm, K) cable clamp, L) hook clamp, M) ergonomic pendant, and N) harness.

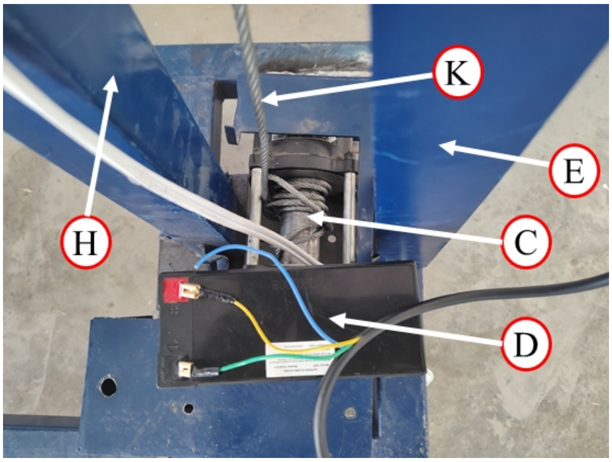

Figure 5: Close-up of electric winch zone (source: own). C) Electric Winch, D) battery, E) reinforced beam, H) mast, and K) cable clamp.

An experimental design was used to validate the functionality of the semi-automatic PLV obtained for lifting and transferring patients. For this purpose, a completely randomized block design (CRBD) reported by Gutiérrez-Pulido and De la Vara-Salazar (2008) was used to determine whether the operability of the semi-automatic PLV for lifting and transferring patients is dependent on the anthropometric measurements (weight and height) of the patients or on the type of course. The results obtained indirectly allowed to define that the design of the semi-automatic PLV is adequate to perform the purpose of lifting and transferring the patient regardless of their weight and height and the type of course. For this purpose, two types of courses were established: (1) Course A.- 8 m total course in a straight line without obstacles and (2) Course B.- 8 m total course with one 90° turn to the left included. The courses were defined as the principal factor (treatments) and the patients as the block factor (blocks). The time (s) of stroke performed by the caregiver [simulating a transfer of a patient from one point (bed) to another (chair)] according to each patient was set as the response variable. All tests were performed indoors. Ten patients were selected (5 men and 5 women) with weights between 45 and 110 kg, heights between 1.45 and 1.85 m and none with any disability. A single caregiver (male, 22 years old, weigh 105 kg and height 1.82 m) was selected for all the tests. The caregiver performed the A course straight ahead and B course in a mixed manner (first section in reverse, reverse turn and second section straight ahead). All the courses were performed by the caregiver at the same cadence (not quantified), but depending on the patient, more transfer time was consumed by the natural maneuvering of the semi-automatic PLV and where it was observed that patients of lower weight and height allowed an almost straight route, while patients of greater weight and height caused slight zigzagging that had to be corrected before continuing the course, which is why more transfer time was consumed. For all the tests, a 3-piece harness (2 for the legs and 1 for the torso) created for this study (not shown) was used. Prior to the tests, the caregiver and all the patients were instructed on how to operate (up, down, and stop) the semi-automatic PLV, as well as the particular conditions of each course. For each patient, each proof was performed in triplicate and the average times were used for ANOVA. Figures 6 and 7 shows the established courses. The times of up or down the patient were not used in the statistical analysis performed. However, on average, the action of lifting the patient (from a lying position in bed to the transport height) consumes an operation time of 18 seconds of the lifting system of the semi-automatic PLV. The action of down the patient (to a sitting position) was not counted. Additionally, and as a demonstration, the stability of the semi-automatic PLV was observed in non-flat terrain (results not presented) where, in general, it was observed that the prototype can move linearly with difficulties, in reverse and according to the type of rough terrain; however, the equipment did not present any fall or effort that would have compromised the properties of the prototype.

Table 2 shows the average times obtained by each patient in each proof. For each patient, the average times of the response variables obtained are registered. Table 3 shows the ANOVA of the CRBD design obtained in

Minitab 19 Statistical Software. The F-Critical value was obtained from theoretical F-distribution tables for 0.05 distribution. In Table 4 and 5, the Tukey pairwise comparisons oriented to the courses and patients are observed, respectively. The values were also obtained by Minitab 19 Statistical Software with grouping of the information by the Tukey method for 95% confidence.

Figure 6: Course A layout. Course has a linear distance of 8 meters. Front wheel was aligned to start line.

Figure 7: Course B layout. Course had a length of 8 meters by 93 centimeters wide. Course had a 90° turn [to left (A)]. Were used traffic signs (located 1 meter separated between them) in order to limit the course. Rear Wheel was aligned to start line of course.

Table 2. Response variables average obtained (source: own).

Course	Operator									
	1	2	3	4	5	6	7	8	9	10
A	25.0	23.8	24.7	23.3	23.4	23.9	25.8	22.4	22.3	26.5
B	42.0	39.5	41.3	39.8	40.4	40.9	43.9	38.6	37.1	44.0

Table 3. Analysis of variance (source: Minitab).

Source	DF	Adj SS	Adj MS	F-Value	P-Value	F-Critical
Course	1	1384.5	1384.5	3218	0.00	5.12
Patient	9	56.24	6.25	14.53	0.00	5.12
Error	9	3.87	0.43			
Total	19	1444.6				

Table 4. Tukey pairwise comparisons: course (source: Minitab).

Course	N	Mean	Grouping	
B	10	40.75	A	
A	10	24.11		B

Means that do not share a letter are significantly different

Table 5. Tukey pairwise comparisons: patient (source: Minitab).

Patient	N	Mean	Grouping				
10	2	35.25	A				
7	2	34.85	A	B			
1	2	33.5	A	B	C		
3	2	33.0	A	B	C	D	
6	2	32.4		B	C	D	
5	2	31.9			C	D	E
2	2	31.65			C	D	E
4	2	31.55			C	D	E
8	2	30.5				D	E
9	2	29.7					E

Means that do not share a letter are significantly different

Considering the established factors and analyzing the ANOVA results, it is established that the type of route and the type of patient (weight and height) affect the response variable. In particular, patients 9 and 10 show be significantly different, which is consistent with the results obtained, since they were the patients with the lowest weight and height (patient 9) and the highest weight and height (patient 10), and where less and more effort, respectively, was invested by the caregiver to transfer the patient. Therefore, it can be concluded that the design and manufacture of the semi-automatic PLV is adequate to be able to perform the function of lifting and transporting people, since it is suitable for performing these functions regardless of the anthropometric measurements of the patient or the type of flat course to be performed. Nevertheless, the operation of the semi-automatic PLV with the target sector of the project should be analyzed to complete the proposed statistical study and, if necessary, to detect areas of improvement for a new prototype design. In addition to the above, the use of the equipment with different caregivers should be analyzed to also rule out this variable according to the strength and cadence that the caregiver may use during the patient transfer movement (future work).

In another context, the design and construction of the semi-automatic PLV was performed according to ISO 10535 standard since the dimensions of the prototype (1000 × 500 × 1800 mm) match the overall dimensions specified by the standard (1100 × 650-840 × 1850 mm). However, the prototype must be evaluated according to the other requirements of the ISO 10535 standard for the adequate clinical validation of these type of devices (future work).

CONCLUSION

It was achieved the design and construction of a semi-automatic patient lift vehicle for lifting patients with motor disabilities bedridden or in wheelchairs according to the dimensions specified in the ISO 10535. The semi-automatic PLV was developed with a remote up and down control system through a mobile interface and by means of a mechatronic system based on an Arduino® UNO and Bluetooth connectivity. The semi-automatic PLV was suitable for lifting and transporting people because the statistical analysis applied, although it was determined that both the type of course and the type of patient (anthropometric measurements) does affect the transfer of people (mobility times), both the design and manufacture of the semi-automatic PLV was relevant and can be used by any person regardless of their weight, height, gender and age. Future work includes developing a new version of the semi-automatic PLV with improved ergonomic and safety standards, as well as full compliance with the ISO 10535 standard. Future work also includes improving the wiring functionality of the mechatronic system and using controller electronic cards with greater processing capacity for better time response in the operation of the prototype. In addition, as a future work will be stablished more experimental designs to have a relation between caregiver abilities regarding to proposed prototype functionality.

SUPPLEMENTARY INFORMATION

The semi-automatic patient lift vehicle obtained was donated to governmental agencies dedicated to the care of people with motor disabilities such as DIF Municipal and Centro de Atención Múltiple VIII located in the Municipality of Pabellon de Arteaga, Aguascalientes, Mexico. At https://www.tecnm.mx/?vista=noticia&id=2820 can be consulted other donations of PLVs with manual lifting system, predecessors of the present work and made in 2022 year. A video demonstrating a semi-automatic PLV movement is available at the link https://youtu.be/clTUO2PaatQ.

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