Design of an autonomous standing frame prototype for older adults with motorized disability

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Abstract: This paper shows the mechanical design of a mechatronic system focused on providing assistance to older adults with motor disabilities. The main objective is to keep these people standing on their lower extremities, facilitating their mobility and at the same time providing greater support to their body structure. The mechanical design of the permanent station was developed using CAD (Computer Aided Drawing) software, including concept design, structural analysis and selection of mechanical actuators; elements designed for this mechatronic system. In addition, it shows the study to ensure ergonomics and safety for users using standards UNE-EN ISO 10535-2006, UNE-EN IEC 60601-1-2010 and EN 13480-2-2002 with the compliance of a structural safety factor through the software CAE (computer-assisted engineering), as well as the adaptability of the design of the system to the various anthropometric measures of the world demographic environment.

1. Introduction

Currently people with a motor disability need a means to mobilize, this means is usually a wheelchair [1], which can cause neuromuscular problems, psychological damage (loss of autonomy) and problems in internal organs [2,3]. This problem arises from the fact that the human body cannot be seated for a long time, which is why it is necessary to implement structures capable of maintaining a standing person giving them support, comfort and facilitating their mobility [4,5,6].

In order to minimize the impact caused by the lack of mobility on the body, mechatronics is applied as a synergistic effect of integration of different areas of knowledge, developing significant advances in areas of medical assistance robotics or rehabilitation as lower or upper extremities. [7,8] or as exoskeletons that assist the user in recovery of movement or permanently [9,10], for specific sectors of the population, such as older adults [11], which over the years have come to accept the use of robots for their assistance or to help them with problems such as mobility within their home [12,13,14], these robots must be able to adjust to the needs of the elderly [15], with the In order to help avoid the social isolation of the same ones that can come to feel due to deterioration of mobility capacity [16] that can often be solved through instrumentation adequate and training on the use of new technologies [17].

The present research is based on the mechanical design of an autonomous standing frame prototype, which is designed to provide independence to the user and improve the quality of mobility of people who have partial motor disability in the lower extremities, the prototype generates the movement of the platform in two axes, with the ability to climb ramps, recognize obstacles and raise the weight of the user to the right position. The fundamental characteristics of this platform is its easy adaptation to the different anthropometric measurements of the population by having a system of adjustable straps and withstanding a load that is greater than the weight of the population average. It also highlights the
ergonomics of the prototype that is tested under the UNE-EN ISO 10535-2006 standard, ensuring that the mechanical design meets the parameters necessary for an ergonomic design.

The research was developed in three stages, the first one collects information from the demographic population, the human anatomy of the target users, all this is included in the design of concepts that allowed to develop the second stage. The second stage develops the 3D model of the structure in conjunction with the joints and drive mechanisms using CAD software. The third stage analyzes the static and dynamic design to assess the safety, ergonomics and mobility of the system using CAE software.

2. Mechanic design

The mobile hosts start its design with the needs of the users (weight, height, safety and comfort) [1], the correct execution of the standing process shown in Figure 1 (a and b used to transport patients with partial disability; c proper posture to get on and off the mobile hosts) and the UNE-EN ISO 10535: 2006 regulations "Cranes for the transfer of persons with disabilities, requirements and testing methods" [18]. This device enables the user to move from a seated position into and maintain an upright position, and to move independently without assistance from a carer. The user is lifted into a standing position by means of a battery-powered electric motor operated by hand control, while the movement of the thoracic support has a safety sensor for the user to stop the standing sequence at any time.

![Figure 1. Automatic standing frame, a) standing posture; b) semi-raised posture; c) sitting posture.](image)

The parameters to be taken into account correspond to performance requirements, ergonomics and safety which are in specific ranges, established in the UNE-EN ISO 10535: 2006 standard. The main parameters are those shown in Table 1. These are taken into account for the design, as indicated in Figure 2, the dimensions comply with the standard and are applied in the present structure, as well as the speed and strength to which the prototype can be subjected. To obtain the adaptability of the equipment to the variable percentile of the users, the concept used to solve this problem is the use of an adjustable strap system that suits the beneficiary to their comfort [19]. The platform to be autonomous requires hollow spaces where the control devices, actuators, sensors and interaction devices are located, critical elements for structural design.

| Parameters                                      | Values             | Denomination in figure 2 |
|------------------------------------------------|--------------------|--------------------------|
| Position of controls                           | Between 800-1200 [mm] | g +h                     |
| Minimum distance between the pedals and the nearest mechanical element | 300 [mm]           | f                        |
| Linear velocity                                 | 0.25 [m/s]         |                          |
| Live load                                       | 120 [kg]           |                          |
| Maximum cylinder force                          | 100 [N]            |                          |

The structure of the prototype must be adapted to the average weight of the global population (62 kg). However, the ISO 10535: 2006 standard suggests establishing the design to support a weight of
120kg, this concept is taken in order to better tolerate the load alive ensuring the correct functioning of the equipment. The Figure 2.a shows the dimensions of the standing platform in its top view, the measurements are defined: a) External width (700 mm), b) Wheel width (246 mm), c) Machine length complement (700 mm) and d) maximum external width between pedals (450mm). The ISO 21542: 2012 standard determines the corridor width is 800mm to 1500 mm, as the maximum external width below the norm ensures that the equipment will be able to move and maneuver easily by facilities that meet this standard. In Figure 2-b the sketch of the side view of the platform can be seen, where: e) Maximum height (1445 mm), f) Height of the leg supports with respect to the base (400 mm), g) Minimum height of the controls (900 mm) and h) maximum height of the controls (1200 mm). These measures comply with the ergonomics requirements regulated in the ISO 10535: 2006 standard.

![Figure 2. Standing frame prototype designed in CAD software; a) top view; b) side view.](image)

In accordance with the material selection criteria: quality, cost, availability and mechanical characteristics specified in EN 13480-2, AISI 1020 steel is selected for the construction of the structure developed with a rectangular tube of (25x50x2) mm. With this material and pipeline, an analysis was carried out using CAE software, applying the load suggested by the ISO 10535: 2006 standard.

### 3. Results

The structure of a mobile host is defined and has its main characteristics regulated according to UNE- EN ISO 10535: 2006. In addition to the form it also stipulates the necessary design loads (120kg live load) and the maximum force that can be applied to the user (100N), finally support standards such as ISO 21542: 2012 [20] were used to regulate the regularized access of wheelchairs to be able to size the equipment correctly for its mobility on ramps and hallways.

| Force | Value [N] | Force | Value [N] |
|-------|-----------|-------|-----------|
| Rw    | 1176      | R2    | 788.49    |
| Rw    | 781.71    | R2x   | 13.64     |
| Rw    | 1083.07   | R2y   | 788.37    |
| R1    | 61.47     | R3    | 1818.05   |
| R1x   | 265.49    | R3x   | 1047.2    |
| R1y   | 402.8     | R3y   | 1485.35   |

The boundary conditions and applied loads shown in table 2, and plotted on the Figure 3, correspond to the most critical case that supports the structure, in which the command is at the highest that is allowed, increasing its distance to the center of gravity.
In the CAE software analysis, the resulting forces applied are placed with the load suggested by the UNE-EN ISO 10535: 2 standards. The results of stress analysis the standing frame are shown in the Figure 4, with a maximum deformation of 0.03165 m, a maximum equivalent stress of von-Mises equal to 97.18 MPa and a minimum safety factor of 15 is obtained for the structure, as shown in Figures 4.a, b and c, respectively.
Figure 4. Finite element analysis using CAE software; a) total deformation, b) von-Mises stress, c) safety factor

The dynamic analysis was performed at four test points to determine how much increases the force required on the linear motor as a function of time in order to visualize the behavior of the structure as the standing frame unfolds. The results are shown in Figure 5 and it is observed that the force changes from a minimum value of 111.81 N to a maximum value of 128.17 N.

Figure 5. Behavior of the force required in the linear motor

The equivalent stresses of Von Mises are calculated in the support structure, the maximum being 91.08 MPa for the case of Figure 6.a; 142.5 MPa in case 6.b; and 203 MPa in the case of 6.c. In all cases, the stresses do not exceed the tensile strength of the material, which is 250 MPa.
The constructed prototype is shown in Figure 7. The built prototype is subjected to tests of durability, forces in movement, immobilizing devices, tests with load and without load. Which are carried out in 20 people with reduced mobility capacity, taking into account their specific characteristics and their age. The standing frame has a joystick unit and two motors that allow for transfer to be carried out unaided. The standing frame can be customized to fit the individual user correctly by a number of easy adjustments. It can adjust to the user’s height electrically by means of a motor unit.

The operational tests of the standing frame were carried out with nine patients of different weights, with the aim of determining the optimum performance point of the prototype. Nine measurements of voltage, current, power and torque were made, varying the load of each patient. The results obtained are shown in Figure 8, and it is observed that the voltage reaches a maximum value of 24.01 V, current 3.09 A, power 74.21 W and torque 5.27 Nm.
Standing frame efficiency is determined based on the torque required in the motor. Figure 9 shows that in the final lifting stage (with a load of 100 kg), to overcome inertia the amperage consumption is 3.1 A, with a voltage of 24.1V, and efficiency of 91.61%. Therefore, the higher the voltage, the better the efficiency.

These parameters define the functionality, ergonomics and safety as shown in table 3. Shedding average values that comply with the standard UNE-EN ISO 10535: 2006 in its section.

| No. | Standard  | Average |
|-----|-----------|---------|
| 1   | Functionality | 85 %    |
| 2   | Ergonomics  | 82 %    |
| 3   | Safety     | 89 %    |

4. Conclusions

The systems of mobile hosts present a greater effectiveness in front of systems of mobility like walkers or wheelchairs that maintain static the lumbar zone, unlike a system of the mobile hosts that allows to realize movements of elevation or descent according to the comfort and desire of the user. The prototype complies with the ergonomics requirements specified in section 4 of the UNE-EN ISO 10535:2006 standard, guaranteeing the ergonomics of the prototype and thus providing greater comfort to the user. The results of the tests carried out show an acceptance between 60% and 84%.
with the established functionality parameters and allows to conclude that the implemented fastening system provides security to the user who uses it. For the next study his automation will be incorporated with the use of machine learning (ML) through automatic learning algorithms with mathematical models based on training data, to make predictions in his autonomous actions.

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