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DESIGN OF A MECHANISM TO ASSIST THE STANDING UP AND SITTING DOWN OF A WHEELCHAIR USER

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ABSTRACT

This paper details the design of a mechanism to assist the wheelchair user during actions like standing up and sitting down. The original structural design of a commercial basic wheelchair has been retained, therefore, the proposed 3-bar mechanism to move only the seat through a linear actuator has been intended to match the dimensions and shaping of a commercial wheelchair. Moreover, the mechanism has been reasoned to be easy to manufacture and install, besides, this must support the weight to load. For this reason, the design is based on kinematic synthesis and results of simulations with SolidWorks showing a correct trajectory of motion and the required force by the actuator in relation to the available device.

Keywords: Wheelchair, 3-bar mechanism, kinematic synthesis.

NOMENCLATURE

L_3	length of link 3, seat of the wheelchair
θ_3	angle which the seat will be moved
d_{2min}	minimal length of the actuator
S	stroke of the linear actuator
RPRR	Revolute – Prismatic – Revolute – Revolute
CAD	Computer Aided Design
RHS	Rectangular Hollow Section

1. INTRODUCTION

According to data from *Wheelchair Foundation*, overall, of the people in the world, approximately 1.85% require a wheelchair. In developed countries more than 95% of people who require a wheelchair have access to one, while in developing countries less than 10% of people have access to one.

The COVID-19 pandemic has broken into adult health and its consequences are still unknown. In this sense Chee, 2020 [1] explored the lived experiences of older adults during COVID-19, where it was found that the absence of caregivers due to the risk of infection affected significantly the daily life of wheelchair users, especially when they needed to get in and out of it. Bellan et al., 2021 [2] studied a population of 238 patients with COVID-19, where some degree of motor impairment was observed in 53.8% of them. In addition, the wheelchair market's growth momentum will accelerate at a compound annual growth rate of 7.14% from 2021 to 2026 [3]. Therefore, it is possible to conclude that there is a need for wheelchair users to be able to perform daily activities more independently, especially when it comes to transferring from the wheelchair to other surfaces and vice versa.

A literature review highlights varied strategies to solve this problematic. For instance, Takemon et al., 2021 [4] proposed an assistance system that helps wheelchair users and their caregivers in the standing up process. Due to the high physical bearing standing up represents to the user, this work's objective is to help in the early stages of the use of wheelchairs. The prototype was designed based on a pneumatic actuator and a micro – computer control system which provides the user the ability to sit down in a slow and safe way. But this system requires all of the devices of a pneumatic circuit, for instance, a compressor, filters and valves. Aguilar-Pérez et al., 2021 [5] presented the design of a multiposition automated wheelchair used to transport quadriplegic patients reconfiguring a manual wheelchair structure. An electric actuator is attached to a four – bar mechanism fixed to each side of a wheelchair's backrest to reach multiposition. In this case, an experimental test is achieved with a simplified structure of a wheelchair. Shi et al., 2021 [6] developed a two degrees of freedom parallel mechanism to allow the adjustment of the user's height and posture while using a toilet wheelchair, solving the problems of posture adaptability between the user and the machine, and height matching in the process of using the wheelchair-assisted toilet. The developed mechanism allows the user to use a toilet without assistance. Golovin, 2021 [7] designed a stabilization control system which helps the user to maintain a vertical posture on inclined surfaces. Nikpour et al., 2020 [8] proposed a stabilization and position controller for two wheeled robotic wheelchairs. Rosero-Montalvo et al., 2019 [9] developed an intelligent system to detect the users' posture.

All the previous works require great modifications of the original structure of a basic wheelchair or a new design of a complete wheelchair, moreover, the cost is rising by the addition of several components. For these reasons, the objective of this paper is to design an economically feasible mechanism based on kinematic synthesis and static analysis to be adapted to a basic commercial wheelchair only using a DC linear actuator.

The remaining of this paper is organized as follows. Section 2 details the general design of the mechanism and the kinematic synthesis; Section 3 brings the results of simulations; and Section 4 gives conclusions.

2. MATERIALS AND METHODS

Since the main goal of this work is to adapt an assisting mechanism to a standard and economically accessible wheelchair, the first step was to acquire one and completely measure it. This allowed us to create a CAD model of the wheelchair based on real dimensions from which the assisting mechanism would be adapted to.

2.1 General design of the mechanism

Based on the trajectory needed for a wheelchair user to get into a standing-up position, the 3-bar RPRR (Revolute – Prismatic – Revolute – Revolute) mechanism shown in Figure 1 is proposed taking into account the dimensions and original structure of the basic commercial wheelchair.

Body 1 represents the DC linear actuator selected, which has the following characteristics:

- Maximum stroke: 20 cm
- Input voltage: 12 VDC, 24 VDC
- Maximum load: 1500 N

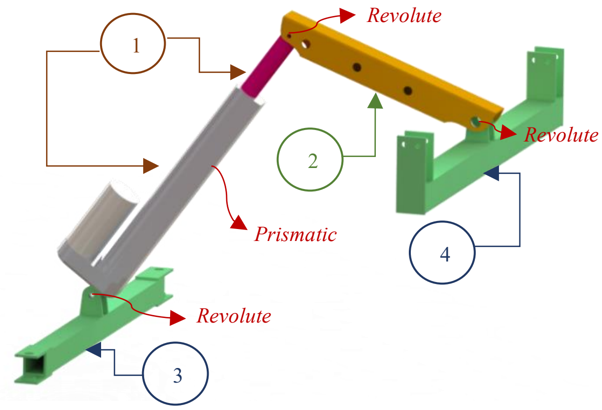

FIGURE 1: PROPOSED MECHANISM.

Body 2 represents the supporting bar of the wheelchair seat and bodies 3 and 4 are the pivots of the entire mechanism. To guarantee that the desired motion is accomplished, a kinematic synthesis process is followed [10].

2.2 Kinematic synthesis

The schematic representation of the proposed mechanism, where the RPR part of the mechanism represents the linear actuator and link L_3 represents the seat of the wheelchair is shown in Figure 2.

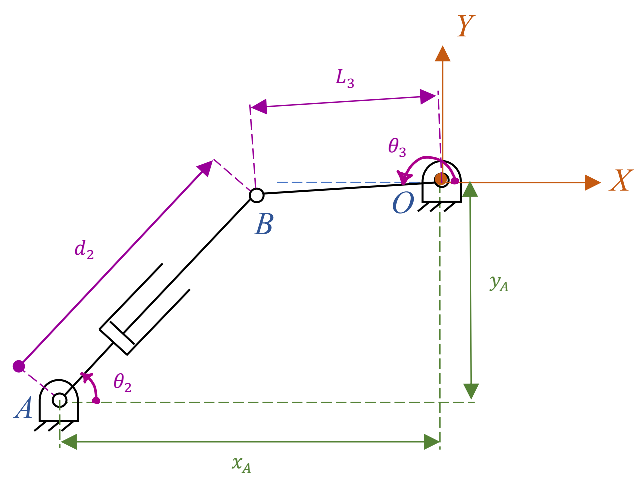

FIGURE 2: RPRR MECHANISM.

The goal of the kinematic synthesis is to obtain the necessary length of link L_3 given starting and final angles of θ_3, therefore for this application, these angles are proposed to be from a seating position (180°) to 135°, shown in (1) and (2). The final angle was selected based on a usual sit-to-stand movement, where approximately at a 45-degree angle between the thigh and the seating surface the force components are at maximum value.

Three more input values are needed, which are given by (3), (4) and (5) where d_{2min} represents the minimum length of the fully retracted actuator and the coordinates x_A and y_A represent the position of point A from Figure 1, these coordinates (as well as the origin of the reference frame) are proposed based on the structure of a commercial wheelchair.

$$\theta_{3i} = 180° \quad (1)$$

$$\theta_{3f} = 135° \quad (2)$$

$$d_{2\,min} = 30\ cm \quad (3)$$

$$x_A = -38.141\ cm \quad (4)$$

$$y_A = -27.179\ cm \quad (5)$$

Additionally, the extension coefficient must be defined as given in (6), where S represents the stroke of the linear actuator.

$$K = \frac{AB_f}{AB_i} = \frac{d_{2min} + S}{d_{2min}} \quad (6)$$

From Figure 1, the AOB loop is preserved, therefore equations (7) and (8) can be defined as:

$$AB_i^2 = (x_A - L_3 \cos\theta_{3i})^2 + (y_A - L_3 \sin\theta_{3i})^2 \quad (7)$$

$$AB_f^2 = (x_A - L_3 \cos\theta_{3f})^2 + (y_A - L_3 \sin\theta_{3f})^2 \quad (8)$$

with equations (6), (7) and (8), a solution for L_3 is given by

$$L_3 = -\frac{a \pm \sqrt{a^2 - b}}{S^2 + 2d_{2min}S} \quad (9)$$

where

$$a = d_{2min}{}^2\left(x_A cos\theta_{3f} + y_A sin\theta_{3f}\right) - (S + d_{2min})^2\left(x_A cos\theta_{3i} + y_A sin\theta_{3i}\right) \quad (10)$$

$$b = S(d_{2min} + S)^2(2d_{2min} + S)(x_A^2 + y_A^2) \quad (11)$$

Varying the actuator stroke $0 < S < 20\ cm$ and substituting values from equations (1) – (5), the length for L_3 can be found through the Figure 5.

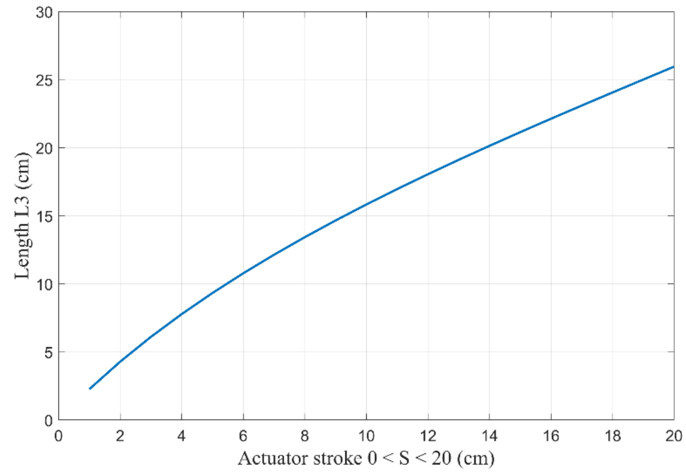

FIGURE 5: LENGTH FOR L3 IN RELATION TO THE ACTUATOR STROKE.

Based on the previous plot, the length of the link L_3 is set at $22\ cm$, which corresponds to a permissible value for the range of the actuator stroke. This length ensures a correct design to keep the original structure of the wheelchair and minimal material for manufacturing.

3. RESULTS AND DISCUSSION

3.1 Assembly of adapted mechanism

Once all the mechanism links have been completely defined it is possible to create an assembly adapted to a commercial wheelchair using said mechanism. This assembly and the trajectory from seating position to 45° is shown in Figure 6. In addition, Figure 7 shows the lateral view of the assembly.

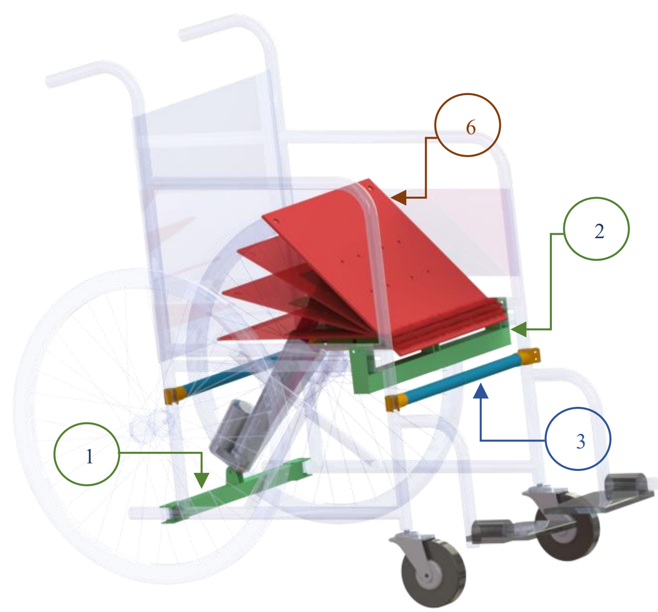

FIGURE 6: ASSEMBLY OF RESULTING MECHANISM ADAPTED TO COMMERCIAL WHEELCHAIR.

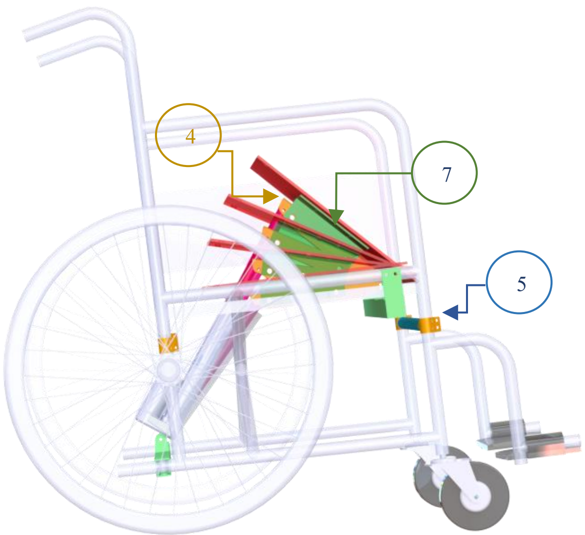

FIGURE 7: LATERAL VIEW OF ASSEMBLY.

The presented assembly was made based on commercial and economically accessible materials, Table I shows a list of the parts added to the commercial wheelchair and their characteristics.

TABLE I
LIST OF PARTS ADDED TO THE COMMERCIAL WHEELCHAIR

Part number	Name	Material	Characteristics
1	Support for actuator	A36 steel	RHS 1×1 *in*, Caliber 12
2	Superior support	A36 steel	RHS 1×1 *in*, Caliber 12
3	Horizontal bracing	A36 steel	Tube ϕ 7/8 *in*, Caliber 18
4	Supporting seat bar	A36 steel	RHS 1 ¼ *X* 1 ¼ *in*, Caliber 12
5	Braces for horizontal bracing	A36 steel	Tube ϕ 7/8 *in*, Caliber 18
6	Seat plate	A36 steel	3/16 *in* thickness
7	Angle	A36 steel	3/16 *in* thickness

Once all materials were defined in the assembly, a motion study performed by *Solidworks Motion* was created to find the force needed by the actuator to complete the desired motion. This *Solidworks* feature allows us to simulate a distributed load applied on the surface of the seat plate and plot the force required by the actuator to support the said load during the whole trajectory described by the mechanism.

A 3-4-5 polynomial velocity profile was proposed, which is a mathematical function used to control the actuator's motion for the purpose of progressively increase its velocity at the start of the motion and then progressively decrease its velocity at the end of the motion. This profile was selected due to its simplicity and common use.

A 16 *cm* stroke is completed by the actuator in 15 *seconds* and then it fully retracts in 15 more seconds, also an 800 *N* force simulating a person's weight of approximately 80 kg was applied vertically to the surface of the plate. Figure 8 shows the resulting plot from the motion study.

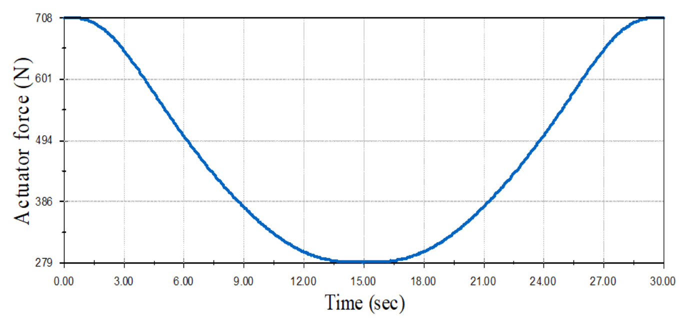

FIGURE 8: RESULTS OF MOTION STUDY.

4. CONCLUSION

Through the development of this work, a CAD model for a mechanism capable of being adapted to a commercial wheelchair to help the user get into a standing up position was created, where the resulting mechanism can move the wheelchair seat from a seating position until to a 45-degree angle.

The results of the kinematic synthesis allowed to find a relation between the length of the link supporting the seat and the stroke needed by the actuator to reach the desired angle. It was concluded that a 22 *cm* link length with a stroke of 16 *cm* was the optimal solution. Once all the mechanism links were defined, commercially available and economically accessible parts for the assembly were proposed. Finally, the CAD model was validated through a simulation where the force needed by the actuator to complete the desired motion was found to be between 279 *N* and 708 *N*, which lies below the maximum allowed load.

Future works will consist of completing the validation of the CAD model through finite element analysis with *ANSYS* and making the proper adjustments if needed. Then, the final mechanism will be manufactured, afterwards it will be adapted to a commercial wheelchair and experimentally tested.

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