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Design of Indoor-Outdoor mobility wheelchair for low resourced settings

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Abstract

This article describes the design of indoor-outdoor mobility wheelchair for Indian settings. The design of such a wheelchair has not been available for the low resourced settings. This work developed a prototype wheelchair with features to provide variable elevation of seat (elevation of 300 mm: seat height from floor - 500 mm to 850 mm), 360 degree rotations of seat and ease of seat transfer to make the wheelchair relevant for accessibility in indoor settings. The device is powered by a battery (24 V 18 Ah LifePo4) and electric motor (350 watt with driving speed up to 20 km/hour) thereby making it suitable for indoor use rather than conventional fossil fuel powered vehicles. Its additional feature of having visibility from other vehicles, front light, and ability of driving on different terrains make it suitable for outdoor use. The mobility wheelchair is affordable (manufacturing cost for prototype was around 325 US $) in India. We have further provided justification for all the technical specifications of the components we used. The wheelchair was fabricated locally in our workshop.

Keywords: Indoor mobility, outdoor mobility, wheelchair, assistive device, design.

1. Introduction

According to the World Health Organization's report, 15 percent of the global population has some form of disability [7]. In India alone, 2.2 percent of the population is identified as having some form of disability [11]. Disabilities can be categorized in two ways. As outlined in the NSS Disability report [11], "Disability can be defined as a limitation of an individual's mobility due to physical, cognitive, intellectual, or sensory impairments. These disabilities encompass locomotor, visual, auditory, speech and language impairments, intellectual disabilities, chronic neurological conditions, and more. Locomotor disability, for instance, pertains to limitations in a person's ability to engage in various activities associated with body movement and manipulation of objects [7]. This form of disability is prevalent among acid attack survivors, individuals cured of leprosy, those affected by conditions like polio, cerebral palsy, dwarfism, muscular dystrophy, and others [11]."

The second classification of disability is provided by the International Classification of Functioning, Disability and Health (ICF). According to the ICF, "Disability can be defined as challenges in human functioning across three main areas:

- Impairments stemming from disruptions in bodily functions or alterations in bodily structures.
- Activity limitations, which manifest as the inability to perform everyday activities like walking, bathing, etc.
- Participation restrictions, representing societal barriers that hinder an individual's involvement in community life, such as discrimination in employment or lack of access to public transportation."

Both of the aforementioned disability classifications emphasize the mobility requirements (for both indoor and outdoor settings) of individuals with locomotor disabilities, as well as the challenges they face in terms of activity limitations and social participation restrictions. To better comprehend the specific needs of disabled individuals, particularly in the Ahmedabad region of India, a needs assessment study was conducted in 2018 focusing on wheelchair users [15]. The study concluded that people with disabilities still encounter challenges when transferring to toilet seats, accessing high and low kitchen storage, and using kitchen counters. Moreover, they struggle to use public transportation for longer journeys, and their wheelchairs are ill-equipped to navigate uneven outdoor terrain for shorter distances. Consequently, they encounter social and economic exclusion due to inadequate outdoor infrastructure and inappropriate indoor designs. Therefore, there is a pressing need for the further development of assistive technology to address the unmet mobility needs of individuals with physical disabilities. In recent years, various countries have made advancements in assistive devices and supportive technologies tailored to the needs of people with locomotor disabilities. We highlight some of these developments which correspond to the unmet needs as we found in the need assessment study. Furthermore, the paper seeks, through the below literature review, to provide recent advancements and innovations concerning wheelchairs and assistive devices, along with understanding affordability factors, technical research specifications, and practical

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applications. This exploration is aimed at enhancing accessibility for individuals with lower limb impairments within the Indian context.

The Robotic exoskeleton was developed for active postural support at Columbia University, United States, in 2019 [12]. It incorporates two rotational-prismatic spherical (RPS) and two universal-prismatic spherical (UPS) kinematic chains, employing micro-linear actuator motors. This system supports the user's trunk and facilitates forward/backward movement from a seated position. In 2021, IIT-Madras in India developed a Standing wheelchair, designed to assist individuals in transitioning from sitting to a standing posture [14]. Crafted from lightweight aluminum, it utilizes a gas spring for consistent force, reducing sudden user movements during the process. In 2020, the researchers in Malaysia introduced a Mechanical jack and scissor lift mechanism, empowered by an actuator motor, capable of raising up to 90 kg in a wheelchair, providing elevated seating [13]. The Home Lift Position Rehabilitation Chair (HLPR), akin to conventional powered chairs, was developed at the National Institute of Standards and Technology in the USA in 2008 [3]. Its tricycle design, featuring drive and steer motors, assists in positioning patients in chairs, on toilet seats, and beds with the aid of nursing staff.

In 2018, Pittsburgh, USA, saw the development of a manual wheelchair elevator clamp system employing a motorcycle jack and adjustable clamps [10]. This system allows individuals with disabilities to engage in throwing sports while seated in their wheelchair. National Taiwan University of Science and Technology, Taiwan, created a seat-adjustable power wheelchair in 2011, consisting of upper and lower segments linked by a linear module incorporating a ball screw, two linear guides, and a DC servo motor [6]. This design enhances the wheelchair's tilting angle. Scooters, primarily designed for outdoor use, have witnessed increased indoor usage. Research conducted at the University of Toronto, Canada, in 2008 and 2010 indicated that existing indoor standards were not met by any of the tested scooters [5] [4]. In 2013, Taiwan introduced an Intelligent robot wheelchair, employing four Mecanum wheels to facilitate multidirectional movement with zero turning radius. It incorporates a Stewart platform with a six-degree-of-freedom universal-prismatic-spherical mechanism, supporting various movements for user comfort and transfer assistance.

Previous research in assistive technologies primarily addressed indoor mobility, including seat adjustments, standing postures, and transfer provisions. The relevance of outdoor mobility performance for indoor use was also assessed, revealing that outdoor mobility scooters were not suitable for indoor environments [5] [4]. Recognizing unmet needs among individuals with locomotor disabilities, we embarked on the development of an assistive device addressing both indoor and outdoor mobility. This device features seat elevation, seat rotation, seat transfer, on-road safety, visibility, and enhanced mobility on rough outdoor terrain. This article outlines the prototype's development.

This manuscript endeavors to expound upon the literature surrounding mobility assistive technology while concurrently elucidating the distinctive attribute of a mobility device. This device ingeniously employs a cost-effective hydraulic jack to confer vertical elevation to the user in a seated posture. Consequently, users can proficiently undertake various indoor activities, encompassing prolonged seating, seamless transfers, adaptable seating heights, and secure outdoor usage attributable to variable elevation capabilities. Furthermore, the manuscript delves into the operational intricacies of the device and substantiates its viability through a comprehensive proof of concept analysis.

2. Design Rationale

The mobility device stands under the imperative of safety and user-friendliness, especially within India's diverse climate. The need assessment study [15] highlights the key challenges faced by individuals with physical disabilities in their mobility. Two prominent issues come to the fore: the lack of suitable infrastructure, such as inaccessible public facilities (toilets, trains, buses, buildings), and the insufficient progress in assistive technology. Assistive technology aims to empower individuals with disabilities for mobility without the need for extensive infrastructure changes. For example, incorporating various seating heights in a wheelchair facilitates access to kitchen and indoor spaces for daily activities. This innovation represents a technological stride in wheelchair design.

Drawing from unaddressed mobility needs (as cited earlier), the following pivotal requisites have been identified:

- Catering to India's varied seasons.
- Universal usability, spanning individuals aged 15 and above, irrespective of gender.
- Functionality both as an outdoor vehicle and an indoor wheelchair, ensuring visibility and road safety in urban and rural contexts.
- Capability to cover distances ranging from 1 to 20 kilometers outdoors.
- Adaptable for indoor use, including variable seating heights for different tasks. The design also incorporates a 360-degree seat rotation to enhance user mobility within indoor settings. Additionally, the device should support seamless user transfers from the seat to a toilet, enabling independent toilet access.
- Provision for accommodating personal items like crutches, lunchboxes, and personal accessories.

These essential mobility requirements have been seamlessly integrated into the design of the new wheelchair. The prototype chair we have developed incorporates key accessibility features, as detailed in Figure 1.

To enhance outdoor safety, a mild steel ring component has been introduced at the front of the device. This component acts as a protective barrier, enhancing user safety in the event of collisions with other vehicles. Furthermore, seat elevation improves user visibility to other vehicles, enhancing safety compared to traditional wheelchair designs.

3. Design and Calculations

In this segment, we expound upon the intricacies of the CAD drawing and accompanying computations that substantiate the technical facets of the prototype. Our initial focus was to formulate a prototype design characterized by three pivotal attributes: a full 360-degree rotation capability, seat height adjustability, and a back support mechanism that can pivot 90 degrees. The latter function facilitates seamless transfers from the device seat to alternate seating, like toilet seats, via a sliding mechanism.

For achieving height adjustability, we employed a scissor mechanism. To enable seat rotation, we employed ball bearings, and for sliding functionality, a straightforward locking mechanism was adopted. The sub-components that constitute these mechanisms are visually depicted in the exploded view of the device (Figure 4) and comprehensively detailed in specification of bill of materials (Table 1).

Features of the device	
Sr No	Features
01	Range of Rotation of a device: 360⁰
	The Range of rotation is a feature provided by the device and its purpose is to provide degree of freedom to the user. The person with restricted mobility can rotate the chair and it can provide enhanced accessibility to the user.
02	Height adjustment of the seat of a device
	Height adjustment of a seat is to reach heights from 500 mm to 800 (ground to seat height) mm to perform activity of daily living. The person with disability needs to reach to various heights in indoor environment during a day. That can be provided with the help of hydraulic jack and the calculation for hydraulic scissor system is also provided in the calculation section.
03	Electric Vehicle
	The proposed device is an electric battery driven vehicle and can be used for indoor mobility. The device uses 24V 18 Ah battery and 350-watt motor that lasts for 15 kms in a single charge. The charging time of the device is around 4 hours. The selection of electric motor is based on the calculation in the design section.
04	Weight carrying capacity
	This device can carry the user weight of up-to 150 kgs and the higher load capacity can be utilized to keep personal belongings of the user such as crutches, ground mobility device etc.
05	Self Transfer and Cushion Seat
	The device seat has foam cushion seat with back support. Back support can be used to transfer from device seat to toilet seat during accessibility in the washroom.

Figure 1. Features of the Device

3.1. CAD Drawing and Device Operation

Before embarking on prototype assembly, we meticulously crafted a 3D design model. This virtual model, aligned with the dimensions of the sub-components, facilitated a thorough examination of potential interference or clearance issues. Subsequently, this design was relayed to both the mechanical workshop teams at the university and Platypus Lab, Ahmedabad, who were entrusted with the fabrication and assembly processes. Collaborative efforts between the Principal Investigator and the workshop teams at both labs culminated in the successful fabrication and assembly of the prototype.

Figure 2 portrays the primary constituents of the device seat, juxtaposed with the underlying technological framework for seat height adjustability. This ensemble comprises four constituents: chair back support, seat cushion, the scissor system, and the device chassis. The chair back support caters to user comfort during prolonged sitting, dropping down by 90 degrees to align with surfaces like toilet seats. The seat cushioning comprises foam cushioning for user comfort. The scissor system incorporates scissor links and a hydraulic jack. The latter, propelled by a small electric motor, drives seat elevation. Hydraulic force is imparted to the scissor links, connecting the seat to the chassis. Notably, the scissor system exhibits a multiplier lifting effect, with hydraulic jack movement yielding twice the lifting distance through the scissor links.

The device's chassis, reminiscent of a ladder in form, fosters straightforward assembly and sub-component integration, particularly pertinent to prototype development. Despite its typical usage in heavy vehicles, this ladder-type chassis was chosen due to its ease of construction and assembly.

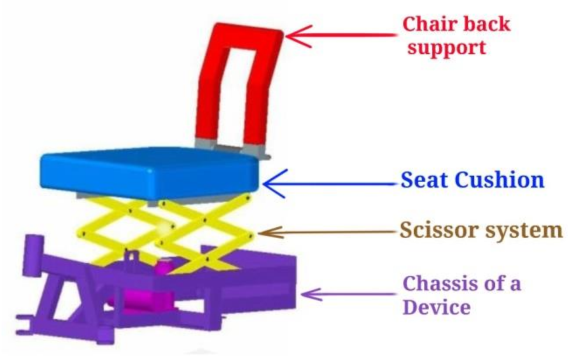

Figure 2. Design of a device with scissor system

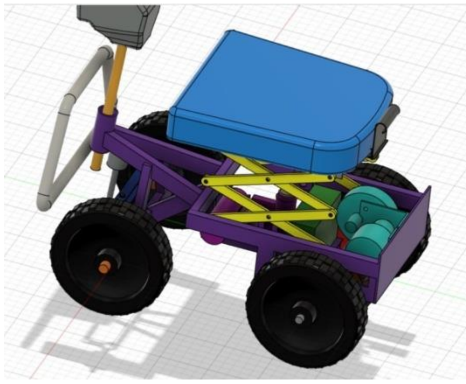

Figure 3. Assembly view of the device

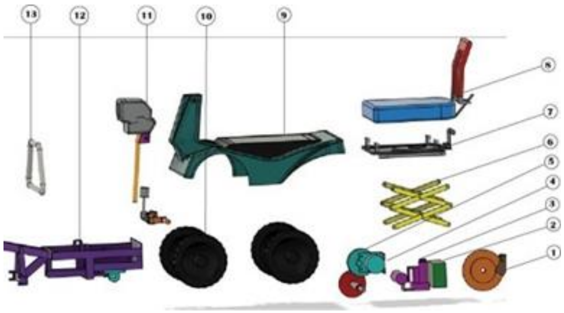

Figure 4. Exploded view of the device design

In the detailed view of the proposed design (figure 4) and bill of materials (table 1) as shown, we used a scissor mechanism and hydraulic jack to adjust the seat's height, ranging from 500 mm to 800 mm (measured from the floor to the seat). This height adjustment allows users to access different levels for their daily tasks. For instance, the lowest seat height, at 500 mm, aligns with the typical height of Indian chairs [16], making it easy for users to sit down and transfer to other seats, like commode seats or other chairs. When the seat height is raised to 650 mm from the floor, it becomes an ideal level for Indian individuals to comfortably work at kitchen counters. At seat heights between 700 mm and 800 mm, tasks such as drying clothes, reaching for items on shelves, or opening doors become more convenient [15]. A seat height of 700 mm is particularly recommended for driving, as it enhances visibility to other road users [15].

Facilitating user convenience, the seat incorporates rotation facilitated by bearings, augmenting adaptability within indoor settings. The vehicle is propelled by a 350 Watt electric motor, employing a chain drive transmission with a driving-to-driven ratio of 3:1. The device's power requisites were approximately calculated as 281.5 Watts (refer to the Design Calculations section), factoring in weight transportation up to 180 kg, encompassing both device and user weights. Braking functionality is realized through a disc brake (Pulsar 150 CC), acting on the rear shaft. The disc brake is affixed to the rear axle, while the device's wheels feature an epoxy inner shell for structure and a rubber exterior for optimal road traction.

Table 1. Bill of materials

S.No	Component Name	Part Specifications
1	Disc Brake	Pulsar 150 disc brake
2	Battery	24V 18Ah
3	Hydraulic Jack	2 Tons jack
4	Electric Motor with controller	350 watt permanent magnet brush type dc motor and 2650 rpm
5	Transmission	chain drive with 3:1 ratio
6	Scissor mechanism	MS material
7	Rotation mechanism	Bearing
8	Seat	Foam type Cushioning
9	Outer body	Plastic
10	Wheel	Diameter – 300 mm, Epoxy material
11	Steering mechanism	Rack and Pinion used in Maruti alto four wheeler
12	Chassis	Material AISI 1030
13	Safety handle	-

The steering mechanism, operating on the rack and pinion principle commonly found in four-wheeler vehicles, controls the motion of the front wheels while maintaining the steering shaft at an ergonomic height of 700 mm for the driver's comfort. Additionally, the vehicle is outfitted with a front light, similar to those on traditional two-wheelers, to enable operation in low-light conditions. The adoption of a ladder-type chassis streamlines assembly intricacies. Within the fabrication lab, core components, encompassing the main driving motor, braking system, hydraulic scissor system, wheels, front and rear axles, steering mechanism, and battery, are methodically mounted onto the chassis. The chosen material for the chassis is AISI Mild steel. Concluding this exposition, the safety handle, crafted from mild steel, adopts a rhombus-shaped form. With sides measuring 210 mm, 210 mm, 250 mm, and 450 mm, this safety feature assumes significance. It can be horizontally locked during outdoor usage, enhancing collision safety. Within indoor environments, the safety handle's vertical pivot configuration optimizes device compactness, offering a pragmatic solution to spatial constraints.

3.2. Design Calculations

Within this segment, we expound upon the design calculations concerning the primary mechanisms and the requisite motor power in the prototype. We initiate our discourse by delineating the power requisites for the driving motor. Subsequently, we delve into an elucidation of hydraulic forces exerted on the hydraulic jack. Lastly, we expound upon the technical intricacies characterizing the scissor link and pin mechanism.

3.2.1. Power Requirements for the driving motor

The formula for power is $P = \omega \times \tau$, where τ is the torque at the wheel (N m) and ω is the angular velocity of the wheel. We will begin by computing T . Recall that

$T = Ft \times r$,

where Ft is the total tractive force required to move a device and r is the radius of the wheel, which in our device was measured to be 0.15 meter, and

$Ft = Rr + Rg + Ra$,

where Rr is the rolling resistance, Rg is the gradient resistance and Ra is the aerodynamic resistance.

3.2.1.1. Rolling Resistance

The rolling resistance Rr is given by the formula $Rr = \mu W$, where μ is the coefficient of rolling resistance and W is the total weight, i.e., weight of the device and the weight of the user. The coefficient of rolling resistance depends on the terrain and a few common values are tabled in table 1.

The highlighted entry is the value of μ that we will use in calculation since this is the kind of road found near housing societies in semi urban areas.

The total weight W is the sum of the weight of the device W1, which is 102 kg and the weight of the user W2, which we have assumed to be 80 kg. Converting it into force weight we get W = 1820 N. Thus, the rolling resistance $R_r = 91$ N

Table 2. Coefficient of Rolling Resistance for various roads [2].

Road surface	μ
Car Tires	
Concrete,asphalt	0.013
Rolled gravel	0.02
Tarmacadam	0.025
UnpavedRoad	0.05
Field	0.1 - 0.35
Truck tires	
Concrete,asphalt	0.006 - 0.01

3.2.1.2. Gradient Resistance

This resistance is described by the formula $Rg = W \times \sin\theta$ where θ is the gradient angle. The gradient angle for ramps according to the standard building guidelines [9, page 4] can be maximum of 4.8 degrees (equivalent with maximum gradient of 1 : 12). So, here we will take it to be 5 degrees. Now computing the resistive force with the values above gives **Rr = 158 N**

3.2.1.3. Aerodynamic Resistance

This resistance is given as: $Ra=0.5\ \rho\ v^2\ Cd\ A$, where ρ is the density of air, taken to be 1.27 kg/m3, v^2 is the velocity of the vehicle, taken to be 10 km/h = 2.77 m/s, Cd is the drag coefficient and A is the area of the device, which was measured to be 0.45 m2.

The drag coefficient depends on the shape of the moving object. The table below gives the values of this coefficient measured experimentally for different body shapes of devices: The highlighted value is the one we will use for calculation, Now, computing the resistance, we get **Ra = 3.94 N**.

Table 3. Drag Coefficients [1].

Body Shape	*Cd*
Sphere	0.45
Long circular cylinder	1.0
High-drag car	≥ 0.55
Medium-drag car	0.45
Low drag-car	≤ 0.3

3.2.1.4. Tractive Force

Now we compute the tractive force. Substituting the values for the resistive forces from above calculations gives us

$Ft = Rr + Rg + Ra$ = 91 + 158 + 3.94 N = 252.94 N.

We will round off and use 253 N as the value for *Ft*.

3.2.1.5. Torque

Using the value for tractive force from above, we now compute the torque as

$\tau = F_t \times r$ = 253 × 0.150 N m = 37.95 N m.

Rounding off, we take τ = 38 N m.

3.2.1.6. Angular velocity

Recall that angular velocity of the wheel measured in radians per second is given by the formula ω = v/r, where v is the velocity of the vehicle in m/s, taken as 2.77m/s and r is the radius of the wheel. Substituting the values gives us ω = **18.52 rad/s.**

3.2.1.7. Power

Finally, computing the power required to move the wheel gives us $P = 703.76$ W.

The device we have made uses transmission through chain drive for convenience reasons and the teeth ratio for driving:driven = 5 : 2. Thus, we will require only 2/5 th of the power from the motor, denoted Pm, to move the device, which turns out to be:

$P_m = P/2.5$ = 703.76/2.5 W = 281.5 W.

Hence, we had chosen a motor with power 350 W. The slightly higher motor value will also compensate for the obstacles and uneven surface on the Indian roads.

3.2.2. Free body diagram for scissor mechanism

Now to design a scissor system, we need to first consider various forces on the system using free body diagrams (FBD). In the figure the free body diagram of a scissor system displays the two applied forces W and Pf , where the force W is due to the weight of the user and the seat above, while the force Pf is the piston force applied through the hydraulic jack.

Notations: W is the weight of the user, P_F is the hydraulic piston force. The kinematic pairs are la- belled from A to H as in the Figure 6, and kinematic links are labeled from 1 to 6.

The link length l is 320 mm. The angles formed between the scissor lift arms and the horizontal plane are computed for the individual positions as shown in Figure 7.

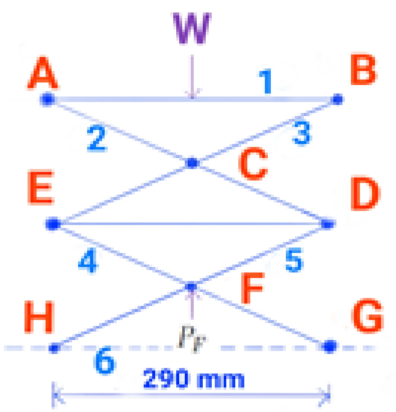

Figure 6. Free body diagram of scissor links

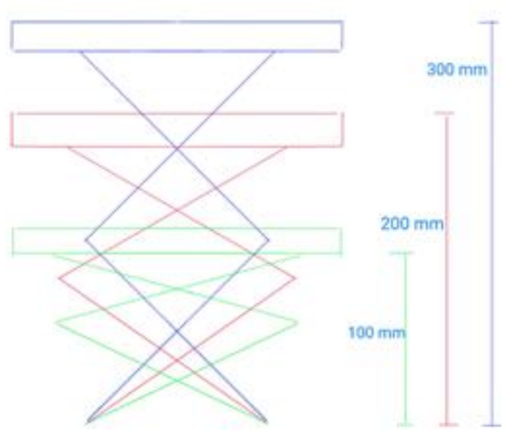

Figure 7. Three Positions of scissor system

$$\beta_1 = \sin^{-1}\left(\frac{100/2}{320}\right) = 8.98^\circ$$

$$\beta_2 = \sin^{-1}\left(\frac{200/2}{320}\right) = 18.2^\circ$$

$$\beta_3 = \sin^{-1}\left(\frac{300/2}{320}\right) = 27.95^\circ$$

The distances between pins for individual locations were computed as (refer fig -2) $d_1 = \cos \beta_1 \cdot l$ = 316, $d_2 = \cos \beta_2 \cdot l$ = 304, d3 = cos β3 · l = 265.

We compute the approximate values of the forces when the scissor system has angle β3 = 27.95, the forces for the remaining scissor angle positions can be computed similarly. To compute the forces on scissor kinematic links for β3 = 27.95, we equate the forces on the links of the scissor system. The horizontal, vertical forces and moment at a point of a link are equated to be zero for the link AB / link 1 as indicated in Figure 7 of link 1. In Figure 7, the maximum weight W of the user was considered 1500N which needs to be lifted by the hydraulic system. The values of the forces are calculated for Figure 8, Figure 9, Figure 10, Figure 11, Figure 12 and stated in Table 1.

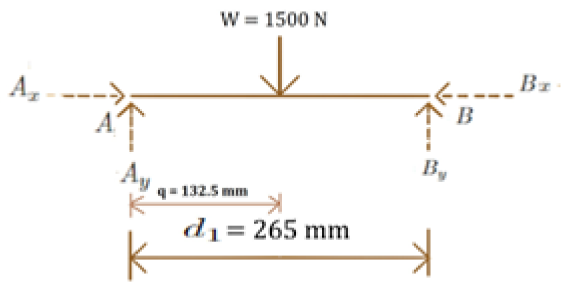

Figure 8. Free body diagram for link 1 / AB

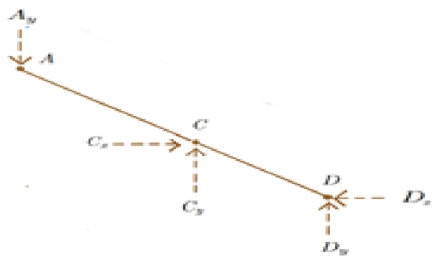

Figure 9. Free body diagram for link 2 / AD

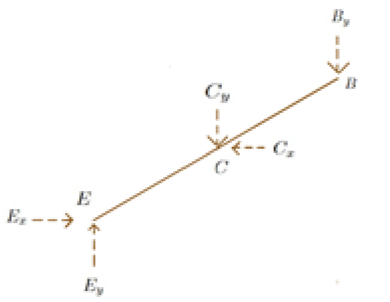

Figure 10. Free body diagram for link 3 / BE

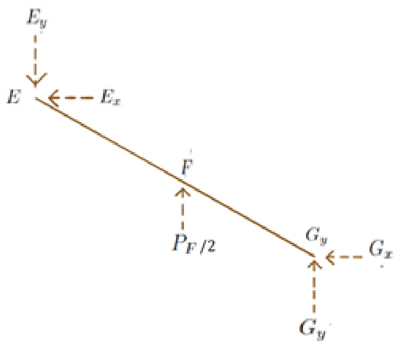

Figure 11. Free body diagram for link 4 / EG

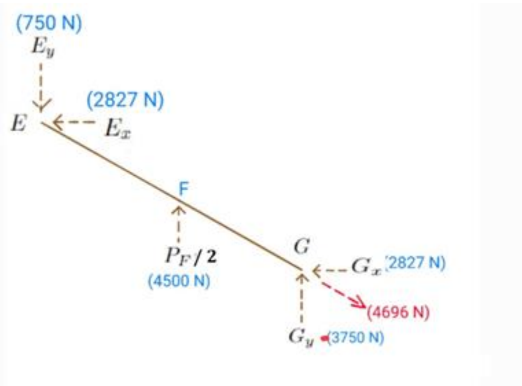

Figure 12. Free Body Diagram of link 4/EG with values of forces

The scissor links are held in place and controlled through a pin joint. All the pin joints are subject to shear forces. The pin used in the scissor system will be subject to the highest force in connecting links 4 and 5. At points G and H, the shear force of 4696 N and point F, 9000 N is applied.

It is evident from the values of horizontal forces and vertical forces for scissor positions of β_1 = 8.98° and β_3 = 27.95° that the values of vertical forces do not change with scissor position; however, values of horizontal forces differ with scissor position. It concludes that the value of piston force does not change, and it remains 9000 N which is equivalent to 900 Kg. Thus, a hydraulic jack readily available in the market with a capacity of 2 Tons (2000 Kg) is used for prototype development. Lastly, in table 1, we summarize the values of forces acting on the kinematic links at different positions (β_1, β_2, β_3) of the scissor system.

For these forces, the breaking points of pin joints are checked since the kinematic links are pin joined. The pin joints are subject to shear forces and the highest resultant forces applied on the pin joint G is 10205 N. We have highlighted all the joints at which the highest shear force is acting. Note that it is for the position β_1. The value of shear stress at G (For β_1 position) calculated to be 130 MPa which is lower than the ultimate shear stress value of Mild steel that is 345 MPa. Thus, the pin will be able to withstand the typical shear forces acting on it under normal use conditions.

Table 4. Forces acting on the kinematic links at different positions (β) of scissor system

Forces	$\beta_1 = 8.98°$	$\beta_2 = 18.2°$	$\beta_3 = 27.95°$
A_x	0	0	0
A_y	750 N	750 N	750 N
B_x	0	0	0
B_y	750 N	750 N	750 N
C_x	9492 N	4562 N	2827 N
C_y	0	0	0
D_x	9492 N	4562 N	2827 N
D_y	750 N	750 N	750 N
E_x	9492 N	4562 N	2827 N
E_y	750 N	750 N	750 N
G_x	9492 N	4562 N	2827 N
G_y	3750 N	3750 N	3750 N
H_x	9492 N	4562 N	2827 N
H_y	3750 N	3750 N	3750 N

4. Prototype development

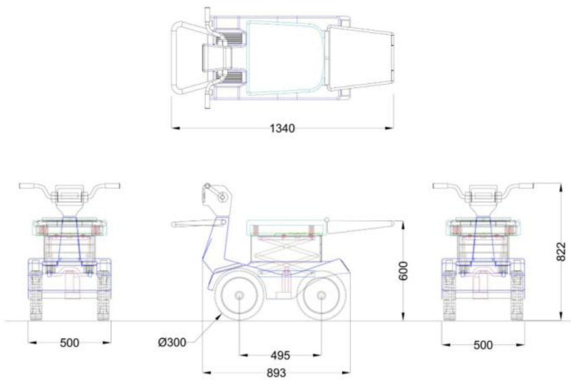

Figure 13. Dimensions of the prototype wheelchair

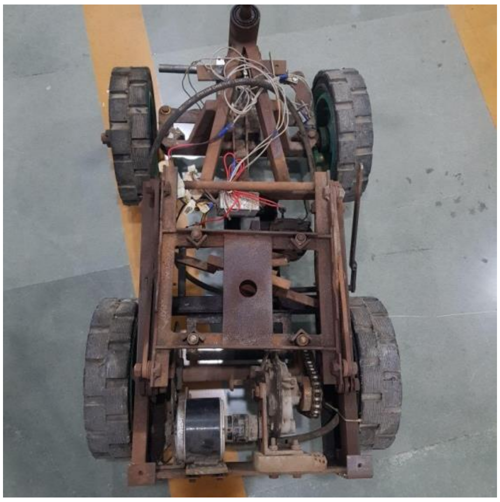

Figure 14. Prototype developed based on the design

Figure 15. Prototype developed based on the design

Figure 16. Prototype with seat

Figure 17. Scissor mechanism of the device

The prototype wheelchair's dimensions, as depicted in Figure 13, closely resemble those of a conventional wheelchair. However, the fabrication process posed a considerable challenge: assembling all the components (as outlined in Table 1) within the confined space of a single prototype. Accommodating the battery, transmission system, hydraulic jack, disc brake, and steering system within these space constraints proved to be a formidable task. The controller of the conventional e-bike compatible for 250 wattmotor was used in the prototype.

Following assembly, the wheelchair's structure is represented in various views, depicted in Figure 14, Figure 15 and Figure 16. Figure 17 offers an actual image of the prototype, highlighting the scissor mechanism's assembly over the hydraulic jack. This scissor mechanism stands as the prototype's most critical component, responsible for elevating the user while seated.

5. Result and Discussion

Figure 18. Rendered view of prototype wheelchair

Figure 19. Actual picture of prototype wheelchair

Figure 20. Picture of prototype (without plastic body) with user

Figure 21. Side view picture of prototype with user

In the previous section, we evaluated our prototype design on the selection of the motor, dimensions of the device and critical components of the hydraulic scissor system. The motor selection of the device is appropriate as per the calculation section. The dimensions of the device as shown in Figure 13 are slightly larger than conventional wheelchairs in terms of width and length. However, the additional features like rotation of seat, elevation of the seating height and transferring from device seat to toilet seat compensate for the slightly larger dimension. The proposed device can be used as an outdoor vehicle as it provides visibility to other vehicles and the wheels of the device are appropriate for the uneven terrain of outdoor conditions along with the durable chassis of the device. The hydraulic scissor system was designed to lift the weight of 150 kgs. We conducted a user trial on the prototype in our workshop and all its features worked well under the normal use conditions. The figure 14 is the rendered images of the prototype wheelchair.

5.1.1. Prototype Testing

The prototype was manufactured according to the design specifications, and Figure 19 displays the completed version of the final prototype. A pre-finished version (without the outer plastic body and back support) was subjected to testing both indoors and outdoors (Figure 20 and Figure 21).

Indoor testing encompassed various environments, including university building hallways with widths ranging from 3 meters to 1 meter, as well as bathrooms with door widths of 0.6 meters. In testing, the device exhibited a 4-meter turning radius; however, when maneuvered by the forward and backward motion of the device, it adeptly executed full turns in areas as narrow as 0.6 meters. Furthermore, the device's brakes effectively prevented skidding on bathroom tiled floors, even under moderately wet conditions. Beyond its mobility attributes, the device facilitates easy transfers from the wheelchair to other seats. Its lowest seat height of 500 mm closely aligns with the standard wheelchair/chair height of 450 mm, and it can be elevated for activities of daily living, reaching up to 850 mm. The device's robust chassis ensures stability even at elevated heights, preventing tipping over when users lean while at an elevated position to reach objects.

The prototype underwent outdoor testing across five distinct road conditions: a tarmac road without significant road bumps, a stone paver block road, a cemented road, a gravel road, and an unpaved road devoid of major potholes (i.e., potholes with a depth exceeding 200 mm). During these tests, the device demonstrated robust performance and stability. Operated at a maximum speed of 20 km/hr, the device was positioned at a seat height of 600 mm from the ground, facilitating comfortable footrest. Importantly, it exhibited superior performance compared to traditional wheelchairs, which are prone to toppling on uneven surfaces commonly encountered in India. Additionally, thanks to the epoxy tires, punctures caused by impacts with stone roads were entirely eliminated. The prototype effortlessly navigated over ramps having a maximum 4 degree of inclination.

There exists room for enhancements in the design, necessitating further comprehensive studies on patients.

5.1.2. Cost Break-Up of making the Prototype Wheelchair

Table 5. Cost Break-Up of Prototype

SR NO	Details of the Part	Cost in USD
1	Battery 24 V 18 Ah LiPo4	100
2	Hydraulic Jack 2 Ton	10
3	Electric Motor 350 watt (driving motor) and 120 watt (viper motor) , and controller	60
4	Scissor mechanism, seat and steering system	30
5	Chassis	50
6	Wheel	30
7	Disc Brake and transmission	20
8	Outer Plastic Body	25
	Total Cost	**325**

6. Conclusion

Design of indoor-outdoor wheelchair is a small step towards designing cost effective multi utility mobility devices for low resource settings. The features of height adjustment, freedom of rotation, easy transfer-ability and it being battery powered makes the wheelchair very suitable for indoor use as no pollution is created in the indoor environment. This enhances the accessibility around the house. Moreover, the design enables the user to travel to nearby places outdoors as well in a safe manner across the various terrains. All the components of the device can be locally procured. The estimated cost of the prototype including the material and manufacturing cost was around 325 USD (Table 5) while the most powered wheelchair costs around 1000 USD.

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References

[1] James Carvill. Mechanical Engineer's Data Handbook. Butterworth-Heinemann, 1994. isbn: 978-0750619608.

[2] H. Bauer et al. Automotive Handbook. Robert Bosch, 1996. isbn: 9781560919186.

[3] Roger Bostelman and James Albus. "Robotic Patient Transfer and Rehabilitation Device for Patient Care Facilities or the Home". In: Advanced Robotics 22.12 (2008), pp. 1287–1307.doi: 10.1163/156855308X344837.

[4] Tilak Dutta et al. "Design of built environments to accommodate mobility scooter users: part I". In: Disability and Rehabilitation: Assistive Technology 6.1 (2011). PMID: 20690862, pp. 67–76. doi:10.3109/17483107.2010.509885.

[5] Emily C. King et al. "Design of built environments to accommodate mobility scooter users: part II". In: Disability and Rehabilitation: Assistive Technology 6.5 (2011). PMID: 21657823,pp.432–439.doi:10.3109/17483107.2010.549898.

[6] Wei-chen Lee, Jyun-An Yao, and Chung-Hsien Kuo. "Development of a seat-adjustable power wheelchair". In: Proceedings 2011 International Conference on System Science and Engineering. 2011, pp. 494–497. doi: 10.1109/ICSSE.2011.5961953.

[7] World Health Organization. World report on disability. 2011, pp. 1–325.

[8] Po Er Hsu et al. "Seat Adjustment Design of an Intelligent Robotic Wheelchair Based on the Stewart Platform". In: International Journal of Advanced Robotic Systems 10.3 (2013), p. 168. doi: 10.5772/55880.

[9] Central Public Works Department India (CPWD). Handbook on Barrier free and Accessibility. 2014. url: https://cpwd.gov.in/Publication/HandbookonBarrier.pdf.

[10] Anand Mhatre et al. "Design and field evaluation of a manual wheelchair seat elevator for throwing events". In: Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference, Arlington, VA, July 13-15 (2018).

[11] Government of India NSS. Report No. 583: Persons with Disabilities in India, NSS 76th Round survey. 2019, pp. 1–209.

[12] Rosemarie C. Murray, ChawinOphaswongse, and Sunil K. Agrawal. "Design of a Wheelchair Robot for Active Postural Support". In: Journal of Mechanisms and Robotics 11.2 (Feb. 2019). issn: 1942-4302. doi: 10.1115/1.4042544.

[13] NazratulhudaHashim et al. "The Development And Design Height-Adjustable Seat (Lift Seat)". In: International Conference on Economics, Education, Social Sciences and Engi- neering, Kuala Lumpur, Malaysia (2020).

[14] Javeed Shaikh-Mohammed et al. "Design journey of an affordable manual standing wheelchair". In: Disability and Rehabilitation: Assistive Technology 0.0 (2021). PMID: 33663308, pp. 1–11. doi: 10.1080/17483107.2021.1892839.

[15] Harshul B. Brahmbhatt. "Need Assessment Study for Wheelchair Users in Gujarat, India". In : submitted (2023).

[16] Ismail Wilson Taifa et al. "Anthropometric measurements for ergonomic design of students' furniture in India", In: Engineering Science and Technology, an International Journal, Volume 20, Issue 1, 2017, Pages 232-239, ISSN 2215-0986, https://doi.org/10.1016/j.jestch.2016.08.004.

[17] Mohammad Al-Khawaldah et al. "Exploration Algorithm Technique for Multi-Robot Collaboration". In: Jordan Journal of Mechanical and Industrial Engineering. April 2011, Volume 5 , Number 2, pp. 177-184. ISSN: 1995-6665.. URL: https://jjmie.hu.edu.jo/files/v5n2/JJMIE-47-11%20Revised%20Adawan(10).pdf

[18] O. Al-Araidahet al. "Conceptual Design of a Single DOF Human-Like Eight-Bar Leg Mechanism". In: Jordan Journal of Mechanical and Industrial Engineering, August 2011, Volume 5, Number 4,pp. 285-289.ISSN: 1995-6665. URL: https://jjmie.hu.edu.jo/files/v5n4/JJMIE-11-10.pdf

[19] Jingpu Li et al. "Optimization of Clutchless AMT Shift Control Strategy for Electric Vehicles". In: Jordan Journal of Mechanical and Industrial Engineering (March 2020), Volume 14, Number 1, pp. 109-117. ISSN: 1995-6665. URL: https://jjmie.hu.edu.jo/VOL-14-1/13-jjmie-445-01.pdf

[20] Yingqi He. "The Electric Vehicle Torque Adaptive Drive Anti-Skid Control based on Objective Optimization". In: Jordan Journal of Mechanical and Industrial Engineering. March 2021, Volume 15, Number 1. pp. 39-49. ISSN: 1995-6665.. URL: https://jjmie.hu.edu.jo/v15-1/06-J644.pdf