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Design of a Horizontal Transfer Mechanism Between Wheelchair and Car for Disabled

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Abstract

This work addresses a significant issue faced by wheelchair-dependent individuals, particularly those using the Perodua Myvi model, who often require assistance for car transfers. The proposed Wheelchair Transferring System aims to alleviate the challenges associated with these transfers, considering that one in three carers may experience back pain due to the strain of lifting objects. The system has been tested successfully, demonstrating functionality and capacity for handling weights up to 100 kg. Focused on the Perodua Myvi model, the primary goal of this work is to enhance the safety and efficiency of wheelchair users' transfers, while also reducing physical strain on carers. The achieved results align well with the objectives, marking significant progress in improving accessibility and overall well-being for people with disabilities and their carers.

1. Introduction

Transportation is a crucial factor in human mobility, particularly for the disabled. While regular individuals can easily operate vehicles, those with physical disabilities face challenges. Various modes like hand-driven tricycles, wheelchairs, and retrofitted vehicles are available, but they often require wheelchair users to exit their chairs[1] for transportation.

Wheelchair users, with limited mobility, encounter difficulties entering vehicles. They face a choice between staying in their wheelchair during travel or transferring to a car seat. Best practices recommend transferring to original seats and utilizing occupant protection systems[2], addressing the unique challenges faced by this group in vehicular mobility. Enhancing the mobility of people with disabilities has been a focus of studies and applications. Several techniques have been explored to increase wheelchair mobility, aiming to provide more accessible options[3] for individuals facing physical challenges.

This work endeavors to streamline the process of transferring patients between a wheelchair and a car seat effortlessly. It employs a motorized screw jack mechanism, driven by a planetary DC geared motor, chosen for its efficiency and reliability. The utilization of the ESP32 Dev Module and Arduino Uno enhances accuracy in control. The integration of the MPU6050 module is pivotal, as it plays a crucial role in checking and maintaining the patient's balance[4] during the transfer. This ensures that caregivers are alerted to any balance issues before initiating the lifting process, emphasizing the work's commitment to safety and reliability throughout the patient transfer between the wheelchair and car seat.

2. Methodology

This section utilizes SolidWorks to visualize the various phases, from initial positioning to transfer operations, in the conceptualization of the system. Specific objectives involve identifying the need for a vehicle entry and exit transfer mechanism, developing a mechatronic system for smooth transitions between a wheelchair and a car, and evaluating the system's performance and cost-effectiveness in production, installation, and maintenance. The aim is to improve accessibility and ease of movement for wheelchair users during vehicle transfers.

2.1 Overview of the system

The assistive device aims to enhance patient transfer from a wheelchair to a car seat using a motorized screw jack mechanism. This mechanism, leveraging intersecting shafts, ensures a smooth and controlled lifting motion, efficiently transferring power from an electric motor. The system, comprising an Arduino Uno, switches, and a DC motor, operates on a 12V battery. The Arduino Uno utilizes its built-in voltage regulator to maintain a steady 5V supply, even though it is designed for input voltages between 7 and 12V. To address component requirements and voltage specifications, switches are connected directly to a 12V source, facilitating effective power distribution. Fig. 1 shows schematic diagram of power supply.

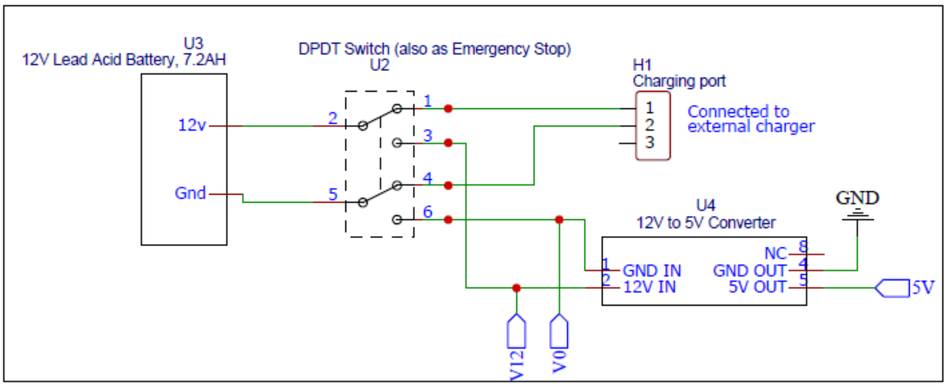
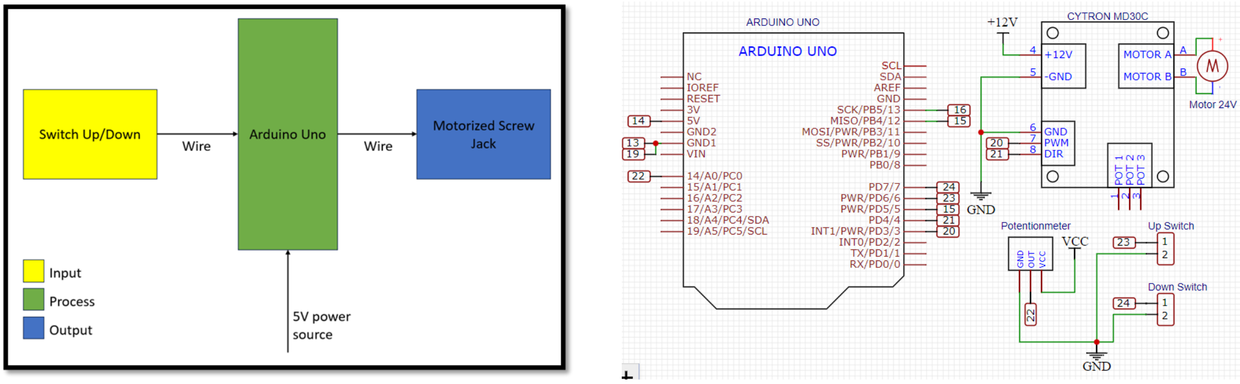


Fig. 1 *Schematic diagram of power supply*

The MPU6050, specifically the accelerometer, is utilized to monitor the wheelchair's balance during the process of lifting and transferring patients from the wheelchair to the car seat. In the first stage, these sensors track patient balance and transmit the data to the ESP32 Development Board for processing in the second stage. The sensor readings are then displayed on the 0.96" OLED display in the third stage. Caregivers can conveniently monitor these readings using the Blynk app on their smartphones. The block diagram of the Motor Control with the updated screw mechanism[5] is shown Fig. 2.



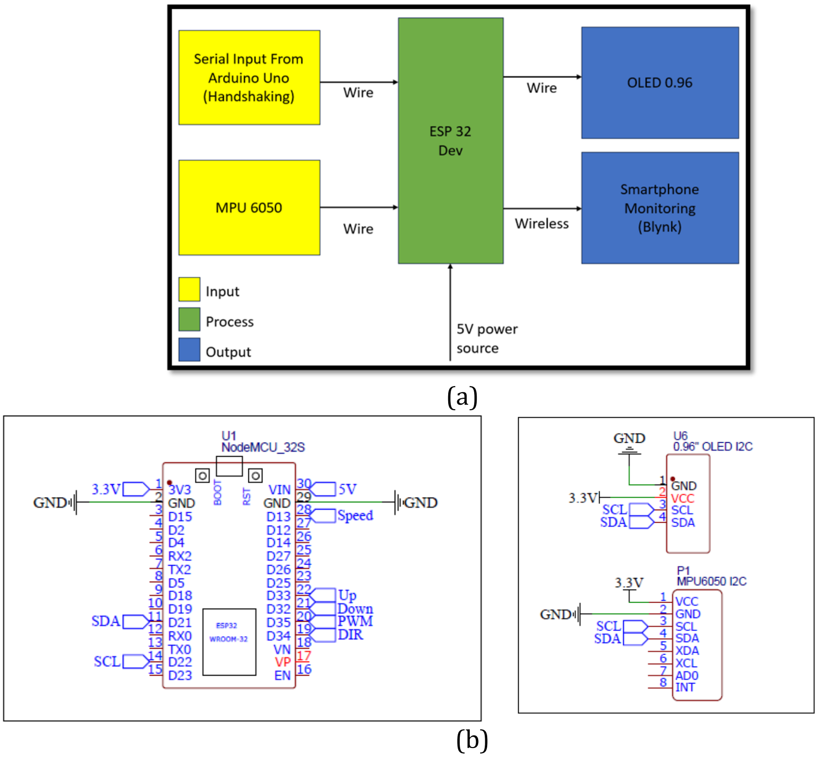
(a) (b)

Fig. 2 *(a) Block diagram of Motor Control (b) Schematic sketch*

The primary power supply for the system is a 12V source, ensuring precise voltage levels through a DC converter. The MPU6050, crucial for monitoring wheelchair balance during transfers, is powered by the converter at 5V. The regulated voltage from the same source is supplied to the 0.96" OLED display (powered at 3.3V) and the ESP32 Development Board, acting as the central processing unit. The DC converter facilitates the necessary voltage adjustments. The IoT monitoring system's block diagram is displayed in Fig. 3.

Smartphone monitoring is achieved through Blynk where the ESP32 Development Board connects to the internet through Wi-Fi and sends real-time sensor data to the Blynk server for viewing remotely. Hence, it contributes to a dependable and successful wheelchair transfer monitoring system. Fig. 4 shows illustration of the system (ESP32 Development Board) connected to the cloud.

In Fig. 5, the flowchart outlines the streamlined process for transferring wheelchair users. Beginning with a lift mechanism for balance, the ESP32 Development board takes control, updating status through an OLED screen and the Blynk app for caregiver monitoring. A switch directs motor commands for efficient lifting and lowering, powered by a DC motor. User-friendly adjustments are made using up and down buttons for the patient transfer sling level, ensuring responsive and flexible wheelchair transfers to and from the car seat.



(a)

(b)

Fig. 3 *(a) Block diagram of IOT Monitoring System (b) Schematic sketch*

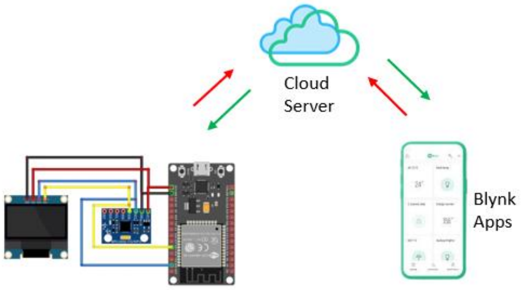


Fig. 4 *ESP32 Development board connected to the cloud*

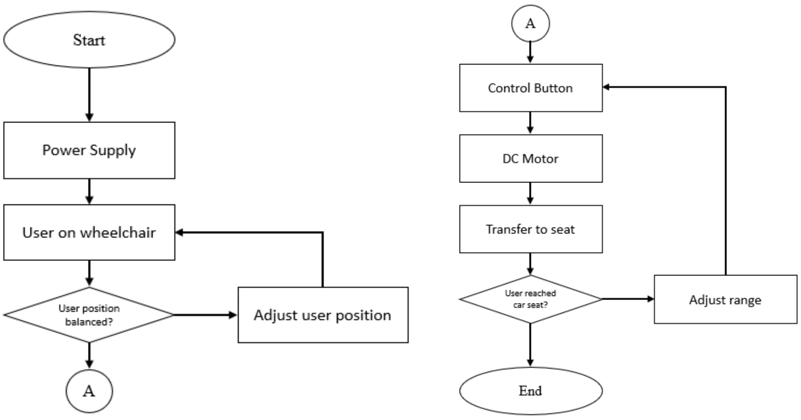
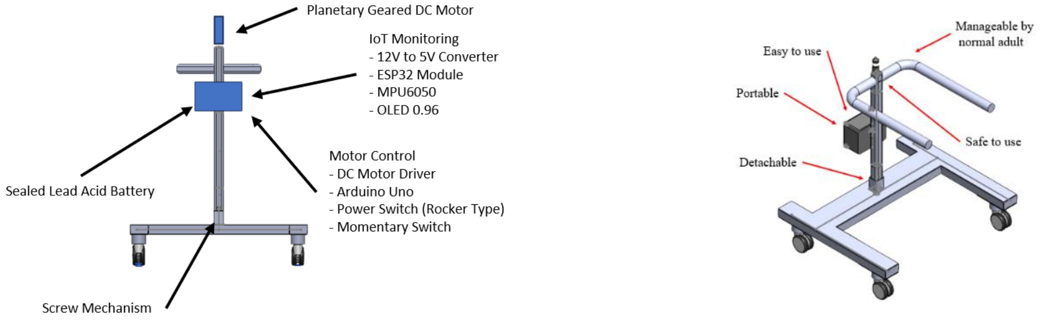


Fig. 5 *Flowchart of the process*

2.2 Prototype

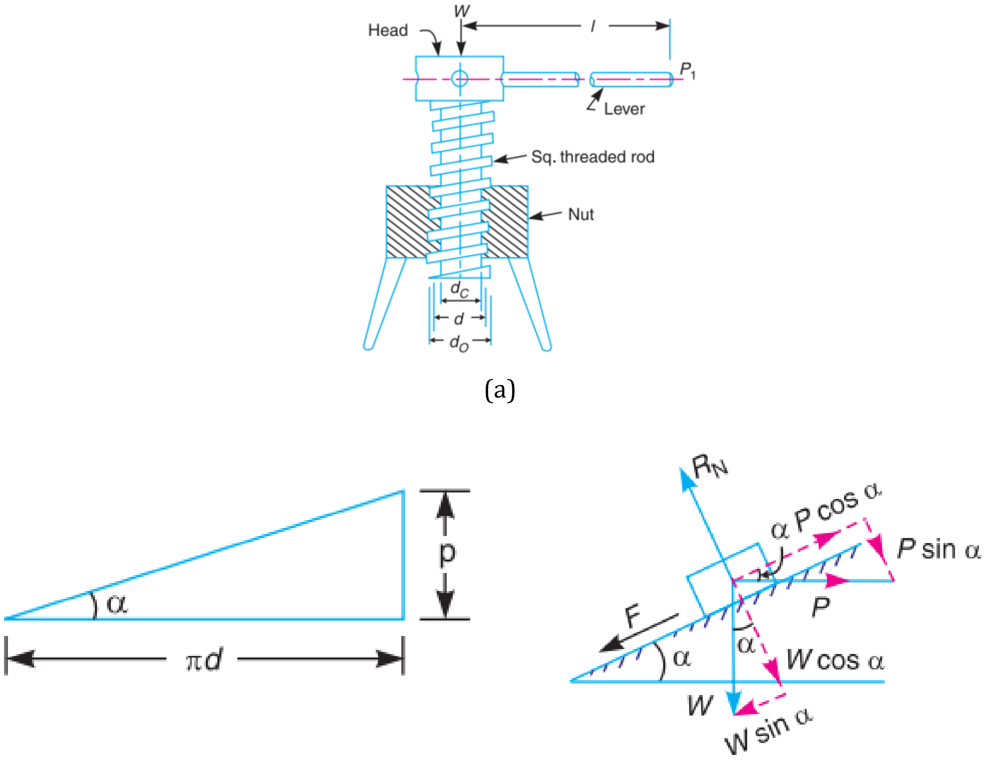
SolidWorks software is employed for designing the system, focusing on creating a 3D drawing. Recognized for its capabilities in generating 2D and 3D sketches, parts, and assemblies, SolidWorks enables virtual design modeling before physical prototyping. A crucial stage involves prototype testing to evaluate the wheelchair transfer mechanism's functionality, usability, and efficiency. Valuable feedback from carers and wheelchair users is collected during testing to identify necessary improvements or modifications for optimizing the assistive device's functionality. Fig. 6 illustrates the foundational design with the proposed component design of the transfer mechanism and the base idea for the concept with design element.

As shown in Fig. 7, patient lifting systems' efficiency is impacted by screw friction. Torque requirements are calculated in order to choose the right DC motor. It is essential to comprehend screw models when choosing components. It is possible to calculate horizontal force (P) and torque (T) by modelling the screw mechanism and applying equations. Screw friction reduction requires careful consideration of design, lubrication, and material selection. Enhancing performance guarantees the effectiveness and security of patient transfer systems. Calculations based on a 100kg load and iron surface friction inform torque requirements for selecting a DC motor. Considering grease coefficients helps reduce friction. These calculations guide the choice of an efficient motor for lifting.



(a) (b)

Fig. 6 *(a) Proposed design for transfer mechanism (b) Base idea of the new concept with design element*



(a)

(b) (c)

Fig. 7 *(a) Model of power jack, (b) Development of a screw, (c) Forces acting on the screw*

For the screw turning upward under the load, the screw horizontal force, P is illustrated in equation (1).

$$P = mg\tan(\alpha + \phi) = \frac{mg(\tan\alpha + \tan\phi)}{1 - \tan\alpha\ \tan\phi} \qquad (1)$$

Equation (2) shows the tangent of the Helix angle and the coefficient of friction (COF).

$$\tan\alpha = \frac{p}{\pi d_m}\ and\ \tan\phi = \mu \qquad (2)$$

where:

μ = the coorfficient of friction
α = helix angle of the screw
p = screw pitch in mm
d_m= effective diameter of the screw in mm
m = mass in Kg
g = gravity ($9.81m/s^2$)

By substituting equation (2) into equation (1), the equation could be represented in equation (3) in term of measured variables and constant.

$$P = \frac{mg(\frac{p}{\pi d_m} + \mu)}{1 - \frac{p}{\pi d_m} \cdot \mu} \qquad (3)$$

For the application of lift, the known values as listed as follows.

Maximum load in the application, $m = 100Kg\ (maximum\ load)$
The gravity, $g = 9.81m/s^2$
Screw pitch, $p = 4mm$
The screw effective diameter, $d_m = 20mm$
Coefficient of friction (steel versus steel), $\mu = 0.16$
Radius of the screw, $r = \frac{d_m}{2} = 10mm$

Equation (4) solving the screw horizontal force, P:

$$P = \frac{100 \times 9.81\left(\frac{4}{20\pi} + 0.16\right)}{1 - (\frac{4}{20\pi} . 0.16)} \qquad (4)$$

$$P = 221.670315N\ @\ 221.67N$$

and equation (5) is the turning torque, *T*, at the screw. Hence, the turning torque needed to lift a 100Kg load is T~2.2Nm.

$$T = P \times r \qquad (5)$$
$$T = 221.670315 \times 10$$
$$= 2216.70315Nmm$$

3. Result and analysis

3.1 Result 1: Feasible studies

3.1.1 Feedback from wheelchair user and caregiver

Continuous improvement of the transfer mechanism includes collecting user feedback through ongoing sessions, prototype testing, and design iterations. Prioritizing user preferences and needs, this study aims to meet the specific requirements of wheelchair users and caregivers. The survey, with 50 participants primarily from the M40 and B40 groups, gathered insights, with 78% identifying as carers and 22% as wheelchair users. Fig. 8 is for a visual representation of respondent percentages.

The high percentage of carer responses reflects their important role in the transfer procedure as well as their interest in finding ways to make transfers more effective and safe. Their suggestions can help the transfer mechanism's design and functionality better suit their unique needs and difficulties. Fig. 9 shows both details.

Designing an affordable and accessible transfer mechanism is crucial, particularly for individuals with lower incomes in the M40 and B40 groups. Survey feedback underscores the significance of cost-effective solutions, with 61.5% of respondents expressing concerns about the necessity of assistive devices and having spent over RM 1000 on such technology. This emphasizes the need to address financial constraints in developing solutions for the target community. Fig. 10 shows the need of assistive device.

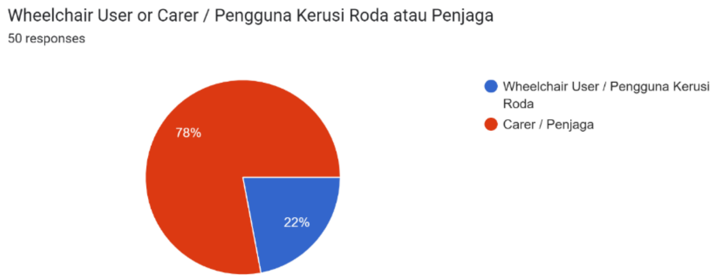
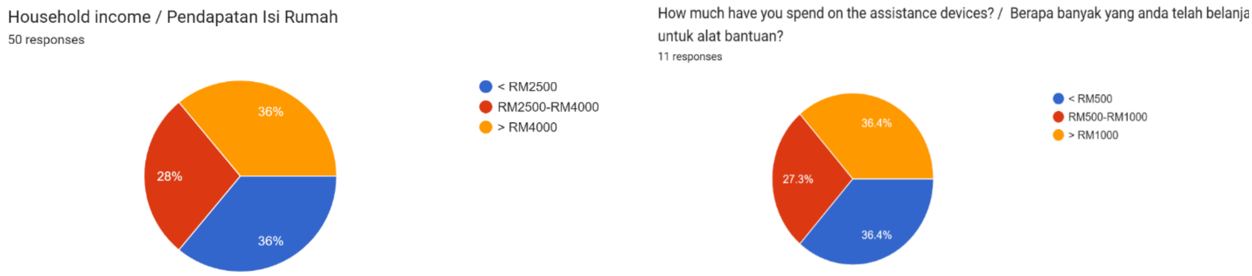


Fig. 8: *Percentage of 50 respondents*



(a) (b)

Fig. 9: *(a) Household income (b) Cost spent on assistance devices*

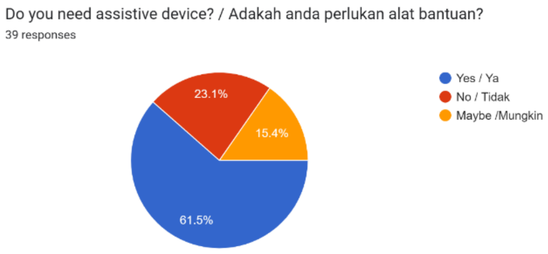
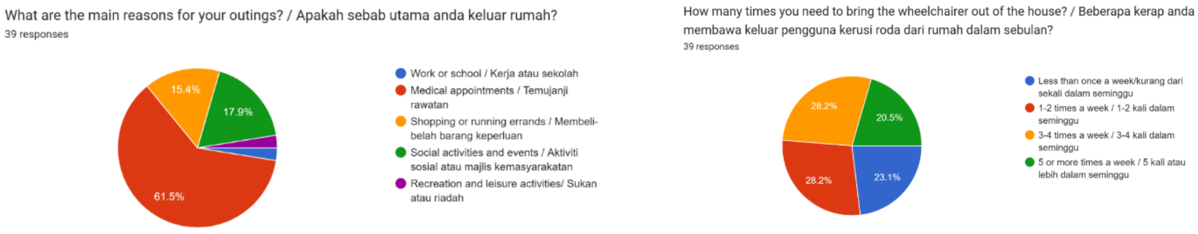


Fig. 10: *The need of assistive device*

This finding emphasizes the crucial function that assistive devices play in society and underlines the demand for affordable assistive technology. It emphasizes the need for such devices to be affordable to ensure accessibility for members of the targeted socioeconomic groups.

3.1.2 Importance of designing transfer mechanism

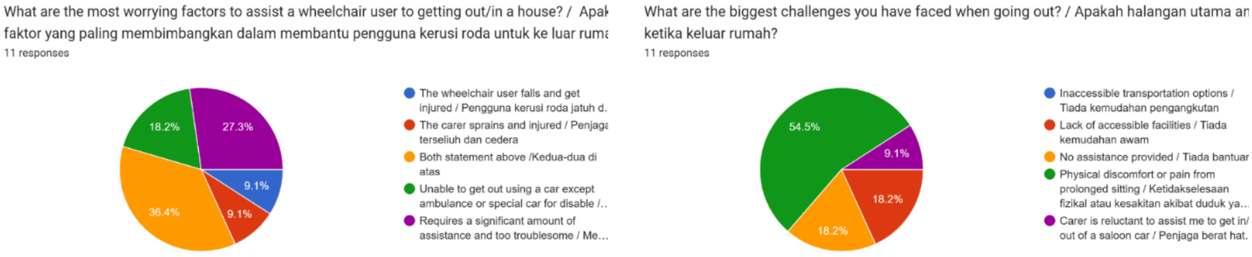
The questionnaire also examined the main reasons for outings, and the frequency of outings. Understanding these elements offers helpful understandings of the requirements and circumstances related to the transfer mechanism. The primary reasons for outings and the frequency of outings are shown in Fig. 11.



(a) (b)

Fig. 11: *(a) Main reasons of outing (b) Frequency of getting out*

Questionnaire findings underscore the importance of assistive devices for both carers and wheelchair users. Approximately 28.2% of respondents need to leave the house three to four times per week, mainly for medical appointments (61.5%). This highlights the device's crucial role in addressing transportation challenges. Common issues such as the risk of falling, back discomfort, and transfer challenges highlight the daily risks faced by wheelchair users and carers. Fig. 12 illustrates these factors, emphasizing the need for an efficient and reliable assistive device in addressing these concerns.



(a) (b)

Fig. 12: *(a) Most worrying factors (b) Biggest challenges*

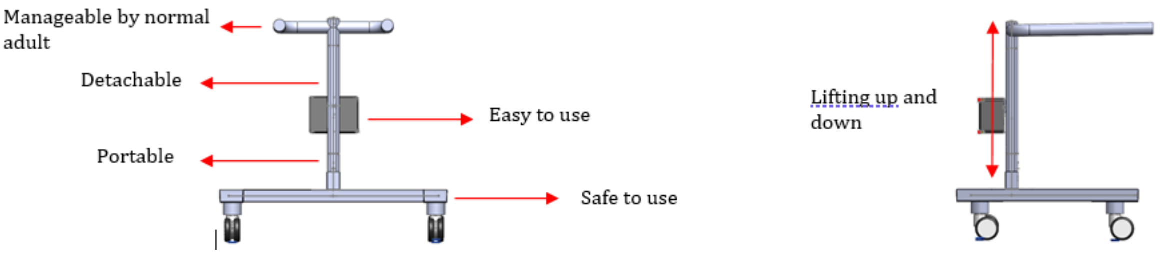
The study highlights concern about falls during transfers (36.4%) and back pain for caregivers during wheelchair-to-car seat transfers. 54.5% experience discomfort from prolonged sitting and transfers, emphasizing the need for a tailored transfer mechanism to enhance well-being for both caregivers and wheelchair users.

3.2 Result 2: Field Implementation

During the field implementation phase of the assistive device, hardware-software synergy is tested in real-world settings. The focus shifts to real-world applications to ensure responsiveness and flexibility during patient transfers. This stage validates technology effectiveness and guides ongoing improvements based on user input and evolving healthcare needs [6].

3.2.1 Hardware design implementation and assembly

The assistive device undergoes meticulous development, transitioning from software design to on-site hardware implementation. Rigorous field testing ensures software functionality, including sensor integration and microcontroller programming. Hardware stability and durability are prioritized through precise engineering and assembly of mechanical components. The Wheelchair Transferring System, designed using SolidWorks, optimizes effectiveness by guiding the assembly process with calculations, components, and material requirements. The SolidWorks sketch design for the Wheelchair Transferring System with proposed design element is shown in Fig. 13 13, which shows both the front and side views (a) and (b), respectively.

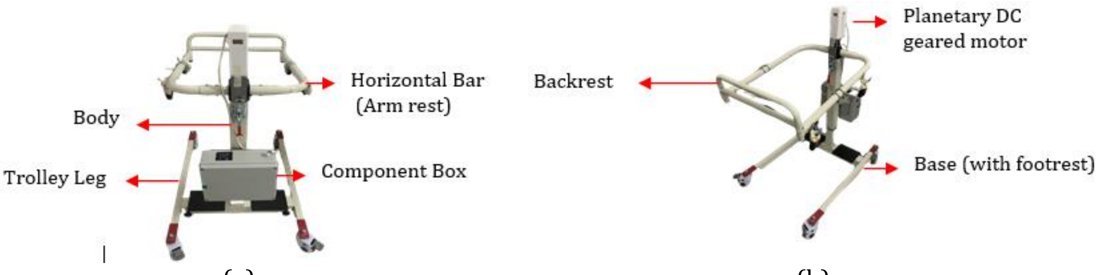


(a) (b)

Fig. 13: *(a) Front view (b) Side view of the main component of transfer mechanism for software design*

The software design serves as a key guide for attaching components and ensuring the functionality of mechanical parts in the SolidWorks environment, offering flexibility for adjustments based on cost and time constraints [7] during the hardware construction phase. This approach enables users to conduct measurements, spot potential issues, and enhance the construction process efficiency before moving forward. Fig. 14 presents the result of the hardware design, showcasing the effectiveness of this software-driven approach in streamlining the construction process.

A custom U-bracket has been intricately designed and integrated into the trolley to securely house the planetary DC motor, ensuring stable and reliable positioning. This thoughtful addition is specifically tailored to enhance the lifting functions within the overall mechanism. The U-bracket's design aligns precisely with the requirements of the planetary DC motor, contributing to the overall efficiency and functionality of the lifting system. Fig. 15 illustrates the U-bracket attached to the planetary DC geared motor, showcasing its purposeful integration.



(a) (b)

Fig. 14: *(a) Front view and (b) Side view of the main component of transfer mechanism for hardware design*

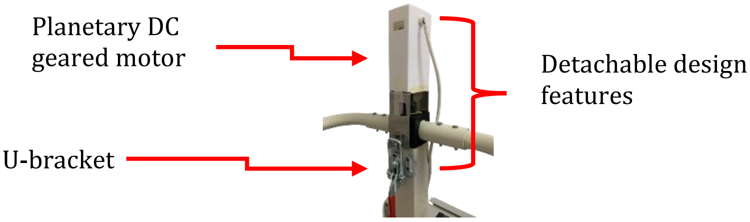


Fig. 15*: U-bracket attached to the planetary DC geared motor*

3.2.2 Weight measurement for parts

The assist trolley consists of six essential parts, including a solid base with a footrest, trolley leg, and a central body hub connecting necessary components. A horizontal armrest enhances maneuverability, and a backrest is included for patient comfort. The trolley is powered by a DC planetary motor for precise movements, and electronic controls are housed in the component box, serving as the control center. The total weight of the transfer mechanism is 24.10 kg, as shown in Fig. 16, demonstrating the comprehensive consideration of weight in the redesign process and not exceed limit of the weight which is 25 kg.

Fig. 16*: Overall weight of transfer mechanism (a) before (b) after*

Table 1: *Measurement of assistant device*

Parts	Quantity	Weight (Kg)	Weight (Kg)
Base (with footrest)	1	3.1	3.1
Trolley Leg	2	3.1	6.2
Body	1	6.4	6.4
Horizontal Bar (Arm Rest)	2	1.7	3.4
Backrest	1	0.8	0.8
Component Box (with DC Motor)	1	4.2	4.2
Total Weight (Kg)			24.1

Table 1 shows the measurements of every part of the assistant device. This orderly separation enables a thorough approach to functionality and design, guaranteeing that every component works in concert to maximize the assist trolley's overall effectiveness.

The meticulous engineering and design considerations have resulted in a significant milestone in optimizing the assist trolley. Through careful planning, the final weight is under 25 kg, ensuring portability and ease of use [8] for both carers and users. The design's easy detachability enhances versatility and usability, showcasing a commitment to dependability. This achievement reflects dedication to delivering a product that exceeds expectations in user convenience, portability, and functionality.

3.3 Analysis 1: Weighing test

Three trials are conducted in the test, each led by a different weighted individual to ensure a thorough analysis of the device's functionality. Table 2 shows three different weights with 100kg of loads as reference with time taken to retracted.

Table 2: *Weight measurement with time taken*

Person	Height (cm)	Weight (Kg)	Time Taken (s)
LOAD		100	43.08
NO LOAD		0	34.24
A	171	80.2	15.88
B	183	65.7	19.52
C	169	58.3	12.96

The weighing test outcomes provide crucial insights into the transfer mechanism's effectiveness for individuals of different weights. Person A, 171 cm tall and 80.2 kg, lifted in 15.88 seconds. Person B, 183 cm tall and 65.7 kg, retracted fully in 19.52 seconds. Person C, 169 cm tall and 58.3 kg, had the quickest lifting time at 12.96 seconds.

3.4 Analysis 2: Time evaluation

The time evaluation test demonstrates the efficiency and time-saving benefits of the assistive device's transfer mechanism compared to traditional methods, especially for tasks like lifting and positioning patients in car seats. The test comprises two parts: the first involves transferring a patient from a wheelchair to a car seat, and the second involves a different transfer scenario. The evaluation, illustrated in Fig. 17, is designed to assess the effectiveness of the mechanized system in enhancing the speed and efficiency of crucial patient transfer tasks, being transferred from wheelchair to car seat and vice versa.

Fig. 17: *Patient being transferred from wheelchair to car seat and vice versa*

The device's efficacy in a variety of transfer scenarios was further highlighted by the even faster completion time of the second part, which represented a more general patient transfer scenario. Table 3 shows the results for both parts of the transfer.

The recorded time in the first section is 2 minutes and 5.24 seconds, during which the patient is moved with the help of the assistive device from the wheelchair to the car seat. The recorded time for the second part, which involves a transfer under different circumstances, is one minute and 57.36 seconds. A 58 kg patient is present in both scenarios.

The outcomes demonstrate the effectiveness and time-saving capabilities [9] of the assistive device with a transfer mechanism. In the scenario of moving a patient from a wheelchair to a car seat, the device completed the task in just over two minutes. Moreover, it demonstrated even faster completion times in a general patient transfer scenario. These recorded times highlight significant time savings compared to conventional techniques, emphasizing the practical benefits of the assistive technology in expediting patient transfer procedures and improving overall patient care.

Table 3: *Result of time taken for transferring patient*

Task	Patient's Weight (Kg)	Time Taken (min)

Wheelchair to Car Seat	58	2:05:24
Car Seat to Wheelchair		1:57:36

4. Conclusion

In conclusion, this work successfully addressed the need for a transfer mechanism through thorough analysis and research, resulting in a functional solution for patient transfers from wheelchairs to cars. Rigorous testing and cost-effectiveness evaluations confirm its reliability.

Moving forward, this work can enhance through ongoing refinement, integrating advanced features, and exploring wireless connectivity. Emphasizing customization, collaboration with medical experts, and regular software updates demonstrates commitment to adaptability. Recommendations stress securing funding for advanced technologies and implementing a user feedback system to prioritize a user-centric approach for advancing patient care and accessibility.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Faaez;* ***data collection:*** *Faaez;* ***analysis and interpretation of results:*** *Faaez;* ***draft manuscript preparation:*** *Faaez and Tee. All authors reviewed the results and approved the final version of the manuscript.*

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