

Mechanism Design and Evaluation of a Threaded Rod-Driven Wheelchair-to-Bed Transformation System

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| KEY WORDS                                                                                                                       | ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
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| Wheelchair<br>Bed conversion<br>Motorized wheelchair<br>Assistive technology,<br>Threaded shaft<br>Patient comfort<br>Mobility. | This study presents the design and simulation-based evaluation of a low-cost multifunctional wheelchair-to-bed transformation system powered by a threaded rod mechanism. Developed to enhance autonomy, comfort, and safety for paraplegic and quadriplegic patients, the proposed system utilizes a self-locking DC motor-driven threaded shaft that enables smooth, controlled transitions between sitting and lying positions without requiring caregiver assistance. Unlike conventional systems that employ hydraulic or hydrostatic actuators often associated with complexity, maintenance challenges, and high cost—this design prioritizes mechanical simplicity, affordability, and user accessibility. The system supports voice and joystick-based control, catering to users with varying physical capabilities. SolidWorks simulations and performance analysis demonstrate that the mechanism completes full transformation in 28 seconds under a 15 kg load, ensuring stability, energy efficiency, and ease of use. Comparative evaluation with existing actuator-based systems confirms the advantages of the threaded rod mechanism in terms of reliability, power consumption, and passive safety. This research introduces a simple and affordable assistive mobility solution with strong applicability in clinical and home care environments. |

1. Introduction

A wheelchair is a vital mobility aid for individuals with walking difficulties, often caused by illness, injury, or disability. For people who experience physical limitations such as paralysis, whether due to trauma, disease, or congenital conditions, a wheelchair becomes not only a tool for movement but also a critical enabler of independence. [1] Broadly, wheelchairs come in two primary forms: manual and powered. Manual wheelchairs require the user or a caregiver to propel the chair using large rear wheels. Powered wheelchairs, on the other hand, are motorized and can be operated by the user with limited physical capability, thus providing greater autonomy for individuals unable to propel a manual chair

independently.[2] Both types have their advantages, but powered wheelchairs are particularly indispensable for individuals with severe mobility impairments such as paraplegia or quadriplegia. These individuals rely on wheelchairs for much more than just mobility; they are essential for performing a wide range of daily activities that would otherwise require external assistance [3,4].

For patients who have lost the ability to walk due to accidents, bomb blasts, or other traumatic events, the challenges in daily life are often compounded by dependence on caregivers for basic activities. These patients often struggle with tasks that we take for granted, such as using the washroom or transitioning between sitting and lying positions. Dependency in

that, this dependence can negatively impact both the patient and caregiver.[5] Being provided with a mobility aid that is versatile, i.e., may provide more than just the sitting position, and such may be a wheelchair, this dependency can be easily minimized, leaving the patients with the right to carry out the necessary things with enhanced ease. An example of a useful solution would be a wheelchair that can also be converted to a bed thus enabling the patient to lie down and rest without help. This does not only make it more independent but also more comfortable, which orients to the long-term patients who spend large amounts of time in a sitting position [3]. Even with the current technological skills on the design of wheel chairs, most of the already designed wheel chairs are inadequate to cover some of the major concerns like foldability [4] , stability, safety and affordability. As an example, although some powered wheelchairs offer motorized propulsion, they might not have components to increase the comfort of a user or to make a wheelchair easy to transport and storage saving space.[6] The incorporation of the Internet of Things (IoT) technology in the use of wheelchairs has helped to enhance the general experience in the last couple of years. The new IoT-connected wheelchairs allow real-time transfer of health data to medical professionals, and they can monitor the patient status remotely, which can be used to implement even more active treatment. Although the solutions come with certain improvements, the need of the broad spectrum of wheelchair users is still lacking as none of them is very comfortable, easy to operate and move in, and to store / transport when not in use. That is why it requires additional research and development in order to explore the limit in terms of wheelchair design.

The trend of research is moving towards the development of multifunctional wheelchair chairs capable of changing their position and into full reclining bed so as to give the patient the flexibility it requires. The aim of designing such a wheelchair is to minimize a dependency on various caregivers, provide a smooth change between sitting and lying positions and enhance the general comfort and efficiency of the wheelchair. Such wheelchairs are designed to have more advanced mechanisms whereby users are able to modify the position of their seat automatically making it fit them better and have higher ergonomic fit.[7] Furthermore, the introduction of other features like customizable seats, foldable structure so that they can be easily stored and transported, or light material to manufacture the wheelchairs will make the wheelchairs to be used by both the patients and the caregivers as well as the healthcare givers. The goal is to create a cost- effective solution that can meet the diverse needs of patients in a variety of care settings,

including hospitals, rehabilitation centers, and home care environments. By improving the quality of life for the patient and reducing the physical strain on caregivers, multifunctional wheelchairs make significant promise in transforming both the healthcare experience and the independence of individuals with mobility challenges [8, 9].

In this context, this paper presents a novel approach to wheelchair-bed transformation using a DC motor-driven threaded rod mechanism. The system is designed to be low-cost, lightweight, and highly stable under patient loads. It offers both voice and joystick control option and emphasizes comfort, safety, and ease of use. The structure of this paper is as follows: Section 2 presents the existing situation analysis, which includes user research, survey findings to define the research scope, and a review of existing literature on wheelchair designs and usage. Section 3 presents the methodology focusing on the design and working principles of the proposed product. Section 4 covers the complete design process, including material and motor selection and the working of the control mechanism. Section 5 discusses the simulation results and comparison with existing mechanisms. Finally, the paper concludes with a summary of findings and suggestions for future improvements.

### *1.1 Motivation*

Paraplegic patients frequently encounter significant limitations in movement that drastically affect their autonomy, comfort, and general quality of life. A significant everyday issue they have is the physical transition between a bed and a wheelchair, which generally necessitates carer help and may result in injury, discomfort, and a loss of dignity. Although numerous assistive technologies are available for mobility and posture control, the majority are either excessively costly, mechanically intricate, or insufficiently auto- mated to guarantee user-friendliness for both patients and carers. The deficiencies in existing solutions underscore the pressing necessity for an economical, dependable, and intuitive system that effortlessly combines the features of a bed and a wheelchair. This initiative is motivated by the aim to restore autonomy and enhance the quality of care for paraplegic patients through the development of an automated, convertible bed-wheelchair system that facilitates independent living and diminishes care reliance.

## **2. Literature Review**

A comprehensive literature review was conducted to examine recent advancements in the design and development of wheelchairs. Beltozar et al. [10] developed a wheelchair that allows the user to adjust

the upper body posture using a customizable back support system, driven by two linear actuators. This innovation enables patients to use the wheelchair as a versatile device for rehabilitation without external assistance. The inclusion of sit-to-stand (STS) and backrest adjustment mechanisms promotes regular exercise, improving blood circulation, which is important as prolonged sitting can reduce lower limb mobility. Zhang Z al. [11] designed a multifunctional wheelchair that can convert into a chair, semi-chair, or stretcher using a lead screw mechanism connected to a pivot joint. The chair's seat is removable to facilitate easier disposal of human waste. A hydraulic jack was incorporated to lift the main arm of the chair for added functionality. Kumar B et al. [12] developed a wheelchair-cum-stretcher with the capability to transform into an electrical mobility aid when navigating stairs. The design included a detachable headrest when converting into a stretcher and utilized hinges and a nut screw mechanism for the transformation process. Ocagli H et al. [13] proposed a Smart Medical Bed with embedded control systems that provide caregivers with enhanced management capabilities. The bed's most notable feature is its navigation system, which allows it to be used within a 60-meter radius of a hospital for optimized patient care.

Selvanesan EN [14] designed a new multifunctional wheelchair with automatic postural adjustments, specifically intended to address users' nursing needs while reducing the workload for nursing staff. Their kinematics analysis showed smooth reclining motion for the wheelchair's backrest, confirming the effectiveness of the mechanism design. To assist individuals with disabilities, an advanced user interface was developed in some studies, allowing patients to operate the wheelchair independently without the need for assistance from caregivers. The wheelchair can be controlled through an Android application by following specific commands displayed on the user's screen, enabling ease of movement without physical strain [15]. In a separate study, an ultralight composite folding "Sit-to- Stand Trainer Frame" was designed to help patients who face significant challenges in changing body configurations. The device uses linear actuators to assist in muscle training, and it was claimed that patients could experience a notable improvement in muscle strength within six weeks of consistent use [16]. Several researchers have highlighted the importance of a user-centric design for wheelchairs. One such study argued that many prototypes were developed without sufficiently considering the specific needs of patients. It pointed out critical challenges related to sensor technology that need to be

addressed to make smart wheelchairs more widely accepted by users. A major issue identified was the balance between cost and accuracy in existing sensors, which must be optimized to increase the adoption of smart wheelchairs [17].

Parthasarathy et al. [18] developed a wheelchair using Arduino UNO as the microcontroller, which enabled reclining through a digital accelerometer and ultrasonic sensors to detect obstacles, with control via a thumb-operated joystick. Furthermore, Mohanavel et al. [19] introduced a simplified wheelchair- cum-stretcher design using a hinge and nut screw mechanism enabling easy transformation between a wheelchair and stretcher. Cao et al. [20] developed a multifunctional wheelchair combining posture adjustment, gait training, and multi-posture transformation, with control through voice commands, buttons, and a mobile terminal. The study included analysis of the wheelchair's functional requirements and kinematic simulation. Reddy et al. [21] designed an ergonomic, stairs-climbing wheelchair with dynamic analysis for smooth motion trans- mission, addressing the need for effective stair navigation. Akhil et al. [22] created a wheelchair that can function in- doors and outdoors, lift a patient from a bed, and double as a walker, using a screw-nut mechanism for movement. Shah et al. [23] developed a folding stretcher integrated into a wheelchair, allowing the stretcher to detach from the main frame for user convenience. The foldable design minimizes space utilization, especially in areas with limited space. Most recently, Xiong et al. [24] developed a multifunctional electric wheelchair with a rehabilitation training mod- ule that includes a leg structure and a crank-rocker mechanism. The rehabilitation module can be adjusted or hidden under the wheelchair, with software detecting the user's intentions for better interaction. Meng et al. [25] introduced a smart wheelchair with three postures sitting, standing, and lying utilizing a bionic shifting mechanism. The design, based on biomechanical characteristics, was simulated using Adams (Automatic Dynamic Analysis of Mechanical Systems) software.

The primary goal of the research is to design a multi- functional wheelchair that can convert into a bed, ultimately aiming to make patients more independent and reduce the physical strain on caregivers. Through a combination of observational research and interviews with patients, care- givers, and medical staff, we gained valuable insights into the current challenges faced by patients during transitions from wheelchair to bed, as well as their overall needs in a health- care setting. Observations were conducted in three hospitals, focusing on the daily activities of

patients, families, and medical staff interacting with nursing beds. The observations highlighted two critical issues. First, new users had difficulty learning to use the bed due to unclear instructions. The manual adjustment controls were placed at the far end of the bed, preventing patients from adjusting it on their own. Fast adjustments by caregivers sometimes cause discomfort.[26] Second, in the rehabilitation process, patients required assistance from multiple nurses to move between the wheelchair and the rehabilitation room, leading to additional discomfort and inconvenience. The feedback collected from patients, caregivers, and healthcare professionals helped refine the design requirements for a multifunctional wheelchair. Nearly 100 percent of patients emphasized the need for a wheelchair that could automatically convert into a bed, with the added benefit of a standing position to improve circulation and prevent muscle atrophy, significantly enhancing their independence. Around 60 percent preferred controlling the wheelchair via a touchpad, while others favored a joystick, highlighting the importance of providing multiple control options to meet diverse needs. Additionally, 90 percent of patients expressed a desire for voice command functionality, allowing hand-free operation, especially for those with limited hand mobility. Nurses expressed a desire for nursing beds that could help patients turn over and move more easily, especially during rehabilitation treatments. This would reduce their physical workload and improve the quality of care provided. Additionally, they mentioned that incorporating artificial intelligence (AI) into the bed could help them communicate with patients more effectively, helping alleviate some of the emotional distress patients might feel. Doctors, on the other hand, highlighted the need for nursing beds that could monitor basic health parameters like blood pressure and body temperature during rehabilitation, allowing them to work more efficiently and closely track patient progress.

**Table 1**

Leading Causes of Spinal Cord Injury by Age Group

| Cause of Injury         | Percentage (%) | Age Group Association                  |
|-------------------------|----------------|----------------------------------------|
| Motor Vehicle Accidents | 38.4           | All age groups                         |
| Falls                   | 31.6           | Predominantly above 65                 |
| Acts of Violence        | 13.8           | More prevalent in younger adults       |
| Sports Injuries         | 8.2            | Common in adolescents and young adults |
| Medical/Surgical        | 4.3            | Older adults                           |
| Other Causes            | 1.3            | Various age groups                     |

Table 1 provides an overview of the leading causes of spinal cord injuries (SCI) across different age groups, based on global data. This highlights the key

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factors contributed to mobility impairments, emphasizing the importance of addressing specific needs in wheelchair design, particularly for patients with varying injury causes and age-related challenges.

### 3. Methodology

The methodology for this research involves a structured and systematic approach to the design, development, and testing of a multifunctional wheelchair that can seamlessly transition between a wheelchair and a bed. The process consists of several key steps, from initial design to manufacturing and assembly. Each step is crucial to ensuring that the final product meets the required functionality, comfort, and safety standards. Figure 1 shows the five major steps involved in methodology.

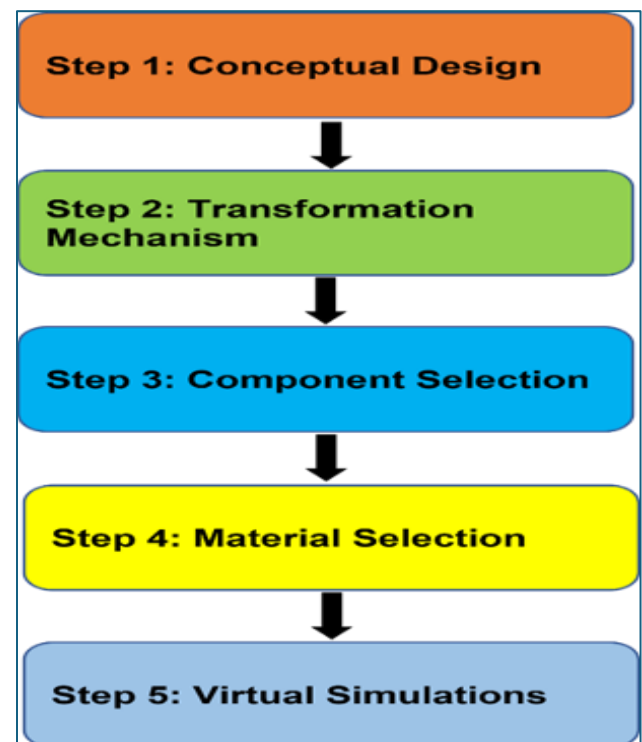


**Fig. 1.** Flowchart showing the five-step methodology followed in the design and development of the wheelchair-to-bed system.

Step 1. The wheelchair design was done under the SolidWorks program which is a strong computer-aid design (CAD) software that was used in 3D modeling and simulation, and product design as indicated in Figure 2. SolidWorks enables accurate models to be generated so that the components of the design would fit each other in a nice way and model the actual performance of the product in real life circumstances. This was necessary to make sure that the wheelchair was to meet the specifications required. SolidWorks was used to design the final product through modeling of its main aspects as illustrated in Figure 2. The customer survey was carried out before the design process, to distinguish the major needs which were transformation into bed, simple operation, low price, being lightweight and multifunctional. The design

included these requirements so that the end product would have satisfied the users.



**Fig. 2.** 3D CAD model of wheelchair developed in Solid Works

Step 2. An elaborate mechanism of transformation that can be used to give the motorized wheelchair an easy and stress-free conversion to a bed-like convenient configuration was crafted. The inspection of some different configurations and streamlining them allowed obtaining mechanical efficiency and stability.

Step 3. The motors and electronic components that were chosen were suitable with respect to the estimated torque and control needs that were also provided by the simulation data. The circuitry and the logic control would be designed with ease of integration and ease of use to the user in the final prototype.

Step 4. The products that will be used to create different parts were chosen by simulations done during design of such parts based on their weight, strength and their intended use. The suggested materials are square pipes to make the frame, rubber to move and leather to seat comfortably.

Step 5. Simulations were done virtually to test the performance of the transformation mechanism as well as the actuation of the motors against load. These simulations had been useful in justifying the proper operations of the design and informed optimization of the design before proceeding to the fabrication phase. The simulation assumes ideal conditions: uniform load distribution, constant motor voltage, rigid body dynamics, and no external vibrations or wear. These assumptions help isolate performance of the mechanism without real-world uncertainties.

The multifunctional wheelchair control system is important to facilitate the ability to use it and change the positions (sitting and bed). Key components include:

- Microcontroller: Arduino Uno

- Voice Module: Bluetooth HC05
- Motor Driver: BTS40A dual H-bridge driver
- Joystick Interface: Two-axis analog joystick module

The wheelchair has the option of controlling it by a joystick or by use of voice thus offering flexibility depending on the physical ability of the user. The microprocessor functions essentially like the brain of the system taking inputs as signals in the joystick or voice command system. Based on the received inputs, the microcontroller sends signals to the motor drivers which direct the movements of the wheelchair. The bed mechanism motors are activated through the motor drivers and are responsible in the transformation of the wheelchair into a bed or adjustment of the angle of the seat to provide comfort. Feedback loops are also present in the system in order to follow the movement of the wheelchair which will allow to maintain high accuracy of positioning and avoid mistakes made in the process of transformation. The feedback makes the wheelchair move in the right direction in accordance to user request and the overall system moves smoothly. The next (from Figure 3) control flow chart shows how the joystick or voice command system interacts with the mechanical aspect of the wheelchair. For voice command we have used the existing circuit by adding a Bluetooth module (HC-05) and link with a mobile app, Arduino Bluetooth Controller. We specified some commands of voice like: Go Forward, Go Backward, Go right, Go left and Stop.

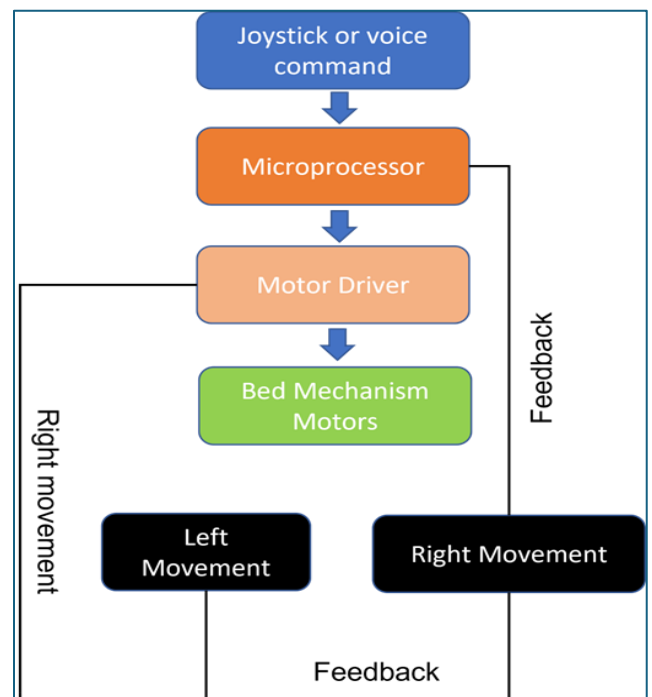


**Fig. 3.** Control flow diagram illustrating the interaction between voice/joystick commands, microcontroller processing, and mechanical actuation

In the event of sudden electrical disconnection, the transformation mechanism passively holds its position due to the self-locking nature of the threaded rod. If signal interruption occurs, the system will not execute any further commands until re-initialization, ensuring safety. A manual override mechanism or external power input can be implemented in future versions to enable emergency operation. Current system architecture favors fail-safe positioning to prevent unwanted movements.

### 3.1 Structural Design and Transformation Mechanism of the Wheelchair-Bed

This section presents the detailed mechanical design, material selection, and transformation mechanism of the proposed multifunctional wheelchair. The focus is on the structural components, motorized actuation system, and the threaded shaft-based mechanism that enables a smooth conversion from sitting to bed.

#### 3.1.1 CAD model and dimensions:

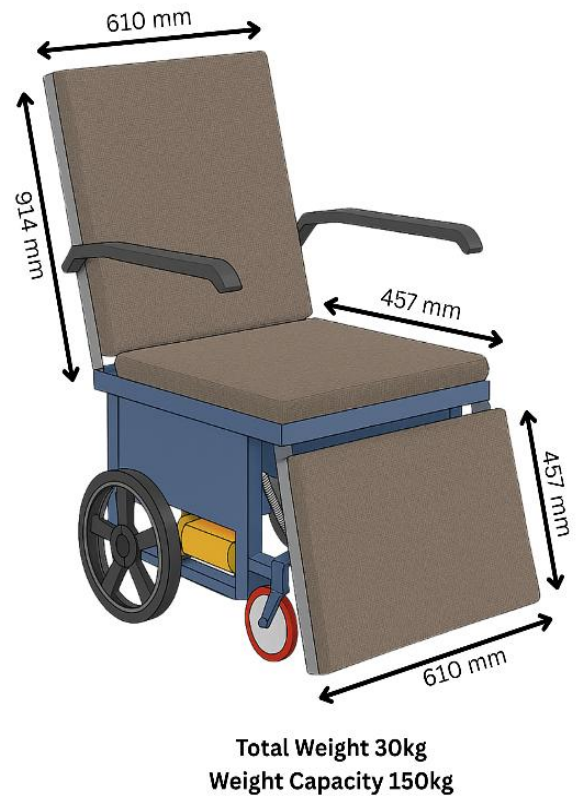
The CAD model of the wheelchair was created using SolidWorks to ensure a comfortable and practical design. It is built to a standard size, with an overall length of about 200 cm, a width of 90 cm, and a bed surface height of 20 cm (without the mattress). This size allows the wheelchair to be used in both sitting and lying positions. Furthermore, the key measurements of different parts are listed in Table 2, the total expected weight of the wheelchair is approximately 30 kg, and it is designed to carry a load of up to 150 kg.

**Table 2**

Technical Specifications of Wheelchair Design

| Attributes       | Dimensions  |
|------------------|-------------|
| Leg Space        | 457 x 610mm |
| Main Seat        | 457 x 610mm |
| Back Seat        | 914 x 610mm |
| Total Bed Length | 1524mm      |
| Total Weight     | 30 kg       |
| Weight Capacity  | 150 kg      |

These dimensions and weight capacity ensure that the wheelchair is both comfortable for the user and sturdy enough to support the intended weight range, making it suitable for a variety of patients. Moreover, Figure



4 demonstrates the 3D CAD model of the wheelchair, visually representing its structure and component layout as per the above specifications.

**Fig. 4.** SolidWorks CAD model of the wheelchair-bed system, illustrating the structural layout and dimensional specifications listed in Table 2

#### 3.1.2 Material Selection:

The wheelchair frame is built using 25x25 mm mild steel square pipes with a 16-gauge (5.08 mm) wall thickness, weighing approximately 1 kg per foot. Mild steel was chosen for its high strength (370–460 MPa), good weldability, and cost-effectiveness. The selected gauge provides sufficient rigidity to support loads up to 150 kg while keeping the overall structure lightweight and easy to fabricate.

#### 3.1.3 Actuating System and Motors specifications:

The wheelchair utilizes two DC motors for actuation. A DJ- 158A high-torque DC motor (24V, 200W, 29.5Nm torque) powers the drive system, ensuring smooth and efficient movement. For bed transformation, a 12V wiper motor with 25Nm torque is employed to adjust the backrest and leg sections via a threaded shaft mechanism. Both motors were selected for their reliability, safety, and suitability for patient load. The system achieves a full transformation from sitting to lying position in under 30 seconds, meeting the performance goals for ease and speed. The

specifications for materials and motors used in the wheelchair are provided in Table 3, which outlines the specifications for each component, including material properties and motor capabilities.

**Table 3**

Component Specifications and Details

| Component                     | Specification                    | Details                                                                                                                             |
|-------------------------------|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Material:<br>Square Pipes     | 16-gauge mild steel square pipes | - Dimensions: 25x25 mm<br>- Wall Thickness: 5.08mm (Gauge 16)<br>- Weight per Foot: 1kg<br>- Strength: High strength and durability |
| DC Motor for Drive Wheelchair | DJ-158A Heavy Torque DC Motor    | - Voltage: 24V<br>- Total Power: 200W<br>- No Load Current: 3.6amps<br>- Motor Speed: 3350 rpm<br>- Torque: 29.5Nm                  |
| DC Motor for Bed Mechanism    | Vehicle Wiper Motor              | - Voltage: 12V<br>- Total Power: 120W<br>- Operating Current: 10A<br>- Speed: 55rpm<br>- Torque: 25Nm                               |

#### 3.1.4 Mechanism Design and Transformation Principle:

The transformation mechanism is based on a threaded shaft and nut assembly, like a conventional nut-and-bolt system. A threaded rod is directly connected to the motor shaft. As the motor rotates clockwise or counterclockwise, the nut-fixed to a linkage rod-moves linearly along the threaded shaft. This nut is connected to either the backrest or leg support section of the wheelchair. When the motor rotates, the nut's linear motion causes the connected section (back or leg) to tilt forward or backward, enabling a smooth transition between sitting and lying positions. The use of a threaded shaft ensures precise, controlled movement and acts as a self-locking mechanism, which holds the position even if power is lost-adding to the safety and reliability of the system.

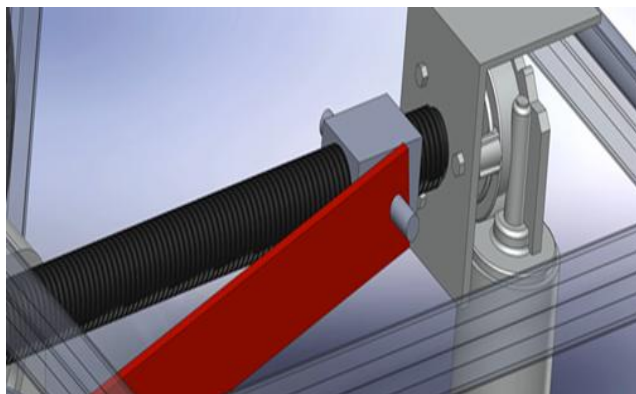


**Fig. 5.** Diagram of the threaded shaft mechanism with the red linkage rod, black threaded shaft, and silver nut

Figure 5 below illustrates the threaded shaft mechanism and its connection to the motor and nut, showing how the red linkage rod, black threaded shaft, and silver nut work together to adjust the backrest or leg support sections. Manufacturing tolerances:  $\pm 0.5$  mm (frame),  $\pm 0.2$  mm (threaded rod). Designed for 150 kg with 1.5 safety factor. Simulated transformation repeatability:  $\pm 2$  degrees. Physical validation is future work.

## 4 Results and Discussion

This section presents the key performance outcomes of the proposed convertible wheelchair-to-bed system. The design evaluation is currently simulation-based. Assumptions include ideal loading, stable voltage, and rigid body dynamics. Physical testing is pending and acknowledged as a limitation. Future work includes empirical validation. The results include mechanical specifications, motion simulation, structural analysis, and motor performance metrics. Each aspect of the design is evaluated to validate its functionality, safety, and efficiency under typical operational conditions. We further discuss the findings by comparing them with existing transformation mechanisms found in similar assistive devices.

An initial user evaluation was done on real life using a limited number of users who included paraplegic patients and attendants. The results of feedback revealed that the transformation process was natural and comfortable and the users expressed their high comfort and ease of usage. An additional clinical testing will be done to prove the performance under prolonged use conditions.

### 4.1 Transformation Efficiency

To evaluate the mechanical performance of the transformation system, a motion simulation was conducted in Solid- Works to analyze the transition from sitting to bed position. The simulation replicates real-world conditions using the threaded shaft mechanism driven by DC motors. The process demonstrates a complete transformation over 28 seconds, driven by two motors controlling the backrest and leg sections independently.

As illustrated in Figure 6(a), the simulation begins with the wheelchair in the initial sitting position, while Figure 6(b) shows the final fully reclined bed position at the end of the transformation cycle. These stages confirm the effectiveness and smoothness of the motion under the given configuration.

For this design, we have taken a standard thread pitch (distance the nut travels per 1 full turn)

Common thread pitch for lead screw:

8 TPI

1 turn = 3.175 mm

Shaft Length: 457.2 mm

$$\begin{aligned} \text{Total turns} &= \frac{\text{Total shaft length}}{\text{Pitch}}, \\ &= \frac{457.2\text{mm}}{3.175\text{mm}} \approx 144\text{turns} \end{aligned} \quad (1)$$

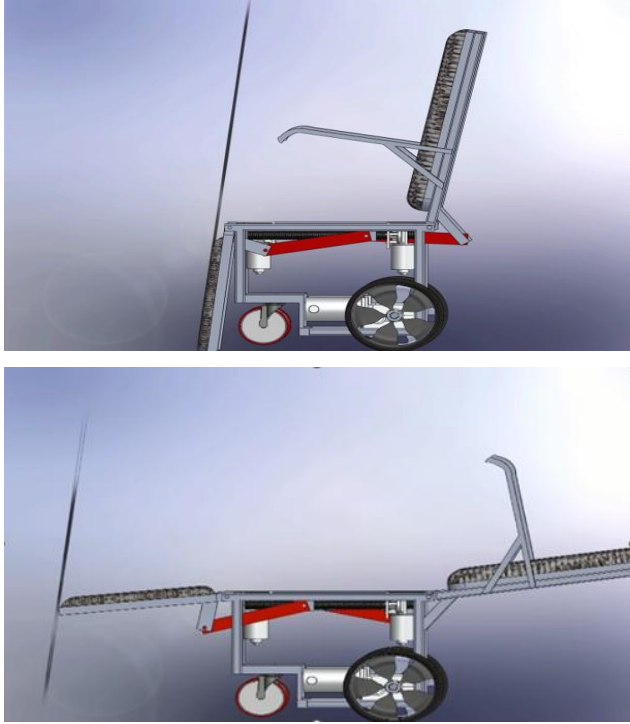


**Fig. 6.** (a) Initial sitting position of the wheelchair at simulation start (b) Fully reclined bed position after 28 seconds of transformation

So, the motor will need to rotate 144 full turns (revolutions) to move the nut along the full shaft.

Transformation Time = 28 sec

$$\text{LinearSpeed} = \frac{457.2\text{mm}}{28\text{sec}} \approx 16.33\text{mm/sec} \quad (2)$$

The linear speed, calculated in Equation (2), is approximately 16.33 mm/sec, allowing the actuator to complete the transformation in 28 seconds. This speed ensures smooth motion that is both safe and comfortable for the user. It also confirms the motor's ability to perform 144 full revolutions without mechanical strain. Faster speeds could compromise user comfort, while slower ones might reduce system responsiveness. Hence, this setting provides a balanced and effective transformation process.

$$\text{MotorRPM} = \frac{144}{28} \times 60 \approx 308.57\text{RPM} \quad (3)$$

To achieve the motion from equation 2, the motor must operate at a rotational speed of about 309 RPM,

as determined in Equation (3). This value ensures that all 144 revolutions are completed within the designated timeframe. It remains well within the functional range of most DC gear motors, supporting reliable and consistent actuation. Maintaining this RPM is essential for synchronizing the linear and rotational components of the system. Any substantial deviation could impact both performance and user experience. So, the motor must rotate at 309 RPM during the transformation.

To calculate the power required by the motor, we use the equation for mechanical power (PPP) in terms of torque (TTT) and angular velocity ( $\omega$ ):

$$P = T \times \omega \quad (4)$$

The torque required to drive the lead screw can be estimated using the following equation for lead screw torque (TTT):

$$T = \frac{F \times d}{2\pi \times \eta} \quad (5)$$

F is the axial force on the nut (N), d is the lead screw diameter (m), and  $\eta$  is the lead screw efficiency (typically 0.3–0.8, unitless). The axial force can be estimated based on the load the lead screw will bear. For example, if the lead screw supports a weight, then the force can be approximated as.

$$F = W \times g \quad (6)$$

The efficiency  $\eta$  of a lead screw can be estimated based on its lead angle and the coefficient of friction using the following formula:

$$\eta = \frac{\tan(\lambda) - \mu}{\tan(\lambda) + \mu} \quad (7)$$

$\eta$  is the efficiency of the lead screw (unitless),  $\lambda$  is the lead angle of the screw (degrees or radians), and  $\mu$  is the coefficient of friction between the screw and the nut (unitless).

The power required by the motor can also be expressed in terms of electrical power consumption. Assuming the motor is supplied with a voltage V and draws a current I, the electrical power  $P_e$  is given by:

$$P = V \times I \quad (8)$$

Time per revolution is equal to 60/motor RPM

For example, if the motor rotates at 309 RPM, so equation 10 would become,

$$\text{Time per revolution} = \frac{60}{309} \approx 0.194\text{sec} \quad (10)$$

The value of 0.194 seconds per revolution indicates how long the motor takes to complete one full rotation at 309 RPM. This is important because each revolution moves the threaded nut a fixed distance, affecting the

speed of the wheelchair's transformation. A shorter revolution time ensures smooth, responsive motion, contributing to both user comfort and mechanical efficiency during the conversion from sitting to lying position.

so we have 309 rpm of motor rotation

$$\omega = \frac{309}{60} \times 2\pi \approx 32.34 \text{ rad/sec} \quad (11)$$

Here,  $\omega$  is rotational speed in rad/s, while RPM is rotational speed in rev/min, and  $2\pi$  is the number of radians in one full revolution. Therefore, equation 11 indicates that a motor spinning at 309 rpm is rotating at 32.34 rad/s. Moreover, we used this outcome for further estimates to calculate the torque required, energy consumption, and system responsiveness.

The threaded shaft used in the transformation mechanism has a total length of 457.2 mm, with a standard thread pitch of 8 TPI (3.175 mm per turn). To achieve full transformation, the motor must complete approximately 144 full revolutions within 28 seconds. This corresponds to a required motor speed of around 309 RPM, resulting in a linear motion speed of 16.33 mm/s for the nut. The average angular speed of the shaft is approximately 32.34 rad/s. This configuration ensures smooth, reliable movement of both the backrest and leg sections during conversion, maintaining patient comfort and mechanical safety. A detailed summary of these key parameters and calculated values is provided in Table 4.

**Table 4**

Summary of transformation mechanism parameters and calculated motion values

| Parameter                        | Value           |
|----------------------------------|-----------------|
| Shaft Length                     | 457 mm          |
| Shaft Length (Metric)            | 457.2 mm        |
| Thread Pitch                     | 3.175 mm/turn   |
| Total Number of Turns            | 144 turns       |
| Transformation Time              | 28 seconds      |
| Linear Speed of Nut              | 16.33 mm/s      |
| Motor Rotational Speed           | 309 RPM         |
| Motor Angular Speed ()           | 32.34 rad/s     |
| Backrest Angular Range           | 80 → 10 degrees |
| Leg Support Angular Range        | 10 → 80 degrees |
| Angular Speed (Back/Leg Section) | 2.5 degrees/sec |
| Time per Revolution              | 0.194 seconds   |

#### 4.2 Motor Performance

The bed transformation mechanism is powered by a 12V DC motor connected to a threaded shaft system.

This motor drives the linear motion required to adjust the backrest and leg support. The system was evaluated under a maximum load of 150 kg, completing the transformation cycle in 28 seconds without any signs of overload or instability.

**Table 5:**

DC Motor Specifications and Performance Metrics

| Parameter                | Value                  |
|--------------------------|------------------------|
| Voltage                  | 12 V                   |
| Power                    | 120 W                  |
| Rated Torque             | 25 Nm                  |
| Operating Current        | 10 A (max)             |
| Measured Peak Current    | 9.7 A                  |
| No-Load Speed            | 55 RPM                 |
| Required RPM (with gear) | 309 RPM                |
| Transformation Time      | 28 seconds             |
| Load Handled             | 150 kg                 |
| Operation Status         | Stable, no overheating |

As mentioned in table 5 the motor maintained steady torque and current throughout the simulation, confirming its suitability for safe and smooth transformation. Its built-in gear reduction provided the necessary speed and torque alignment for the threaded shaft mechanism.

#### 4.3 Comparative analysis with existing studies

In this section we compared our proposed study with the state-of-the-art studies. Several existing studies have proposed the use of hydraulic systems for the transformation of wheelchairs into beds. This study compares three different transformation mechanisms used in wheelchair-to-bed systems: the threaded shaft mechanism (this study), conventional hydraulic actuators, and the recently proposed hydrostatic system designed by Denis et al. [27]. Each system demonstrates distinct advantages and trade-offs in terms of cost, complexity, energy efficiency, control precision, and applicability in compact assistive devices. The threaded shaft mechanism introduced in this work offers a highly efficient and low-cost solution for wheelchair-to-bed transformation. With minimal mechanical complexity and low energy consumption, it is well-suited for use in both clinical and home care environments. The use of a self-locking threaded rod eliminates the need for external braking systems, enhancing safety by maintaining position even in the event of power loss. Moreover, the design itself is easy to maintain so it can be used by the patient as well as the carer over a long period of time. Although its smoothness of motion is average, due to average loads and durations associated

with the operations of the system, its reliability is adequate. In addition, comparatively, the hydraulic system designed by Simran et al. [14] outstands in ways of smooth and strong movement, which is why more similar systems are preferred in hospital-quality devices that should be really precise and heavy. But it has the disadvantage of being more mechanically complex; having fluid pumps, hoses and control valves. That adds weight and space as well as

augments the possibility of a malfunction because of the fluid leak or pressure disbalance. In addition, it requires regular maintenance in order to work properly and this would be inefficient in in-home situations or among low-income users. Although sufficient, control precision cannot be compared or contrasted with the feedback-controlled electric systems applicable in the threaded shaft mechanisms.

**Table 6**

Comparison Between Threaded Shaft Mechanism and Hydraulic System

| Feature                        | Threaded Shaft Mechanism (This Study) | Hydraulic System (Simran et al. [14])    | Hydrostatic System (Denis et al. [27])                |
|--------------------------------|---------------------------------------|------------------------------------------|-------------------------------------------------------|
| Transformation Method          | Threaded shaft + DC motor             | Hydraulic actuator                       | Reconfigurable hydrostatic actuators                  |
| Mechanical Complexity          | Low                                   | High                                     | Moderate to High (fluidic + passive system)           |
| Weight                         | Light (~30 kg total device weight)    | Heavy (fluid + cylinders)                | Moderate (lighter than traditional hydraulic systems) |
| Maintenance Requirement        | Minimal                               | Frequent (fluid levels, seals, pressure) | Moderate (some fluid system checks needed)            |
| Cost                           | Low                                   | Moderate to High                         | High (advanced components and control)                |
| Control Precision              | High (via motor feedback)             | Moderate                                 | High (fluid sharing + passive control units)          |
| Failure Risk                   | Low (self-locking threads)            | Higher (leaks, pump failure)             | Low (designed with failure redundancy)                |
| Energy Consumption             | Low                                   | Moderate to High                         | Low to Moderate (due to passive efficiency)           |
| Smoothness of Motion           | Moderate to High                      | High                                     | Very High (fluid dynamics allow seamless transitions) |
| Suitability for Compact Design | Yes                                   | Limited                                  | Moderate (depends on actuator lay)                    |
| Power Backup / Self-locking    | Passive self-locking on power loss    | Requires power for lock maintenance      | Designed with passive safety mechanisms               |

The hydrostatic actuator system presented by Denis et al. [25] marks a significant advancement in transformation mechanisms. Designed originally for wearable robotics, this system uses reconfigurable fluid circuits and passive force control to achieve very smooth motion and high adaptability. It also supports energy efficiency through intelligent fluid sharing among actuators. Importantly, the hydrostatic mechanism reduces the need for complex control software by integrating mechanical intelligence into the actuators themselves. However, these benefits come at the cost of increased design complexity and higher material and integration expenses. While promising for future high-performance assistive devices, this system may currently be less feasible for low-cost, portable wheelchair applications without significant cost reductions.

In summary, each system serves a different use case. The threaded shaft mechanism remains the most practical and accessible for wide deployment,

especially in resource-constrained environments. Hydraulic systems, while proven, are becoming outdated due to their maintenance and failure risks. The hydrostatic system, though promising, still requires further optimization for affordability and simplicity before it can replace more conventional methods in everyday assistive technology.

#### 4.4 Design Limitations

Despite its functional advantages, the current design has some limitations. The total weight (approximately 30 kg) may be challenging for some caregivers to lift or transport without assistance. The system also lacks power backup in the event of prolonged outages. The voice recognition system may occasionally misinterpret commands in noisy environments. Future designs could incorporate lighter materials, a battery backup unit, and enhanced voice control algorithms.

## 5. Conclusion

This study focused on designing a multifunctional wheelchair that serves as a mobility aid and transforms into a bed, providing greater independence for patients with mobility impairments. The design emphasizes comfort, ease of use, and safety. Our method uses a threaded shaft connected to a motor, making it different from traditional hydraulic systems that, although they work smoothly, tend to be heavier, more complicated, and need more maintenance. Our system, inspired by a nut-and-bolt mechanism, offers a simpler and more efficient solution that still delivers on performance while reducing weight and cost. The wheelchair was designed with user comfort in mind, featuring an ergonomic layout that includes a leg space of 457 x 610 mm and a back seat of 914 x 610 mm. With a load capacity of up to 150 kg, it's designed to accommodate a wide range of patients. During testing, the wheelchair demonstrated smooth operation in both wheelchair and bed modes, with positive feedback on comfort and stability from users. The motor system worked out and the feedback control system made the motion of transfers between positions free. The results have been encouraging, but still there are reasons to improve. Among them is the general weight of the wheelchair which can then be reduced so that it is even more transportable and easy to maneuver. Beside this, it is possible to improve the feedback system that will enable more accurate control, particularly when it comes to patients with restricted movements. Compared to more complicated hydraulic systems, it is a simple quick and economical way to de-sign a system that eases transition between positions. The outcomes have been encouraging though there are weaknesses that should be addressed in the future. Another area to tackle is the total mass of the wheelchair because making the mass less may render it even more comfortable to transport and move. Furthermore, the feedback mechanism might also be optimized, which would help to control patient movement even better, including those who display limited mobility. Compared to any more complicated type of hydraulic system, the design is relatively simple to install and is cost effective and does not require any added complexity that is not warranted. Future work will aim to optimize the motor feedback system and reduce overall weight to enhance portability. The design remains a practical and scalable alternative to more complex hydraulic systems.

#### Credit authorship contribution statement

The study's conception and design were a collaborative effort by all authors. Bilal Khan, Mahad Aurangzeb, Mohammad Dawood Farrukh and Abdul Muqsit contributed significantly to the data collection, experimental work, and preliminary analysis. Kmail

Lodhi provided critical input during the formulation of the methodology and interpretation of results. Bilal Khan led the initial drafting of the manuscript. All authors reviewed, provided constructive feedback, and contributed to revising the manuscript. Final approval of the version to be published was given by all authors, reflecting their collective contribution and agreement with the work's integrity and accuracy.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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