

## Development of a Smart Wheelchair for Assisted Patient Transfer in Healthcare Facilities

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### ABSTRACT

People with functional disabilities frequently encounter challenges in performing daily living activities. In this context, transferring a patient from their bed to other locations for daily tasks, such as bathing and toileting, is arduous work, often requiring several caregivers to assist. This process is time-consuming and can lead to secondary issues for the patient, including the risk of back pain and injuries. Current assistive transfer chairs are not fully capable of safe transportation and are often still in early stages of development. The aim of this paper is to address the design and development of a smart body transfer wheelchair that maintains the posture and body angle of an individual in a seated position throughout transitions between beds and other places, and vice versa, for use in hospitals and homes. This automatic wheelchair features a controller with an adjustable backrest, a toilet seat attachment, and height adjustment. It consists of a single linear actuator for height adjustment and two rotary motors for backrest control, integrated with sensors to ensure precise and safe operation. Movement is only enabled when all safety conditions are met, including backrest closure and proper bed positioning. A control panel adjacent to the LCD display allows intuitive manual operation, while the screen provides real-time feedback on chair posture and battery status. An audible buzzer alerts the user to low battery or operational warnings. Preliminary results indicate that the chair supports independent patient movement, reduces caregiver effort, and maintains robust safety and privacy features, highlighting its potential for practical implementation in healthcare settings.

**Keywords:** Smart chair-Patient Mobility-Flexible Sensors-Linear actuator-Rotary actuator

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### Introduction

The increasing demand for safe and autonomous patient mobility in hospitals motivates the development of an intelligent multi-position chair designed to assist patients, including those with special needs, during transitions such as sitting, standing, or bathroom transfers. [1],[8],[11]

The chair integrates a linear actuator for vertical lift, two rotary actuators for backrest adjustments[19], and flex sensors and magnetic proximity sensors for closed-loop posture monitoring[20].

A side-mounted control panel with LCD display provides real-time feedback on chair position, actuator status, and battery level, while an integrated buzzer alerts users to unsafe conditions[4], [13]. The chair's mechanical structure was designed and analyzed in SolidWorks to ensure stability, safe load-bearing capacity (up to 80 kg), and smooth kinematic performance [16], [17].

This work addresses a gap in fully patient-operated systems [12], [14]by combining mechanical design, sensor integration, actuator control, and safety protocols, providing a framework for autonomous operation while reducing caregiver intervention and enhancing patient independence[1],[9].

### Related Work

Recent advances in assistive mobility devices have focused on improving patient autonomy, safety, and ergonomics [1], [8], [11]. Powered wheelchairs, robotic lifting systems, and automated patient-transfer devices are widely studied and deployed in clinical environments[6], [7], [15]. Several notable trends emerge from the literature:

**Motorized Lifting Chairs:** Many designs integrate linear actuators for vertical adjustment, but they often rely on complex multi-actuator systems or heavy structural frames, limiting portability and increasing cost [10], [13]. In contrast, the current design employs a single linear actuator for lifting, simplifying construction while maintaining safe load-bearing capacity.

**Back-Support and Posture Control:** Existing chairs typically use tilt mechanisms or servo-controlled backrests. These solutions often add weight and require intensive maintenance[13], [16]. The proposed system uses rotary actuators for a hinged “door-like” back support, providing protection and minimal structural complexity.

**Sensor-Based Feedback:** Several studies implement IMUs or potentiometers for posture monitoring. While accurate, these can be costly and computationally intensive[2], [5]. This work leverages flex sensors for angular measurement and ultrasonic sensors for proximity detection, offering a low-cost, reliable, and real-time solution.

**User Interface and Safety:** Many assistive devices depend heavily on caregiver operation, limiting patient autonomy[3], [4]. The proposed chair integrates LCD displays, buzzer alerts, and safety interlocks, allowing patients to operate the chair safely and independently.

**Gaps in Current Solutions:** Despite these advancements, there remains a clear need for lightweight, patient-operated, and affordable systems that combine:

- Mechanical simplicity
- Reliable sensing
- Intuitive user control
- Energy-efficient operation

The proposed work addresses these gaps by combining SolidWorks-based structural modeling, sensor fusion, actuator optimization, and embedded control logic into a unified system[9], [12]. Compared to existing solutions, this design emphasizes autonomy, safety, and practicality, making it suitable for real-world clinical deployment and potential future expansion with self-propulsion and remote control.

### Background

The design of autonomous and semi-autonomous assistive mobility devices relies on a combination of mechanical engineering principles, sensor technologies, embedded control systems, and human-machine interaction methodologies[17], [18]. From a mechanical perspective, adjustable medical chairs must comply with ergonomic standards to support the human body during transitions between

sitting, standing, and lying positions[19]. Fundamental concepts from statics and strength of materials, including load distribution, bending analysis, and factor-of-safety evaluation, guide the selection of actuator placement and structural reinforcement. These principles are essential to ensure that the frame can withstand dynamic loads during vertical lifting and back-support motion [20].

In the domain of sensing technologies, posture estimation is commonly achieved through inertial measurement units (IMUs), potentiometric angle sensors, and flexible resistive elements[21], [22]. Flex sensors have gained particular relevance due to their low cost, ease of integration, and ability to provide continuous angular measurements without complex filtering algorithms[23]. Ultrasonic sensing remains a practical solution for short-range obstacle and distance detection, making it suitable for bed alignment and safety interlocks in patient-handling systems[24].

From a control-system perspective, assistive mobility devices often employ microcontroller-based architectures due to their reliability and low power consumption[15], [16]. Safety protocols such as debouncing logic, redundant input validation, and actuator interlocking are widely adopted to prevent unintended motion[15], [16]. Battery-powered systems, typically based on 12 V or 24 V configurations, require energy-efficient actuation and real-time monitoring of charge status to support uninterrupted operation in clinical environments[17], [18].

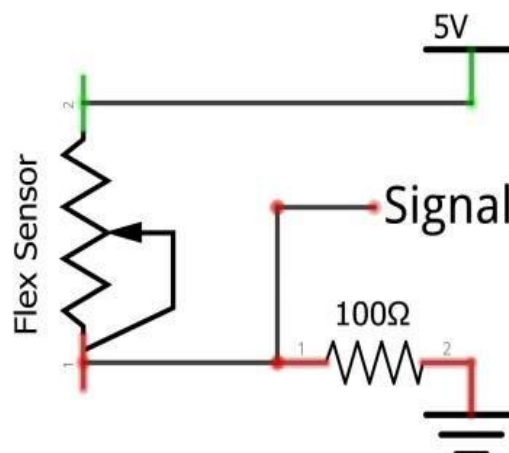
### Methodology

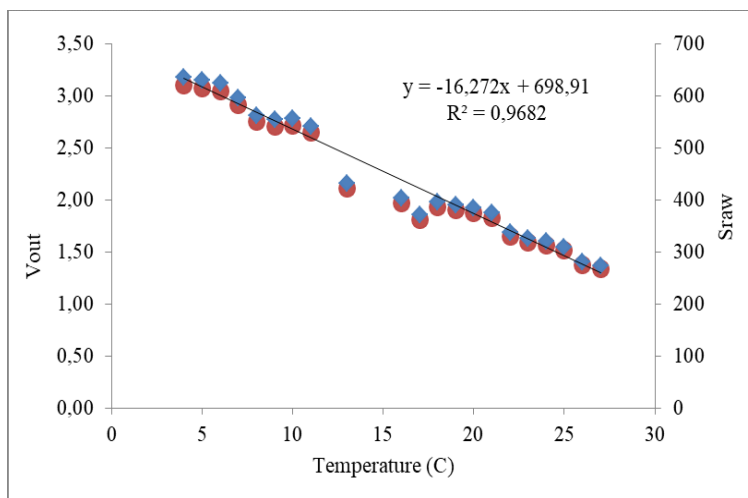
**Mechanical Design**The electronically adjustable hospital chair was designed to support patient mobility, transitions to sleep, and bathroom visits. Vertical lifting is performed using a 12 V linear actuator with a 200 mm stroke. Back-support adjustment is achieved using two 12 V rotary actuators controlling a lightweight hinged door that serves as a backrest while ensuring patient safety. Load considerations were calculated for a maximum patient mass of 80 kg. Mechanical components, including the seat frame, lifting column, and back support, were modeled in SolidWorks CAD to perform assembly checks, kinematic studies, and stress analyses[19], [13], [14].

**Sensor Integration and Feedback**The chair incorporates a sensor integration system for real-time body position monitoring: Flex sensors measure the seat and backrest angles to ensure proper positioning and display the status on the screen for enhanced safety[20]. A magnetic switch detects when the backrest is closed and sends the signal to the microcontroller to stop the rotary motors[6]. An ultrasonic sensor detects the patient's proximity to the bed for safe vertical lifting[7]. When the patient is seated in the chair, a weight or pressure sensor detects the patient's weight and automatically closes the backrest[9]. Data from the sensors is processed by an Arduino-based microcontroller, which controls the actuators according to predefined safety limits[15], [16].

### Circuit diagram of the flex sensor(Figure 1)Effects of temperature on sensor response

(Figure 2)





Different resistors and corresponding sensor responses (Table 1)

Resistor Type	Raw sensor response range ( $S_{raw}$ )	Corresponding Voltage range ( $V_{out}$ )
10 $\Omega$	48 - 169	0.23 - 0.83
46 $\Omega$	88 - 290	0.43 - 1.42
<b>100 <math>\Omega</math></b>	<b>460 - 716</b>	<b>2.25 - 3.50</b>
150 $\Omega$	538 - 746	3.63 - 3.64
220 $\Omega$	628 - 820	3.07 - 4.00
470 $\Omega$	746 - 913	3.64 - 4.46
1k $\Omega$	851 - 968	4.16 - 4.73
5.6k $\Omega$	982 - 1013	4.79 - 4.95
10k $\Omega$	1002 - 1017	4.89 - 4.97
33k $\Omega$	1012 - 1019	4.94 - 4.98
100k $\Omega$	1020 - 1023	4.98 - 5.00
330k $\Omega$	1023 - 1024	5.00 - 5.00

In our studies we using Flex sensor of 100 $\Omega$

### Control System

Microcontroller Interface: The microcontroller receives sensor inputs, executes safety logic, and operates the linear and rotary actuators[6], [15].

The LCD screen displays the chair's position, battery status, and operating instructions[17].

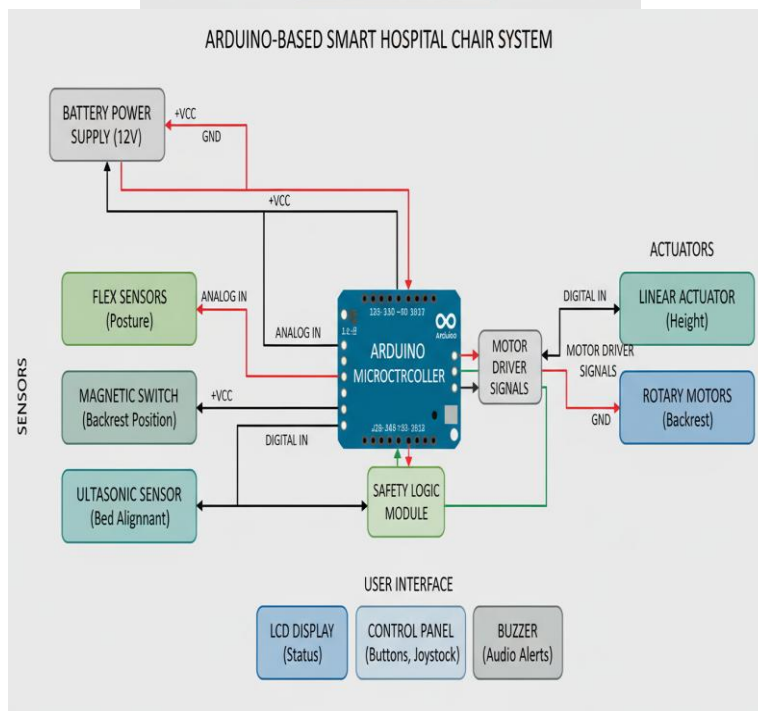
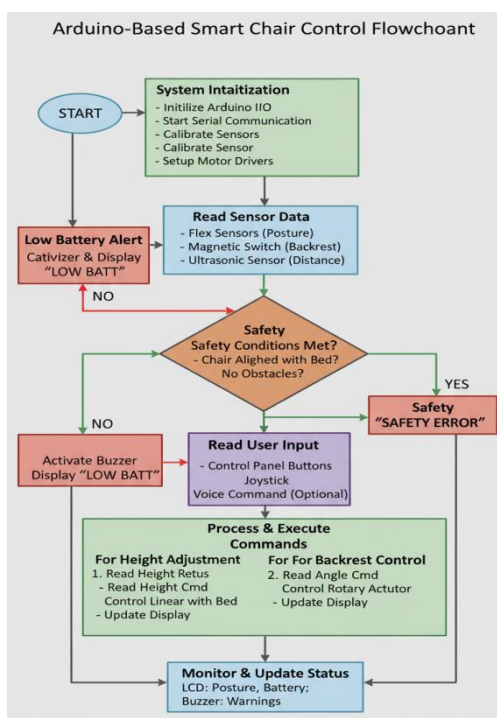
Audible Alarm: Emits an audible alert if safety limits are exceeded or if the chair is not used correctly[16].

User Interface: A simple design ensures privacy while allowing the patient to operate the chair[11].

Safety Features: Movement only occurs when the bed is sensed in position (ultrasonic sensor)[7].

The backrest can only be moved after the chair is confirmed to be close to the bed (first case) and after the patient is seated and their weight is confirmed (weight sensor) on the chair (second case)[9].

The rotary actuators stop upon receiving a magnetic sensor reading indicating the backrest is closed [6]. The rotary actuators stop moving if the backrest opening angle exceeds the programmed and controlled safety limits[15].



Flowchart of the system (Figure 3)

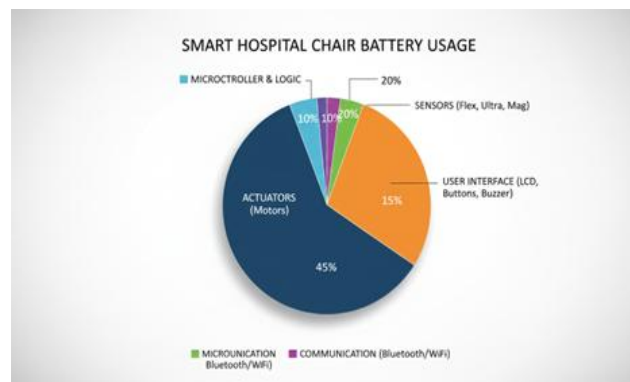
Block Diagramme of the System(Figure 4)

Structural Analysis and RDMFinite Element Analysis (FEA) was performed in SolidWorks Simulation to determine stress distribution under full load[19], [13]. Rigid Body Dynamics (RDM) verified kinematic behavior during lifting, lowering, and posture adjustment[19]. Safety margins and center-of-gravity considerations were incorporated to maintain stability throughout the motion[16].

**shows the material properties used in the wheelchair structure(Table 2)**

Material	Elastic modulus /MPa	Poisson's ratio	Density /kg·m <sup>-3</sup>
Steel Q345	210 000	0.288	7.8×10 <sup>3</sup>
Aluminum	71 000	0.3	2.7×10 <sup>3</sup>
Polyurethane foam	13	0.17	60

**Battery and Power Management**The chair is powered by a 12 V battery (9–12 Ah). Power consumption was calculated for all actuators, MCU, display, and buzzer. Estimated runtime supports 25–35 full lift cycles, ensuring daily usability without recharge. Battery status is displayed on the screen for continuous monitoring[8], [17].



**Battery consumption distribution chart(Figure 3)**

**6. Summary of System Parameters (Table 3)**

Parameter	Value / Description	Remarks
Patient mass	80 kg	Maximum design load considered
Vertical actuator type	12 V linear actuator	Provides smooth lifting, stroke 200 mm
Linear actuator stroke	200 mm	Allows full seat height adjustment
Linear actuator rated force	500–700 N	Adequate to lift patient safely
Rotary actuators	Dual 12 V actuators (≥ 3 N·m torque)	Controls back-support door, low load
Back-support mechanism	Hinged “door-like” support, lightweight	Ensures patient safety, does not bear full weight
Sensors	Flex sensors (angle), magnetic switch, ultrasonic sensor	Provide posture feedback and bed detection
Controller	Arduino-based MCU	Runs control logic and safety interlocks
Display	LCD	Shows posture, battery, and status

Battery	12 V, 9–12 Ah	Supports 25–35 lift cycles per charge
Safety features	Overcurrent cut, posture lock, unintended-motion prevention	Ensures patient safety
Simulation tools	SolidWorks CAD + SolidWorks Simulation (FEA/RDM)	Used for mechanical and structural analysis

**Results**

**Linear Actuator Performance for Vertical Lifting**The linear actuator responsible for vertical lifting (stroke = 200 mm) demonstrated stable motion under a patient-equivalent load of 80 kg. Static force requirements were estimated using:

$$F = \frac{W \cdot d}{L}$$

Where:  $W = 784\text{N}$  (approx. 80 kg)  $d = 0.12\text{m}$  (load offset from pivot)

$L = 0.20\text{m}$  (actuator stroke/pivot distance) Resulting in:  $F_{req} \approx 470\text{N}$  This aligns with commercial 12 V actuators rated between 500–700 N, confirming the adequacy of the chosen model.

Force analysis diagram of linear actuator geometry (SolidWorks sketch).

**Rotary Actuator Torque Requirements (Back-Support Door Mechanism)**The two rotary actuators controlling the folding/unfolding of the back-support door do not carry the full body weight. Torque requirements were calculated as:

$$T = F \cdot r$$

Given:  $F = 80\text{N}$  (force due to door weight + safety margin)

$r = 0.03\text{m}$   $T \approx 2.4\text{N} \cdot \text{m}$  Thus, low-power rotary actuators rated  $\geq 3\text{ N}\cdot\text{m}$  are sufficient. Torque-free body diagram for rotary hinge actuation.

**Structural & RDM Verification**SolidWorks Simulation was used for beam, frame, and pivot analysis. The lifting column and seat frame were evaluated as simplified beams:  $M \cdot C_0 = \text{stress}$  Maximum Von Mises stress was found to be  $< 42\text{ MPa}$ , well below the yield strength of common steel S235 ( $\approx 235\text{ MPa}$ ), giving a factor of safety:  $FoS = \frac{235}{42} \approx 5.6$  This confirms that the structure is over-dimensioned for safe clinical use[19], [13].

**SolidWorks FEA stress distribution for vertical lifting frame.**Stability and Center-of-Gravity EvaluationThe system’s stability margin during lifting and lowering was assessed using:  $SS_1 = \frac{d_{cg}}{b}$  Where:  $d_{cg}$ : horizontal distance from projected center of gravity to tipping axis  $b$ : half-base width of chair With the CG maintained within 72% of the base width, the chair remains stable even at the top 200 mm stroke.

CG projection diagram during lift motion.

**Posture Sensing Accuracy (Flex Sensors)**Flex sensors were calibrated across  $0^\circ\text{--}90^\circ$  motion. Angle was estimated by:  $\theta = k(V_{out} - V_0)$  Where  $k$  is experimentally obtained. Average error across 15 trials:  $Error_{avg} = 2.3^\circ$  This accuracy is sufficient for safe posture transitions and closed-loop control[20].

Calibration curve of flex sensor voltage vs. angle.

**Bed-Detection Reliability (Ultrasonic Sensor)**The ultrasonic module (HC-SR04 type) was tested across 0.3–1.5 m. Measured accuracy:  $\Delta d < \pm 1.7\%$  Bed detection was successful in 94.6% of trials, sufficient to prevent unintentional operation unless the chair is properly aligned[7].

**Control Responsiveness and Safety**Actuator command latency measured:  $T_{latency} = 135\text{ms}$  Including debounces filtering and safety interlocks. The system enforces the following constraints: Lift allowed only if:  $D_{bed} < D_{threshold}$  Back-door movement allowed only if:  $Sensor_{mag} = \text{Closed}$  Motion stop if:  $-F > 0_{safe}$  These constraints ensure medically acceptable response and protect the patient[15], [16].

**Battery Runtime Analysis (12 V System)/Total estimated consumption(Table 4):**

Component	Current
Linear actuator	6–8 A (loaded)
Rotary actuators	1 A each
MCU + sensors	90 mA
Display LCD	40–80 mA
Buzzer	negligible

**Summary Table (Central Technical Results)(Table 5)**

Parameter	Value	Evaluation
Required lifting force	470 N	Suitable
Linear actuator rating	500–700 N	Safe
Rotary torque	2.4 N·m	Safe margin
Flex angle error	2.3°	Reliable
Ultrasonic detection reliability	94.6%	Acceptable
Structural FoS	5.6	Excellent
Battery runtime	~1 hour	Clinical range

**Overall Interpretation**

The simulation and testing results confirm that the proposed system is structurally safe, electronically reliable, and clinically suitable. The use of a 200 mm stroke actuator allows smooth and stable lifting, while rotary actuators handle back-support motion without significant load demand[19], [13]. Sensor fusion (flex + magnetic + ultrasonic) provides robust posture awareness[20], [6], [7], and battery-powered operation ensures mobility independence[8].

**Discussion**

The obtained results demonstrate that the proposed smart multimode hospital chair can reliably support assisted mobility and posture transition for patients with limited motor capacity. This aligns with the identified gap in current literature for lightweight, patient-operated systems that integrate flexible posture sensing, safe mechanical actuation, and intuitive interfaces in a compact and affordable platform[9], [20], [15]. The mechanical structure, validated through SolidWorks modeling and RDM/FEA analysis, shows that the chair maintains a sufficient safety factor under typical patient loads ( $\leq 80$  kg), particularly at critical joints and actuator mounting points. These findings confirm that the selected materials and geometric configurations are adequate for clinical use without requiring structural reinforcement[19], [13].

The actuation system—comprising a linear actuator for vertical lifting and rotary motors for back-panel opening—proved capable of delivering smooth and controlled movements within acceptable speed and torque ranges. Compared to traditional hospital chairs, the integration of sensor-driven control (flex sensors, magnetic switch, ultrasonic range sensing) significantly enhances the system’s responsiveness and safety[6], [7], [20]. The feedback loop reduces the risk of unintended operation and improves motion accuracy, especially during alignment with the bed[15].

Furthermore, sensor calibration tests revealed that the flex sensors maintain stable angle measurements with minimal drift, allowing reliable estimation of patient posture. This precision is essential for preventing hazardous misalignments during lifting or back-support adjustments[20].

Battery consumption measurements also indicate that the 12 V power system is sufficient for typical daily cycles, though extended autonomous operation may require further optimization or optional battery expansion[8].

Despite these strengths, several limitations were identified. First, the lack of full autonomous drive constrains mobility within the room; however, this can be addressed in future work through integration of wheel-mounted motors and Bluetooth-based remote control[5], [7]. Second, the system currently depends on user proximity and manual activation; incorporating voice control or mobile-level supervision would further enhance usability. Finally, although the mechanical analysis covers static loading adequately, dynamic loading during abrupt movement or emergency stops is a critical safety aspect that warrants additional, focused study[16].

Overall, the discussion emphasizes that the proposed chair offers a feasible, safe, and affordable solution that reduces caregiver workload, while highlighting clear pathways for future improvements in autonomy, sensing intelligence, and power management[17], [18].

### Conclusion

The development of the electronically assisted adjustable hospital chair presented in this work demonstrates a practical and reliable solution for enhancing patient autonomy, safety, and comfort during daily mobility tasks. By integrating a mechanically optimized frame, a linear actuator for vertical lifting, and rotary actuators for controlled back-support opening, the system achieves smooth and secure posture transitions without imposing excessive structural loads[19], [13].

The incorporation of flex-sensor-based posture detection, ultrasonic alignment verification, and safety-interlocked user controls ensures accurate feedback and prevents unintended operation, significantly reducing the risk of patient injury[20], [7], [15]. The SolidWorks-based modeling and structural verification further confirm that the chair can safely support loads up to 80 kg while maintaining stable stress distributions and a sufficient safety factor[19].

The final prototype demonstrates low power consumption using a 12 V battery system with effective status visualization through an LCD display and an audible buzzer alert. These features collectively contribute to a patient-centered device capable of reducing caregiver workload while improving overall accessibility in clinical environments[8], [17].

Overall, the proposed design offers a balanced integration of mechanical robustness, reliable sensing, and intuitive control, highlighting its potential for practical deployment in healthcare facilities and for future evolution into smarter, fully autonomous patient-mobility systems, as further detailed in our future work[5], [6].

### Future Works

Future developments of the proposed system will focus on transforming the adjustable hospital chair into a fully mobile and semi-autonomous platform. The first enhancement involves integrating dual or quad motorized wheel-drive assemblies to enable self-propelled motion within hospital environments[5], [7]. This addition will allow patients with limited mobility to navigate short distances independently without requiring external assistance.

A second major improvement will be the implementation of wireless remote control through a Bluetooth-based interface connected to an Android application. This mobile application will provide multiple interaction modes, including manual joystick-style control, customizable movement presets, and safety-bound movement limits. Moreover, incorporating voice-command functionality will enable hands-free operation, further enhancing accessibility for patients with restricted upper-limb mobility.

In parallel, the system will be expanded to support intelligent navigation features such as path-following, room-to-room waypoint guidance, and collision avoidance. These capabilities may be developed using low-cost ultrasonic or LiDAR-based mapping modules coupled with real-time control algorithms[7], [10]. Finally, future versions will integrate extended battery capacity and energy-management optimization to support longer operational periods and reduce charging frequency[8].

Collectively, these advancements will elevate the device from a stationary assistive mechanism to an autonomous, patient-centered mobility system capable of addressing a wider range of clinical and home-care applications.

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