Advanced Sciences and Technology Journal

ASTJ vol. 3 no. 1 (2026) P 1074
10.21608/astj.2025.394593.1074
https://astj.journals.ekb.eg/

# Smart Wheelchair with Head-Tilt Control Interface

Ahmed I. Mohamed[1*], Ahmed K. Ahmed[1], Ahmed N. Ali[1], Bishoy S. Mansour1, Karim S. Mahfouz[1], Mahmoud A. ismael[1], Mahmoud A. Mohammed[1], Muhammad H. Muhammad[1], and Moataz Elsisy[2]

[1]*Mechatronics Engineering Department, Faculty of Engineering and Technology, Egyptian Chinese University, Cairo, Egypt*
[2]*Mechanical Design and Production Department, Engineering Faculty, Cairo University, Giza, Egypt*
[*]*192000263@ecu.edu.eg*

**ARTICLE INFO**

**Article history:**
Received 15 June 2025
Revised 21 August 2025
Accepted 28 September 2025
Available online 22 November 2025

**Handling Editor: Prof. Dr. Mohamed Talaat Moustafa**

**Keywords:**
Mechanical Design
Sizing
Literature Review

**ABSTRACT**

People with severe motor disabilities often face significant challenges in using traditional wheelchairs due to limited or no voluntary movement in their hands or arms. This lack of independent mobility greatly impacts their ability to perform daily tasks, reduces their autonomy, and affects their overall quality of life. To address this critical issue, the present project proposes the development of a smart wheelchair system operated through head-tilt control. By detecting the angle and direction of the user's head movements, the system enables intuitive, hands-free navigation, allowing users to control both direction and speed with ease. To ensure safety, the wheelchair is equipped with distance sensors that detect nearby obstacles and automatically prevent collisions. Additionally, a gesture-based on/off feature has been implemented to avoid unintended activations, enhancing both reliability and user confidence. Initial testing has shown that the system responds accurately to user commands, navigates effectively around obstacles, and provides a practical, low-cost solution to improve mobility. This innovation holds great promise for empowering individuals with severe physical impairments, enabling them to lead more independent and fulfilling lives.

## 1. Introduction

Mobility is one of the most essential elements for human autonomy, participation, and dignity. It plays a critical role in enabling individuals to perform daily activities, access education, participate in social interactions, and live independently [1]. For individuals with severe physical disabilities such as those caused by spinal cord injuries, cerebral palsy, muscular dystrophy, or neurodegenerative diseases mobility becomes a significant challenge. In many such cases, patients lose full or partial control of their limbs, particularly their hands and arms, which makes it nearly impossible to operate standard wheelchairs that require manual effort or joystick-based control.

Traditional mobility aids, while effective for individuals with partial impairments, are not suitable for patients with advanced physical limitations. Even electric wheelchairs, which offer powered movement, often require some degree of upper limb functionality to operate joysticks or touch panels. As a result, many individuals are left dependent on caregivers, reducing their independence and impacting their psychological and emotional well-being.

To address this, researchers and engineers have explored various human-machine interface (HMI) technologies aimed at enabling alternative control methods. These include voice recognition, eye-tracking, brain-computer interfaces (BCIs), and head-movement detection. Among these, head movement detection stands out due to its practicality, low cost, and relatively high reliability. Head control is especially suitable for users who retain neck and head mobility even when other motor functions are severely compromised.

## 2. Literature Review

2.1 Pajkanović, A., & Dokić, B. (2013). Wheelchair control by head motion.

The work by Pajkanović and Dokić (2013) serves as a cornerstone for designing and implementing head motion-based control mechanisms for electric wheelchairs as shown in Fig.1. Their study addresses the challenges faced by individuals with severe physical disabilities, such as quadriplegics, who cannot operate traditional wheelchair controls. The authors propose a system that integrates accelerometers to detect head movements and convert them into commands to control the joystick in the wheelchair as shown in Figure 2. This paper not only provides a technical overview of the system's components but also discusses its adaptability to various electric wheelchair models. Experimental results demonstrated a high success rate in interpreting head motions, with safety mechanisms incorporated to address unintended commands. Byemphasizing affordability and modularity, this research bridges a critical gap in accessible mobility solutions [2]

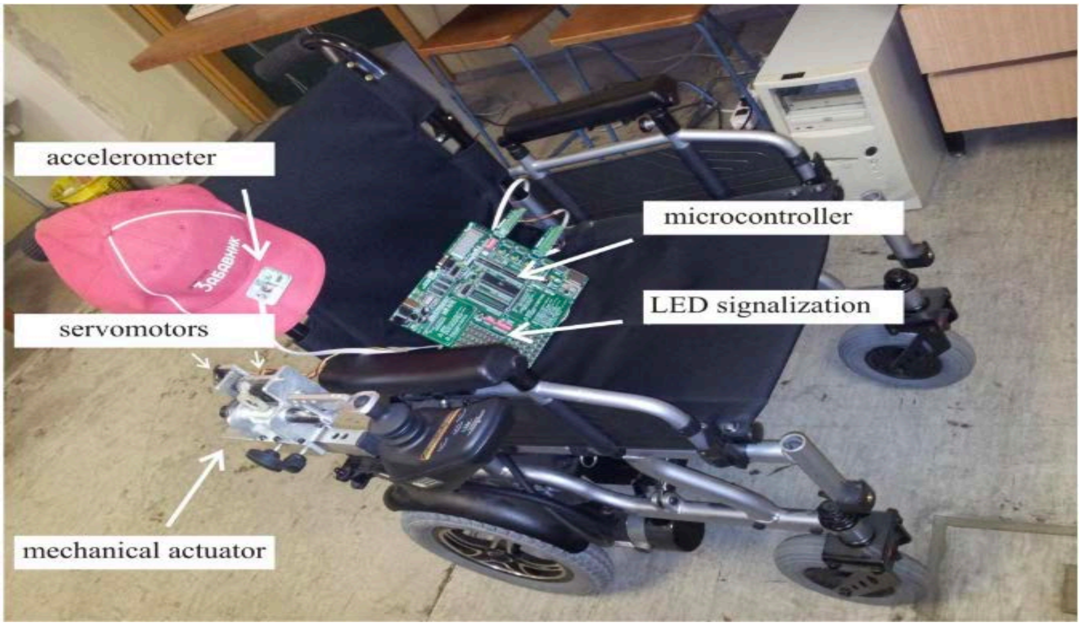


**Fig.1** wheelchair using head movement.

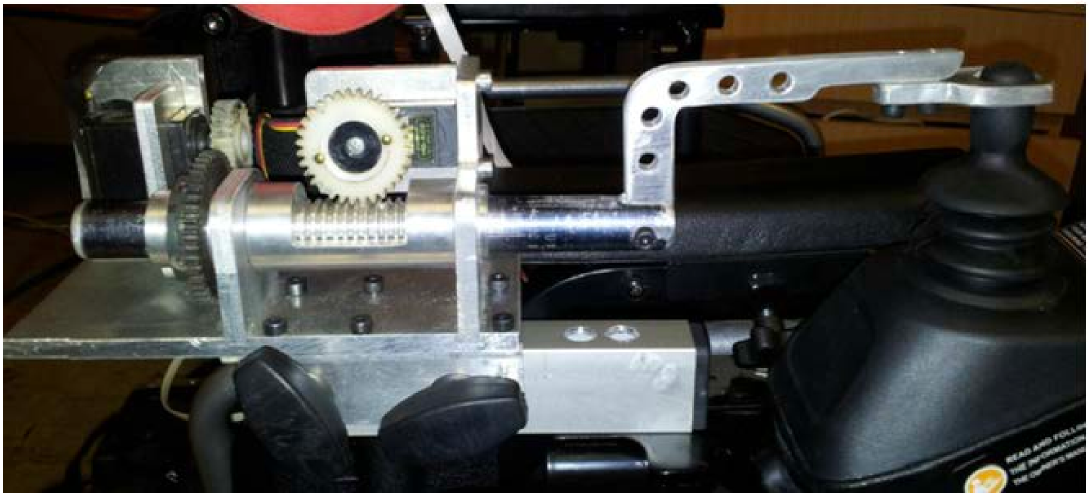

**Fig.2** joystick control of the wheelchair.

2.2 Ding D., Cooper, R. A. (2005). Electronic powered wheelchair control**.**

They offer a foundational review of input devices for electronically powered wheelchairs. This study examines the evolution of assistive technologies, It provides a comparative analysis of various input methods. The authors highlight the advantages and limitations of early control systems, such as joystick-based and voice-activated systems, paving the way for the development of more intuitive and user-friendly interfaces. Their insights into user preferences and technological constraints underscore the need for adaptable systems that cater to diverse user capabilities. [3].

2.3 Paulo R. Ferreira Jr., Paulo de Almeida Afonso (2023). Autonomous Navigation of Wheelchairs in Indoor Environments using Deep Reinforcement Learning and Computer Vision**.**

Their study primarily focuses on autonomous systems, the integration of advanced sensors and machine learning models offers valuable insights for head-motion control technologies. LiDAR sensors provide precise environmental mapping as shown in fig.3, which, when combined with head-motion inputs, could enhance wheelchair navigation accuracy and safety. The authors' emphasis on real-time obstacle detection and route optimization aligns with the goals of head-motion systems to provide seamless and secure mobility [4].

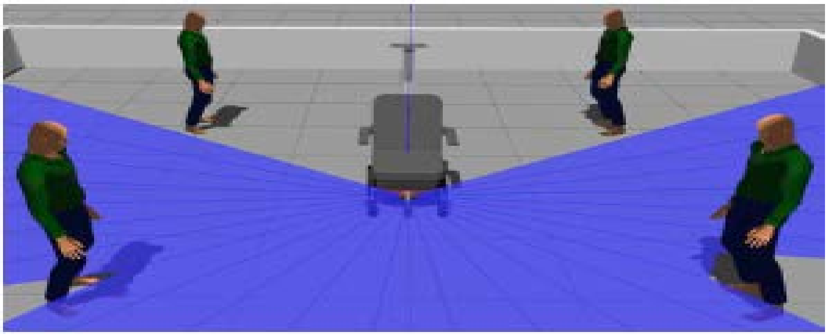

**Fig.3** Lidar sensor for collision avoidance.

2.4 Abiri, R., et al. (2018). A comprehensive review of EEG-based brain-computer interface paradigms. Abiri R., et al., provide a comprehensive review of EEG-based brain-computer interface (BCI) paradigms as shown in fig.4, which share conceptual similarities with head-motion control mechanisms. BCIs enable direct communication between the brain and external devices, bypassing traditional input methods. While BCIs are more complex and costlier than head-motion systems, their emphasis on precision and adaptability offers lessons for refining motion recognition algorithms. [5].

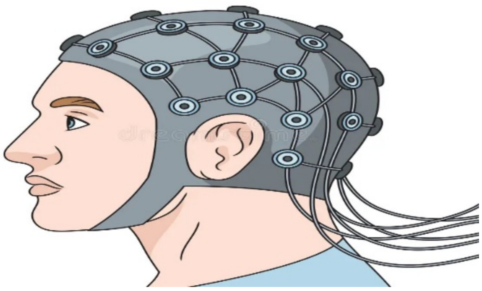

**Fig.4** EEG Sensor.

2.5 Plesnick S., et al. (2014). Eye-controlled smart wheelchair

Introduce an eye-controlled smart wheelchair as shown in fig.5, demonstrating an alternative hands-free control system for individuals with severe disabilities. Their work emphasizes the importance of intuitive interfaces that reduce user effort and cognitive load. Although focused on eye-tracking, as shown in fig.6 the principles of designing accessible and responsive systems are directly applicable to head-motion controls. They discussion of calibration techniques and error reduction strategies provides a framework for addressing similar challenges in head-motion systems. This paper complements the body of research by highlighting the diversity of hands-free control methods and their potential integration [6].

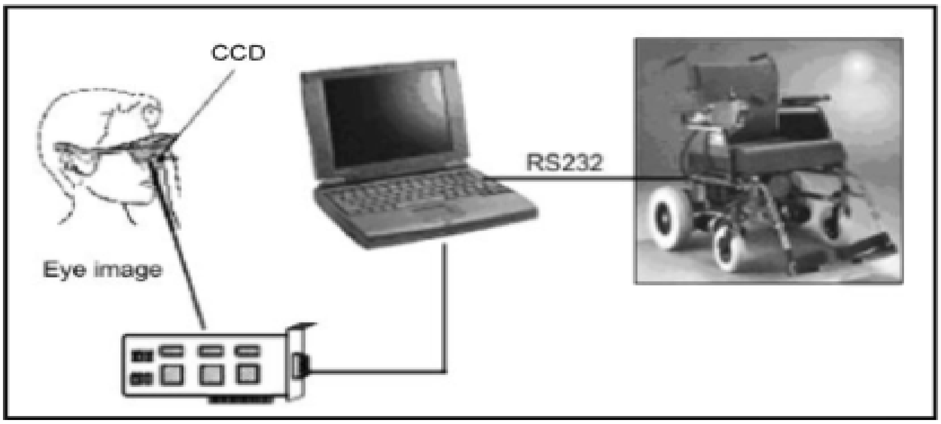


**Fig.5** convert eye motion to a wheelchair motion.

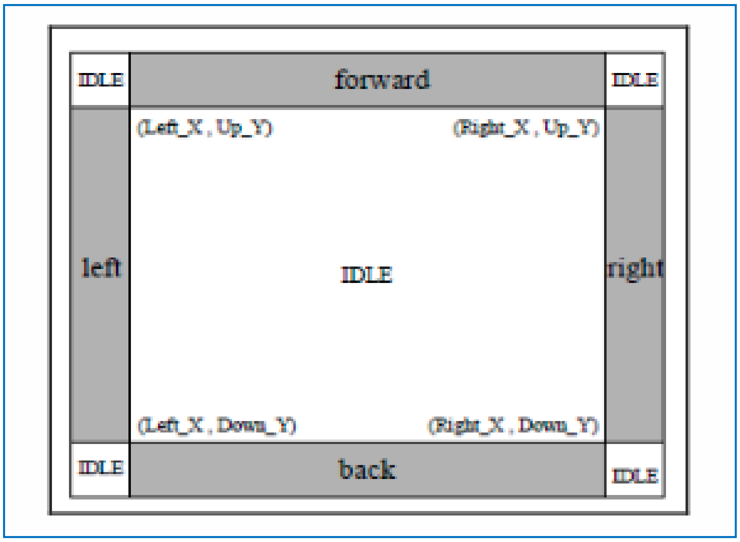


**Fig.6** illustrates where to see to move the wheelchair.

2.6 Sahoo S. K., Choudhury B. B. (2024). Autonomous navigation and obstacle avoidance in smart robotic wheelchairs.

It focusses on real-time obstacle detection and avoidance systems for smart wheelchairs, emphasizing the role of safety in assistive technologies. Their study employs advanced sensors and algorithms to enhance navigation in dynamic environments. While not directly addressing head-motion controls, the technologies discussed, such as ultrasonic and infrared sensors, can be integrated into head-motion systems to improve user safety and confidence. [7].

## 3. Objective

The primary objective of this project is to develop an intelligent, user-friendly **smart wheelchair** that enables individuals with severe physical disabilities particularly **quadriplegic patients** to move independently using only their head movements. The system is designed to recognize intentional head gestures and convert them into movement commands (e.g., forward, backward, left, right), enabling hands-free operation for users who cannot control their limbs.

This objective is achieved through:

- Designing and implementing a complete smart electric wheelchair system.
- Developing a mechanical structure optimized for motor integration and sensor mounting.
- Implementing a head-tilt-based control system using the MPU6050 IMU sensor for hands-free navigation.
- Integrating front and rear TOF sensors to detect obstacles and ensure safe movement in all directions.
- Designing an electronic control architecture using dual microcontrollers for efficient and modular processing.
- Implementing safety mechanisms including automatic stop when obstacles are detected and gesture-based ON/OFF control.
- Ensuring smooth and responsive motion control based on the user’s head movement.

## 4.Project Specification

- Frame Material: Aluminum profile
- Driving Range: Up to 30 km per full charge
- Maximum Speed: 6 km/h
- Maximum Load Capacity: 100 kg
- Motors: Dual 250W DC motors (2 × 250W)
- Battery: 24V, 40Ah rechargeable battery
- Control Interface: Head tilt motion detection
- Incline Capability: 5 degrees ramp
- Obstacle Avoidance: 8 TOF (Time-of-Flight) distance sensors (5 front, 3 rear).

## 5.Mechanical Design

### 5.1 Frame of wheelchair

The structural frame of the wheelchair system was custom-designed using aluminium profiles, specifically 3060 and 3030 T-slot extrusions. These profiles were selected due to their excellent strength-to-weight ratio, modularity, and ease of assembly. The T-slot design allows for flexible mounting of components such as sensors, controllers, and brackets without the need for welding or complex fabrication. The 3060 profile (30mm × 60mm) was used for the main load-bearing sections to ensure rigidity and stability under the user's weight and system load. The 3030 profile (30mm × 30mm) was utilized in less load-intensive areas to reduce overall weight while maintaining structural integrity. The total weight of the frame alone, without any additional components or electronics, is approximately 6.5 kilograms. This lightweight structure contributes to the overall efficiency of the wheelchair by reducing the load on the motors, thereby enhancing battery life and manoeuvrability.

**Figure.7** Assembly of wheelchair frame

### 5.2 Finite Element Analysis

A finite element analysis (FEA) was conducted on the mechanical structure of the wheelchair, which includes the aluminium frame, the motor with its custom steel mounting bracket, and the caster wheel brackets. The analysis was performed under a static vertical load of 100 kg (≈ 981 N) to simulate the weight of a typical user.
This assessment aims to evaluate the structural integrity of the frame under realistic loading conditions, ensuring it meets the safety and strength standards required for indoor and outdoor powered wheelchairs.

**Simulation Details**

Load Applied: 100 kg (static vertical load)
Analysis Type: Static structural analysis
Excluded Components: Wheels, batteries, and upper body attachments.

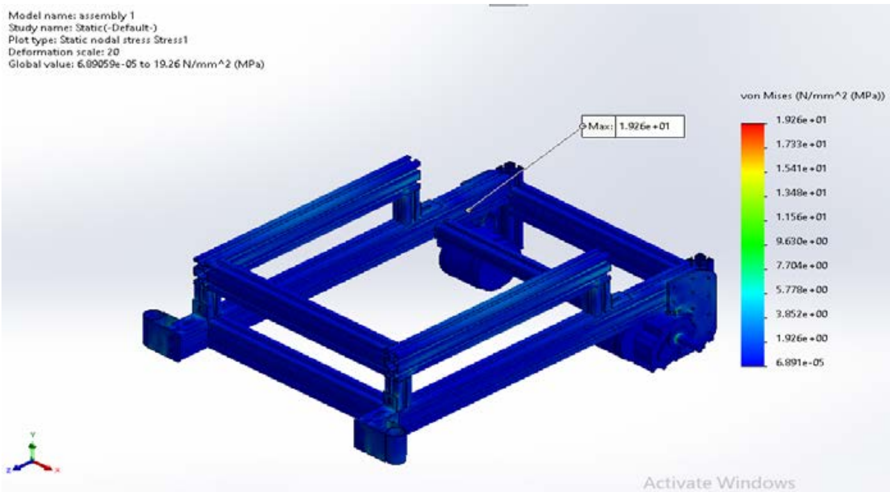


**Fig.8** Maximum nodal stress

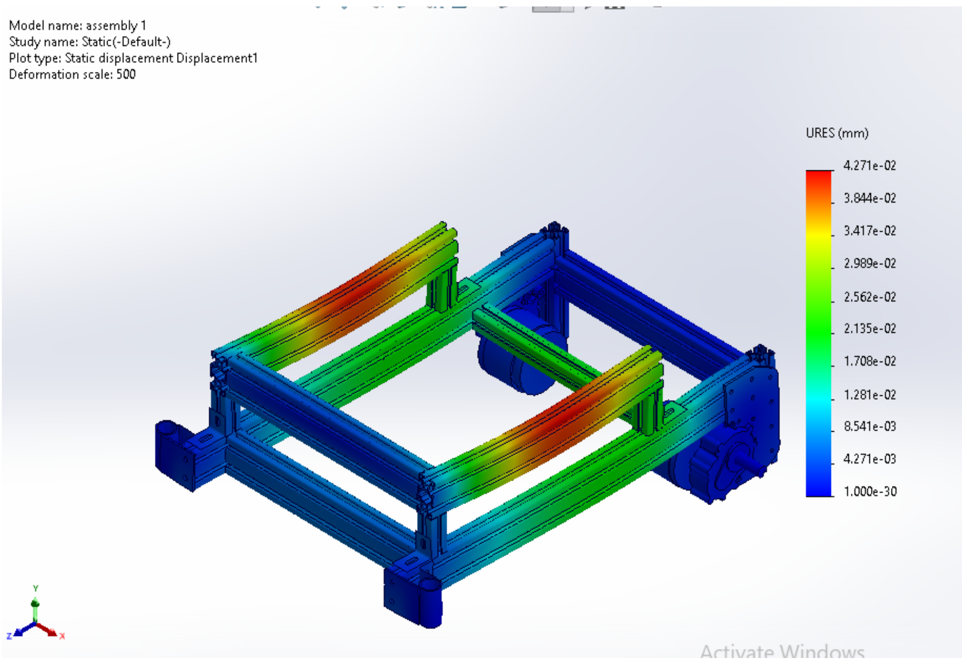


**Fig.9** Deformation analysis

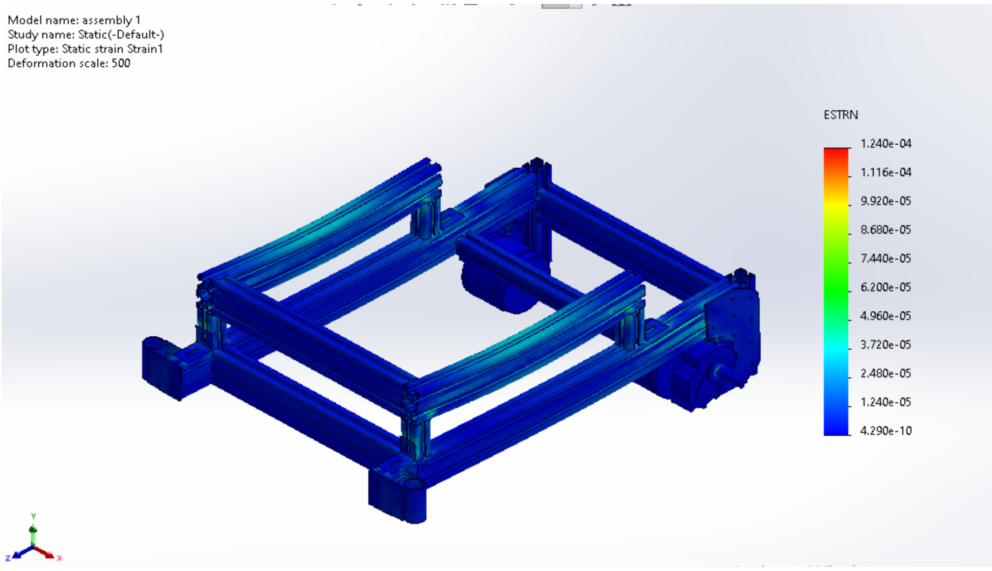


**Fig.10** strain

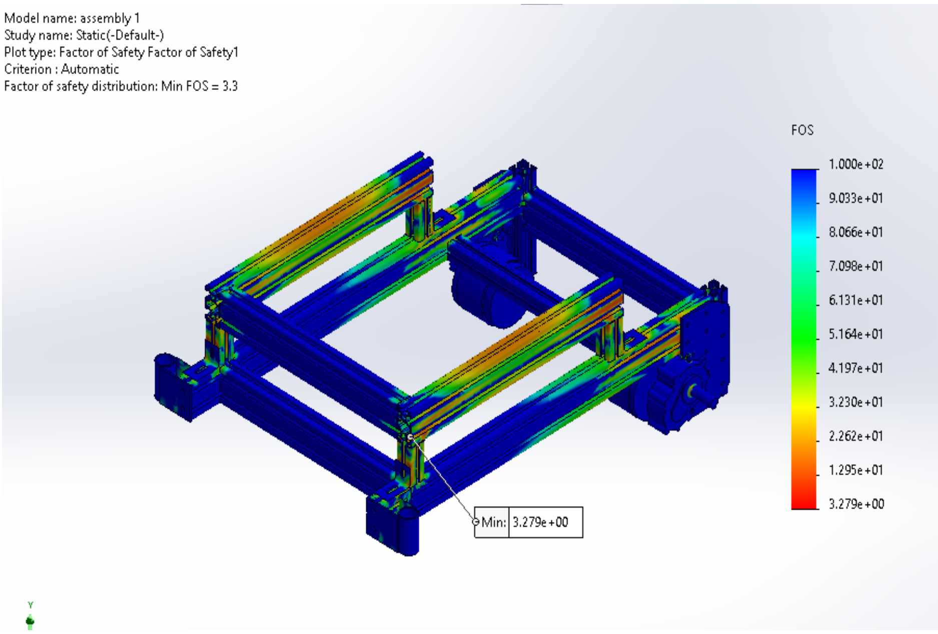


**Fig.11** Minimum factor of safety for wheelchair

**TABLE 1**

**Stress analysis results**

| Parameter | Value | Interpretation |
|---|---|---|
| Maximum Nodal Stress | 19.26 MPa | Within safe limits; well below material yield strength |
| Maximum Displacement | 0.0427 mm | Very small; confirms high frame rigidity |
| Maximum Strain | $3.720 \times 10^{-5}$ | Low strain; purely elastic deformation |
| Minimum Factor of Safety | 3.3 | Excellent margin; complies with ISO 7176-8 recommendations |
| Applied Load | 100 kg (981 N) | Simulates typical user weight in static condition |

According to ISO 7176-8 (Requirements and test methods for static, impact and fatigue strengths), powered wheelchair structures must withstand user weights with an adequate margin of safety. A factor of safety above 2.0 is generally acceptable. The obtained FOS of 3.3 exceeds this minimum requirement, demonstrating the frame's compliance with international safety standards for powered wheelchairs.

The results of the structural analysis show that the frame design is safe, rigid, and within the elastic range under expected loads. The low displacement and strain values, combined with a high factor of safety, confirm that the frame is capable of supporting users reliably during typical operation, both indoors and outdoors.

## 6. Electrical& Electronic Design

6.1 Electrical & Electronic Components

- Arduino Nano ×2
- BTS7960 Motor Driver×2
- MPU6050 IMU Sensor
- VL53L0X ToF Distance Sensors ×8
- Voltage Sensor Module
- Step-Down Buck Converter (12V to 5V)
- 5V Linear Voltage Regulator (e.g., AMS1117)
- DC Gear Motors ×2
- Battery (12V) ×2
- Buzzer
- Push Button / Power Switch
- Connecting Wires & Jumpers
- Terminal Blocks
- LED Indicators

### 6.2 Electronics Assembly Box

Fig.12 shows the electronics control box of a smart wheelchair project equipped with a head tilt control interface. The system is designed to allow users to control the wheelchair's movement by simply tilting their head. At the core of the system is the master Arduino Nano located in **Frame A**, which receives motion data from an MPU sensor mounted on the user's head. When the user tilts their head in a particular direction, the MPU sensor detects the motion and sends the data to the master Arduino. Based on this input, the Arduino determines the appropriate direction and activates the motors to move the wheelchair accordingly.

For safety, the system includes a slave Arduino Nano in **Frame B**, which is responsible for processing signals from Time-of-Flight (TOF) sensors and infrared proximity sensors. These sensors continuously monitor the wheelchair's surroundings to detect obstacles. The slave Arduino processes this safety data and sends real-time feedback to the master Arduino, which can halt or redirect movement if a potential collision is detected, ensuring safe navigation.

The wheelchair's motors are driven by two BTS7960 motor drivers, with **Frame C** controlling the left motor and **Frame D** controlling the right motor. These high-power drivers provide precise and reliable control of motor functions. Powering the entire system is a DC-DC step-down converter in **Frame E**, which reduces the 24V supplied by the wheelchair's batteries down to 5V to safely power the Arduino boards. Altogether, this integrated setup enables intuitive, head-gesture-based mobility while maintaining obstacle avoidance and safety for the user.

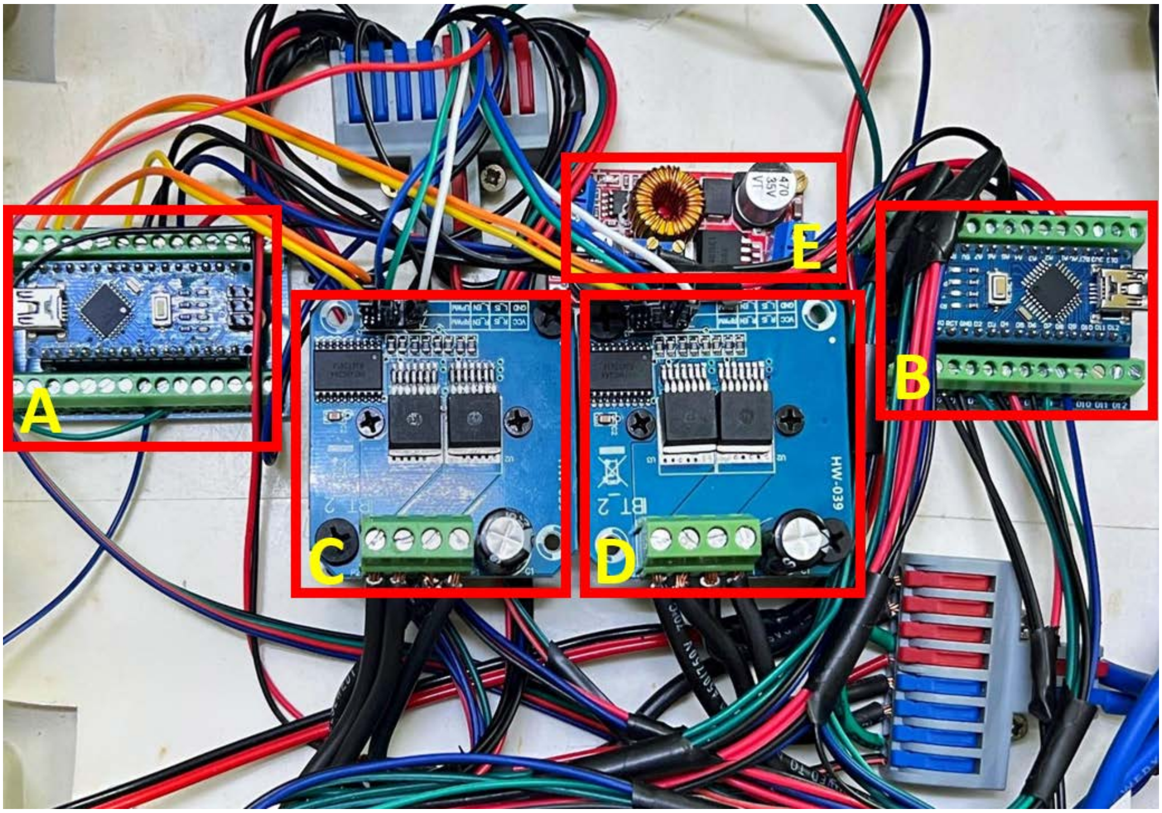


**Fig.12** Electronics Assembly Box

6.3Circuit Diagram

This presented circuit diagram, developed using Proteus software, illustrates the complete interconnection of all sensors within the system. This comprehensive schematic serves as a detailed reference for understanding the intricate relationships and functional dependencies among the various components. By clearly depicting how each sensor is integrated into the system, the diagram enhances comprehension of the overall system architecture and operational flow.

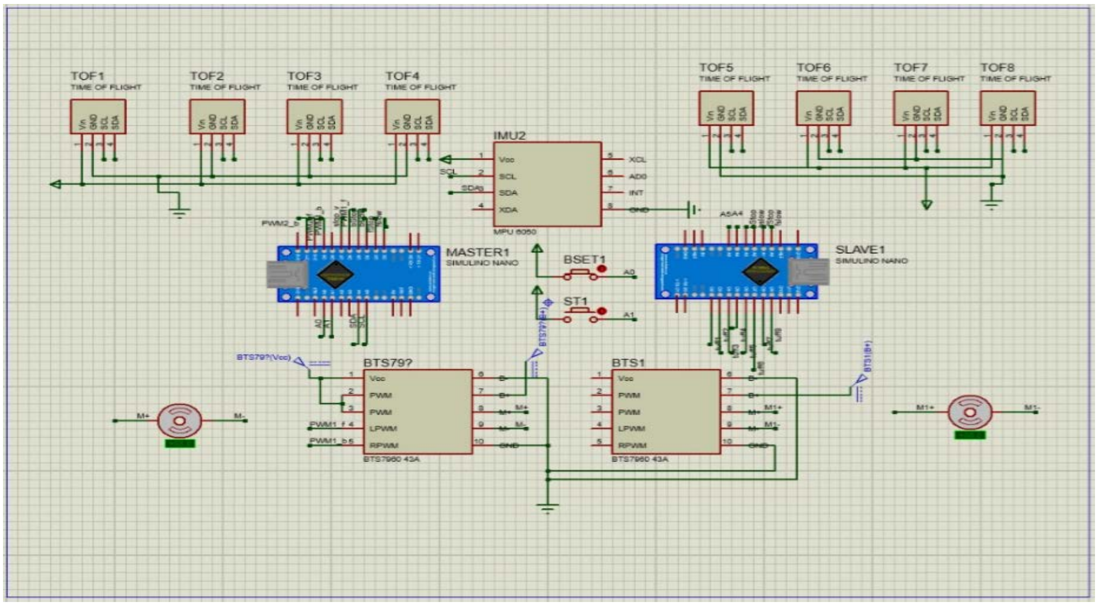


**Fig.10** strain

### 6.4 System Block-Diagram

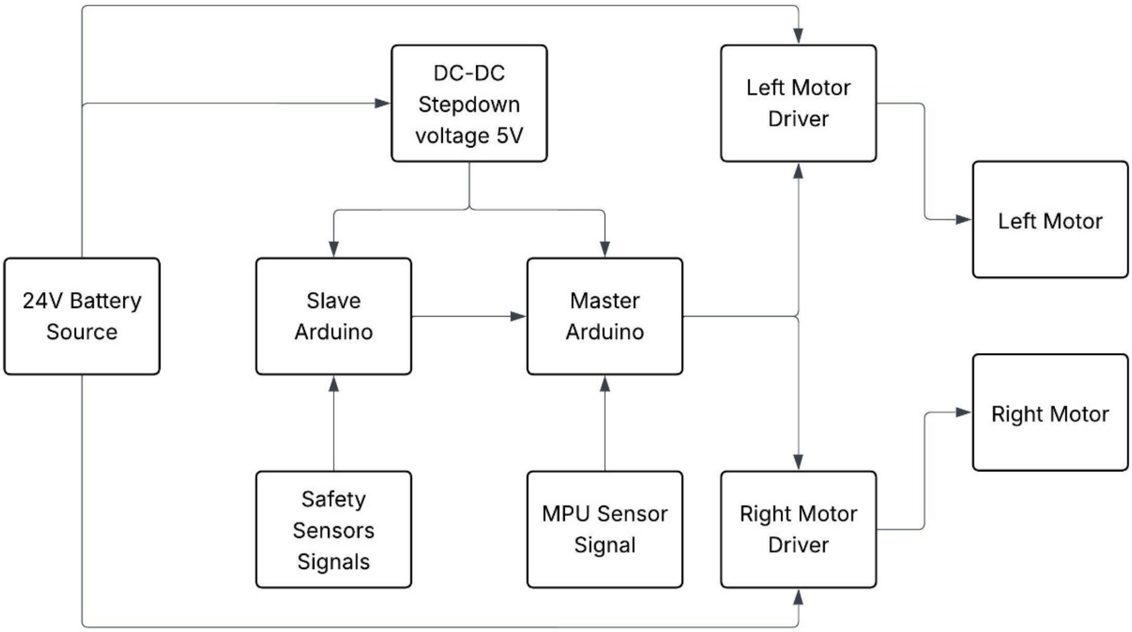


**Fig.14** System Block-Diagram

## 7. Motor & Battery Sizing

### 7.1 Actuating selection:

Electric wheelchairs usually have dual motors (for independent control of each wheel). Motor power can range from 180W to 600W per motor, depending on the model and intended usage (indoor vs. outdoor). For motor power calculation:

friction force:

$$F_f = m \times g \times C_r \qquad (1)$$

where $F_R$ is the friction force, $C_r$ is the coefficient of rolling friction, it most often indicated around 0.012, and the product of mass and gravitational acceleration, mg, is the weight of the object. m is the sum of the mass of the wheelchair and the weight capacity. Let us assume that the mass of the wheelchair is 65 kg with batteries, and weight capacity being 100 kg, as previously mentioned, g=9.81m/s^2.

$$F_R = 165 \times 9.81 \times 0.012 = 19.5\text{N}$$

Slope Force:

$$F_{slope} = m \times g \times \sin(\theta) \qquad (2)$$

where $\boldsymbol{\theta}$ is the angle of ramp, $\boldsymbol{\theta}$ =5 degree.
A ramp angle of **5 degrees** was selected based on international standards such as **ISO 7176-5** and **ADA guidelines**, which recommend a maximum slope of approximately **4.76° (1:12 ratio)** for wheelchair ramps. This value is commonly rounded to **5°** in engineering calculations as a realistic standard for safe accessibility.

$$F_{slope} = 165 \times 9.81 \times \sin(5) \approx 141\,\text{N}$$

Aerodynamic Force:

$$F_{ad} = \frac{1}{2} \times C_D \times A \times \rho \times V^2 \qquad (3)$$

where $F_{ad}$ is aerodynamic force, $C_D$ is Drag coefficient, it is equal 1.5 for wheelchair. $A$ is frontal area for wheelchair, let the Hight equal 1.2m and wide equal 0.55m. $\rho$ is the density of air, $\rho$=1.225 kg/m^3 and $V$ is velocity, it equal 6km/h.

$$F_{ad} = \frac{1}{2} \times 1.5 \times 0.66 \times 1.225 \times (1.67)^2 \approx 1.7\text{N}$$

Acceleration Force

$$F_{acc} = m \times a \qquad (4)$$

Assuming the chair accelerates to 6 km/h (1.67 m/s) in 4 seconds:

$$a = \frac{1.67}{4} = 0.41\ m/s^2$$

$$F_{acc} = 165 \times 0.41 = 67.65N$$

Total force:

$$F_{total} = F_R + F_{ad} + F_{slope} \ (5)$$

Where $F_{total}$ is sum of eq (1), (2), (3) and (4).

$$F_{total} = 19.5 + 141 + 1.7 + 67.65 \approx 230\text{N}$$

Power of Motor:

$$P = \frac{F_{total} \times V}{\eta}$$

where $\eta$ Efficiency of motor, it equal 0.9.

$$P = \frac{230 \times 1.67}{0.9} \approx 426.7\ \text{W}$$

we Select (MY1016Z) 250w
The total required power is approximately **427W**.
Since the wheelchair uses **two 250W motors** (totalling **500W**), this setup is appropriate, with factor of safety ~17% over the calculated requirement, ensuring reliability and performance for both indoor and outdoor use.

### 7.2 Battery selection:

We aim to have a range of 30 km. We did a real test on motors and found that rated currant consumption at no load is 4 A more or less and at load 6A for both.

**TABLE 2**

**High Voltage Side (24V components)**

| Component | Qty | V | I (each) | Total Power (W) |
|---|---|---|---|---|
| 2 × DC Motors (KS-1016W) | 2 | 24V | ~3.5A | 2 × 24 × 3.5 = 168W |
| 2 × BTS7960 (control side) | 2 | 24V | ~0.01A | 2 × 24 × 0.01 = 0.48W |
| Step-down Converter (eff. 90%) | 1 | 24V | TBD from 5V load | calculated below |

Total 24V Power Load = ~168.48W

**TABLE 3**

**Low Voltage Side (5V components)**

| Component | Qty | V | I (each) | Total Power (W) |
|---|---|---|---|---|
| 2 × Arduino Nano | 2 | 5V | 0.04A | 2 × 5 × 0.04 = 0.4W |
| 1 × MPU6050 | 1 | 5V | 0.004A | 1 × 5 × 0.004 = 0.02W |
| 8 × VL53L0X TOF Sensors | 8 | 5V | 0.019A | 8 × 5 × 0.019 = 0.76W |
| 1 × LED Indicator (Stop) | 1 | 5V | 1A | 1 × 5 × 1 = 5W |

Total 5V Power Load = 6.18W

<u>Total Power on Battery (24V) Side:</u>

$$\boldsymbol{p_{total}} = 168+0.48+6.87 = 175.35\text{w}$$

<u>Current Draw from 24V Battery</u>

$$I = \frac{P}{V} = \frac{175.35}{24} \approx 7.3A$$

Total time motor work at maximum speed 6km/h and move 30km.

$$time = \frac{30}{6} = 5\text{h}$$

Total capacity need

$$total\ capacity = 5*7.3 = 36.5Ah$$

So, we need battery with total capacity 36.5Ah and can also reach high current to apply the demand of the motor in starting.
We chose a sealed lead acid battery over a lithium-ion battery due to cost considerations. we choose (VRLA Smart Series Batteries -40ah-12v), and from datasheet

**TABLE 4**

**Constant current discharge characteristics unit: Amp/Block (at 25°C, 77°F)**

| F.V/Time | 10min | 15min | 30min | 60min | 2h | 3h | 4h | 5h | 8h | 10h | 20h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.60V | 87.2 | 67.2 | 40.2 | 24.7 | 14.6 | 10.5 | 8.40 | 7.18 | 4.94 | 4.07 | 2.16 |
| 9.90V | 84.6 | 65.6 | 39.4 | 24.3 | 14.5 | 10.5 | 8.36 | 7.14 | 4.91 | 4.06 | 2.15 |
| 10.2V | 81.1 | 63.2 | 38.2 | 23.7 | 14.4 | 10.4 | 8.30 | 7.09 | 4.87 | 4.05 | 2.15 |
| 10.5V | 77.6 | 61.0 | 37.3 | 23.0 | 14.2 | 10.3 | 8.24 | 7.04 | 4.84 | 4.03 | 2.13 |
| 10.8V | 73.2 | 57.8 | 35.9 | 22.2 | 13.8 | 10.0 | 7.99 | 6.83 | 4.69 | 4.00 | 2.12 |

From Table.4 We found the battery give 5h if the current is approximately 7A, so the rang could be ~ 30km.

## 8. Algorithm

First, the system is toggled on/off via a physical button for safety and define the neutral head position. Once activated, the user must perform a double right-twist (45° each) along the neck's rotation axis to confirm readiness as shown in **figures 15-16**, preventing accidental inputs. Directional control is achieved by tilting the head in one of eight directions (front, back, left, right, and four diagonals). Movement triggers when tilt exceeds 15°, with speed scaling proportionally up to maximum at 45° tilt. If the sensor reads an obstacle in 100 cm range the speed reduced to the half. If the head returns to <15° or >45° the system is deactivated and the wheelchair stops immediately. For deactivation twist head to the right

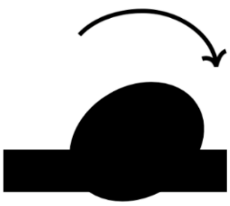

**Fig.15** twist head to the right.

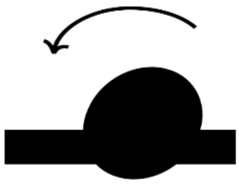

**Fig.16A** twist head back to the neutral position.

## 8.2 Main directions

1. Front

Description: Head facing straight forward.

Use: Move forward.

**Fig.17** head tilt forward

2. Back

Description: Head tilted upward, chin raised, looking toward the ceiling.

Use: Move backward.

**Fig.18** head tilt backward

3. Left Description: Head tilted sideways to the left (ear toward left shoulder).

Use: Turn wheelchair left.

**Fig.19** head tilt to the left.

4. Right

Description: Head tilted sideways to the right (ear toward right shoulder).

Use: Turn wheelchair right.

**Fig.20** Head tilt to the right.

5.Diagonal directions

- Front-Left (Diagonal Tilt), Description: Head tilted forward and slightly to the left.

  Use: Move forward + left.

- Front-Right (Diagonal Tilt), Description: Head tilted forward and slightly to the right.

  Use: Move forward + right.

- Back-Left (Diagonal Tilt), Description: Head tilted backward and slightly to the left.

  Use: Move backward + left.

- Back-Right (Diagonal Tilt), Description: Head tilted backward and slightly to the right.

Use: Move backward + right

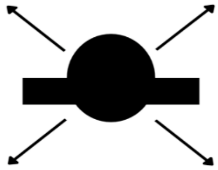

**Fig.21** diagonal directions of head movement

## 9. Results

The developed head-tilt-controlled wheelchair system was tested in real-world conditions and demonstrated efficient, responsive, and accurate performance. At first, users perceived the control mechanism to be unconventional. Moving the wheelchair by tilting the neck was unusual and caused some neck discomfort during the first sessions. However, after just a few days of practice (typically less than five), users became accustomed to the control style. This adaptation is similar to learning to drive a car: initially uncomfortable, but soon becomes second nature.

The head-controlled wheelchair system was successfully implemented and tested in real-life scenarios. The

**Fig.22** Final product

9.1 System Responsiveness***:***

The wheelchair responded accurately to head tilt gestures. When an obstacle was detected by the sensors, the system stopped movement within approximately 100 milliseconds, with a stopping distance deviation between 5 cm and 10 cm, depending on the current speed.
Motion Control & Accuracy:
The movement was generally smooth and highly accurate. The system effectively handled forward, backward, and turning commands. In some undefined head positions, minor shaking or jitter was observed, particularly at higher speeds, but it diminished significantly at lower speeds.
Learning Curve & User Adaptation:
Initially, users found the system slightly challenging due to the unconventional neck-based control. Some discomfort or neck fatigue was reported during the first days. However, most users adapted quickly, typically within 3 to 5 days, after which control became natural—similar to the learning curve experienced when first learning to drive a car.

***9.2 Design & Comfort:***

The helmet used for detecting head motion was **lightweight**, **adjustable**, and **comfortable** for prolonged use. It was well-suited to different head sizes due to its flexible design.

**Fig.23** Helmet

Start/Stop Gesture Detection:

The gesture for enabling or disabling motion (a quick double turn of the head to the right) was functional and generally reliable. However, in some unusual head orientations, it was occasionally triggered unintentionally.

## 10. Discussion

The results confirm that the proposed head-tilt-controlled wheelchair system offers a practical and intuitive alternative for individuals with limited hand mobility. Despite the initial learning curve, users were able to quickly adapt to the control method within a few days of usage.

The system provides **continuous and responsive control**, allowing users to command the wheelchair direction and speed based solely on head tilt angles. The **absence of dead zones** means even small head movements result in proportional system responses, giving the user more direct and real-time control.

Although most motion was stable and smooth, minor unintended vibrations occurred in undefined or ambiguous head postures. These effects were minimal, especially at reduced speeds, and could be further improved by refining angle thresholds or introducing adaptive filtering techniques.

Obstacle detection through ultrasonic or TOF sensors worked reliably, with the system stopping promptly to avoid collisions. This safety mechanism enhances the system's usability in real-world environments.

The head gesture-based activation and deactivation feature also worked effectively, allowing hands-free control over system engagement. However, improvements are needed to avoid accidental triggers from specific head movements or postures.

In conclusion, the system demonstrated strong functionality, safety, and comfort. It offers a promising solution for smart, low-cost, and hands-free wheelchair navigation, particularly suited for users with severe physical limitations.

## 11. Conclusion

In this project, we successfully designed and implemented a smart wheelchair system controlled by head movements using the MPU6050 sensor. The system enables users with limited limb mobility to navigate forward, backward, and stop safely using natural head gestures. We developed a reliable hardware setup including dual Arduino boards, TOF sensors for obstacle detection, and a motor driver for motion control, all integrated to ensure smooth and responsive operation.

Through testing, we observed that users were able to adapt to the control method within a few days, with motion becoming intuitive and comfortable over time. The system exhibited good performance in both indoor and outdoor environments, with accurate obstacle detection and responsive movement control. While occasional minor vibrations were noted during undefined gestures, overall performance was stable and efficient.

The project demonstrates the value of combining embedded systems, motion sensors, and assistive technology to improve the quality of life for people with physical disabilities. It also highlights the importance of user-centered design and iterative testing in developing practical and impactful engineering solutions.

## 12. Reference


[1] L. Li, et al., "Head Gesture-Based Wheelchair Control Using IMU Sensors," *IEEE Sensors Journal*, 2020.

[2] Pajkanović, A., & Dokić, B. (2013). Wheelchair control by head motion, SERBIAN JOURNAL OF ELECTRICAL ENGINEERING,10(1),135-151

[3] Ding D., Cooper, R. A. (2005). Electronic powered wheelchair control, IEEE Control Systems Magazine,22-34.

[4] Paulo R. Ferreira Jr., Paulo de Almeida Afonso (2023). Autonomous Navigation of Wheelchairs in Indoor Environments using Deep Reinforcement Learning and Computer Vision,1-23.

[5] Abiri, R., et al. (2018). A comprehensive review of EEG-based brain-computer interface paradigms , Journal of Neural Engineering 1-43.

[6] Plesnick S., et al. (2014). Eye-controlled smart wheelchair, IEEE Canada International Humanitarian Technology Conference,1-4.

[7] Sahoo S. K. , Choudhury B. B. (2024 ). Autonomous navigation and obstacle avoidance in smart robotic wheelchairs, Journal of Decision Analytics and Intelligent Computing,4(1),47-66.