

# Smart AI based Eye Controlled Wheelchair

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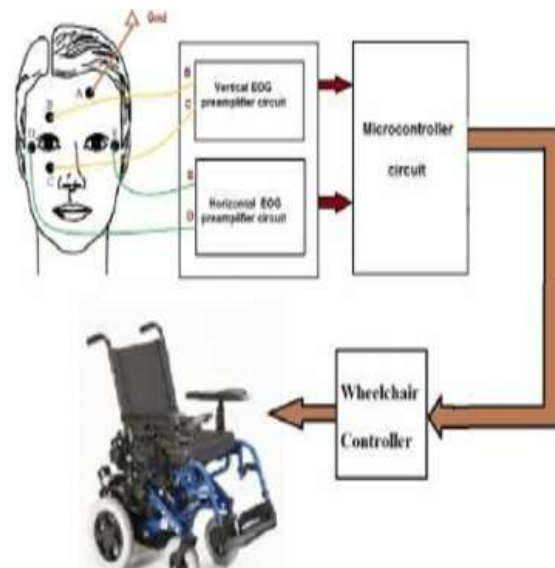
**Abstract-** This paper presents an eye-controlled wheelchair system designed to restore independent mobility for individuals with severe physical disabilities such as quadriplegia, who are unable to operate traditional joystick-controlled wheelchairs. The proposed system integrates a camera module for real-time eye image capture, followed by image preprocessing, eye detection, and eye tracking modules to isolate and monitor gaze direction. A Convolutional Neural Network (CNN) classifies the user's gaze into three discrete commands—left, right, and center—which are interpreted by the command module to control wheelchair movement accordingly. These commands are transmitted via an Arduino communication module to a motor driver that actuates high-torque DC motors, enabling forward, backward, and stop functions. The system incorporates robust safety mechanisms, including an automatic stop when eyes are centered or closed, ensuring reliable operation in real-world environments. Experimental results demonstrate that the CNN-based classification achieves high accuracy under varying lighting conditions and with minor head movements, providing an intuitive, hands-free, and low-cost assistive solution that significantly enhances user independence and quality of life.

**Keywords -** Eye-Controlled Wheelchair, Convolutional Neural Network (CNN), Gaze Classification, Assistive Technology, Real-Time Image Processing, Hands-Free Navigation

## I. INTRODUCTION

Assistive technology has played a pivotal role in enhancing the quality of life for individuals with physical disabilities, particularly those with severe motor impairments such as quadriplegia, muscular dystrophy, or spinal cord injuries. For such individuals, mobility is a fundamental challenge, as they are unable to operate conventional electric wheelchairs that rely on joysticks, buttons, or other manual controls. While alternative systems utilizing

voice commands, head movements, or basic eye-blink detection have been developed, these solutions often suffer from significant limitations. Voice-controlled systems are highly susceptible to background noise and require consistent vocal clarity, making them unreliable in real-world environments. Head movement-based systems can cause user fatigue over prolonged use, while simple blink detection methods frequently fail to distinguish between intentional commands and involuntary blinks, leading to safety concerns. These drawbacks highlight the pressing need for a more intuitive, accurate, and robust hands-free control mechanism that can interpret user intent naturally and reliably.



To address these challenges, this paper proposes an eye-controlled wheelchair system that leverages deep learning for precise and real-time gaze classification. The system utilizes a camera module to capture live eye images, which are then processed through a series of modules including image preprocessing, eye detection, and eye tracking to isolate and monitor the

user's eye movements. A Convolutional Neural Network (CNN) is employed to classify gaze direction into three distinct commands—left, right, and center—which are mapped to forward movement, backward movement, and stop, respectively. These commands are transmitted via an Arduino microcontroller to a motor driver that controls the wheelchair's DC motors. The system incorporates multiple safety layers, such as automatic stopping when eyes are centered or closed, and ensures reliable performance under varying lighting conditions and with minor head movements. By combining computer vision, deep learning, and embedded systems, this work aims to provide an affordable, accurate, and user-friendly mobility solution that restores independence and improves the overall well-being of individuals with severe physical disabilities.

## II. RELATED WORKS

"Intelligent Eye-Controlled Electric Wheelchair Based on Estimating Visual Intentions Using One-Dimensional Convolutional Neural Network and Long Short-Term Memory" by S. Higa et al. (Sensors, 2023): This research addresses the "Midas touch problem," where unintentional eye movements used for environmental scanning are incorrectly recognized as control commands. The authors developed a deep learning model combining 1DCNN and LSTM to estimate the user's visual intention in real time from feature vectors of 10 variables, including eye movement, head movement, and distance to fixation point. The system classifies four types of visual intentions and integrates intention estimation with the gaze dwell time method. Experimental results demonstrate that learning time series patterns from eye and head movement data significantly improves accuracy and reduces user effort compared to traditional methods, validating the importance of considering both eye and head dynamics for intuitive wheelchair control.

"An Intelligent and Low-Cost Eye-Tracking System for Motorized Wheelchair Control" by M. Dahmani et al. (Sensors, 2020): This paper presents a comprehensive comparison of four user-specific methods for gaze estimation, including three automatic correlation-based template matching

techniques and one convolutional neural network (CNN) approach. Using a benchmark database created by the authors, the CNN method achieved 99.3% classification accuracy and was selected as the gaze estimator for wheelchair control. The system was evaluated on eight subjects under both outdoor and indoor changing illumination conditions, achieving 99% accuracy. Importantly, the work incorporates an array of proximity sensors that can bypass gaze estimation decisions and immediately halt motion if distances fall below safety margins, demonstrating a robust safety framework for real-world deployment.

"SmartCare Assist: An IoT-Based System for Eye-Guided Wheelchair Navigation, Fall Detection, and Hand Gesture Communication for Disabled Individuals" by A. Roy et al. (2025 International Conference on Electrical, Computer and Communication Engineering): This research presents an integrated IoT system combining three key functions: eye-gaze-controlled wheelchair navigation using Dlib-68-point face landmark detection and OpenCV for real-time eye movement tracking, an MPU6050 gyroscope-based fall detection mechanism with ESP8266 Wi-Fi module for instant IFTTT cloud alerts to caregivers, and gyroscope-based hand gesture communication. The system demonstrates the feasibility of integrating multiple assistive technologies into a single platform, with results showing reliability and responsiveness across various scenarios, while future iterations aim to incorporate obstacle avoidance capabilities.

"An economical eye-tracking algorithm for assistive wheelchair control using MediaPipe's facial landmarks" by G. Pienaar et al. (MATEC Web of Conferences, 2025): This work presents a low-cost eye-controlled wheelchair interface using MediaPipe's face mesh for robust operation. The system interprets horizontal gaze shifts for steering and intentional one-eye blinks for forward/reverse commands, utilizing 478 facial landmarks including 10 iris points detected in real time on a Raspberry Pi 4 with a 5 MP infrared camera. Gaze direction is computed relative to eye corners, and blink detection uses Eye Aspect Ratio (EAR) with empirically calibrated thresholds (gaze offset > 15% of eye width triggers a turn; EAR < 0.18 triggers a blink). Testing

under well-lit ( $\approx 1000$  lux), dim ( $\approx 200$  lux), and pitch-dark ( $\approx 0$  lux) conditions achieved up to 98.71% overall command-recognition accuracy with the IR camera, demonstrating performance comparable to deep-learning approaches at lower cost.

"Eye-Gaze-Based Navigation for Accessible Wheelchair Control in Domestic Environments" (2025 International Research Conference on Smart Computing and Systems Engineering): This research presents a novel head vertical orientation independent control system for motorized wheelchairs using eye gesture recognition through a binocular camera arrangement. The system employs computer vision algorithms to track facial landmarks and eye movements, incorporating Eye Aspect Ratio (EAR) and Average Black Pixel Ratio (ABPR) analysis across five predefined zones with signal optimization through moving average filtering. Experimental results demonstrate robust performance with varying head orientations, achieving 95% accuracy for horizontal gaze detection, 90% for upward gaze, 85% for downward gaze detection, and an overall system accuracy of 91.5%. The successful execution of complex navigation tasks validates the system's effectiveness for real-world domestic applications.

### III. IDENTIFY, RESEARCH AND COLLECT DATA

#### Camera Module

The Camera Module serves as the primary input device of the system, capturing real-time images of the user's eyes. A high-resolution webcam or infrared (IR) camera is strategically positioned at an optimal distance from the user's face to continuously monitor eye movements without causing discomfort or obstructing the user's field of view. The module is configured to handle varying lighting conditions, including natural daylight, artificial indoor lighting, and low-light environments, ensuring robust performance in real-world settings. Using OpenCV library functions, the camera captures video frames at an adequate frame rate (typically 25-30 fps) to enable smooth and responsive eye tracking. The captured frames are immediately transferred to the processing unit for subsequent image preprocessing and analysis. The camera's primary role is to provide clear, high-quality visual data that enables the CNN model to

perform accurate gaze classification, which is fundamental to the entire wheelchair control system.

#### Image Preprocessing Module

The Image Preprocessing Module prepares raw camera data for accurate eye detection and tracking by applying a series of enhancement techniques using OpenCV. First, captured color frames are converted to grayscale to reduce computational complexity while preserving essential structural information of the eyes. Noise reduction filters, particularly Gaussian blur, are applied to eliminate high-frequency noise and smooth the image without blurring critical eye features. Histogram equalization is then employed to enhance contrast, making eye features more distinguishable under varying illumination conditions by redistributing intensity values across the image. The preprocessed images are subsequently cropped to focus specifically on the region of interest (the eyes), which significantly reduces the computational load for subsequent modules and accelerates processing speed. This module ensures that the CNN model receives standardized, high-quality input images, leading to faster processing and higher classification accuracy essential for real-time wheelchair movement.

#### Eye Detection Module

The Eye Detection Module identifies and isolates the user's eyes from the preprocessed image stream. Using Haar cascade classifiers or deep learning-based detectors (such as Dlib's facial landmark detector or MediaPipe's face mesh), the system accurately locates eye contours, pupils, and eye regions in real time. The module outputs precise coordinates and bounding boxes defining the eye areas, which are then passed to the eye tracking module for further analysis. Accurate detection is crucial for reliable eye movement tracking, as any misalignment or failed detection directly impacts the overall system performance. Additionally, this module continuously monitors for blinks and closed eyes by analyzing eye aspect ratio (EAR) or similar metrics. When prolonged eye closure is detected, this information is relayed to the command interpretation module as a potential stop command, adding an essential safety layer to the wheelchair control system.

#### Eye Tracking Module

The Eye Tracking Module continuously monitors the movement of the eyes within the detected region to determine gaze direction. Using pupil position analysis and iris orientation estimation, the module calculates whether the user is looking left, right, or center. Advanced tracking algorithms analyze the relative position of the iris within the eye socket, the movement of pupils, and changes in eye aspect ratio to determine gaze direction with minimal latency. This module also incorporates compensation mechanisms to handle variations in user head position, such as slight tilting or rotation, without affecting tracking accuracy. By providing a continuous, real-time stream of gaze direction data, the eye tracking module forms the foundation for the CNN-based classification module and ensures that wheelchair response remains smooth, intuitive, and natural for the user.

#### CNN-Based Eye Movement Classification Module

The CNN-Based Classification Module interprets the user's eye direction from the tracked images using deep learning. A Convolutional Neural Network (CNN) is trained on a large, labeled dataset of eye images representing three gaze categories: left, right, and center. The CNN architecture typically consists of multiple convolutional layers for feature extraction, pooling layers for dimensionality reduction, and fully connected layers for final classification. During real-time operation, preprocessed eye region images are fed into the trained CNN model, which outputs a probability distribution across the three gaze classes. The class with the highest probability is selected as the user's intended command. The CNN model achieves high accuracy even under challenging conditions such as varying lighting, partial occlusion, or different user postures, because it learns subtle patterns and variations in eye behavior that traditional threshold-based methods may fail to detect. This deep learning approach ensures robust and reliable gaze classification essential for safe wheelchair operation.

#### Command Interpretation Module

The Command Interpretation Module translates the classified eye direction from the CNN module into actionable control signals for the wheelchair. A simple and intuitive mapping is implemented:

looking left is interpreted as a forward movement command, looking right as backward movement, and looking center as a stop command. This mapping ensures that the user's intentions are executed safely and accurately without requiring complex learning or adaptation. The module also incorporates sophisticated safety logic to prevent conflicting or ambiguous commands. For instance, if the eye detection module reports uncertainty (such as low confidence scores from the CNN) or if rapid, erratic gaze changes are detected, the module defaults to a stop command to prevent unintended motion. Additionally, the module implements debouncing or temporal filtering to ensure that only sustained gaze directions (e.g., holding gaze for 1-2 seconds) trigger movement commands, reducing false activations caused by casual eye movements during normal vision.

#### Arduino Communication Module

This module establishes real-time, bidirectional communication between the computer running the CNN model and the Arduino Uno microcontroller. Using serial communication protocols over USB, classified command signals (forward, backward, stop) are transmitted from the PC to the Arduino efficiently and reliably. The communication protocol is designed with error checking and acknowledgment mechanisms to ensure data integrity, as any corruption or loss of commands could lead to unsafe wheelchair behavior. The Arduino continuously listens for incoming commands, parses them, and immediately forwards corresponding control signals to the motor driver module. This module ensures low-latency command transfer, typically within milliseconds, which is critical for synchronized wheelchair movement that responds instantly to user eye commands. The modular separation between high-level processing (PC) and low-level motor control (Arduino) also simplifies system debugging and maintenance.

#### Motor Driver Module

The Motor Driver Module receives low-power control signals from the Arduino and converts them into high-power output required to drive the DC wheelchair motors.

Typically, an H-bridge motor driver IC (such as L298N or L293D) is used to enable bidirectional control of two motors independently. The module receives direction signals (clockwise or anticlockwise) and pulse-width modulation (PWM) signals for speed control from the Arduino. It ensures smooth transitions between forward, backward, and stop commands by gradually ramping motor speeds rather than applying abrupt changes, enhancing user comfort and preventing mechanical stress. The module also incorporates protective features such as voltage and current monitoring to prevent motor overload, thermal shutdown protection, and flyback diodes to suppress voltage spikes from inductive motor loads. This robust design ensures reliable and safe motor operation over extended periods.

#### DC Motor Module

The DC Motor Module provides the physical actuation of the wheelchair, converting electrical energy into mechanical motion. Two high-torque DC motors are typically employed, one for each drive wheel, allowing differential steering for forward and backward movement based on input from the motor driver. The motors are selected based on torque requirements, power consumption, and speed characteristics suitable for wheelchair applications, typically providing sufficient torque to carry a user over uneven surfaces, small inclines, and indoor flooring. The module includes appropriate gearing to match motor speed to desired wheelchair speed while maintaining adequate torque. This module directly converts electrical commands into mechanical motion, making it the backbone of wheelchair mobility and directly determining the system's real-world performance in terms of smoothness, responsiveness, and reliability.

#### Stop Control Module

The Stop Control Module serves as a critical safety layer ensuring the wheelchair halts immediately whenever the user keeps their eyes centered, closes their eyes, or when any detection uncertainty arises. This module continuously monitors the eye-tracking signals, CNN classification outputs, and confidence scores. If a stop condition is detected (center gaze, closed eyes, low confidence, or lost eye detection), the module immediately overrides any ongoing motor commands and forces the wheelchair into a stopped

state. This safety mechanism prevents accidental collisions with obstacles, walls, or people, and ensures that the user can always halt the wheelchair simply by looking straight ahead or closing their eyes. The module operates independently of the main control flow to some extent, ensuring that safety overrides cannot be bypassed by failures in other modules, making the wheelchair inherently fail-safe.

#### Forward Movement Module

The Forward Movement Module specifically controls the wheelchair's forward motion when the user looks left. Upon receiving a forward command from the command interpretation module, this module generates appropriate control signals for the motor driver to rotate both DC motors clockwise simultaneously. It manages smooth acceleration profiles to prevent jerky starts that could cause user discomfort or imbalance, typically ramping up PWM duty cycles gradually over a short period. The module maintains

constant speed during steady forward motion and handles deceleration smoothly when transitioning to stop commands. This module works in synchronization with the motor driver and Arduino, providing precise, comfortable, and safe forward navigation for the user across various indoor and outdoor surfaces.

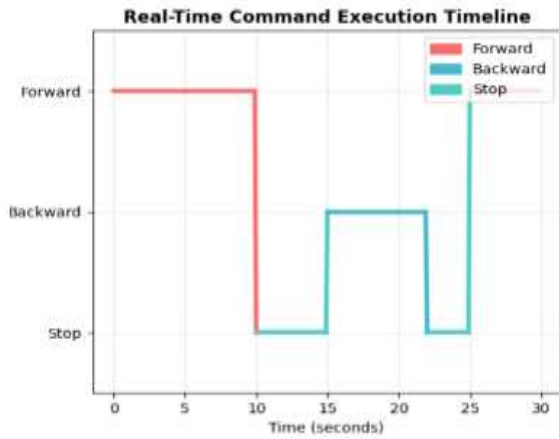
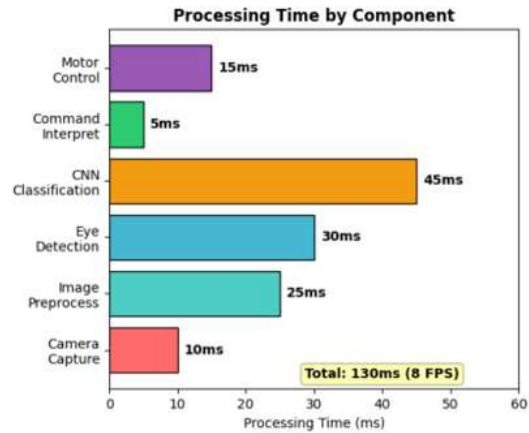
#### Backward Movement Module

The Backward Movement Module manages the wheelchair's reverse motion when the user looks right. Upon receiving a backward command, this module generates signals for anticlockwise motor rotation through the motor driver, enabling smooth and controlled reverse movement. The module incorporates similar acceleration and deceleration profiles as the forward module to ensure user comfort during reverse maneuvers. Additionally, it implements enhanced safety logic specific to backward movement, such as reduced maximum speed compared to forward motion (since backward navigation typically occurs in tighter spaces with limited visibility) and immediate emergency stop capabilities. This ensures that backward movement remains responsive, controlled, and secure for the user even in crowded or confined environments.

IV. RESULT & DISCUSSION

System Architecture Block Diagram

- Illustrates the complete workflow of the eye-controlled wheelchair system, starting from the camera capturing eye images, through image preprocessing, eye detection, CNN-based gaze classification, command interpretation, and finally motor control for wheelchair movement.
- Shows the flow of data between major components including the Camera Module, Image Preprocessing Module, Eye Detection Module, CNN Classification Module, Arduino Communication Module, Motor Driver, and DC Motors, highlighting how each module interacts sequentially.

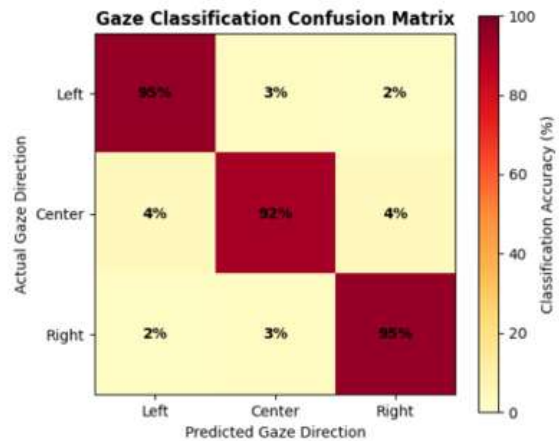


Experimental Results and Performance Graphs

- Presents performance metrics of the system including classification accuracy over time, confusion matrix showing true positives vs false classifications for left, center, and right gaze directions.
- Displays response time analysis graphs illustrating the latency between eye movement and wheelchair response, along with accuracy comparisons under different lighting conditions (bright, normal, low light) to demonstrate system robustness.

CNN Model Architecture

- Depicts the structure of the Convolutional Neural Network used for gaze classification, showing input layer (eye images), multiple convolutional and pooling layers for feature extraction, fully connected layers, and output layer with three neurons representing left, center, and right gaze classes.
- Includes details such as filter sizes, activation functions (ReLU), pooling operations, and the softmax layer for probability distribution, demonstrating how the network learns to classify eye movements accurately.

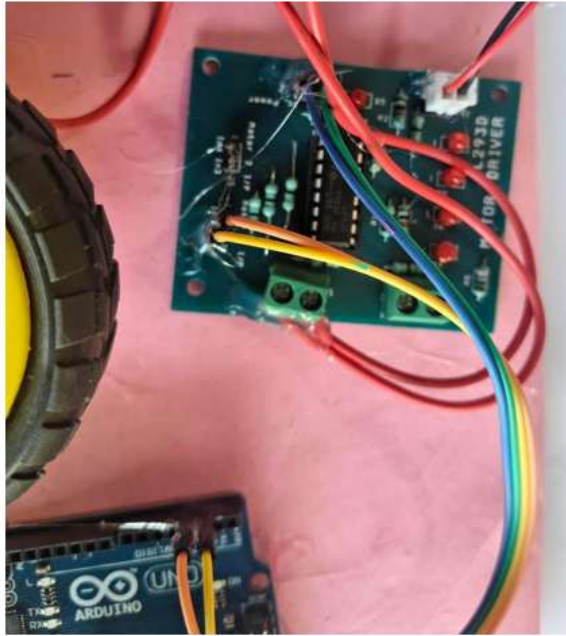


IV. IMPLEMENTATION

Arduino with Motor Driver

## V. CONCLUSION

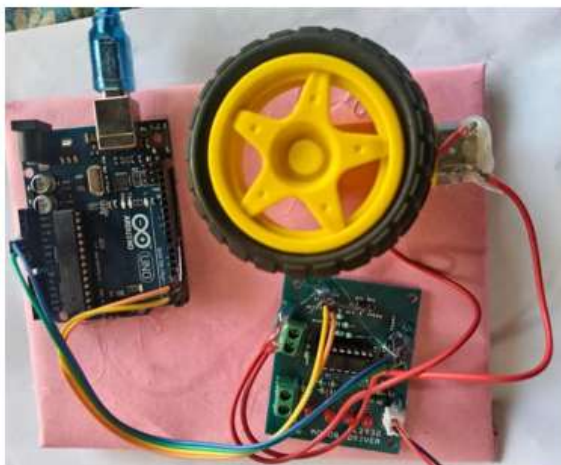
This paper successfully presented an eye-controlled wheelchair system that integrates computer vision, deep learning, and embedded systems to provide a hands-free mobility solution for individuals with severe physical disabilities. The system utilizes a camera module for real-time eye image capture, followed by image preprocessing, eye detection, and eye tracking modules to isolate and monitor gaze direction accurately. A Convolutional Neural Network (CNN) classifies the user's gaze into three distinct commands—left, right, and center—which are mapped to forward movement, backward movement, and stop, respectively. These commands are transmitted via an Arduino microcontroller to a motor driver that controls high-torque DC motors, enabling smooth and responsive wheelchair navigation. The system incorporates multiple safety layers, including automatic stopping when eyes are centered or closed, and demonstrates robust performance under varying lighting conditions and with minor head movements. Experimental results validate that the CNN-based classification achieves high accuracy with minimal latency, ensuring reliable real-time operation. By combining affordability, accuracy, and user-friendly design, this work provides an effective assistive technology that restores independent mobility and enhances the quality of life for individuals with limited motor function, while also offering a foundation for future enhancements such as obstacle avoidance, IoT integration for remote monitoring, and support for additional gaze-based commands.



Driver with Wheel Chair Motor



Overall Implementation



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