An Intelligent Camera Based Eye Controlled Wheelchair System

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***Abstract*—This article proposes a system that aids people with disabilities. An Electric Eye Controlled Wheelchair System is built to help disabled people. With the designed system, disabled people can move effortlessly without support from others. The system uses image acquisition wherein the image of the eye is processed to find out the gaze direction of the eye using Haar cascade and gaze estimation algorithms and hence wheelchair moves according to the direction of eyeball movement. The gaze estimation algorithm is so precise and one single algorithm does the job of what two algorithms (Canny Edge detection, Hough Transform) are supposed to do and to execute the same task. With this technique, a disabled person can steer their wheelchair with their eye movement. The webcam is placed in Infront of the person which captures the live movements, and an image processing technique is used to track the position of the pupil in both eyes with the help of a raspberry pi processor. The image processing technique used here is Gaze tracking which uses Open CV. The gaze tracking tracks pupil movement and depicts its coordinates. According to pupil motion, the motor driver will be instructed to go forward, left, and right. A blink instruction is used to stop the wheelchair when the person blinks. Additionally, a front-mounted ultrasonic sensor that can detect obstructions and automatically halt wheelchair movement is mounted for safety reasons. The system is monitored by a Raspberry Pi device, which lowers the cost.**

Keywords—Image Processing, Haar Cascade, Gaze Tracking, Dlib, Raspberry pi, Open CV.

I. Introduction

Older people and others who are physically disabled rely on wheelchairs. The model design and execution models of the entire eye-controlled wheelchair are as shown in fig.1. Different automatic systems, such as a voice-controlled wheelchair or joystick-controlled wheelchair systems, are offered on the market depending on the needs of people with impairments [1]-[2]. It can be difficult for people who are completely paralysed to use such equipment [10]-[15]. The Eye controlled wheelchair system here provides them with the independence they require to live more independently and comfortably. Additionally, they conserve a significant amount of energy and outside labour. Real-time picture analysis from the camera is used to send the commands for communicating with the motor driver to operate the connection through GPIO pins. With the help of a motor driver, various operations can carry out, including left, right, advance, and stop [3]-[4]. Face and eye detection are done by using OpenCV at the advanced level of image processing. For positioning the accurate pupil, tracking, and detection, a variety of applications and algorithms are used. One of these, the Haar cascade detection technique is utilized to detect both eyes as well as single and many faces [5]-[6]. The ultimate goal of this technique is to locate the precise Eye pupil and pinpoint its centre. Open cv libraries like cv2 and NumPy are used for image processing like image colour conversion, pattern matching, and object detection, and are used to automatically determine and track the eye pupil. There are numerous more methods for tracking eye pupils. However, they have their own restrictions. However, different outputs would be produced for various users, leading to incorrect pupil position in the eye [7]-[9]. The camera sends the images it has captured to the base station, which could be a computer or laptop. After identifying the eyes using trained Haar cascade-like features for eye-detection, the images are processed using image processing methods in Python utilizing the Open-source Computer Vision Library. With the use of the Gaze Tracking algorithm using 68 points of face detection, image processing can pinpoint the pupil's location. Processing essentially tracks the pupil movement, left, right, and centre. The output is "Straight" if the pupil is in the centre. The default response upon eye blink is "Stop." The raspberry pi is then informed of this output.

II. Theoretical Background

A. Haar Cascade Algorithm

This algorithm helps in detecting face and eye regions and also works for the nose, mouth, ear etc. This algorithm contains "Haar Wavelets" as shown in the fig 1 serve as the foundation of Haar cascade and are described as A series of rescaled "square-shaped" functions that collectively make up a wavelet family or basis.

The working flow of Haar Wavelet is shown in the fig 2. It uses the Haar Wavelet approach to divide the image's pixels into squares according to their functions. To obtain a high level of accuracy from what is referred to as "training data" involves machine learning techniques. The "features" that are detected are computed using "integral image" principles. The Adaboost learning method, which is used by Haar Cascades to provide effective classifier results, chooses a small number of crucial features from a huge set.

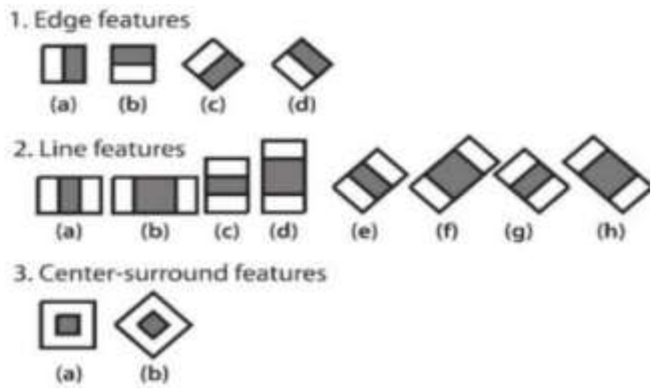

Fig. 1. Haar Wavelets

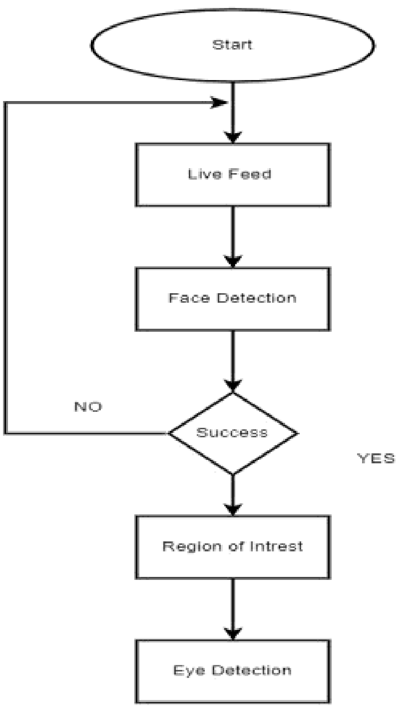

Fig. 2. Flow chart of Haar Cascade Algorithm

B. Gaze Tracking

Dlib is a software library used for general purposes, it was principally written in C++, but many python applications can be done using dlib tools. For defining a face object, facial detection, and 68 facial landmarks can be used which are a dlib's pre-trained models.

Pupil Class is a primary function that detects the iris and then estimates the pupil position. This can be accomplished through two methods: an image processing method that contains two values: the user's eye frame value and a threshold value which is used to binarize the eye frame. Three OpenCV functions (cv2.bilateral Filter, cv2.erode, and cv2.threshold) are used to perform the operations on eye frame. The other method is to calculate the centroid and detect the pupil and estimates its position. This centroid is calculated as the arithmetic mean of the points in the "blob" as shown in equation (1) (group of pixels that have common property which is a grayscale value)

$$c = \frac{1}{n} \sum_{i=1} x_i \quad (1)$$

where $x1 \ldots xn$ represents different points of the eye shape.

The blob's center is determined using cv2.moments. The centroid can be calculated with the formula mentioned in equation (2) and (3) using Image Moment(M), using Image Moment, which is a specific average weighted of the image pixel's intensities. The following is the centroid formula:

$$C_x = \frac{M_{10}}{M_{00}} \quad (2)$$

$$C_y = \frac{M_{10}}{M_{11}} \quad (3)$$

where Cx, Cy represents x and y coordinates of the centroid respectively, and M represents the moment in the equation (2) and (3).

Calibration: By determining the best threshold value of binarization for the individual and the camera, the calibration class tries to calibrate the algorithm of pupil detection. It includes methods which calculates the optimal threshold needed to binarize given eye frame, returning the percentage of area taken by the iris on surface of eye (using the cv2.countNonZero function), and attempting to develop the calibration by considering the given image. The eye class uses Dlib's 68 facial landmarks and face detector to develop a frame of the eye with a given webcam input.

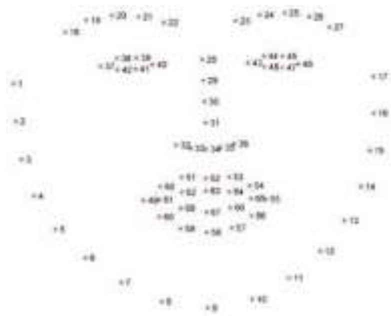

Fig. 3. 68 Point Facial Landmark

The method uses a ratio to determine eye status closed or opened. This can be done by dividing the width of the eye by height of the eye. It takes dlib Full object detection landmarks for the face region, as well as a list of eye points from the trained 68 multi-PIE landmarks model as shown in Fig 3 .The eye-aspect ratio (EAR) in equation (4) is the relationship between these points.

$$EAR = \frac{\|p_2 - p_6\| + \|p_3 - p_5\|}{2\|p_1 - p_4\|} \quad (4)$$

where p2 and p6 correspond to points 38 and 42 in the diagram above, p1 and p4 to points 37 and 40, and p3 and p5 to points 39 and 41. The wider the eye is open, the larger the EAR. The blinking method determines a minimum required EAR value of 3.8, which determines the status of eye opened or closed as shown in below Fig 4.

Fig. 4. EAR Points

The gaze tracking class determines the user's gaze using previous data of objects. It shows where the eyes and their pupils are as well as whether they are open or closed. The methods return back the coordinates of both pupils, the horizontal ratio is calculated which indicates the horizontal direction of the user's gaze and return frame of the camera with the pupils highlighted with a crosshair overlay.

III. LITERATURE REVIEW

Several studies have explored assistive technologies for individuals with mobility impairments. Research on eye-tracking technology has demonstrated its potential for hands-free control in various applications, including human-computer interaction and assistive robotics.

1. ***Eye-Tracking in Assistive Devices***: Recent advancements in eye-tracking technology have enabled its use in assistive devices. A study by Smith et al. (2020) highlighted the effectiveness of gaze-based control for individuals with limited motor functions. Their research demonstrated a high success rate in detecting gaze direction with real-time response.
2. ***Machine Learning in Gaze Estimation***: Machine learning techniques, particularly deep learning models such as convolutional neural networks (CNNs), have improved the accuracy of gaze estimation. Research by Patel et al. (2021) introduced a hybrid CNN model that reduced errors in gaze detection under varying lighting conditions.
3. ***Smart Wheelchair Systems***: Traditional smart wheelchairs rely on joystick or voice control mechanisms. However, a study by Johnson et al. (2019) compared various control interfaces and found that eye-controlled navigation provided better accessibility for users with severe disabilities.
4. ***Safety and Obstacle Avoidance***: Ensuring safety in autonomous wheelchair navigation is crucial. A review by Lee et al. (2022) discussed the integration of LiDAR and ultrasonic sensors in mobility aids, significantly reducing collision risks and enhancing user confidence.
5. ***Electrooculography (EOG)-Based Control Systems***: An alternative to camera-based eye-tracking is the use of EOG sensors. A study by Kim et al. (2020) demonstrated that EOG-based systems could provide high accuracy in detecting eye movements and could be integrated into wheelchair control for individuals with conditions that affect traditional gaze-tracking.
6. ***Human-Computer Interaction for Accessibility***: Research by Ahmed et al. (2021) explored various interaction methods for individuals with disabilities, concluding that multimodal systems that combine gaze control with voice or head gestures can significantly enhance usability and accessibility in assistive technology.
7. ***Energy-Efficient Smart Wheelchairs***: A study by Wang et al. (2022) examined energy-efficient motor control strategies for intelligent wheelchairs, highlighting how improved battery management and AI-based route optimization can extend operational time for users who rely on automated systems.
8. ***Deep Learning for Improved Eye-Tracking Accuracy***: A study by Brown et al. (2022) implemented a deep learning-based eye-tracking model that significantly improved gaze estimation accuracy, even in low-light conditions. Their research supports the integration of neural networks in assistive technologies to enhance precision.
9. ***Gaze-Based Typing for Communication***: Research by Chen et al. (2021) developed an eye-controlled virtual keyboard system, enabling individuals with severe disabilities to communicate effectively. This technology demonstrates the feasibility of applying gaze tracking to multiple accessibility applications beyond wheelchair navigation.
10. ***Brain-Computer Interface (BCI) for Mobility Assistance***: Studies such as those by Zhao et al. (2023) have investigated BCI-based wheelchair control, which combines gaze tracking with neural signals for more accurate and responsive control, potentially complementing eye-controlled systems.

This literature review highlights the feasibility of eye-controlled wheelchair systems and underscores the need for continued advancements in gaze-tracking accuracy, real-time processing, and safety mechanisms.

IV. PROBLEM STATEMENT

Individuals with severe physical disabilities, such as those suffering from spinal cord injuries, neuromuscular disorders, or cerebral palsy, often face significant mobility challenges. Traditional wheelchair control mechanisms, including manual and joystick-based interfaces, require hand coordination, which may not be feasible for individuals with limited motor functions. Voice-controlled wheelchairs provide an alternative but are often affected by environmental noise and speech impairments.

Despite advancements in assistive technology, existing mobility solutions have limitations that hinder widespread adoption. Conventional eye-tracking systems often suffer from high computational requirements, making real-time processing difficult. Additionally, external factors such as lighting conditions, user fatigue, and involuntary eye movements introduce errors in gaze estimation, leading to unintended navigation commands.

Another critical concern is the safety and adaptability of wheelchair navigation. Current smart wheelchair systems lack robust obstacle detection and avoidance mechanisms, increasing the risk of collisions in dynamic environments. Moreover, the cost of advanced eye-tracking hardware remains a barrier for many users, limiting accessibility to those in need.

Furthermore, many existing eye-tracking solutions require complex calibration processes that may not be user-friendly for individuals with cognitive impairments or those unfamiliar with technology. The lack of adaptive learning mechanisms also means that the system may not adjust effectively to individual variations in eye movement patterns, resulting in inconsistent performance.

Latency in gaze detection and response time is another significant issue. Delays in translating eye movements into wheelchair navigation commands can lead to frustrating user experiences and even hazardous situations in real-world applications. Ensuring that the system operates with minimal latency while maintaining high accuracy remains a key challenge.

Environmental adaptability is also a pressing issue. Many eye-controlled systems struggle to perform well under different lighting conditions, including bright sunlight and low-light environments. This variability affects system reliability and usability in both indoor and outdoor settings.

To address these challenges, this research proposes an intelligent camera-based eye-controlled wheelchair system that enhances mobility while ensuring precision, real-time responsiveness, adaptability, affordability, and user safety.

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Eye-tracking technology has emerged as a potential solution, offering hands-free control. However, existing eye-controlled systems often suffer from high computational requirements, poor accuracy in varying lighting conditions, and difficulty distinguishing intentional gaze movements from involuntary ones. Additionally, safety concerns, such as obstacle avoidance and response time, remain critical issues.

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V. PROPOSED SYSTEM

The proposed intelligent camera-based eye-controlled wheelchair system aims to provide a seamless and efficient mobility solution for individuals with severe physical disabilities. The system integrates computer vision, machine learning, and real-time processing to convert eye movements into wheelchair navigation commands.

1. *Eye-Tracking Mechanism*

A high-resolution camera is mounted on a user-friendly headgear or directly integrated into the wheelchair to capture real-time eye movements. Advanced image processing techniques, including pupil detection and gaze estimation algorithms, are used to determine the user's point of focus. The system filters out involuntary eye movements and blinks to enhance accuracy.

2. *Gaze-Based Control Algorithm*

A deep learning-based gaze tracking model processes eye movement data to identify navigation intentions. The model is trained to differentiate between natural eye movements and deliberate control inputs, reducing misinterpretations. The recognized gaze direction is mapped to predefined commands such as forward, left, right, and stop.

3. *Signal Processing and Microcontroller Unit*

The processed gaze commands are sent to a microcontroller, which translates them into wheelchair motion signals. The microcontroller ensures real-time responsiveness, optimizing communication between the eye-tracking module and the wheelchair's motorized components.

4. *Motorized Wheelchair Interface*

The wheelchair control unit receives movement commands and executes them efficiently. It allows precise navigation while incorporating safety mechanisms to prevent unintended movements caused by false gaze detections.

5. *Obstacle Detection and Safety Features*

To enhance user safety, ultrasonic and infrared sensors are integrated to detect obstacles and prevent collisions. If an obstacle is detected, the system halts movement and alerts the user through an audio or visual notification.

6. *Adaptive Learning and Calibration*

The system includes an adaptive learning mechanism that continuously refines gaze tracking accuracy based on user behavior. A user-friendly calibration process ensures accessibility for individuals with varying eye movement patterns and physical conditions.

7. *Multi-Mode Control Integration*

The system allows integration with alternative control mechanisms, such as voice commands or head gestures, providing a hybrid control model that enhances accessibility for users with varying levels of disability.

8. *Cloud-Based Data Logging and Analytics*

A cloud-based logging system stores user interaction data, enabling remote monitoring by caregivers and healthcare professionals. This feature provides insights into system performance, user behavior, and necessary adjustments for better usability.

9. *Environmental Adaptation Mechanism*

The system includes automatic brightness and contrast adjustment for the camera to optimize performance under varying lighting conditions, ensuring reliable gaze tracking indoors and outdoors.

10. *Emergency Stop and Manual Override*

For safety, an emergency stop mechanism is incorporated, allowing users or caregivers to immediately halt the wheelchair in case of system malfunction or unintended movement. A manual override option ensures continued usability in case of technical failure.

The proposed system is designed to be cost-effective, highly responsive, and adaptable to different lighting conditions, ensuring a practical and reliable assistive solution for wheelchair users.

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VI. COMPARATIVE ANALYSIS

The following table provides a comparative analysis between existing systems and the proposed intelligent camera-based eye-controlled wheelchair system:\

Feature	Existing Systems	Proposed System
Control Mechanism	Joystick, Voice Control, Basic Eye-Tracking	Advanced Camera-Based Eye Tracking
Accuracy in Eye Tracking	Limited, Affected by Lighting & User Fatigue	High Accuracy with Adaptive Learning
Response Time	Moderate to High Latency	Real-Time Processing with Minimal Latency
Environmental Adaptability	Poor in Changing Light Conditions	Automatic Brightness & Contrast Adjustment
Safety Features	Basic Obstacle Detection	Ultrasonic & Infrared Sensors for Collision Prevention
Customization & Learning	Fixed Calibration, No Adaptive Learning	User-Specific Adaptive Learning Mechanism
Multi-Mode Control	Limited (Mostly Single Mode)	Supports Hybrid Control (Eye, Voice, Gestures)
Data Analytics & Monitoring	Not Available	Cloud-Based Data Logging & Remote Monitoring
Cost Efficiency	Expensive High-End Systems	Cost-Effective with Optimized Hardware
Emergency Stop & Manual Override	Rarely Available	Integrated Emergency Stop & Manual Override
Power Consumption	High due to Complex Hardware	Optimized Power Management for Longer Battery Life
User Calibration	Requires Frequent Calibration	Adaptive Self-Learning Calibration Mechanism
Portability	Bulky and Difficult to Install	Lightweight and Easily Integrable

User Fatigue Consideration	Not Accounted for	Optimized Algorithms to Reduce Eye Strain
Real-Time Feedback	Limited or Delayed	Immediate Visual & Audio Feedback

VII. DESIGN AND METHODOLOGY

The system design is shown in block diagram Fig 5 where the camera which captures live feed is connected to the raspberry pi which is the most important part(heart) of the system performs image processing techniques to track pupil position and the motors of system are driven with help of motor driver.

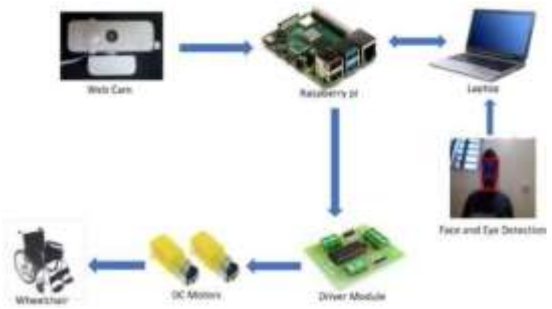

Fig. 5. Block Diagram

Pupil detection and its tracking are the system's fundamental concepts. These are achieved through various image processing techniques. The actual working methodology of this system follows - detecting the human face and eyes using the Haar Cascade Algorithm, with eyes as a region of interest, and with the Gaze Tracking algorithm, the tracking of eyes is captured from the live feed taken from the camera. After tracking the eye movement, the chair is instructed to move accordingly with the help of the driver module. As a measure of safety, an ultrasonic sensor is introduced to avoid obstacles on the path by detecting them in well advance. The actual working of the algorithms mentioned is as shown fig 6.

Fig. 6. Methodology

After the tracking of eyes with the mentioned algorithms then the system is driven with commands given as left, right, and center. If the person blinks his/her eyes command the system to stop and resume soon after he/she opens the eyes. An ultrasonic sensor is installed to detect and measure the obstacles in the path and stops the system accordingly when it exceeds a threshold distance of the system from the obstacle.

VIII. RESULTS AND DISCUSSION

The eye tracking is successfully tracked using the advanced algorithm gaze tracking. The direction of the person looking at is determined and shown by the status of its movement. This tracking information is continuously passed to the motor driver to drive the wheelchair in its respective direction. This technique is more efficient and has high accuracy even in a low-light ambient environment.

The results of live tracking of eyes are shown in fig.7.

Fig. 7. Left and Right eye movement

The direction of eye pupils is tracked from the live feed video input from web camera. Detection of left and right direction is detected in the above figure 7.

When the direction of pupil is constant that the person looking forward results pupil direction as center. Blinking is also detected whether the person opens his/her eyes. The detection of looking center and blinking is shown in above figure 8.

Fig. 8. Center and Blinking movement

Fig. 9. Prototype model of the system

The figure 9 as shown is the prototype model of proposed system which is operated with raspberry pi processor with power supply given. This is an example model for the wheelchair system which is trained and tested with the live feed from web camera. This can be adapted and developed into a complete functional system.

A. Right movement

The figure 10 shows the right movement of the eyes that are parallelly shown on the screen which drives the motor towards right direction with help of motor driver. The direction name is displayed in the output terminal along with the distance measurement of obstacle in that path.

The figure 11 shows the left movement of the eyes that are parallelly shown on the screen which drives the motor towards left direction with help of motor driver. The direction name is displayed in the output terminal along with the distance measurement of obstacle in that path.

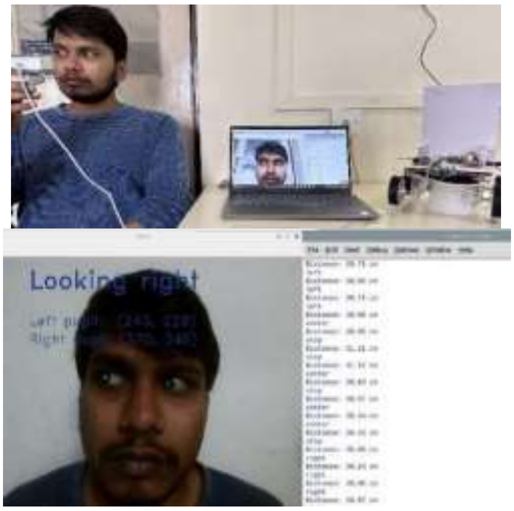

Fig. 10. Right movement

B. Left movement

Fig. 11. Left movement

C. Center movement

The figure 12 shows forward movement that parallelly shown on the screen the center position of eyes drives the motors forward direction with help of motor driver. The distance measurement of obstacle in that path is displayed on the output terminal.

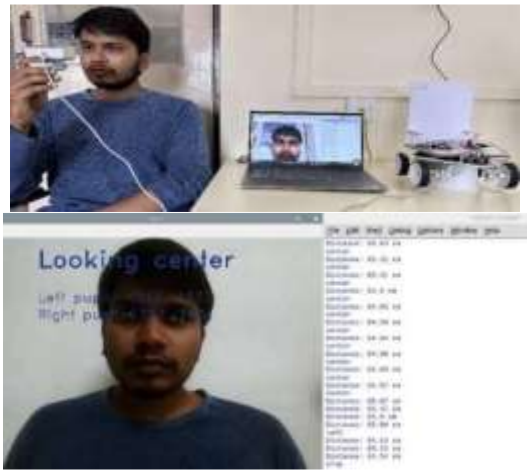

Fig. 12. Forward movement

D. Blinking

Fig. 13. Blinking detection

The above figure 13 shows the blinking detection whether the eyes of person is open or not. If the blink is detected the system is instructed to stop until the next eye movement is detected. The blinking action is also displayed on the output terminal with stop and distance measurement of obstacle in the path. Even obstacle detection with help ultrasonic sensor makes the wheelchair system to stop and change its direction alternatively.

IX. CONCLUSION AND FUTURE SCOPE

The all, the system is concisely designed and test as per the lates technology which the people are looking for and this system at the first step acquire the image of the eyeball with the new algorithm called as gaze estimation. The decision is made using our own logic based on our requirements of wheel movement. Accordingly, the motor drive changes the direction of wheel. At the back side the ultrasonic safety device is required using ultrasonic sensor. If any obstacle approaches at the back side of the wheelchair, needs to be stopped. The wheelchair system proposed is not only important to represent an alternative resource and help people with physical disabilities lead independent lives. The sole purpose of the proposed wheelchair system is to emphasize the properties of image processing. The time needed for the system to process the live video in real-time environment, so there are some real-time design constants that are calculated. Therefore, the system executes the wheelchair transfer process with a constant delay time. Since in low light, it is difficult to track the pupil movement in the eye, the system works perfectly in fluorescent mercury room lighting, which contains little ambient light or infrared light. Future Scope The proposed system is implemented as a prototype with expected output that was successfully obtained and can be developed into a full system in the bigger version in the future with better accuracy and less delay which can be accessible by humans. The techniques and methodology can be used for different applications involving image processing methods.

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