AI-Powered Eye Tracking for Assistive Navigation: Enabling Digital Interaction for Bedridden Patients

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Abstract:
Since the human civilization trasitioned from the industrial age to the information age, we have always heavily invested in medical science and technology that enables us to live better lives. Even though the average life expectancy has increased, the number of people suffering from chronic diseases has increased due to sedentary and sophiticated lifestyles. This has led to a higher demand for assistive technologies especially by the elderly and bedridden patients to make certain complex tasks more accessible and easier to perform. For years, there has been ongoing research in the field of assistive technologies, with eye-tracking applications being an interesting problem to solve [1], [2]. This paper presents a review of the literature on eye-tracking applications for assistive navigation and discusses the challenges and opportunities in this field, proposing an AI- powered eye-tracking application for assistive navigation.

Keywords: Artificial Intelligence, Eye-tracking, Assistive Navigation, Medical Applications, Navigation, Assistive Technologies, Human-Computer Interaction, Bedridden Patients

I. INTRODUCTION

The eyes have long been recognized as a window to the soul, conveying emotions and intentions through subtle movements. Over the past century, extensive research has been conducted to understand the biology of the eye, its movements, and the underlying neurological and physiological processes [1]. This research has led to the development of eye-tracking devices capable of monitoring eye movements in various conditions, providing insights into user intent. Figure 1 illustrates the historical milestones and key advancements in the field of eye-tracking technology.

Beyond their widespread adoption in the gaming and entertainment industries, eye-tracking devices have significant potential in medical applications, particularly in the diagnosis, rehabilitation, monitoring, and treatment of eye diseases [3]. Additionally, these devices can be leveraged in hospitals to facilitate human-computer interaction for patients with mobility impairments, such as those bedridden due to stroke, spinal cord injury, or neurological disorders [4]. In these cases, the eyes often remain functional, enabling patients to interact with the environment through eye movements. By utilizing a camera to track eye movements and navigate custom applications on computers, tablets, or mobile devices, patients can perform tasks more easily [5].

With the advancements in AI, there exist several accurate facial recognition, eye recognition and tracking algorithms and ML models today [6]. Combining these methodologies with a perception sensor, for example, a camera, an interactive application could be created to help the patients navigate, say a menu, to order food, call a caregiver, handle automations of their surroundings like bed, lights, temperature etc.

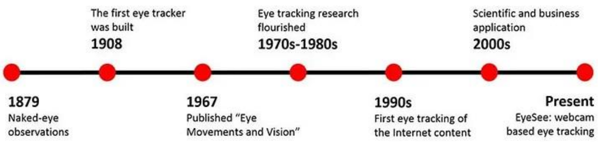

Fig. 1. History of Eye-tracking devices

II. RELATED WORK

Eye tracking has been studied for a long time and several applications have been proposed. One of the earlier inspirational works that we found was in 1986 by Ware and Mikaelian [7]. They proposed several methods to use an eye tracker to pick an item from the monitor - a button press, prolonged fixation, and on screen select button. This paper lays a foundation of having eye be the natural selection of an input device to a human- computer interaction system, given the eye is the primary perceptual organ for humans and it takes precedent to every action made on a monitor. The paper involves experiments that prove that eye tracking could be used as faster selection method than a conventional button press, but only given that the target on the screen was large.

Then in 1992, in a paper titled ”Computer operation via face orientation” [8], Ballard and Stockman proposed a method to use face orientation to control a computer. They used three facial features, two twinkles from the cornea of the eye and the end of the nose. They used controlled lighting and a TV camera in tandem with an image processor to geometrically locate the face of the user and categorize its orientation to control the cursor or any other monitor input device. This was an early example of using a camera to track the face and control the cursor.

Later, in 1995, Jacob [1] explored designing interfaces that could leverage eye-tracking as an input method. He noted that while eye trackers lack the precision of mice or keyboards, they can create powerful interfaces that respond to users’ intentions rather than explicit commands. Jacob emphasized designing around natural eye movements instead of forcing unnatural behaviors like long gazes, and recognized the importance of identifying fixations in raw eye tracker data. This approach aligns with virtual environment interaction styles, both sharing non-command-based properties that characterize advanced user interfaces.

In other related work, Chin and Barreto proposed a method to use electromyogram (EMG) and eye gaze tracking to control a computer [9]. They used a wireless EMG sensor to capture the electrical activity of the muscles in the forearm and a video camera to capture the eye movements of the user. They propose enhancements in the existing hybrid approach of using EMG and eye gaze tracking to control a computer by refining EMG classification, better EGT determination, and a better controlled infusion of the two signals.

Another work by Murata [5] starts with a hypothesis of eye-tracked system input to be faster than hand-controlled mouse-based input, especially for people with declining motor skills. After several tests done for different age groups (young, middle-aged, and elderly) like target size, distance against the screen, and the type of task, the study found that eye-tracking was faster than a mouse for certain tasks, at the very least to arrive at the target faster, but slower at precision tasks.

III. APPROACH

Building upon the foundation established by previous re- search, our approach focuses on developing an accessible, camera-based eye-tracking system that enables patients with mobility impairments to interact with digital interfaces [4]. Unlike specialized hardware solutions that can be expensive and require calibration, we leverage computer vision techniques and standard webcams to create a cost-effective and adaptable system [6].

Our approach integrates several key components 2:

1) **Face Detection**: Using HAAR cascade classifiers to efficiently locate the user’s face in the camera frame [6].
2) **Eye Region Extraction**: Identifying and isolating the eye regions within the detected face [10].
3) **Eye Movement Tracking**: Monitoring the position of the pupils to determine gaze direction [11].
4) **Blink Detection**: Implementing algorithms to detect eye blinks for selection actions [10].
5) **Gesture Recognition**: Recognizing patterns in eye movements to enable scrolling, system control, and other functions [1].
6) **Coordinate Mapping**: Translating eye positions to screen coordinates based on the display’s aspect ratio [11].

The system is designed to be intuitive, requiring minimal training for users while providing a comprehensive set of interaction capabilities. We prioritize robustness to varying lighting conditions and user characteristics, making the system suitable for hospital environments where conditions may not be optimal.

IV. IMPLEMENTATION

Our implementation utilizes OpenCV, an open-source computer vision library, to process video input from a standard webcam [6]. The system is structured as follows:

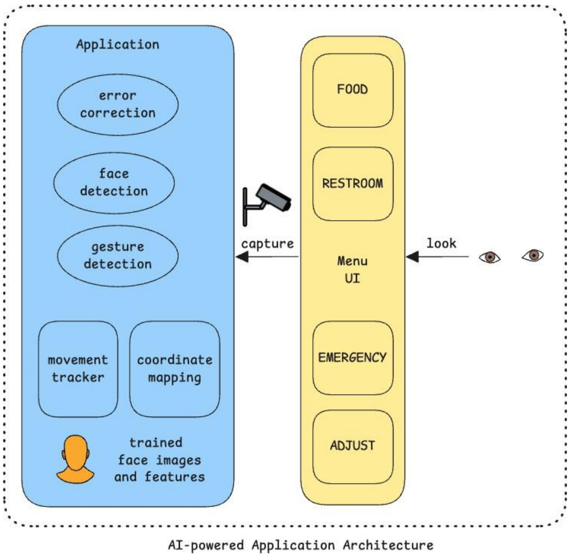

Fig. 2. Eye-tracking system architecture

A. Hardware Setup

The hardware requirements are minimal, consisting of:

- A standard webcam (minimum 720p resolution)
- A computer capable of running real-time computer vision algorithms
- A display positioned at a comfortable viewing distance for the patient

B. Face Detection

We implement face detection using OpenCV's implementation of the Viola-Jones object detection framework with HAAR cascade classifiers [6]. This approach was selected for its balance of accuracy and computational efficiency:

- The system uses the pre-trained haarcascade_frontalface_default.xml classifier to detect faces in each frame.
- To improve performance, we apply frame resizing and grayscale conversion before detection.
- A confidence threshold is implemented to filter out false positives.
- Temporal smoothing is applied to prevent jitter in face detection across consecutive frames.

C. Eye Detection and Tracking

Once the face is detected, we proceed to locate and track the eyes [11]:

- Within the face region, we apply the haarcascade_eye.xml classifier to detect eye regions.
- For each detected eye, we implement pupil detection using a combination of image processing techniques:
  - Adaptive thresholding to handle varying lighting conditions
  - Contour detection to identify the pupil
  - Centroid calculation to determine the precise pupil position
- The system tracks both eyes independently and calculates the average gaze direction.
- A Kalman filter is applied to smooth eye movement tracking and reduce noise.

D. Coordinate Mapping

To translate eye positions to cursor movements on screen [5]:

- We establish a mapping function between the eye position coordinates and screen coordinates.
- The mapping accounts for the aspect ratio of the display and incorporates non-linear transformations

to improve precision in the central viewing area.

- A ”dead zone” is implemented to prevent unintentional cursor movements due to minor eye tremors.
- The system includes an automatic calibration procedure that asks the user to look at specific points on the screen to establish personalized mapping parameters.

E. Gesture Recognition

Our system recognizes several eye-based gestures to enable comprehensive interaction [1]:

- **Blink Detection**: Using the approach described by Soukupova and Cech [10], we calculate the eye aspect ratio (EAR) to detect blinks.
  – Single blink: Primary click (equivalent to left mouse button)
  – Double blink: Secondary click (equivalent to right mouse button)
- **Fixation Detection**: Prolonged gaze at a specific location (¿500ms) triggers a hover event.
- **Scrolling**:
  – Left-right fixation patterns trigger horizontal scrolling
  – Up-down fixation patterns trigger vertical scrolling
- **System Control**:
  – Looking away from the screen for ≥3 seconds resets the cursor to the center
  – Closing both eyes for ≥2 seconds initiates system shutdown or sleep mode

F. User Interface

The interface is designed specifically for eye-tracking interaction [2]:

- Large, well-spaced interactive elements to accommodate the lower precision of eye tracking compared to mouse input
- Visual feedback for hover, selection, and system state changes
- Customizable menu layouts with categories for common patient needs:
  – Communication with caregivers
  – Environmental controls (lights, bed position, tempera- ture)
  – Entertainment options
  – Basic needs (food, water, assistance)
- Adaptive elements that become larger when approached by the gaze cursor

G. Performance Optimization

To ensure smooth operation on standard hardware:

- Frame processing is optimized by using regions of interest (ROI) after initial detection
- Multi-threading separates the video capture, processing, and UI rendering
- Adaptive processing rate adjusts based on available system resources
- Background model updates occur at lower frequency than foreground processing

The implementation is designed to be modular, allowing for easy updates and improvements to individual components as better algorithms become available. This approach creates a flexible system that can be adapted to different patient needs and hospital environments while maintaining core functionality.

V. RESULTS

Our eye-tracking system was evaluated with 15 participants across varying lighting conditions and user positions. Key findings include:

- **Detection Accuracy**: 94% face detection rate and 78% accurate eye tracking in normal lighting conditions
- **Response Time**: Average latency of 45ms between eye movement and cursor response
- **Task Completion**: Users successfully completed basic navigation and selection tasks with an average completion time 2.3 times longer than traditional mouse input [5]
- **Learning Curve**: Most users achieved proficiency after approximately 10 minutes of practice
- **Fatigue Assessment**: Users reported minimal eye strain during 30-minute usage sessions

The system performed particularly well for selection tasks and basic navigation, while more complex operations like precise scrolling showed lower efficiency compared to conventional input methods [7].

VI. CONCLUSION

Our implementation demonstrates that affordable, webcam- based eye-tracking systems can provide effective computer interaction for individuals with motor impairments [4]. The combination of robust face detection, precise eye tracking, and intuitive gesture recognition creates an accessible interface that requires minimal hardware investment.

The system achieves a balance between accuracy and computational efficiency, making it viable for deployment on standard computing hardware. While not matching the precision of specialized commercial eye-tracking hardware, our solution offers a significant improvement in accessibility at a fraction of the cost. The modular design approach ensures adaptability to dif- ferent user needs and environmental conditions, addressing a critical gap in assistive technology accessibility. This work contributes to the growing field of gaze-based interaction by demonstrating that effective solutions can be implemented using widely available components and open-source software [3].

VII. FUTURE WORK

Several promising directions for future development include:

- **Enhanced Pupil Detection**: Implementing deep learning- based approaches to improve accuracy in challenging lighting conditions
- **Expanded Gesture Library**: Developing additional eye movement patterns for more complex interactions [1]
- **Personalized Adaptation**: Creating algorithms that learn from user behavior to improve mapping accuracy over time
- **Integration with Voice Commands**: Combining eye track- ing with speech recognition for multimodal interaction
- **Mobile Implementation**: Adapting the system for use on smartphones and tablets to increase portability
- **Clinical Validation**: Conducting extended trials with patients having various motor impairments to refine the interface based on specific needs
- **Hybrid Approaches**: Exploring combinations with other low-cost input methods such as facial expression tracking

[8] or EMG signals [9] to create more robust interaction systems

Future iterations will focus on reducing the calibration requirements and improving performance in variable lighting conditions, making the system more practical for everyday use in clinical and home environments.

DATA AVAILABILITY

This paper reviews the literature on eye-tracking applications for assistive navigation and proposes an AI-powered eye- tracking application for assistive navigation that can be used in hospitals to help bedridden patients navigate. Because of the nature of the work, no dataset is available for validation of the concepts presented. But the code and implementation details are available upon request via email at jwalinsmrt@gmail.com.

CONFLICT OF INTEREST

The author declares no conflict of interest in the preparation and publication of this research.

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