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HCI Based on Facial Movement for People with Upper Limb Disparities

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Abstract

Human-machine interfaces, or HMIs, are important for improving the usability and accessibility of digital systems. Eye movement-based HMIs offer a new and user-friendly way to interact with technology, especially for digital display systems. These technologies enhance user experience and accessibility by allowing users to control and modify digital devices with their natural gaze behaviour. This study reviews the concepts, processes, challenges, and applications of eye-tracking technology in HMIs. It emphasizes the potential of these systems in both assistive and mainstream applications. The study highlights significant scientific contributions, identifies hardware and software innovations, evaluates usability, and discusses possible future developments. HMI systems have evolved to support various users, including those with physical limitations, by using complex mechanisms and manual controls. Keyboards, mice, and touchscreens are examples of traditional manual technologies that have dominated digital display interaction. Alternative methods have been developed for those without hands, including voice control, eye tracking, and modified devices. The development and history of manual HMI systems, the challenges faced by individuals without hands while utilizing traditional interfaces, and the most recent technical developments that offer accessible solutions are all examined in this review of the literature. The assessment highlights developments in inclusive design while also pointing out areas that require further research to provide equitable access to digital systems [4].

KEYWORDS*: Human-Computer Interaction (HCI), Human-Machine Interface (HMI), Blink Detection, Pupil Movement, Facial Landmark Detection, Eye-Gaze Technology, Eye-Tracking, Assistive Technology, Hands-Free Computing, Upper, Limb Disabilities [1].*

1. Introduction

Artificial The rapid evolution of digital display technology necessitates the development of new, user-friendly interfaces. Human-Machine Interfaces (HMIs) have progressively altered how humans use technology by enabling seamless control and communication. Eye-tracking technology, which offers hands-free and intuitive interaction features, is the most promising of all. Because these systems use gaze as an input method, which enables users to explore, choose, and modify digital content with minimal physical effort, they are particularly beneficial for people with mobility issues. Eye-tracking devices employ advanced techniques including infrared lighting, video-based tracking, and machine learning algorithms to recognize and analyse eye movements. These methods provide precise information about fixation areas and gaze direction, laying the foundation for gaze-based interaction with digital displays. While early iterations focused on basic functions like cursor control, recent advancements have expanded their ability to include complex interactions in dynamic environments. Numerous industries, including marketing, medical diagnostics, gaming, and assistive technology, may use eye-tracking in HMIs. For those with disabilities, gaze-based solutions offer a lifeline to independence and communication. In addition to providing valuable insights into human behaviour for consumer and medical research, they enhance immersion and involvement in virtual reality and gaming. Despite their promise, eye-controlled HMIs have a number of challenges. Issues with accuracy, user fatigue, environmental interference, and high costs limit their widespread acceptability. To overcome these challenges, constant innovation in hardware design, algorithm development, and system integration will be required. Furthermore, privacy and data accessibility continue to raise ethical concerns. Human–Computer Interaction (HCI) focuses on designing and developing computer systems that are easy, efficient, and comfortable for humans to use. Traditional computer interaction mainly depends on input devices such as keyboards, mouse, and touchscreens. However, individuals with upper limb disabilities or disparities often face significant challenges while using these conventional devices. This creates a barrier to accessing digital technology, communication tools, and assistive systems that are essential in daily life. To overcome these limitations, researchers and developers are exploring alternative interaction methods, including systems based on facial movement recognition. Facial movement-based HCI allows users to control computers or digital devices using facial expressions such as eye blinking, eyebrow movement, head tilting, and lip movement. These systems use cameras, sensors, and artificial intelligence techniques to detect and interpret facial gestures as input commands. [11]

The eye-ball tracking for motor-free control of a mouse pointer [6], utilizing a combination of Viola-Jones, Kanade-Lucas-Tomasi (KLT), and Circular Hough transform algorithms. This system addresses the pressing need for practical applications of advanced image processing algorithms. While previous research has successfully tracked iris movements, its application was limited to specific contexts, such as head-mounted displays. The proposed system, however, enables mouse pointer control through eye movements, facilitating computer accessibility for individuals with motor disorders. By integrating Viola-Jones for eye region extraction, KLT for real-time tracking, and Circular Hough transform for iris detection, the system achieves robust performance across varying lighting conditions and distances from the screen. Additionally, the system introduces a blink-based clicking mechanism, enhancing user interaction. Despite challenges faced by individual algorithms, their synergistic integration demonstrates superior performance in eye-tracking accuracy. The authors aim to develop an open-source software package, prioritizing simplicity for widespread adoption and future contributions from researchers and users alike. This innovative approach not only enhances accessibility but also showcases the potential of image processing algorithms in real-world applications. The utilization of Electrooculogram (EOG) signals in human-computer interface (HCI) systems has gained significant attention due to its reliability, cost-efficiency, and non-invasive nature. EOG signals, generated by the potential difference between the cornea and retina of the eye, offer a promising solution for controlling computer interfaces and hardware devices through eye movements. The Researchers have developed various systems, integrating hardware and software components, to capture, process, and utilize EOG signals for cursor control and hardware manipulation [12]. These systems typically involve electrode placement for signal acquisition, amplification, filtering, analog-to-digital conversion, and classification algorithms such as Support Vector Machine (SVM) and Linear Discriminant Analysis (LDA) for interpreting eye movements. The hardware implementation involves instrumental and operational amplifiers, filters, microcontroller units like Arduino, and power supply units. On the software side, Python programming facilitates calibration, classification, and cursor movement control. The combination of EOG-based HCI systems with hardware control enables applications like robotic manipulation and wheelchair navigation, providing a promising avenue for assistive technology and human-computer interaction.[6]

This paper provides a thorough evaluation of the latest advancements in eye-tracking technologies for digital display systems. It looks at the core concepts of these systems, discusses gaze-based interaction strategies, and evaluates the limitations and real-world applications. In order to improve eye-tracking HMIs and create more accessible and engaging digital experiences, the study examines current research. Human-Machine Interface (HMI) systems have traditionally depended on manual controls for interaction with digital display systems. Users have traditionally used keyboards, mice, joysticks, and touchscreens as their primary means of entering commands and navigating digital environments. These manual systems now offer extremely high-levels of accuracy, utility, and efficiency because to decades of development. However, their reliance on hand-based touch excludes those who are unable to use their hands due to congenital conditions, injuries, or other restrictions. As digital systems became more and more integrated into daily life, the workplace, and education, it became clear that other engagement strategies were needed. Systems that can satisfy a variety of user needs have been developed by researchers and developers. ranging from advanced eye-tracking systems and brain-computer connections to adaptive technologies like foot pedals and devices for sipping and puffing. From complex eye-tracking systems and brain-computer interfaces (BCIs) to flexible technology like foot pedals and sip-and-puff devices, a variety of solutions have been created to bridge the accessibility gap. This paper reviews the progress of manual HMI systems as well as the development of various interface strategies. It examines the technical and sociological challenges of developing inclusive systems, the effectiveness of current approaches, and the opportunities for future advancement. By acknowledging the limitations of manual interfaces and the advancements of adaptive technology, the paper aims to provide guidance for the design of fair HMI systems. Facial movement-based interaction offers a non-invasive, cost-effective, and user-friendly solution that enhances accessibility and independence for people with upper limb impairments. It enables users to perform tasks such as typing, controlling cursors, operating applications, and communicating without requiring physical hand movement. As technology advances, facial recognition and gesture-based interfaces are becoming more accurate, reliable, and widely adopted in assistive technology. Therefore, HCI based on facial movement plays an important role in improving the quality of life for individuals with upper limb disparities by promoting digital inclusion and equal access to technology. [5]

Fig.1. Eye-tracking computer

2. Literature Review

Artificial Intelligence (AI) technologies have rapidly transformed the way people make decisions in everyday life. Research across disciplines such as computer science, psychology, human-computer interaction (HCI), and behavioural economics has explored both the opportunities and challenges of this transformation.

I) Manual HMI Systems' Development

Devices for human input were a major component of the initial generation of HMI systems. Typewriters, for example, allowed text input in early computer systems and were the forerunners of current keyboards. An important turning point was reached in 1964 when Engelbart invented the computer mouse, which introduced point-and-click functionality and completely changed graphical user interfaces (GUIs). Touchscreens further simplified manual interaction by allowing direct connection with digital displays and doing away with the requirement for auxiliary devices [3]

II) The Benefits and Drawbacks of Manual Systems

The precision, speed, and familiarity with manual systems make them valuable. Keyboards and mouse continue to be the industry standard for applications requiring accuracy and productivity. However, users with physical disabilities face accessibility challenges due to their reliance on hand coordination and fine motor skills. For instance, classic mice require hand movement, but touchscreens demand finger dexterity, making it impossible for people without hands to use these devices efficiently.[21]

III) Manual Adaptive Devices

Adaptive manual devices rethink conventional systems in an effort to overcome these constraints. Among the examples are: Foot-Controlled Mice. By using the air pressure created by sipping or blowing into a straw, users can enter commands using sip-and-puff systems. Voice-Assisted Keyboards: These keyboards combine speech recognition and keyboard features to help people with restricted hand mobility [8]

IV) Technology for Eye-Tracking

Through the removal of physical input, these systems offer a user-friendly, hands-free interaction mode. Research has shown that dwell-based and blink-based controls are efficient for activities like selection and navigation (Majaranta and Räihä, 2002, for example) [10]

V) Systems for Voice Control

For users who are unable to use manual input, voice control has grown in popularity. Natural language processing (NLP) is used by voice assistants such as Siri, Alexa, and Google Assistant to carry out orders, look up information, and manage electronic devices. Voice-controlled systems work especially well for easy activities, but they might not be able to handle complicated procedures that call for multi-step orders. [24]

3. Research Methodology

The study of Human–AI Interaction (HAI) and its influence on daily decision-making requires a multidisciplinary methodological approach, combining qualitative and quantitative research techniques. This methodology review examines commonly used methods in existing research and explains how they help in understanding the role of Artificial Intelligence in everyday human decisions.[25]

A) Data Collection and Preprocessing

I) Data Collection:

The dataset of facial images were gathered under many different lights so to ensure the strength and broadness of the system. Different individuals belonging to different age groups, ethnicities, genders etc. were included in the dataset so that all faces could be accounted for. Facial images have been taken at various angles and orientations in order to mimic real-world situations and make the system work better under varying [23]

II) Preprocessing Techniques:

Preprocessing techniques including scaling, normalization, grayscale conversion, etc. were employed to standardize facial photographs and lessen computing load. To reduce background noise that can obstruct precise facial feature identification, noise reduction algorithms were used. Rotation translation flipping and other picture augmentation techniques were used to change the dataset, adding variation and strengthening the system's resistance to user-provided inputs or indications. In order to eliminate low-quality photos and guarantee the reliability of data sets in subsequent phases of analysis, Quality Assessment criteria were employed. [2]

III) Data Augmentation:

Data augmentation techniques were applied in order to expand the dataset's size and diversity. These techniques included brightness modifications, scaling, random rotations, and translations. By creating augmented images that mimicked various facial expressions, postures, and lighting conditions, the model's capacity to generalize with data that has not been seen before was enhanced. [22]

B) Identification of Facial Landmarks

Common Histogram of Oriented Gradients (HOG) features, which record local gradients in facial regions, serve as the foundation for the previously created Dlib model for facial landmark detection. The model separates the image's facial and non-facial parts by combining the HOG feature with an alinear classifier. To ensure robustness to changes in facial shape and position, faces are detected at several scales using an image pyramid. A window of a specific size is used to repeatedly scan the image in order to find possible faces, and a sliding window is used to locate facial regions in an image. After detecting a face, Model 68 correctly predicts 2D facial landmarks, such as the points that represent the eyes, nose, mouth, and face shapes. By acting as stand-ins for facial form and movement, these markers enable accurate control of facial movement-based HCI based on nuanced facial cues. High accuracy and resilience in a variety of facial situations, angles, and lighting circumstances are hallmarks of the Dlib facial mark recognition pattern. The model's strong feature representation, effective classification system, and effective detection method all contribute to its performance. The model's generalizability and adaptability to various facial features and environmental conditions are guaranteed by a vast training set of data sets. Because the facial mark recognition model operates in real time, it can be used in interactive applications like facial movement-based mouse cursor control. Flexible and responsive communication is made possible by the model's smooth integration into real-time systems. [14]

C) Ear, or Eye-aspect ratio

Focusing on the central region of the eye, Eye-Aspect-Ratio (EAR) is a characteristic composed of well-known facial landmarks [20]. Eyelids and eye centers are two important features whose geometric correlations are used to compute EARs. Eye closure, such as squinting, is indicated by a decrease in the EAR value, and eye opening is indicated by an increase. The EAR offers a quantitative assessment of ocular behaviour and is a reliable tool for identifying ocular mobility and expression. [9]

D) Ratio of Mouth Aspect (MAR)

A novel characteristic that focuses on the mouth region and was created utilizing well-known facial landmarks is the

Mouth-Aspect-Ratio (MAR) [21]. The cross-section of the distance and important locations, including the face's center, are used to compute the MAR. Speech or snoring are examples of an open mouth, whereas a reduction in the MAR value denotes a closed mouth. Speech-related actions and gestures can be more easily recognized thanks to MAR's accurate depiction of face movements and gestures [15]

E) HCI Movement Controll

Establishing a link between specific facial gestures and matching cursor movements is part of the mapping of recorded facial movements to mouse cursor movements. The goal of the mapping method is to ensure that users can interact with the computer interface in a seamless manner by using facial movements to control the mouse pointer in an intuitive and green manner. Every recognized facial movement, such as blinking, squinting, winking, or opening the mouth, is associated with a particular cursor manipulation action. While winking may also result in a cursor click or selection action, blinking or squinting, for example, can be linked to cursor motion in some instructions. In order to provide precise and responsive cursor manipulation, the mapping is made to accommodate the expressiveness and diversity of face gestures. Additionally, the manipulate mapping technique may enable many facial gestures at once, enabling users to efficiently perform complex cursor manipulate movements. The eyeball tracking for motor-free control of a mouse pointer [6], utilizing a combination of Viola-Jones, Kanade-Lucas-Tomasi (KLT), and Circular Hough transform algorithms. This system addresses the pressing need for practical applications of advanced image processing algorithms. While previous research has successfully tracked iris movements, its application was limited to specific contexts, such as head-mounted displays. The proposed system, however, enables mouse pointer control through eye movements, facilitating computer accessibility for individuals with motor disorders. By integrating Viola-Jones for eye region extraction, KLT for real-time tracking, and Circular Hough transform for iris detection, the system achieves robust performance across varying lighting conditions and distances from the screen. Additionally, the system introduces a blink-based clicking mechanism, enhancing user interaction. [11]

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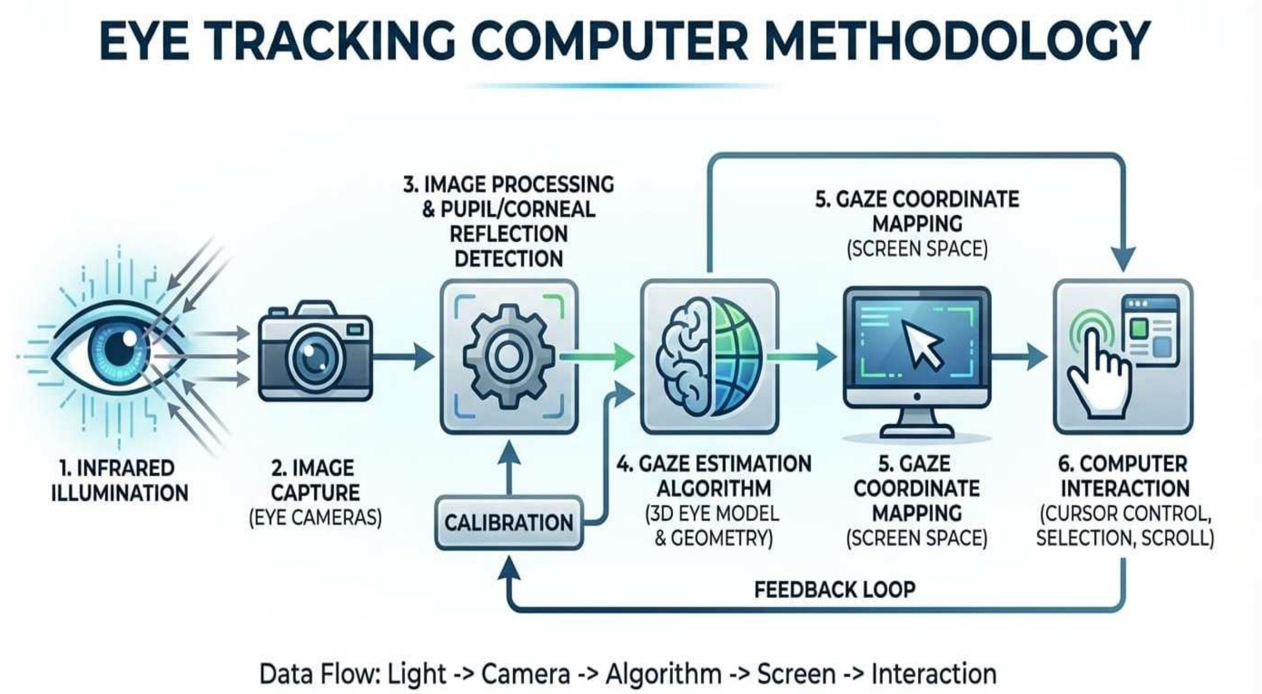
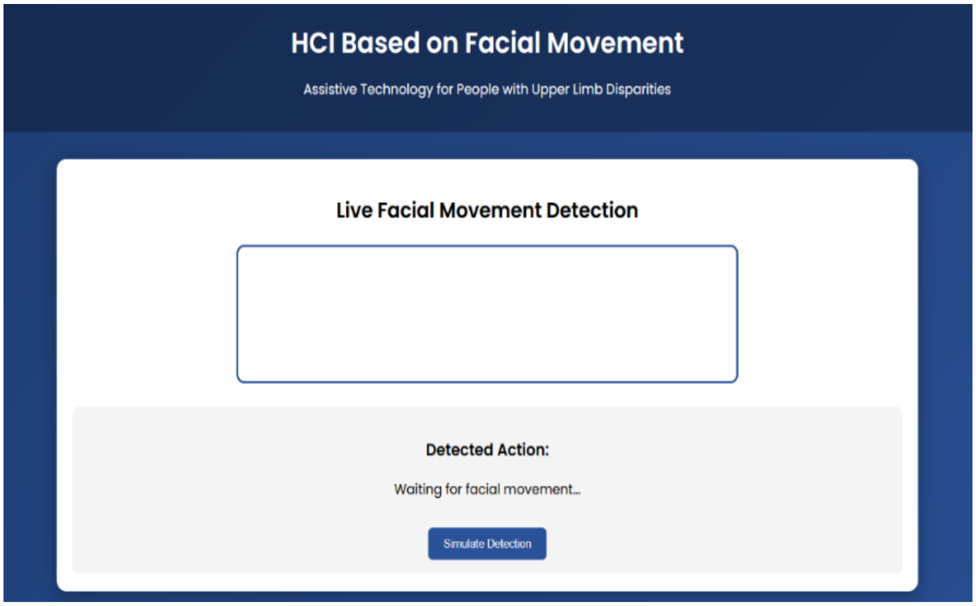


Fig.2. Eye Tracking Computer Methodology

4. Result



HCI Based on Facial Movement

Assistive Technology for People with Upper Limb Disparities

Live Facial Movement Detection

Detected Action:

Waiting for facial movement...

Fig.3.Facial Movement-Based HCI System Result

5. Conclusion

The facial movement-based HCI system that is being demonstrated provides a quick and innovative method of human-computer interaction. The device gives users effective and hands-free cursor control by incorporating facial landmark detection. But also. The accuracy of facial movement recognition has to be improved, particularly in difficult situations like changing lighting or a variety of facial expressions. The system's performance and user experience can be improved by the next generation of adaptive algorithms, which can dynamically modify sensitivity and detection thresholds depending on the unique characteristics of each person and the surrounding environment. The privacy precautions to protect user information gathered during facial movement recognition and guarantee data security. The advent of human-machine interfaces (HMIs) controlled by eye movements represents a transformative step in the evolution of accessible and efficient technology. These systems leverage natural gaze behaviors, allowing hands-free operation of digital displays, thereby empowering users with diverse physical capabilities. [3]

By leveraging technology like computer vision and machine learning, these system provides accessible and adaptable interface, By synthesizing technological advancements, usability studies, and real-world applications, this review underscores the potential of eye-tracking systems to revolutionize interactions across various domains. These methodologies enable precise tracking of eye movements, providing the core functionality for such interfaces. The applications of eye-tracking HMIs are farreaching. From assistive technologies that enhance the quality of life for individuals with disabilities, While the benefits of gaze-based HMIs are undeniable, ethical and cost-related. The collection and processing of biometric data raise significant privacy concerns, as discussed by Stokkermans et al. (2021). Ensuring informed consent and robust data security protocols is imperative to maintaining user trust. Furthermore, the high costs associated with eye-tracking hardware limit accessibility for underserved populations. Addressing these barriers is crucial to achieving equitable adoption of such technologies [19].

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