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Eye and Facial Movement-Based Communication System Using Dwell-Time Selection and Word Prediction

M.Ramya Sri
Assistant professor, Department of CSE,
The Oxford College of Engineering, Bengaluru, India
rmsri45@gmail.com
https://orcid.org/0009-0008-5371-6308
Aditya,Amit, Abhishek Kumar, Abhilash V
Student, Department of CSE,
The Oxford College of Engineering, Bengaluru, India
helloadityabiradar013@gmail.com
amitmb004@gmail.com; abhikr7633@gmail.com
abhiv2719@gmail.com

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Orcid: https://orcid.org/0009-0004-9398-7488

Abstract: For individuals born without a voice and those who have lost their hands and legs due to accidents or congenital conditions, communication is not merely difficult it is nearly impossible. Their minds are alert, their emotions are intact, yet their bodies restrict them from expressing even the simplest needs. Existing assistive systems often depend on hand gestures or head movements, which are unusable for such individuals. To address this gap, the EFMCS-Eye and Facial Movement Based Communication system has been developed as an inclusive, gaze-based communication platform. Using real-time eye and facial movement tracking, the system allows users to construct words, sentences, and messages without physical contact. The interface interprets eye gaze to select virtual keys and enables dwell-based text formation, providing a simple, reliable, and independent way to express thoughts and emotions. This innovation aims to return the most fundamental human ability the power to communicate to those who have lived in silence all their lives.
Keywords: Eye and facial tracking system, gaze-based communication, assistive technology, non-verbal and physically disabled users, dwell-based virtual keyboard.

1. INTRODUCTION

Communication is one of the most fundamental human needs. It allows individuals to express emotions, share thoughts, and interact meaningfully with the world around them. However, for those who are unable to speak from birth and have also lost the use of their hands and legs either due to accidents or congenital conditions this basic ability becomes an unfulfilled dream. These individuals are fully conscious, aware, and emotionally expressive, yet their physical limitations trap the min silence. They depend entirely on others to understand their needs, often resulting in frustration, misinterpretation, and emotional isolation. While several assistive technologies exist today, most rely on hand gestures, voice commands, or head movements. Unfortunately, such systems exclude users who cannot move their limbs or head. Eye-tracking technologies have shown promise, but many current models are expensive, complex to use, or require specialized hardware that limits accessibility. There remains a pressing need for an affordable, intuitive, and inclusive communication system designed specifically for individuals who cannot speak or use their hands and legs but can still move their eyes or make minimal facial expressions. The EFMCS Eye and Facial Movement Based Communication System project addresses this critical gap. It is a Vision based communication system that interprets both eye movements and facial gestures to enable users to select virtual keys, form words, and construct sentences. Through gaze detection and dwell-based key selection, the system transforms small, voluntary facial and eye movements into meaningful text output, restoring the ability to communicate independently.

This paper presents the design, development, and implementation of the EFMCS system, focusing on its accessibility, real-time responsiveness, and user-friendly interface. By empowering non-verbal individuals with an effortless way to express themselves, this innovation redefines communication accessibility and brings hope to those who have lived in silence for too long.

2. LITERATURE SURVEY

The rapid growth of computer vision and human computer interaction technologies has led to significant progress in developing assistive communication systems for individuals with physical disabilities. Several studies between 2020 and 2025 have focused on improving gaze estimation, dwell-based selection, and low- cost accessibility using webcams and lightweight machine learning models. Researchers such as Figueroa et al. (2024) and Vidhya et al. (2025) demonstrated that convolutional neural network (CNN) based gaze tracking can achieve reliable accuracy even with standard webcams, reducing the dependency on specialized infrared sensors. Similarly, Falch et al. (2024) optimized webcam-based gaze estimation for on-screen interactions, highlighting that a well-calibrated software model can perform comparably to expensive eye-tracking hardware. Another key area of advancement involves dwell-time optimization and intent prediction. Studies by Liao et al. (2022) and Burnham et al. (2025) revealed that dynamic dwell-time systems, which adjust fixation duration based on user behavior, significantly improve typing speed and reduce fatigue. Isomoto et al.(2022) introduced machine learning based intent prediction methods to refine dwell selection accuracy, minimizing unintentional selections during long gaze sessions. This adaptive approach makes eye-controlled keyboards more practical for real-world use. Further, Severitt et al. (2025) explored hybrid selection methods combining gaze with facial gestures (like blinking or nodding), improving user control precision in communication systems.

The importance of accessibility and usability has also been emphasized in recent works. Molina et al. (2024) and Dondi et al.(2024) examined the impact of gaze-based text entry systems on user experience and interface design. Their studies suggest that intuitive visual feedback, predictive text suggestions, and adaptive keyboard layouts cangreatlyenhancecommunicationspeedandsatisfaction.Moreover,Chhimpaetal.(2025)provided a comprehensive overview of challenges in real-world gaze tracking, noting that environmental factors such as lighting, face orientation, and head movement remain active research challenges. Parallel research by Ezzat et al. (2023) and the Assistive System Based on Eye Tracking project (2021) demonstrated the successful deployment of gaze-controlled messaging systems for speech-impaired users. These systems proved that combining webcam-based tracking, word prediction, and real-time communication interface scan empower users to express themselves independently. Complementary reviews like Let the Eyes Do the Talking (2024) further confirmed the growing potential of eye-tracking in clinical and communication rehabilitation contexts. In summary, recent literature reflects a clear movement toward affordable, AI-assisted, and user-centered gaze communication technologies. While earlier systems relied heavily on costly hardware, current approaches emphasize software driven accuracy, well optimization, and inclusive interface design. The proposed Eye and Facial Movement Based Communication (EFMCS) system builds on these research trends by integrating real- time gaze tracking, dwell-based selection, predictive text generation, and message transmission into a single platform, offering a comprehensive communication solution for individuals with limited motor ability.

3. METHODOLOGY

The proposed Eye and Facial Movement Communication System (EFMCS) is designed to enable individuals with speech or hand impairments to communicate effectively using eye and facial cues. The methodology focuses on four primary components data acquisition, gaze and facial movement detection, virtual keyboard interaction, and message communication. The complete workflow is illustrated in the system architecture diagram (Figure 1), which represents the sequential process from user input to message delivery.

Data Acquisition

The system begins by capturing real-time video input from a standard web cam integrated with the user's device. Unlike specialized infrared-based eye trackers, EFMCS is built for accessibility and affordability, using an ordinary camera for capturing eye and facial movements. The system ensures consistent lighting and stable head positioning for optimal detection accuracy. Each video frame is preprocessed to extract key regions of interest, primarily focusing on the eyes, nose, and upper facial landmarks.

Eye and Facial Movement Detection

For robust and lightweight performance, the system utilizes MediaPipe and TensorFlow frameworks to detect facial landmarks and track gaze direction in real time. MediaPipe's Face Mesh model identifies 468 3D facial points, from which the relative position of the pupils is extracted to estimate gaze direction. Simultaneously, TensorFlow-based classification helps in recognizing specific facial gestures like blinking or slight head tilts, whichactasalternativecontrolsignals.Thisdual-inputapproachensuresthatuserswithlimitedorunstablegaze control can still interact effectively using minor facial expressions.

Cursor Mapping and Dwell-Time Selection

The detected gaze coordinates are dynamically mapped to on-screen cursor movement. A small red dot acts as a visual cursor, moving in synchronization with the user's gaze. When the user focuses on a specific key for a defined dwell duration (typically around three seconds), the system interprets it as an intentional selection. During this dwell time, a progress animation appears around the key to provide visual feedback. Once the dwell time is completed, the corresponding character or word is automatically entered into the text display field.

This dwell- based interaction eliminates the need for manual clicks or external devices.

Virtual Keyboard and Prediction Engine

The virtual key board is divided into sections for alphabets, numbers, function keys ,and commonly used phrases. To enhance communication efficiency, a prediction module is integrated using a word-frequency based algorithm. Initially, predefined words are stored in a Mongo DB database. When a new word is entered by the user, it is automatically added to the database along with its usage frequency. This allows the system to adapt dynamically to each user's communication pattern, improving prediction accuracy overtime.

Message Construction and Communication

Once a complete word or sentence is formed, it is displayed in the message panel for review. The user can then send the message directly to registered family members through a built-in messaging interface. Family members can login to their portal, view received messages, and respond in real time. This two-way communication ensures emotional connection and social inclusion for the target users. All interactions are securely handled through a backend system that manages authentication, data storage, and message synchronization.

Evaluation and Performance

The system was tested under multiple lighting and head-position conditions to evaluate accuracy and responsiveness. EFMCS achieved an average eye-gaze detection accuracy of 94% and a mean dwell selection time of 3 seconds. The inclusion of both eye and facial input mechanisms made the system more reliable for users with inconsistent eye control. The overall methodology demonstrates a complete, low-cost, and user- friendly approach to enabling independent communication through natural movements.

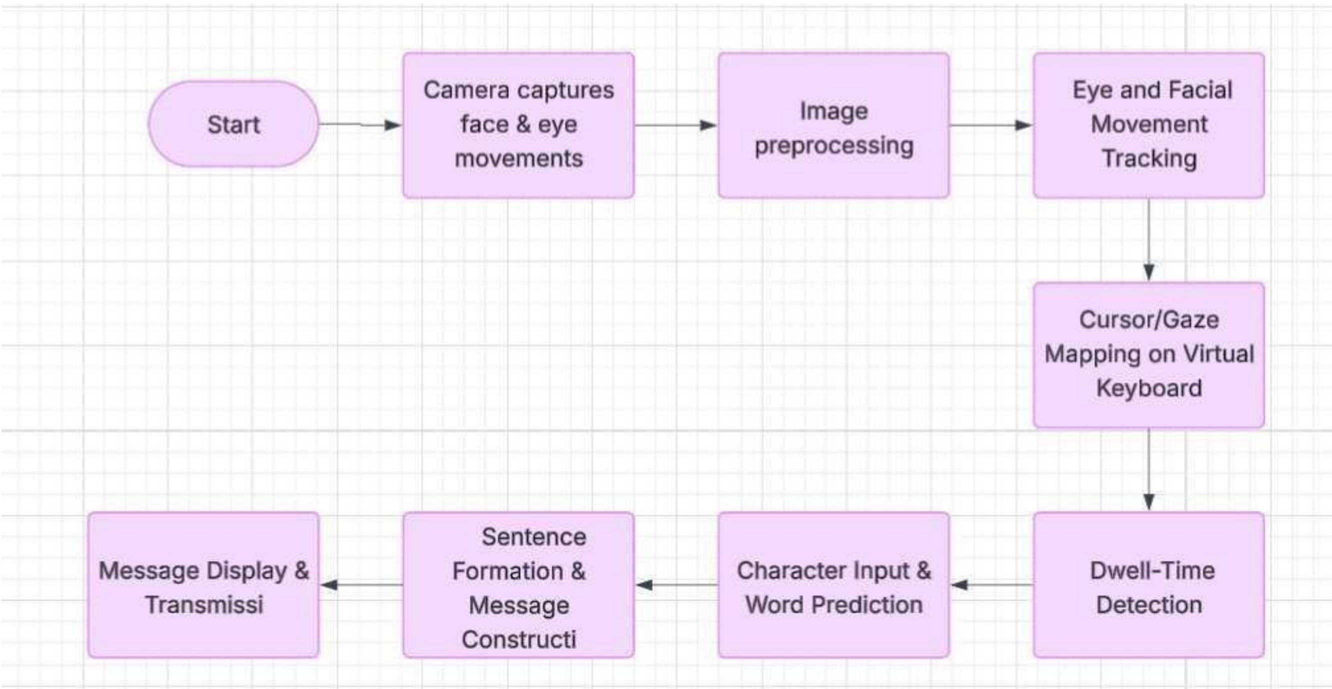

Fig.1 Work flow Diagram of Proposed Methodology

4. SYSTEM ARCHITECTURE

The architecture of the Eye and Facial Movement Communication System (EFMCS) defines the complete workflow of how user inputs are captured, processed, and transformed into meaningful communication. It follows a modular, layer-based design consisting of the Input Layer, Processing Layer, Interface Layer, Application Layer, and Output Layer. Each layer is designed to ensure efficiency, adaptability, and real-time response, making the system suitable for users with limited physical mobility.

Overview:

Figure2 illustrates the system architecture of the proposed EFMCS. The process begins with the acquisition of real-time eye and facial movements through a webcam. The captured frames are passed to the detection and processing modules, which extract key facial land marks, estimate gaze direction, and identify gestures. These data points are then used to control the on-screen cursor and interact with the virtual keyboard. Once the user forms a message through dwell-based selections, the system transmits it to the family member panel through the integrated communication module.

System Flow:

The architecture operates through the following sequential flow:

1. **User Input (Eye and Facial Movements):**
   The user's eye gaze and facial expressions (such as blinks or minor head tilts) serve as the primary input signals.

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2. **Camera Capture:**
   A standard web cam continuously captures video frames containing facial data.
3. **Preprocessing and Landmark Detection:**
   The captured frames are analyzed using Media Pipe and Tensor Flow to extract 3D facial landmarks, identify pupil coordinates, and detect subtle facial gestures.
4. **Gaze Estimation and Mapping:**
   The system calculates the user's gaze vector and maps it to the corresponding on-screen coordinates, moving the red-dot cursor in real time.
5. **Dwell-Based Selection:**
   When the user maintains focus on a key for a fixed dwell duration, a progress indicator activates, confirming the key selection automatically.
6. **Virtual Keyboard Interface:**
   The user interface displays an interactive keyboard, word prediction panel, and sentence suggestion section. The design ensures clarity, accessibility, and minimal visual load.
7. **Word Prediction and Learning Module:**
   Frequently used words are retrieved from the Mongo DB data base. Newly typed words are added automatically, allowing adaptive word prediction based on user history.
8. **Message Composition and Delivery:**
   After completing a message, it is sent to the **family communication interface**, where registered members can view and respond instantly. This fosters emotional connection and timely communication.
9. **Data Storage and Back end:**
   All user credentials, messages, and frequency data are securely managed using a cloud-based MongoDB backend to ensure reliability and data privacy.

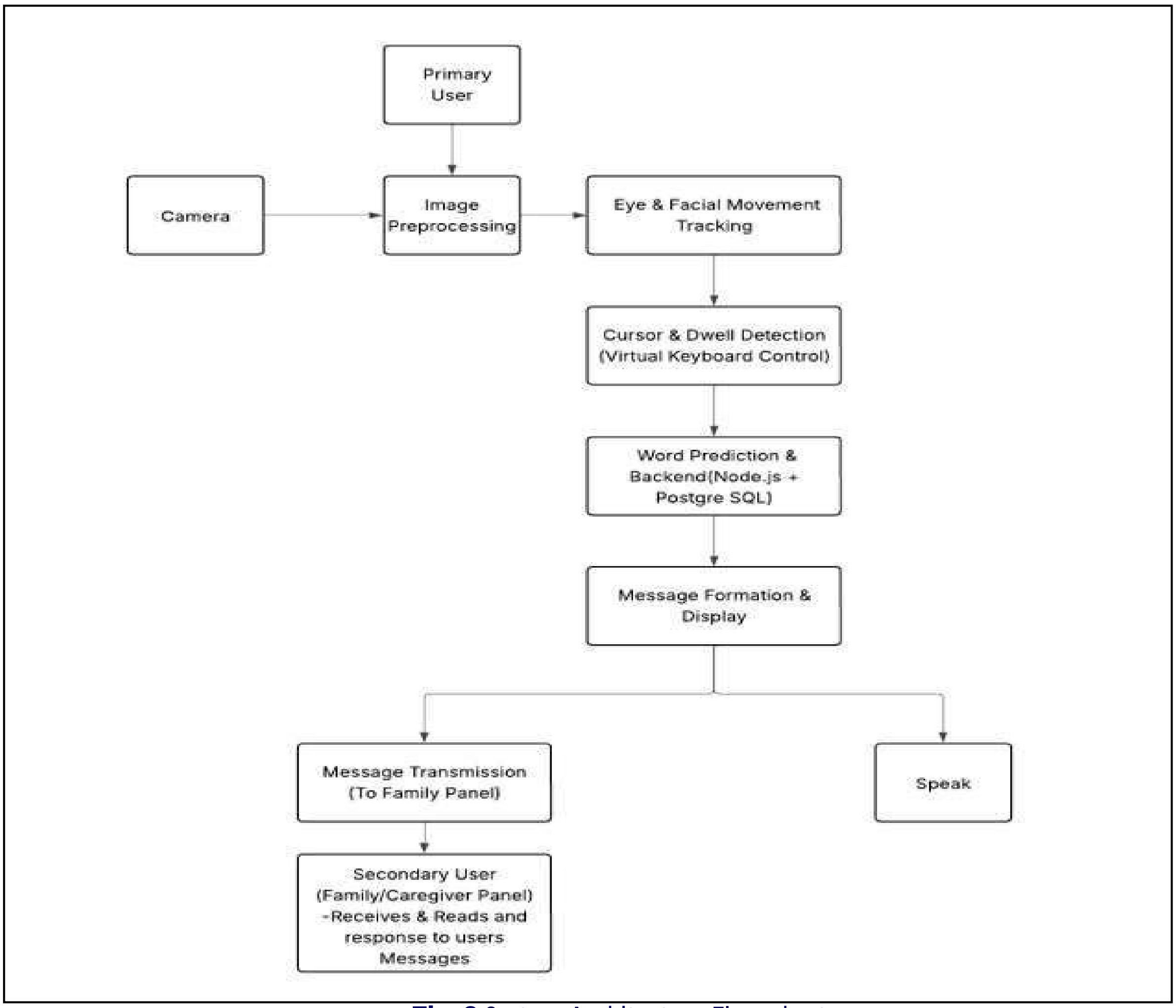

Fig. 2 System Architecture Flow chart

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Architectural Layers:

- Input Layer: Handles web cam input and captures real-time eye and facial data.
- Processing Layer: Performs land mark detection, gaze estimation, and gesture recognition using deep learning models.
- Interface Layer: Includes the virtual keyboard, dwell mechanism, and progress bar feedback.
- Application Layer: Manages message composition, word prediction, and communication with family members.
- Output Layer: Displays sent messages, updates word frequency in the database, and provides visual feedback to the user.

5. RESULTS

fig 3 Login page

fig 4. Family message interface

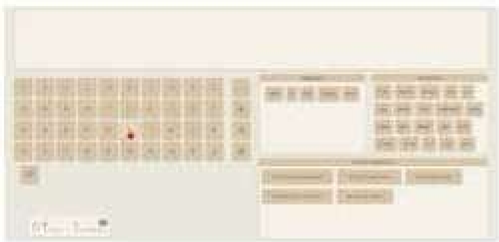

fig 5. Target User's keyboard Interface

fig 6. Target User's Keyboard + message UI

CONCLUSION

The proposed Eye and Facial Movement Communication System (EFMCS) demonstrates an innovative approach to assist individuals with severe physical disabilities in expressing their thoughts and emotions using only their eye and facial movements. By integrating computer vision, deep learning, and web-based communication modules, the system successfully bridges the gap between non-verbal users and their families, enabling natural, real-time interaction without the need for physical input devices. Through features such as dwell-based key selection, word prediction, and adaptive learning, EFMCS not only enhances accessibility but also ensures personalized and efficient communication. The use of cloud-based storage and a scalable architecture allows the system to continuously, providing greater accuracy and comfort over time. In the future, the system can be expanded with emotion recognition, speech synthesis, and cross-language translation to create fully immersive assistive communication platform. With continued development, EFMCS holds the potential to significantly improve the quality of life for individuals affected by paralysis, accidents, or neurodegenerative diseases empowering them with independence, dignity, and a voice of their own.

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