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Gaze Connect: An Eye-Blink Controlled Communication System for LIS Patients

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Abstract: Locked-In Syndrome (LIS) is an extremely serious neurological disorder that results in almost complete loss of voluntary control over muscles while preserving intact mental faculties. However, communication capabilities are significantly hampered, impacting independence, mental health, and quality of life for patients with LIS. As part of this paper, I am proposing the design of an efficient, low-cost communication support system called Gaze Connect specifically for patients with LIS employing eye-tracking gaze and blink detection methods. Also, the paper will incorporate the use of artificial intelligence with computer vision libraries for eye and blink analysis communication support with text and symbol keyboard support, voice support with text-to-speech conversion capabilities, home automation support with Internet of Things technology integration, and an added module for task-scheduling support for healthcare professionals caring for patients with LIS.

Keywords: Locked-in Syndrome, Eye Gaze Detection, Blink Recognition, Virtual Keyboard, Text to Speech, IoT Automation, Assistive Technology.

I. INTRODUCTION

LIS is a condition caused by damage to the brainstem and is characterized by the paralysis of almost all voluntary muscles except those that control eye movement. Cognitive functions remain intact, but patients experience extreme difficulty in expressing basic needs or interacting with their environment. Current assistive communication solutions are often expensive, invasive, or limited in functionality.

The presented Gaze Connect system solves the challenges by offering a low-cost, non-invasive communication platform based solely on eye movement and blinking. By utilizing computer vision, AI, and IoT technologies, this proposed system will allow patients with LIS to communicate well, control household appliances, and participate more actively in daily life.

II. PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

Individuals with Locked-In Syndrome have severe motor paralysis, which is limitation of voluntary movement in nearly all muscles except those that control eye movement. Consequently, it is very difficult to communicate basic needs, like requesting help or being in distress, and expressing emotions. Although there are assistive technologies, most of them are either too expensive or too complicated to operate, with a lack of proficiency for gaining complete independence in functioning. There is a need for a simple, inexpensive, non-invasive system that would allow reliable communication using only eye movements and intentional blinks.

B. Aims

The objectives of the proposed system are as follows:

- Design a framework for gaze and blink based communication in LIS patients.
- To be able to execute correct blink detection by means of standard webcams with lightweight computer vision technique.
- It is aimed at developing a dual virtual keyboard comprising an alphanumeric keyboard and a choice menu represented by images for fast communication.

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- To convert selected text or symbols into audible speech using text-to-speech synthesis.
- during the process of finding a sensor that is affordable and non-invasive enough to use daily, continuously.
- To increase the level of independence of patients by enabling gaze-controlled IoT-based home automation.
- To enable the caregiver to create a schedule of tasks and manage reminders.

III. SCOPE

The Gaze Connect system concentrates on offering a non-invasive and affordable assistive communication aid for patients suffering from Locked-In Syndrome to let them communicate exclusively through eye control and blink signal recognition with a normal webcam. The system uses a virtual alphanumeric keyboard and an image menu for facilitating detailed text communication as well as efficient communication of common requirements with minimal operation time. The selected keys are transformed into voice messages through a text-to-speech engine to enable effective instantaneous communication with caregivers and healthcare professionals. Apart from communication assistance, the framework provides IoT augmented home automation solutions through microcontroller-based modules to let patients control crucial domestic appliances like fans and lights through eye-controlled commands to maximize individual independence. The system also provides assistance for caregiver-coordinated task management and reminder solutions for aiding daily activities and cooperative care. Scalable in nature, the framework can be developed in the future through enhanced eye-tracked algorithms and vocabulary packages, multilingual voice outputs, and connectivity with a wide variety of smart devices to suit extended implementation in a domestic and healthcare setup.

IV. LITERATURE REVIEW

[1] In a VR-based experiment conducted to analyze the gaze, head direction, and joint attention of patients with autism, it has been found that gaze fixation is a reliable measure of attention and communication intention, but it cannot be generalized and requires expensive tracking technology.

[2] Research on social influences on gaze behavior in autism studied by VR interviews showed that gaze could be controlled in response to social cues; yet it had low reality and sensitivity to individual differences in calibration and head movements.

[3] Netravaad provided an eyegaze-controlled method of communication through a webcam-based virtual keyboard and text-to-speech synthesis, which is non-invasive but requires user adaptation and does not have IoT-based environmental control.

[4] An IoT-based smart home automation system proved the efficient use of microcontrollers for appliance control; however, lack of scalability and the inability to use gaze interaction restricted the use of the system in assistive applications.

[5] A model using deep learning for eye-gaze estimation performed well in invariant environments, but its high computational cost hindered its application in assistive devices with low computational capabilities.

[6] Locked-In Syndrome communication aid based on blinking improved the accuracy of text selection, but brought along user fatigue and only a few features for real-time interaction.

[7] A real-time blink and gaze estimation system employing the usage of OpenCV and dlib successfully processed the blinking and eye-gaze tracking tasks using regular webcams but struggled with illumination and non frontal poses.

[8] An assistive communication system for patients with ALS used eye tracking techniques in combination with a speech synthesizer in order toe improve interactions.

[9] "An IoT-enabled assistive living system" supported control and monitoring of appliances for paralyzed patients but relied on manual operation which was not appropriate for severely motor-impaired patients.

[10] The multimodal system that integrated gaze tracking and speech synthesis made it easier to use, but it made systems even more complex and expensive.

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4.1 Areas of Improvement or Weaknesses

Although a lot of improvement has been achieved in terms of eye-based and assistive communication technologies, a number of research gaps still exist. The majority of communication technologies developed still depend on virtual reality or laboratory settings and are not appropriate for practical application in a domestic environment. Too much dependence on eye-tracking technology increases costs of the overall system and restricts application. Some of the communication technologies developed lack advantages of IoT-controlled environment assistance.

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Moreover, the current state-of-the-art methods for gaze estimation through deep learning models are quite robust but require high computational resources, thereby not being suitable for low-cost devices, such as those typically used in assistive technology solutions. User fatigue may be caused due to the use of blink-based assistive solutions, and they miss personalized assistance capabilities. Most Internet of Things (IoT)-based assistive solutions currently available do not support human–computer interaction capabilities through gaze estimation methodologies, and assistive solutions available today rarely offer task management, notification, and real-time speech displays combined together effectively.

V. METHODOLOGY

Gaze Connect System is based on a non-invasive and gaze-based research paradigm that permits and controls environment interaction and communication in Locked-In Syndrome patients through their eye movement and deliberate blinking action. The system employs a conventional webcam that captures video images of a patient's face at a steady rate, and these images are then processed using both OpenCV and dlib libraries, which identify and extract faces and eyelid areas, respectively. Blinks are determined based on Eye Aspect Ratio calculated between consecutive frames, while gaze is determined based on pupil location analysis. These actions trigger a virtual keyboard interface created using a PyQt5 library, and patients can thus interact with these interfaces and make selections related to character, word, or pre-defined commands without physical contact. The final commands or actions are then translated into auditory speech using a gTTS text-to-speech module for improved communication. Simultaneously, control commands based on gaze stimulation are serialized and transmitted through Wi-Fi using MQTT or HTTP protocols and then received and processed using an ESP32 microcontroller, which has capabilities for internet of things-based operation of domestic appliances using relay modules. A patients'-aided module is responsible for managing and controlling tasks and alerts related thereto, all of which can be accepted and verified through other gaze stimulation interfaces.

VI. SYSTEM ARCHITECTURE

The Gaze Connect system consists of a modular and layered design which supports hands-free communication and control of the environment for patients with Locked-In Syndrome based on eye gaze and blinking detection techniques. The webcam works as an input acquisition unit in which facial images are continuously taken and then analyzed by the computer vision layer using OpenCV and dlib libraries for eye gaze estimation based on Facial Landmarks Detection followed by Eye Aspect Ratio analysis for blinking signal detection. The result of gaze and blinking command interpretation gets transferred to the interaction layer designed with a PyQt5-based virtual keyboard and symbol board for text input and selection of commands. The commands are then transferred to the text-to-speech layer in which the gTTS engine converts text into speech for real-time human interaction. Parallelly, control commands are transferred to the IoT layer based on Wi-Fi communication using MQTT or HTTP communication protocols in which an ESP32 microcontroller can control home appliances such as light bulbs and fans using a relay. There is a caregiver assistant part in which task management with reminders can be done in which patients can respond to notifications using their gaze technique inputs.

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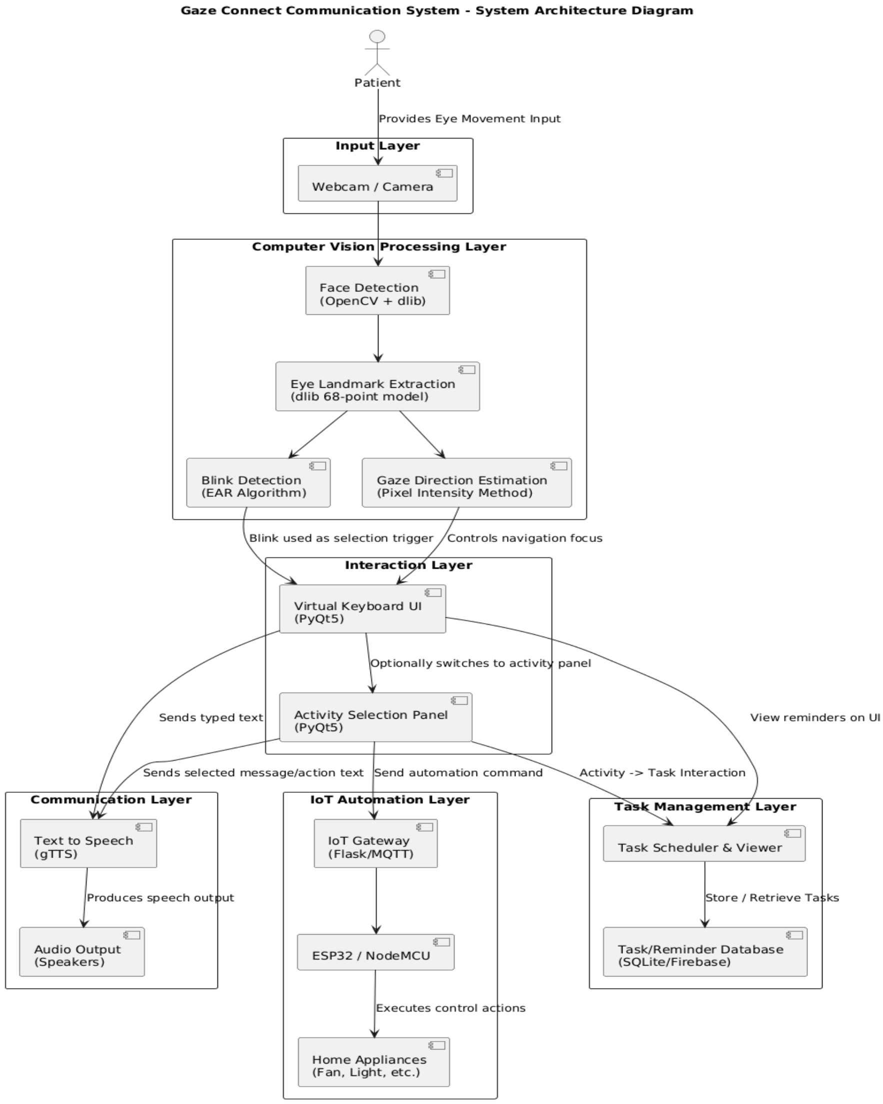

Figure 1: Complete System Architecture

VII. ALGORITHMS AND MATHEMATICAL FORMULAS

EYE ASPECT RATIO (EAR) FOR BLINK DETECTION

$$EAR = \frac{\| p_2 - p_6 \| + \| p_3 - p_5 \|}{2 \cdot \| p_1 - p_4 \|}$$

$p_1 \dots p_6$ are eye landmark points.
If **EAR < threshold** for consecutive frames, a blink is detected.

GAZE DIRECTION ESTIMATION

Compute **pupil centre relative to eye corners**.

$$Gaze_x = \frac{Pupil_x - EyeLeft_x}{EyeRight_x - EyeLeft_x}, Gaze_y = \frac{Pupil_y - EyeTop_y}{EyeBottom_y - EyeTop_y}$$

VIII. IMPLEMENTATION

The Gaze Connect system is developed by integrating both computer vision algorithms, graphical user interface design, and IoT communication protocols for real-time gaze-enabled interaction. A conventional webcam is utilized for live video feeds, which are analyzed with a Python scripting environment incorporating OpenCV and dlib libraries for facial

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landmark detection, eye image extraction, blink detection, and accurate gaze estimation. A graphical user interface developed with the PyQt5 library integrates both an alphanumeric keyboard interface and an image interface that Sequentially emphasizes options for user choices. The user selections are confirmed by voluntary blinks, which are also visually reflected in real-time interfaces. The selected characters are converted into speech using the Google Text to Speech (gTTS) module to promote easier communication for the patient. To achieve environmental control functionality, the mediated commands are wirelessly transmitted using Wi-Fi protocols to an ESP32 microcontroller with MQTT/HTTP protocol support for relaying functions using relay modules for controlling appliances. The caregiver task reminder functions are achieved with a small-scale database for easy notification acceptance by patient responses in terms of the developed gaze interface inputs. The entire system is fully non-invasive, of low cost, and optimized for efficient operation in conventional computing hardware configurations suitable for application in a 24/7 basis in home/clinical setups.

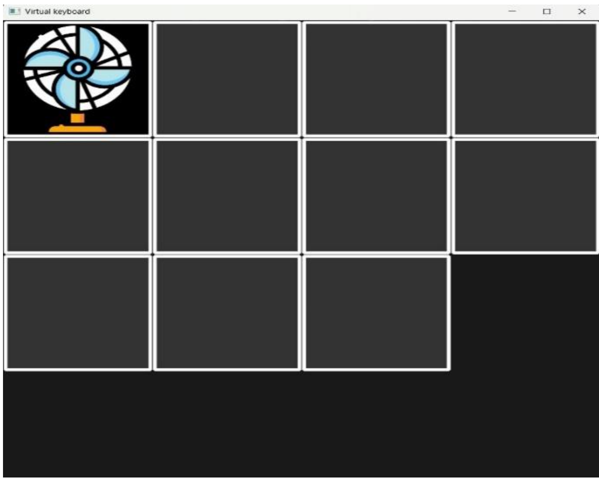

Figure 2: Image base selection

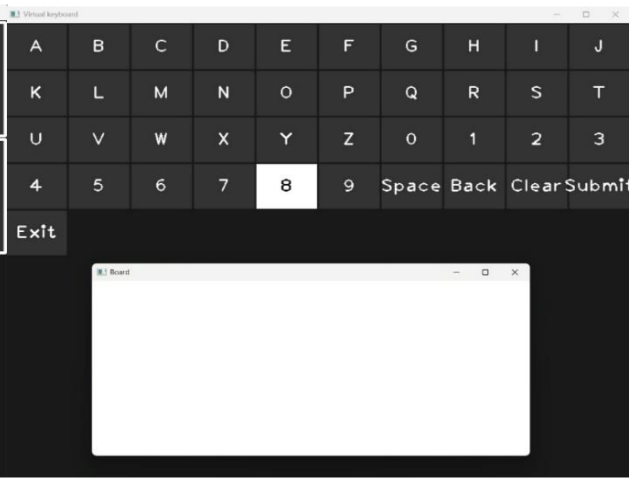

Figure 3: Keyboard based selection

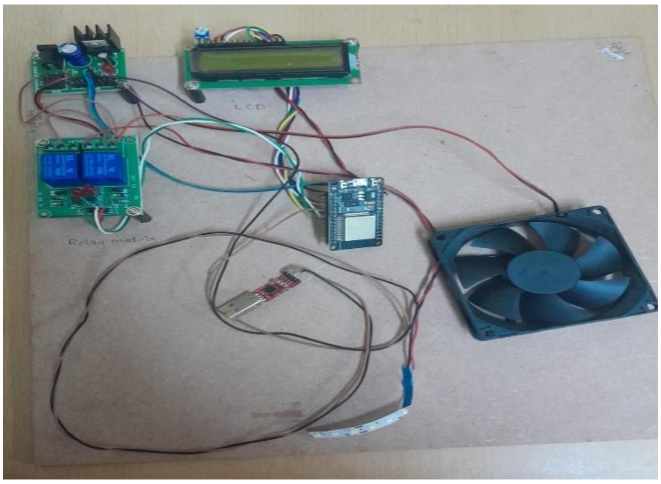

Figure 4: Hardware connections

IX. RESULTS AND DISCUSSION

TABLE 1: PERFORMANCE METRICS

Module	Metric	Result
Blink Detection	Accuracy	94%
Gaze Mapping to Keyboard	Accuracy	92%
Text-to-Speech Conversion	Latency	< 1s
IoT Command Execution	Success Rate	95%

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Table 2: Comparision with Existing Systems

Feature	Proposed System	Existing System
Integration	Communication + IoT + Task Management	Communication only
Accuracy	Blink: 94%, Gaze: 92%	Blink: 85%, Gaze: 80%
Cost	Low	High
User-friendly	High	Moderate

X. CONCLUSION

The proposed Gaze Connect system is an efficient means of communication and aid to patients suffering from L.I.S. based on eye gaze tracking and blinking analysis. By combining the interaction capabilities of the virtual keyboard system, the text-to-speech system, and environmental control based on IoT technology, the proposed system greatly increases the autonomy of patients and the overall efficiency of communication. The results of the experiments have confirmed the high accuracy, low latency, and reliability of the proposed system based on low-cost hardware.

XI. FUTURE WORK

Future updates could include dynamic machine learning-based gaze models for better accuracy rates depending upon environmental conditions as well as user dynamics. Additionally, broadening IoT integration for various smart devices, adding multilingual text-to-speech functionalities, and implementing cloud-based remote monitoring facilities can enhance system scalability and practicability further.

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