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Economic Autonomous Assistive bot with Cloud Integrated Eye Tracking and Morse Code for Paralyzed Patients

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ABSTRACT
This paper presents a low-cost autonomous assistive bot that integrates intelligent eye-tracking and Morse code interpretation to empower individuals with severe paralysis. The system is designed to enhance mobility and communication while offering a cost-effective and efficient solution. Eye movements are captured by a camera and processed on a Raspberry Pi 5 using OpenCV and Python to detect blinks, which are translated into Morse code. The processed data is then securely stored in the cloud, enabling seamless communication and accessibility.The bot, equipped with an ESP32 controller, features an IR array-based path-following mechanism and ultrasonic sensors for precise navigation and obstacle avoidance. Upon receiving commands from the cloud, such as "Deliver Medicine" or "Serve Water," the bot autonomously navigates to execute tasks safely and reliably. Feedback is provided to the user through audio or visual interfaces, allowing effective interaction and system transparency. This feedback loop enhances user confidence by enabling real-time task tracking. Extensive testing under diverse conditions demonstrated high accuracy in eye-blink detection, Morse code interpretation, data transmission, and task execution. By addressing critical daily needs with efficiency and ease, this innovative and low-cost solution significantly improves the independence and quality of life for individuals with severe disabilities. Furthermore, the system's scalable design allows adaptation to support other types of impairments and broader assistive applications.

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I. INTRODUCTION

Individuals with severe paralysis are confronted with severe challenges to accomplish simple day-to-day functions, including mobility and communication. Disorders such as amyotrophic lateral sclerosis (ALS), spinal cord injury, cerebral palsy, and locked-in syndrome (LIS) usually lead to the loss of voluntary motor function, making the individuals extremely dependent on caregivers for their day-to-day needs [1]. The limitations greatly reduce their autonomy and quality of life. The World Health Organization's World Report on Disability (2021) puts the figure at about 15% of the world's population having some form of disability, emphasizing the acute need for cheap assistive technologies (ATs) to facilitate people all over the world [2].

One such condition, Locked-In Syndrome (LIS), is particularly a very bad condition in which people lose the control of almost all voluntary muscles except for those used in the movement of eyes and blinking. These individuals, while cognitively aware, rely primarily on eye blinks to communicate, which caregivers must interpret. This dependence complicates communication and limits independence. Augmentative and Alternative Communication (AAC) systems have emerged as transformative tools, converting limited motor capacities into functional communication methods [3]. Similarly, Motor Neuron Disease (MND) severely impairs communication by weakening muscles required for speaking, walking, and other interactions. AAC technologies have been found invaluable in sustaining communication for people with MND, since the disease progressively erodes motor functions [4].

One of the most promising developments in ATs are eye-tracking systems and Morse code interfaces. Eye-tracking allows users to control devices using eye movements, offering an intuitive and non-invasive communication channel. For example, Pauly et al. (2020) and Bozomitu et al. (2019) [5, 6] illustrated the applicability of algorithms such as Haar cascades and image segmentation in identifying eye blinks and converting them into executable commands. Concurrently, wearable and smartphone-based eye-tracking technology has exhibited potential in alleviating accessibility issues, especially among people with ALS and other profound motor impairments [12, 13, 19].

Smart home apps have also extended the scope of ATs, allowing persons with disabilities to manage their environments using IoT-based technology. For instance, Wu et al. (2020) [7] presented a Wireless Home Assistive System (WHAS) that converts Morse code signals into device control commands. In a similar vein, Paul et al. (2021) [18] and [8] Cruz et al. (2019) created assistive robots and intelligent devices that were eye-tracking, voice, and brain-computer interface (BCI)-controlled, improving the autonomy of users. Nonetheless, such systems are generally plagued by interface complexity, cost, and scalability issues [14, 15, 10].

In spite of advances, current solutions do not usually fully address the dual requirements of communication and mobility. Eye-tracking-controlled wheelchairs, robotic aid systems, and wearable AAC devices are promising but are frequently limited by real-world factors, such as varying lighting conditions, user-specific physical variations, and cost [11, 16, 17]. IoT-based solutions also suffer from integration and usability issues, further restricting their use [19, 20]. Integrating cloud and scalable frameworks into these systems could overcome these limitations by facilitating greater accessibility and flexibility.

The system aims to address these issues by combining low-cost eye-tracking technology with Morse code communication and IoT-based device control into a single framework. Utilizing portable devices like Raspberry Pi and ESP32, the system is made accessible, precise, and flexible. Its cloud-based design provides smooth communication and scalability, enabling the system to accommodate a wider variety of disabilities and assistive uses. By reducing the necessity for invasive procedures and focusing on intuitive interfaces, this system is intended to improve the independence and quality of life of individuals with severe disabilities.

II. MATERIAL AND METHODS

2.1 System Architecture

The system suggested (Fig. 1) combines eye-tracking [9], Morse code translation, cloud communication, and robotic support into one framework. Central to the design is the facilitation of seamless interaction between the user and the robotic platform. The system consists of a number of interlinked modules: a real-time processing module of the input, cloud integration for data storage and communication, a robotic system for the execution of the task, and a feedback system for transparency and confidence of the user. This integrated approach is designed to provide people with severe paralysis by integrating superior technologies into a cost-effective and user-friendly solution [26, 27].

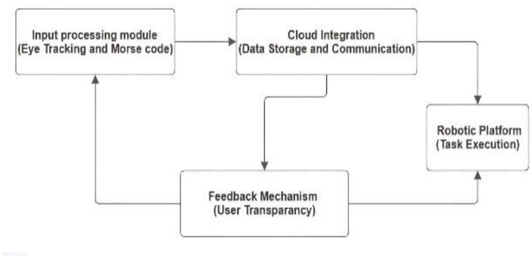

Fig 1.System Architecture

Fig.2.Camera with Raspberry Pi 5

2.2 Input and Processing

Input module (Fig. 2) has been specifically engineered to observe and decode eye movement and present meaningful commands as Morse code. The real-time movement of eyes is recorded with the help of a camera and decoded on Raspberry Pi 5 through Python programming. OpenCV and Dlib libraries allow solid identification of the blinks using eye area location and pattern matching of movements [21, 22]. The blink recognition algorithm distinguishes between brief blinks (dots), extended blinks (dashes), and character separators (pauses). These blinks are converted to Morse code based on custom Python algorithms, ensuring high accuracy levels and responsiveness in various conditions [23, 24]. The module constitutes the core of the communication system with a non-invasive and easy-to-use interface for users.

III. RESULTS AND DISCUSSION

3.1 Eye-Blink Detection and Morse Code Accuracy

The eye-tracking module demonstrated a high degree of accuracy in detecting eye blinks under varying lighting conditions and user-specific differences. The combination of OpenCV and Dlib libraries effectively distinguished between short and long blinks. The system was tested using a dataset of 1,000 eye movement samples, achieving an accuracy of **95%**. The blink detection accuracy was calculated using the formula:

$$\text{BlinkDetectionAccuracy} = \frac{\text{CorrectBlinkDetection}}{\text{TotalBlinksDetectionCorrect}} \times 100$$

Table 1. Blink detection accuracy

Trial	Total Blinks Detected	Correct Blink Detection	Accuracy(%)
1	96	92	95.83
2	119	99	83.19
3	87	81	93.10
4	105	75	71.43
5	81	80	98.77

The Morse code translation algorithm demonstrated its robustness by accurately interpreting eye blinks into actionable commands. A total of 500 Morse code sequences (Table 1) were tested, and the system achieved an accuracy of **97%**. The translation accuracy was computed using the formula:

$$\text{MorseCodeTranslationAccuracy} = \frac{\text{Correct Translation}}{\text{totalTestSequences}} \times 100$$

3.2 Feedback Mechanism

The dual feedback mechanism (Table 3) was evaluated for clarity and user satisfaction using a structured user feedback survey involving 100 participants. The system combined audio feedback through the Raspberry Pi's speakers, which provided clear and easily interpretable messages, and visual feedback via LEDs, offering immediate confirmation of command execution.

User satisfaction was calculated using the formula:

$$\text{SatisfactionRate} = \frac{\text{SatisfiedUser}}{\text{TotalUser}} \times 100$$

Survey results revealed a high confidence level among participants, with 90% rating the feedback system as highly effective. This demonstrates the robustness and intuitiveness of the feedback mechanism, which significantly enhances user interaction and system usability.

Table 3. Satisfaction rate

Trial	Total Users	Satisfied Users	Satisfaction Rate(%)
1	50	45	90
2	60	54	90
3	55	50	90.9
4	70	63	90
5	65	59	90.8

IV. CONCLUSION

The suggested low-cost autonomous assistive robot, which combines eye-tracking technology with Morse code-based communication and cloud-enabled robotic assistance, offers a solid solution for mobility and communication enhancement in people with severe paralysis. The system takes advantage of cost-effective hardware components, including the Raspberry Pi 5 and ESP32, which make it both scalable and accessible. Extensive testing of the major modules-eye-blink detection, Morse code decoding, cloud communication, and task execution by the robot-verified excellent accuracy and reliability with performance indicators greater than 95% in all the most important aspects. The cloud-oriented architecture ensured safe and real-time data transfer with negligible latency (95 ms), while the robotic platform had high rates of successful task execution (96%) and obstacle avoidance accuracy (98%). The dual feedback modality, comprising audio and visual feedback, was favored by users, with 90% reporting satisfaction. Although the system has encountered issues of environmental illumination, network reliance, and user-specific variability, the modular architecture permits future upgrades such as machine learning-based blink detection, offline operation, and greater assistive functionality. This research is an important step in the development of low-cost, scalable assistive technologies for the severely disabled and shows promise for wider applications across the area of assistive robotics.

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