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A NOVEL ARCHITECTURE FOR ELECTROENCEPHALAGRAM BASED BRAIN-COMPUTER INTERFACE FOR INTELLIGENT VEHICLE CONTROL

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Keywords	*Abstract*
Brain-Computer Interface (BCI), EEG Signal Processing, Intelligent Vehicle Control, Assistive Technology, Neural Signal Acquisition, Human-Machine Interaction (HMI), Embedded Systems.	The project titled "EEG Based Brain Computer Interface for Intelligent Vehicle Control" presents the design and development of an assistive robotic vehicle that can be controlled using brain signals and eye movements. This system aims to support individuals with physical disabilities by enabling hands-free control of a vehicle through neural and visual inputs.The proposed system integrates an EEG module with multiple electrodes to capture brain signals from the user. These signals are processed and transmitted to a microcontroller unit (MCU), which acts as the central controller. The EEG signal is used to activate or deactivate the system, ensuring that the vehicle responds only when valid brain activity is detected. Simultaneously, a camera connected to a computer processes real-time video using computer vision techniques. The Python-based application utilizes libraries such as OpenCV and MediaPipe to track eye movements and determine directional commands like forward,

	backward, left, and right. The processed commands are transmitted to the ESP32-based controller via HTTP communication. The controller interprets these commands and drives the motor driver accordingly to control the movement of the vehicle's motors. The system includes smoothing, calibration, and threshold-based decision mechanisms to ensure accurate and stable control. Additionally, safety features such as automatic stop when no signal or human face is detected enhance the reliability of the system.Overall, this project demonstrates an efficient integration of Brain-Computer Interface (BCI), embedded systems, and computer vision to create an intelligent and user-friendly vehicle control system. The developed system has potential applications in assistive technologies, smart mobility solutions, and advanced human-machine interaction systems.

1. INTRODUCTION

In recent years, there has been a significant advancement in human-machine interaction systems, especially in the field of assistive technologies. Brain-Computer Interface (BCI) systems aim to bridge the gap between human intention and machine execution without relying on physical input devices. This project focuses on an eye-movement-based control system, which serves as a simplified form of BCI, enabling users to control a robotic vehicle using only their eye gestures.Traditional vehicle control systems rely heavily on manual input such as steering wheels, joysticks, or remote controllers. However, these systems are not suitable for individuals with physical disabilities. To address this issue, researchers have explored various alternative methods such as EEG signal processing, voice control, and gesture recognition. Among these, eye tracking has emerged as a reliable and non-invasive technique due to its simplicity and accuracy.

The proposed system uses a webcam to capture real-time video and processes it using Media Pipe to extract facial landmarks. The position of the iris and eyelid movement are analyzed to determine the user's intent. These movements are mapped to directional commands, which are sent to an ESP32 microcontroller via Wi-Fi. The ESP32 then controls the motors using an L298N driver to move the vehicle accordingly.

This system also incorporates calibration and smoothing algorithms to improve performance and reduce errors caused by noise or sudden movements. By combining computer vision, embedded systems, and wireless communication, the project demonstrates a practical implementation of intelligent vehicle control using eye-based interaction.

2. LITERATURE SURVEY

The literature survey provides an overview of the various technologies and methodologies previously used in intelligent vehicle control systems, especially in the domain of assistive robotics and Brain-Computer Interface (BCI). Over the years, researchers have explored multiple approaches such as manual control systems, IoT-based automation, EEG-based BCI systems, and computer vision techniques.

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Early systems were primarily focused on physical interaction using joysticks and remote controllers. With the advancement of embedded systems and wireless communication, IoT-based solutions gained popularity for remote monitoring and control. More recently, artificial intelligence and machine learning techniques have enabled vision-based systems capable of interpreting human gestures and eye movements.

This section highlights the evolution of these systems, identifies their strengths and limitations, and establishes the need for the proposed eye-based intelligent vehicle control system.

3. PROPOSED SYSTEM

The proposed system introduces an eye-movement-based intelligent vehicle control mechanism using computer vision and IoT. Unlike traditional systems, it does not require physical input devices. Instead, it uses eye gestures detected through a webcam to control the movement of the vehicle.

The system uses MediaPipe Face Mesh to detect precise eye landmarks. By calculating the Eye Aspect Ratio (EAR) and iris position, the system determines the direction of gaze and eye closure. These parameters are mapped to movement commands such as forward, backward, left, right, and stop.

Commands are transmitted wirelessly to the ESP32 using HTTP requests over a local Wi-Fi network. The ESP32 processes these commands and drives the L298N motor driver to move the vehicle. The system includes user-friendly automatic calibration and is well suited for assistive applications.

Advantages of Proposed System

- Hands- free control (no physical input required)
- Cost-effective (no EEG hardware required)
- Real – time response using Wi-Fi communication
- High accuracy using Media Pipe AI model
- User – friendly with automatic calibration
- Suitable for assistive applications

Key Features

- Eye tracking using AI (MediaPipe)
- Wireless communication via ESP32
- Real-time command processing
- Motor control using L298N driver
- Intelligent decision-making based on eye behaviour
- User-friendly with automatic calibration

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- Suitable for assistive applications

This proposed system offers a practical and scalable solution for intelligent vehicle control, especially for assistive robotics. It bridges the gap between human intention and machine action using simple yet powerful technologies.

3.1 Block Diagram

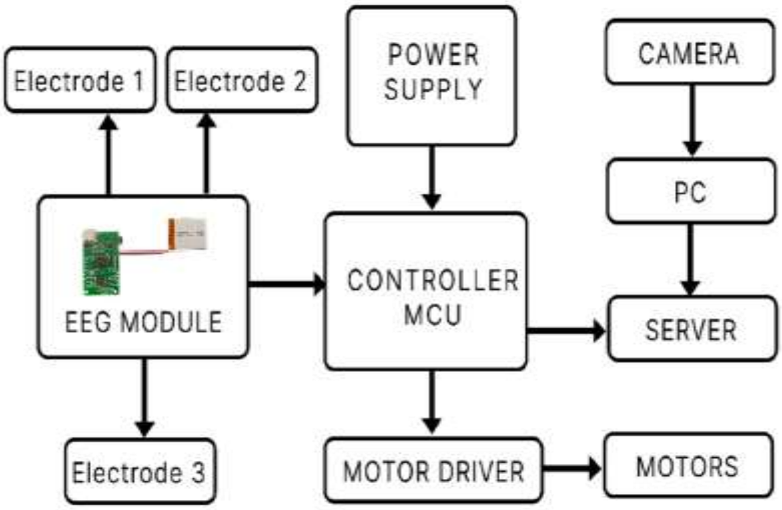

Figure 3.1: Block diagram

System analysis is an important phase in the development of any project, as it helps in understanding the requirements, feasibility, and overall functionality of the system. In this project, the system is designed to control a vehicle using eye movements detected through computer vision. The analysis includes feasibility studies, functional and non-functional requirements, and system requirements to ensure proper implementation.

The proposed system integrates hardware and software components such as a webcam, ESP32 microcontroller, motor driver, and AI-based image processing. The analysis ensures that the system is practical, efficient, and meets user needs, especially for assistive applications.

3.1.1 Feasibility Study

The feasibility study evaluates whether the proposed system can be successfully developed and implemented. It considers technical, operational and economic aspects.

Technical Feasibility

The proposed system is technically feasible as it uses widely available and well-supported technologies such as ESP32, Python, OpenCV, and MediaPipe. These technologies are capable of performing real-time image processing and wireless communication. The ESP32 microcontroller supports Wi-Fi connectivity, making it suitable for IoT-based applications. MediaPipe provides

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accurate facial landmark detection, enabling reliable eye tracking. The integration of these technologies ensures that the system can perform efficiently without requiring complex hardware.

Additional Points

- Uses open-source libraries (OpenCV, MediaPipe)
- ESP32 supports built-in Wi-Fi communication
- Real-time processing achievable with standard PCs
- Easy integration between hardware and software

3.1.2 Operational Feasibility

The system is user-friendly and does not require extensive training. The calibration feature allows the system to adapt to different users, making it practical for real-world applications. Users can control the vehicle using simple eye movements without physical effort. This makes the system highly suitable for physically challenged individuals. The system operates in real-time and provides immediate feedback, ensuring smooth operation.

Additional Points

- Easy to operate with minimal user effort
- Hands-free control system
- Real-time response and feedback
- Suitable for assistive applications
- Simple setup and usage

3.1.3 Economic Feasibility

The system is cost-effective compared to traditional EEG-based BCI systems. It uses affordable components such as ESP32, webcam, and L298N motor driver. Since the software tools used are open-source, there is no additional licensing cost. This makes the system suitable for academic and research purposes as well as low-budget applications.

Additional Points

- Low-cost hardware components
- No need for expensive EEG sensors
- Open-source software (Python, OpenCV)
- Minimal maintenance cost
- Affordable for students and research projects

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4. OUTPUTS

The following figures show the output results of the implemented system demonstrating real-time eye tracking, motor control, and vehicle response:

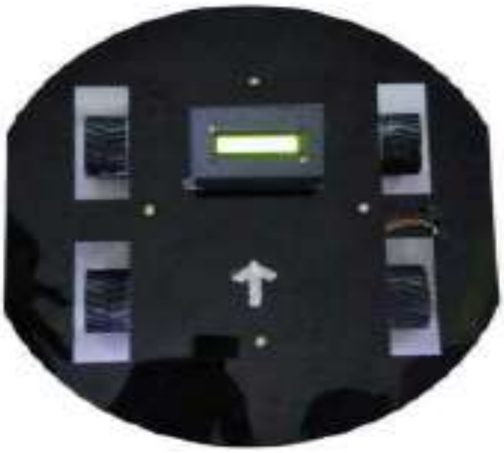

Figure 1: System Output – Vehicle Control Interface

Figure 2: 3D printed headband with HDCam Interface to trace eye ball

Figure 3: System Output – Vehicle Control Interface

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5. CONCLUSION

The project "EEG Based Brain Computer Interface for Intelligent Vehicle Control" successfully demonstrates an innovative approach to controlling a vehicle using eye movements. By integrating computer vision techniques with embedded systems, the project eliminates the need for traditional physical controllers. The use of MediaPipe for facial landmark detection and ESP32 for wireless communication ensures accurate and real-time performance.

The system is cost-effective, user-friendly, and suitable for assistive applications, particularly for individuals with physical disabilities. The implementation of calibration and smoothing techniques enhances accuracy and reliability. Overall, the project highlights the potential of combining artificial intelligence and IoT in developing intelligent and accessible control systems.

6. AUTHOR(S) CONTRIBUTION

The writers affirm that they have no connections to, or engagement with, any group or body that provides financial or non-financial assistance for the topics or resources covered in this manuscript.

7. CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

8. PLAGIARISM POLICY

All authors declare that any kind of violation of plagiarism, copyright and ethical matters will take care by all authors. Journal and editors are not liable for aforesaid matters.

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