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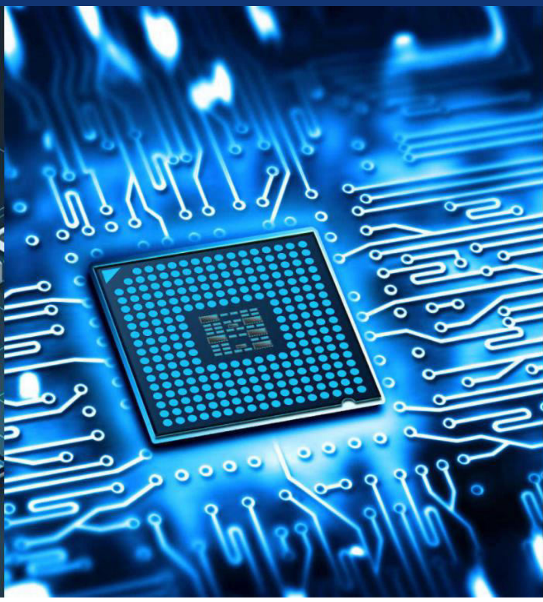


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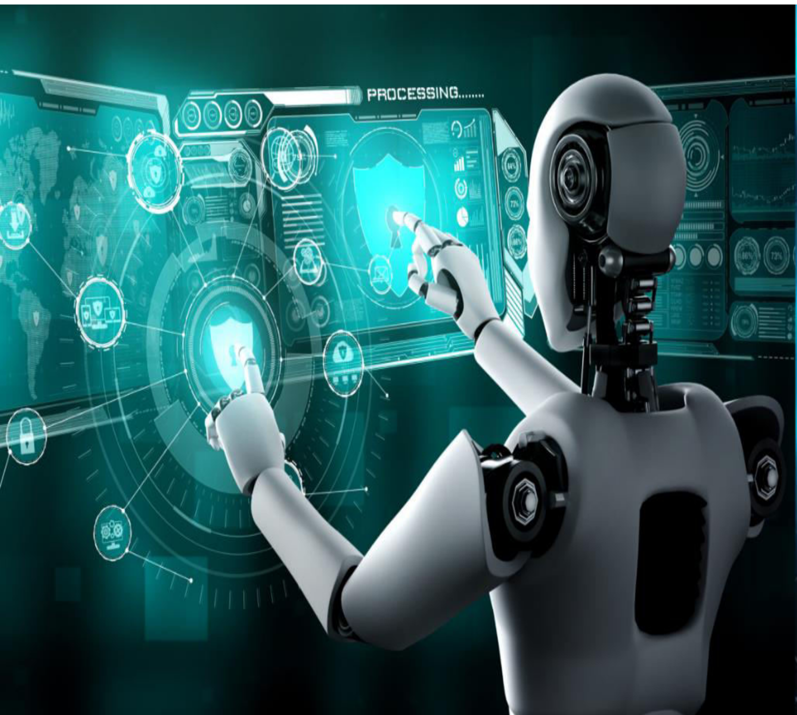

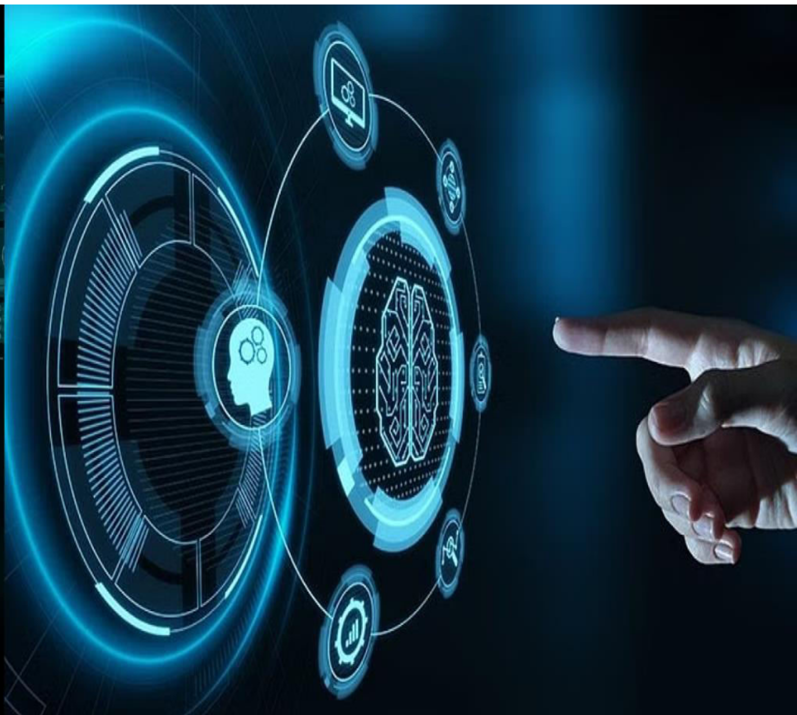

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IoT-Based EOG Wheelchair with Fall Prevention Using ESP32

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ABSTRACT: We report the development of a gaze-driven, IoT-enabled smart wheelchair that addresses the mobility and safety needs of people living with severe motor impairments such as quadriplegia, ALS, spinal cord injury, and locked-in syndrome, by combining eye-movement control with real-time caregiver alerting and onboard fall prevention. The control architecture centres on an ESP32 microcontroller that acquires eye-movement signals through a minimal three-electrode arrangement (right, left, and reference), cleaned and amplified by the X-pill Bio Amplifier before analogue-to-digital conversion. Lateral gaze controls turning, a deliberate single blink initiates forward motion, and a rapid triple-blink sequence commands the wheelchair to halt. Forward obstacle sensing is handled by an HC-SR04 ultrasonic module paired with a local buzzer for immediate audio feedback, while an MPU-6050 six-axis IMU watches for dangerous tilt angles and free-fall signatures that indicate a patient fall. Propulsion is delivered by a pair of 12 V, 60 RPM gear motors controlled through an L298N H-Bridge driver. On detection of either hazard, the ESP32 pushes an instant alert to the caregiver's smartphone via the Blynk cloud platform over the onboard Wi-Fi link. Bench evaluation on a scaled prototype demonstrated 93.75% command accuracy, complete obstacle and fall detection, and near-perfect alert delivery. Together, these capabilities form a low-cost, minimally invasive assistive device that gives severely paralysed individuals a realistic route to independent movement.

KEYWORDS: Electrooculography (EOG); ESP32; Wheelchair; Fall Prevention; IoT; Blynk; MPU-6050; Assistive Technology; X-pill Bio Amplifier; HC-SR04

I. INTRODUCTION

Spinal cord injury affects roughly 280 million people worldwide, and countless additional individuals live with degenerative neurological disorders — including ALS, muscular dystrophy, stroke sequelae, and locked-in syndrome — that strip away voluntary movement [1]. In the most severe cases, limb function is lost entirely, placing both manual and powered joystick wheelchairs completely out of reach for the patient. Round-the-clock caregiving — which costs an Indian family roughly ₹3,000–5,000 per month — imposes a heavy financial strain while also eroding the patient's sense of autonomy, dignity, and emotional health.

Among the bio-signal modalities explored for assistive interfaces, electrooculography (EOG) stands out because the extra-ocular muscles governing eye movement almost always remain functional regardless of the degree of bodily paralysis [2]. The operating principle rests on the stable corneo-retinal potential that arises from metabolic activity within the retinal pigment epithelium: the anterior corneal surface maintains a resting positive charge relative to the posterior retina, establishing a standing voltage of approximately 0.4–1.0 mV that rotates with the globe [3]. Peri-orbital electrodes placed around the eye detect these shifts as the gaze direction changes, and after differential amplification and band-pass filtering the resulting waveforms can be reliably decoded into directional commands [3][4].

Existing prototypes have verified the principle of EOG-driven wheelchairs across several hardware platforms including Raspberry Pi [5], Arduino Uno [6], and PIC [7], yet all share two notable shortcomings: the absence of any IoT reporting channel that could warn a distant caregiver of a fall or collision, and a reliance on five-electrode, dual-channel amplifier configurations that increase both setup time and wearer discomfort.

To close these gaps, this work introduces an ESP32-centred gaze-controlled wheelchair with five distinguishing features: a streamlined three-electrode EOG front-end using the X-pill Bio Amplifier; firmware-level classification of gaze direction and blink patterns into mobility commands; onboard fall recognition via the MPU-6050 IMU; proximity-based obstacle braking with the HC-SR04 sensor; and cloud-based emergency push notifications delivered to caregivers through the Blynk IoT platform over Wi-Fi. The outcome is a self-contained, budget-friendly assistive device designed specifically for patients whose eye movements represent the last remaining voluntary motor channel.

II. RELATED WORK

The foundational work by Barea et al. [8] showed that neural-network classification of EOG signals could guide wheelchair navigation, though their implementation depended on costly laboratory instrumentation that limits practical deployment. Chacko et al. [7] brought the cost down by building their system on a PIC16F877, achieving four-direction control with a simple proximity alarm, but their platform offered no connectivity beyond the local buzzer and no mechanism to detect patient falls.

Allwyn Gnanadas et al. [4] chose a Raspberry Pi host running Python classifiers and an AD620 instrumentation amplifier, confirming that commodity single-board computers can sustain the required signal processing workload. Mulam et al. [2] coupled AD Instruments acquisition hardware with MATLAB-based offline classification, achieving perfect accuracy over 80 trials across four participants — though the workflow was tethered to a desktop computing environment.

Nila et al. [5] recognised the importance of remote oversight by embedding a BLE iBeacon for caregiver location tracking alongside ultrasonic obstacle avoidance, pointing toward the IoT direction that the present work fully realises. Borkar et al. [6] enhanced user flexibility by fusing EOG with accelerometer-based head tilting, broadening applicability to patients who retain limited upper-limb movement.

Collectively, these studies establish a strong foundation, yet no prior design simultaneously delivers a minimal three-electrode interface, cloud-based emergency alerting, and hardware-level fall detection within a single low-cost microcontroller. The platform described here achieves all three.

III. SYSTEM DESIGN AND ARCHITECTURE

A. System Overview

Five interconnected subsystems form the complete architecture: the EOG front-end for signal capture and conditioning; the ESP32 processing core for waveform analysis and command dispatch; the H-Bridge motor drive for mobility; a dual-sensor safety layer for obstacle and fall detection; and the Blynk cloud link for remote caregiver alerting. Their interconnection is depicted in Figure 1.

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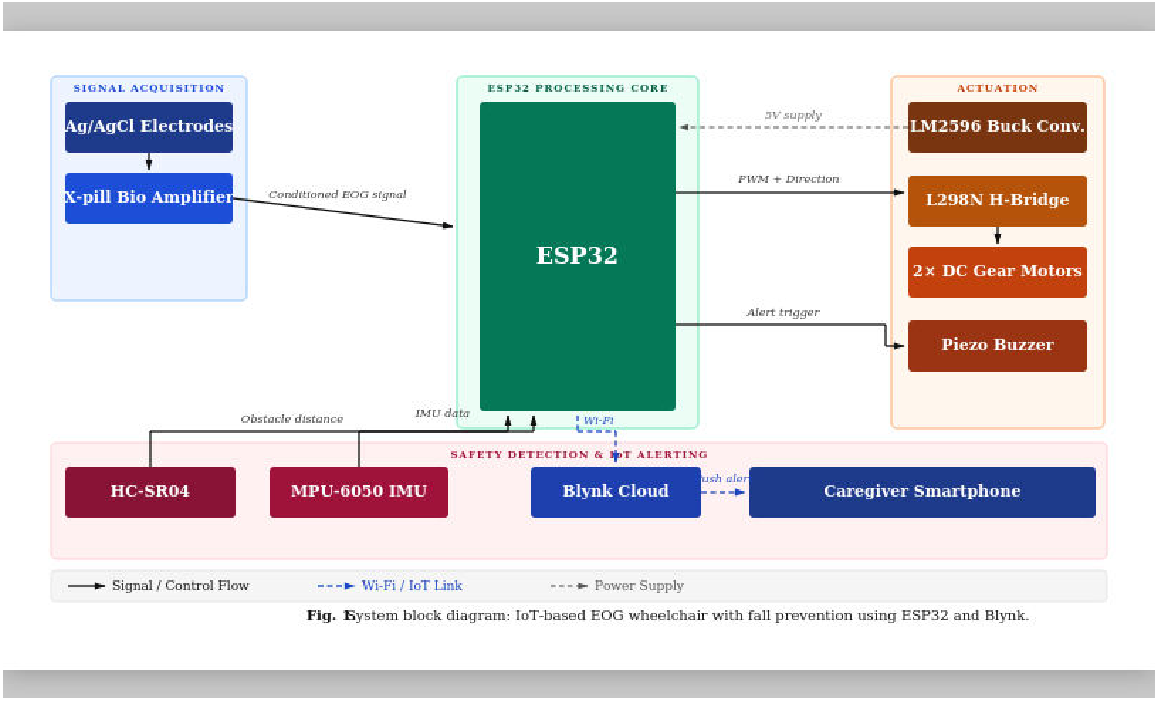

Fig.1. System Block Diagram

B. EOG Signal Acquisition — X-pill Bio Amplifier & 3 Electrodes

The corneoretinal standing potential — a steady voltage of roughly 0.4–1.0 mV maintained between the anterior (positive) cornea and the posterior (negative) retina — is the physical basis of EOG measurement [3]. Signal pickup employs only three Ag/AgCl skin electrodes: a sensing electrode at the lateral canthus of each eye and a common reference electrode secured to the mastoid process. Halving the electrode count relative to the conventional five-electrode layout reduces both skin preparation time and wearer fatigue without sacrificing the horizontal-axis resolution needed for wheelchair steering.

The X-pill Bio Amplifier applies high-gain differential instrumentation amplification to the sub-millivolt inter-electrode signal; an integrated band-pass network (0.1–30 Hz) suppresses slow electrode drift, mains interference, and overlapping EMG energy. The conditioned output drives the ESP32's 12-bit ADC at 200 Hz, providing twenty samples per blink for reliable event detection.

C. Eye Movement-to-Command Mapping

Command recognition is performed entirely in firmware: a lightweight adaptive peak-detector operates on the incoming 200 Hz sample stream. The mapping protocol is as follows: Look Right → Turn Right; Look Left → Turn Left; Single Blink (< 400 ms) → Move Forward; Triple Blink (three blinks within 2 s) → Stop. A 5-minute personalisation routine locks detection thresholds to each user's specific signal profile before first use.

D. Obstacle Detection — HC-SR04 Ultrasonic Sensor

A forward-facing HC-SR04 transducer provides continuous proximity surveillance. Distance is computed from the round-trip propagation time: Distance (cm) = (Time of Flight × 343) / 2. Should the computed range fall below the 30 cm safety threshold, the controller simultaneously cuts motor power, activates the piezo buzzer, and logs an obstacle event to the Blynk cloud dashboard.

E. Fall Detection — MPU-6050 IMU

The MPU-6050 fuses a ±16 g triaxial accelerometer with a ±2000°/s gyroscope and communicates via I2C. A free-fall condition is declared when the vector magnitude $|a| = \sqrt{(ax^2 + ay^2 + az^2)}$ stays below 0.4 g for a minimum of 80 ms,

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confirmed by a follow-on impact above 2.5 g. A separate tilt branch raises an alarm when pitch exceeds ±20° for over one second. Both paths trigger motor shutdown, buzzer activation, and a Blynk push alert.

F. Motor Drive — L298N and 12 V, 60 RPM DC Motors
Mobility is provided by two independently driven 12 V, 60 RPM gear motors, one per drive wheel. An L298N dual full-bridge IC translates the ESP32's logic-level direction bits and PWM duty-cycle signals into the high-current switched outputs each motor demands. Differential speed or opposite polarities produce turning without a mechanical differential. An LM2596 switching regulator provides a tightly regulated 5 V rail for all logic and sensor circuitry, isolating them from battery voltage sag.

G. IoT Notification — Blynk Platform
The on-chip 802.11 b/g/n radio connects the ESP32 to any nearby access point; a project-specific authentication token establishes a persistent session with the Blynk server. Three virtual data streams carry event data: V1 for obstacle triggers, V2 for fall triggers, and V3 for continuous motion-state reporting. No dedicated server or static IP address is required; any home or ward Wi-Fi router is sufficient.

IV. HARDWARE COMPONENTS AND SPECIFICATIONS

The system is built around an ESP32 dual-core microcontroller (240 MHz, 520 KB SRAM) with integrated Wi-Fi (802.11 b/g/n) and a 12-bit ADC [9]. As described in Section III-B, EOG signals are acquired via three Ag/AgCl electrodes, conditioned by the X-pill Bio Amplifier (0.1–30 Hz bandpass), and sampled at 200 Hz.

Propulsion is delivered by two 12 V, 60 RPM gear motors controlled through an L298N dual full-bridge H-Bridge driver. Obstacle detection is handled by a forward-facing HC-SR04 ultrasonic sensor with a usable range of 2–400 cm and 0.3 cm resolution. Fall and tilt detection is provided by an MPU-6050 six-axis IMU (±16 g accelerometer, ±2000°/s gyroscope) communicating over I2C. An LM2596 buck converter supplies a regulated 5 V rail for all logic and sensor circuitry, isolating them from battery voltage fluctuations.

Cloud alerting is implemented via the Blynk IoT platform, which leverages the ESP32's on-chip radio to push instant notifications to the caregiver's Android or iOS smartphone without requiring a dedicated server or static IP address. A detailed bill of materials including individual part numbers and full electrical ratings is provided in Appendix A.

V. METHODOLOGY AND SOFTWARE IMPLEMENTATION

A. Signal Processing Pipeline
Inside the ESP32, ADC samples enter a ten-point running-mean filter to suppress residual high-frequency noise. An adaptive thresholder places detection boundaries at $\pm 2\sigma$ of a 30-second baseline calibration, scaling naturally with each user's electrode contact quality. A finite-state machine suppresses spurious re-triggering by locking the detector until the signal returns to baseline.

B. Blink Detection Algorithm
Blink detection exploits the morphological signature of eyelid closure: an EOG transient exceeding 3σ in amplitude that resolves in under 400 ms, distinguishable from an upward saccade's shallower, longer-lasting deflection. For the emergency-stop gesture, a time-stamped buffer logs each qualifying blink; three entries within any rolling two-second window dispatch the stop command.

C. Fall Detection Logic
The inertial sensor is sampled at 50 Hz. The free-fall branch flags a condition when $|a|$ stays under 0.4 g for at least 80 ms, followed by impact confirmation above 2.5 g. The tilt branch flags an emergency when pitch exceeds ±20° from upright for over one second. Either branch outcome shuts the motors, fires the buzzer, and dispatches a Blynk notification.

D. Blynk IoT Integration
The Blynk client handles broker handshaking and maintains the session across brief connection gaps. Three named log-events cover the hazard scenarios: "obstacle", "fall_detected", and continuous writes to V3 for live motion-state

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streaming. Under typical indoor Wi-Fi conditions, the full notification path from sensor trigger to the caregiver's phone screen completes in roughly one to two seconds.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

Performance evaluation was conducted in a controlled indoor environment using a scaled prototype chassis (approximately 30 × 25 cm). One healthy adult participant wore the three-electrode EOG harness and executed a predefined battery of commands. Table 1 consolidates all performance results — directional control and safety system detection — in a single overview.

TABLE 1. SYSTEM PERFORMANCE RESULTS

Command	Trials	Correct	Accuracy	Avg. Latency
Look Right → Turn Right	20	19	95%	210 ms
Look Left → Turn Left	20	19	95%	215 ms
Single Blink → Forward	20	18	90%	290 ms
Triple Blink → Stop	20	19	95%	340 ms
Overall	**80**	**75**	**93.75%**	**264 ms**

TABLE 2. SAFETY SYSTEM PERFORMANCE

Test Scenario	Trials	Detected	Detection Rate	Notes
Simulated Forward Fall	10	10	100%	—
Sideways Tilt > 20°	10	9	90%	1 miss: manual correction
Obstacle at < 30 cm	15	15	100%	—
Blynk Notification Delivered	35	34	97.1%	1 miss: Wi-Fi drop

The 90% accuracy on forward-motion commands is attributable to spontaneous reflexive blinks coinciding with head movement. Fusing the EOG blink detector with an orbicularis oculi EMG channel, or applying a higher detection threshold during active head rotation detected by the gyroscope, should substantially reduce this specific error mode. The 95% success rate on triple-blink stop commands validates the design decision to require three time-constrained events, as the probability of three involuntary blinks clustering within any two-second window is low enough to make false emergency stops rare.

The single undetected lateral tilt occurred because the chassis was manually corrected within the one-second dwell-time guard. The sole Blynk notification failure was a transient Wi-Fi association loss that lasted approximately 3 seconds before the ESP32 automatically reconnected.

Table 3 places the proposed system in the context of prior EOG wheelchair platforms.

TABLE 3. COMPARISON WITH RELATED EOG WHEELCHAIR SYSTEMS

System	Platform	Electrodes	Accuracy	IoT	Fall Det.	Obstacle
Chacko et al. [7]	PIC16F877	5	~90%	No	No	Yes
Allwyn et al. [4]	Raspberry Pi	5	~92%	No	No	No

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Mulam et al. [2]	Arduino	5	100%	No	No	Yes
Nila et al. [5]	Arduino	2	N/A	BLE only	No	Yes
Proposed System	**ESP32**	**3**	**93.75%**	**Yes (Wi-Fi)**	**Yes**	**Yes**

Across all surveyed systems in Table 3, only the present design simultaneously offers cloud-based emergency alerting, integrated fall sensing, and a three-electrode EOG interface. Consolidating Wi-Fi, Bluetooth, a 240 MHz dual-core CPU, and a 12-bit ADC into a single ESP32 die removes the radio add-on boards that inflate the bill of materials in Arduino-centric designs.

VII. CONCLUSION AND FUTURE WORK

This work has presented a complete end-to-end gaze-driven wheelchair platform that unifies bio-signal control, proximity safety, fall detection, and cloud connectivity within the compact, low-cost ESP32 ecosystem. Prototype evaluation returned an overall gaze-command accuracy of 93.75%, a mean response latency of 264 ms, perfect obstacle braking performance, and a 97.1% cloud alert delivery rate. The minimal three-electrode configuration meaningfully reduces the burden of donning the device, and the Blynk cloud layer finally closes the caregiver awareness gap that has persisted across virtually all prior EOG wheelchair prototypes.

The development roadmap includes scaling the platform to a full-sized wheelchair frame with appropriate high-torque drive motors, appending GPS-based outdoor tracking, providing spoken feedback to the user, training personalised machine-learning classifiers to handle inter-subject variability in EOG morphology, and ultimately conducting ethics-approved clinical trials with motor-impaired participants.

VIII. ACKNOWLEDGMENT

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