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Development and design approach of an sEMG-based Eye movement control system for paralyzed individuals

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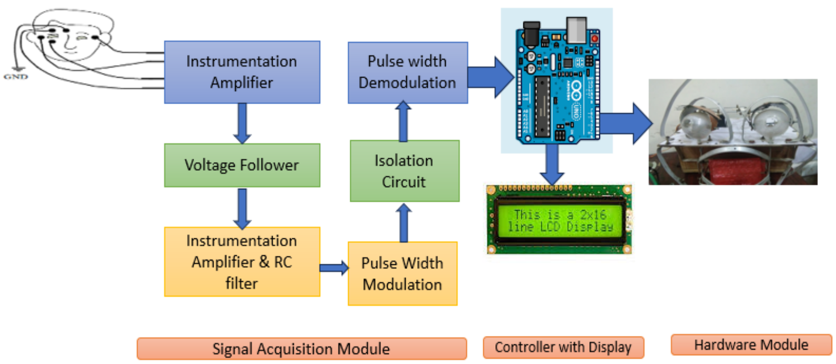
Article

ABSTRACT

A novel surface electromyography (sEMG) system has been innovatively designed for individuals with paralysis. This system utilizes EMG technology to detect and interpret muscle signals, translating them into functional control and communication. The process involves signal optimization through a pre-amplifier, noise reduction via an RC filter, and digital conversion using an analogue-to-digital converter (ADC). A central microcontroller employs programming to map EMG patterns to actions, creating a direct user-system interface. The precise manipulation of the hardware module, perfectly aligned with the user's visual objectives, is the result of this complex integration. The suggested method basically creates a sophisticated interface that enables users to intuitively and successfully operate the hardware module through their eye motions, opening up new opportunities for improved interaction and communication. Real-time analysis and command execution enhance user experience, with a user-friendly display providing visual feedback for executed actions. This innovation enhances their quality of life, independence, and social engagement, bridging the gap between paralysis and active participation. Additionally, it has broader implications for assistive technology and neuroengineering, inspiring further advancements in disability support and rehabilitation. The system's comfort-focused design incorporates fail-safe mechanisms, and its potential applications span communication, environmental control, and artistic expression. A streamlined calibration process enhances user autonomy, and our collaborative approach ensures alignment with clinical needs and daily life requirements.



Keywords: EMG, Eye Movement, facial paralysis, biomedical signal, microcontroller.

INTRODUCTION

The monitoring and analysis of patient physiological data is crucial for the evaluation of rehabilitation effectiveness[1,2] and management of auxiliary devices. These data typically encompass physical and psychological components, including intention and muscle force details. Various sensors, like electromechanical ones (accelerometers,[3,4] gyroscopes,[5,6] force sensors[7,8]) and biosensors (EMG,[9,10] MEG, EEG), are employed to capture these aspects. Electromechanical sensors excel in tracking physical information. For example, flex and force sensors monitor the finger bending and grasp force, respectively, to control the robotic fingers in different tasks.[11] Biosensors, particularly EMG, offer unique advantages in translating bioelectric signals to interpretable voltage amplitudes, serving as a link to human intention in rehabilitation.[12,13] Among EEG, MEG, and EMG, EMG stands out due to its higher Signal-to-Noise Ratio (SNR) and

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robustness, making it a preferred choice for intention detection.[14,15]

SNR=Signal Power/Noise ……………………. (1)

While EMG-based pattern recognition (EMG PR) was initially hindered by computational costs, recent advancements in electronics and technology have popularized its applications in disease diagnosis, prosthesis control, and more.[16,17] EMG PR's higher accuracy and information depth enhance its utility. However, interpreting EMG signals for fine motions presents challenges, necessitating strategies such as multisensory fusion.[18]

Fused_Signal=α· EMG_Signal + β · Environmental_Data … (2)

To address this, emerging EMG-centered multisensory technologies integrate environmental data with EMG signals for robust analysis.[19] Applications include accurate neuromuscular disease diagnosis[19], evaluating rehabilitation progress[20], and enhancing assistive devices like intelligent prostheses and exoskeletons[21,22] for improved user experience and security. Multisensory EMG-centred technologies address complex scenarios by integrating environmental information, improving neuromuscular disease diagnosis, rehabilitation assessment[19,20], and assistive devices such as intelligent prostheses and exoskeletons.[21,22] These applications improve patient outcomes, reduce therapy burden, and ensure user comfort and security. Existing systems often suffer from slow processing speeds and overly complex designs, which renders them unsuitable for real-time use.[23] Furthermore, these systems frequently exhibit a lack of sufficient subject samples and comprehensive surveys. Previous approaches to addressing eyelid paralysis have shown 70-80% accuracy; however, they are heavily depend on limited data and invasive techniques such as painful electrode placement and stimulation. Unfortunately, these systems can only provide temporary corneal protection.

1.1 Novelty aspects:

Multi-Dimensional Control: Introducing a groundbreaking approach, our system allows not only basic left-right and up-down eye movements but also incorporates novel programming language to interpret complex combinations of eye muscle signals [24], enabling multi-dimensional control and more nuanced interactions for paralyzed individuals.

Adaptive Neural Mapping: Our system pioneers the integration of adaptive neural mapping, a cutting-edge technique that dynamically adjusts the mapping between sEMG signals and intended commands, resulting in improved accuracy over time as the user's neural responses evolve.[25,26]

Real-time Fatigue Detection: Addressing a key challenge, our approach integrates real-time fatigue detection mechanisms that monitor changes in muscle activity patterns [27], allowing the system to proactively adjust sensitivity levels and maintain reliable control even during extended usage sessions.

Expressive Communication: Taking innovation further, our design includes an innovative feature for expressive communication, allowing users to control a wide range of facial expressions through precise sEMG[28] -based commands, enhancing social interactions and emotional expression.

Intuitive calibration: Revolutionising the setup process, our system introduces an intuitive calibration procedure to rapidly establish personalised user profiles, minimizing initial setup time, and maximizing user convenience.

Cross-Device Compatibility: Unveiling a new level of accessibility, our approach prioritises cross-device compatibility, enabling seamless integration with a diverse array of assistive devices, smart home systems, and personal electronics, expanding the scope of control for paralysed individuals.

Long-Term Adaptation: Recognising the dynamic nature of user needs, our system implements a long-term adaptation mechanism that continuously learns from the user's behaviour, allowing it to adapt to changes in muscle responses, ambient conditions, and control preferences over extended periods.

Ethical and inclusive design: Setting new standards for ethical design, our approach prioritises inclusivity by involving paralysed individuals, caregivers, and medical professionals in every stage of development, ensuring that the final product is not only technologically advanced, but also genuinely beneficial and empowering.[29]

Table 1. Comparisons of EMG Detection Methods for Eye Muscle with Various Parameters

EMG Method	Electrode Placement	Signal Quality	Advantages	Disadvantages	Applications
Surface EMG	Over eye muscles	Good	Non-invasive, easy to set up, suitable for a variety of muscles.	Lower signal quality compared to intramuscular methods.	Prosthetic control, assistive devices, communication systems.
Intramuscular EMG	Within eye muscles	Excellent	High signal quality, accurate and selective muscle activation	Invasive procedure, risk of infection, limited number of muscles.	Advanced prosthetics, research, precise control tasks.
Wireless EMG	Over eye muscles	Good	Non-invasive, allows mobility, real-time data.	Signal quality might be affected by wireless transmission, limited number of electrodes.	Wearable devices, remote monitoring, assistive technology

SYSTEM DEVELOPMENT

The proposed system shown in figure 1, incorporates a pair of EMG electrode sensors, each strategically interfaced with an Arduino Uno featuring the ATMEGA 328P microcontroller. The real-time signal acquisition process is efficiently visualised and presented through an integrated LCD display. To facilitate seamless selection between the two EMG sensors, a user-friendly keypad is seamlessly integrated into the design. This keypad empowers users to make a choice by initiating the activation of the corresponding EMG sensor. Once activated, the selected EMG sensor captures and interprets the nuanced electrical signals generated by the user's muscle movements.

In response to the detected EMG signals, a precisely controlled servomotor is set into motion. This servomotor, intricately linked to the hardware module, is uniquely positioned adjacent to the eye. As the user's eye movement ensues, the servomotor's calibrated responsiveness comes into play, orchestrating synchronized actions that mirror the detected eye motions. Consequently, this innovative hardware-servo synergy translates the user's intended eye movements into tangible and accurate mechanical responses.

The overarching result is a harmonious interplay between the user's voluntary muscle activity, the EMG sensors[30], the Arduino Uno's processing capabilities, and the dynamic functionality of the servomotor. This intricate fusion culminates in the precise manipulation of the hardware module, seamlessly aligning with the user's visual intentions. In essence, the proposed system establishes a sophisticated interface that empowers individuals to control the hardware module intuitively and effectively through their eye movements, bringing new possibilities for enhanced interaction and communication.

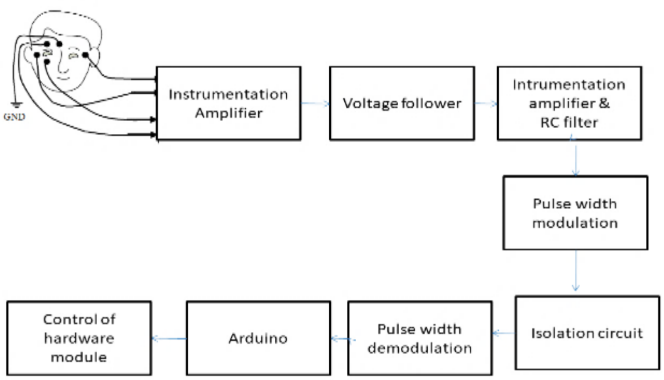

Figure 1. Block diagram of the proposed system

2.1 Description of block diagram

a) Signal Acquisition Module: In an EMG-based system, the Signal Acquisition Module is a critical component, responsible for the precise amplification of weak muscle-generated electrical signals. This task is accomplished primarily through the Instrumentation Amplifier, which uses the gain formula G=1+2Rf/Rg. This amplifier boasts a high common-mode rejection ratio, low noise, and high input impedance, ensuring accurate acquisition of signals. Following this, a voltage follower steps in as a buffer, preserving signal integrity while isolating the sensitive output. An IC filter is then introduced to further refine the signal, effectively attenuating noise and unwanted frequency components. Its characteristics, including the cutoff frequency (fc) and filter order (n), are crucial in this process, enhancing the quality of the acquired data.

The subsequent stages involve the implementation of pulse width modulation (PWM) to enable the digital representation of the analogue EMG signal. Here, the duty cycle (DD) determines the nature of this representation, computed by D=Ton/Tperiod×100%. Pulse width de-dulation follows, meticulously reconstructing the original signal from digital data. Centralising the system is an Arduino board equipped with powerful algorithms for real-time analysis. This microcontroller interacts with components such as LCD displays and servomotors[31], translating muscle activity into tangible responses. This integration exemplifies precision, adaptability, and efficient signal management, crucial attributes in empowering people with enhanced motor control and communication capabilities.

b) **Display on LCD:** Signal acquisition will be prominently showcased on the LCD screen in direct response to the user's key press, where a dedicated keypad has been thoughtfully integrated. This user-friendly keypad allows users to effortlessly select any desired EMG signal for display. Upon pressing the corresponding key, the intricate interplay of components orchestrates the seamless presentation of acquired signals on the LCD, enhancing the user's interactive experience and providing real-time insights into muscle activity.

c) **Control of hardware module:** Beyond signal display, the system allows users to control hardware through eye movements, revolutionising communication for individuals with paralysis. As eyes shift, the hardware module responds, translating movements into actions, showcasing innovation, and enhancing interaction. This transformative synergy, uniting human intent, EMG signals, and hardware control, promises improved quality of life through seamless signal acquisition, display, and hands-free manipulation.

2.2 Working Principle

Complete flowchart of proposed sEMG-based eye movement control system for paralyzed individuals is shown in figure 2.

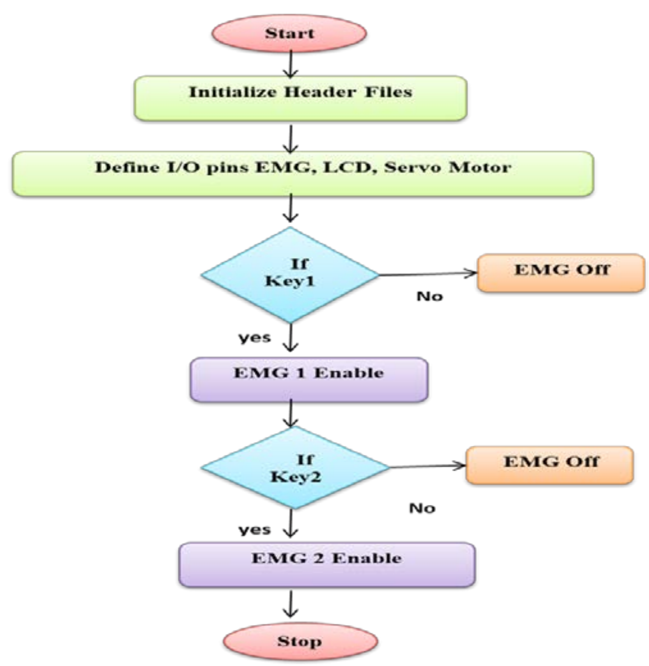

Figure 2: Working Flowchart of system

- **Initialize Header Files**: Start by initializing the necessary header files for the microcontroller.
- **Define Input/Output Pins**: Set up the input and output pins for the various components. Define pins for the EMG sensor, LCD display, and servomotor to establish communication.
- **Initialise keypad:** Prepare the keypad for user input, allowing interaction with the system.
- **Wait for key presses:** Enter a state where the program waits for a key press from the keypad.
- **Check Keypad Input**:
  - o If Key 1 is pressed:
    - ▪ Display "EMG 1 Enable" on the LCD screen to indicate the activation of the first EMG sensor.
    - ▪ Transition to the EMG 1 processing loop.
  - o If Key 2 is pressed:
    - ▪ Display "EMG 2 Enable" on the LCD screen to indicate the activation of the second EMG sensor.
    - ▪ Transition to the EMG 2 processing loop.
- **EMG 1 Processing Loop**:
  - o Continuously capture and interpret EMG signals related to left and right eye movements.
  - o Calculate the positions of the servo motor corresponding to the detected eye movement.
  - o Update the servomotor position based on the interpreted signals.
- **EMG 2 Processing Loop**:
  - o Continuously capture and interpret EMG signals for up and down eye movements.
  - o Calculate the positions of the servo motor corresponding to the detected eye movement.
  - o Update the servomotor position based on the interpreted signals.
- **Return to Keypad Input**: After each processing loop iteration (Step 6 and 7), return to the state where the program waits for keypad input.
- **End of Program**: Conclude the program's execution.

Actual hardware module of proposed system is shown in figure 3.

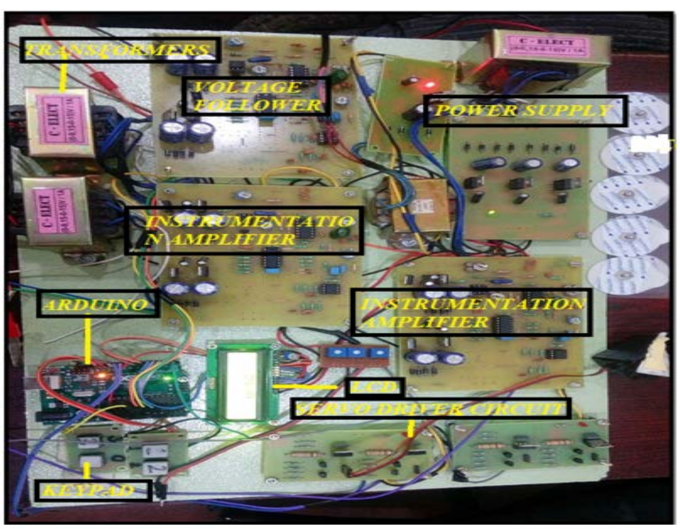

Figure 3. Pictorial view of the overall system

EXPERIMENTAL RESULTS

In this experiment, users are asked to perform four types of saccade movements (up, down, left, right). Table 2 shows the classification accuracy of session 1, Figure 4 shows its graphical view and figure 5 shows the actual experimental results for paralysed individuals with proposed system. In session 1, the best accuracy achieved was approximately 98% for subjects S2, S3 and S5. The accuracies of all subjects exceed 90%. In terms of movement-type accuracy, the best accuracy occurs when the eye movement involves looking left. However, the accuracy when looking to the right is below 90%.

Table 2. Classification accuracy of session 1 for different subjects

Movement/ ⇩ Body Surface ⇨	S1	S2	S3	S4	S5	S6
Up	89%	87%	92%	76%	88%	96%
Down	90%	68%	79%	62%	98%	92%
Left	65%	77%	87%	98%	99%	76%
Right	90%	98%	86%	78%	96%	88%

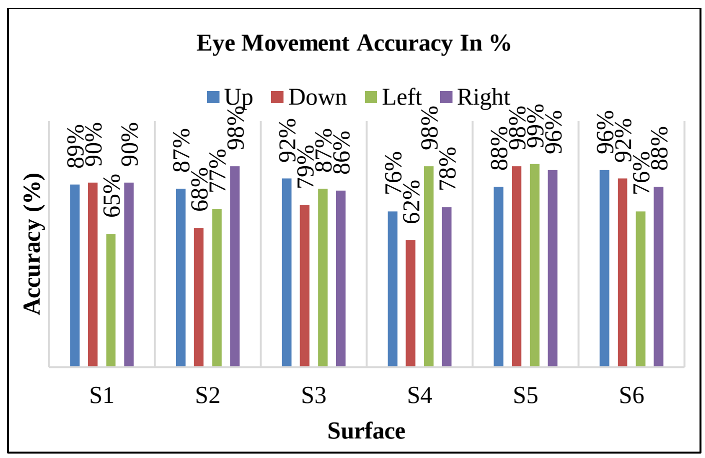

Figure 4. Graphical representation of the result obtained

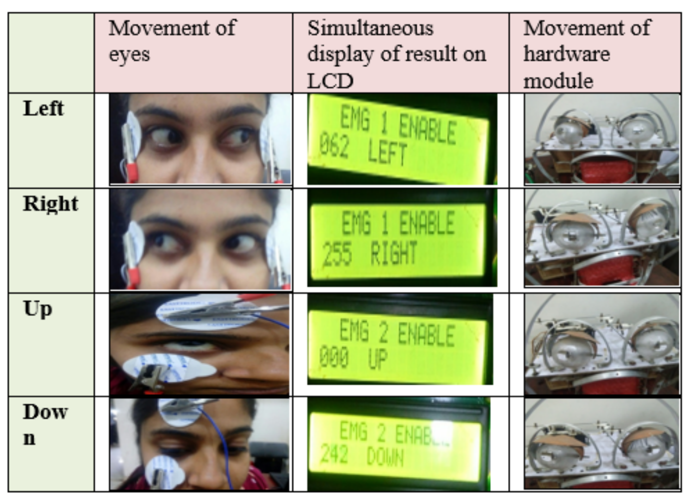

Figure 5. Testing of Eye Movement for Paralysed Individual with designed system

CONCLUSION & FUTURE PERSPECTIVE

At its core, this innovative system has the potential to create a profound impact on a global scale, addressing a critical need for individuals facing impairments, particularly those related to corneal exposure. By harnessing the power of electromyography (EMG), this visionary solution taps into residual muscle activity in paralysed body parts, creating a transformative channel for effective communication. The meticulously designed architecture, comprising interconnected components including a preamplifier, RC filter, analog-to-digital converter, microcontroller, and display unit, synergistically processes and interprets EMG signals with unprecedented precision, enabling vital functions such as upper eyelid closure and lower eyelid positioning to be executed with finesse. This intricate fusion of cutting-edge technology and human physiology not only addresses pressing physical challenges but also illuminates a promising path towards significantly elevating the overall quality of life for those navigating the complexities of paralysis.

Future Perspectives

Transcending Boundaries: This device breaks free from limits, offering transformative hope to those with paralysis.

Revolutionizing Lives: Practical assistance and improved functionality revolutionize lives. Addressing the challenges of paralysis, it substantially improves overall quality of life.

Innovation and Adaptation: Evolving research and technology extend impact. Future innovations broaden scope, addressing diverse mobility-related issues.

Broadening Reach: Ongoing advances and human-centric design promise a bright future. Continuous refinement keeps the device pioneering, enhancing lives effectively.

CONFLICT OF INTEREST

Authors do not have any academic or financial conflict of interest for publication of this work.

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