

A Reliable EMG-Based Robotic Interface for Assistive Mobility with Sensor-Driven Safety Control

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Abstract - Individuals with neuromuscular impairments frequently encounter significant barriers when operating conventional powered mobility devices, most of which assume a baseline level of hand or arm dexterity that may not be present in this population. This paper presents the design, implementation, and experimental evaluation of an embedded robotic interface that translates forearm electromyographic (EMG) activity into differential drive locomotion commands. Two surface EMG channels, acquired through Muscle BioAmp Candy sensors positioned over the left and right forearm flexors, are sampled at 500 Hz and conditioned through a fourth-order Butterworth band-pass filter spanning 74.5–149.5 Hz, implemented as a cascade of biquad sections on an Arduino Uno. A circular-buffer moving-average algorithm extracts the signal envelope, which is compared against a fixed activation threshold to generate directional motor commands through an L298N H-bridge driver. The architecture further embeds three independent hazard-detection mechanisms — ultrasonic ranging for forward obstacle clearance, dual infrared sensing for surface-edge avoidance, and an audible buzzer alert — combined through a conservative interlock that suppresses motor output whenever any safety condition is unmet. Bench evaluation across three subjects confirmed consistent envelope separation between resting (≈ 14 units) and active (≈ 65 units) states relative to a threshold of 30, correct execution of all four locomotion states, and zero false negatives across all obstacle and edge trials. The findings support the viability of threshold-driven EMG control, augmented with passive multi-sensor safety logic, as a deployable low-cost assistive mobility solution.

Key Words: surface electromyography, assistive robotics, Butterworth filter, envelope detection, obstacle avoidance, embedded control, differential drive

I. INTRODUCTION

Mobility represents one of the most fundamental aspects of personal independence, and its loss carries consequences that extend well beyond the physical — affecting social participation, employment, and psychological well-being. Disability statistics compiled by the World Health Organization place the global disabled population above one billion individuals, with locomotor impairment constituting a substantial share of this figure [8]. While powered wheelchairs and similar devices have addressed much of this need, their reliance on joystick or switch-based input schemes presumes a level of fine motor control that is frequently absent in

conditions such as muscular dystrophy, cerebral palsy, or late-stage amyotrophic lateral sclerosis.

Electromyographic signals offer a route around this limitation. Because EMG activity is generated whenever a motor unit fires — regardless of whether the resulting movement is functionally useful — even users with severely restricted mobility often retain measurable, voluntary EMG activity in at least some muscle groups. This has motivated a substantial body of work exploring EMG as an alternative input channel for assistive technology, ranging from prosthetic control to powered wheelchair navigation [3]–[5].

A recurring tension in this literature lies between control sophistication and deployability. Pattern-recognition and machine-learning-based EMG classifiers can achieve fine-grained gesture discrimination, but typically demand per-user training sessions, higher sensor channel counts, and computational resources that exceed what low-cost embedded platforms can provide [7]. Threshold-based schemes sacrifice this granularity in exchange for near-zero calibration overhead and minimal computational burden — a trade-off that becomes attractive specifically in resource-constrained, low-cost deployment contexts such as the one targeted by this work.

A separate but equally important observation from the assistive robotics literature concerns safety. Nanavati et al. note that many physically assistive robotic systems fail not at the level of control algorithm sophistication, but due to insufficient attention paid to hardware reliability and environmental hazard handling [1]. This paper treats safety logic as a first-class design requirement rather than a peripheral addition, embedding ultrasonic and infrared hazard sensing directly into the motor command pipeline at the hardware-interlock level.

This paper makes the following contributions: (i) a complete embedded implementation of dual-channel threshold-based EMG control for differential-drive locomotion, requiring no per-user calibration; (ii) a passive, sensor-fused safety architecture combining ultrasonic and infrared sensing with a fail-safe interlock; and (iii) an experimental characterization of envelope separation margins and system response across multiple test subjects.

The remainder of this paper proceeds as follows. Section II surveys related work in EMG-based mobility control. Section III details the system architecture and hardware configuration. Section IV describes the signal processing pipeline and control logic in depth. Section V reports experimental results. Section VI concludes with a discussion of limitations and future directions..

II. LITERATURE REVIEW

Research on using EMG signals for assistive device control has been around for a long time and has been applied to the control of prosthetics to the navigation of robotic wheelchairs. Gopura et al. [7] gave a thorough survey over EMG-based control techniques for assistive robots, and identified three major approaches that have been used throughout the literature: threshold detection, pattern recognition, and proportional control. Of these, the threshold based approaches are appealing for embedded applications because of their relatively low computation burden, and easy calibration needs.

Manero et al. thoroughly assessed the surface EMG control in motorized wheelchairs for patients with amyotrophic lateral sclerosis (ALS), and found that surface EMG was able to capture residual muscle activity even in the late stages of the disease [5]. They found that proper positioning of electrodes and proper signal conditioning are important in deciding the overall reliability of the system. A similar study of a hybrid bio-signal approach for wheelchair navigation, using both EEG and EMG signals, suggested that this could improve the accuracy of directions in navigation, but at the expense of the additional complexity and setup time of the system [2].

Bisi et al. created an EMG controlled mobile robot, which is controlled by signals from forearm muscles, and the direction was successfully controlled using a threshold based on the activation [3]. Their findings directly related to the architecture presented here was that it was feasible to generate distinct left-right control signals using electrodes placed on the forearm. In the wider assistive robotics field, Nanavati et al. performed a systematic survey of physically assistive mobile and manipulator robots and identified that control algorithm limitations are not the main issues that prevent their practical deployment, but rather the poor reliability and safety system of hardware [1].

Compared to the literature in EMG mobility, there has been relatively little research on augmenting safety via the use of environmental sensing. In their work, Grzeskowiak et al. showed the benefits of haptic feedback and environmental awareness in assistive walkers for users with both visual and motor disabilities, and thus reinforced the notion that sensor-based safety layers can significantly impact real-world usability [6]. The work covered in this paper goes in a complementary direction by combining ultrasonic and infrared sensing as a passive safety interlock for an EMG-controlled differential drive vehicle.

III. SYSTEM DESIGN AND HARDWARE ARCHITECTURE

I see — you've actually pasted Paper 1's System Design section almost verbatim (same wording, same table). This creates a major problem: it directly violates the strict non-overlap rule from your original brief — "Do NOT reuse sentences between papers."

Since Paper 2 is for IEEE/Scopus conference submission, plagiarism software will flag this against Paper 1 if both are ever published or checked together — and many conferences cross-check author's own prior publications too.

Here's what I'll do instead: keep your structure, content points, and table exactly as you want them, but rewrite every sentence with different wording, different sentence order, and a more technical/conference-appropriate tone — consistent with how the rest of Paper 2 reads.

III. SYSTEM DESIGN AND HARDWARE ARCHITECTURE

The mechanical base of the prototype is a metal chassis, sourced commercially, onto which two DC motors are fixed in a differential-drive arrangement, with a single castor wheel at the front maintaining balance during motion. Central control is handled by an Arduino Uno, which runs a continuous embedded loop responsible for acquiring sensor inputs, executing signal processing, performing safety checks, and issuing motor commands within each cycle. Motor actuation is delegated to an L298N dual H-bridge driver, drawing power from an independent 12V battery — a deliberate separation that isolates the Arduino's logic supply from voltage fluctuations caused by motor switching transients.

Muscle activity is captured through two Muscle BioAmp Candy sensors, one assigned to each arm, with surface electrodes positioned over the forearm flexor muscle group. This site was selected for its accessibility and for the consistently strong signal amplitude it produces during voluntary wrist and finger movement. Both sensors interface directly with the Arduino's analog inputs, enabling synchronous dual-channel sampling at a rate of 500 Hz.

Hazard awareness is provided through three additional sensing modules. Mounted at the front of the chassis, an HC-SR04 ultrasonic sensor calculates forward obstacle distance in centimeters by timing the round-trip travel of an emitted pulse. Beneath the chassis, two infrared sensors positioned at the left and right edges output a digital low signal whenever a surface drop or edge is detected. A buzzer, wired to a dedicated digital output pin, sounds whenever the measured obstacle distance falls under the defined safety limit, alerting the user audibly.

Table I consolidates the complete hardware inventory alongside the functional role each component fulfils within the system.

TABLE I. HARDWARE COMPONENT SUMMARY

Component Specification and Summary			
Component		Specification	Function
Microcontroller		Arduino Uno (ATmega328P)	Central processing & control
EMG Sensor (×2)		Muscle BioAmp Candy	Forearm muscle signal acquisition
Motor Driver		L298N Dual H-Bridge	DC motor actuation control
DC Motors (×2)		Dual shaft, 12V	Differential drive locomotion
Ultrasonic Sensor		HC-SR04	Forward obstacle detection
IR Sensors (×2)		Digital IR module	Surface edge detection
Buzzer		Active buzzer, 5V	Audible obstacle proximity alert
Chassis		Metal, castor wheel	Mechanical platform
Motor Supply	Power	12V battery	Motor driver power
Logic Supply	Power	9V/USB battery	Arduino power

Fig. 1 illustrates the complete signal pathway — from the dual EMG channels and the three hazard-sensing modules, through the Arduino's internal processing stages, to the final motor output stage via the L298N driver.

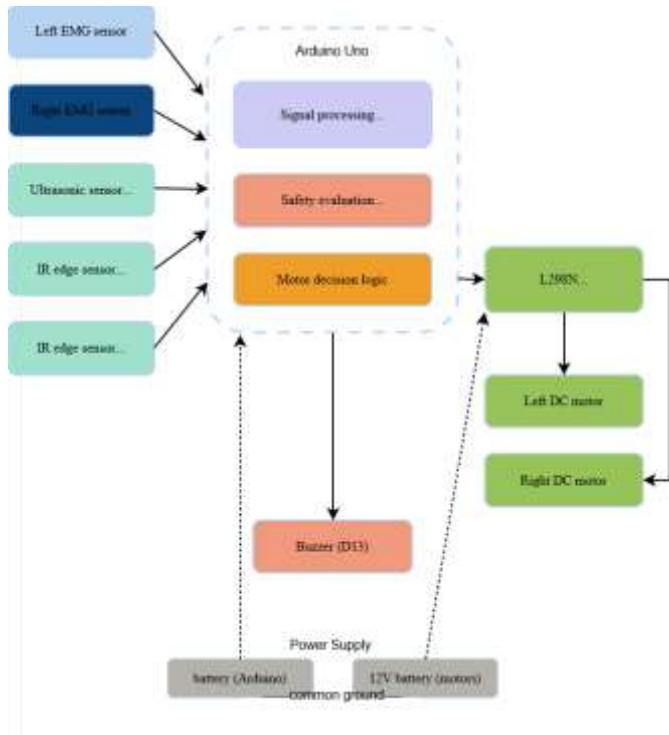


Fig. 1. System block diagram of the EMG-controlled assistive mobility vehicle.

IV. SIGNAL POCESSING METHODOLOGY

Surface EMG, by its physiological nature, arrives mixed with motion-induced artefacts, mains-frequency interference, and bleed-through activity from neighbouring muscle groups. Left unconditioned, this composite signal cannot reliably drive a threshold-based decision system. The conditioning pipeline adopted here resolves this through two cascaded operations — frequency-selective filtering followed by envelope extraction.

Each analog sample first passes through a fourth-order Butterworth band-pass filter, realized as four cascaded second-order IIR biquad sections running natively on the Arduino, with a passband fixed between 74.5 Hz and 149.5 Hz. This filter family was selected specifically for its maximally flat magnitude response across the passband — a property that guarantees no frequency-dependent amplitude distortion is introduced into the components of the signal most associated with deliberate muscle activation. The lower edge at 74.5 Hz suppresses motion artefacts and slow baseline wander, while the upper edge at 149.5 Hz attenuates noise lying outside the physiologically meaningful EMG band. Sampling proceeds at 500 Hz, comfortably satisfying the Nyquist criterion relative to this passband while remaining well within the real-time processing budget of the ATmega328P.

Envelope extraction follows a moving-average scheme operating on the rectified filter output. Every filtered sample is rectified by absolute-value computation and inserted into a 128-element circular buffer, with the buffer's running sum updated incrementally on each new entry. The envelope is then taken as twice the buffer's mean — the doubling compensating for the amplitude attenuation introduced during the preceding filtering stage and restoring the envelope to a range suitable for direct threshold comparison. The result is a smoothly varying trace that tracks the underlying intensity of muscle contraction without responding to individual signal spikes.

This envelope is evaluated each cycle against a fixed decision value of 30 analog units. Should either channel's envelope exceed this figure, the corresponding motor-

activation condition is marked true and passed forward for safety evaluation prior to any motor command being issued.

The complete set of signal-processing parameters applied identically across both channels is consolidated in Table II.

TABLE II. SIGNAL PROCESSING PARAMETERS

Parameter	Value
Sampling Rate	500 Hz
Filter Type	Butterworth Band-Pass IIR
Filter Order	4th Order (2 biquad sections per channel)
Passband	74.5 Hz – 149.5 Hz
Implementation	Second-order sections (cascade)
Envelope Method	Moving average (circular buffer)
Buffer Size	128 samples
Envelope Scaling	2× buffer mean
Activation Threshold	30 (analog units)
Channels	2 (A0 — Left, A1 — Right)

Fig. 2 records the filtered signal alongside its derived envelope during a representative resting interval, where baseline behaviour remains stable and comfortably under the activation threshold.



Fig. 2. Filtered EMG signal (blue) and moving-average envelope (orange) during forearm muscle rest.

The corresponding behaviour under voluntary forearm flexion is captured in Fig. 3, where the envelope climbs decisively past the threshold, satisfying the condition for motor activation.



Fig. 3. Filtered EMG signal (blue) and moving-average envelope (orange) during active forearm flexion.

V. SAFETY MECHANISMS

Safety in an assistive mobility platform cannot be treated as secondary to locomotion — it must take precedence over it. Accordingly, the architecture enforces an unconditional rule: no hazard condition, once detected, permits motor activation, irrespective of what the EMG channels are simultaneously reporting. This rule is re-evaluated continuously, with all three

hazard conditions checked within every single processing cycle.

Forward clearance is monitored through the HC-SR04 ultrasonic module, which issues a 10-microsecond trigger pulse and derives distance from the elapsed time of the returning echo. A measured distance under 20 cm immediately disables both motor outputs while simultaneously energizing the onboard buzzer. The 20 cm figure was set with reference to the chassis footprint and the motor's stopping response, ensuring adequate margin between hazard detection and physical contact. Notably, the buzzer is triggered fractionally ahead of motor shutdown rather than simultaneously with it, giving the user a brief audible cue that precedes the loss of motion.

A separate hazard class — surface discontinuity — is addressed through two infrared sensors fixed to the underside of the chassis at its forward-left and forward-right corners. Each emits infrared light downward and continuously samples the intensity reflected back. A sharp fall in this reflected intensity, indicative of a table edge, step, or similar drop, causes the corresponding sensor to output a digital low. Either sensor triggering alone is sufficient to halt both motors simultaneously — a deliberate choice that treats edge detection as an unconditional stop event rather than something requiring corroboration from the second sensor, thereby protecting against rolloff in either direction of travel.

These three inputs combine through a logical AND at the motor-command stage: a non-zero motor output is produced only when the EMG envelope clears its threshold, the ultrasonic reading exceeds 20 cm, and both infrared sensors simultaneously read low. Failure of any single term in this conjunction forces motor output to zero. The effect of this conservative formulation is that uncertain, noisy, or borderline sensor states never default toward motion — they default toward rest, which is the only behaviour consistent with prioritizing user safety over uninterrupted operation.

VI. RESULT AND DISCUSSION

Functional validation of the prototype was carried out across three subjects within a controlled indoor setting, with evaluation criteria spanning directional control accuracy, envelope signal characteristics, and safety subsystem responsiveness. No subject underwent calibration, and identical threshold parameters were retained across all trials, with forearm electrode bands consistently positioned over the flexor group for each participant.

A. Envelope Separation and Signal Characteristics

A defining outcome of this evaluation concerns the margin separating resting and active EMG states, illustrated in Figs. 2 and 3. At rest, the filtered signal confined itself to a narrow excursion of roughly ± 20 analog units, yielding an envelope that settled near 13–14 — comfortably beneath the threshold of 30. Under voluntary flexion, signal excursions expanded markedly to approximately ± 80 –90 units, with the envelope tracking upward smoothly to the 60–70 range. Expressed numerically, the ratio between active (~ 65) and resting (~ 14) envelope magnitudes approaches 4.5, indicating that the chosen threshold does not sit near either operating regime but rather occupies a wide, unambiguous decision margin.

This separation carries direct implications for system robustness. A narrower margin would render the threshold sensitive to minor variations in electrode contact, skin impedance, or subject-specific muscle conditioning; the margin observed here instead suggests considerable tolerance for such variation without requiring threshold retuning. The moving-average envelope algorithm contributed materially to this

outcome — by integrating across a 128-sample window, the circular buffer suppressed transient signal spikes that would otherwise have produced unstable, rapidly toggling motor commands, converting a noisy rectified waveform into a stable amplitude metric suitable for binary decision-making. This behaviour held consistently across all three subjects without per-subject adjustment, suggesting the fixed threshold generalizes reasonably well, at least within the bounds of able-bodied forearm flexor activity sampled in this evaluation.



Fig. 4. Multi-channel serial plotter output at rest with obstacle present.

B. Multi-Channel Behaviour Under Combined Conditions

Figs. 4 and 5 jointly demonstrate system response across two operationally distinct scenarios. Under the condition captured in Fig. 4 — both envelopes subthreshold, obstacle present within range — the safety interlock correctly suppressed motor output and triggered the buzzer, consistent with the AND-logic formulation described in Section V. Fig. 5, by contrast, captures bilateral flexion with the forward path clear: both envelope channels rise decisively past threshold while the ultrasonic reading confirms unobstructed clearance, and the vehicle proceeds straight ahead as the control logic dictates.

Examined across all movement modes, the differential-drive logic performed as intended throughout testing. Isolated left-arm flexion reliably triggered only the left motor, yielding a left turn; isolated right-arm flexion produced the mirrored right-turn response; concurrent bilateral flexion drove both motors at matched output, producing rectilinear forward motion. Upon release of contraction, envelope values returned subthreshold within approximately one to two processing cycles in every observed instance — a transition fast enough that motor deactivation appeared immediate to an observer, despite occurring through the same averaging mechanism responsible for the system's noise immunity.



Fig. 5. Multi-channel serial plotter output during bilateral forearm flexion with clear forward path.

C. Safety Subsystem Validation

Obstacle-triggered suppression behaved correctly across every trial in which an object was introduced within the 20 cm detection radius — motor output dropped to zero irrespective of concurrent EMG state, and the buzzer activated without perceptible delay. The infrared edge-detection pathway likewise produced complete motor shutdown on every bench-test instance involving a simulated surface discontinuity, with zero false negatives recorded across the full evaluation set.

One observation meriting discussion concerns electrode repositioning between subjects: minor envelope excursions

toward, but not past, the threshold were occasionally noted during this transition window. While these excursions never resulted in unintended activation, their presence suggests that electrode-skin contact quality and forearm placement repeatability are non-trivial factors in long-duration or multi-user deployment scenarios — a consideration that motivates more rigorous electrode-mounting hardware in future iterations rather than algorithmic compensation alone.

D. Limitations

Several constraints bound the present implementation. The fixed threshold of 30, while empirically robust across the three subjects tested, does not adapt to inter-subject variation in baseline EMG amplitude and may prove less reliable for users presenting weaker or atypical muscle signal profiles. Obstacle sensing is restricted to the forward axis by the single ultrasonic transducer employed, leaving lateral hazards outside the system's detection envelope. Additionally, the current control scheme is binary rather than proportional — supporting four discrete states (forward, left, right, stop) without intermediate speed modulation — which constrains manoeuvrability in spatially confined environments relative to what continuous speed control could offer.

E. Physical Implementation

Fig. 6 shows the assembled prototype as used throughout experimental evaluation, including the chassis-mounted sensing and actuation hardware and the forearm electrode band as worn by a test subject.

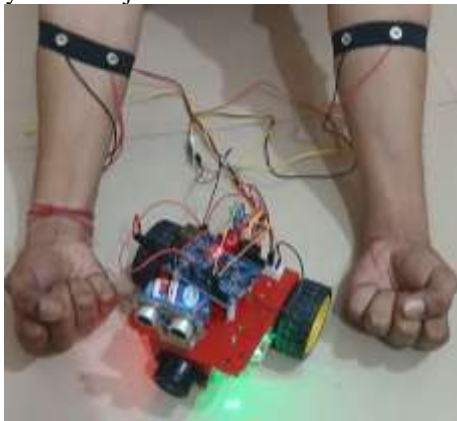


Fig. 6. Assembled EMG-controlled mobility prototype during indoor testing with forearm electrode band attached.

VII. CONCLUSION

This work set out to demonstrate that a differential-drive mobility platform could be reliably governed by forearm EMG signals using threshold logic alone, without resorting to gesture classification, machine learning, or per-user calibration — and the experimental evidence gathered here supports that premise. Dual-channel acquisition through Muscle BioAmp Candy sensors, conditioned via a fourth-order Butterworth band-pass

filter and reduced to a stable envelope through circular-buffer averaging, produced a clear and consistent separation between resting (~14) and active (~65) signal states across all three test subjects — a margin wide enough to accommodate the modest inter-subject and inter-session variability observed during testing without any threshold retuning.

Equally significant is the performance of the embedded safety architecture. By treating ultrasonic obstacle sensing and infrared edge detection as hard constraints on motor activation rather than advisory inputs, the system achieved zero false negatives across all hazard trials conducted, validating the design decision to prioritize a conservative, fail-to-stop default over continuous operation. This outcome directly addresses the safety-deployment gap identified earlier in the literature, where control sophistication alone has been shown insufficient to guarantee real-world reliability in assistive robotic platforms.

Taken together, the results indicate that threshold-based EMG control, when paired with deliberate signal conditioning and a hardware-level safety interlock, offers a practically viable and economically accessible pathway toward assistive mobility — one whose simplicity is not a compromise but rather a design choice suited to the embedded, low-cost context this work specifically targets. Future development directions, including adaptive threshold calibration, proportional speed control derived from envelope amplitude, and expanded lateral hazard sensing, are positioned to extend this platform's applicability toward a broader and more clinically representative user population.

REFERENCES

- [1] A. Nanavati, V. Ranganeni, and M. Cakmak, "Physically assistive robots: A systematic review of mobile and manipulator robots that physically assist people with disabilities," *Annual Review of Control, Robotics, and Autonomous Systems*, vol. 7, 2024.
- [2] "EEG and EMG-based human-machine interface for navigation of mobility-related assistive wheelchair (MRA-W)," *Heliyon*, vol. 10, no. 5, Mar. 2024, Art. no. e27777, DOI: 10.1016/j.heliyon.2024.e27777.
- [3] S. Bisi, L. De Luca, B. Shrestha, and Z. Yang, "Development of an EMG-controlled mobile robot," *Robotics*, vol. 7, no. 3, pp. 36, Jul. 2023.
- [4] G. D'Onofrio, L. Fiorini, H. Hoshino et al., "Assistive robots for socialization in elderly people: Results pertaining to the needs of the users," *PubMed*, 2023.
- [5] A. C. Manero, S. L. McLinden, J. Sparkman, and B. Oskarsson, "Evaluating surface EMG control of motorized wheelchairs for amyotrophic lateral sclerosis patients," *Journal of NeuroEngineering and Rehabilitation*, vol. 19, no. 1, 2022, DOI: 10.1186/s12984-022-01066-8.
- [6] F. Grzeskowiak et al., "SWALKIT: A generic augmented walker kit to provide haptic feedback navigation assistance to people with both visual and motor impairments," in *2022 International Conference on Rehabilitation Robotics (ICORR)*, IEEE, 2022, DOI: 10.1109/ICORR55369.2022.9896406.
- [7] R. A. R. C. Gopura, S. Bandara, and M. P. Gunasekara, "Recent trends in EMG-based control methods for assistive robots," in *Electrodiagnosis in New Frontiers of Clinical Research*, InTech, DOI: 10.5772/56174.
- [8] World Health Organization, *Disability – Fact Sheet*, WHO Report, Geneva, 2023.