



Muscle-Signal Controlled Assistive Mobility Interface with Multi-Sensor Safety Integration

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Abstract- People with disabilities in their mobility are a large population worldwide who have a need for intuitive and reliable assistive technologies. In these settings, the human machine interaction is a very interesting approach through electromyography (emg) signals, which are naturally produced during voluntary muscle movement. This work explains the design of a low-cost robotic mobility vehicle for a muscle signal controlled assistive prototype, which is able to independently process forearm emg signals of both arms. Two muscle bioamp candy sensors record the signal from the user's forearm and then the signal is filtered by a 4th order butterworth band pass filter from 74.5hz to 149.5hz, followed by a moving average envelope detector. Using an arduino uno microcontroller and l298n motor driver, a threshold-based decision layer is used to convert the envelope values into motor direction control. In addition to motion control, the system includes an ultrasonic sensor for detecting obstacles near the driver and two infrared sensors to detect the edges of the surfaces where the driver is standing, to send this information to a safety interlock that can override the motor control system when dangerous conditions are detected. Three subjects were tested, and consistent and reliable directionality was achieved in all intended modes of movement. The integrated safety architecture proved successful for avoiding unwanted motion in the event of an obstacle or edge detection, thus confirming the multi-sensor system approach for low-cost assistive mobility systems.

Keywords: Electromyography, assistive mobility, emg envelope detection, filter, obstacle avoidance, differential drive, Arduino.

I.INTRODUCTION

Being able to move from one place to another independently is crucial for human autonomy, but there are many people in the world who suffer from conditions that seriously limit their ability to move about without the help of others. World Health Organization estimates that more than one billion people suffer some form of disability, and mobility impairment is one of the most common disabilities [8]. Assistive devices such as manual and powered wheelchairs have long been available to this population; however, they generally depend on hand/arm dexterity which may not be available to many users, especially those with lower limb weakness or neuromuscular disorders.

Another control mode that has been proposed is surface electromyography, which takes advantage of the fact that even people with severe motor impairments have some amount of muscle activity remaining. The EMG based control does not need any pressing of a button or a joystick, it only requires a voluntary muscle contraction – no matter how small – so it is accessible to a larger audience of users. EMG signals have been shown to be a viable control signal for robotic mobility devices [3], [5] but in practical applications noise, variability in electrode locations and limitations on real-time processing by embedded hardware can create some obstacles.



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Current systems often use a complex classification algorithm or a gesture recognition pipeline with high accuracy and require high computational resources and meticulous calibration for each user [2], [7]. Simple but strong architectures can be more suitable for low resource or community level deployment. While simple to apply, threshold-based control can provide satisfactory control performance with proper signal conditioning and safety device design.

This work tackles this deficiency and proposes a prototype robotic mobility vehicle for which the movements of the forearms of both left and right arms independently control the direction of rotation of the differential drive chassis. Straight line motion occurs when both arms are moving at the same time, and unilateral motion occurs with one arm moving in one direction, and the other arm moving in the other direction. Important: Motor commands are constantly checked for safety: There is an ultrasonic sensor to detect obstacles in front, and two infrared sensors to detect edges under the chassis. Motor operation is immediately suspended whenever any safety condition is detected, regardless of the EMG input state and a buzzer sounds the alarm to warn the user of obstacle proximity.

The rest of this paper is organized as follows. In Section 2, the relevant literatures that focus on EMG-based assistive robotics are presented. The architecture and design of the hardware is described in Section 3. The signal processing methodology is described in Section 4. The safety mechanisms are discussed in section 5. Results and discussion are given in Section 6. The work is completed in Section 7.

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

The prototype is a commercially available metal chassis which has two DC motors attached to it in the differential drive pattern and a castor wheel at the front for balancing. An embedded loop is formed in the Arduino Uno microcontroller that collects sensor data, processes it, evaluates the safety and determines motor commands. The motor actuation is controlled with an L298N dual H-Bridge driver that is provided with power from a separate 12V battery so that the voltage to the Arduino is not affected by the switching noise of the motors.

Two Muscle BioAmp Candy EMG sensors are used for muscle signal acquisition (one for each arm); surface electrodes are placed on the flexor area of the forearm. This positioning was chosen because it is easy to access and because it generates a good amplitude of signal when the wrist and fingers are moved voluntarily. The sensors are connected directly to the analog input of the Arduino, allowing their dual channel signals to be sampled at 500 Hz simultaneously.

There are three other modules for environmental sensing. The HC-SR04 ultrasonic sensor, located at the front of the chassis, uses round-trip pulse travel time to determine the distance to an obstacle ahead (in centimeters). Two infrared sensors are located under the chassis at the left and right edges that provide a digital low signal when a drop or an edge is detected. When obstacle proximity is below the defined safety distance, a buzzer that is connected to a digital output pin will sound an audible warning to the user.

Table I summarizes the key hardware components and their functional roles within the system.

TABLE I. HARDWARE COMPONENT SUMMARY

Component Specification and Summary		
<i>Component</i>	<i>Specification</i>	<i>Function</i>
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 Power Supply	12V battery	Motor driver power
Logic Power Supply	9V/USB battery	Arduino power

The overall system architecture is illustrated in Fig. 1, depicting the signal flow from dual EMG sensors and environmental sensors through the Arduino processing core to the motor output stage.



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

IV. SIGNAL POCESSING METHODOLOGY

The raw surface EMG signal is always contaminated by motion artefacts, power line interference, and neighbouring muscle crosstalk. These signals are not adequate to control a threshold based control system if they are not properly conditioned. Here this is solved by two successive steps, namely band pass filtering, and envelope detection.

The analog input is first fed into a 4th order Butterworth bandpass filter with a passband between 74.5Hz and 149.5Hz, which consists of 4 second order infinite impulse response (IIR) biquad sections, all of which are directly implemented on the arduino. The Butterworth design was chosen because it has a flat frequency response for the magnitude of the frequency components in the passband, and thus preserves the frequency components that are most representative of voluntary muscle movements without amplitude distortion. This lower cut-off value of 74.5 Hz helps to reject low frequency motion artefacts and motion baseline drift, and the upper cut-off value at 149.5 Hz reduces high frequency noise outside the physiologically relevant EMG frequency spectrum. With a sampling frequency of 500 Hz, this matches the Nyquist criterion well, and is also feasible for the real-time processing of the ATmega328P processor.

After being filtered, the envelope detection is done in a moving-average fashion. The absolute value of every filtered sample is calculated and stored in a circular buffer with 128 samples. The content of the buffers is accumulated, and the envelope value is calculated by multiplying the buffer mean by 2. This operation effectively creates a slowly varying amplitude envelope of the rectified EMG signal which represents the intensity of the muscle contraction. The doubling factor is a function of the attenuation that occurs in the filtering stage, which brings the envelope values back to a realistic amplitude range.

The envelope that is created is then compared to a preset value of 30 (in arbitrary analog units on the Arduino). If the envelope of either channel goes over this limit, then that motor activation condition is true and needs to be evaluated for safety before sending a motor command.

Table II provides a summary of the signal processing parameters applied to both channels

TABLE II. HARDWARE COMPONENT SUMMARY

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 captures the filtered EMG signal and its computed envelope during a representative resting state, demonstrating stable baseline behavior well below the activation threshold.



Fig. 2. Filtered EMG signal (blue) and moving-average envelope (orange) during forearm muscle rest. Fig. 3 shows the corresponding signal behavior during voluntary forearm flexion, where the envelope rises well above the threshold, triggering a valid motor activation condition.



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



V. SAFETY MECHANISMS

Assistive mobility devices must always be designed and used to keep the user safe first, and ensure the continuity of the mobility service. An essential feature of this system design is that activation of the motor is never permitted to occur when a hazard condition is detected, no matter what state the EMG inputs are in. Each processing cycle, the three different safety conditions are monitored in real-time.

The HC-SR04 ultrasonic sensor is used for forward obstacle detection, it has a 10-microsecond trigger time and the time it takes for the echo to return is used to calculate distance. If the distance calculated is less than 20cm, both motors are disabled and the buzzer on the board is activated to warn the user. This stopping distance was chosen to ensure it was long enough with the chassis sizes and motor responsiveness. Importantly, the buzzer rings slightly before the motors actually stop, providing the user with some sensory feedback before the motors stop.

Surface edge detection uses two infrared sensors that are located under the chassis at the left and right corners forward. These sensors shoot down infrared light and measure reflected intensity. If either sensor detects a sudden decrease in reflectance, a digital low signal is produced, which signals a table edge, staircase or surface discontinuity. The control logic will consider the triggering of the two edges as a full stop event; both motors will be stopped at the same time, allowing the car to not roll down the stairs or ledges.

It is actually a logical AND condition where the motor command is only sent if the EMG envelope is above the threshold and the distance to the obstacle is greater than 20cm and both edge sensors are low at the same time. If any one condition is failed, the motor output is set to 0. This is a conservative design that means that when the sensor has a gray or fuzzy reading, it reverts back to the stopped position, thus preventing unintended motion.

VI. RESULT AND DISCUSSION

The prototype was then functional tested with three subjects in a room environment and tested for directional control response, envelope signal behavior, and safety system performance. No calibration or user-specific parameters were adjusted for any of the subjects and all subjects used forearm mounted electrodes attached to Muscle BioAmp Candy sensors.

A. EMG Signal Behavior

Figures 2 and 3 show the difference between the resting and active forms of the muscle on one channel. The filtered EMG signal during rest was oscillating within a very small bandwidth of about ± 20 analog units and the computed envelope settled around 13-14, which is much below the activation threshold of 30. Signal amplitude was significantly larger for voluntary forearm flexion, with peaks of $\pm 80-90$ analog units. The envelope tracked gently and smoothly to about 60-70, giving a nice clear and unambiguous crossing of the threshold. The separation between the resting envelope (~ 14) and active envelope (~ 65) is a margin of ~ 4.5 times greater than the threshold value, which shows good discrimination between intentional activation and baseline muscle noise.

The moving-average envelope detection approach proved particularly effective in this context. Rather than responding to individual signal peaks — which would introduce erratic motor switching — the 128-sample circular buffer smoothed transient spikes into a stable amplitude representation. This behavior was consistently observed across all three subjects without requiring any threshold

adjustment, suggesting that the fixed threshold of 30 analog units is appropriate for the forearm flexor muscle group with this electrode configuration. Fig. 4 presents the multi-channel serial plotter output recorded during the resting state with an obstacle placed within the detection range of the ultrasonic sensor.



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

B. Multi-Channel Control Behavior

Figure 4 and Fig. 5 show the multi-channel nature of the system under varying conditions. In the case of both EMG envelopes below threshold and ultrasonic sensor detecting a close obstacle as shown in figure 4, the motors were correctly disabled and the buzzer was turned on as expected. Figure 5 shows a situation with no obstacle, and both envelopes clearly pass threshold, while the ultrasonic reading shows that there is no obstruction in the forward path, which means that the vehicle is naturally moving forward, as expected.

The differential drive control logic functioned well in all movements. Left isolated arm flexion always elicited the left motor and resulted in a left turn. Isolated rigidity of the right arm gave rise only to a right turn, which was produced by the right motor. When both motors were flexed at the same time, they were driven at equal levels and the result was straight line forward motion. In all cases, the envelope values below threshold were returned to following the release of muscle contraction, with the process beginning within about 1 to 2 processing cycles.



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

C. Safety System Performance

In all test cases the obstacle detection interlock worked as expected. When an object was positioned within (20cm) of the ultrasonic sensor, the outputs of the motor regardless of whether the EMG signal was on or off, were suppressed and the buzzer was given immediate audible feedback. The infrared edge sensors also completely shutdown the motor when they detected a surface discontinuity during the bench test, and no false negatives were detected during the evaluation sessions.

It is important to note that some minor envelope fluctuations were observed during repositioning of the electrodes between subjects that brought the system close to but did not consistently exceed the threshold. This implies that the quality of the electrode contact and consistency of forearm positioning may play a role in reliability in a longer-term use scenario, which will be important for future hardware development improvements.



D. Limitations

There are a few limitations in the prototype that need to be recognized. Fixed threshold of 30 is not adaptable to inter subject variability in amplitude of muscle signals, which may be problematic for users with less or unusual EMG signals. The single axis ultrasonic sensor only detects obstacles in front of it, and not ones that are on the side. In addition, the current control scheme does not support speed modulation, and only supports four movement states: forward, left, right and stop, which will result in less navigational precision in confined environments

VII. CONCLUSION

A proof-of-concept assistive prototype of a forearm muscle-signal-controlled robotic mobility vehicle was developed and evaluated. The system achieved an accurate directional control function based on an EMG threshold with dual-channel EMG acquisition, fourth-order Butterworth band-pass filtering and moving-average envelope detection, all of which were implemented in real time on an Arduino Uno microcontroller. The separation between resting envelope values (~14) and active contraction values (~65) was good to justify the use of the fixed threshold approach with this electrode placement and muscle group.

The integrated safety architecture (ultrasonic obstacle detection, infrared surface edge sensing and a hardware-level motor interlock) always protected against unintended movements during all test scenarios when operating in hazardous conditions. Feedback from an audible buzzer was also provided to increase awareness during proximity to the obstacles.

The prototype is functional but further development should include an adaptive threshold to account for inter subject variability, expansion of obstacle sensing to the lateral directions and the inclusion of proportional speed control based on envelope amplitude. Meaningful next steps towards eventual practical deployment would be miniaturization of the hardware platform and evaluation with a larger number of users with various profiles of mobility impairment.

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.



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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.