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Neurorehabilitation Robot-Assisted for Stroke Recovery: Hybrid Exoskeleton Assistive Limb (HEAL)

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ABSTRACT

Conventional rehabilitation techniques that require manual intervention and the use of devices are identified as having several drawbacks. These include limited features, fatigue for both patients and therapists during prolonged rehabilitation sessions, time-consuming procedures, high operational and maintenance costs for devices, a lack of motivation for patients, limited accessibility, and challenges in measuring or monitoring rehabilitation progress. In response to these challenges, the Hybrid Exoskeleton Assistive Limb (HEAL) is introduced as a tailored solution with distinctive features. These features include real-time electromyographic (EMG) monitoring, a therapist-friendly graphical interface, and advanced techniques in the rehabilitation process. HEAL utilizes robotics-assisted rehabilitation for repetitive, precise, and controlled movements, enhancing brain-muscle motor function, developing muscle strength, and providing a wide range of motion. The system focuses on upper limb robotic rehabilitation and consists of an EMG to read muscle responses, an Arduino microcontroller for signal processing, and a high-torque precision servo motor for controlling limb movements. HEAL emphasizes the Brain-Muscle-Computer control process rather than passive rehabilitation, which relies on external forces to move the muscles, as demonstrated by the therapist. HEAL is particularly suitable for neurorehabilitation, emphasizing recovery and improvement of function in individuals with neurological disorders or injuries, especially in stroke patients. HEAL's ability to tailor rehabilitation programs individually offers personalized rehabilitation, considering each patient's unique needs, goals, and abilities. It utilizes advanced technologies for targeted and efficient rehabilitation. The HEAL device is cost-saving with a compact design, positioning it as a promising and comprehensive solution in stroke neurorehabilitation.

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1. INTRODUCTION

Stroke, the second-leading global cause of mortality and primary contributor to disability, presents an escalating public health challenge. The 2022 World Health Organization (WHO) study underscores a disconcerting trend: a 50% increase in the lifetime risk of stroke over 17 years, projecting a staggering 1 in 4 individuals to encounter a stroke during their lifetime. Within Malaysia, stroke ranks as the third leading cause of death, with 2019 statistics revealing 47,911 incident cases, 19,928 fatalities, 443,995 prevalent cases, and a consequential loss of 512,726 Disability-Adjusted Life Years (DALYs) [1].

Difference between ischemic strokes, constituting 80% of cases, and hemorrhagic strokes, comprising the remaining 20%, underscores the vascular complexities. Ischemic strokes arise from cerebral blood flow obstruction due to clots, while hemorrhagic strokes stem from ruptured brain arteries, culminating in debilitating brain tissue damage and elevated intracranial pressure. Rehabilitation assumes paramount importance in the aftermath of stroke, particularly via physical therapy that endeavors to restore fundamental movements, encompassing hand dexterity, ambulation, and postural control, aimed at reinstating mobility, equilibrium, and motor coordination [2].The focal impairment of the upper limbs, consequent to strokes primarily affecting the middle cerebral artery, precipitates pervasive challenges in daily functioning. Marked by substantial muscle atrophy and compromised shoulder joint stability leading to subluxation and debilitating pain, these complications profoundly impact the quality of life for stroke survivors [3][4]. Neurorehabilitation using robotic exoskeleton rehabilitation devices involves the use of advanced robotic technology to assist individuals with neurological impairments in their recovery process. This approach is particularly relevant for individuals who have experienced stroke, spinal cord injury, traumatic brain injury, or other neurological conditions that result in motor deficits.

PERKESO Neuro-Robotics Rehabilitation & Cybernics Centre, the first of its kind in Malaysia and ASEAN, offers cutting-edge technology like Cyberdyne HAL from Japan to aid clients with spinal cord or brain injuries—such as paralysis, neurodegenerative diseases, and stroke rehabilitation [5]. However, centers like PERKESO face problems due to relying on imported tech, which is costly and requires external experts for maintaining the rehabilitation devices. Considerable advancements, traditional stroke rehabilitation methods exhibit inherent shortcomings. Their time-intensive nature, coupled with physical and financial burdens for both patients and therapists, alongside limited precision, insufficient motivation, and challenges in progress measurement, necessitate exploration and integration of more innovative strategies [6]. Rehabilitation robotics is an emerging field that holds great promise. Innovative devices like Cyberdyne's Hybrid Assistive Limb (HAL) and the cable-driven arm exoskeleton (CAREX-7) demonstrate significant technological advancements and may provide solutions for improving stroke rehabilitation [7][8][9]. However, it's essential to acknowledge that robotic rehabilitation methods also come with disadvantages. Challenges such as high initial costs, potential technical issues, and the need for specialized training for both therapists and patients may impact widespread adoption and accessibility. Despite these challenges, the continuous development and refinement of robotic rehabilitation technologies offer a promising avenue for enhancing stroke recovery outcomes.

The objective of this project is to develop an upper limb stroke rehabilitation device by providing a precise, accessible, and engaging therapy platform. Hybrid Exoskeleton Assistive Limb (HEAL) works by detecting electromyogram (EMG) signals from the muscles when a person moves. It uses Arduino Mega 2560 microcontroller to process and interpreting these signals. Then, it displays the person's improvement on a simple screen with pictures and buttons (GUI). This helps in creating therapy sessions that are personalized for each person's specific requirements. Our HEAL (Hybrid Exoskeleton Assistive Limb) is developed using the local technologies which improve operation and maintenance costs. HEAL device is recognize as Cybernoid technology, offering an advanced neurorehabilitation robot system. This robotic exoskeleton device, interfacing of human and machine, enhances gait function in patients with slow neuromuscular disorders. HEAL aims to provide a powerful solution for stroke rehabilitation focusing on neuro-rehabilitation. Its personalized approach meets the various needs of stroke survivors, creating a supportive environment for better recovery and improved rehabilitation outcomes.

2. MATERIAL & METHOD

2.1. Mechanical Properties

The exoskeleton, as shown in Figure 1, was designed specifically to assist the left upper arm and forearm of the patient. Its primary function is to enable elbow flexion/extension. Aluminum was chosen as the material for the exoskeleton due to its lightweight nature, facilitating comfortable wear for the patient. Additionally, aluminum's inherent resistance to corrosion and oxidation ensures the exoskeleton's long-term durability. The upper arm section of the exoskeleton features a grip, while the forearm part incorporates two grips, providing essential support to both the arm and forearm. The structure comprises two links connected by a revolute joint. Belts are utilized at each grip to secure the exoskeleton to the upper arm and forearm.

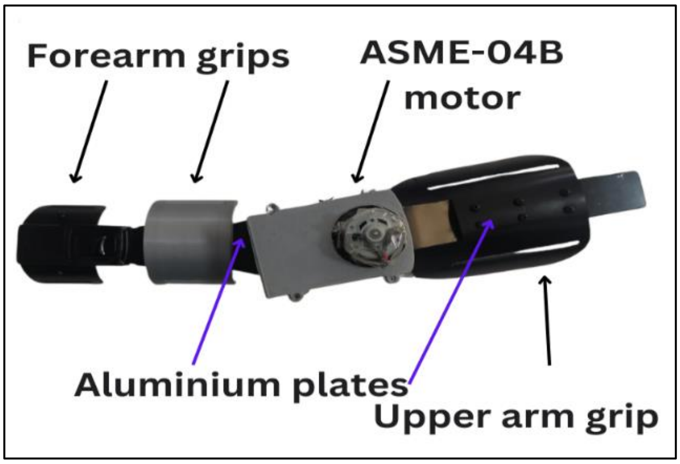


Figure 1. Hybrid Exoskeleton Assistive Limb (HEAL)

2.2. Angonist-Antagonist Muscle Model

The force a muscle applies to its associated joint can be expressed as an exponential function of the muscle's activation, A, as explained in [10]. This is activated by the difference between the current muscle length, l and an input parameter, a threshold length, λ(t). In addition, a component in the formulation represented by the letter I is proportionate to the rate at which the muscle length changes. Consequently, these components are regarded in the whole activation equation as:

$$\mathrm{A(t)} = [l(t-d) - \lambda(t) + \mu(t) i(t-d)]^{+} \tag{1}$$

where [x]+ = x in the absence of $x \leqslant 0$ and 0 otherwise. The unloading response of human arm muscles is when the reflex delay d is seen. Since every muscle has at least one antagonistic muscle acting on the same joint, we will be discussing here the most fundamental actuation component of the human neuro-muscle-skeletal system: an antagonistic pair of muscles. With reference to [10], the two muscles' respective forces, f1 and f2, are:

$$\begin{gathered} f_1 = \rho\left(e^{\delta A_1} - 1\right) \\ f_2 = -\rho\left(e^{\delta A_2} - 1\right) \\ A_1 = Rq(t-d) - \lambda_1(t) + \mu(t) R\dot{q}(t-d) \\ A_2 = -Rq(t-d) - \lambda_2(t) - \mu(t) R\dot{q}(t-d) \end{gathered} \tag{2}$$

In the previous equation, $l = Rq$, where q is the forearm's angular position with respect to the arm and R is the instantaneous lever arm.

When two agonistic and antagonistic muscles contract on the same joint, their forces balance out as shown in Figure 2:

$$\tau + R(f1 + f2) = 0 \tag{3}$$

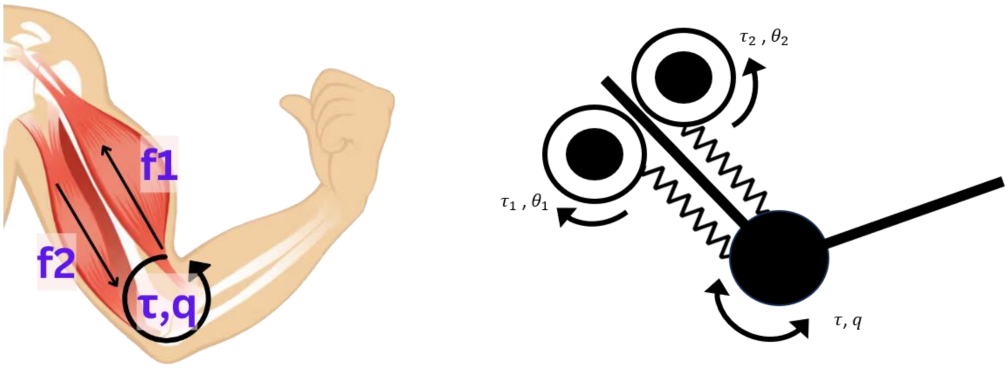


Figure 2. Human agonist-antagonist actuation systems with main variables underlined. q is joint angle, and τ is the external torque. f1 and f2 are the forces exerted by the biceps and triceps respectively.

The external torque is represented by τ. From Eqs. (2) and (3), the force equilibrium under static condition in the absence of any external load (i.e., τ = 0, q = 0) is obtained.

$$\begin{gathered} f_1 = -f_2 \\ e^{\delta(Rq-\lambda_1)} = e^{\delta(-Rq+\lambda_2)} \\ q = \frac{r}{R} \end{gathered} \tag{4}$$

where r :=$\frac{\lambda_1+\lambda_2}{2}$, is referred in literature as r-command. The derivative of the external torque τ with respect to the link location is the stiffness at equilibrium σ.

$$\sigma = \frac{\partial\tau}{\partial q}\bigg|_{q=\frac{\lambda_1+\lambda_2}{2R}} = 2\rho\delta R^2 e^{\delta c} \tag{5}$$

where c := $\frac{\lambda_2-\lambda_1}{2}$, This is known as co-activation or command in the literature

2.3. Robotic Exoskeleton Model

In this study, we're focusing on a specific kind of robot called the VSA antagonistic architecture [11]. Figure 2 shows the mathematical model how it works. It has two motors connected to the output shaft using some special springs. Each motor and its springs act like a muscle. In a previous study [12], they talked about why they chose these special springs, comparing them to how muscles work in general.

Similar to Eq. (2), we suggest the following features

$$\begin{gathered} \tau_1 = \gamma e^{\beta(q-\theta_1)} - u \\ \tau_2 = \gamma e^{\beta(-q+\theta_2)} + u \end{gathered} \tag{6}$$

Here, τ_1 and τ_2 represent the torques applied by each motor to the link. The constants β , γ and u depend on the chosen mechanical components. Similar to Eq. (3), we enforce the equilibrium of forces.

$$\tau + \tau_1 + \tau_2 = 0\,u \tag{7}$$

In this context, τ considers the external load, while τ_1 and τ_2 represent the torques applied by the motors to the link. The force balance under static conditions with no external load (meaning τ =0 and $q = 0$) and Eqs. (6) and (7) lead to the following

$$\begin{gathered} \tau_1 = -\tau_2 \\ => \ e^{\beta(q-\theta_1)} \\ => \ e^{\beta(-q+\theta_1)} \\ q = \frac{\theta_1+\theta_2}{2} \end{gathered} \tag{8}$$

We can find the stiffness, σ as a function of θ_1 and θ_2 by calculating the derivative of the external torque with respect to the link position q evaluated at equilibrium, thus,

$$\sigma = \frac{\partial\tau}{\partial q}\bigg|_{q=\frac{\theta_1+\theta_2}{2}} = 2\gamma\beta e^{\beta(\frac{\theta_2-\theta_1}{2})} \tag{9}$$

Observing mathematical expressions in (2), (4), (5) for human actuation and equations (6), (8), (9) for robotic actuation, it is evident that motor positions q_1 and q_2 play a similar role to activation lengths l_1 and l_2. Moreover, with the right selection of system parameters, these two behaviors are equivalent. Muscular systems model could be beneficially utilized with the ultimate goal of designing assistive robots powered by artificial muscles to work alongside human joints. However, in this study, we depend on single-channel EMG actuation targeting the bicep muscle, where the model reference τ_2 , θ_2. The mathematical representation model is suitable for dual-channel mode (e.g., bicep and tricep muscles), although it is not explicitly addressed in this work.

2.4. Electrode Placement

Electromyography (EMG) is a technique crucial for evaluating muscle function and health by measuring muscle electrical activity. When placing electrodes on the bicep muscle, precise positioning is vital for accurate readings. The bicep, comprising the long and short heads, requires careful electrode placement along its muscle fibres, typically in parallel to its length. One standard method involves positioning two electrodes, one closer to the shoulder and another nearer to the elbow enabling the capture of electrical signals during muscle contraction and relaxation. This setup provides valuable insights into the bicep's activity. Figure 3 illustrates the recommended EMG electrode placement on the bicep, maintaining a 2-centimeter distance between electrode 1 and electrode 2. The distance between EMG electrodes significantly influences signal quality. Maintaining a recommended distance of 2 centimetres or less is crucial. Larger distances between electrodes result in decreased signal pickup and an increase in noise [13]. The greater the distance between electrodes, the more susceptibility to interference and the weaker the signal detection. This proximity serves several essential purposes: minimizing interference from neighbouring muscles, enhancing resolution for analysing muscle activity patterns, amplifying signal amplitudes for clearer interpretations, and enabling specificity in isolating distinct portions of the muscle. Therefore, precise electrode placement with the recommended distance between electrodes is imperative for accurate recording and analysis of the electrical signals generated by the bicep muscle during various movements. This accuracy aids in diagnostics, rehabilitation, and the assessment of muscle performance.

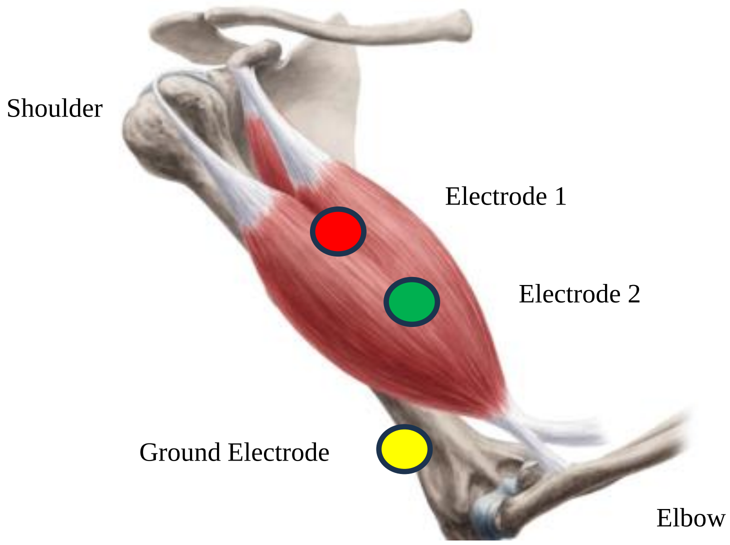


Figure 3. EMG electrodes placement at bicep muscle

2.5. EMG Signal Baseline and Thresholding

Everyone can have a distinct baseline for their bicep muscle EMG signal due to variations in muscle strength, size, and neuromuscular control. To establish a personalized threshold for EMG values, an exercise involving lifting a light weight load (200g) from 0 degrees to 120 degrees can be conducted. The choice of using a lightweight arm movement and exercise is based on the nature of the muscle (bicep), which contracts depending on forearm size and bone density. Therefore, a lightweight weight load is employed in the exercise to maintain consistency across all test subjects. The volunteer test subjects are aged 22-23 years, with an average weight of 70 kg and uniform arm dimensions, including length and width. It is crucial to minimize errors during the experiment, particularly during thresholding calibration, to ensure the accuracy and reliability of the data collected. This accuracy is essential for effectively controlling the servo motor movement and implementing the signal processing algorithm. During this process, the EMG signals generated by the bicep muscle are recorded. The movement pattern involves lifting the weight load gradually from a straight-arm position (0 degrees) to a flexed-arm position (120 degrees), engaging the bicep muscle. This exercise allows for the capture of EMG signals at different degrees of muscle contraction, thereby creating a range of values from minimum to maximum activation levels. By analyzing these recorded EMG signals, one can identify the minimum and maximum values exhibited by the bicep muscle during this specific exercise for that individual. These values serve as a personalized reference range, enabling the adjustment of threshold values of EMG according to the patient's unique condition and capabilities. This personalized approach enhances the accuracy of interpreting EMG data and ensures that thresholds are set appropriately for assessing the patient's muscle function and progression during rehabilitation.

2.6. System Block Diagram

The Hybrid Exoskeleton Assistive Limb (HEAL) integrates an Arduino Mega 2560 as its central control, managing ASME-04B high-power robotic motors and interpreting muscle electrical activity through an electromyography (EMG) sensor. Figure 4 shows the block diagram of HEAL device. The system begins by capturing electromyography data from the bicep, which is then transmitted to the Arduino Mega 2560 microcontroller. This controller, equipped with specific algorithms, interprets the signal, directing the high-torque servo motor to execute corresponding movements in the exoskeleton. The processed data is then presented and managed through a graphical user interface on a computer.

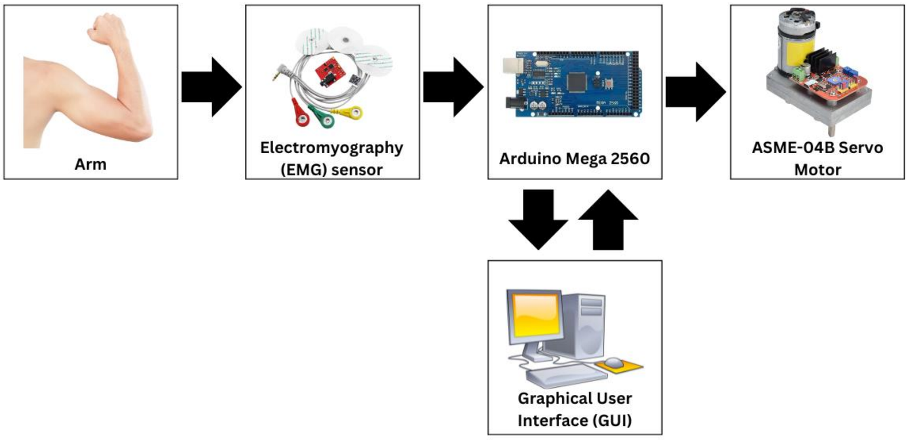


Figure 4. HEAL device’s block diagram.

2.7. Motor Movement

Surface EMG sensors are commonly used in literature as a useful measure of muscle activation. EMG electrodes are used to detect a motor unit action potential (MUAP), which is defined as the sum of the action potentials from each muscle fiber in a single motor unit. We approximate the muscle fiber activation (A_i) as being proportionate to the envelope of the associated EMG signal (E_i) given the tiny muscular surface area under consideration, deferring the implementation of more intricate algorithms to future research.

$$\theta = q - \alpha E \tag{10}$$

where α is considered as a gain. Remember that Eq. (10) does not require an additional control loop because it maps the subject's predicted goal muscle length onto its robotic equivalent. In this way, the muscle-like dynamics of the actuator are exploited instead of being eliminated [14]. It will be evident from the experimental validation that a control rule like the one in Eq. (10) effectively enhances user performance.

2.8. Electronic Component

HEAL incorporates an Arduino Mega 2560 as its central control unit, overseeing ASME-04B high-power robotic motors and interpreting muscle electrical activity via an EMG sensor module kit. The Arduino Mega 2560 as the primary control system for our exoskeleton was deliberate due to its extensive I/O ports, robust processing capabilities, strong community support, scalability, and user-friendly development environment. Its multitude of digital and analog pins easily accommodated various sensors and devices. Furthermore, the microcontroller in use possesses a 10-bit Analog-to-Digital Converter (ADC) resolution. This feature is particularly advantageous for sampling the EMG signal. The 10-bit ADC resolution signifies the microcontroller's ability to convert analog signals from the EMG sensor into digital values with high precision. In the context of electromyography, where capturing subtle variations in muscle activity is crucial, a higher ADC resolution allows for a finer and more detailed representation of the EMG signal, contributing to the accuracy and sensitivity of the overall system.The microcontroller's prowess in real-time control and signal processing, programmed using C++, handled complex computations and algorithms efficiently. Troubleshooting and integration were simplified by the support from the Arduino community and numerous communication options. Ultimately, the Arduino Mega 2560 and the C++ language emerged as the optimal combination for ensuring stability and flexibility in our rehabilitation exoskeleton's control system.

The EMG sensor module is based on AD620 IC. This instrumentation amplifier excels in measuring bipolar EMG signals with its high CMRR, low offset voltage, wide input range, adjustable gain, low noise, low power consumption, and single-supply operation, ensuring accurate and reliable signal amplification in diverse applications. On the other hand, surface EMG electrodes placed on the targeted muscle, capturing electrical activity during arm flexion/extension. Proper electrode placement, skin preparation, and minimal movement during measurements are crucial to reduce noise and interference. In the signal processing algorithm, averaging and low-pass filtering is implemented to extract desired EMG signals while eliminating unwanted noise. Averaging smoothens signal noise, and the low-pass filter attenuates high-frequency noise, preserving lower frequency components. The filtering equation involves time intervals, resistor, capacitor values, continuously updating the filtered output, and the user-adjusted average. Equation below shows the implementation of filtering technique algorithm for the EMG signal.

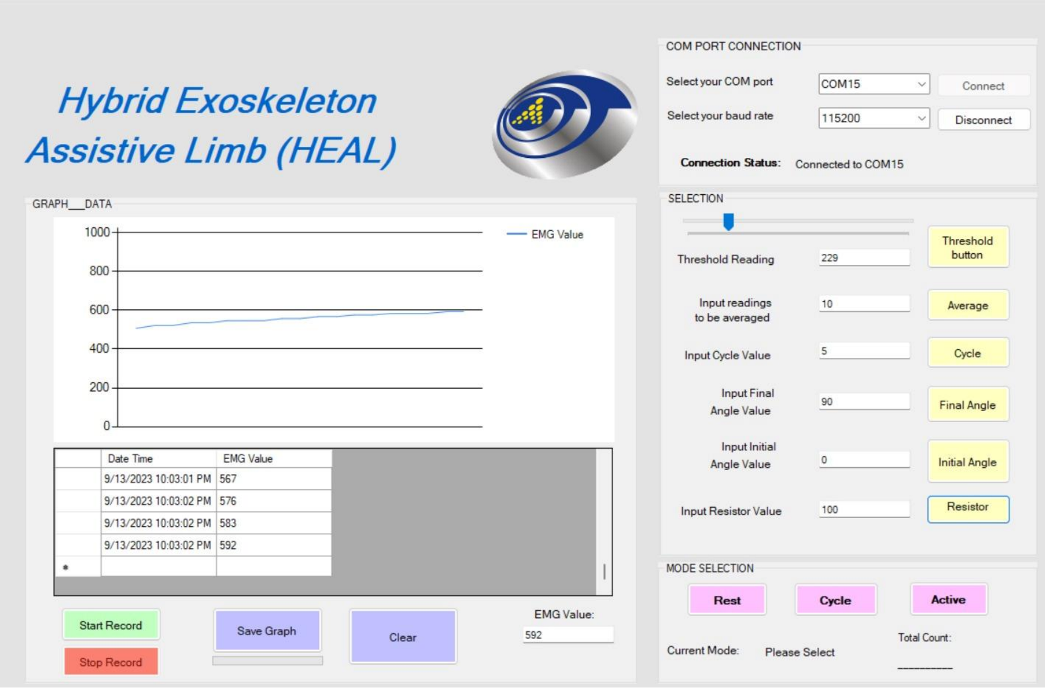
$$\mathrm{filteredValue} = \left(1.0 - \frac{\mathrm{dt}}{\mathrm{R} * \mathrm{C}}\right) * \mathrm{filteredValue} + \left(\frac{\mathrm{dt}}{\mathrm{R} * \mathrm{C}}\right) * \mathrm{average} \tag{11}$$

where dt represents time interval in seconds, R represents resistor value in ohms, C represents capacitor value in farads, filteredValue represents filtered output value, which is continuously updated, average represents current average value that user adjusted.

The ASME-04B High Torque Motor has been meticulously chosen for the exoskeleton's movement. This servo motor is selected for its high precision movement, boasting a high torque of up to 380kg.cm at 24V. Its strong power is ideal for elevating a patient's forearm during rehabilitation exercises and other robot applications [15]. Its stability is a key factor in ensuring patient safety, demonstrating the capability to maintain stability even in scenarios where fuses are blown. This stability control mechanism establishes a secure torque environment, proving to be essential for the overall stability and safety of the exoskeleton. The ASME-04B motor is externally powered using a 15V,5A power supply. Meanwhile, a 9V battery will be supplied to both the Arduino Uno and the EMG sensor module.

2.9. Graphical User Interfacing

To enable precise control and rehabilitation capabilities of the Hybrid Exoskeleton Assistive Limb (HEAL), an advanced control system and a specialized graphical user interface (GUI), shows in Figure 5, were developed. The GUI was designed using the Windows Forms application within the C# programming language, an integral component of the Microsoft .NET framework. Employing Visual Studio as the Integrated Development Environment (IDE) facilitated seamless integration and streamlined development for this project. Utilizing Windows Forms technology, the GUI offers an intuitive and adaptable platform for creating a sophisticated user interface tailored for therapists. Its primary function is to administer and calibrate the rehabilitation exercises specifically designed for individual patients. The GUI facilitates therapist-HEAL interaction by enabling the establishment of a connection via a serial communication port, allowing the selection of baud rates to ensure optimal device communication.



Hybrid Exoskeleton Assistive Limb (HEAL)

COM PORT CONNECTION
Select your COM port: COM15
Select your baud rate: 115200
Connection Status: Connected to COM15

SELECTION
Threshold Reading: 229
Input readings to be averaged: 10
Input Cycle Value: 5
Input Final Angle Value: 90
Input Initial Angle Value: 0
Input Resistor Value: 100

GRAPH__DATA

	Date Time	EMG Value
	9/13/2023 10:03:01 PM	567
	9/13/2023 10:03:02 PM	576
	9/13/2023 10:03:02 PM	583
	9/13/2023 10:03:02 PM	592
*		

EMG Value: 592

MODE SELECTION
Current Mode: Please Select
Total Count: ________

Figure 5. Graphical user interface for HEAL.

Key functionalities within the GUI include the adjustment of threshold values to align with the patient's condition. Additionally, fine-tuning of the total values read and resistor values is available, crucial for achieving consistent and stable readings. Parameters such as cycle value, initial and final angles can be modified through the interface, providing customizable exercise requirements. Moreover, the GUI facilitates real-time graph visualization and the option to save data in Excel format. This feature offers therapists valuable insights into the ongoing rehabilitation process, aiding in comprehensive analysis and patient progress tracking. The interface also incorporates a mode selection feature, allowing therapists to choose between Active mode, Cycle mode, and Rest mode. Each mode serves distinct rehabilitation purposes, providing tailored exercises suited to the patient's needs and current rehabilitation phase.

2.10. Rehabilitation Features

Therapist can also select to start and stop the monitoring session and save the data into excel file for analyze on patient’s progress and treatment outcome. Through this process, therapists can save their time from relaunching the GUI every time a new patient starts their treatment. Therapists have the flexibility to initiate and halt monitoring sessions at their discretion, allowing them to focus their attention precisely when needed. Furthermore, the data collected during the treatment sessions can be logged and exported to an excel file, creating a great repository for post-session analysis. Therapists can easily monitor patient progress, treatment selection decision. GUI needed to integrate with the Arduino Mega 2560 board to ensure a robust and dependable connection for controlling the HEAL. Therapists can fine tune the critical parameters, such as signal averaging to reduce noise, adjust low pass filter settings for cleaner EMG signals which we adjust the resistor value when capacitor value is set as constant, specify motor angles for targeted exercises, and set threshold values for “Active Mode”, cycle selection for “Cycle Mode”. Figure 6 shows the function flow chart of mode selection in GUI.

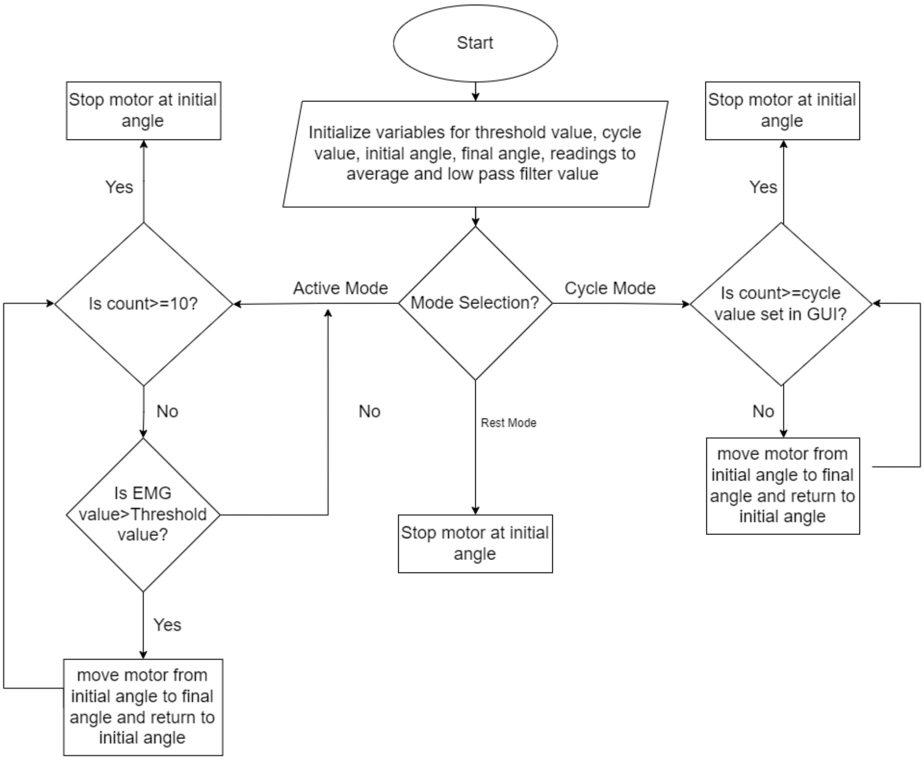


Figure 6. Function flow chart for mode selection in GUI

3. RESULTS AND DISCUSSION

Our system features two distinct operational modes, "Active Mode" and "Cycle Mode," designed to monitor a patient's muscle activity through EMG values during upper limb rehabilitation shows in Figure 5. Active Mode within HEAL functions as a responsive system, emulating Active Range of Motion (AROM) exercises by actively engaging patients in their rehabilitation process. In conjunction with Electromyography (EMG) signals, this mode uses data on muscle activation in real time to initiate and assist forearm raising. When EMG values are detected that are higher than personalised threshold value that are adjusted according to the patient's highest EMG value as shows in Figure 7, HEAL reacts by offering tailored assistance and progressively moving the limb from an initial to a final angle that is predetermined (between 0° and 70°) shows in figure 8. A customised rehabilitation experience is generated by this progressive movement, which is precisely adjusted to the patient's individual muscle strength. The Graphical User Interface (GUI) of the system shows real-time electromyography (EMG) data, which allows therapists to carefully watch and record the muscular contraction patterns. This is important for evaluating muscle engagement, relaxation stages, and overall therapy progress.

On the other hand, Cycle Mode feature simulates PROM (Passive Range of Motion) workouts by automatically carrying out pre-planned rehabilitation cycles. Based on PROM principles, this mode carefully avoids joint stiffness and pain by coordinating controlled limb motions. Cycle Mode makes a significant contribution to comprehensive therapy procedures by reproducing this essential early-stage rehabilitation phase. The system's programmable parameters, which include averaged input readings, initial and ultimate angle values, resistor values, and cycle values, are used by therapists to customise treatment to each patient's maximal EMG value. By precisely tailoring the rehabilitation routine to each patient's unique muscle strength, this custom calibration maximises its effectiveness.

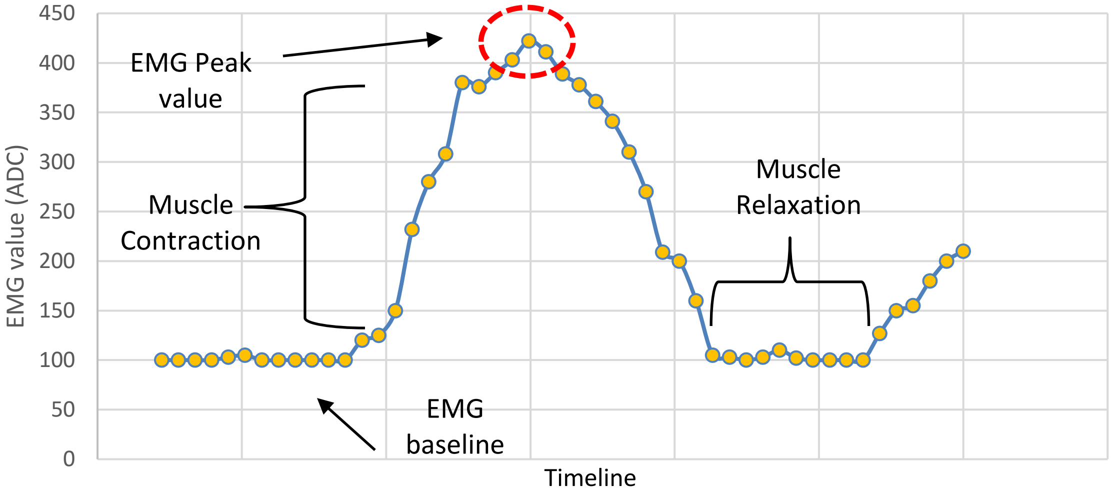


Figure 7. EMG signal during muscle contraction and relaxation

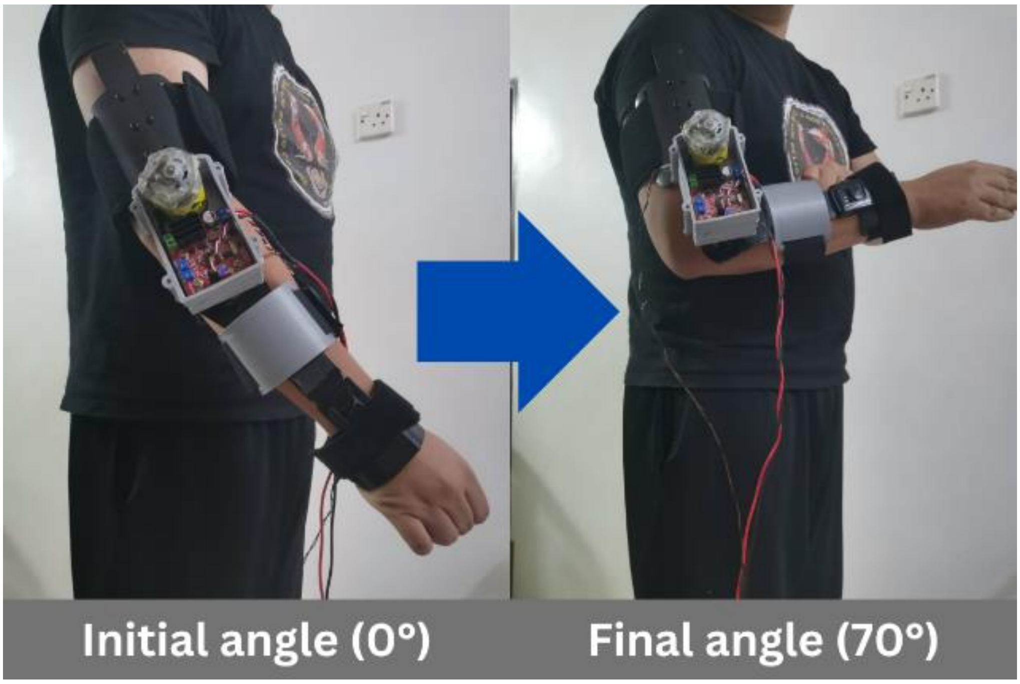


Figure 8. Movement from initial angle to final angle

Table 1. Test of difference EMG electrodes distances

		Mean Value (ADC)	Peak Value (ADC)	Standard Deviation
T1	Position 1 (2cm)	196.12	210	9.55
	Position 2 (4cm)	175.23	190	20.18
	Position 3 (6cm)	165.11	173	22.05
T2	Position 1 (2cm)	193.74	209	8.58
	Position 2 (4cm)	190.3	198	22.24
	Position 3 (6cm)	155.2	176	24.15
T3	Position 1 (2cm)	195.74	210	8.81
	Position 2 (4cm)	184.32	170	30.76
	Position 3 (6cm)	152.38	165	23.94
T4	Position 1 (2cm)	190.1	227	6.16
	Position 2 (4cm)	177.59	184	25.81
	Position 3 (6cm)	138.23	159	23.57

In addition to displaying real-time EMG data, the HEAL interface gives therapists the capacity to track patterns in muscle activity, initiate system reactions, and carefully record treatment data for in-depth examination. Additionally, the system incorporates a "Rest" button to emphasise safety. This function functions as an instantaneous interrupt mechanism, giving therapists the ability to quickly stop any mode and gradually restore the device to its starting angle, which will ensure patient safety and comfort. The dual-mode system from HEAL's inherent adaptability provides a flexible and nuanced approach that can be tailored to meet a variety of rehabilitation goals. Through the integration of both passive and active exercise paradigms, HEAL endeavours to coordinate a thorough upper limb rehabilitation process that is precisely customised to meet the individual needs of every patient and expedite their rehabilitation trajectory.

An experiment was conducted to determine the optimal distance for EMG electrode placement. This experiment involved the participation of four men, all within the age range of 22 to 23 years. To comprehensively assess the impact of electrode placement, three different distances which are2cm, 4cm, and 6cm were selected for testing. Every distance was tested 50 times, carefully recording the data obtained from these EMG readings. Following analysis of the data, tabulated results were obtained for comparison and conclusion.

After a proper evaluation of the data collected, a pattern became apparent. As the distance between the EMG electrodes increased, it was evident that both the mean and peak values consistently declined. Every person examined within the designated age range showed the same pattern. Furthermore, a fascinating relationship between the standard deviation and the electrode implantation distance was found. The standard deviation consistently decreased as the distance between the electrodes grew. Notably, a lower standard deviation suggests more stability in the data that was gathered. This result is consistent with previous EMG study assumptions, indicating that higher data variability is caused by an electrode arrangement that is positioned closer together.

The combination of these observations and statistical analysis produced an important finding: position 1, where the electrodes were positioned 2 cm apart, was shown to be the most ideal location for EMG electrodes based on the characteristics examined. This conclusion was reached based on the pattern of declining peak and mean values together with a decline in standard deviation. The selection of the 2 cm distance showed a tendency toward EMG readings that were steadier and more reliable. This crucial discovery highlights the significance of taking electrode placement distance into account for more precise and trustworthy data collection and processing, and it has positive implications for next EMG research and applications.

4. CONCLUSION

HEAL emerges as an innovative solution designed specifically for upper limb rehabilitation in response to the prevalent challenges posed by strokes. The current conventional rehabilitation techniques, including constraints on time and costs, patient motivation issues, therapist and patient fatigue, accessibility limitations, and inadequate progress tracking, underscore the urgent need for more effective approaches. HEAL addresses these challenges by offering efficient and innovative robotic neurorehabilitation experience. With features such as real-time EMG monitoring, an intuitive GUI fostering therapist communication, and adaptable operational modes, HEAL presents a promising shift in the paradigm of rehabilitation methodologies. Significantly, HEAL's actual performance aligns with expectations; the EMG module consistently produces low-noise signal values, affirming the device's dependability and efficacy. As a suggestion for future enhancements, incorporating triceps signals could potentially improve the sensitivity of the exoskeleton robotic system, further refining the capabilities of the HEAL device for more personalized and nuanced rehabilitation interventions in the future. Furthermore, the ASME-04B motor ensures a consistent and steady range of movement, reinforcing HEAL's potential as a reliable and effective tool in the realm of robotic neurorehabilitation for stroke patients.

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