ADAPTIVE CONTROL SYSTEM USING ELECTROMYOGRAPHIC SIGNALS FOR A STANDING ASSIST DEVICE FOR INDIVIDUALS WITH MOTOR IMPAIRMENTS

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Abstract - According to the 2022 World Health Organization report, over 1.3 billion people worldwide live with some form of disability, highlighting the growing need for effective rehabilitation technologies. Verticalization—assisting patients in achieving and maintaining an upright posture—is a critical component of rehabilitation for individuals with motor impairments. This paper presents the design, development, and initial evaluation of an adaptive standing frame control system that utilizes electromyographic (EMG) signals to enable semi-active patient participation in postural transitions. The system integrates hardware components such as a MyoWare EMG sensor, a high-precision analogue-to-digital converter (ADS1115), a Raspberry Pi 4B single-board computer, and a motor driver to control a lifting mechanism. The control algorithm calibrates individual muscle activity, filters real-time EMG data, and adjusts motor speed accordingly, providing responsive assistance during sitting-to-standing movements. The prototype was successfully assembled and activated, demonstrating the feasibility of using electromyographic signals for real-time control of rehabilitation devices, and the flexibility of the system allows for further enhancements and adaptation for user-specific needs. The results of internal testing indicate that the system responds reliably to muscle-generated signals and may serve as a foundation for future rehabilitative devices based on human-machine interaction. With continued refinement, extended functional testing, and clinical validation, it has the potential to evolve into a fully certified assistive device suitable for therapeutic use in rehabilitation centres or home-based care settings.

Keywords: Verticalization, Rehabilitation technology, Electromyography (EMG), Adaptive control system, Assistive devices, Motor impairments, Raspberry Pi, Muscle signal processing, Semi-active assistance, Standing frame.

1. Introduction

Based on the 2022 disability report by the World Health Organization (WHO), around 1.3 billion individuals—roughly 16% of the world's population—live with some type of disability. Over the last ten years, this number has grown by over 270 million, mainly due to shifts in demographics and health patterns, such as the aging populations in many nations [28].

Rehabilitation serves as a cornerstone in addressing the needs of individuals with disabilities. The impact of rehabilitation on their lives extends beyond physical recovery and includes emotional, social and functional dimensions. Gartmann et al. [9] describe flexible, individualized rehabilitation programs that promote patient engagement and continuity of care through the involvement of caregivers. Madsen et al. [18] highlight the benefits of community-based rehabilitation approaches, which emphasize real-world participation and inclusive practices. From a societal perspective, Luo et al. [17] emphasize that rehabilitation constitutes a fundamental human right essential for social reintegration. Their findings confirm that access to effective rehabilitation, particularly in underserved rural areas, positively correlates with education and awareness. Collectively, these studies affirm that

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well-structured rehabilitation can significantly improve life quality, autonomy and community participation, highlighting the importance of accessible, adaptable and patient-centered interventions. Nonetheless, a persistent challenge remains in translating these principles into rehabilitation devices and protocols that adapt in real time to individual patient needs. In summary, rehabilitation aims not only to restore lost function but also to enhance quality of life, promote autonomy and facilitate social reintegration.

Tailored rehabilitation interventions help individuals recover motor skills, manage daily tasks, and reduce reliance on caregivers [26]. Importantly, rehabilitation is not confined to physical therapy alone. Gartmann et al. [9] emphasize that involving family members and carers can strengthen emotional support and foster motivation during recovery. Madsen et al. [18] further demonstrate that outdoor, naturalistic rehabilitation environments enhance social participation and mental well-being, offering valuable opportunities for reintegration and independence. These findings underscore the role of rehabilitation in promoting both physical improvement and psychosocial resilience.

Among various therapeutic strategies, verticalization is recognized as a critical intervention that enables individuals to achieve and maintain an upright posture. This process is vital for improving circulation, preventing complications related to prolonged immobility, and enhancing physical and social interaction. Verticalization is particularly beneficial for individuals affected by neurological conditions [30], musculoskeletal impairments, or physical disabilities [2]. Beyond its physiological advantages, verticalization contributes significantly to psychological well-being and social reintegration.

To support verticalization, a wide range of standing assist devices has been developed. These include mechanical, electromechanical, and robotic systems, designed to meet the varying functional needs of patients at different stages of recovery. For example, sit-to-stand assistive chairs equipped with pneumatic mechanisms [11] facilitate smoother and safer transitions to standing. Passive exoskeletons provide structural support to assist with voluntary postural adjustments [8]. While these devices offer increased mobility, they often require manual calibration and lack sensor-driven adaptability, potentially reducing user comfort and limiting therapeutic benefits.

A distinct category within standing assist devices is referred to as verticalizers—mechanical systems that actively or passively assist patients in achieving and maintaining upright posture. These devices are typically categorized into [27]:

• Static Stationary Verticalizers are primarily used during the early stages of rehabilitation when patients lack the strength or balance for active posture control. However, their immobility can restrict patient engagement and prolong dependency.

• Mobile Static Verticalizers enable patient transport while in an upright position, increasing flexibility in care settings, yet they often compromise on the range of movement and require considerable therapist involvement.

• Dynamic Upright Trainers assist users who can maintain an upright posture for extended periods, enabling partial walking or stepping functions. Nevertheless, these systems often follow rigid protocols that do not adapt to the real-time physiological state of users.

Advanced devices such as robotic tilt tables (e.g., Erigo® Pro) combine functional electrical stimulation (FES) with automated passive limb movements to support recovery in neurological patients. Kim et al. [14] demonstrated that these devices improve lower-limb muscle strength and mobility by facilitating joint movements in sub-acute stroke patients. Similarly, Rosenfelder et al. [24] reported that the Erigo® Pro helps prevent orthostatic hypotension and promotes cardiovascular stability in patients with disorders of consciousness, with longer upright positioning linked to better recovery outcomes. This suggests that such devices are well-suited for individuals recovering from stroke or traumatic brain injuries. However, these systems follow predefined movement protocols without real-time physiological adaptation, which limits their responsiveness to individual patient needs.

Other notable verticalization tools also have some rehabilitation issues. For example, manual standing frames and harness-based systems provide more active patient participation but often trade off with user comfort and safety concerns during prolonged use [10]. Moreover, sit-to-stand assistive chairs [29] and electromechanical gait trainers [12] incorporate mechanical or robotic assistance but rarely integrate comprehensive sensor feedback to modulate therapy in real time. Electromechanical gait trainers combine robotic assistance with real-time feedback to support verticalization and facilitate walking re-education [12]. These devices aim to enhance motor recovery by providing guided movement patterns, yet their adaptability to individual patient needs remains limited. Robotic-assisted systems incorporate sensors and adaptive algorithms to personalize therapy, targeting motor learning and neuroplasticity, particularly in post-stroke patients [4, 16]. Despite these technological advancements, many of these solutions still rely on predefined movement protocols and lack comprehensive real-time physiological adaptation. Exoskeletons, as wearable robotic devices, support joint movement and enable upright, assisted walking for individuals with lower-limb paralysis [19], but they too face challenges in dynamically responding to fluctuating patient states.

The increasing pace of robotization has led to the development of rehabilitation devices that are more sophisticated, ergonomic, and environmentally conscious. Recent efforts prioritize eco-mobility, designing systems that minimize environmental impact while maximizing functional outcomes for users [6]. Such innovations address not only clinical effectiveness but also the ethical imperative to reduce healthcare's carbon footprint. However, despite these significant strides, many existing verticalization devices still require manual adjustments by therapists and lack intelligent, user-centered adaptability that could actively respond to patients' changing physical states and rehabilitation progress.

The limitation of systems following fixed movement patterns without real-time physiological feedback has been extensively discussed in the literature. For example, Iosa et al. [13] emphasize that the absence of dynamic physiological feedback significantly reduces robotic systems' ability to tailor therapy effectively, thus limiting treatment outcomes. Similarly, Bó et al. [1] argue that the lack of interaction force feedback constrains therapists' ability to fine-tune interventions during sessions, thereby diminishing therapeutic benefits. Chien et al. [5] further highlight that many robotic-assisted therapies still lack robust personalization mechanisms, restricting their potential to deliver truly tailored rehabilitation experiences. Moreover, Ranzani et al. [22] point out that numerous clinical trials have demonstrated only marginal improvements with robotic interventions compared to conventional therapies, underscoring the pressing need for enhanced adaptability to individual patient conditions.

This paper presents the design and evaluation of an innovative verticalization device intended to support the rehabilitation of individuals with movement dysfunctions. Emphasizing adaptability, sustainability, and technological integration, the proposed system aims to enhance user autonomy, contribute to therapeutic outcomes, and advance the field of assistive mechatronics in healthcare.

While existing verticalizers support upright posture through preprogrammed sequences or manual adjustments, few systems incorporate real-time biofeedback. By addressing the current limitations of verticalization devices, this work aims to contribute significantly to enhancing patient-centered rehabilitation outcomes. The aim of this work is to integrate EMG-based adaptive control to personalize therapy intensity and duration. The proposed system incorporates modern hardware components, including a Raspberry Pi single-board computer, electromyographic (EMG) sensors for real-time muscle activity detection, and motor drivers, enabling responsive, user-specific control of the verticalization process.

The primary objective of this work is to create a functional prototype that enhances the usability, comfort, and therapeutic effectiveness of verticalizers by incorporating physiological signal feedback. This study details the conceptual framework, component selection, hardware construction, and software implementation, followed by an initial evaluation of the system's potential to improve rehabilitation outcomes in individuals with movement dysfunctions.

2. System Description

This section provides an overview of the adaptive standing frame system developed to assist patients with motor impairments during rehabilitation. The system is designed to facilitate verticalization by supporting users in the transition between sitting and standing positions through a semi-active control mechanism based on electromyographic (EMG) signals.

The primary design objective was to create a control system for the verticalizer that adaptively influences the entire process of lifting and lowering the body, based on information obtained from muscle tension sensors attached to the user's body. The sensor measures muscle activation through electrodes placed on areas such as the upper arm or forearm, where muscle signals can be effectively detected. Depending on the detected muscle tension value, the control system regulates the operation of the lifting mechanism.

The lifting is achieved via safety straps attached to the user's body, which are wound or unwound by a motor to raise or lower the patient. The process of verticalization can be divided into four stages:

- Active attempt of limb muscle contraction,
- Detection of muscle tension at the initiation of the lifting movement through measurement electrodes,
- If the muscle tension exceeds a certain threshold, the control system activates the lifting motor to maintain tension in the safety straps and prevent falls,
- Stabilization of the patient in an upright position.

Such a system allows for semi-active patient participation throughout the verticalization process. The muscle tension sensor is typically placed on areas allowing effective measurement, such as the upper arm or forearm. Active involvement of the patient in achieving an upright posture positively influences motivation for rehabilitation and generates neural stimuli from the brain to the affected limb. Moreover, during the process, the patient can concentrate on performing the movement, partially distracting from discomfort or pain caused by position changes.

As shown in Figure 1, the adaptive verticalizer consists of the muscle tension sensor (1), control system (2), motor with lifting mechanism (3), attachment belt (4), battery (5), switch (6), and table (7).

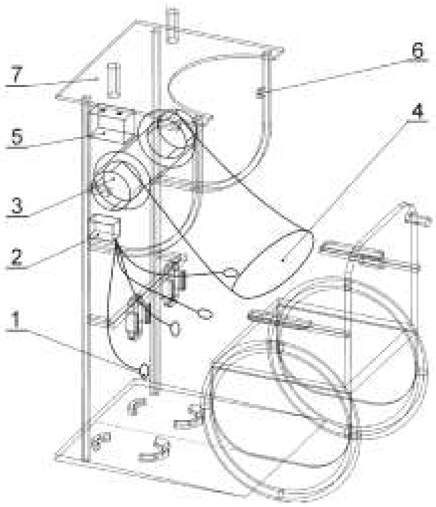

Figure 1: Schematic diagram of the adaptive verticalizer: muscle tension sensor (1) control system (2), motor with lifting system (3), attachment belt (4), battery (5), switch (6) and table (7).

The system integrates hardware and software components to detect voluntary muscle activation, process biosignals, and control a motorized lifting mechanism. The overall architecture includes a sensing subsystem (EMG sensor and ADC), a control unit (Raspberry Pi 4B - referred to as Raspberry Pi hereafter), a motor driver, and mechanical components (lifting strap, frame). The system architecture is summarized in the block diagram shown in Figure 2.

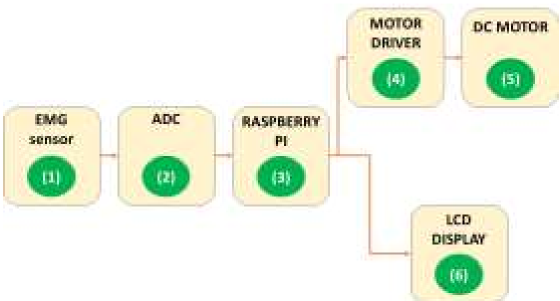

Figure 2: Block diagram of the control system for the adaptive standing frame

The muscle signal is acquired by the MyoWare Muscle Sensor (1), converted to digital form by the ADS1115 analogue-to-digital converter (2), and transmitted to the Raspberry Pi (3) via the I2C bus. The processed data is used to generate control signals sent to the L298N motor driver module (4), which controls the direction and speed of the DC motor (5). The current signal values and system messages are displayed on the LCD screen (6).

The primary aim is to enhance patient engagement during rehabilitation, promoting neuromuscular activation and improving safety and comfort through adaptive assistance. The system also provides real-time feedback to users via an LCD display to increase motivation and awareness during therapy sessions.

2.1. Design Objectives

The key objectives guiding the design and development of the control system were:

- To create an adaptive control system that responds in real time to voluntary muscle contractions, enabling semi-active patient participation during standing and sitting movements.
- To employ surface electromyography (EMG) signals as the primary input for detecting muscle activation, ensuring a direct physiological link between patient intent and device action.
- To develop a reliable and precise hardware platform capable of accurate EMG signal acquisition, real-time processing, and smooth motor control.
- To ensure system safety by implementing threshold-based activation and controlled motor speed to prevent sudden or unintended movements.
- To design the mechanical components (lifting mechanism, frame, support straps) for ergonomic and adjustable patient support, allowing customization to individual needs.
- To incorporate user feedback mechanisms (LCD display) to improve usability and therapeutic engagement.
- To create a modular and scalable system architecture that can be further enhanced with additional sensors or advanced control algorithms in future iterations.

3. Materials and Methods

This section details the hardware components, system integration, and software algorithms implemented to realize the adaptive control of the standing frame. The methodology encompasses the selection of sensors and actuators, the design of the control architecture, as well as the software implementation facilitating real-time muscle activity monitoring and motor control. Emphasis is placed on the integration of electromyographic signal acquisition with motorized assistance to enable a responsive and user-adaptive rehabilitation device.

3.1. Hardware Components

The developed adaptive standing frame control system consists of several key hardware components:

- Raspberry Pi 4B: Serving as the central processing unit, this single-board computer runs Raspberry Pi OS and handles signal acquisition, processing, and motor control. Communication with peripherals is achieved through I2C and GPIO interfaces.
- MyoWare EMG Sensor: A compact electromyography sensor that detects muscle electrical activity by measuring surface muscle potentials through electrodes. This sensor is typically positioned on the arm or forearm to capture voluntary muscle contractions relevant to the standing process. The MyoWare Muscle Sensor used for signal acquisition is shown in Figure 3.

Figure 3: MyoWare Muscle Sensor used for muscle voltage signal acquisition [25]

- ADS1115 Analog-to-Digital Converter (ADC): A 16-bit ADC module interfaced via I2C, responsible for converting the analogue EMG signals into digital data with high precision and low noise, critical for accurate muscle activity detection. The DFRobot ADS1115 ADC utilized in the system is illustrated in Figure 4.

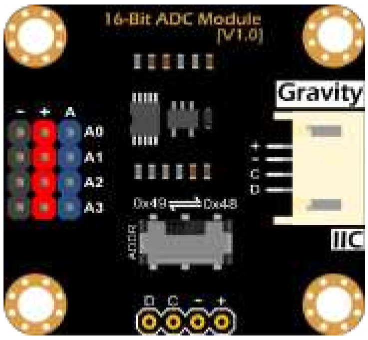

Figure 4: DFRobot ADS1115 Analog-to-Digital Converter [5]

- Brushed 775 DC Motor: Operating at 12 V with a nominal torque of approximately 0,2 N·m, this motor drives a custom-designed gear mechanism with a reduction ratio of approximately 162:1, enabling an effective output torque near 30 N·m to safely assist patient verticalization.
- L298N Motor Driver Module: A dual H-bridge driver allowing bidirectional motor control. It receives PWM signals for speed control and digital inputs for direction, powered from a 12 V supply with onboard voltage regulation to power logic circuits. The L298N motor driver module used is presented in Figure 5.

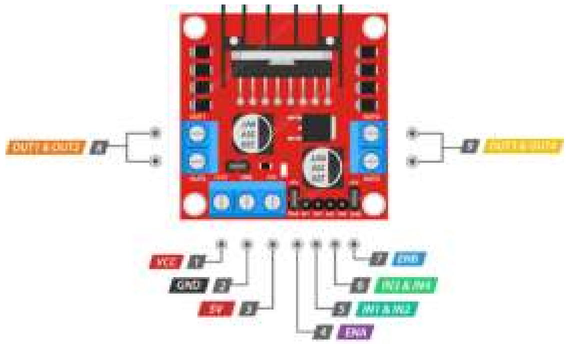

Figure 5: L298N Motor Driver Module [15]

- 16x2 Character LCD Display: Employed for real-time system status feedback, this display operates in 4-bit mode and interfaces with the Raspberry Pi through GPIO pins, providing user-readable information such as muscle signal levels and operational states.
- Mechanical Frame and Lifting Mechanism: The system incorporates a steel tubular frame with adjustable knee supports and a torso support platform. A lifting strap wound around a drum connected to the motor enables smooth verticalization by tightening or loosening the strap based on motor rotation. Components of the verticalizing mechanism are shown in Figure 6.

Figure 6: Components of the verticalizing (lifting) mechanism [20]

This combination of hardware ensures the standing frame responds effectively to user muscle activation, facilitating safe and controlled patient support.

3.2. System Integration

The complete circuit connection diagram illustrating the interconnection of system components is depicted in Figure 7. All components are interconnected according to the designed wiring schematic.

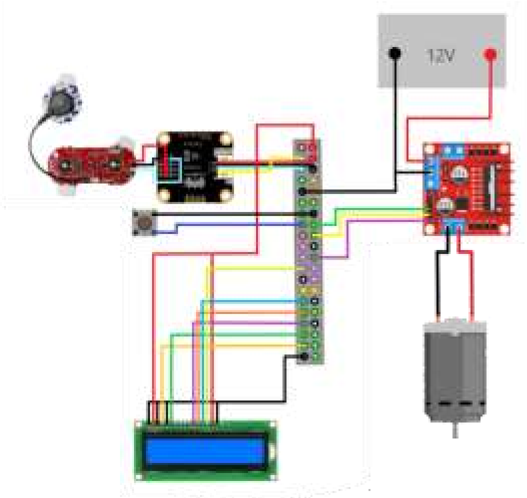

Figure 7: Circuit connection diagram of the control system

The EMG sensor is connected to channel A0 of the ADS1115 analogue-to-digital converter, which communicates with the Raspberry Pi via the I2C interface. Specifically, GPIO pins IO2 (SDA) and IO3 (SCL) handle data exchange.

The motor is driven through the L298N motor driver module. Control signals for motor direction are provided by GPIO pins IO23 and IO24, while speed control is achieved using a PWM signal from pin IO25. The L298N motor driver module is powered by a 12V battery and also supplies logic-level voltage to the Raspberry Pi via its integrated 5V regulator.

The LCD display receives power from the Raspberry Pi and communicates through several GPIO pins (IO13, IO6, IO5, IO11) configured for data transfer and control.

The core functionality of the system is based on real-time EMG signal analysis. When the measured muscle activity exceeds a preset threshold, the control algorithm triggers motor activation. The motor then tightens the lifting strap, gradually supporting the patient's movement until they reach a stable upright position. This integration allows for semi-automatic, responsive operation that adapts to the user's muscular engagement.

3.3. Adaptive Control Algorithm

The control software was developed in Python using the Thonny IDE on the Raspberry Pi OS (formerly Raspbian). Python was chosen due to its readability, flexibility, and a rich ecosystem of libraries facilitating GPIO configuration, I2C communication, PWM signal generation, time management, and system command execution.

Upon system startup, the program enters a standby mode, awaiting user confirmation via a push button. This confirmation indicates that the EMG sensor with surface electrodes has been properly positioned on the patient's muscle.

To accommodate individual differences in muscle signal amplitude and electrode placement, a calibration routine is performed immediately after user confirmation. During the first 5 seconds, the system records peak muscle activity to determine the maximum EMG voltage level. This is followed by a 5-second measurement of resting muscle activity to establish the baseline noise level. Calibration progress and current values are continuously displayed on the LCD screen to provide real-time feedback to the user.

After calibration, the main control loop begins. EMG signals are continuously acquired and converted from analogue to digital form via the ADS1115 ADC using the I2C bus. To reduce noise and fluctuations inherent in surface EMG signals, the digital data are smoothed using an Exponentially Weighted Moving Average (EWMA) filter.

Motor activation is triggered when the filtered EMG voltage exceeds 50% of the calibrated maximum level. The filtered signal value is then converted into a proportional PWM duty cycle, which is sent to the L298N motor driver module. This enables smooth and responsive motor control, dynamically adjusting speed and direction based on real-time muscle activity, thus assisting the patient in verticalization.

User interaction with the system is facilitated via a single button: a short press toggles the motor direction to allow strap loosening or sitting assistance, while holding the button for three seconds initiates a safe system shutdown. Throughout operation, the current muscle activation level, expressed as a percentage of the calibrated maximum, is continuously updated on the LCD screen to provide immediate feedback to the user and caregiver.

3.4. Software Libraries

The software relies on several Python libraries to support hardware interfacing and control functions:

- RPi.GPIO – for configuring GPIO pins, generating PWM signals, and monitoring input states.

- time – for managing delays and timing-related operations.
- os – to execute system-level commands such as shutdown procedures.
- DFRobot_ADS1115 – a dedicated library to interface with the ADS1115 ADC over I2C, enabling precise analog signal acquisition.

4. Results and Discussion

Following the completion of the hardware integration and software development, the prototype of the adaptive control system for the standing frame was successfully assembled and activated. All system components—both mechanical and electronic—functioned in accordance with the predefined specifications. The overall appearance of the standing frame with the installed control system is shown in Figure 8.

Figure 8: Adaptive standing frame prototype used for laboratory testing

The EMS sensor effectively detected analog voltage changes associated with muscle contraction, converted via the ADS1115 ADC, and transmitted to the Raspberry Pi. The implemented two-phase calibration procedure individualized upper and lower voltage thresholds, accounting for user-specific muscle tone and electrode placement.

Signal stability and noise reduction were achieved through the application of an EWMA filter, providing stable input for motor control. Motor actuation was controlled by a PWM signal proportional to the filtered muscle signal, with activation threshold set at 50% of the calibrated maximum voltage. Motor direction was reversed by a single button press, and holding the button for three seconds deactivated the system. The DC motor and gear assembly, mounted underneath the tabletop of the standing frame, is illustrated in Figure 9.

Figure 9: Motor with gear assembly mounted under the tabletop of the standing frame

Figure 10 shows the design and implementation of the gear mechanism: part (a) presents the schematic view of the gear system and motor housing, while part (b) displays the final printed assembly.

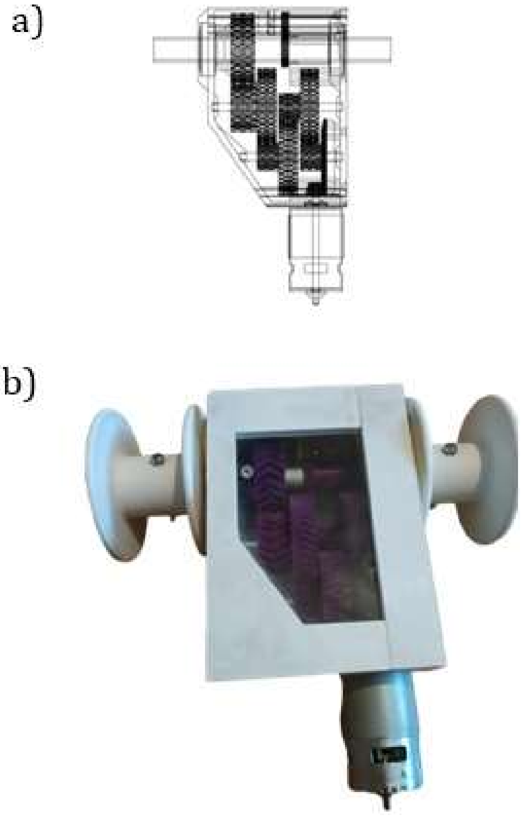

Figure 10: Gear mechanism integrated with the motor: (a) design schematic with housing [20]; (b) 3D-printed and assembled version used in the prototype

The LCD display provided real-time feedback, indicating the percentage of the current signal relative to the calibrated maximum, as well as displaying relevant system messages. From an ergonomic standpoint, the control unit was mounted on top of the table for visibility and accessibility, while the drive mechanism was installed underneath to improve safety and reduce visual clutter.

Although numerical testing was not conducted, laboratory demonstrations confirmed the system's functionality, responsiveness to voluntary muscle activation, and alignment with the project's initial design specifications. The calibration routine successfully individualized the threshold levels, ensuring consistent operation across different users.

One limitation of the current study is the absence of clinical or quantitative evaluation. Nonetheless, the functional verification conducted in a laboratory context lays a solid foundation for future empirical validation and clinical trials.

The implemented design demonstrated the feasibility of using electromyographic signals for real-time control of rehabilitation devices, and the flexibility of the system allows for further enhancements and adaptation for user-specific needs.

Research performed by Rea et al. [23] highlights that customizing assistive devices according to individual anthropometric data can significantly enhance their usability and effectiveness. Specifically, these researchers employed simplified human body models—composed of multiple segments and joints based on anthropometric measurements—to simulate user-device interaction. Such an approach not only evaluates the mechanical function of the device but also incorporates ergonomic factors like user comfort and movement trajectories. Although the current study did not incorporate anthropometric modelling, integrating such simulations in future development stages could provide valuable insights to optimize device design for individual users and improve overall rehabilitation outcomes. This practice is particularly important as it addresses the variability in user anatomy and movement patterns, which can critically impact the effectiveness and safety of assistive devices.

A related study on a pneumatic sit-to-stand assistive chair [11] explored the use of a mechanically driven system utilizing a pneumatic cylinder to reduce muscular effort during the sit-to-stand transition. The results demonstrated a measurable decrease in activity of key lower limb and trunk muscles, such as the rectus abdominis and quadriceps femoris, when using the device. While this confirms the device's effectiveness in reducing physical demand, its operation is based on fixed mechanical assistance and does not adapt to individual user characteristics such as weight, muscle strength, or degree of disability.

In contrast, the system developed in this project incorporates adaptive control based on real-time EMG signals, enabling individualized assistance levels. Unlike the purely passive pneumatic solution, this approach has the potential not only to support movement but also to engage the user actively in the sit-to-stand task. This makes it potentially suitable not only for support but also for rehabilitation, encouraging muscle activity and user participation.

However, the pneumatic system was evaluated quantitatively through surface EMG in a sample of healthy individuals, providing valuable physiological data. While the system presented in this work has not yet undergone a similar quantitative validation, the preliminary functional testing confirmed that the intended assistive behaviour was achieved. Further studies will be required to replicate similar EMG-based assessments on target populations, such as older adults or individuals with mobility impairments, to fully assess the clinical relevance and effectiveness of the adaptive system.

Another related solution is presented in a study involving a pneumatically actuated lift walker designed to assist users during the sit-to-stand transition [3]. This device provides purely vertical motion via bilateral gas springs, delivering a constant upward force of approximately 890 N to reduce physical effort. It was successfully tested on able-bodied individuals and a subject with incomplete spinal cord injury, showing a significant reduction in lower and upper limb effort, as well as a smoother transition compared to a standard walker. However, the assistive force is fixed and mechanically passive, meaning it cannot adapt to the user's condition or effort in real time. In contrast, our system incorporates adaptive, EMG-based control, enabling dynamic adjustment of the support force based on muscle activity. This personalized support may encourage active engagement of the user, making the system more suitable not only for assistance but also for rehabilitation purposes. Furthermore, while the pneumatic walker is fully mechanical and does not require external power, our approach integrates biofeedback and programmable control logic, offering a more versatile and interactive rehabilitation tool.

Overall, the results confirm the feasibility and potential of the proposed adaptive system, with future work focusing on clinical validation and integration of anthropometric modelling to further tailor the device to individual users.

Compared to existing assistive devices that offer fixed or purely mechanical support, the proposed system introduces a biofeedback loop allowing real-time adaptation to the user's muscle effort. While some commercial or experimental solutions integrate robotic actuation or pneumatic lifting mechanisms, these often lack physiological responsiveness or remain inaccessible due to cost and complexity. By contrast, our system bridges this gap with a lightweight, flexible architecture that maintains safety and responsiveness while remaining affordable and customizable. This positions the device as a viable option for further clinical development, particularly for home-based or outpatient rehabilitation scenarios.

5. Conclusions

This work presented the development and implementation of a prototype adaptive control system for a standing frame intended to support the rehabilitation of individuals with motor impairments. The primary design objective was to incorporate the patient into the postural transition process by enabling partial control of motor speed through voluntary muscle activation.

The system architecture combined a muscle voltage sensor, an analogue-to-digital converter, a Raspberry Pi control unit, and a DC motor with a driver circuit. The control software, developed in Python, included features such as sensor calibration, real-time signal filtering, and PWM motor control. The LCD interface and physical button provided the user with intuitive control and feedback capabilities.

The prototype fulfilled all design requirements and proved to be functionally sound. Although clinical validation remains to be conducted, the results of internal testing indicate that the system responds reliably to muscle-generated signals and may serve as a foundation for future rehabilitative devices based on human–machine interaction.

From a broader perspective, the project demonstrates the potential of integrating electromyographic biosignals into assistive technologies. With further refinement and testing, such systems could provide more personalized and engaging rehabilitation experiences, encouraging user participation and improving outcomes for patients with limited mobility.

The scientific novelty of this work lies in the real-time adaptive control of a standing assist device using electromyographic signals processed through a low-cost platform. While EMG-based control has been previously explored in high-end systems, this prototype demonstrates that a personalized, semi-active rehabilitation experience can be delivered using accessible hardware and simple algorithms. The calibration routine ensures user-specific adjustment, and the signal-based control loop encourages active neuromuscular engagement during postural transitions. This approach contributes to the development of user-centered, responsive rehabilitation technologies that prioritize patient agency and therapeutic relevance.

5.1. Future Improvements

While the current prototype fulfills its intended purpose and demonstrates the feasibility of semi-active user control in standing frame rehabilitation, several enhancements may be considered in future iterations of the system:

- **Wireless communication**: Introducing Bluetooth or Wi-Fi modules would allow for remote monitoring, control, and data logging. This would facilitate therapist supervision and improve the ability to track user progress over time.
- **Multimodal biofeedback**: The addition of sensors such as heart rate monitors, pressure sensors, or inertial measurement units (IMUs) could provide richer physiological context, enabling more personalized and adaptive assistance levels.
- **Advanced user interface**: A graphical touchscreen display could replace the current LCD, offering a more intuitive interaction experience, easier calibration, and real-time feedback visualization.
- **Mobile application integration**: Developing a companion mobile application would allow users or caregivers to configure device settings, visualize historical data, and monitor rehabilitation progress in a user-friendly environment.
- **Real-time system architecture**: Upgrading the control system to operate under a real-time operating system (RTOS) could enhance responsiveness, determinism, and reliability—particularly important in medical or safety-critical applications.

The developed system constitutes a robust foundation for future research and development efforts. With continued refinement, extended functional testing, and clinical validation, it has the potential to evolve into a fully certified assistive device suitable for therapeutic use in rehabilitation centers or home-based care settings.

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