Portable Rehabilitation System for Stroke Patients with Hemiplegia using Limb Movement Recognition and EMG

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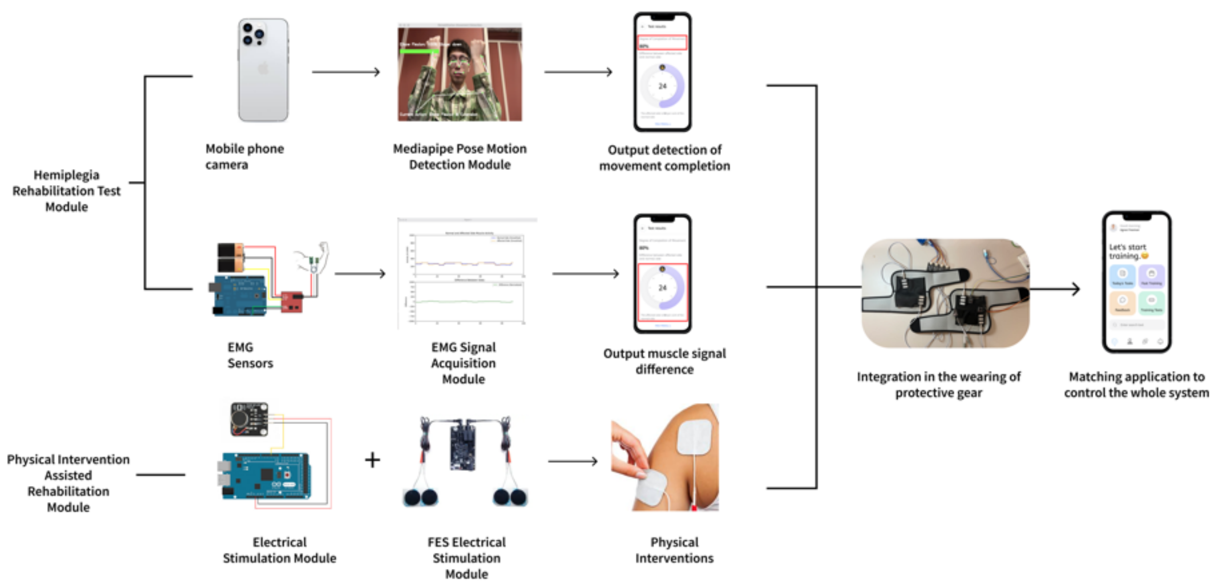

Figure 1: Overall System Architecture Diagram

Abstract

Existing rehabilitation training for post-stroke hemiplegic patients depends primarily on the guidance of the clinicians. However, training effectiveness is influenced by various factors, including training intensity, and there is no immediate feedback and objective evaluation data. This work introduces a portable rehabilitation support system that combines motion capture, electromyography (EMG) and physical feedback (vibration, electrical stimulation). By comparing the difference in EMG signals between the normal and affected sides during standard movements, the system quantifies rehabilitation progress and highlights muscle activation differences. The accompanying mobile app can provide stage-by-stage rehabilitation guidance to help patients choose exercises that are appropriate for their level of performance, and potentially allows online consultation with a physician for immediate feedback. This approach can possibly integrate evaluation, training recommendations, telehealth assistance, and physical therapy in one place to create an accessible and tailored home rehabilitation program.

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CCS Concepts

• **Human-centered computing** → **Interaction devices**; **Interactive systems and tools**.

Keywords

Stroke Rehabilitation, Electromyography Analysis, Home-Based Recovery, Motion Detection

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1 Introduction

Stroke is a serious global medical problem [3], usually caused by a blood clot blocking a cerebral blood vessel or a ruptured blood vessel that causes blood to leak into the surrounding area [13], and is characterised by high morbidity and disability. Stroke is the leading cause of chronic disability worldwide [10] and severely affects the quality of life of survivors [19]. The main symptoms include hemiparesis and complications such as sensory, cognitive, language and visual impairments [8]. According to the World Health Organization, 80% of stroke survivors experience varying degrees of motor dysfunction, and more than 60% of survivors continue to experience upper limb dysfunction in the chronic phase [11]. Therefore, effective rehabilitation of limb function is essential to improve the daily life of stroke survivors.

Following their release from the hospital, stroke patients frequently need extended home rehabilitation to improve and maintain movement of their limbs. However, many current rehabilitation systems are designed primarily for hospital use and require ongoing involvement of physicians. Intensive and regular rehabilitation exercises are essential for stroke recovery, as demonstrated by studies; however, many patients struggle to consistently adhere to the rehabilitation regimens recommended by their physicians [22]. Obstacles like inadequate professional oversight, challenges in tracking rehabilitation progress, and a lack of feedback systems significantly impede effective rehabilitation at home.

To address these issues, this project introduces an intelligent home rehabilitation assessment and training system. This study highlights the system design's background and goals, detailing the distinct functional modules developed and suggested future enhancements, to thoroughly showcase the system's research significance and practical value.

2 Implementation

2.1 Design Goals and System Requirements

Most current stroke rehabilitation devices rely on single-function approaches such as functional electrical stimulation (FES) [4], electromyography (EMG) [17] or brain-computer interfaces (BCIs) [9]. However, practical use in the home is limited by cost, complexity, and space requirements [2, 5]. These factors highlight the need for more integrated and applicable closed-loop rehabilitation systems. This study intends to tackle these issues by creating an affordable and accessible rehabilitation program. We propose a home rehabilitation system with the main design objectives of adapting to home scenarios, real-time dynamic feedback, and multimodal closed-loop intervention. The system simplifies the operation process, reduces hardware costs, supports daily use by patients and their families, and ensures ease of installation and operation. The system merges motion recognition and EMG signal evaluation to deliver immediate, interactive feedback on patient progress. This feature allows patients to track their rehabilitation efforts and stay motivated. Additionally, it facilitates the rapid integration of remote physician guidance and personalized training recommendations to enhance patient adherence and improve overall rehabilitation efficiency. Finally, the system integrates exercise testing, EMG data and physical stimulation into a closed-loop process to optimize training.

2.2 System Architecture

The system is currently being developed for the upper limb, The system diagram is shown in Figure 1.

EMG Signal Acquisition and Analysis Module: Mirror therapy is a technique used to promote hemiplegic limb rehabilitation by influencing the activity of the affected side through mirror feedback of the movement of the healthy side [1], using four EMG sensors to detect the flexion and extension activity of the patient's affected side and the normal side, respectively. During mirror movement studies have shown that the electrodes are placed on the intermediate region of the biceps and triceps muscles, which can be a better solution to the assessment of the flexion and extension function of the upper limb [24]. The sensor signals were relayed to the host computer through an Arduino, where real-time filtering and sliding-window smoothing were executed within a Python environment. Signal normalization and differential analysis was conducted to emphasize the differences in muscle activation levels between the affected and normal sides, assisting both the patient and physician in evaluating the effectiveness of rehabilitation.

Motion Detection Module: Capturing the spatial orientation and angles of the shoulder, elbow, and wrist is achievable with a mobile phone camera using MediaPipe Pose, facilitating the observation of upper limb movements. These moveemtns consist of shoulder flexion/extension, elbow flexion/extension, and forward/backward rotation of the forearm and can effectively indicate the upper limb gait state [6, 12, 23]. The training process is standardized by calculating the percentage of a completed gait cycle in real time and aligning the patient's amplitude of each detected movement to a standard value, leaving a range from 0 to 1. This standardized procedure assists in regulating variables and ensuring uniform measurement conditions at various time intervals. This improves the reliability of the EMG signal comparison and the assessment of differences between muscles on the affected side and those on the normal side.

The system automatically records the difference between the EMG of the affected side and the EMG of the normal side when the exercise is completed to a fixed percentage and records the data in a table to generate a record of the rehabilitation progress. The system supports the switching of the three exercise modes to cover different training scenarios for a comprehensive assessment of the rehabilitation process as shown in Figure 3.

Vibration and electrical stimulation assisted rehabilitation module: The system triggers moderate vibration or electrical stimulation on the affected side automatically based on real-time assessment, or can

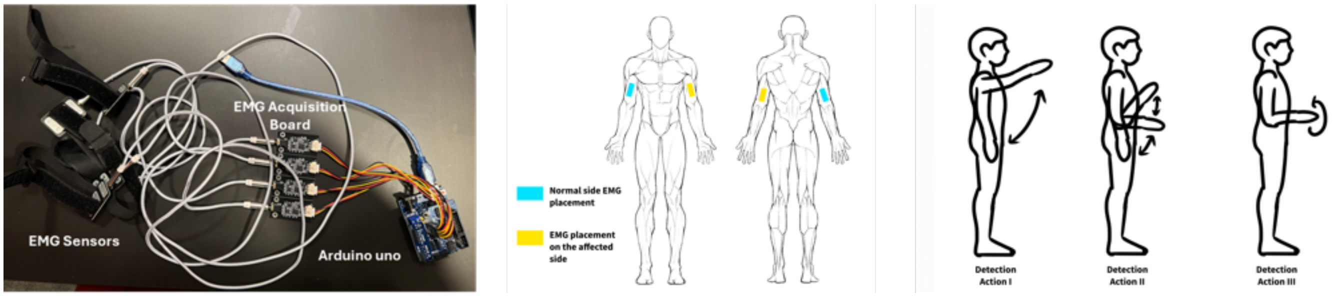

Figure 2: Left image: Image of the EMG components. Middle image: EMG placement. Right image: Movements completed for rehabilitation

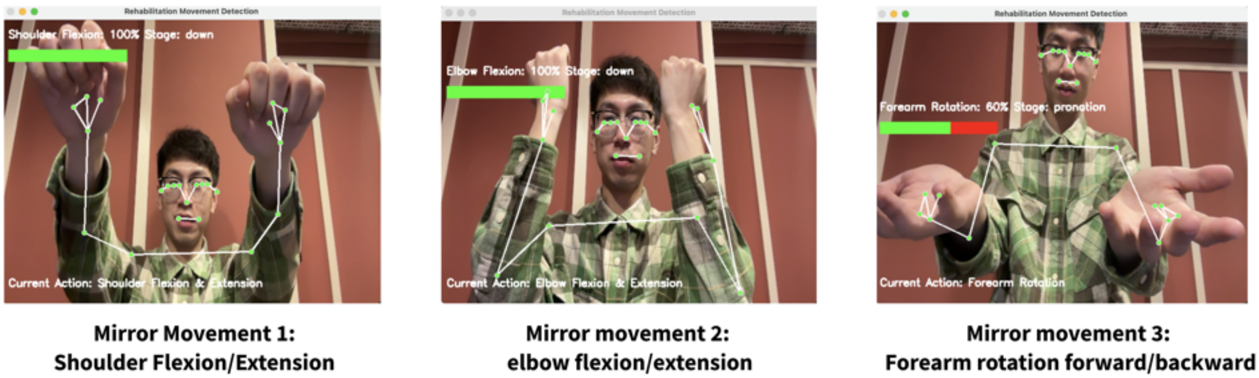

Figure 3: Mediapipe output delivering feedback on gait stage for these respective movements.

be manually activated by the patient according to the users need to relieve muscle stiffness, improve blood circulation, reduce spasticity, and promote nerve activation and muscle reconstruction [7, 21]. Through this closed-loop intervention, patients can receive physical reinforcement as soon as it is needed outside of clinical settings, thus improving muscle activation and rehabilitation efficiency. In order to solve the problems of inaccurate positioning of the EMG sensors due to inconsistent EMG placements for hemiplegic users, the sensors and the physical stimulation components were fixed inside the elbow strap shown in Figure 4. The elbow pad was used due to the ease of equipping it and improving the reliability between uses.

Mobile Application Module: The application uses Matplotlib to plot real-time muscle activity curves, differential curves and movement completion on the display terminal. This real-time data is combined with stage-by-stage training tutorials and remote consulting functions, to provide patients with personalized rehabilitation recommendations and long-term trend analysis [16]. Core functions include training plan recommendation, recovery trend visualization and dynamic data synchronization, and community interactions. The current system achieved the expected design goals.

3 Discussion

Current limitations of the system consist of the EMG signal being susceptible to various artifacts such as motion, leading to partial low signal to noise ratio. In addition, the current detection range focuses on the upper limbs and is not sufficiently adaptable to multi-joint or lower limb movements.

In future work, we will further improve signal processing to optimize signal stability and accuracy of the current prototype by integrating existing physiological sensing toolkits (e.g., PhysioKit [15]) and machine learning approaches to assess and enhance signal quality [14]. The system will also be extended to include a lower limb rehabilitation module to add more patient-friendly motion detection modules to support the assessment and training of complex full body movements. To improve wear comfort and accuracy of electrode placement, the design of the guard and the layout can be fabricated with soft materials such as Silicone building on our recent study [18]. This would help on consistency of EMG placements. Finally, it would also be interesting to explore how to extend this portable rehabilitation support capability in social biofeedback settings where users could be motivated with shared goal setting [20].

4 Conclusion

In this study, a multimodal integrated rehabilitation system was designed that combined motion detection and electromyographic

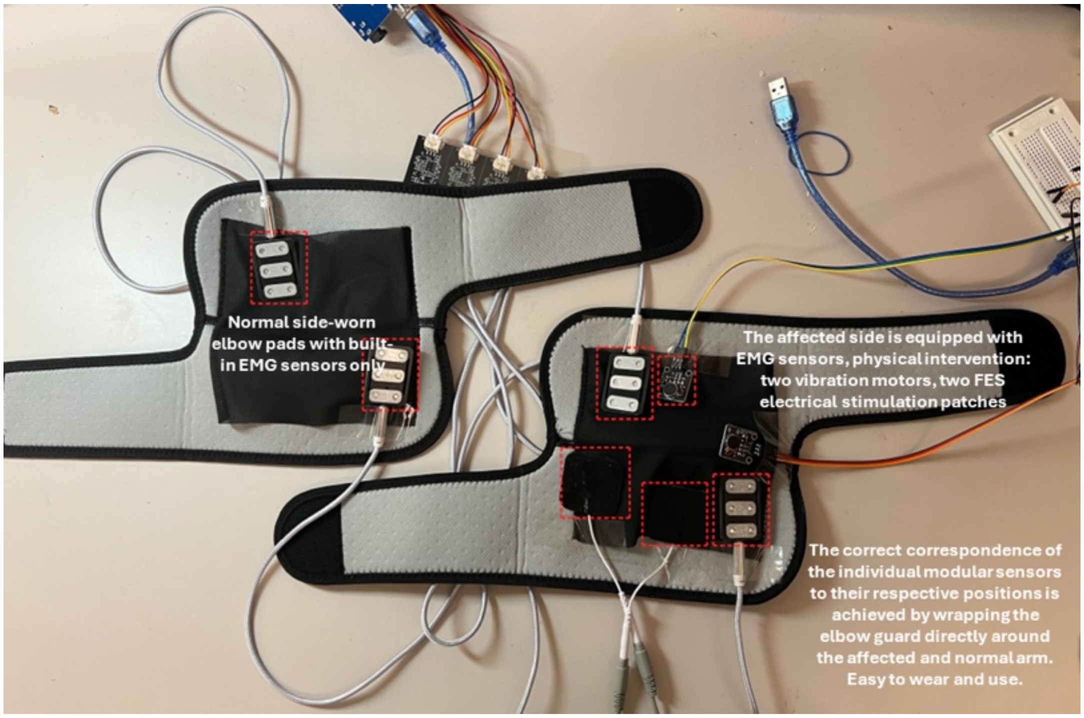

Figure 4: Elbow pads with electric stimulation pads, vibration motors and an Arduino built in

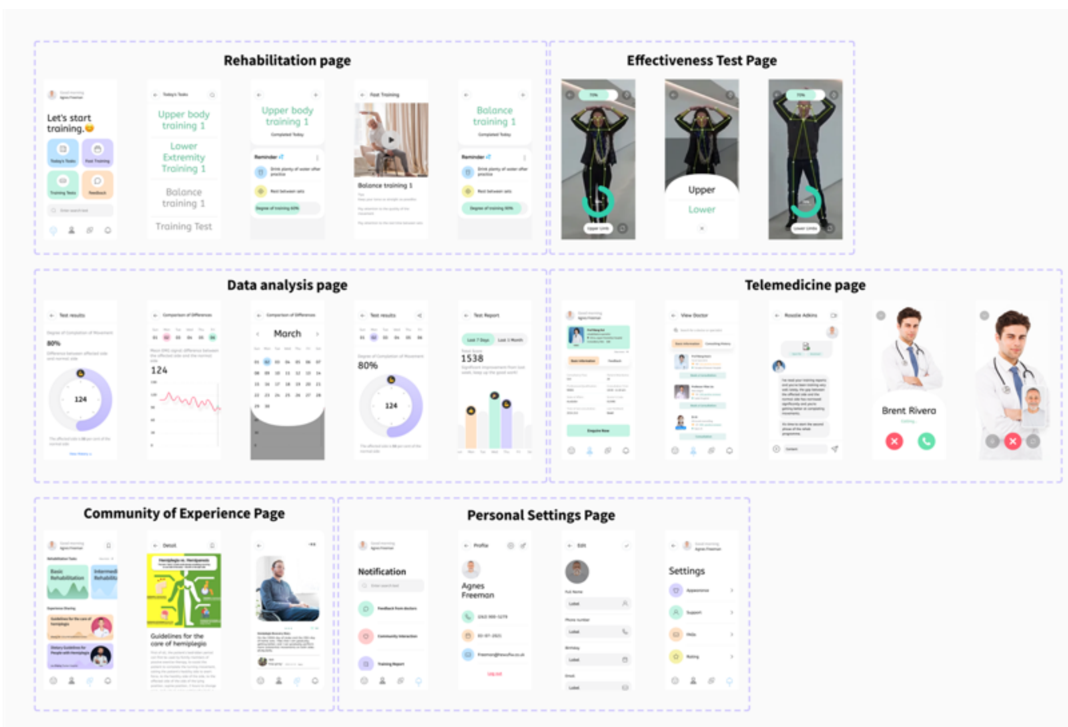

Figure 5: User interface for the mobile application

signal analysis to effectively improve the accuracy and efficiency of rehabilitation assessment and training for hemiplegic patients through real-time data feedback, closed-loop training interventions, and personalized rehabilitation suggestions. The system simplifies the operation process of the equipment and optimizes the applicability of home scenarios, providing a more convenient and intelligent solution for rehabilitation medicine. In the future, through the validation of the system with improved preprocessing reliability, the practicality and promotion value of the system is expected to be further enhanced, thus facilitating home training for more hemiplegic stroke patients. In the conference demonstration, participants will experience the device functions using the elbow pads with built-in EMG sensors and the physical assistive stimulation modules on the affected and normal sides. Participants will be guided to complete the mirrored test movements and use a computer or mobile phone to observe the completion of the test movements and the difference in EMG via visual feedback describing the difference between the movement of the left and right arm. In addition, the user interface for the accompanying application will be experienced on site to simulate the process of experiencing the use of the device by a rehabilitated patient.

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