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Neuro Assist: EMG-Based Smart Hand Rehabilitation Glove with TENS Therapy

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Abstract: Hand rehabilitation plays a critical role in restoring motor function for patients affected by neurological and musculoskeletal disorders such as stroke, and tends on damage. This paper presents Neuro Assist, an EMG based smart hand rehabilitation glove integrated with Transcutaneous Electrical Nerve Stimulation (TENS) therapy. The proposed system combines an adaptive tends on driven actuation mechanism with electromyography (EMG) signal acquisition to assist finger movements based on the user's muscular intent. Additionally, TENS therapy is incorporated to enhance muscle activation, improve neural response and reduce pain during rehabilitation. The dual therapy approach aims to accelerate recovery, reduce dependency on manual physiotherapy and provide a low cost, wearable solution suitable for both clinical and home based rehabilitation environments. Experimental evaluation demonstrates effective assisted finger motion and reliable EMG based control, indicating the feasibility of the proposed system for hand rehabilitation applications.
Keywords: Hand rehabilitation, EMG sensor, TENS therapy, tendon driven actuation, wearable medical device.

I. INTRODUCTION

Hand function impairment is a common consequence of neurological and musculoskeletal disorders significantly affecting a patient's ability to perform daily activities. Conventional rehabilitation methods require prolonged physiotherapy sessions under clinical supervision which can be time consuming, expensive and physically demanding for patients. As a result, there is an increasing demand for wearable and assistive rehabilitation devices that enable repetitive training and home-based therapy. Recent advancements in biomedical sensors and embedded systems have enabled the development of smart rehabilitation gloves capable of assisting hand movements. Among these, electromyography (EMG) based systems are particularly effective as they capture the user's muscle activation signals enabling intent driven assistance. Furthermore, Transcutaneous Electrical Nerve Stimulation (TENS) has been widely used in rehabilitation to reduce pain and improve neuromuscular activation. This work proposes an integrated rehabilitation glove that combines EMG based intent detection, tendon driven finger actuation and TENS therapy. The objective is to develop a compact, affordable and effective rehabilitation system that enhances recovery outcomes while ensuring user comfort and safety.

II. LITERATURE REVIEW

The study by Hanetal. Proposed a wearable rehabilitation glove using bionic fiber reinforced actuators to assist finger motion. The actuator design mimics biological muscle behavior and provides smooth movement during therapy. However, the actuator fabrication process is complex and increases system cost.[1] Xie et al. developed a smart rehabilitation glove using shape memory alloy (SMA) actuators for stroke recovery. The system provides a light weight and compact wearable structure suitable for rehabilitation. However, SMA actuators haves low response and heating issues, limiting continuous operation.[2] Szeto and Nyquist studied the use of transcutaneous electrical nerve stimulation (TENS) for pain control and neuromuscular stimulation. Their research showed that electrical stimulation can improve muscle activation during therapy. However, improper parameter settings may cause discomfort or ineffective stimulation.[3]

Al-Fakih et al. proposed an EMG based human–machine interface for rehabilitation applications. The system allows assistive devices to be controlled using muscle activity signals. However, EMG signals are highly sensitive to noise and electrode placement.[4]

Khushaba et al. presented methods for EMG signal processing and pattern recognition for rehabilitation robotics. The study discussed filtering and classification techniques for accurate muscle activity detection. However, these techniques require complex computation and calibration.[5]

Zhang et al. reviewed several of trobotic gloves for hand rehabilitation. The study highlighted the advantages of flexible materials that improve safety and comfort during therapy. However, many soft robotic systems require complex pneumatic actuation systems.[6]

Polygerinos et al. developed a soft robotic glove for assistance and home-based rehabilitation. The device allows patients to perform rehabilitation exercises outside clinical environments. However, the system uses advanced materials that increase manufacturing cost.[7]

Ozawa and Fujita proposed a tendon driven wearable assistive device for hand rehabilitation. The tendon mechanism provides efficient force transmission and natural finger movement. However, precise tension control is required to prevent excessive force.[8]

Accoto et al. studied tend on driven actuation systems for upper limb rehabilitation. Their research demonstrated that tendon mechanisms allow light weight and wearable rehabilitation devices. However, the mechanical design and calibration can be complex.[9]

Johnson discussed the clinical use of TENS therapy for rehabilitation and pain management. The study highlighted its effectiveness in improving neuro muscular stimulation during therapy. However, therapy effectiveness depends on proper electrode placement and stimulation parameters.[10]

III. PROPOSED SYSTEM

The proposed system, Neuro Assist, is a wearable hand rehabilitation device designed to assist patients suffering from neurological and musculoskeletal disorders such as stroke and peripheral nerve damage. The system integrates electromyography (EMG) signal acquisition, tendon driven actuation, and Transcutaneous Electrical Nerve Stimulation (TENS) therapy to provide both mechanical assistance and therapeutic stimulation during rehabilitation exercises. The primary goal of the proposed system is to develop a portable, cost effective, and efficient rehabilitation solution that enables patients to perform repetitive therapeutic exercises with minimal supervision. By utilizing EMG signals to detect voluntary muscle activity, the system allows intent driven control of finger movements, thereby encouraging active patient participation and improving rehabilitation outcomes. The overall architecture of the system consists of four major sub systems EMG signal acquisition sub system, control and processing subsystem, tend on driven actuation subsystem and TENS stimulation subsystem. These subsystems work together to detect muscle activity and provide appropriate assistance for finger movement.

A. EMG Signal Acquisition Subsystem

The EMG signal acquisition subsystem is responsible for detecting electrical activity generated by muscle contractions in the fore arm. Surface EMG electrodes a replaced on the forearm muscles responsible for finger flexion and extension. These electrodes capture bioelectric signals that indicate the user's intention to move the fingers. Since EMG signals are typically very weak and susceptible to noise, the acquired signals undergo signal conditioning, which includes amplification, filtering, and noise reduction. The conditioned signals are then transmitted to the microcontroller for further processing.

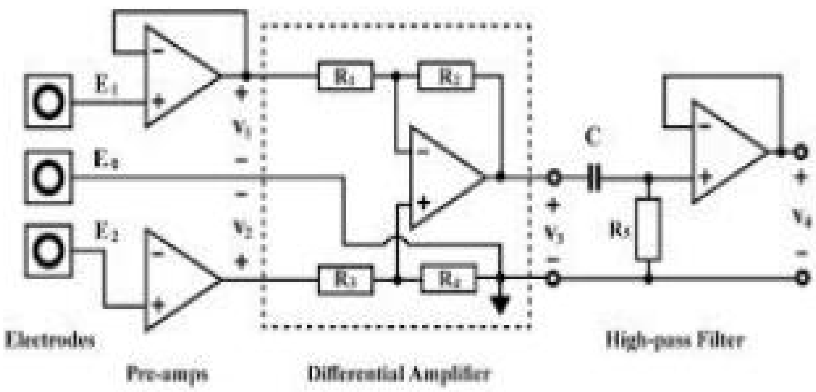

Fig.1: EMG CIRCUIT

B. Control and Processing Subsystem

The control and processing subsystem serves as the central unit of the system. It is implemented using an Arduino Uno microcontroller, which processes the EMG signals and generates appropriate control signals for the actuation and stimulation modules. Athres hold-based algorithm is used to detect significant muscle activity. When the EMG signal exceeds a predefined threshold level, the microcontroller interprets it as the user's intention to perform finger movement. Based on this detection, the controller activates the actuation and stimulation modules accordingly.

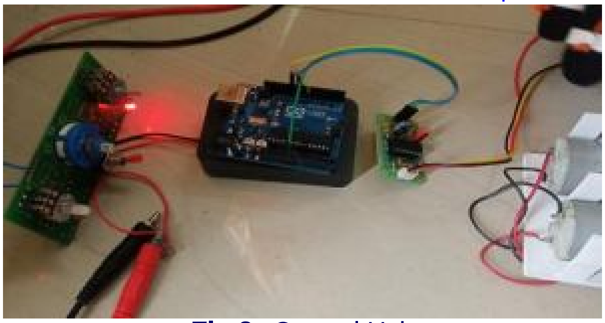

Fig.2: Control Unit

C. Tendon Driven Actuation Subsystem

The tend on driven actuation subsystem is responsible for assisting finger movement during rehabilitation exercises. The subsystem consists of 30 RPMDC motors connected to tendon cables integrated within the rehabilitation glove.

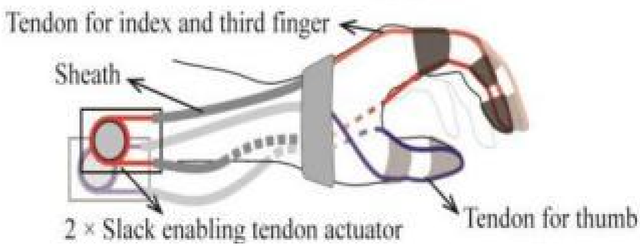

Fig.3: Tendon

When the microcontroller detects muscle activation, it generates pulse width modulation (PWM) signals to drive the motors. The motors pull the tendon cables, causing the fingers to bend and perform flexion or extension movements. This mechanism mimics the natural tend on structure of the human hand and provides smooth and controlled finger motion.

D. TENS Stimulation Subsystem

The TENS stimulation sub system provides electrical stimulation therapy to support neuro muscular recovery. The TENS module delivers controlled electrical pulses through electrodes placed on the forearm muscles. These electrical pulses stimulate sensory nerves and muscles, which help improve blood circulation, enhance muscle activation and reduce pain during rehabilitation sessions. The microcontroller activates the TENS module simultaneously with finger movement assistance to maximize therapeutic effectiveness.

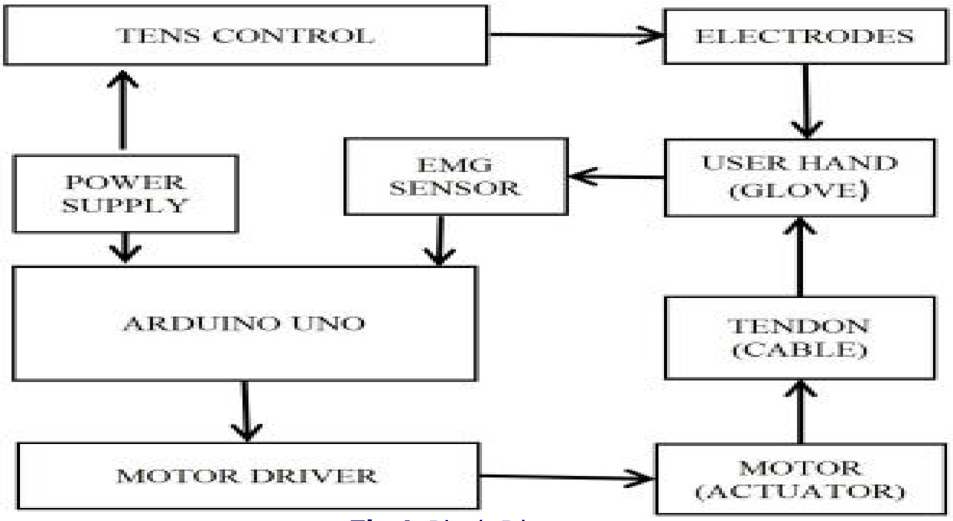

Fig.4: Block Diagram

IV. DESIGN OF REHABILITATION GLOVE

The rehabilitation glove is designed as a light weight wearable interface that enables controlled finger movement during therapy sessions. The glove is constructed using flexible and breathable materials to ensure comfort during prolonged use. The design allows the glove to fit different hand sizes while maintaining proper alignment of the fingers and joints.

A. Glove Structure

The glove structure forms the base of the rehabilitation device. It is designed to securely hold the fingers and provide mechanical support for the tendon driven actuation system. Finger guiding channels are integrated into the glove to maintain the correct direction of finger movement and prevent unnatural bending during operation. Reinforced sections are in corporate near the finger tips and knuckles to with stand repeated mechanical stress during rehabilitation exercises.

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B. Tendon Cable Mechanism

The glove uses a tendon cable mechanism to assist finger motion. Flexible cables are attached along the dorsal side of Each finger and connected to DC motors positioned near the adjacent side of hand.

Fig.5: GLOVE DESIGN

When the motors rotate, the tendon cables are pulled, causing the fingers to bend. When the tension is released, the fingers return to their natural position through the elastic band. This mechanism provides smooth and natural finger movement.

C. Actuator Placement

The actuators, primarily motors, are mounted near the hand to reduce the load on the fingers. This configuration improves comfort and reduces fatigue for the user. The placement also allows efficient force transmission while maintaining a compact and light weight design.

D. Ergonomic and Safety Considerations

The glove design in corporate several ergonomic and safety features to ensure user comfort and reliable operation. Soft padding is included at critical contact points to prevent skin irritation. The tension of the tend on cables is carefully adjusted to avoid excessive force on the fingers. In addition, software based safety mechanisms limit the maximum motor rotation and stimulation duration to prevent potential injury.

V. HARDWARE AND SOFTWARE IMPLEMENTATION

A. Hardware Implementation

The hardware implementation of the Neuro Assist system integrates biomedical sensing, embedded processing, actuation, and the rapeutic stimulation modules into a compact wearable rehabilitation device. The system is built using commercially available components to maintain low cost and ease of development. The central component of the system is the Arduino Uno microcontroller, which functions as the main processing unit. It receives EMG signals from the sensor module, processes the data, and generates control signals for the motors and TENS stimulation module. The EMG sensor module is used to detect electrical activity generated by muscle contractions in the forearm. Surface electrodes a replaced on the skin above the flex or muscles responsible for finger movement. The EMG module amplifies and filters the small bioelectric signals before sending them to the analog input of the microcontroller. The actuation system consists of motors connected to tend on cables attached to the glove. When the microcontroller detects muscle activation, it generates PWM signals that drive the motors. The motors pull the tendon cables, producing controlled finger flexion or extension. The TENS therapy module delivers low voltage electrical pulses through electrodes placed on the fore arm. These pulses stimulate nerves and muscles to improve neuromuscular response and reduce rehabilitation pain. The microcontroller activates the TENS module during therapy sessions based on the detected EMG activity. A motor driver circuit is used to regulate the power supplied to the motors, ensuring stable operation and preventing overload conditions. The entire system is powered by AC adapter enabling the device to be used in home based rehabilitation environments.

B. Software Implementation

The software for the Neuro Assist system is developed using the Arduino Integrated Development Environment (IDE). The program is responsible for acquiring EMG signals, processing the data and controlling the mechanical and therapeutic components of the system. The microcontroller continuously reads analog EMG signals from the sensor module. Since EMG signals contain noise and fluctuations, the software applies basic signal processing techniques such as smoothing and threshold detection to determine whether a valid muscle contraction has occurred. Once the EMG signal exceeds the predefined threshold value, the microcontroller interprets it as an intentional muscle movement. The controller then generates PWM signals to actuate the motors through the motor driver, which pull the trend on cables and assist finger movement. At the same time, the system may activate the TENS module to provide electrical stimulation that supports muscle activation and rehabilitation therapy. The software also includes safety mechanisms that limit the maximum range of motor movement and restrict stimulation duration to prevent discomfort or injury. The hardware components include an Arduino Uno, EMG sensor module, motors, motor driver, TENS unit, power supply and wearable glove structure. The EMG sensor output is connected to the analog input of the microcontroller, while motors are driven through PWM signals via motor driver.

The software is developed using the Arduino IDE. The program continuously reads EMG signals, applies basic signal conditioning and determines the user's intent. Based on the detected intent, the system actuates the motors and optionally triggers TENS stimulation. Safety limits are implemented in software to restrict excessive finger movement and stimulation intensity.

VI. RESULTS AND DISCUSSION

The prototype rehabilitation glove was developed using a commercially available protective glove as the base structure. 3D printed tend on guide brackets were mounted along each finger and nylon tend on cables were routed from the fingertip anchors to the 30RPM gear DC motor housing located near the hand. Experimental testing showed that the trend on driven mechanism successfully assisted finger flexion while maintaining smooth motion. The elastic return system effectively restored finger extension when the motor released tension. The EMG sensor was able to detect muscle activation signals from the forearm muscles and trigger the motor when the signal exceeded the defined threshold. The relay interface also successfully controlled the external electro therapy device during therapy cycles. The system demonstrated that combining EMG based control with attend on driven mechanism can provide an effective and low cost rehabilitation solution along with the following advantages and limitations. Dual Therapy Rehabilitation: The integration of EMG based assistive actuation with TENS therapy enables simultaneous motor assistance and neuro muscular stimulation, improving rehabilitation effectiveness. Intent Driven Control: EMG based detection of voluntary muscle activity promotes active patient participation, supporting neuroplasticity and faster recovery. Low Cost Implementation: Use of commercially available components such as Arduino, low cost EMG sensors, and motors makes the system affordable and accessible. Wearable and Portable Design: The glove based form factor allows convenient use in both clinical and home based rehabilitation settings. Customizable Therapy: Motor assistance and TENS intensity can be adjusted to suit individual patient requirements. Reduced Therapist Dependency: Supports repetitive training without continuous manual physiotherapy supervision. Mechanical Wear: Tendon driven mechanisms may experience cable slack and wear over prolonged usage. TENS Safety Constraints: Improper electrode placement or excessive stimulation may cause discomfort, necessitating medical guidance. Restricted Degrees of Freedom: It primarily supports basic finger flexion and extension.

VII. CONCLUSION AND FUTURE SCOPE

This paper presented Neuro Assist, an EMG based smart hand rehabilitation glove integrated with TENS therapy. By combining intent driven assistance with electrical stimulation, the proposed system enhances rehabilitation effectiveness while maintaining a low cost and wearable design. The prototype demonstrates the feasibility of the approach for both clinical and home based rehabilitation. Future work will focus on miniaturization, wireless connectivity and extensive clinical validation. The proposed EMG based smart rehabilitation glove demonstrates the potential of combining wearable robotics; tend on driven mechanisms and electro therapy support for hand rehabilitation. However, several improvements can be implemented in future work to enhance the performance and usability of the system. Advanced signal processing algorithms and machine learning techniques can be in corporate to improve the accuracy of EMG signal interpretation and enable more precise control of finger movements. Individual finger actuation using multiple motors can also be implemented to provide more natural and independent finger rehabilitation exercises. In addition, integrating wireless communication technologies such as Wi-Fi would allow remote monitoring of rehabilitation progress by therapists. The system can also be enhanced by incorporating soft robotic actuators or flexible sensors to improve comfort and adaptability. Furthermore, the development of a mobile application for therapy monitoring and control could support home based rehabilitation programs. These improvements can make the system more intelligent, user friendly and suitable for large scale clinical applications.

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