A Survey on Wearable Exoskeleton for a Paralyzed Hand

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Abstract

In the rapidly evolving field of rehabilitation technology, muscle and joint disorders can severely limit mobility and may lead to paralysis, particularly in the arms and hands due to conditions like strokes, spinal cord injuries, and neurological disorders. Traditional therapies often lack effectiveness in restoring motor function and cannot be customized to meet individual patient needs. To address these challenges, researchers have developed wearable exoskeletons designed to restore hand movement. These devices utilize motors to mimic the natural movement of fingers which are controlled by EMG sensors that detect muscle activity and finger position. Furthermore, Machine Learning techniques, such as K-Nearest Neighbour and Support Vector Machine (SVM), enhance the device ability to recognize hand gestures and improve responsiveness. In this paper, various techniques are reviewed on the design of exoskeletons and the Machine Learning techniques used for hand movement detection. This innovative approach has the potential to significantly improve rehabilitation outcomes and enhance the quality of life for individuals affected by paralysis.

Keywords: Motors, EMG sensor, Microcontroller, Machine Learning, Human-Human interaction, Exoskeleton, Neurological disorder, Rehabilitation

Introduction

Stroke is a life-threatening condition caused by the death of brain cells, often results in paralysis, affecting approximately 55% to 75% of survivors. The type and severity of paralysis can vary widely depending on the location of the brain damage. Similarly, spinal cord injuries can lead to hand paralysis, significantly impairing both physical function and emotional well-being. The upper limb or hand paralysis can also happen through spinal cord injury, neurological disorder, blood clothing, and strokes - leading to 29% of the cases. Both stroke and spinal cord injuries can have long-lasting effects on a person's quality of life, requiring ongoing rehabilitation and support.

Monoplegia occurs when paralysis only impacts one arm or one leg [1]. Another one is a Parkinson disease that affects the nervous system, specifically the parts of the body controlled by the nerves. Hemiplegia is paralysis of the muscles of arm and leg on one side of the body commonly caused by stroke. It may also affect the sensation, memory, and understanding.

There are various traditional therapies for the treatment of the paralyzed hand, one of which is mirror therapy where mirror is placed between the affected and the non-affected hand and the patient observes the image of the non-affected hand in the mirror, and imagines the affected hand making the same movement [2]. Other therapies for upper limb improvement include weight-bearing exercise, passive stretching of the hand like spreading the hands using splint or making fist by holding the object, and wrist exercise.

The wearable exoskeleton will be the game changer and allows the physiotherapist to assist patients paralyzed hand to regain the muscle strength. Rehabilitation can help patients to relearn skills that were lost due to stroke [8]. Wearable robotic exoskeleton has great potential in rehabilitation therapy by providing physical assistance to patients [5]. Prosthetic hand assist techniques are being rapidly used for upper limb rehabilitation [1].

Machine Learning techniques can be employed to detect muscle onset and offset while opening and closing the fist or identifying hand gesture for fine motor movements. Various Machine Learning techniques like K-Nearest Neighbour (KNN), Support Vector Machine (SVM), and Deep Neural Network were used by the researchers to detect hand gestures [14].

Literature Review

In this study, 14 papers are being reviewed to present the survey on the wearable exoskeleton for hand rehabilitation. The papers reviewed represent a wearable hand exoskeleton to assist person with the hand paralysis using EMG sensor to provide high intensity to the muscles and improves grasping capability of the hand.

A 3D printed prosthetic hand was designed to assist patients with hand paralysis to provide high intensity and improves grasping capability. Patients used a prosthetic hand to open and close the hand or to pick up and lift the object. EMG data was collected using EMG sensors, connected with Arduino UNO and servo motors to control hand.[1]

Human-machine interaction system was proposed based on the concept of mirror therapy. Surface EMG was used to collect data from non-affected hand which classify the hand gestures using machine learning model. The STM32F103 was used to integrate DC motor and other sensors. Flex sensor and pressure sensors were used to process the signals coming from the sEMG. Machine Learning algorithms like Support Vector Machine (SVM), k-NN, and subspace k-NN were used for pattern recognition.[2]

A tendon-driven motor glove was developed driven by linear actuator powered by DC micro motor. Flexion sensors and force sensors are also mounted on each finger. Wi-Fi interface was implemented to send and receive control signals. [3]

An exoskeleton was designed to assist a person with disability to perform routine tasks. EMG sensors were used to acquire the signals from the muscles of the hand and convert them into voltage and then fed to a signal conditioning circuit. Microcontroller was programmed to rotate servo motor according to the voltage received from the EMG sensors. The exoskeleton works effectively for normal functioning of the daily activities of an exoskeleton for hand rehabilitation.[4]

The portable tendon-driven soft exoskeleton glove was developed for hand rehabilitation and assistance. Thermoplastic polyurethane (TPU) was used for a 3D printing of the exoskeleton. DC motors were implemented on each finger which was controlled using ATmega2500 microcontroller. The pinch, cylindrical grasp force, and maximum grasp size were measured using two flat surface resistors and two force surface resistors.[5]

A robotic hand was designed to control the soft glove placed on the healthy hand. The goal was to perform mirror therapy on the robotic hand. Two experiments were performed, the one was feature extraction and gesture recognition, and other was real-time performance for sensing actuation combination of the glove. The output of the flex sensor was evaluated using Arduino and sent it to servo motor to perform the same action.[6]

A low-cost muscle stimulator integrated with IoT was designed to provide a user-friendly environment. The feedback system was developed to receive voltage and send to the IoT device which could be used to determine muscle strength. The IoT device sends data to a cloud server and stored against the ID of each user so that physiotherapist can monitor the patient.[7]

The author studied the dataset of 2880 simulated sEMG signals for signal-to-noise ratio and time to train a hidden single layer fully connected neural network. DEMMAN's performance was used to evaluate sEMG signals and provide reliability prediction of muscle onset/offset in simulated and real sEMG signals. The proposed work predicted onset/offset timing of muscular recruitment of the machine learning based methods.[8]

Neuro-muscular Electrical Stimulator (NMES) was implemented and integrated with Human-to-Human Interface (HHI) in the rehabilitation process for stroke patients from which a controller can control the motion of the subject by injecting their own signal. The EMG detects the electrical signals transmitted from the motor neurons when there is muscle contraction. The signals were detected at the receiver's side by NMES and send to the actuators which helped subject to move their hand by mimicking the movements of the controller. The NMES is a device that use electrical impulses to activate muscle contraction and delivered through electrode placed on the skin near the targeted muscles.[9]

Deep Learning model was applied to sEMG-based gesture recognition where EMG data was represented as images. The Temporal Convolutional Network (TCN), type of CNN was used to determine the type of the gesture formed by the hand. The proposed system used real-time simulation for an existing sEMG database where 20 samples of sEMG signals were used as an input to the model.[10]

A remote rehabilitation system was developed that integrates a IoT based connected robot for wrist and forearm rehabilitation and uses Support Vector Machine (SVM) to classify the design for the estimation of muscle fatigue based on the features extracted from the EMG signal acquire from the patient. The rehabilitation robot integrates the biomechanics of the forearm and wrist joints into rehabilitation protocol. The SVM classifier was used to estimate muscle strain based on feature extracted from the EMG signal acquired from the patient.[11]

Reinforcement Learning method was presented to observe muscle fatigue. The method is based on Gaussian State-Space Model (GSSM) that utilizes the Recurrent Neural Network (RNN).

The GSSM functions filter that converts an observable environment into a state representation vector. Reinforcement Learning learns a task through reward signals collected from interactions with an environment that occurs in a discrete time. RL-GSSM was trained to control arm movements through muscle stimulation under progressive muscular fatigue.[12]

A drop foot syndrome stimulator was developed where a person faces difficulty in lifting the front part of the foot. Functional Electrical Stimulator (FES) uses Force Sensitive Resistors (FSR), programmable microcontroller, transmitter, receiver, and electrodes. The system helped many patients with foot drop problem to move easily and comfortably. It worked by supplying electrical pulses to the nervous system to stimulate paralyzed muscles by producing muscular contractions.[13]

An EMG based robotic hand was proposed and controlled by the user focus on the control of an individual finger of the robotic hand. The MYO armband was used to collect the EMG data from the user’s hand. The Machine Learning algorithms like Linear Discriminant Analysis (LDA), Support Vector Machine (SVM), K-Nearest Neighbour (KNN), and Deep Neural Network were used to classify hand gesture. The data was collected on 10 subjects on MATLAB using MYO SDK for 6 different gestures including rest position.[14]

Conclusion

Various papers are reviewed on the design and development of the wearable hand exoskeleton used to assist patient with the paralyzed hand. Wearable exoskeletons represent the solution for hand rehabilitation, addressing challenges faced by patients with paralysis from conditions like strokes and spinal cord injuries. These innovative devices leverage advanced technologies such as EMG sensors, servo motors, Microcontrollers, and Machine Learning algorithms like SVM, K-NN, and Deep Neural Networks to restore hand movement and improve patients' quality of life. The EMG based technology is used to collect the data from the healthy hand for the gesture recognition and control the movement of the prosthetic in real-time. Future developments could revolutionize rehabilitation therapy by providing more personalized, effective, and accessible solutions for individuals with hand paralysis.

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