Exoskeleton Arm for Rehabilitation and Activity Assistance

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Abstract- Upper extremity disorder (UED) is a major problem in society. A systematic review, published in 2006, reported a prevalence of upper limb disorders that ranged between 2% and 53% in different populations, with higher rates in students and working individuals, often a quite common complication after stroke affecting approximately 85% of survivors. Impaired upper extremity function limits the performance of activities of daily living (ADLs) and decreases social participation. Novel therapeutic techniques have been introduced to promote upper extremity function but due to lack of therapist professionals and assistive devices not everyone has access to these facilities, nor are these facilities accessible round the clock to help the user with their needs. As a result, there is a significant gap between required and available health services. The objective of this project is directed at developing a novel type of powered exoskeleton to facilitate easy movement of the arm of an upper limb mobility-disabled individual and enabling them to work at their own efficiency involving daily chores. The developed product will be designed to address some common recurring problems which are still unanswered. The exoskeleton arm will be equipped with smart technology for assisting mobility and fit, a gesture control option for repeated exercises of rehabilitation, and the capability to aid in various activities of daily life.

Keywords- ADLs, Assistive Exo-arm, Gesture control, Dynamic Fit, IMU sensor, EMG, Bowden Tube, UED, Rehabilitation.

I. INTRODUCTION

The objective of this project is directed at developing a novel type of powered exoskeleton to facilitate easy movement of the arm of an upper limb mobility-disabled individual and enabling them to work at their efficiency involving daily chores.

UED is a major problem in society. A systematic review, published in 2006, reported a prevalence of upper limb disorders that ranged between 2% and 53% in different populations, with higher rates in students and working individuals, often a quite common complication after stroke affecting approximately 85% of survivals Impaired upper extremity function limits the performance of activities of daily living (ADLs) and decreases social participation. Combining wearable robotic exoskeletons and human-machine interfaces is a promising avenue for the restoration and substitution of lost and impaired functions.

After researching statistics and the impact of UED, the results showed that a general state in most stroke survivors is paralysis of one side of the body. Motor rehabilitation research has shown that to speed up the recovery process of the upper limb function, activity-dependent interventions can be used to assist the use of the paralyzed limb.

Furthermore, in the rehabilitation of the hand motor function, the major concern has been how to achieve the optimum restoration of hand function. By performing bilateral movement training, the arm motor function of the impaired limb of the stroke survivor can be enhanced due to the plasticity of the human brain.

1. Description:
The solution proposed is a lightweight supportive arm framework accounting for three main joint mobility from shoulder to fingers, the whole system would be electrically powered motor driven and actuated with the help of cables, microcontroller, and force & angle sensors, weaving a fine compromise between physical rehabilitation and ADL assistance.

The main functionalities that would be included are:

1.1 **Mobility and dynamic fit:** Most products in circulation today don't have an auto-adjustment or auto-swaddle facility which negatively affects comfort. The solution proposed answers the problem using smart technology integrated air pockets which function by use of gyroscope and force sensor in real-time.

1.2 **Gesture Control:** Incorporated to facilitate by replicating the repetitive rehabilitation exercises for strength building; gesture control will work for assisting the user by giving control and automating the activity in the process by the use of EMG and position sensors.

1.3 **Activities of daily life (ADL):** Our device employs the natural recruitment strategy, which only activates the necessary class of muscle fibers about the perceived required force instead of artificial stimulation (where most of the muscles around electrode patches are recruited leading to side effects). It would measure the force needed to deliver adequate stimulation to move their limbs. In Cases where only weak contraction is generated, the exoskeleton is meant to detect this and kick in to complete the intended movement.

2. Approach:
The most promising solution for the problem sets out to be a portable therapeutic device that is to be designed for an assistive hand motor function rehabilitation that a physically challenged person or stroke survivor can use for bilateral movement practice all while assisting them in day-to-day activities too. Out of 31 degrees of freedom out of which 7 major are for the shoulder to wrist joint and the rest 21 for the hand of a human arm (shoulder to fingers), the prototype of the hand exoskeleton allows 24 with 19 active degrees of freedom.

The device is designed to be portable so that the user can engage and assist in other activities while using the device. A prototype of the device will be fabricated to provide complete mobility for joints and powered assistance for active DOF joints along with flexion and extension motion of individual joints of the impaired arm based on the movements of the healthy arm. In addition, testing of the device on a healthy subject will be conducted to validate if the design met the requirements.

The device will also be designed to address some common recurring problems which are still unanswered by combining the concepts of both therapeutic and assistive exo-arm for round-the-clock care of a person. The exoskeleton arm will be equipped with smart technology for assisting mobility and dynamic fit, a gesture control option for repeated exercises of rehabilitation, and the capability to aid in various activities of daily life.

This project is directed at developing a novel type of powered exoskeleton to facilitate easy movement of the arm of an upper limb mobility-disabled individual and enabling them to work at their own efficiency involving daily chores.

II. IMPLEMENTATION

The project begins with the study of human anatomy, as understanding the range of motion, actuation of joints and DOF is very crucial for setting initial goals regarding the Exoskeleton. To obtain information related to the quantitative analysis of Human joints, we used BOB (Biomechanics of Body) simulation software, software that provides a reasonable analysis of expected performance before manufacturing. Post the understanding of anatomy, the next important part is to decide which DOF for joints that needs external power assistance while keeping other DOF passive (not externally Powered).

The data obtained by the BOB simulation gives a solid idea for selecting the DOF which needs to be powered. Analyzing the data it was decided to keep 1 active DOF for shoulder, elbow, and wrist, whereas for fingers keeping 6 active DOF. The passive DOF for the shoulder are 2, 1 DOF per wrist and elbow and 5 passive DOF for fingers.

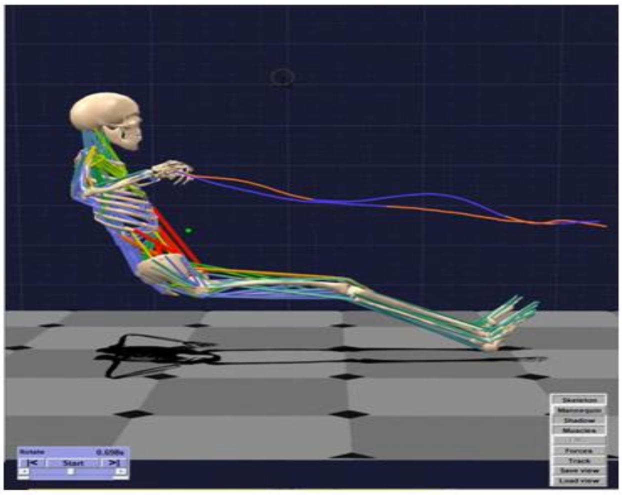

Fig 1.Hand Trajectory Given.

The next step is the design process of the exoskeleton followed by kinematic modeling of the exoskeleton considering the anthropometric data of the standard human arm. From a mechanical point of view, the exoskeleton should be kinematically reductant like a human arm. It is essential to derive D-H parameters to kinematically analyze the whole system. D-H convention allows the construction of the forward kinematics function by composing the coordinate transformation into one homogeneous transformation. Transformation forms the link to determine the elementary translations and rotations.

The human arm model made in MATLAB SIMULINK is used to determine the required torques for respective joints, and path planning to avoid the region of low manipulability. Based on the acquired torques, DOF, and rotation the selecting and designing of motor and cable-based pulley actuation systems is employed, the actuation system is based on the feedback control system.

To accommodate ADL features through natural recruitment strategy the force feedback control system is employed. The data collection is done by the force and flex sensor attached to the hand. The data is sent to Raspberry pi 4 which determines the user’s need for power. Pull solenoid is used for actuation whereas the locking mechanism is done through the Bowden tube. The problem regarding the mobility fit is solved by equipping the vertical support bars, stabilizers, and breathable fiber wrapped along the joint.

The control function of dynamics fit was carried out by Raspberry pi 4 quad ARM Cortex A72 processor. The gesture control system is integrated with the exoskeleton by Raspberry pi via Arduino. The EMG and IMU sensors are used to determine the muscle activity and 3D space position respectively. The data gathered at the raspberry pi microprocessor guide the DC motors for actuation of exoskeleton via Cables. The 3D modeling of the arm is carried out by using the Solidworks software, for further stress analysis Ansys workbench was used.

Manufacturing of the chassis is carried out using 3D printing using ABS material. The manufacturing involves 3 sections, the first section of shoulder to the elbow, 2nd phase of elbow to wrist, and the 3rd section of 5 fingers. Additive manufacturing is chosen to build complex parts and for a low cost. Assembly of individual parts after manufacturing was done manually. Cables and motors are designed to be mounted on the back static plate as well as on the arm chassis. Bulky components like battery packs and pulleys were placed on the backplate.

The first section from shoulder to elbow was actuated by Bowden cables where the actuator motor will be placed on the static plate. The second section from the elbow to the wrist was attached to the first section via motors directly mounted on the arm joints. The third section from wrist to fingers was joined. Flex sensors are placed at the back of the finger to calculate muscle movement.

To reduce wire length and save on cost, microcontrollers were placed on the arm such that all the components are approximately equidistant from the controller. Dynamic fit control module and assembly are to be fitted directly on the arm.

III. METHODOLOGY

Fig 2. Methodology Flow Chart.

IV. DESIGN

An exoskeleton arm will be built for the right hand as 70-80% of people are right-handed and perform their major tasks with this hand. The primary goal of the exoskeleton chassis is to hold all the equipment and provide support to the user. The chassis structure will be 3d printed in sections using ABS plastic.

1. Mechanical Characterization:
Exo-arm was divided into 3 sections- the first section will be from shoulder to elbow. The second section will be from elbow to wrist. The third section will be from wrist to hand which will later be divided into 5 fingers.

Further, the section parts will be assembled. Components and joints for designed movement will be mounted on the section parts. Since the arm is designed to be portable and lightweight, only sensors and cables can be placed on the arm, other bulky components such as the battery, pulley, and motors will be placed on the back of the user on a static solid plate.

The prototype of the hand exoskeleton allows 24 with 19 active degrees of freedom. This is done to ensure arm mobility of the user and activate and power specific joint movements.

2. Actuation and Control:
Force produced and angle achieved by the arm will be monitored by force and flex sensors for the wrist and elbow. These sensors will be placed on the user's arm and the specific location and the data will be stored and further processed by Microprocessor. Data processed by the microprocessor will then be used to calculate and actuate motors and pulleys.

The flex sensor resistance changes when the metal pads are on the external bottom of the curve. It is used as it is light in weight and it's simple. It is used to avoid damages to the connector and the user's arm due to flexion efforts. In this, the flex sensor is used to measure the exo-skeleton angular motion which coincides with the patient elbow joint angle, for flexion-extension movements in real-time. The force-receiving module, NI USB DAQ device, is used for receiving force signals from the force sensor via the force amplifier module.

We will be using-BoB/EMG (Biomechanics of Body) to display EMG signals as graphical data and overlay measured muscle activity on a synchronized animated skeleton with the color-coded muscle activations. BoB/EMG can also display associated muscle information, for example, muscle length, muscle contraction velocity, and muscle force. Also, BoB can display the names of the muscles as they move and generate forces assisting with the understanding of the activation pattern. Depending on

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the muscle activation, a linear force is calculated and the fingers to be moved are actuated.

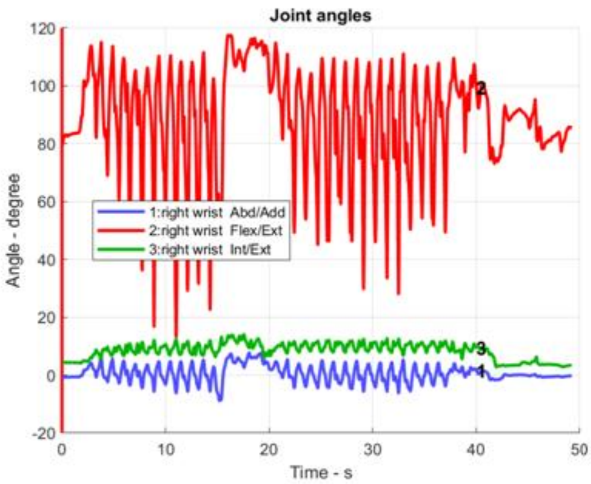

Fig 3. Joint Angles.

For achieving and powering these joints, we will be using a combination of cable-driven and DC motor actuation or stepper motors. A cable-driven actuating system is used to transmit force and torque to each joint of the exoskeleton arm. Therefore, this design can reduce the robot arm's weight and cost.

The cables chosen will be Bowden Cables. It is a mechanical transmission system that consists of an internal flexible metal and an external flexible plastic cover. They provide high strength during flexion of the arm.

The battery which we will be using will be a Li-Po battery 3S 5500mAh (lithium polymer-based 12-volt battery). The storage capacity will be decided further according to design.

V. SOCIAL IMPACT

More than 6 million people in India have mobility-related disabilities. This restricts them from freely moving around and traveling which, in turn, leaves them with very few options to lead a better life. Though there are many causes of these mobility-related disabilities, and many of them are not treatable, they can be aided with the help of exoskeletons.

Given the current state of rehabilitation facilities and the workload on already short-staffed therapists in India, things have only escalated for the worst. A large fraction of individuals who need such facilities either don't have access or can't afford them. To give better insight, according to a 13 city-based research conducted in India, The current costs of stroke rehabilitation range anywhere from Rs 90,000 to Rs 600,000, depending on hospitals where the services are sought for.

The study found that supervised home-based rehabilitation - facilitated through a special manual of exercises and supervised home-based care was found completely safe and is likely to reduce the costs of hospital-based rehabilitation services. In view of this, a Robotic exoskeleton will be an efficient solution that will bridge this gap of shortage of health professionals and low-cost standardized rehabilitation for people with mobility-related disabilities helping them regain independence and aiding them in daily activities.

VI. FUTURE SCOPE

Future enhancements could be stretching out to bring down appendages and exoskeleton for both hands. At present anticipating Virtual rehabilitation considering Coronavirus circumstance and shortage of rehabilitation workforce. Investigating and introducing a distinctive actuator framework and expansion of new sensor framework which we kept away from because of time and cost contemplations.

Expansion of DOF for exoskeleton intended to give help with ADL, mobility, and fit, and gesture control with the assistance of BOB and Matlab Simulink for future improvement and optimization of the design.

A further idea of control modes fusing the deliberate power will permit more adaptable preparing programs. Asian illustration, the speed of the direction could be different by the obstruction of the patient against the development which is estimated by the power sensors. This would permit the framework to synchronize with the patient and abstain from compelling the circumstance of the activities onto the patient. The solace of the restoration program and perhaps the achievement could be improved by thusly.

Plan to incorporate C1-C5 level of injury-The degree of injury cut-off was set because sensible hand capacities are needed to hold the assistive gadget and to start weight works out. Absence of hold can be defeated because of the new plan and actuator and signal control. The next broad plan and framework for Prolonged utilization of exoskeleton should be checked for various strain skin zones, as it might bring about changes in their skin structure that are probably going to stall with a base measure of shear to handle this.

VII. CONCLUSION

Upper-limb exoskeleton systems have important implication value in motion assistance and rehabilitation applications. New challenges in the research and development of this technology were identified and discussed, focusing on the mechanical design, controls strategy, mode of actuation and power transmission, and exoskeleton design modeling based on the human upper-limb anatomy. It is noted that the mechanical design of these systems is still heterogeneous due to their broad applications. So far, there are no standard criteria for the design and performance evaluation of robotic exoskeletons.

Therefore, more R&D is required for the design of novel mechanisms by considering the complex human biomechanics, specifically for shoulder and wrist joints. Additionally, more research is required to develop evaluation criteria for the control methods, which may lead to evaluating and comparing the different studies.

The physical interaction between humans and robots is also very important and has not been addressed satisfactorily in most of the recently developed systems. Hence, a framework is required to quantify the influence of robotic exoskeletons on the human upper limb to account for comfort and compliant interaction.

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