Developing a Smart Exoskeleton Robot with a Novel Design for Elbow Rehabilitation

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Abstract:- The disability in the upper limbs of adults is usually caused by a stroke or accidents that cause defects to the natural movement of the elbow. Such impairments have a significant impact on healthcare needs and expenses. Sensory, motor, cognitive, and psychological deficiencies are possible symptoms of the impairments, which require specialized treatment to be resolved. In particular, the restoration of upper limb function needs a lengthy duration of rehabilitation treatment, even if it is begun at an early stage. As a result, the inability to perform activities of daily living (ADLs), which are directly related to quality of life, is greatly reduced by impaired arm and hand functioning. Exoskeleton robots can be a solution for the rehabilitation of such patients. Exoskeleton robots are a special type of wearable robots controlled by computer systems with the main aim of restoring movement. The main setback in current technologies of exoskeleton robots is that they are not portable and are expensive. This study is aimed at creating a portable, cost-effective smart exoskeleton robot for elbow rehabilitation. We have integrated smart technologies into the exoskeleton robot which could help in the mobile operation of the exoskeleton robot. Effective rehabilitation aims for perfect accuracy and positive outcomes. This kind of robot has a variety of advantages compared to a conventional rehabilitation robot.

Keywords*: Exoskeleton, Rehabilitation, Limbs, Elbow.*

1. Introduction

Adults affected by strokes or accidents end up with upper limb disabilities that impair the elbow's normal range of motion. The restoration of upper limb function necessitates a lengthy duration of rehabilitation treatment, even if it is started at an early stage. As a result, inability to perform activities of daily living (ADLs), which are directly related to quality of life, is greatly reduced by impaired arm and hand functioning. Exoskeleton robots are a distinct type of professional service robots that are used in a variety of applications and are designed to mimic the movements of the human body. These robots support human mobility vitally.

The use of upper limb exoskeleton robots for neuromuscular disease patients undergoing rehabilitation is carried out. Using biomechanics modelling, the exoskeleton can imitate the motion of a human limb. Numerous patient-specific factors may also need to be taken into account because they have the potential to influence how well the treatment works. Overall, the recent developments in the field of upper limb exoskeleton robots is studied [1]. The study developed and evaluated 12 pneumatic muscles of various sizes and materials. The experiments revealed that muscles with higher tensile modules had better load bearing capacity and less hysteresis, but they also had weaker contraction and force characteristics. At various pressures and loading circumstances, the styrene-based muscle with a 12mm bladder (S12LB) demonstrated the best force and deflection properties [2].

A soft wearable elbow support exoskeleton with a compliant tendon-sheath actuator is proposed. It uses a neural-network-enhanced torque estimation controller (NNETEC). The surface electromyography (sEMG) sensors, inertial measurement units, force sensors, and motor encoder feedback signals are combined to create the NNETEC approach. The results show that this method can achieve higher power assistance efficiency when compared to the proportional control strategy and the sEMG-based assistive control strategy without neural-network adjustment [3]. The work deals with the complete design of the rehabilitation robot with pneumatic artificial muscles. On the basis of kinematic analysis of the upper limb, a designed variant of robotic device is an exoskeletal system has seven degrees of freedom (DOF). The shoulder joint has three DOFs, the elbow joint has two DOFs, and the wrist joint has two DOFs. Each joint is driven by a couple of pneumatic artificial muscles (PAM) [4].

The mechanical framework of the robot is made of lightweight materials, and the robotic joint mechanism is designed based on gait biomechanics to ensure portability. The springs are chosen to maintain high intrinsic compliance for the most of a gait cycle while preserving the ability to deliver the peak force. The EMG results show that major leg muscles are activated at a lower level during the test, and their regular gait pattern is preserved [5]. Most of rehabilitation robots focus on one joint or a local group of joints such as hand or wrist. Multi-contact robotic device for rehabilitation of coordination seems to have advantages. Patients underwent 45 min of robot therapy, 3 times a week for 8 weeks during chronic stage of stroke (>6 months) and results showed statistically significant improvement. But improvement was not clinically significant. Lack of tools and metrics to assess inter-joint coordination is a setback [6].

Study compares upper limb traditional physical therapy (TT) versus robot-assisted therapy (RT) to see which has longer-lasting effects on subacute stroke patients. 48 subacute stroke patients who performed upper-limb therapy with a planar end-effector robotic system (Experimental Group-EG) or TT (Control Group-CG) participated in a randomized controlled follow-up research. The upper limb Robot-assisted therapy may lead a greater reduction of motor impairment in subacute stroke patients compared to Traditional Therapy [7]. Upper limb exoskeleton robots are classified considering the characteristics of their mechanical design or software systems like the applied segment, the DOF, the method of actuation, the method of power transmission, the application domain, the linkage configuration, the control method. Exoskeleton robots use electric actuation, hydraulic actuation, pneumatic actuation and other types of actuation methods. In order to increase wearer safety and career awareness, inertial measurement unit (IMU) sensors and global positioning system (GPS) can also be incorporated into exoskeleton robots [8].

Platform-based systems make up the majority of upper limb exoskeletons. The actuation methods that can be used to create portable upper arm exoskeletons are quantitatively analyzed in this work along with their specifications. The actuation methods are electric motor, hydraulic actuator, pneumatic actuator, electroactive polymer (EAP), ultrasonic motor, shape memory alloys. The main methods in passive rehabilitation – software based solution and hardware based solution are compared [9]. A wearable elbow exoskeleton for tremor suppression (WEETS) is presented as an alternative to traditional treatments based on surgery and medication. To reduce tremor in the elbow joint, the WEETS system employs a new configuration and programmable rotating semi-active actuator (RSAA) based on magnetorheological fluid. The findings indicate that the WEETS can reduce elbow tremor significantly, in terms of angular velocity and acceleration magnitude [10].

Methodology

Elbow extension and flexion are two major movements that occur at the elbow joint. The works aims at facilitating these movements in stroke or accident prone patients who should undergo rehabilitation. As an alternative to traditional rehabilitation, we propose our smart exoskeleton robot for rehabilitation. The angle and speed of movement of human arm with respect to the elbow joint are two important factors that will be controlled using our exoskeleton robot. Oscillating movement of three angles, 30˚, 60˚, 90˚ with three speeds low (8.5 rpm), medium (10.5 rpm) and high (12.5 rpm) are chosen. Angle and speed control is simultaneous.

The proposed exoskeleton structure is a 3D printed structure. It is modelled using Onshape cloud based CAD platform according to the fit and dimensions of a standard human elbow. Figure 1 shows the CAD models of top and bottom part of exoskeleton robot.

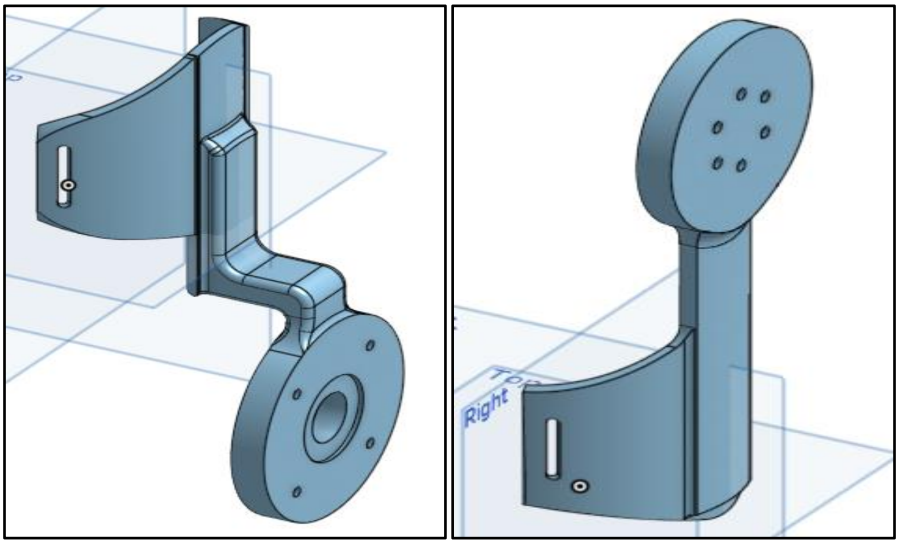


Figure 1: CAD models designed in Onshape platform

The exoskeleton structure is powered by a high torque (12.6 Kg.cm) NEMA 23 stepper motor which enables the movement of the elbow for rehabilitation. The exoskeleton structure is controlled by IoT embedded system. The IoT embedded system consists of two Arduino Uno boards, a Bluetooth module (HC05), Stepper motor controller (TB6600) and a Stepper motor (NEMA 23). The Figure 2 shows the workflow in the IoT embedded system.

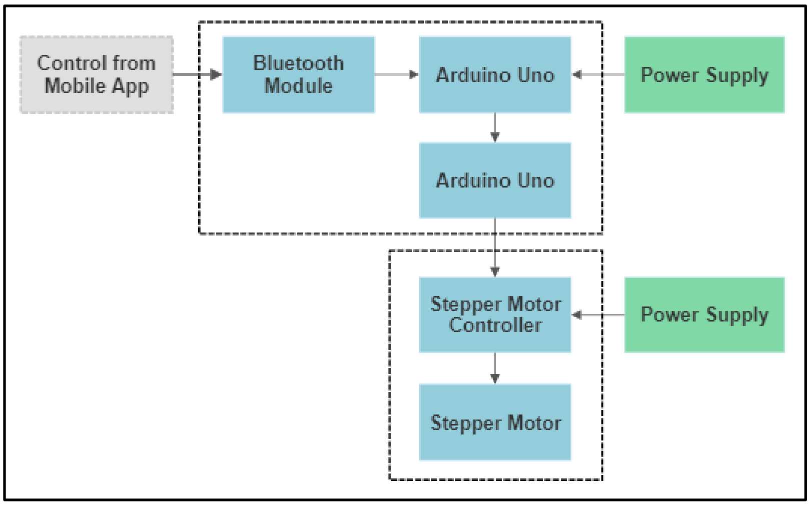


Figure 2: Workflow in IoT embedded system

Arduino Uno is a microcontroller board based on microchip ATmega328P. It is an open source development board used to interact with and control various electronic components. Two Arduino Uno boards are used to facilitate in simultaneous control of angle and speed of the exoskeleton robot without any lag. A total of 6 variables (3 angles & 3 speeds) are controlled using two Arduino Uno boards. Arduino IDE (Arduino Integrated Development Environment) is used for writing and compiling the program codes into the Arduino Uno module. Programs developed on Arduino IDE can be transferred directly by connecting computer/laptop to Arduino Uno via USB port.

Wireless connection of IoT embedded system with smartphone is facilitated by a Bluetooth module. HC05 Bluetooth module is used for our work. It works on (RX/TX) for sending and receiving data. It supports Serial Port Protocol (SPP) which is helpful in sending/receiving data to/from a microcontroller. The stepper motor used is NEMA 23 (12.6 kg.cm). It is a 2-phase stepper motor with holding torque of 12.6 kg.cm, step angle of 1.8˚ and 200 steps per revolution. The operating current of this motor is 2.8 A and voltage 2.5V. The motor is compact in size and delivers smooth and consistent torque at high speeds.

TB6600 is a stepper motor driver used for the control of two-phase stepper motors. It is compatible with Arduino and similar microcontrollers that can output a 5V digital pulse signal. TB6600 stepper motor driver has a vast range of power input of 9-42 VDC power supply with supply current of 0-5 A and output 4A peak current. It supports both direction and speed control. The power is supplied at two ends, one at Arduino Uno section and another at stepper motor section. The power supply is done through two AC adapters with output of 12V and 2A. Figure 3 shows the IoT embedded system.

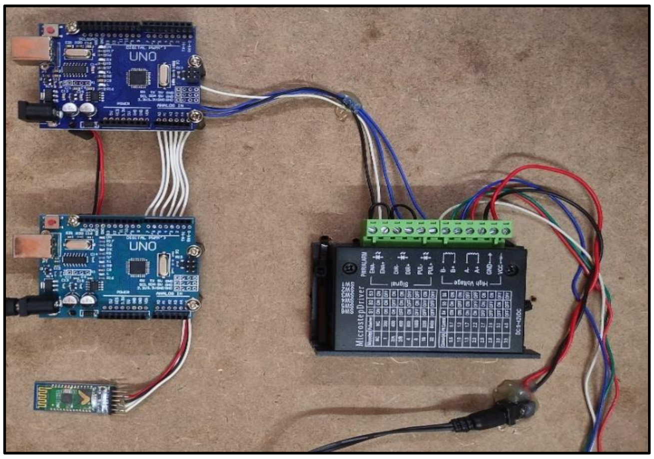


Figure 3: IoT embedded system

The exoskeleton structure is fabricated using Fused Deposition Modeling (FDM) using Polylactic acid with white natural colour. Polylactic acid is chosen as it exhibits good strength and is also economical. The tensile strength of PLA is 37 Mpa with about 6% elongation. PLA has density of 1.3 g/cm3. The layer height is 0.2mm with 100% infill density. The stepper motor is fastened to the top part of the exoskeleton robot. A motor coupling hub having inner diameter of 8mm is used to connect the stepper motor shaft of 8mm diameter to the bottom part of the exoskeleton robot. This coupling helps in reducing slip during operation. Figure 4 shows the 3D printed exoskeleton structure with stepper motor.

Figure 4: 3D printed exoskeleton structure with stepper motor

The IoT embedded system and the 3D printed exoskeleton structure with the stepper motor together form the proposed smart exoskeleton robot for elbow rehabilitation. Two power inputs, one to the Arduino module and another to the stepper motor module facilitate working of the exoskeleton robot. Figure 5 shows the proposed smart exoskeleton robot for elbow rehabilitation.

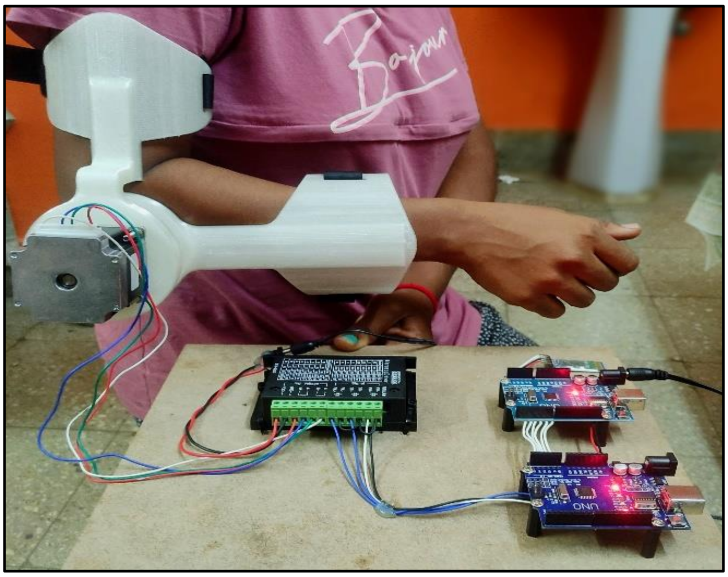


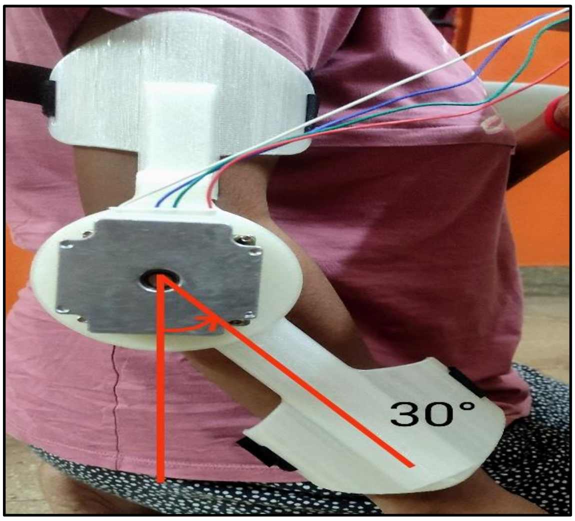
Figure 5: Smart exoskeleton robot for elbow rehabilitation

Results and Discussions

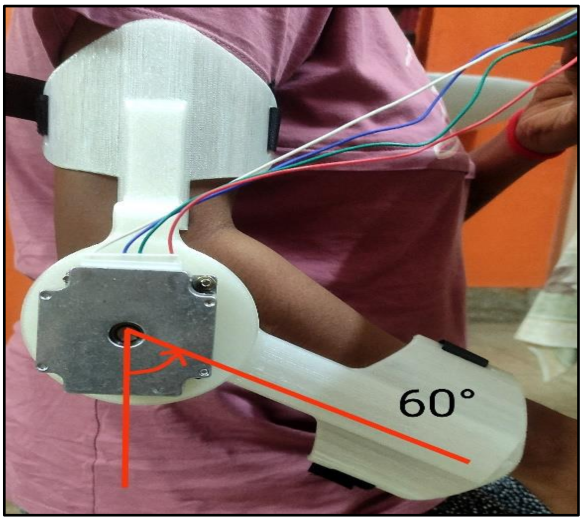
The exoskeleton robot is wearable onto the elbow using two velcro straps. One holds onto the upper arm and the other holds onto the forearm of the human with the motor joint placed right over the elbow joint. Once worn, the exoskeleton can be controlled wirelessly via Bluetooth using smartphone application (App-Arduino Bluetooth Control). The application enables pairing between the smartphone and the Bluetooth module of the IoT embedded system.

Oscillating angle control with three angles, 30˚, 60˚, 90˚ and speed control with three speeds, low (8.5 rpm), medium (10.5 rpm) and high (12.5 rpm) can be done simultaneously using the smartphone application. Flexion and Extension occur at the elbow joint. The normal range of movement is from 0˚-140˚ but only 30˚-130˚ is required for most of the activities of daily living (ADLs). The main objective of our exoskeleton robot is to speed up the healing process and restore the range of motion of the elbow joint. The oscillations between fixed angles aid at regaining the natural movements of the elbow. It helps to improve the strength, flexibility and movement of the affected muscles and tendons of the elbow. The initial treatment can be started with lower speeds and lower angles so that stress is not imparted on the recovering muscles. Gradually, the speeds and angles can be increased based on the improvements shown by the patient in the previous treatment sessions. Figure 6(a),(b) and (c) show angle of movement of 30˚, 60˚ and 90˚ respectively.

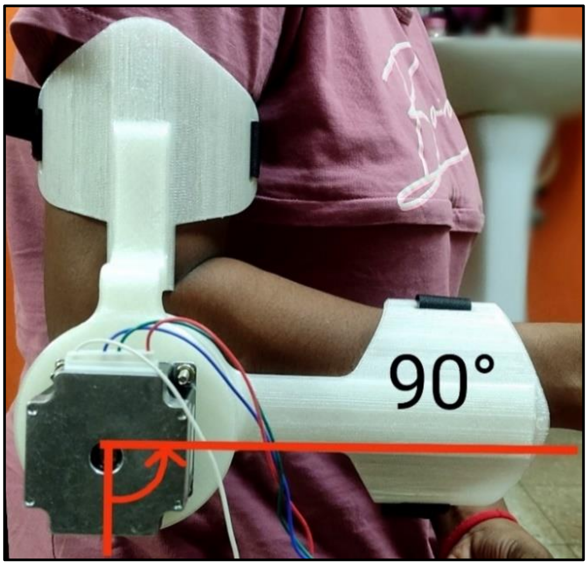
It is very important to be noted that although we have proposed the exoskeleton robot for the elbow rehabilitation of patients, the treatment conditions, constraints, angle specifications, speed specifications, treatment duration, session durations and other important decisions are to be taken by a professional doctor (Physiotherapist or Physiatrist) depending upon the patient condition. The use of this exoskeleton robot should be combined with a professional advice. Also, the recovery of patients undergoing elbow rehabilitation with the proposed exoskeleton robot depends upon the severity of the injury, cooperation shown by the patient towards rehabilitation sessions and also depends on the health condition of the patient.



6. (a)



6. (b)



6. (c)

Figure 6: (a), (b), (c) showing angle of movement 30˚, 60˚ and 90˚ respectively

2. Conclusion

The development of a smart exoskeleton robot for elbow rehabilitation is carried out. The aim of this work was to develop an effective rehabilitation device which could potentially replace traditional rehabilitation procedures at the same time provide added benefits to the patient. The proposed exoskeleton robot has incorporated smart technology for its working. Also, another drawback of existing rehabilitation devices is that they are very bulky and not economical for use on an individual patient. The proposed work is both portable and economical. The smartphone application based control makes the exoskeleton robot very user friendly. By using this exoskeleton robot for rehabilitation, recovery can be seen in patients effectively and at the same time save them a lot of money which they would have otherwise spent on traditional rehabilitation sessions.

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