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Human Upper-Extremity Rehabilitation Trainer (Hurt)

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Abstract

With the evolving trends and growing population there arise the need of assistive supporting and rehabilitation devices which are either used for improvising the strengths of the human or to offer an assistance to regain the lost motion of a particular limb joint. Particularly the musculoskeletal diseases are getting increased in the younger age due to work environment and aging and as a consequence the need of assistive devices is on the rises. The current demand is for designs that are adaptable and affordable, and for these designs, design perspectives must be considered in order to create fewer complex designs and ease production restrictions. The paper proposes a novel idea to offer rehabilitation to the lost motion on the human upper limb and develops a cost-effective upper extremity exo-skeleton to address the post stroke patients. Design analysis is carried out to obtain the important joint motions for offering rehabilitation to the user with easily available components in an affordable way. The Degrees of Freedom with respect to the human upper limb joint is kept in mind in designing the model to offer effective rehabilitation at minimal cost. The developed model is a self-sustaining, battery-operated and detachable design which can be placed in compact places.

Keywords: Rehabilitation trainer, Physiotherapy trainer, Upper extremity exo-skeleton, limb rehabilitation, Physical disability.

1. Introduction

Exoskeletons for the upper limbs are electromechanical systems that interact with the user to provide power amplification, aid, or replacement of motor function. Most of the elderly people are affected with back pain and limb joint pain due to aging. These problems may be overcome either by using medicine or via external treatment like physiotherapy or assistive robotics like the exo skeletons. Stroke has surpassed heart disease as the leading cause of disability and death globally. Exoskeleton robots, as a tool for fast mobility function recovery in stroke patients, can minimize complications and hence reduce the stroke fatality rates. Prosthesis and orthosis are the two main forms of upper-limb robotic systems. Since 1883 when the notion was first developed [1] in many nations, stroke is still the top cause of adult disability and a summary for developing upper limb exo-skeleton hardware systems augmentation and assistive for elderly people is made. Repetitive training is the most effective way to regain independence following a stroke. Some customizations [2] in the upper body exoskeleton like easy to use, carry and wear for geriatrics may be attempted to improve the user comfort and ergonomics.

Therapy robots can relieve the stress on therapists by replacing human intervention and offering perfect therapies that adhere to the following stroke rehabilitation principles: task specificity, high intensity and repetitive robotic operation resulting in an optimized therapy. Robotic training can help therapists' elderly people with their workload, but it is not always the best option [3]. The paper also made a novel study to compare the end effector and exo robots directly in chronic stroke patients with moderate-to-severe upper limb disability for deeper understanding. stroke incidence will rise as the population's average life expectancy rises [4]. A brief overview and detailed summary [5], [6] are given for upper extremity rehabilitation exo-skeletons and the major gaps are identified to facilitate potential scope for future developments. The importance of DOF is elucidated by [7] which incorporates both active and passive DOFs in its model. A detailed study of modifiable capillary and life related risk factors [8] in at-risk elderly people in the finish geriatric intervention study to prevent mental impairment [9] and disability.

The elderly people are a significant health concern particularly in long term care setting and hence a detailed study and analysis is made to a set of people above 80 years of age in the last 20 years and concluded with an overview of the past few years trend [10]. Home based physiotherapy and home-based devices are rare for elders. One such approach with a cost-effective upper limb with the three-dimensional analysis has been carried out [11]. For the mobility of the upper limb exoskeleton a human–robot cooperative controller using an electrical actuator that is primarily controlled by force sensor inputs to provide three degrees of freedom is designed [12]. Support for overhead work [13] keeping in mind the benefits to be offered for the industrial workers in order to reduce the shoulder muscle activity is designed and evaluated. Adopting a new technology in the workplace might be difficult since the technology may have unintended safety and health repercussions. [13], [14] with unexpected tests for usability, shoulder range postural control, spinal loading during overhead work simulation.

A 3DOF DC motor powered exo-skeleton [15] is purpose built for offering the additional torque to its user comprising the features of position and torque control. [16] gives a brief

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about the human and robot interaction for rehabilitation and training purposes especially for stroke patients and made in-depth analysis for post stroke conditions. Motion Assistive Robotic-Exoskeleton for Superior Extremity (ETS-MARSE) [17] and ABLE [18] are 7DOF upper limb exo-skeleton [19] has been developed with DC servo motors for rehabilitation training and is tested with human subjects for effectiveness. ABLE [18] is also tested for its adaptability to the industrial environment by making an ergonomic study. An intended exoskeleton is built for rehabilitation of the upper limb to offer training to the spinal cord injuries and explores the range of robotic measures for quality and smoothing as a physiotherapy to the impairment [8], [9], [20] following stroke. Experimentally tested a dynamic analysis force controller for the motion of the upper limb using an electrical actuator for its effectiveness [21]. Using myoelectric control to restore rehabilitation in patients with spinal cord injury [20] were analysed for specific areas in the upper and forearm muscles for impairment persons [9]. Detailed review for upper limb were analysed for the last twenty years of exo skeletons versions and intelligence and machine power [22]. Cost effective robot with the design considerations for upper limb also per-formed as a physical therapy [23].

Muscular and physiological simulations and their joint dynamics can be acquired using the OpenSim [24]–[26] software for enhancing deeper musculoskeletal study to enable deeper under-standing on the human structure so as to design viable devices. The limb movement [27] of ten test subjects and their muscle data were captured using the EMG signals for moving to random positions, wearing an exo-skeleton system which were later used for setting control parameters. The Forward Kinematics [28], [29] of the robotic end effector system were analysed and [29] gave broader in-sights on the lower limb exo-skeleton torque analysis thereby elaborating on the actuator selection criterion.

2. Design analysis

The OpenSim [24]-[26] programme was used to create the human body's upper limb joints, which are portrayed in Figure 1. The shoulder joint has three degrees of freedom (DOF), the elbow joint has one, and the wrist joint has two. As our design constraint [27], we used 2 DOF for the shoulder on the coronal plane (Abduction-Adduction) and Sagittal plane (Flexion-Extension), 1 DOF for the elbow on the Sagittal plane (Flexion and Extension), and 1 DOF for the wrist on the Transverses plane (Ulnar flexion and Radial flexion). These are the main parameters for providing rehabilitation to the human upper limb. Figure 2 depicts the rehabilitative exo-skeleton trainer's proposed 3D model.

The therapy training sequence for the human upper limb joint with the aiding device is elaborated in Figure 3 with which the trajectory planning can be made using the controller.

3. Developed model

The prototype model's lightweight aluminium frames were used in its development, and it included a straightforward and efficient control system that included an electric linear actuator as the primary actuation device, controlled by an Arduino mega 2560 microcontroller, and an L298 dual bridge motor driver with a joystick module as the input controlling device for motion. The produced prototype of the exo-skeleton meant for the therapeutic training of the human upper limb is depicted in Figure 4, Figure 5, and Figure 6, showing how it operates in accordance with the sequence provided in Table 1's DH table. The wiring is made simple with basic relay logic features to reduce circuit complexity and make debugging easier. It is controlled with Arduino, an open-source controller, with the aid of a joy stick module to allow for simple motion control by the user or wearer.

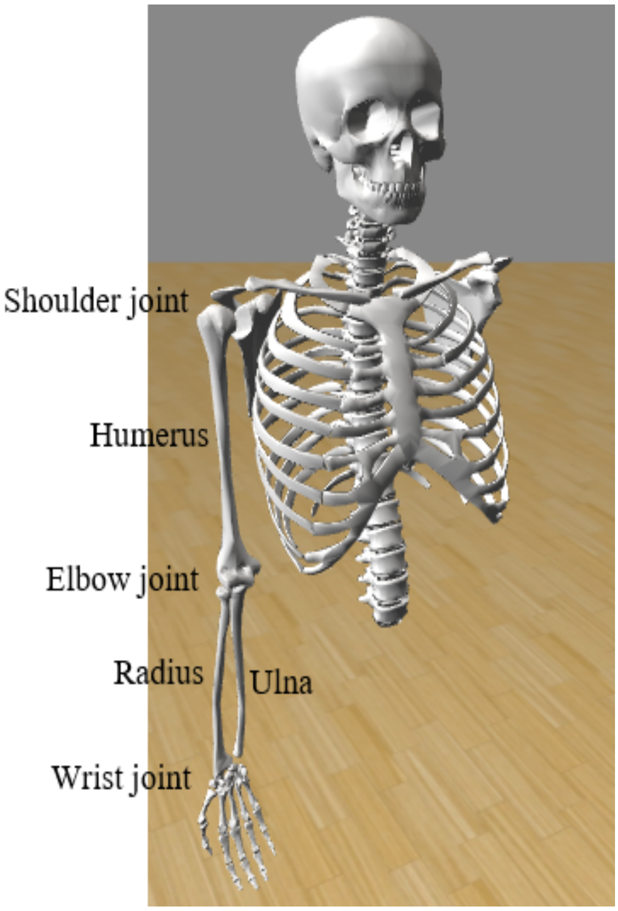

Fig.1 Skeletal structure of human upper extremity simulated using OpenSim.

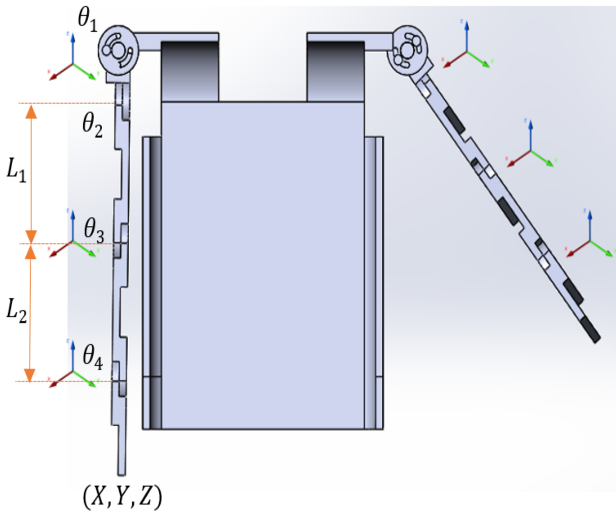

Fig.2 Exo-skeleton trainer front view design model

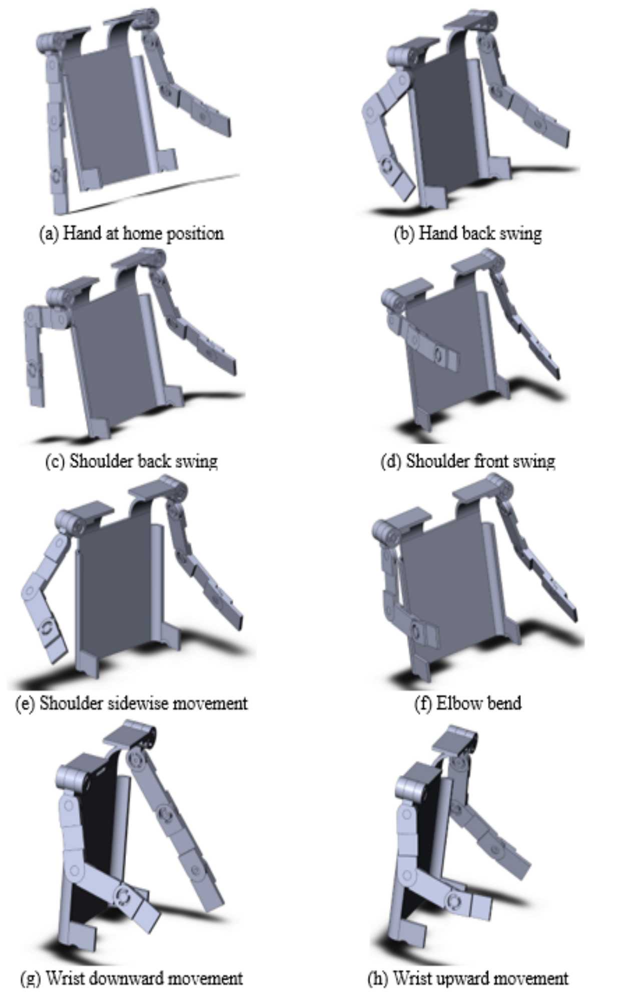

Fig.3 Simulated movements of the various upper limb exercising positions.

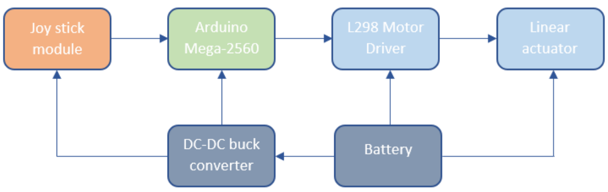

Fig. 4 Process sequence of the prototype.

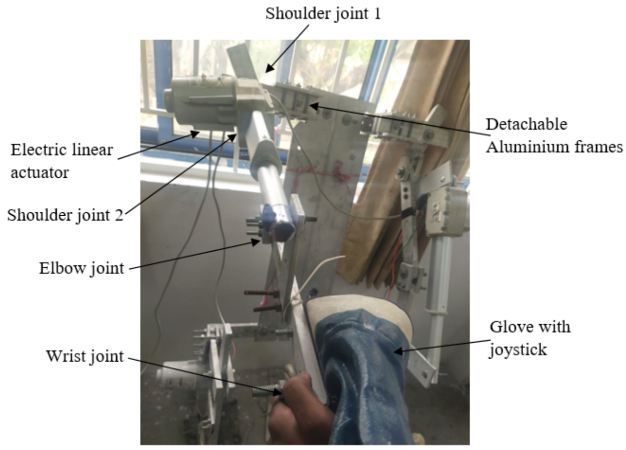

Fig.5 Prototype model of the designed upper extremity trainer exo-skeleton.

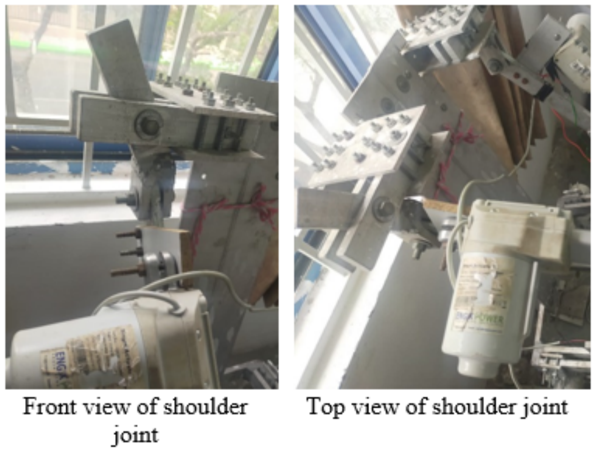

Fig.6 Shoulder joint of the developed model

4. Results and discussion

Exoskeletons for the upper limb are meant to work in tandem with the human upper limb and are connected to the human arm in many places. This necessitates a robot that can adapt to various arm lengths. Furthermore, the research and commercially accessible prototypes are contrasted and analyzed, with an emphasis on the mechanical problems. The joint constraints over the aforementioned design with respect to X, Y and Z axis according to the Coronal, Sagittal and Transverse axis is elucidated in the Table 1 below by considering the Denavit-Hartenberg parameters [28, 29].

Table 1. DH parameters for the Upper limb constrained motion

	Joint	Twist (α_{i-1})	Link length (a_{i-1})	Joint Distance (d_i)	Joint angle (θ_i)
Shoulder	1	0	0	0	θ_1
	2	0	0	0	θ_2
Elbow	3	0	L_1	0	θ_3
Wrist	4	0	L_2	0	θ_4

$$ {}_0^1T = \begin{bmatrix} \cos\theta_1 & 0 & 0 & 0 \\ \sin\theta_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}_1^2T = \begin{bmatrix} \cos\theta_2 & 0 & 0 & 0 \\ \sin\theta_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}_2^3T = \begin{bmatrix} \cos\theta_3 & 0 & 0 & L_1 * \cos\theta_3 \\ \sin\theta_3 & 0 & 0 & L_1 * \sin\theta_3 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}_3^4T = \begin{bmatrix} \cos\theta_4 & 0 & 0 & L_2 * \cos\theta_4 \\ \sin\theta_4 & 0 & 0 & L_2 * \sin\theta_4 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$^4_0T = {}^1_0T * {}^2_1T * {}^3_2T * {}^4_3T$$

$$^4_0T = \begin{bmatrix} C\theta_1 * C\theta_2 * C\theta_3 * C\theta_4 & C\theta_1 * S\theta_2 * C\theta_3 * S\theta_4 & 0 & C\theta_1 * C\theta_2 * C\theta_3(L_1 + L_2 * C\theta_4) \\ 0 & 0 & 0 & S\theta_1 * C\theta_2 * S\theta_3(L_1 + L_2 * C\theta_4) \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The translational matrix for the aforementioned DH parameter is obtained in which by applying the joint angles the forward kinematics coordinates can be obtained since the link lengths L_1 and L_2. Since the actuators are fixed at shoulder and elbow joints, the angles θ_1, θ_2 *and* θ_3 are considered, neglecting the passive joint θ_4 of the wrist in arriving the forward kinematics equation as explained in the Equations (1), (2) and (3) which can be used in controlling the actuators to reach the maximum set position for offering limb specific therapy.

$$X = L_1C\theta_1C\theta_2 + L_2C\theta_1C\theta_2C\theta_3 \quad (1)$$

$$Y = L_1S\theta_1C\theta_2 + L_2S\theta_1C\theta_2C\theta_3 \quad (2)$$

$$Z = L_1S\theta_2 + L_2S\theta_2S\theta_3 \quad (3)$$

This paper discusses the upper limb exoskeleton as a physiotherapy device for the elderly people. The novelty of this paper is the use of electric linear actuators which is one of the most cost effective yet featured solution. Here the obtained 4 DOF for the human upper limb Viz, shoulder has 2 DOF, elbow has 1 DOF and wrist has 1 passive DOF which is proposed and built. The forward kinematics were applied and with which we have calculated the DH table values as in Table 1 for the human upper limb joints. The proposed methodology adapts linear actuators which offer a good amount of linear force to move the hand and the speed of movement of the piston is in such a way that it will not harm the user's limbs at any cost and even in the case of electrical power failure the piston stops in its position thus preventing from damaging the limbs of the user. Thus, the system allows the user in participating in a rigorous and continuous rehabilitation training to regain the lost muscular action of his / her limb.

The proposed methodology is economically viable as it made use of readily available low-cost components and is made completely of aluminium frames which is also less in weight when compared to other low-cost alternatives. The Table 2 elucidates the components used for building the upper extremity rehabilitation trainer.

Table 2. Cost analysis of the components

S.No	Components	Unit cost (₹)	Qty	Total cost (₹)
1	Linear actuator 24VDC	5200	4	20,800
2	Arduino Mega-2560	1200	1	1200
3	L298 motor driver	130	2	260
4	Lithium Polymer battery 11.1V 2600mAh	2100	2	4200
Total				**₹.26,460**

With the given battery back-up, the system can function continuously for 2 hours for providing rehabilitation to the user assuming the ideal conditions without any external loads being attached to the system and considering the frictional parameters into account. The developed model is built in modular approach as the joints are bolted which can be detached when not in use thus reduces the work area when unutilized.

5. Conclusion

The current trend is moving towards the world in which the need and role of exo-skeleton is on the rise which is either used in assisting the humans due to locomotion impairments or offering strength augmentation involving heavy weight lifting activities. The era had already begun in which the exo-skeleton owes a positive impact in the human life leading to enhancing the human life by minimizing or eradicating the flaws and limitations faced by the humans. Upon combining the robotic therapy with the conventional methods could lead to enhanced solutions which could result in improved treatment. Cost effective and adaptable designs are the need of the hour to make the exo-skeleton systems available and affordable to the common public for which the design perspectives have to be kept in mind so as to develop fewer complex designs to remove and reduce the manufacturing constraints. The need of medical exo-skeletons is on the rise as the number of accidents and identification of new musculoskeletal diseases either due to aging or work environment is getting increased day by day which requires an assistive and supportive device to regain the lost muscle action.

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