Design and Fabrication of an Actuated Hand Exoskeleton for Stroke and Post Traumatic Rehabilitation

Ubaid A. Shafi, Anum Pervez, Fahad A. Kamal, Rabia Ejaz, Umar S. Khan, and Javaid Iqbal

***Abstract*—**The human exoskeleton is predominantly a helping mechanism for patients of hand paralysis which assists them in physiotherapy exercises. The proposed design utilizes a four bar mechanism and a lead screw for each finger. 4 DC motors of 6V each are used for actuation of the four fingers. EMG signal from the arm of patient can be used to control the movement of the finger or it can be hardwired and controlled via H-bridge and exercises can be preprogrammed. The mechanism is foremost very economical to fabricate, simple to control and safe to manipulate.

***Keywords*—**4 bar mechanism; exoskeleton; lead screw; robotic hand.

I. Introduction

EXOSKELETON glove is a robotic hand which is worn externally to improve the strength of a person who is deprived of functional hand owing to age, wound, or illness. It is so assembled that its joints coincide with the joints of impaired hand which wears it. It thus creates improved motion by transferring the force exerted on exoskeleton's joint to the joints of human's hand.

Accidents, injuries, trauma and strokes can cause the spinal cord weakness which in turn results in partial paralysis and neuromuscular disorders [1]. In United States over 250,000 cases spinal cord injuries have been accounted [2]. The 1998 census reports that about 624459 peoples in Pakistan are disabled [3] and in 2012 , 964463 persons are found crippled according to a report which shows an increased in disability rate of 2.65% as compared 2.54 % in 1998 [4]. Age is also a major factor contributing as 20% of people in world have crossed 65years of age and prediction says that 35% will cross this age by 2050 [5]. Another study reveals that after late 50s, the chances to get paralyzed double after every decade, among which 70% cases require a therapist [6].

A person with an impaired hand requires constant therapy to regain strength to perform daily life work such as griping, pinching, holding or shaking hand etc. Such treatment is called rehabilitation [7]. Recently a case study was performed to estimate the needs of chronic paralyzed patients [8] and fact was that in Activities of Daily Living (ADL) the most demanded function to recover is the hand ability. Another research states that about 40-50% returns to work after thorough rehabilitation [9], but this rehabilitation therapy involves a dedicated therapist, enormous amount of time, money and resources. All this can be reduced due to the progression in the modern technology. Miniature electronic circuits, reduced actuators and batteries, permanent fixing techniques and improved control made it possible for exoskeletons to be wearable just like a glove on displaced or weak human hand hence enabling them to perform the activities of daily life.

Ibrahim et. al. have worked to fabricate a prototype of such glove in Pakistan [10]. Their design employed four servo motors with the basic mechanism of thread and pulley. The problem in mechanism discovered is unwinding of thread from the pulley while in motion which render it unable to move. This design insufficiency provokes a need to redesign the whole mechanism again.

The design presented in this paper imitates the non-functional hand as naturally as possible, affordable to commoners, light weight and aesthetically attractive.

This paper is ordered as follows: Section II explains the related work while Section III-IX highlights the design goals, mechanism, analysis and specification.

II. Related Work

The advancements of the technology in the Wearable Robots/Exoskeleton field have been booming in the past 5 years. Foremost the exoskeletons are employed in military such as Berkeley Lower Extremity Exoskeleton for power augmentation (BLEEX) [11] and robots for the rehabilitation purpose of paralyzed patients.

In the field of robotics, hand exoskeleton is a widely exploited area by engineers and scientists. Keio University's professionals have developed a mechanism which employ passive clutches to drive a three-fingers non-isomorphic hand [12].

A 4 DOF index finger successfully employing master slave configuration was conceived by lelieveld, he used haptic interface with active and passive multi-point feedback [13].

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Haptic effects of consumer were also studied at university of Wisconsin by Springer and Nicola, on a four bar single finger prototype [14]. At PERCRO lab, a four fingered, multi phalanx hand was developed with the ability to apply force on each part of the finger [15]. PERCRO also initiated to create a

3 DOF finger exoskeleton hand which can put forth controlled force on the finger tips via working with haptic technology in virtual atmosphere [16]. Stergiopoulos proposed an exoskeleton hand with two fingers having 3 DOF each and a thumb having 4 DOF, which aimed at VR grasping simulations [17]. Italian Institute of Technology (IIT) utilized an optimized RRR un-actuated mechanism to provide 45N of force in their exoskeleton, which can be used for tele-operation, VR and Human- Robot-Interaction (HRI) [18].

IIT also fabricated another un-actuated Hand Exoskeleton system (HEXOSYS) prototype with 4 bar mechanism having

4DOF per finger [19].

III. Design Goal

Owing to it complex joints and motion, human hand is a difficult system to replicate. After carefully reviewing all of the available mechanism, a need to design a mechanism under constraints and limitation has to be achieved having following set points.

- Low sum of expenditure of the mechanism
- Plug and Play mechanism
- Low weight mechanism
- The actuation strategy
- The strength of the mechanism
- The HMI (Human Machine Interface) Risk Factor
- Aesthetics attractiveness

Following the design goals a mechanism with complex joints and greater number of actuators cannot be employed. The exo skeleton so developed has started with the approach in mind that it should be less complex and easily controllable.

The lead screw is actuated via DC motor of 6V, which rotates lead screw and this in turn will move the input link in linear

IV. Device Mechanism

The mechanism so designed is the one which meets the design criteria i-e; is simple to actuate, economical to fabricate and can be operated safely. The design consist of a 4 bar mechanism having a 4 DOF, where each finger is having 1

DOF. A lead screw is employed to convert the rotary motion into linear motion, that will push the 4 bar mechanism forward and backward to mimic the motion of hand. Simple DC motors are used to actuate each finger of hand. The design specifications for the lead screw and 4 bar mechanism are shown in Table I and II.

TABLE I
DESIGN SPECIFICATION FOR LEAD SCREW

Length	5.6cm
Pitch of thread	1mm
Depth of thread	1mm
Diameter	2cm
Total no of threads	56
Material used	Aluminum

TABLE II
DESIGN SPECIFICATIONS FOR THE 4 BAR MECHANISM

Link#01(Input link)	5.6cm rod of diameter 1cm
Link#02(Coupler link)	8cm
Link#03(Output link) curve link	Approximately 5.8cm radius, quarter circle
Supporting links	1)3cm
	2)3.75cm
Material used	Aluminum

The lead screw is actuated via DC motor of 6V, which rotates lead screw and this in turn will move the input link in linear fashion. The input link transmits this force to the coupler link and as a result the curve link moves in curve path. The output curved link is to be fastened to the middle phalange of patient

hand, so the output motion enables the finger to move by providing it enough force and curve path.

V. Static Analyisis

Static and dynamic analysis was carried out on mechanism made on PRO-ENGINEER software. The following results were gained from the analysis

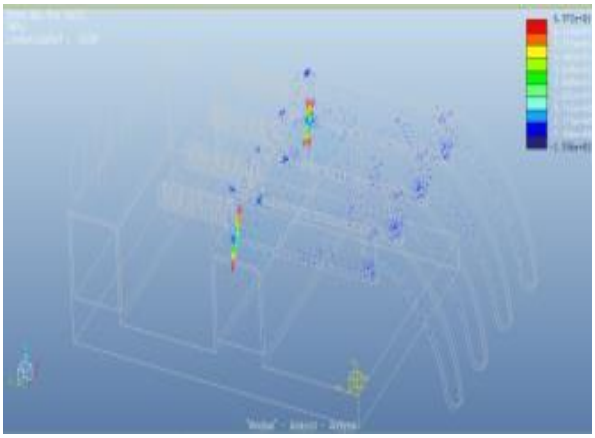

Fig. 1 Stress vectors

Constraint is applied on the base plate of the mechanism, the static analysis on Fig. 1 and Fig. 2 shows that stress and displacement analysis respectively.

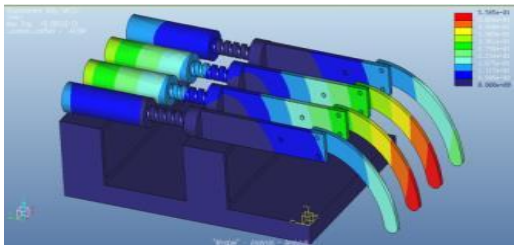

Fig. 2 Displacement

The graph shown in Fig. 3 explains the displacement on the tip of finger joint, it shows that initially the finger moves linearly, i.e. straight line motion, and at the end the finger follows a curve path. This exactly defines the motion of the finger when it's moved by glove.

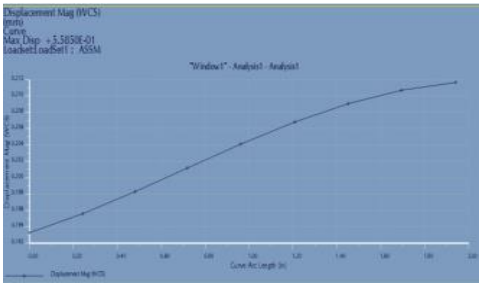

Fig. 3 Displacement graph on the tip of the finger joint

TABLE III
ANALYSIS FEATURES

Analysis features:	
Mass of the object	19.10347 lbm.
Mass moment of inertia:	Ixx: 6.85605e+04
	Ixy: -3.03730e+04
	Iyy: 2.85169e+04
	Ixz: -2.71531e+03
	Iyz: -5.30666e+03
	Izz: 9.11206e+04
Center of Mass Location Relative to WCS Origin:	(9.95488e+00, 1.60023e+01, 1.45673e+00) cm
Displacement(mm)	Maximum-displacement-mag: 2.198800e-02
	Maximum-displacement-x: -2.734747e-03
	Maximum-displacement-y: -6.941496e-03
	Maximum-displacement-z: 2.102337e-02
Stress/strain:	Maximum-stress-prin*: 3.904381e+06
	Maximum-stress-vm*: 5.358297e+06
	Maximum-stress-xx*: -1.656750e+06
	Maximum-stress-xy*: 5.995721e+05
	Maximum-stress-xz*: 8.552079e+05
	Maximum-stress-yy*: -1.147396e+06
	Maximum-stress-yz*: -1.025264e+06
	Maximum-stress-zz*: -5.527717e+06
	minimum-stress-prin*: -5.659688e+06
	strain-energy: 6.195599e+01

Fig. 4 shows the stress on finger tip, which implies that the stress increases as finger moves. The stress is maximum when the displacement is maximum.

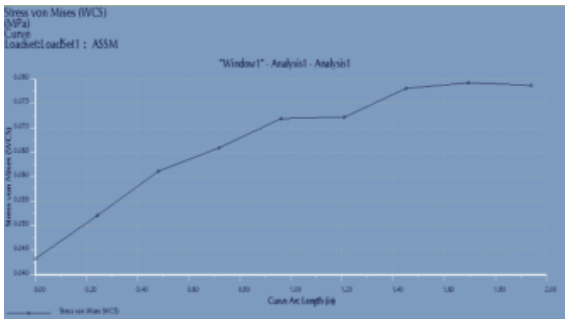

Fig. 4 Stress on the tip of the finger:

VI. MECHANISM ANALYSIS

The design is divided into two mechanisms for ease of understanding. The first one is 4 bar slider crank and the next link to which finger is attached forms a 3 bar mechanism driven by the 4 bar slider crank mechanism. Sliders are used to change linear motion into semi-rotating motion.

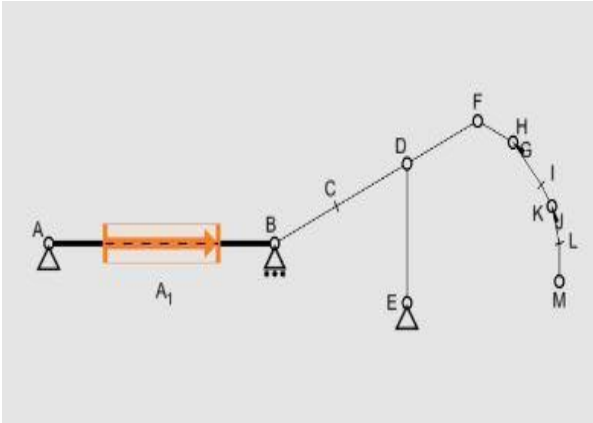

Fig. 5 free body diagram

Slider-crank mechanism incorporated is shown in Fig. 6

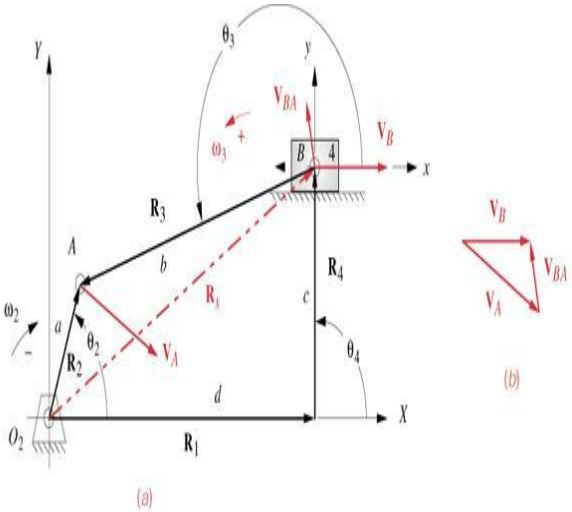

Fig. 6 crank slider

This slider is basically a lead screw driving the rocker i.e the slider is made input in this mechanism. The 3 bar mechanism is attached to the crank extended, which is shown in Fig.2. The Vector equations are as follows:

$$R_1 + R_2 - R_3 - R_4 = 01 \quad (1)$$

$$ae^{j\theta 2} + be^{j\theta 3} - ce^{j\theta 4} - de^{j\theta 1} \quad (2)$$

Equation 1 and 2 are the standard 4 bar equations used for the position and acceleration analysis. Where R1 –R4 are the links lengths, and Euler's form is written in the equation 2, Euler form is given in eq. 3.

$$ej\theta = Cos\theta + Sin\theta \quad (3)$$

The 3 bar linkage attached to the extended crank is basically formed when the mechanism is worn by a hand where a finger also acts like a 2 bar linkage. The 3rd bar is formed by the curved link attached to extended crank. This curved link will follow the motion of the crank. This motion is limited by finger constraints.

VII. Device Prototype

The first prototype for the proof of concept was made by wood. It was un-actuated and the purpose was to check whether the end-effecter so designed follows the correct path and also if there is any constrained in the movements of different joints. Instead of lead screw, the input link was made to move manually in linear manner to verify the output curve motion.

The first wooden prototype when wore and manually driven follows a good curved path, without any impact on other fingers. It outputs a reachable workspace for the movement of finger from full flexion to full extensio n. The smooth movement of every joint confirms that the design so conceived is functional and effective.

Fig. 7 Wooden Prototype

VIII. Device Specification

Table IV
Device specifications

MECHANICAL	1 DOF/finger
	Linear actuator(lead screw)
	Simple 4 link mechanism
	Small DC motors
	Supporting link limit output motion to fingers workspace
	Low complexity
ELECTRONICS	Low cost circuitry
	small board
	Ease of assembling circuit
	Insulation via nylon plate
ERGONOMICS	High torque output
	Light weight
	Low volume
	Cost effective
	Plug n play mechanism
	Portable
	Collisions-free
	Human machine interface risk considered

IX. Working Model

The full working model was fabricated as a next step using aluminum metal. All of the four fingers are assembled on the metallic base plate. Each finger is actuated using small DC motor of 6V. The mechanism is integrated to the control board and functionality of all the fingers was tested. The motion was smooth, slow and without jerks.

Fig.8 Complete working model

X. Conclusion

The design and fabrication of first prototype of portable, externally wearable glove with 6V DC motors, lead screw as linear actuators and 4 bar mechanism have been developed and tested. It is capable of providing minimum required force on the patient's hand. Moreover the robotic hand has been pre-programmed for various physiotherapy exercises. The glove has the three foremost design gains i.e. its light weight, economical and a simple design.

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