JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

HAND REHABILITATION PROTOTYPE DEVICE FOR A SPINAL CORD INJURED PATIENT

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ABSTRACT

In this paper, a post-spinal cord injured therapeutic device has been developed for hand motor function rehabilitation. Hands are important parts of our body. Major daily activities of life are being performed by using hands. Spinal cord injured patients need rehabilitation courses. There is a need to develop a home-based hands rehabilitation device to support the rehabilitation courses. A robotic glove system was designed to actuate fingers movement with a cable secured to a fabric glove via plastic pipe guides. The wires are attached to the fingertips on the glove on one end and to servomotors on the other end. The servomotors hold the carpal bones of the hand, which reels the cable line to bend the fingers in either flexion or extension. The actuating of wrist movement carried out through servo motor attached with the glove through "L" metal clamps and servo motor firmly tighten over the wrist with the help of Elastic wrist splint. The position and force at which the fingers & wrist spin can be controlled with ARDUINO programming. It is capable of current limiting the servomotors. Various control methods for the glove were implemented, including switch and vocal programs.

Keywords: Rehabilitation, Spinal Cord, device, Impaired, Flexion, Extension

1. INTRODUCTION

The last example of a disease that affects human mobility is Spinal Cord Injury (SCI). Word Health Organization report of 19 November 2013, every year around the word, between 2,50,000 and 5,00,000 people suffer a spinal cord injury[16,1] There are two levels of paralysis caused by spinal cord injuries: complete paralysis below the neck (C4 injury) and partial paralysis below the waist (L1 injury). In addition, the SCI patient may not recover from the paralysis, and it is likely that they will incur significantly high medical costs throughout their lifetime. The average cost of SCI health care for somebody with C1-C4 SCI is most expensive in the first year following injury and then decreases significantly over time [16, 1]. These expenses are generally included inpatient hospital charges and costs, nursing homes, outpatient therapies, vocational rehabilitation, and miscellaneous payments. Standard treatment to rehabilitate the SCI patients is assisted manually by treadmill training. Physical therapists correct the patient's gait based on experience and the patient's condition. However, this method demonstrates some disadvantages, including inconsistent applied assistive pushing force to the patient's leg and a short duration of clinical rehabilitation. Moreover, this traditional therapy is labor-intensive and imposes a substantial economic burden onto the national health care system limiting the capability of the clinical service [17, 18].

In the past, robotics may be an irrelevant solution to improve the standard and quality of rehabilitation. In the Industrial sector, robots have become increasingly common, especially in automatic manufacturing processes. People generally perceive robots to be "industrial" in nature. The application of robotics for rehabilitation had not been forced this idea by that time. However, robotics technologies have been advanced in many aspects, including both hardware and software development, the concept of combining robotics and rehabilitation has recently been encouraged. Based on the problems of the standard rehabilitation methods mentioned earlier, such as the lack of sensing and inadequate humanitarian assistance issues, several researchers have applied robotics knowledge to various rehabilitation applications and demonstrated numerous advantages [20].

In summary, utilizing robotics technologies for rehabilitation applications promises to enhance the current rehabilitation standard to a higher quality level. Rehabilitation services will have several novel capabilities, such as reliable motion sensing for gait diagnosis and consistent force/torque assistance for gait training. Therefore, robotics will clearly be an important aspect of future medical treatment [17, 18].

In this research, the home-based rehabilitation device was developed to support the rehabilitation of a patient who has met a car accident and his spinal Cord (C4 to C6) is injured and to minimize the burden of the therapist. The device applied the active-assisted movement, and the focus was on the patients' hands. The hands become significant due to their functions in daily life activities (manipulating things etc.). The major aim of this paper is to design and develop a post-spinal injured remedial system that can assist the spinal cord injured patient flex/extension of fingers and abduction/adduction of wrist of the impaired hand.

2. DESIGN CONSIDERATION

Design and fabrication of hands rehabilitation device were started with the design consideration phase. It refers to the conceptual design of the device, ergonomics, and technical factors. It is important to ensure a better device can be produced from this project.

2.1 Conceptual Design

Fingers:

Conceptual design refers to the general concept that is applied to the device. This project employed the semi-automatic cable-driven mechanism for finger extension and no mechanism needed for flexion in this case because fingers of such patient are in folded position and finger automatically return back after the release of stretch in its natural position. The wire is used to move the finger during extension, as shown in Figure 1. The fingers are moving inward or straighten when pulling the cable (Figure 1), and it moves back to the normal position by releasing stretch from the cable (Figure 2). This concept was applied to all fingers. The concept gives more flexibility to the device to move and control each finger.

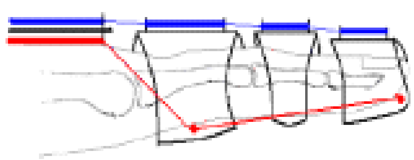

Fig.No. 1. THE DESIGN CONCEPT FOR FINGER EXTENSION (10)

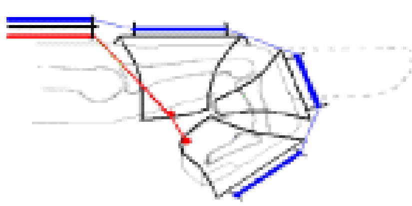

FIG.NO. 2: THE DESIGN CONCEPT FOR FINGER FLEXION (10)

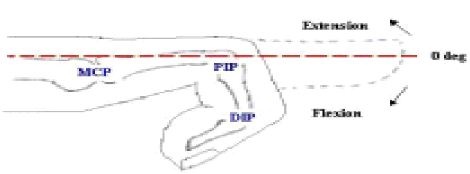

Fig. No. 3: FINGER JOINTS AND POSSIBLE RANGE OF MOTION (5)

The fingers joint motion refers to the maximum extension and flexion range of the fingers that need to be considered to prevent the fingers from overstretching or injuries, as shown in Figure 3. Finger joints and the possible range of motion [5]

The DIP was designed to have between 0 to 15 degrees flexion degrees. Lastly, the MCP was designed with an extension between 0 to 45 degrees with flexion between 0 to 85 degrees with no extension. The PIP was designed with the extension between 0 to 10 degrees and the flexion between 0 to 100 Emphasize is on the DIP (Distal Interphalangeal), PIP (Proximoval Interphalangeal) and MCP Metacarpophalangeal) joint. The extension and flexion of the DIP, PIP, and MCP are summarized in Table 1, and it was based on [5] [13-15]

Table 1. : The DIP, PIP, and MCP EXTENSION AND FLEXION (5)

Joint	DIP	PIP		MCP	
	Flexion	Extension	Flexion	Extension	Flexion
Range (Degrees)	0 – 15	0 – 10	0 - 100	0 - 45	0 – 85

Wrist:

Wrist Articulation:

The wrist joint is capable of two degrees of rotation which allow it to form the posture depicted, as shown in Fig. No. 4.

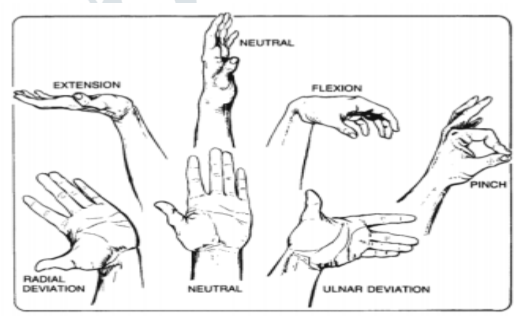

Fig. No. 4: DEPICTION OF HAND WRIST POSTURES (7)

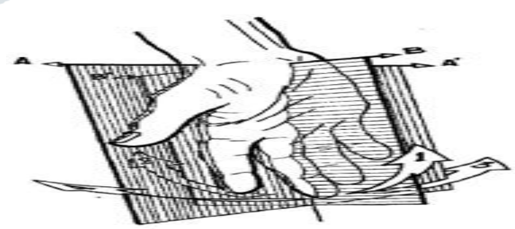

Fig. No. 5: WRIST MOVEMENT AXIS OF ROTATION (4)

The two degrees of wrist freedom are shown in Fig.No.5 and allow four different movements as indicated by the arrows. The extension (arrow 2) and flexion (arrow 1) are rotations about axis AA,' and radial deviation (arrow 4) and ulnar deviation (arrow 3) are rotations about axis BB'. It should be noted that the terms abduction and adduction can be used interchangeably with radial deviation and ulnar deviation, respectively. Anthropometric data collected by Barteretal [2] and compiled by Pheasant [7] gives the range of motion in the wrist for the 5th, 50th, and 95th percentile male as shown in Table No.2.[13]

Table No. 2. JOINT RANGE DATA

	5th	50th	95th	
Joint	%ile	%ile	%ile	SD
Wrist flexion	70	90	110	12
Wrist extension	78	99	120	13
Wrist abduction(radial deviation)	12	27	42	9
Wrist adduction(ulnar deviation)	35	47	59	7

2.2 Ergonomics Factor

The ergonomics factor refers to the comfort and safety of the user. The ergonomics factor in this project focused on the measurement of hand size and finger joint motion.

Every human possesses a different hand size, but in this case, according to the comfort of the patient, cloth gloves are used. There is a need to consider the average size of hand gloves for the design purpose. The hand size includes the handbreadth and length. The size of hand glove breath was decided to be around 6 to 8 cm and 18 to 21 cm for the hand length case the material used for preparing the movement of the wrist is very limited, common, and readily available in the market. This portion of the device consists of" L" shaped connecting metal linkages, Servo Motor and Elastic Wrist splint for providing firm support to the servo motor, and wrist for rehabilitation of the wrist through this device. [21]

2.3 Technical Factor

Technical factor refers to ARDUINO Programming control system, motor, and material selection for the device. In this project, the on/off and vocal control was applied to facilitate the patient to control the wire movement independently without the assistance of any therapist. The on/off switch or vocal control is located at a suitable position for comfortably operate by the patient. At the moment, there are no sensors applied to the device, and the movement of the extension was based on mechanical movement. [21]

Fingers:

MG90S servomotor,[6] Metal gear with one bearing: We can use any servo code, hardware, or library to control these servos. Good for beginners who don't want to build a motor controller with feedback and gearbox, especially since it will fit in small places. It comes with three horns (arms) and hardware. The motor is considered to have a low-speed motor that provides 0.1s/60 degrees for no-load conditions. The low-speed motor was considered applicable to operate the semi-automatic cable-driven mechanism. Besides, the low rotating speed of the motor can avoid over-stressing the fingers and injuries.

Table 3. MOTOR SPECIFICATION (6)

Nominal power	Nominal voltage D.C.	Torque		No. Load
		Nominal	Stall	Speed
0.98N	4.8v-6.0v	1.8kgf.cm	2.2kgf.cm	0.1s/60degree(4.8 V)

In this project, the cloth glove was selected as the material for the device due to its easily machined properties. The Cloth also is a lightweight material and can easily mount on the human hand. The material was fabricated using the Numerical control (N.C.) spinning machine [19, 21]. The Kevlar-K 49 thread was used in order to pull and release the forces from the motor [19, 21].

Components are used for jointing of finger & wrist device together and rigidly fixing on the wrist of the patient hand. Such component is readily available in the local market, which is made of steel with a brass coating. The number of holes is provided for making it fastening easier with another linkage at the desired position. It is shown in Fig. No. 6.

Fig.No. 6: "L" LINKAGE FASTENER

Tower Pro MG995 55G Metal Gear Servomotor [3]: It is used for providing movement to the wrist. Its feature is as under

Table No. 4: MOTOR SPECIFICATION (3)

Nominal voltage, D.C.	Torque		No. Load
	Nominal	Stall	Speed
4.8v-7.2v	8.5kgf.cm at 4.8v	10 kgf.cm at 6v	0.2s/60degree at 4.8v and 0.16s /60degree at 6v

3. ASSEMBLY AND PERFORMANCE

Based on the design consideration, the finger rehabilitation device was designed using computer-aided design software. The designs with 3D simulation were developed in this project. The simulation was applied to identify any problems that occurred before the prototype was fabricated. In this section, the final simulation, prototype, and discussion are presented, which is shown in Fig. No.7.

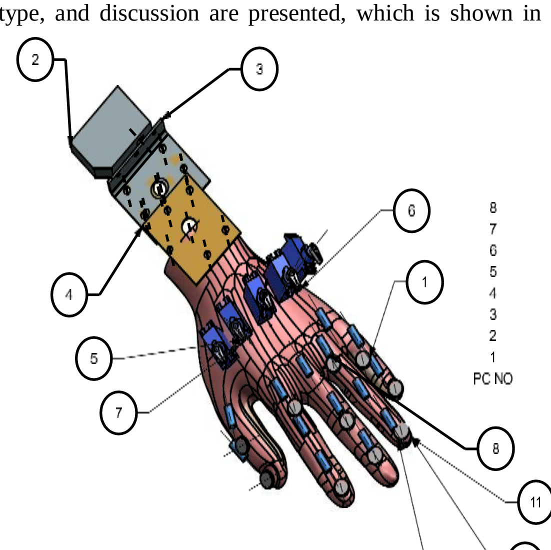

Fig.No 7: PROTOTYPE 3- D MODEL

Components:

The components used for assembling of prototype model are shown and discussed in detail as below. All Components used in making this device are readily available and cheaper in cost. None of the components were specifically fabricated in making this prototype model. The device is very simple and involves a low cost to make in the approach of people all categories in society.

Table No. 5 COMPONENTS OF DEVICE

COMP. NO.	NAME OF COMPONENT	QTY.
1.	VIBRATOR	10
2.	MOTOR 2	1
3.	STRIP A	1
4.	STRIP B	1
5.	MOTOR CAM	5
6.	MOTOR SG90	1
7.	MOTOR ASSEMBLY	5
8.	SLEEVE	14
9.	GLOVE	1
10.	HAND	1
11.	GLOVE ASSEMBLY	1

3.1 The Simulation

The device was designed with all parts are assembled using a glove that consists of the extensor cables, finger ring, middle band, thumb support, and wristband, as shown in Figure 6. In total, five mechanical pulling cables were used in order to perform the extension and flexion movement. The Finger ring was designed to fit the pulling cables to the fingers. It had a strong attachment with the pulling cables and fixed the fingers to the device during the extension and flexion movement. The middle band was embedded in order to give a balance to the pulling system and fix the pulling cable.

3.2 The Prototype

The functioning of the device is shown in Figures No. 7, 8, 9 & 10. The device was capable of performing the extension & flexion movement of fingers and abduction and adduction movement of the wrist of the impaired hand.

Fig.No. 7. FINGER FLEXION MOVEMENT

Fig. No. 8. FINGER EXTENSION MOVEMENT

Fig.No.9 WRIST ADDUCTION MOVEMENT

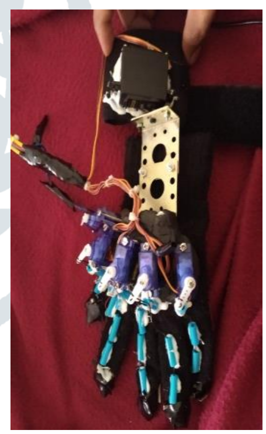

Fig. No. 10 WRIST ABDUCTION MOVEMENT

4. RESULT

In general, the conceptual design of a semi-automatic wire-driven mechanism is considered acceptable to produce the extension and flexion movement for finger rehabilitation as well as the abduction and adduction movement of the wrist.

5. CONCLUSIONS AND FUTURE WORKS

In this project, the low-cost prototype for the hand rehabilitation device was developed. The 'know-how' on medical device development had been acquired from this project. The future work includes improving the device's mechanism, and different approaches can be applied. Besides, extensive discussions with the therapist need to be considered.

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