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# Design, Analysis and Control of the 4 Fingers Rehabilitation Robot

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ABSTRACT

**Background:** People who have lost their ability to walk, shake hands or even talk due to brain stroke may revert their ability back to normal or near normal with the assistance of rehabilitation robots. Previous literature reviews of rehabilitation studies have shown that, in most cases, repeated movement of a patient's member can help restore the function of the injured member in patients, in which, the use of robots can be very effective.
**Methods:** The method of this research is the experimental method. The paper aims to investigate the ability of a parallel robot for rehabilitation of injured fingers. The motions of human finger joints for physical therapy purposes has been investigated and been considered as the optimal route of the design process and as the set point of control procedure of robot movements. The proposed robot has been designed with the right choice of kinematic loops, where the robot pursues the optimal path to rehabilitation, and at the same time, does not come into direct contact with the patient, allowing the patient to be more tolerant as they feel more comfortable and at ease. In addition to the above-mentioned advantages, the designed robot reduces the number of operators as well as the number of parameters necessary to change and control the algorithm for different patients.
**Results:** After presenting the robot's conceptual design, the kinematics analysis of the robot was dealt with. In the next step, the dynamic equations of the robot were extracted. Ultimately, using the control methods, the position, stability and efficiency of the rehabilitation robot was simulated. Finally, the constructed prototype of the robot is presented and control method and program sectors are introduced.
**Conclusion:** The proposed robot for rehabilitation of four fingers with a simplified design and low cost of manufacturing could be used in robotic applications in home based care for disabled people.


## Introduction

People may be faced with disability and weakness in any of their organs for many reasons including the consequences of various disasters, accidents or illnesses. These effects usually alter the individual's mobility. In addition to stroke, diseases such as spinal cord injury, organ disturbances, Parkinson's disease, paralysis and neurological diseases, even a simple bone fracture may lead to the tearing of nerves and tendons, resulting in impaired motor activity. [1]

Rehabilitation refers to a set of co-ordinated medical, educational, occupational, social and therapeutic services and interventions that are provided to rehabilitate a disabled person and maximize the level of performance in order to achieve an independent life in the community. Rehab also restores part of the physical inabilities lost

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due to various reasons, including spinal cord injury, stroke, muscular disorder, and surgery, so that the patient is able to attain the desired level of physical and mental functionality.

Physiotherapy is the simplest and most primitive means of rehabilitation. Physiotherapy is a set of normal repetitive activities under the supervision of a physiotherapist to restore the patient's movability. Issues such as a shortage of physicians and workers, high costs of patient transfer and competent physiotherapists are among the factors that increase the cost of physical therapy and defines the need for an alternative tool. According to information provided by the Iranian Statistics Centre in 2015, about 40% of the country's households suffer in some way from a kind of disability problem. As the age of the population increases, the percentage of motor disabilities will be higher, and the health of the elderly will become one of the issues which will have a negative effect on the community.

Additionally, the elderly are a group of people in every society who need rehabilitation more than other sectors of society, so research needs to be done to improve the effectiveness of rehabilitation techniques and as treatments have advanced, many of these diseases can be cured over time. According to the Ministry of Health and Medical Education, strokes are the second leading cause of death and the leading cause of physical disability. According to the latest statistics, about 40% of the disabled population in the country suffer from motor disability problems.

Furthermore, move rehabilitation therapies for patients with paralysis and spinal cord injury require an average of about 6 months' treatment, which is relatively long and overwhelming. On the other hand, advanced devices in the rehabilitation centers are expensive and the need for a physiotherapist per patient is necessary; these problems cause the patient to abandon the treatment process. Therefore, the above points highlight the benefits of rehabilitation robots.

Rehabilitation of patients with disability in motion is time consuming, costly and requires patience. In addition, the availability of competent therapists is a challenge for patients. A home based design rehabilitation tool in accordance with the patient's medical needs is a solution. In recent times, robots have become widely used for medical applications. The replacement of disabled members, the creation of desirable surgical facilities, extensive use of rehabilitation, the training of physically disabled children, and many growing applications, including those that are assigned to the field of medical science make up the growing popularity of robots [2].

One of the most common applications of medical robots is in other rehabilitation applications including reconstruction robots, artificial limbs and treatment robots.[3] Auxiliary robots help people with disabilities and make their daily activities unproblematic, and allow them to be less dependent on others. For example, they can help people with daily tasks such as eating and drinking. Intelligent wheelchairs are other types of robots which help to alleviate the problems of disabled people. Furthermore, robotic treatments are a valuable tool used to restore the lost abilities of people due to heart attack or brain stroke.

These rehabilitation robots were first introduced in the early 1960s [4]. In 1991, at at The Massachusetts Institute of Technology (MIT), a novel robot named as *MIT-Manus*, was introduced to study the potential that robots might assist in and quantify the neuro-rehabilitation of motor function. Later in 2004, an evaluation of this neurosensory system was performed [5]. Then other systems such as Programmable Universal Manipulation Arm (PUMA), with PUMA240 [6], Rehabilitation Robotic system (REHAROB) for upper limb physiotherapy including two co-operating robotic arms [7]. Hand Exoskeleton Rehabilitation Robot (HEXORR) [8]. Northeastern University Virtual Ankle and Balance Trainer (NUVABAT) [9]. Locomotion Assistant system (LUKOMAT), a robot-assisted walking therapy that uses a body weight support system to suspend individuals while their legs are attached to robotic legs that assist with basic walking functions [10], and others were developed to rehabilitate the organs of the body.

For finger rehabilitation, the Easy Soft Glove (EsoGlove), that is meant to conform to natural hand movements [11], or the a soft wearable hand robot (EXO Glove), with 12 degrees of freedom [12], or the Spider hand gloves that can be resized for each user [13] and the Gloreha Sinfonia™ gloves, a rehabilitation glove which supports fingers joints motion, while detecting voluntary active motion [14].

Clinical studies have shown that physiotherapy with exoskeleton robots can increase the activity of brain motor receptors after a stroke; this can have an effective role in improving the function of the patient's damaged organ. Using these wearable skeins, virtual experiments could be used to measure the performance of the device and improve rehabilitation, as well as demonstrating the effectiveness and even making improvements to the design and analysis of body movements, based on each individual patient. Undoubtedly, the minimal cost, personalization and customization are the benefits of rehab robots which cannot be ignored. Stroke patients who suffer from a lack of movement of the limbs (especially their fingers) and also patients who are affected by post-accident traumas rehabilitation can benefit from wearable robots for rehabilitation. This has led to the importance of rehabilitation robots in every country, especially in advanced countries, as a basic requirement and a way to help people to return to their daily life routines.

As fingers are known as one of the most influential joints of the human body; when fingers are hurt or damaged, the patient's life is severely affected. As a result, rehabilitation of the fingers is more important than other joints and organs and has always been seen as one of the main challenges in physiotherapy. Rehabilitation of the fingers is a process that involves various exercises, which must be done by a specialist physician or by rehabilitation machines/robots [15].

Finger rehabilitation involves treating and improving the functions of the hands and arms, improving fingers, wrists and strengthening the muscles of the upper limb, where the following conditions may have occurred:

- Post-surgical complications
- Neurological injuries
- Post-burn injuries
- Different syndromes
- Fractures
- Finger joint injuries
- Arthritis of the hand

What is discussed in this thesis is the use of model-based control techniques to control the status of the final implementer and to achieve the robot's predetermined dynamic behavior in the field of power control. Although several degrees of freedom of rehabilitation robots are usually expressed by a multi-input/multi-output model system, many industrial controllers for such robots in previous studies, including several linear controllers have been designed to control the movement of joints. In reviewing the work carried out on the finger rehabilitation robot in the past, such a method has been used to control the robot, due to the difficulty of obtaining the dynamic model of parallel robots. But the structure of parallel robots that includes closed kinematic chains, severely limits the effectiveness of such controllers. Therefore, in this paper, only the position control is examined, and the robot's force control, with using advanced control techniques in multivariable control and nonlinear control, is suggested for future works [16, 17].

The main objective of this paper is to control a rehabilitation robot with a degree of freedom, using a programmable controller, to perform a range of therapeutic, auxiliary and flexible exercises for the fingers of patients who, for reasons such as spinal cord injury, stroke, muscle disorder or surgery have lost their ability to move. In supplementary exercises, the amount of force needed by the patient is measured and adjusted automatically according to the patient's disability.

## Design and Modelling

### *Human Anatomy*

Human anatomy is one of the essential basic sciences applied in medicine. The discipline of human anatomy consists of three parts. The first part of the macroscopic anatomy which could be examined without using a microscope, the second part of the microscopic anatomy, which is detectable by microscopy, and the third part of the evolutionary anatomy recognizes the human body from birth, which compares the anatomy of a normal human being with a sick person and referral of the disease to a particular section of the body that has a problem [18].

### *Fingers Therapeutic Exercises and Rehabilitation*

Fingers are recognized as one of the most effective and influential members of the body. Rehabilitation of the fingers is a process that involves performing various exercises. If we want to determine the process for doing these exercises for each patient, rehabilitation exercises can begin with inactive exercises. In these exercises, the patient does not need to exert any force and the robot provides all the necessary force for movement. The purpose of such exercises is to completely shift the active range of motion to restore the flexibility and range of motion of the patient; the second phase continues with auxiliary exercises, in which, it evaluates the force exerted from the patient and the rest of the force is provided by the robot, with the aim of increasing the strength of the patient's muscles. Finally, a rehabilitation exercise, which involves resistance from the robot is used to increase the agility and coordination of the nerves and muscles of the individual [19].

Effective movements to rehabilitate and improve the movement of the hands and fingers increase the strength of the injured tissues and enhance their mobility and reduce pain and fatigue and prevent dryness and stiffness of the joints. Depending on the patient's condition, physiotherapists usually recommend certain movements and exercises to help extend the range of the joints, while others improve the muscle and tendon's performance by means of tensile motion [20].

### *Modeling*

When dealing with the physical model of a system, modeling is crucial since the demand for physical systems and simplified operation procedures and achieving a better understanding of system safety requirements; better understanding of the system and safety is of upmost importance. The lack of a physical system means that it is possible to access new designs or technologies without the need for a physical sample; in addition, there is no risk of system interruption.

Other advantages of the mathematical model include:

- Using the mathematical model of the system instead of the physical system, makes it possible to evaluate various methods and parameters, change the time scale and the possibility of access to irreducible quantities.
- Using the system model, we will always have a better understanding of the system due to the existence of mathematical relations between the system inputs and outputs and the simplifications that are made in most cases.
- Safety is another issue that should be considered when working with the physical system. A physical sample is obtained at a cost and it requires training.

### *Flexible Arm (Finger) Model*

In most researches, two major methods for flexible arm modeling have been used. The first and most common method is the Assumed Modes Method (AMM) in which the abnormality of the end of the arm is represented by a series of separable functions. This series is an infinite series, and each sentence in this series represents one of the vibrational modes [21]. The second method is a Finite Element Method (FEM), in which the flexible arm is shown as a series of smaller rigid elements. The accuracy of this method depends on the number of limited elements to be considered [22]. These two methods are a nonlinear model of the system, but here we are using a simpler model that is both linear and accurate for our goal of finger control [23].

Figure 1-A shows the flexural length (L) and Deviation Rate (D) at the end of the arm. If the end of the arm rotates about 2π radians then it has a length equal to 2πL. The actuator of each link of the robot is a Direct Current (DC) motor. The DC motor torque ($T_m$), is proportional to the motor current ($I_m$), as:

$$T_m=\eta_m K_t I_m$$

Where ($K_t$) and ($\eta_m$) are constant torque and motor efficiency, respectively.

According to Figure 1-B:

$$I_m=\frac{V_m-E}{R_m}$$

Where E is the retraction force of the motor. Induction resistance is also ignored due to its small ($R_m$).

As well as:

$$E=K_m\dot{\theta}_m$$

$$\theta_m=K_g\theta$$

$$T_{output}=\eta_g K_g T_m$$

Where is the angular displacement of the motor ($\theta_m$), the motor retraction force ($K_m$) and the gearbox conversion ratio ($K_g$) and gearbox efficiency ($\eta_g$).

So results:

$$T_{output}=\frac{\eta_m\eta_g K_t K_g (V_m-K_g K_m\dot{\theta})}{R_m}$$

Thus the torque relation to the arm and the voltage applied to the motor, which is the input of the system is obtained.

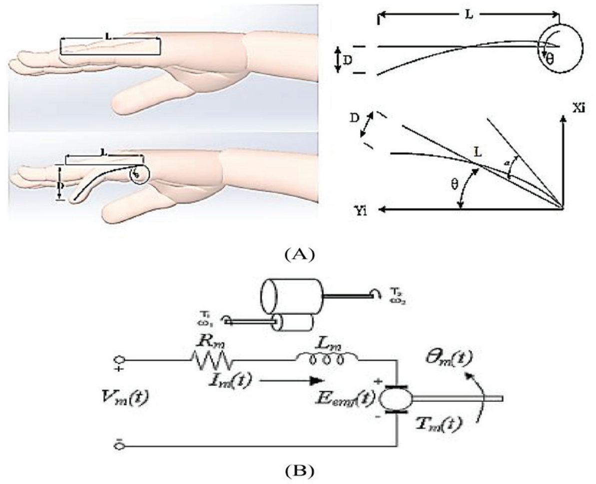



**Figure 1:** A) Flexible arm design, B) DC motor model

## Control and Simulation

The purpose of controller design is to use a system that can influence the behavior of the mechanism in order to achieve an optimal output, and to make specific and desired changes to the mechanism.

To achieve more precise control, the controlled variables must be measured and compared with the reference input in order to correct the intruder signal according to the input/output difference to the system applied as a result of the error. To achieve the desired performance in the system, the control of the system should be carried out in the form of a closed loop circuit. The PID (Proportional-Integral-Derivative) controller is a closed loop control method; using this controller causes the error between the measured variable and the desired value to be reduced by calculating their difference and then the corrective action and adjustment can be made. This type of controller is used in this project to control the speed and angle of the motor flow in the mechanism [24].

### *Proposed Control Algorithm/Law*

The control system used in the proposed mechanism is a closed loop control system, in which the output has a direct effect on the input. In this structure, the speed and motor angles are calculated using the PID controller. The controller acts based on control feedback, which means that if a discrepancy is detected, the amount of correction is calculated and applied. The output of the re-measurement system and any required correction are calculated. Also, by using a force sensitive sensor, the ability of the patient to move their fingers is measured so that if the patient can move their fingers with minimal force, motor proportional to the force applied by the patient will slow down and continue to move otherwise it will continue at a predetermined constant speed.

### *Methods for Setting the PID Controller*

Each process has unique characteristics even when the equipment is the same. For example, environmental changes, airflow, ambient temperature and air pressure may change per hour, so the settings for the PID must be selected to match these environmental changes and variables in use. In general, there are three approaches to determining an optimal combination of these settings, namely, Manual Tuning Method, Tuning Heuristics and Steady-State Oscillation.

Often the processes are very complex, but by knowing some information, especially as regards to the speed with which the error is corrected, it is possible to obtain an initial level of adjustment. In other words, the operator estimates the amount of correction parameters needed to achieve the desired response in a way that the proportional, integral, and derivative parameters of the system are adjusted and corrected individually within the specified system using the test and error method. The work done in this study to control PID is a manual tuning method, based on Zigler-Nicols Method, [24].

- The $K_p$ coefficient is raised by a specified value to oscillate the controlled output in the stability range. (This is called $K_c$).
- The output of the system is checked to obtain the period of T swing.
- Used to calculate controller coefficients from the following table.

| | $K_p$ | $K_i$ | $K_d$ |
|---|---|---|---|
| P | 0.5 $K_c$ | ∞ | 0 |
| PI | 0.45 $K_c$ | $0.54\frac{K_c}{T}$ | 0 |
| PID | 0.6 $K_c$ | $1.2\frac{K_c}{T}$ | 0.075 $K_c$.T |

$K_c$ is 5.3 and T is 0.0012 and the PID coefficients are as follows:

| | | |
|---|---|---|
| $K_p$=3.2 | $K_d$=0.00055 | $K_i$=365 |

*Design of DC Motor Controller*

Direct Current (DC) motors are widely used in robotics and electrical equipment due to their high reliability and low cost. One of the reasons for using these types of motors is simple control of speed or position, as well as the compatibility of DC motors with new digital systems. The most important advantage of direct current electric motors compared to other electric motors is to increase productivity and reduce their power consumption. To design a DC motor controller, the mathematical model of the engine must first be obtained. Then, by choosing the proper structure for the model, the inner ring and the outer ring could be designed.

As illustrated in Figure 2, it is apparent that a PID controller works better, equally in terms of energy and permanent error in both open loop controller and proportional closed loop controller.

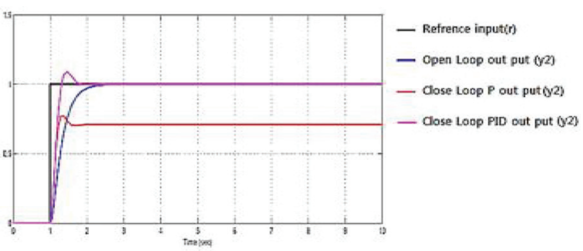



**Figure 2:** Output of closed loop systems, open loop and PID controller

## Build, Implement and Test Results

In the structure of the former rehabilitation equipment, rehabilitation robots were investigated mostly in terms of the static and motor characteristics of the human body, including design challenges in the proposed robot, the mechanism of transmission, the production of torque in the joints, the uniformity of movement, bending and joints opening as well as the similarity of the mechanical properties of the system with the natural joint of the human hand [25]. It attempts to increase the flexibility of the system against external forces in the structure of the mechanism, as well as the ability to accurately control the power, reduce the impact of shocks caused by the engine's speed and eliminate the effect of shifting the gear in the gearbox.

*Position Control the of the Robot*

This section includes features to control the movement of the robot, including the range of motion, duration of training and the required rest time. It is worth noting that the range of motion is the most important of these parameters [26]. In the design of motion, the fingers depend on the motion range, which means that by moving one of the fingers (except the thumb), the other fingers will move in the same direction [27]; then the fingers move together and they have a motion-dependent relationship, so they avoid moving independently from the other fingers, and a continuous motion system is designed to reduce the complexity of the system and also simplify the weight of the rehabilitation robot (Figure 3) [28].

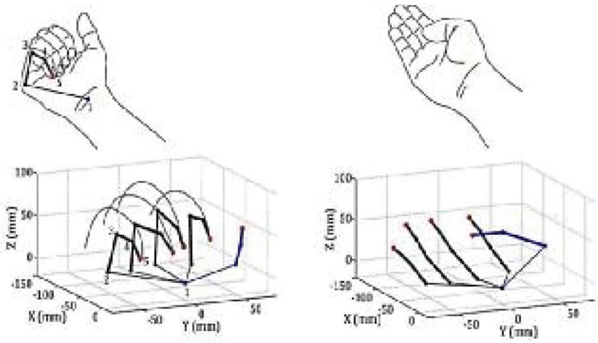



**Figure 3:** Four-finger movement gestures

*Introducing the Mechanisms*

The proposed rehabilitation robot is a mechanism for moving the fingers with 1 degree of freedom. The design of the proposed structure was carried out by the *SolidWorks* software, and the robot control system has been implemented by the *Arduino* board; the motion mechanism is a 12-volt direct current encoder gear motor driven by the engine driver and designed to reduce the weight of the robot. The switching power supply has been used; also, a patient-sensitive power sensor has been used to control the patient's ability [29].

The mechanism is easily mountable on the patient's hand, compatible with the large variation of finger sizes and imposes no limitations on the desired range of movement. The structural features of the proposed mechanism include the reduction of the number of motors, the elegant structure of the components with PLA (Poly Lactic Acid) materials and 3D printing, lightweight structure and lightweight compared to similar mechanisms.

*Mechanism's Structure*

The mechanism is designed with more than 100 pieces and weighs about 150 grams using the SolidWorks software. This software has been used due to its high speed, user-friendliness, ability to provide animation of the model during assembly or demounting, and the capability to communicate with all software applications in comparison with other software design. After design, the parts were printed and made using a three-dimensional printer device, where plastic materials were used to optimize the designed mechanism to be as light as possible (Figure 4).

The propulsion system is powered by an incandescent gearbox; that can alter the speed as demanded. In closed-loop motor control systems, the encoder senses the rotor position and declares it to the controller. An electric pulse generator produces a square wave, which can be used to calculate the speed or angle of rotation of the motor's shaft by counting the number of pulses at any given time. (Motor specification: Voltage is 12VDC, speed is 100 r/min, current is 0.2A, power is 0.95W)

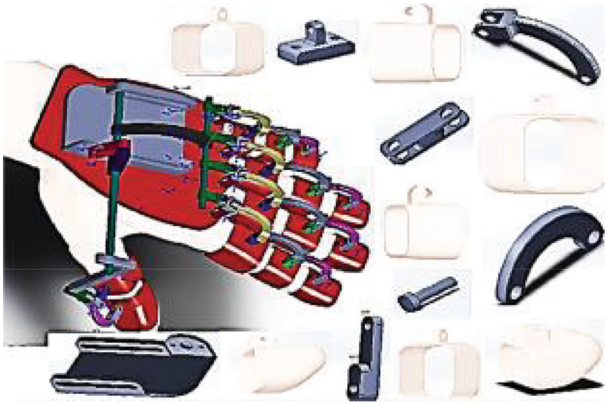


**Figure 4:** An overview of the mechanism component design using SolidWorks software

The speed and position control of the engine are carried out by the Arduino Uno board. The Arduino widget features a high level of programming language simplicity and rich library of free codes which are widely available.

The sensor used in this project, is a Force Sensitive Resistor (FSR) sensor that is low-cost and easy-to-install, that can detect physical strength, compression, and weight. This resistor is composed of two distinct parts separated by a spacer layer. This sensor in fact, detects whether the amount of applied force is inadequate; the resistance would be infinite, which decreases as the pressure exceeds. As previously mentioned it is easy to set up and at the same time has a high degree of precision.

*Schematic Design*

Proteus software is one of the strongest electronic simulation software, with a high performance in simulating programmable ICs (Microcontrollers). The main features of Proteus software can be power, ease of use, flexibility, reliability and high accuracy. According to the information obtained in relation to the design of the proposed robot, the schematic of the circuit and how the parts are placed in the Proteus software environment is first implemented so that the physical construction can be made with the least possible errors.

*Function of the Mechanism*

By programming the *Arduino* board, the microcontroller would be capable of driving the motors which could result in the closure or opening of fingers. If the patient can insert the minimum force on the FSR sensor, in the same proportion the engine slows down.

As shown in Figure 5-A & B, the engine is located at the desired location, and by applying the motor control command to the engine and rotating the motor shaft clockwise or counter clockwise, consequently, the lever connected to the motor shaft moves (lever number 2). The whole mechanism will start to operate and will cause the fingers rings to be opened and closed.

The lever attached to the motor shaft (lever No. 2) must transfer the motor power to the side arm (lever No. 3) to maintain the system by moving the adjacent pivots, causing linear movement of the connected rod (lever No. 1). By this movement the lever moves the whole mechanism forward or backward, leading to movement

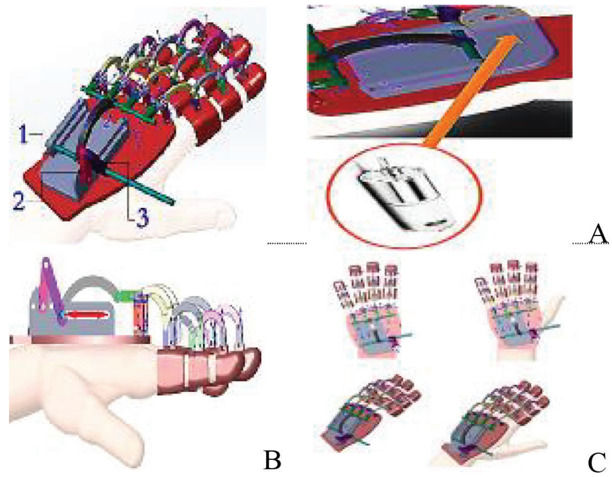



**Figure 5:** A) The proposed location of the robot's engine, B) linear motion causes the overall movement of the mechanism, C) How to connect the robot to the user's hand

in all the joints connected to the fingers and opens, thus closing the fingers of the patient.

Figure 5-C illustrates the assembly method of the rehabilitation robot on patient's hand. The engine produces a linear motion with the help of a lever arm. The quantity of this force can be changed by adjusting the amount of rotation of the motor. This force is transmitted through the primary arm to the other arms, so that the whole mechanism moves at once. The angle of the arms moves with the help of a DC electric motor.

Evaluating the ability of the user to move the fingers is important. Hence, to measure the patient's ability, a force sensitive resistance sensor is used which is placed on the finger tip of the mechanism. A power-sensitive resistive sensor can be controlled by measuring resistive changes when the pressure is applied to sensors in the normal direction (10g to 10kg). The information received is transferred to the microcontroller so that it can control the speed of the movement of the fingers in accordance with the rehabilitation program. Thus, rehabilitation movements can be set at a minimum or maximum speed relative to the patient's motor ability.

This mechatronic system is linked by a control subsystem; the *Arduino* board is the heart of this control subsystem, which controls the speed and position of the motor by receiving feedback from a force sensitive sensor. In Figure 6 a diagram of the mechatronic system implementation of the fingers rehabilitation robot is shown.

## Test Results and Future Recommendations

*Findings of the Research*

Sensory-motor therapies have a positive effect on the patient's rehabilitation process. Important therapeutic factors include exercise duration, exercise intensity and repeatability of rehabilitation exercises. The use of robotic technology in medicine, especially rehab, has increased dramatically during the past decade. Research suggests that robots can provide patients with an effective and efficient rehabilitation method and be of

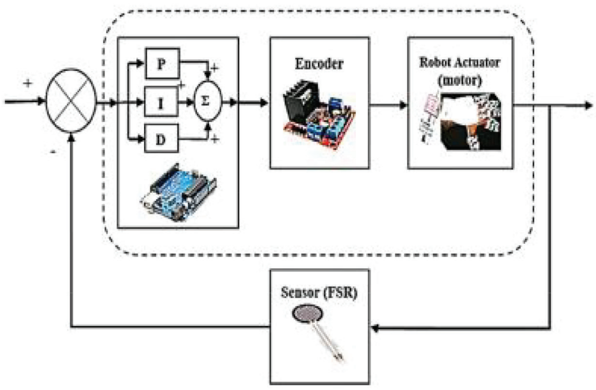



**Figure 6:** Block diagram of feedback control loop of system

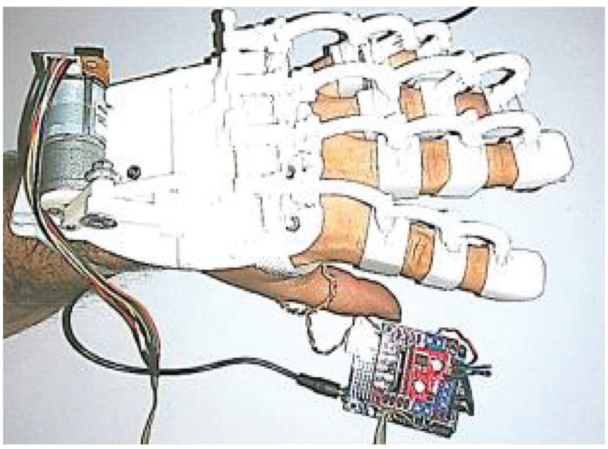


**Figure 7:** Finger Rehabilitation Robot

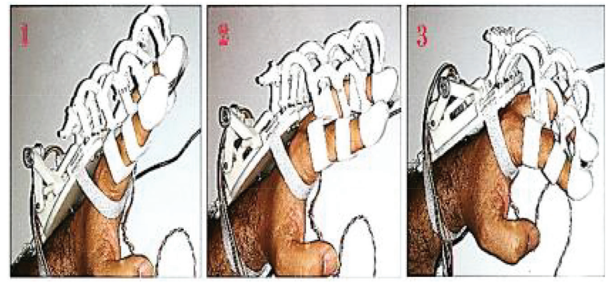


**Figure 8:** How the finger rehabilitation robot assembles on fingers

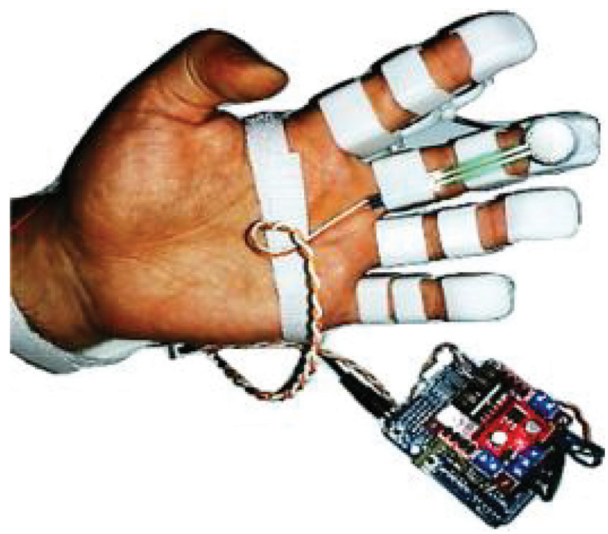


**Figure 9:** The location of the force sensor

great assistance to physiotherapists. The main aim of this thesis was to create a new wearable robot with a degree of freedom for the rehabilitation of fingers, as presented in Figure 7.

The designed mechanism is able to flex the four fingers of a patient by utilization of a DC electric motor, by closing and opening the fingers inwardly and outwardly. If the patient can add a minimum force to the fingertips, during the exercise, the motor will automatically adjust itself in proportion to the force applied by the patient; it reduces the speed compared to the previous stage, which causes the mechanism to move at a new pace. As the applied force increases, the speed of motor and mechanism reduces relatively. As a result, the greater the force exerted by the patient, the slower the speed of the motor and the mechanism slows down to zero so the patient can gradually recover their ability. Figure 8 shows how the mechanism operates.

A force-sensing resistor collects the data in the form of magnitudes and transfers the data to the microcontroller, so that it can control the speed of the motor and move the fingers in accordance with the designed program. By incorporating such a method, the rehabilitation can be controlled effectively so that rehabilitation movements are set at the minimum or maximum speed of the patient's actual motor ability (Figure 9).

*Test Result*

As can be seen in Figure 10-A, the angular position of the motor output can follow the angular position well in the simulation with the time of the connection and the maximum power output. In order to improve the efficiency of the DC motor, the angular momentum of the PID controller is manually adjusted.

Also, according to Figure 10-B, the current overshoots at the moment that the armature repositions, and additionally the current's settling time flow is low.

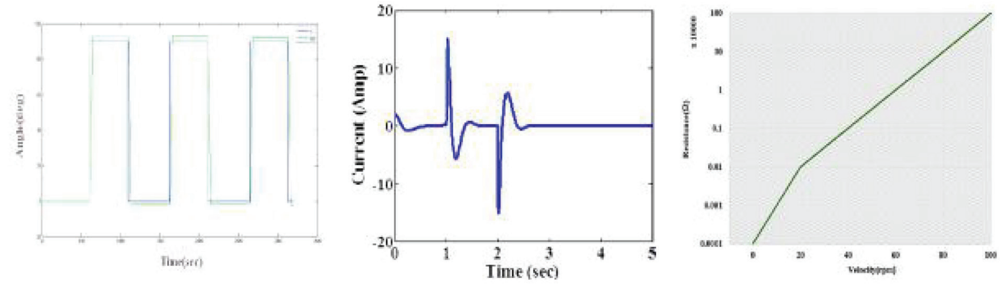
The suggested values are based on the engine output settling time and maximum overshoot position. The simulation results show a decrease in settling time and overshoot in the maximum angular position of the engine; therefore, the performance of the motor's outlet position improves with the reference input.

Figure 10-C, shows the function of the sensor in the designed mechanism. The pressure applied by the patient to the sensor is resistive (ohm). If the sensor subjected to more power, the value of read-through sensors is zero, and if the power is not applied to the resistance sensor it reads as mega-ohm;

This information is transmitted to the microcontroller so that after processing it can control the speed of the motor and move the fingers in accordance with the rehab program.

*Constraints and Features of the Mechanism*

The significant point in designing a rehab robot is knowing the purpose that the rehab robot is being built for. In designing the above discussed mechanism, as




A B C

**Figure 10:** A) Angular position of the output relative to the reference, B) Changes of armature's current, C) The relationship between the performance of the FSR sensor and the motor speed

far as the health of the patient's finger is concerned, the design focuses mainly on the comfortableness of the robot, in terms of degrees of freedom, and also the method of communication between patient and the robot, rather than fear of using the robot. This thesis attempts to provide a new wearable robot for finger rehabilitation, which has unique features compared to existing designs [30, 31], some of which include:

- Low weight of structural elements due to the use of plastic materials (PLA)
- Reduction of heavy components and engines compared to existing designs [32], (the proposed mechanism uses one motor for the four fingers)
- The use of an appropriate electronic structure to reduce the lengthy wires, number of parts, resulting in reduced discomfort
- Continuous mechanical design structure
- Safe and ergonomic design adaptable to patient's fingers
- Use of PID controller to reduce and eliminate errors
- Feedback from the condition of the patient's finger movement

*Future Recommendation*

In robotics systems, one can never rule out the existence of unknown dynamics models and the external disturbances that could damage the robot. The control system that deals with the effects of these factors has always been a challenge. It is hoped that in the future, with the development of an entirely new mechanism, the possibility of rehabilitation for all five fingers will be possible. In this regard, the initial design has been made, where the system defects have to be checked and addressed accordingly. It is recommended that the robot be used by several patients to resolve any potential problems (Figure 11).

## Conclusion

In this paper, a new and improved mechanism for finger hand rehabilitation is proposed. The proposed design managed to achieve the expected level of movement like that in human fingers and succeeded in improving the movement of fingers for patients who have lost the ability to use their fingers effectively. The notable features of the proposed mechanism include the modification of complex mechanisms, simpler motion control, movement integrity, low weight, convenient wearability of the components on the human hand and the smoothness of finger movements compared to similar robots previously built. In order to improve the efficiency of the DC motor, the designed controller has been manually adjusted for the required angular position. The proposed gain values of the controller are based on the rehabilitation time that could be regulated by the user, and the maximum output torque of the actuator, that could also be regulated during the rehabilitation process.

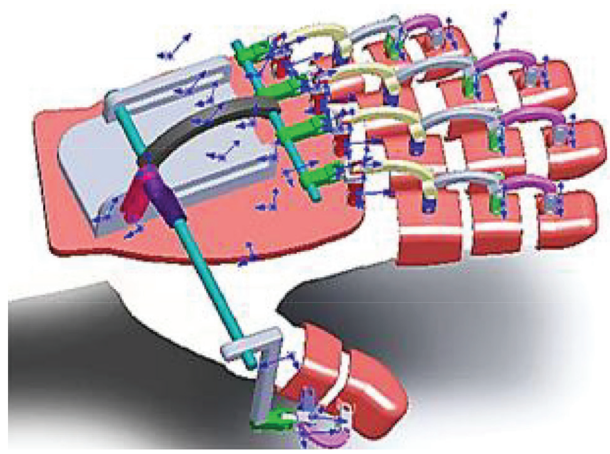


**Figure 11:** Overall view of the proposed robot

**Conflict of Interest:** None declared.

## References


1. Montazeri A. Road-traffic-related mortality in Iran: a descriptive study. Public health. 2004; 118(2):110-3.
2. Kardan M, Rahagi MI. Robot-Borne PLC-Based Control System Used for Lower Limbs Rehabilitation. Modares Mechanical Engineering. 2015; 15(4):58-66.
3. Edwards K, Alqasemi R, Dubey R. Design, construction and testing of a wheelchair-mounted robotic arm. InProceedings 2006 IEEE International Conference on Robotics and Automation (ICRA). 2006; 3165-3170.
4. Allen JR, Karchak Jr A, Ernest L. Bontrager. Design and fabrication of a pair of Rancho anthropomorphic arms. Technical report, The Attending Staff Association of the Rancho Los Amigos Hospital, Inc; 1972.
5. Krebs HI, Ferraro M, Buerger SP, Newbery MJ, Makiyama A, Sandmann M, Lynch D, Volpe BT, Hogan N. Rehabilitation robotics: pilot trial of a spatial extension for MIT-Manus, J Neuroeng Rehabil. 2004; 1(1):5-20.
6. Rao R, Agrawal SK, P. Scholz J. A robot test-bed for assistance and assessment in physical therapy. Advanced Robotics. 2001;

14(7):565-78.
7. Toth A, Fazekas G, Arz G, Jurak M, Horvath M. Passive robotic movement therapy of the spastic hemiparetic arm with REHAROB: report of the first clinical test and the follow-up system improvement. In9th International Conference on Rehabilitation Robotics (ICORR). 2005:127-130.
8. Schabowsky CN, Godfrey SB, Holley RJ, Lum PS. Development and pilot testing of HEXORR: hand EXOskeleton rehabilitation robot.J Neuroeng Rehabil. 2010; 7(1):36-52.
9. Ding Y, Sivak M, Weinberg B, Mavroidis C, Holden MK. Nuvabat: northeastern university virtual ankle and balance trainer. In2010 IEEE Haptics Symposium. 2010:509-514.
10. Bernhardt M, Frey M, Colombo G, Riener R. Hybrid force-position control yields cooperative behaviour of the rehabilitation robot LOKOMAT. In9th International Conference on Rehabilitation Robotics (ICORR). 2005:536-539.
11. Biggar S, Yao W. Design and evaluation of a soft and wearable robotic glove for hand rehabilitation. IEEE Transactions on Neural Systems and Rehabilitation Engineering. 2016; 24(10):1071-80.
12. Rudd G, Daly L, Jovanovic V, Cuckov F. A Low-Cost Soft Robotic Hand Exoskeleton for Use in Therapy of Limited Hand–Motor Function. Applied Sciences. 2019; 9(18):3751-3766.
13. Kuswanto D, Iskandriawan B, Mahardhika PS. Power Grip Exoskeleton Design as Rehabilitation Devices for Post-Stroke Survivors. In2018 1st International Conference on Bioinformatics, Biotechnology, and Biomedical Engineering-Bioinformatics and Biomedical Engineering. 2018; 19(1):1-6.
14. Villafañe JH, Valdes K, Imperio G, Borboni A, Cantero-Téllez R, Galeri S, Negrini S. Neural manual vs. robotic assisted mobilization to improve motion and reduce pain hypersensitivity in hand osteoarthritis: study protocol for a randomized controlled trial. Journal of physical therapy science. 2017; 29(5):801-6.
15. Chu CY, Patterson RM. Soft robotic devices for hand rehabilitation and assistance: a narrative review. J Neuroeng Rehabil.2018; 15(1):9.
16. Li M, Xu G, Xie J, Chen C. A review: Motor rehabilitation after stroke with control based on human intent. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine. 2018; 232(4):344-60.
17. Heo P, Gu GM, Lee SJ, Rhee K, Kim J. Current hand exoskeleton technologies for rehabilitation and assistive engineering. International Journal of Precision Engineering and Manufacturing. 2012; 13(5):807-24.
18. Kumar A, Singh T, Kumar A. Hand Anatomy. Biometrics Research Laboratory, Department of Electrical Engineering, Indian Institute of Technology Dehli, New Dehli, India. 2009:1-1.
19. Furtado LS, Borges ID, Carvalho JC, Gonçalves RS. Using the Planar 3-RRR Parallel Manipulator for Rehabilitation of Human Hand. InProc. Of ABCM Symposium Series in Mechatronics 2014; 6(1):535-542..
20. Li SZ. Encyclopedia of Biometrics: I-Z. Springer Science & Business Media; 2009.
21. Rahimi HN, Nazemizadeh M. Dynamic analysis and intelligent control techniques for flexible manipulators: a review. Advanced Robotics. 2014; 28(2):63-76.
22. Zhang C, Yang T, Sun N, Zhang J. A Simple Control Method of Single-Link Flexible Manipulators. In2019 3rd International Symposium on Autonomous Systems (ISAS). 2019:300-304.
23. Rahmani B, Belkheiri M. Adaptive neural network output feedback control for flexible multi-link robotic manipulators. International Journal of Control. 2019; 92(10):2324-38.
24. van Heusden K, Soltesz K, Cooke E, Brodie S, West N, Gorges M, etal. Optimizing robust PID control of propofol anesthesia for children; design and clinical evaluation. IEEE Transactions on Biomedical Engineering. 2019.
25. Romero J, Tzionas D, Black MJ. Embodied hands: Modeling and capturing hands and bodies together. ACM Transactions on Graphics (TOG). 2017; 36(6):245-255.
26. Furuya S, Nakamura A, Nagata N. Acquisition of individuated finger movements through musical practice. Neuroscience. 2014; 275:444-54.
27. Ali MH, Khairunizam WA, Adnan NH, Seah YC, Bakar JA, Razlan ZM. Analysis of finger movement by using motion information from GloveMAP and motion capture system. International Journal of Mechanical and Mechatronics Engineering. 2013; 13(3):24-31.
28. Polygerinos P, Wang Z, Galloway KC, Wood RJ, Walsh CJ. Soft robotic glove for combined assistance and at-home rehabilitation. Robotics and Autonomous Systems. 2015; 73:135-43.
29. Louis L. working principle of Arduino and u sing it. International Journal of Control, Automation, Communication and Systems (IJCACS). 2016; 1(2):21-9.
30. Ates S, Haarman CJ, Stienen AH. SCRIPT passive orthosis: design of interactive hand and wrist exoskeleton for rehabilitation at home after stroke. Autonomous Robots. 2017; 41(3):711-23.
31. Villafañe JH, Valdes K, Imperio G, Borboni A, Cantero-Téllez R, Galeri S, Negrini S. Neural manual vs. robotic assisted mobilization to improve motion and reduce pain hypersensitivity in hand osteoarthritis: study protocol for a randomized controlled trial. Journal of physical therapy science. 2017; 29(5):801-816.
32. Ben-Tzvi P, Danoff J, Ma Z. The design evolution of a sensing and force-feedback exoskeleton robotic glove for hand rehabilitation application. J Mech Rob. 2016; 8(5):051019.