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A Low Cost of an Exoskeleton Finger for Stroke Patient

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ABSTRACT

Hand motor impairment poses a significant obstacle for stroke survivors, profoundly affecting their capacity to perform crucial daily tasks. This impairment frequently includes an inability to flex fingers effectively. This research is dedicated to the development of a low-cost exoskeleton finger tailored for stroke patient rehabilitation. The proposed exoskeleton finger boasts characteristics of being lightweight, affordable, and straightforward to manufacture. Moreover, it prioritizes portability and user-friendliness. The design integrates PLA material, springs, servo motors, and Arduino Uno technology. The study introduces two distinct exoskeleton finger designs, with one of them incorporating a glove component. Both exoskeleton finger variations comprise three degrees of freedom (DOF), three links, and two joints. The findings show that the exoskeleton finger's ability to effectively maneuver a paralyzed finger into different positions as commanded, facilitating the rehabilitation process. Furthermore, both designs exhibit reliability in aiding the opening and closing exercises of impaired fingers.

1. Introduction

According to the World Health Organization (WHO), between 250,000 and 500,00 people suffer spinal cord injuries every year due to road accidents, trauma, common etiologies of myelopathy include autoimmune, infectious, neoplastic, vascular, and hereditary degenerative diseases [1]. To regain their lost abilities and continue their normal daily activities, these individuals require prompt and consistent therapy. Due to the shortage of physiotherapists, it is not always possible for patients to receive long-term rehabilitation training. According to The Malaysian Physiotherapy Association, they estimate that there are currently 2,759 active physiotherapists in the nation, or 0.88 per 10,000 people. As a result, there is a need for additional physiotherapists who are trained and competent [2]. A rehabilitation system that allows the patient to carry out rehabilitation exercises independently would be a solution to this difficulty.

Hand motor impairment is a common disability among stroke survivors and affects their ability to perform activities of daily living (ADL). Throughout the rehabilitation process, stroke patients

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regain partial / total motor hand function [3]. Research by Ockenfeld *et al.,* [4] has designed an exoskeleton hand robotic training device for a person after stroke to provide training to their impaired hand using an exoskeleton robotic hand that is actively driven by their own muscle signals. Hand exoskeletons can be broadly classified into assistive devices designed to replace impaired hand functioning, rehabilitation systems that aim to restore functionality lost due to injury or medical conditions, and augmentation exoskeletons designed to improve grasping abilities above normal levels [5].

The research on the finger rehabilitation has grown significantly such as in Sarac *et al.,* [6], Lu *et al.,* [7], Ohnuki *et al.,* [8], and Narita *et al.,* [9]. The group in Sarac *et al.,* [6] had developed a hand exoskeleton for a wearable device that provide realistic kinesthetic feedback to the user's fingers through active force transmission over a series of mechanical components. Meanwhile, Triolo *et al.,* [10] had proposed robotic exoskeleton devices that provide compliance with therapeutic treatment and improve hand function after stroke and other trauma. Shields *et al.,* [11] presented a prototype of a powered hand exoskeleton that was designed to fit the gloved hand of an astronaut and compensate for the stiffness of the pressurized space suit. This will prevent the productive time spent on extravehicular activity from being constrained by fatigue of the hand. According to Wege and Hommel [12], hand injuries are a common problem. Since hand injury rehabilitation takes longer, the higher number of hand injuries has an impact on the economy and the people injured. To improve the results of therapy and reduce the cost of rehabilitation, a hand exoskeleton was developed. Additionally, the hand exoskeleton was specifically designed to meet the requirements of medical applications. Guo *et al.,* [13] have proposed exoskeleton upper limb rehabilitation robots are increasingly applied to help hemiplegic patients to implement rehabilitation training, which makes up the shortage of rehabilitation only depending on doctors.

Moreover, Shahid and Khan [14] have designed a hand exoskeleton that incorporates a thumb along with the fiber link; An independent 2 DOF thumb link must be included, which must have a link with the remaining four fingers to operate independently. This design was proposed because the bone structure of human fingers is considered. Meta-carpaophalangeal (MCP) joint, proximal interphalangeal PIP joint, and the distal interphalangeal DIP joint are the three main joints. The links to these joints are the posterior phalange, middle phalange, and distal phalange, respectively. In order to move these joints, blood is pumped into the blood vessels to tighten the muscle and fat surrounding the bone structure and move the finger link to a particular point in space. A similar technique is also used to grip objects. A single finger consists of three revolute joints and a single actuator that drives these joints, respectively.

Meanwhile, the group in Zhou *et al.,* [15] introduced a whole new design of the hand exoskeleton consisting mostly of electronic motors, gears, twisted wires, and 3D-printed shells. The hand exoskeleton has six components which are index finger, middle finger, ring finger, little finger, thumb, and palm. Other design by Jeong *et al.,* [16] modelled the schematic of the proposed exoskeleton. In their structure, the exoskeleton frame is attached to the fingertip which is linked and actuated by the actuator on the back of the hand. Its kinematic performance such as range of motion and DOF was verified. An experiment was performed for two cases: extended and flexed fingers. In the experiment, three film-type force sensors were attached to the bottom side of each phalanx of the index finger [13].

Thus, drawing inspiration from the hand exoskeleton, this research introduces a newly developed, cost-effective exoskeleton finger. The proposed device is designed to be both portable and user-friendly. Notably, the combination of its affordability and straightforward manufacturing process makes this exoskeleton finger design a novel contribution in this field.

2. Methodology

2.1 The Hand Exoskeleton

It is essential to understand the human hand before the exoskeleton finger can be developed using Solidworks. The hand, also known as the Manus, is a human extremity that is placed at the distal end of an arm or forelimb. It consists of a palm with five fingers connected to the forearm by the wrist. With 27 bones and 24 degrees of freedom, human hands are regarded one of the most complex mechanical systems in the body, as depicted in Figure 1. The phalanges, which are proximal, medial, and distal to the digits, make up 14 of these bones. Each finger is connected to the wrist by five metacarpal bones [17-20].

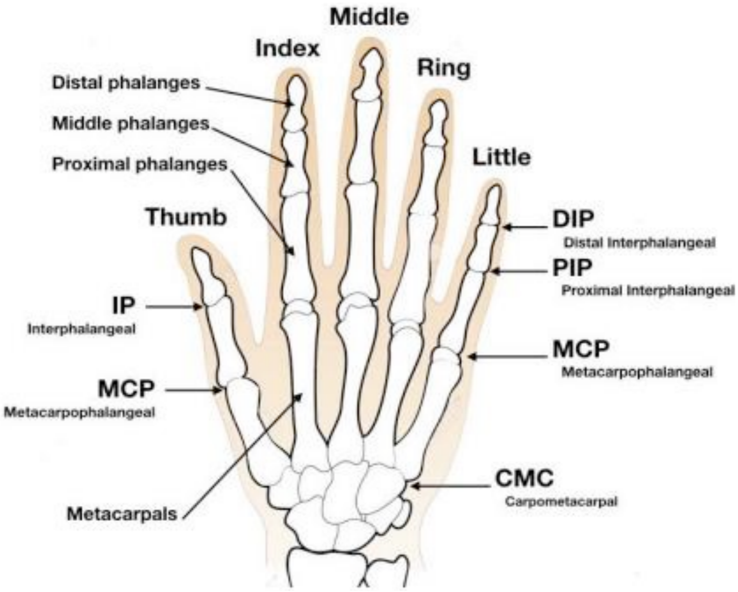


Fig. 1. Human Hand Anatomical

2.2 SolidWorks

Utilizing a 3D printer, depicted in Figure 2, the exoskeleton finger developed in Solidworks undergoes a printing process. Several preparatory steps are necessary before the actual printing of the exoskeleton finger can commence. Various applications of Solidworks tailored for distinct purposes are detailed in Mansor *et al.,* [21], Moses *et al.,* [22], Aman *et al.,* [23], Ariffin *et al.,* [24], and Kamaruzzaman *et al.,* [25]. Fundamentally, Solidworks encompasses three interconnected module types: the part, the assembly, and the drawing as shown in Figure 3, which collectively contribute to the comprehensive design.

To transform the 3D file into G-Code, the use of a slicer within the Cura software is essential (refer to Figure 4). Cura stands as an open-source slicing application designed for 3D printers. Compatible with a wide range of desktop 3D printers, this software supports prevalent 3D file formats including STL, OBJ, X3D, and 3MF, as well as image formats like BMP, GIF, JPG, and PNG. Once the G-Code file is generated, it can be transmitted to the printer to initiate the fabrication of the physical object.

Fig. 2. 3D Printer

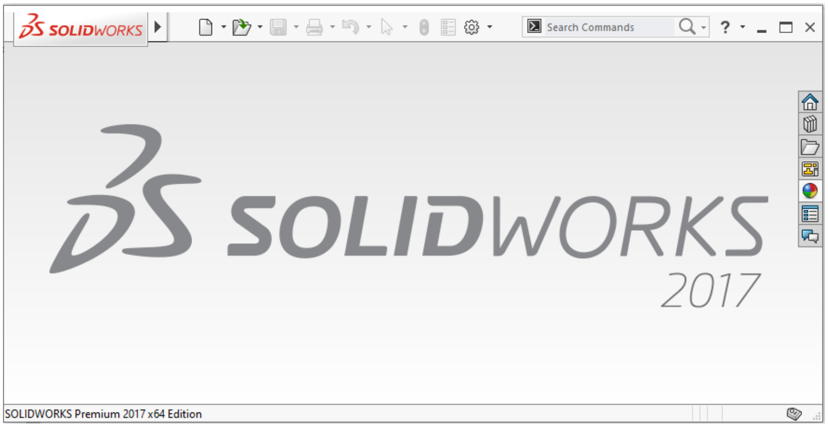


Fig. 3. Drawing an exoskeleton finger using Solidworks

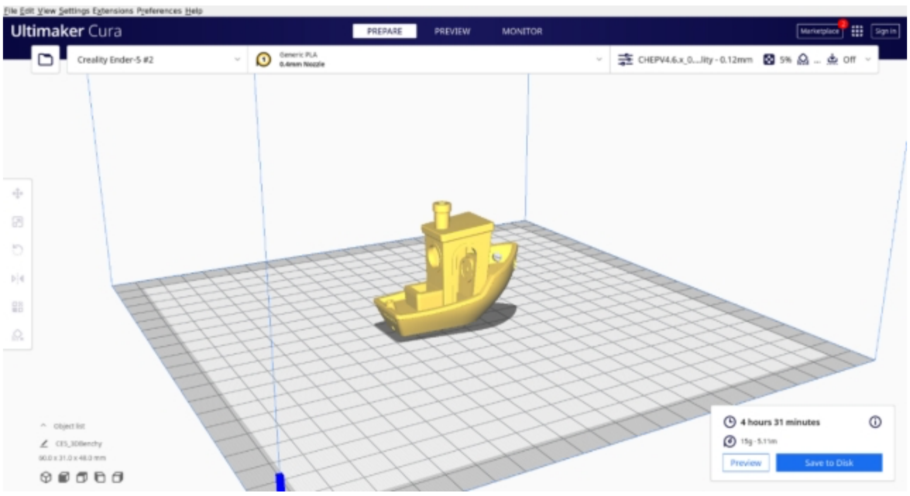
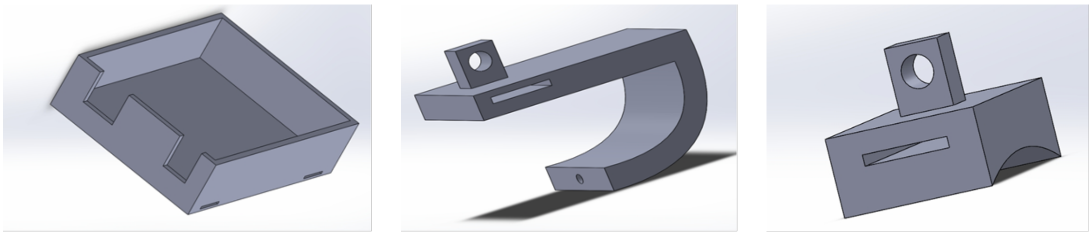


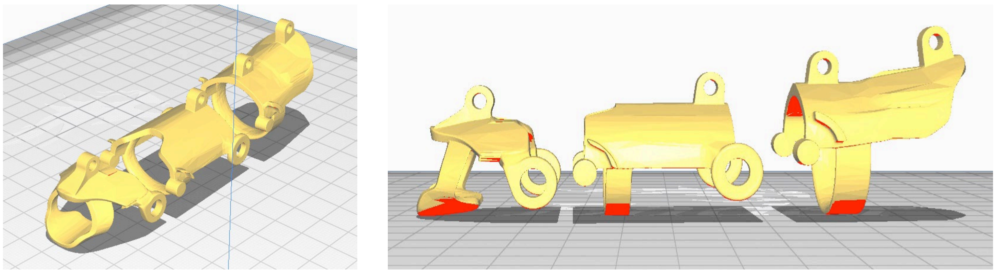
Fig. 4. Cura slicing application

There are two different designs of the exoskeleton finger that have been established. The first design depends solely on the PLA material and direct attach to the finger once the printing is completed. Thus, the design is shown in Figure 5. On the other hand, the second design requires the glove to comfort the user during rehabilitation process. The proposed exoskeleton finger can be found in Figure 6. In particular, Figure 5(a), Figure 5(b), and Figure 5(c) illustrate the design of Arduino casing, support for distal phalanges and support for middle and proximal phalanges for finger 1. Meanwhile, Figure 6(a) and Figure 6(b) exhibit the exoskeleton finger 2 from from and side view respectively.



(a) (b) (c)

Fig. 5. First design of exoskeleton finger by using Solidworks; (a) Arduino Casing, (b) Support for Distal Phalanges, (c) Support for Middle and Proximal Phalanges



(a) (b)

Fig. 6. Second design of the exoskeleton finger using SolidWorks; (a) front view, (b) side view

2.3 Coding

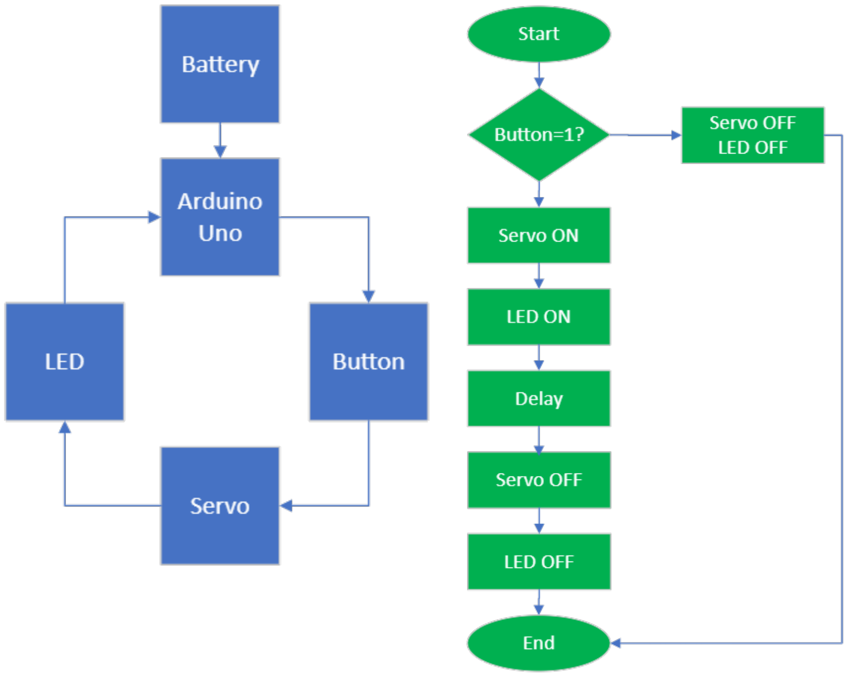
To execute the project, the coding is established as shown in Table 1. In principle, motor movement coding is required to allow the exoskeleton finger open and close.

Table 1
Project Coding

Exoskeleton finger 1	Exoskeleton finger 2
#include <Servo.h>	#include<Servo.h>
#define Servo_PWM 6 provides PWM signal	Servo Myservo;
Servo MG995_Servo;	int pos;
void setup()	void setup()
{	{
Serial.begin(9600); MG995_Servo.detach();	Myservo.attach(3);
delay(2000);	}
MG995_Servo.attach(Servo_PWM);	void loop()
Serial.println("0");	{
MG995_Servo.write(180);	for(pos=0;pos<=180;pos++){
delay(3000);	Myservo.write(pos);
MG995_Servo.detach();	delay(50);
delay(2000);	}
MG995_Servo.attach(Servo_PWM);	delay(1000);
}	for(pos=180;pos>=0;pos--){
MG995_Servo.attach(Servo_PWM);	Myservo.write(pos);
}	delay(50);
void loop()	}
{	delay(1000);
Serial.println("0");	}
MG995_Servo.write(0);	
delay(3000);	

2.4 System Integration

Figure 7 illustrates the flow chart for the integration of the exoskeleton finger system. The exoskeleton finger powered by a battery. It will be connected to Arduino Uno for controlling. The button is used to turn the servo on, which means that when the button is pressed, the servo will turn on. When the button is pressed again, the LED will turn on.



(a) (b)

Fig. 7. System integration flowchart; (a) block diagram, (b) project development process

Figure 8 depicts the circuit diagram of the servo motor utilized for joint movement. This diagram was generated using Proteus Professional. It is evident that two servo motors have been employed. Servo motor 1 is responsible for governing the interior of the finger, inducing the closure of the hand's palm. In contrast, servo motor 2 is positioned on the upper part of the hand to oversee the palm's opening. The coordination between these motors is orchestrated as follows: when servo motor 1 is engaged, the hand clenches, concomitantly prompting servo motor 2 to disengage. Conversely, when servo motor 2 is activated, the hand opens, and servo motor 1 concurrently disengages. This synchronization characterizes the routine during each instance of the rehabilitation exercise.

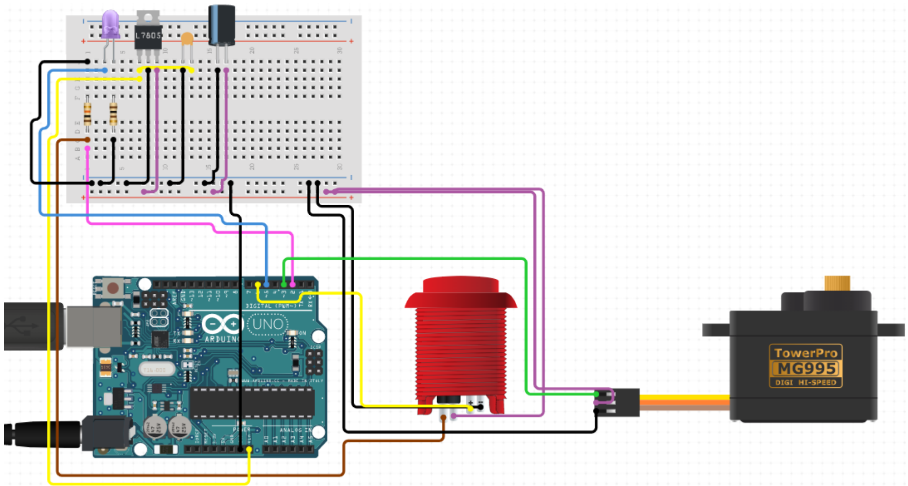


Fig. 8. Circuit drawing for system integration

2.5 Servo Motor, Spring and String

The main purpose of this project is to design the exoskeleton finger for stroke patients. It is vital to perform the closing and opening manoeuvre to allow the rehabilitation process of the finger. This is a therapy for stroke patient. In this project, MG995 servo motor as shown in Figure 9(a) plays an important role to allow closing and opening finger. More specifically, a spring as depicted in Figure 9(b) is used to connect between two joints that allow opening when motor moving anticlockwise direction. Meanwhile, the string, as shown in Figure 9(c), is used to connect the finger and palm for closing when the motor moves clockwise.

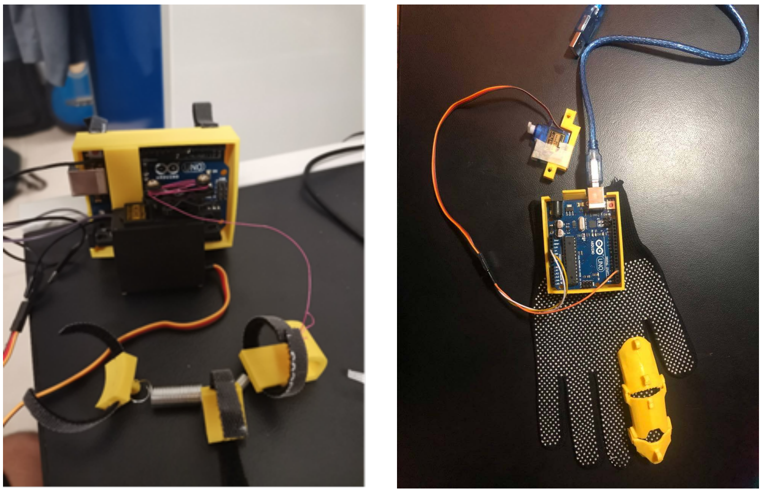
(a) (b) (c)

Fig. 9. Servo motor and spring; (a) servo motor, (b) springs, (c) strings

3. Results

3.1 Prototype

The prototype of the envisioned exoskeleton fingers is clearly illustrated in Figure 10. Specifically, Figure 10(a) provides a glimpse of the assembly process for exoskeleton finger 1, where each part is meticulously connected to the impaired finger. In contrast, exoskeleton finger 2 is designed to be worn with the assistance of a dedicated glove, as demonstrated in Figure 10(b). This glove serves as a medium to attach the exoskeleton finger 2 securely before it is worn. The visual representations in these figures encapsulate the practicality and user-centric design considerations of the proposed exoskeleton finger prototypes.



(a) (b)

Fig. 10. Prototype of exoskeleton fingers; (a) exoskeleton finger 1, (b) exoskeleton finger 2

3.2 Performance

The operating system for both devices is similar. To allow closure and opening, the servo motor will start turning clockwise for three seconds to roll the string. The finger will be pulled towards the palm (i.e., closing state). After three second, the motor will turn anticlockwise to release the string. In this process, the string is loosened, and the spring acts as the tension between the finger to pull it back to the initial place (i.e., the opening state). The process will continue until the servo motor is manually powered off. See Figure 11 and Figure 12 for rehabilitation exercise for each exoskeleton finger. Note that only one motor can move the finger at a time, thus, a maximum of five motors are required to perform the closing and opening activities for the entire paralyzed fingers (i.e., five fingers). Moreover, the base of the controller compartment is large, making it uncomfortable to use. This drawback can be improved for future development. Nonetheless, the proposed exoskeleton fingers are still reliable for the rehabilitation process.

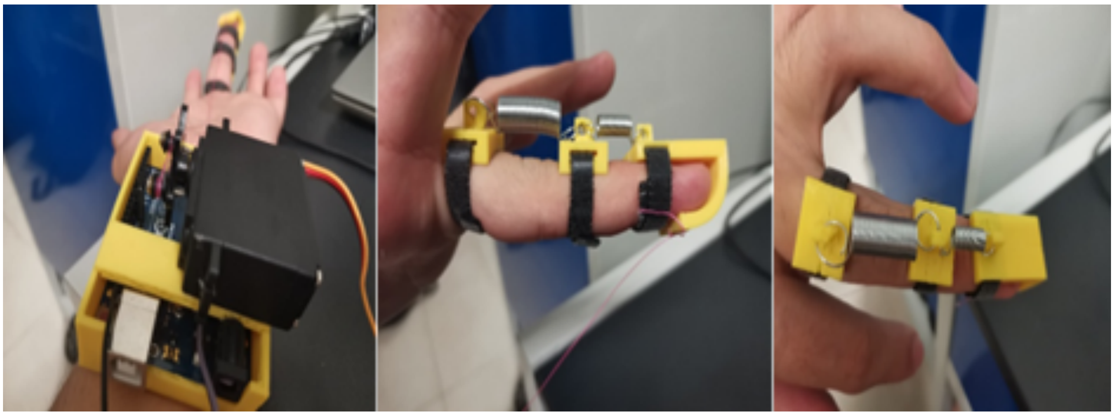


Fig. 11. Testing of the proposed exoskeleton finger 1

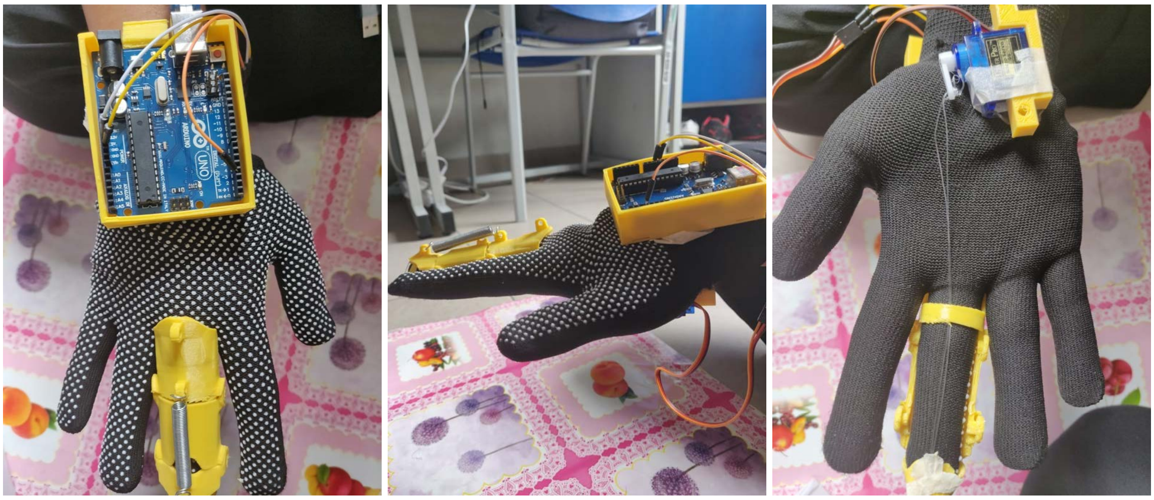


Fig. 12. Testing of the proposed exoskeleton finger 2

3.3 Cost

Table 2 presents a comprehensive breakdown of the components essential for the exoskeleton finger project. It outlines the quantities of each component and their corresponding costs. Each component plays a distinct role in the overall design and operation of the exoskeleton finger, contributing to its functionality. The total cost of RM151 signifies that the project's expenses remain within a reasonable and accessible range. This cost analysis holds significant importance in effective project planning, ensuring that financial considerations are appropriately managed. The selection of cost-effective elements, such as the Arduino Uno, servo motors, and PLA material, highlights the project's commitment to creating an affordable solution for stroke patient rehabilitation. This choice reinforces the idea that the exoskeleton finger is designed with accessibility and practicality in mind. Notably, the incorporation of the glove and velcro tape underscores considerations for user comfort and secure fitting. By considering both the affordability of components and the user's experience, the exoskeleton finger project demonstrates a holistic approach that aligns with the needs of stroke patients. This strategic blend of cost-effectiveness and user-oriented design showcases the project's potential to offer meaningful impact within the realm of stroke rehabilitation.

Table 2
Project cost

No	Components	Quantity	Price
1	Arduino Uno	1	RM45.00
2	Servo Motor	1	RM21.00
3	Spring	1	RM15.00
4	Velcro tape	5	RM10.00
5	PLA	1	RM50.00
6	Glove	1	RM10.00
7	String	1	RM5.00
Total			RM151.00

4. Conclusion

Two low-cost, lightweight, portable exoskeleton fingers have been successfully proposed and presented. The mechanical design of the hand exoskeleton satisfies the stroke patient when performing the closure and opening of the paralyzed finger. Exoskeleton finger 1 is directly attached on the finger when wearing it, while exoskeleton 2 uses a glove for closing and opening finger. However, some modifications are required, as the proposed exoskeleton finger can fit only one finger at a time during the rehabilitation process. The design needs to comfort the entire five fingers of patients when performing closure and opening exercise. Hence, apart from simple design, portability, and low cost, compact is one of the main criteria to consider for future design.

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References

[1] Ab Aziz, Ab Wafi, Jamaludin Jalani, Sujana Mohd Rejab, and Amirul Syafiq Sadun. "Preliminary Findings on EEG-Controlled Prosthetic Hand for Stroke Patients Based on Motor Control." In *Control, Instrumentation and Mechatronics: Theory and Practice*, pp. 105-117. Singapore: Springer Nature Singapore, 2022. https://doi.org/10.1007/978-981-19-3923-5_10

[2] Abaraogu, Ukachukwu Okoroafor, Juliet Chinonso Edeonuh, and Jose Frantz. "Promoting physical activity and exercise in daily practice: current practices, barriers, and training needs of physiotherapists in eastern Nigeria." *Physiotherapy Canada* 68, no. 1 (2016): 37-45. https://doi.org/10.3138/ptc.2014-74

[3] Mohamaddan, Shahrol, Herman Khamis, Annisa Jamali, Saidatul Ardeenawatie Awang, Noor Ayuni Che Zakaria, and Akihiko Hanafusa. "Development and Control of Hand Exoskeleton System Using Intended Movement." In *2021 IEEE 3rd Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS)*, pp. 9-12. IEEE, 2021. https://doi.org/10.1109/ECBIOS51820.2021.9510702

[4] Ockenfeld, Corinna, Raymond K. Y. Tong, Evan A. Susanto, Sze-Kit Ho, and Xiao-ling Hu. "Fine finger motor skill training with exoskeleton robotic hand in chronic stroke: stroke rehabilitation." In *2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR)*, pp. 1-4. IEEE, 2013. https://doi.org/10.1109/ICORR.2013.6650392

[5] Du Plessis, Tiaan, Karim Djouani, and Christiaan Oosthuizen. "A review of active hand exoskeletons for rehabilitation and assistance." *Robotics* 10, no. 1 (2021): 40. https://doi.org/10.3390/robotics10010040

[6] Sarac, Mine, Massimiliano Solazzi, and Antonio Frisoli. "Design requirements of generic hand exoskeletons and survey of hand exoskeletons for rehabilitation, assistive, or haptic use." *IEEE Transactions on Haptics* 12, no. 4 (2019): 400-413. https://doi.org/10.1109/TOH.2019.2924881

[7] Lu, Guangda, Ning An, and Zhiyuan Liu. "Design and Kinematics Analysis of a Bionic Finger Hand Rehabilitation Robot Mechanism." In *2019 34rd Youth Academic Annual Conference of Chinese Association of Automation (YAC)*, pp. 715-718. IEEE, 2019. https://doi.org/10.1109/YAC.2019.8787600

[8] Ohnuki, Nanami, Yuta Furudate, Sadayoshi Mikami, Kaori Chiba, and Yuji Ishida. "Automated Voluntary Finger Lifting Rehabilitation Support Device for Hemiplegic Patients to Use at Home." In *2020 Fourth IEEE International Conference on Robotic Computing (IRC)*, pp. 275-279. IEEE, 2020. https://doi.org/10.1109/IRC.2020.00050

[9] Narita, Takumi, Kaori Chiba, Yuji Ishida, Yuta Furudate, and Sadayoshi Mikami. "Direct Finger Illumination Method for Biofeedback of Involuntary Movement for Rehabilitation Assist Device." In *2022 IEEE 4th Global Conference on Life Sciences and Technologies (LifeTech)*, pp. 109-111. IEEE, 2022. https://doi.org/10.1109/LifeTech53646.2022.9754892

[10] Triolo, Emily R., Martha H. Stella, and Brett F. BuSha. "A force augmenting exoskeleton for the human hand designed for pinching and grasping." In *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, pp. 1875-1878. IEEE, 2018. https://doi.org/10.1109/EMBC.2018.8512606

[11] Shields, Bobby L., John A. Main, Steven W. Peterson, and Alvin M. Strauss. "An anthropomorphic hand exoskeleton to prevent astronaut hand fatigue during extravehicular activities." *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans* 27, no. 5 (1997): 668-673. https://doi.org/10.1109/3468.618265

[12] Wege, Andreas, and Günter Hommel. "Development and control of a hand exoskeleton for rehabilitation of hand injuries." In *2005 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 3046-3051. IEEE, 2005. https://doi.org/10.1109/IROS.2005.1545506

[13] Guo, Jian, Nan Li, Shuxiang Guo, and Jiange Gao. "A LabVIEW-based human-computer interaction system for the exoskeleton hand rehabilitation robot." In *2017 IEEE International Conference on Mechatronics and Automation (ICMA)*, pp. 571-576. IEEE, 2017. https://doi.org/10.1109/ICMA.2017.8015880

[14] Shahid, Talha, and Umar S. Khan. "Design of a low cost multi degree of freedom hand exoskeleton." In *2014 International Conference on Robotics and Emerging Allied Technologies in Engineering (iCREATE)*, pp. 312-316. IEEE, 2014. https://doi.org/10.1109/iCREATE.2014.6828386

[15] Zhou, Yifang, Pu Zhang, Kai Xiao, Jia Luo, and Jianyu Yang. "Research on a new structure of hand exoskeleton for rehabilitation usage." In *2017 4th International Conference on Information Science and Control Engineering (ICISCE)*, pp. 1126-1130. IEEE, 2017. https://doi.org/10.1109/ICISCE.2017.234

[16] Jeong, Dasom, Inseong Jo, and Joonbum Bae. "Analysis on the force distribution of various grasps for the design of a hand exoskeleton." In *2014 11th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, pp. 127-131. IEEE, 2014. https://doi.org/10.1109/URAI.2014.7057412

[17] Jamil, Muhamad Faizal Abdul, Jamaludin Jalani, Afandi Ahmad, and Amran Mohd Zaid. "An Overview of Anthropomorphic Robot Hand and Mechanical Design of the Anthropomorphic Red Hand-A Preliminary Work." In *Towards Autonomous Robotic Systems: 16th Annual Conference, TAROS 2015*, Liverpool, UK, September 8-10, 2015, Proceedings 16, pp. 13-18. Springer International Publishing, 2015. https://doi.org/10.1007/978-3-319-22416-9_2

[18] Maw, Jonathan, Kai Yuen Wong, and Patrick Gillespie. "Hand anatomy." *British Journal of Hospital Medicine* 77, no. 3 (2016): C34-C40. https://doi.org/10.12968/hmed.2016.77.3.C34

[19] Vargas, Angélica, Karla Chiapas-Gasca, Cristina Hernández-Díaz, Juan J. Canoso, Miguel Ángel Saavedra, José Eduardo Navarro-Zarza, Pablo Villasenor-Ovies, and Robert A. Kalish. "Clinical anatomy of the hand." *Reumatología Clínica* 8 (2012): 25-32. https://doi.org/10.1016/j.reuma.2012.10.004

[20] Brown, Hugh G. "Functional anatomy of the hand." *Orthopedic Clinics of North America* 1, no. 2 (1970): 199-204. https://doi.org/10.1016/S0030-5898(20)30524-1

[21] Mansor, Nuratiqa Natrah, Muhammad Herman Jamaluddin, Ahmad Zaki Shukor, and Syaiful Asyraf Abdul Razib. "Development of Portable Wireless Parking Sensor Device." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 30, no. 3 (2023): 9-15. https://doi.org/10.37934/araset.30.3.915

[22] Moses, Larry Sundaran, Md Tasyrif Abdul Rahman, Abdul Hamid Adom, Mohd Ridzuan Mohd Jamir, Mohd Al Hafiz Mohd Nawi, and Mohd Hafif Basha. "An Analysis of The Material and Design of an Exhaust Manifold for A Single-Cylinder Internal Combustion Engine." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 30, no. 2 (2023): 163-175. https://doi.org/10.37934/araset.30.2.163175

[23] Aman, Sidra, Dennis Ling Chuan Ching, Mohd Zuki Salleh, and Zulkhibri Ismail. "Heat Generation Effects on Maxwell Nanofluid Passing Over an Oscillating Vertical Plate." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 28, no. 2 (2022): 348-355. https://doi.org/10.37934/araset.28.2.348355

[24] Ariffin, Nuruddin, Kamarul-Azhar Kamarudin, Ahmad Sufian Abdullah, and Mohd Idrus Abd Samad. "Crash Investigation on Frontal Vehicle Chassis Frame using Finite Element Simulation." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 28, no. 2 (2022): 124-134. https://doi.org/10.37934/araset.28.2.124134

[25] Kamaruzzaman, Muhammad Amien, Hassrizal Hassan Basri, and Mohd Nasir Ayob. "Design and Simulation of a Customize Three-axis Gimbal Structure using Finite Element Analysis Method." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 30, no. 1 (2023): 158-167. https://doi.org/10.37934/araset.30.1.158167