

## Advancing Hand Rehabilitation: Designing a Motorized Exoskeleton for Middle Finger Control with SolidWorks and IoT Integration through Blynk

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### ARTICLE INFO

### ABSTRACT

#### Keywords:

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The paper addresses the need for advanced assistive rehabilitation technologies by developing a motorized exoskeleton finger controlled by an ESP32 microprocessor, L298N motor driver and N20 motor. The integration with the Blynk app for remote control enhances user experience and adaptability. The study not only demonstrates the effectiveness of the prototype but also outlines future improvements such as adding sensors for feedback control and optimizing for user comfort. By exploring innovative sensor designs and integration techniques, developers can enhance the capabilities of the motorized exoskeleton and further advance assistive technologies for individuals with physical impairments. The prototype was tested using Blynk Web dashboard and Blynk IoT application for control, with two push buttons enabling manual control of the middle finger movements. In automatic mode, the system allows for controlling the distance and speed of the finger movement. The design process involved using Ultimaker CURA for 3D printing and SolidWorks for mechanical design, ensuring precise integration of hardware and software components. The mechanical design, created using SolidWorks, showcased intricate details such as the ring link for the middle finger, finger lock pin and panel joints for the finger motor. These results demonstrate the successful development and testing of the motorized exoskeleton prototype, highlighting its potential for enhancing assistive rehabilitation technologies for individuals with upper limb impairments.

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## 1. Introduction

Motorized exoskeletons have gained significant attention in recent years for their potential to assist individuals with physical impairments and enhance human performance in various tasks. The integration of Internet of Things technology in the development of motorized exoskeletons has opened up new possibilities for enhancing control and user experience. This paper will explore the development of a motorized exoskeleton specifically designed for middle finger control, with a focus on IoT integration and its potential impact on the field of assistive technologies [1]. One of the key challenges in the development of motorized exoskeletons is to ensure precise and intuitive control mechanisms [2,3]. In the context of a middle finger-controlled exoskeleton, IoT technology can enable real-time feedback and synchronization between the user's finger movements and the exoskeleton's response. This can lead to more natural and fluid control, enhancing the user's overall experience and efficiency in performing tasks that require fine motor skills. Furthermore, the IoT integration in the exoskeleton design can facilitate data collection and analysis, providing valuable insights into the user's behaviour and performance. This data-driven approach can enable personalized adjustments and optimizations, making the exoskeleton more adaptable to individual user needs and preferences. Additionally, the data collected can contribute to the advancement of ergonomic design principles for future exoskeleton iterations [4,5].

In the realm of assistive technologies, the development of a motorized exoskeleton for middle finger control using IoT holds significant potential to improve the quality of life for individuals with upper limb impairments. By incorporating IoT capabilities, the exoskeleton can offer enhanced adaptability, allowing users to perform a wider range of tasks with greater precision and control. This advancement aligns with the overarching goal of assistive technologies, which is to promote independence and inclusion for individuals with disabilities [6,7]. Moreover, the integration of IoT in the exoskeleton's design can pave the way for remote monitoring and support functionalities. Through connectivity with other smart devices or platforms, the exoskeleton can enable healthcare professionals or caregivers to remotely monitor usage patterns, provide assistance and offer timely interventions as needed. This remote support feature can contribute to a more comprehensive approach to assistive technologies, addressing not only physical support but also fostering a sense of connectedness and support within the user's social environment [8-10].

The potential impact of IoT integration in the development of motorized exoskeletons expands beyond immediate control and user experience improvements. It also opens doors to advancements in the field of biomechanics and human augmentation. Through extensive data collection and analysis enabled by IoT, researchers and developers can gain deeper insights into the intricacies of human movement and behaviour, leading to the refinement of exoskeleton designs for both assistive and performance-enhancing applications [11,12]. The adaptability and personalized adjustments afforded by IoT integration could revolutionize the way exoskeletons are utilized in various settings. For individuals with physical impairments, this means a tailored support system that not only enhances their motor skills but also accounts for their unique needs and capabilities. The potential for remote monitoring and support functionalities through IoT connectivity reinforces the idea that assistive technologies are evolving towards a more holistic approach, addressing not just physical limitations but also social and emotional well-being [13,14].

One of the critical components in the development of a motorized exoskeleton with IoT integration is the sensor technology. Sensors play a crucial role in enabling real-time feedback and synchronization between the user's finger movements and the exoskeleton's response. By accurately capturing the movements and gestures of the middle finger, sensors allow for precise control and seamless interaction with the exoskeleton [15]. In the context of middle finger control, various types

of sensors can be explored, such as flex sensors, capacitive sensors or even optical sensors. These sensors can detect the bending or movement of the user's middle finger and transmit this data to the exoskeleton system, initiating the corresponding movements or actions. The choice of sensors is essential in ensuring the accuracy and responsiveness of the exoskeleton to the user's commands, ultimately enhancing the overall user experience and control.

Furthermore, incorporating advanced sensor technologies, such as inertial measurement units or pressure sensors, can enable the exoskeleton to gather detailed and sophisticated data about the user's finger movements and pressure exerted during interactions. This wealth of data can contribute to a deeper understanding of the user's motor capabilities and behaviours, facilitating personalized adjustments and optimizations for the exoskeleton's responsiveness and support. As the field of sensor technology continues to evolve, developers can explore innovative sensor designs and integration techniques to further enhance the capabilities of the motorized exoskeleton. The seamless fusion of advanced sensor technology with IoT integration positions the motorized exoskeleton for middle finger control as a leading example of how assistive technologies can harness connectivity and data-driven insights to empower individuals with physical impairments [16,17].

The development of a motorized exoskeleton for middle finger control using IoT represents a significant advancement in the field of assistive technologies [18]. The integration of IoT technology not only enhances the precision and intuitiveness of control mechanisms but also enables personalized adjustments and remote support functionalities. This innovation holds the potential to improve the quality of life for individuals with upper limb impairments by promoting independence, inclusion and a more comprehensive approach to assistive technologies [19-21]. It is evident that motorized exoskeletons integrated with IoT technology hold great promise for assisting individuals with physical impairments, particularly in tasks requiring fine motor control [22]. This project aims to address this gap by designing a motorized exoskeleton specifically tailored for middle finger control using SolidWorks for mechanical design and Blynk for IoT integration [23]. Through this project, we seek to advance hand rehabilitation techniques by providing a novel solution that combines mechanical engineering principles with IoT technology.

## **2. Methodology**

This section outlines the methodology employed in the design, fabrication and control of a motorized finger exoskeleton, aiming to augment hand movements and capabilities.

### *2.1 Hand Exoskeleton*

Before the exoskeleton finger can be created using SolidWorks, it is important to comprehend the human hand. The hand is a human extremity that is situated at the distal end of an arm or forelimb and is also referred to as the Manus. It is made up of five fingers on a palm that is joined to the forearm at the wrist as shown in Figure 1.

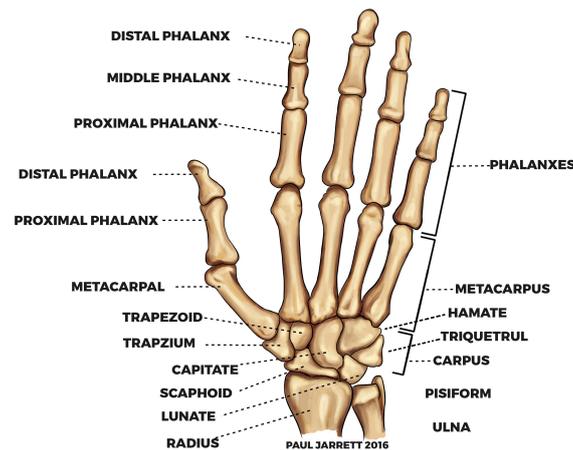


Fig. 1. Hand anatomy [24]

This intricate structure illustrates the presence of 14 bones known as phalanges, categorized into proximal (interphalangeal joint), medial (metacarpophalangeal joint) and distal elements that distributed across the digits. Furthermore, each finger is connected to the wrist through five metacarpal bones. This intricate arrangement of bones facilitates the hand's dexterity and fine motor control, laying the foundation for the design and development of an effective exoskeleton finger. While in Figure 2 shows the anatomy of a human finger with joints.

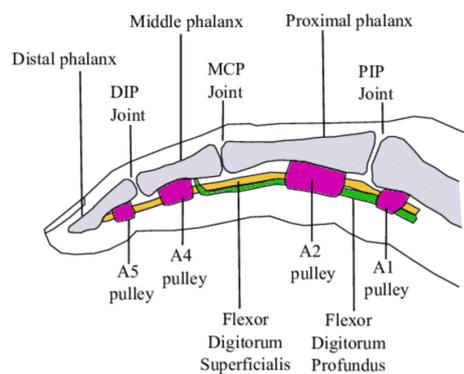
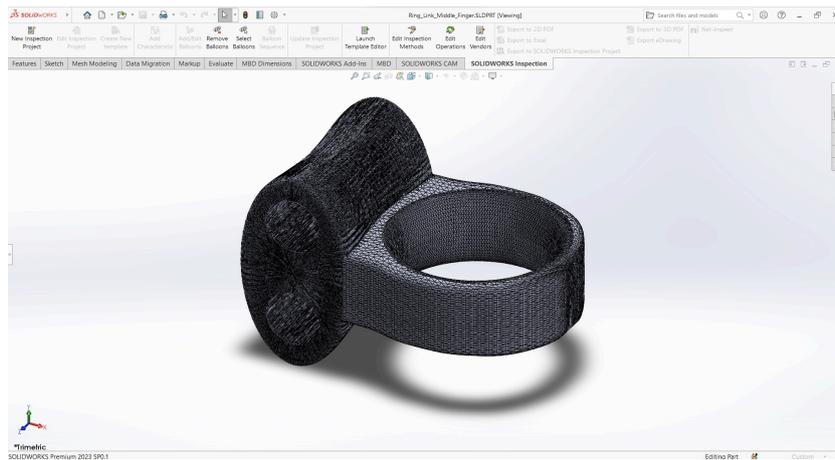


Fig. 2. Finger anatomy joints

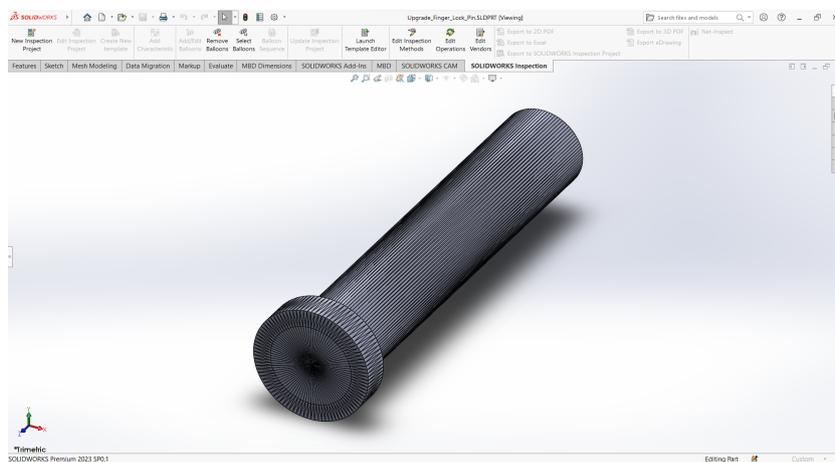
## 2.2 SolidWorks and Ultimaker CURA

The mechanical design of the finger exoskeleton was created using SolidWorks, capitalizing on its robust 3D modelling capabilities, parametric design features and efficient assembly tools. SolidWorks served as the ideal platform for constructing intricate mechanical structures such as the finger exoskeleton. Figure 3 to Figure 12 provide a detailed visual exploration of the step-by-step part-by-part design process. More specifically, Figure 3 illustrates the design of the ring link for the middle finger, emphasizing precision in geometry and connection points.



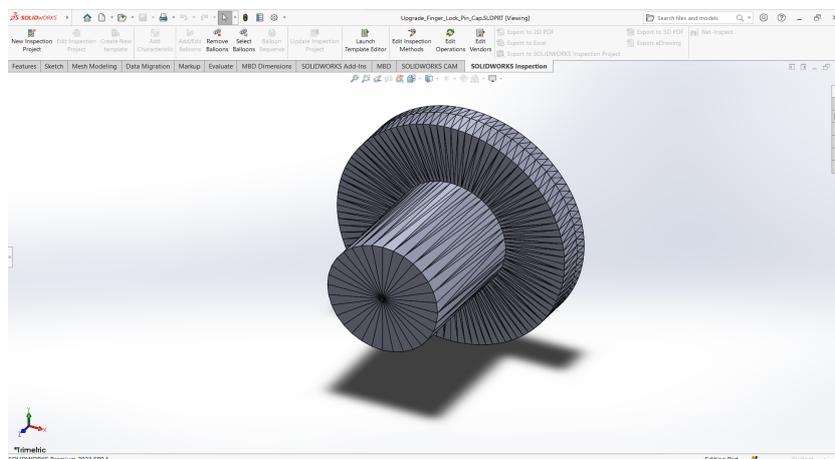
**Fig. 3.** Ring link middle finger

Figure 4 showcases the important role of the finger lock pin, revealing design intricacies critical for functionality.



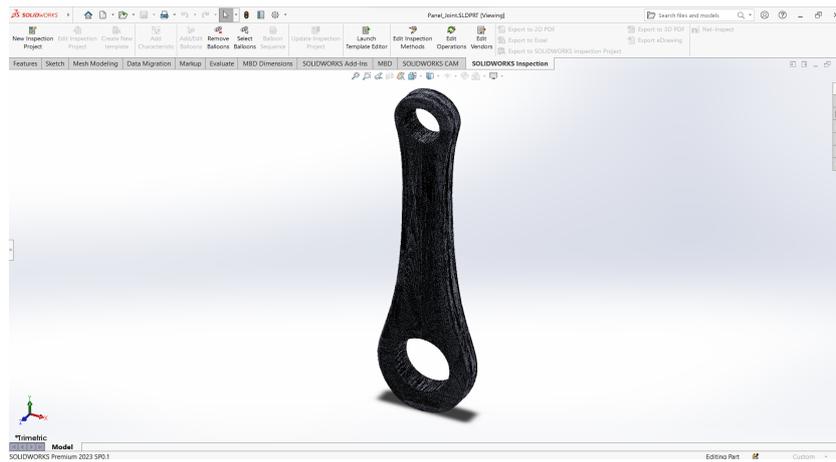
**Fig. 4.** Finger lock pin

Figure 5 sheds light on the finger lock pin cap, highlighting its role in ensuring stability.



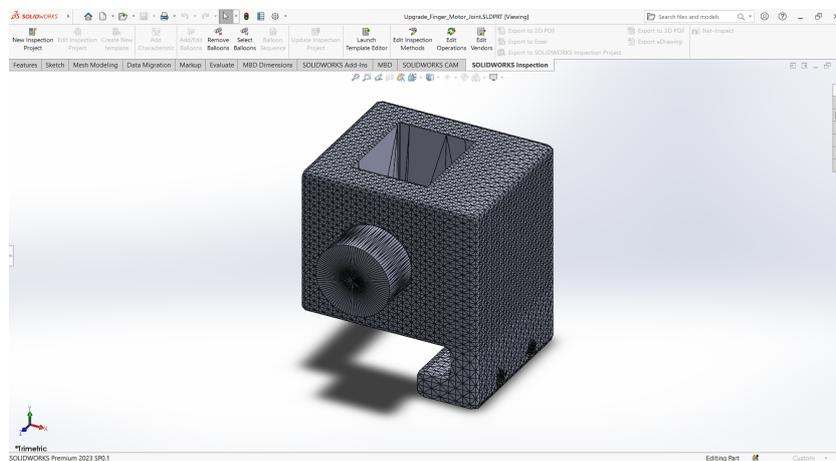
**Fig. 5.** Finger lock pin cap

In Figure 6, the panel joint's modular nature is depicted through its two-piece configuration.



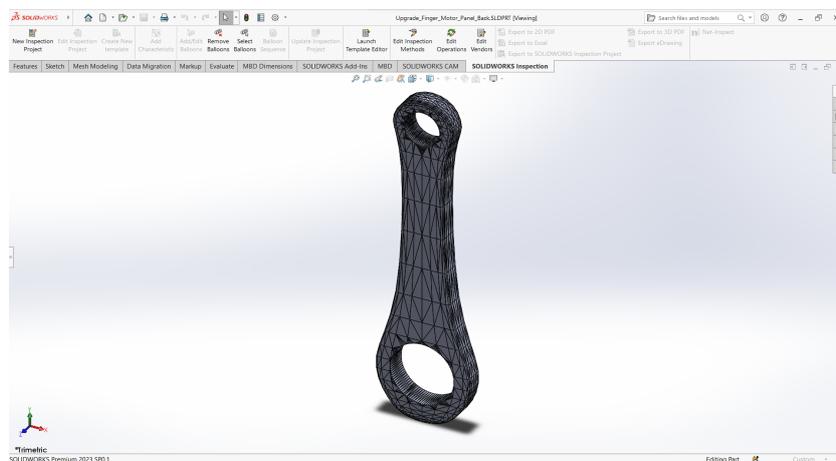
**Fig. 6.** Panel joint (2 pieces)

Figure 7 unveils the finger motor joint's design specifics, crucial for seamless integration.

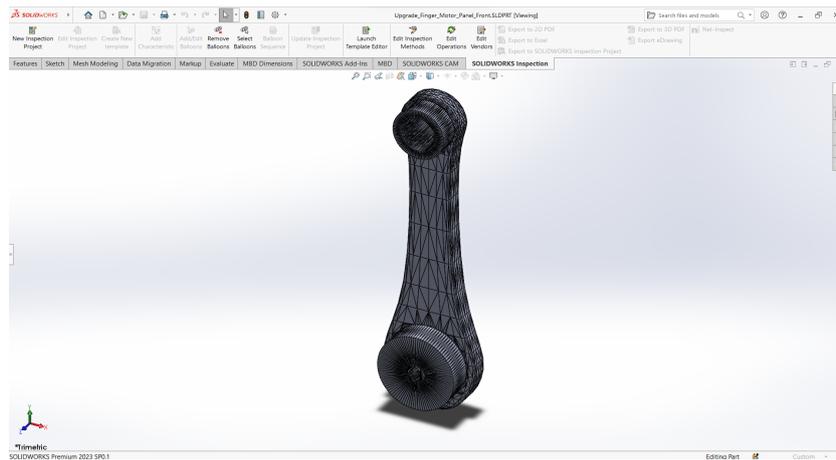


**Fig. 7.** Finger motor joint

Figure 8 and Figure 9 showcase the front and back panels housing the finger motor, emphasizing ventilation, accessibility and structural integrity.

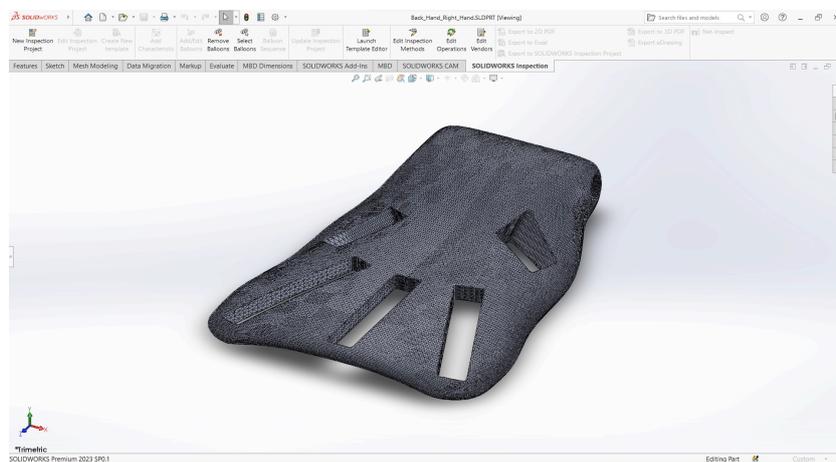


**Fig. 8.** Finger motor panel back



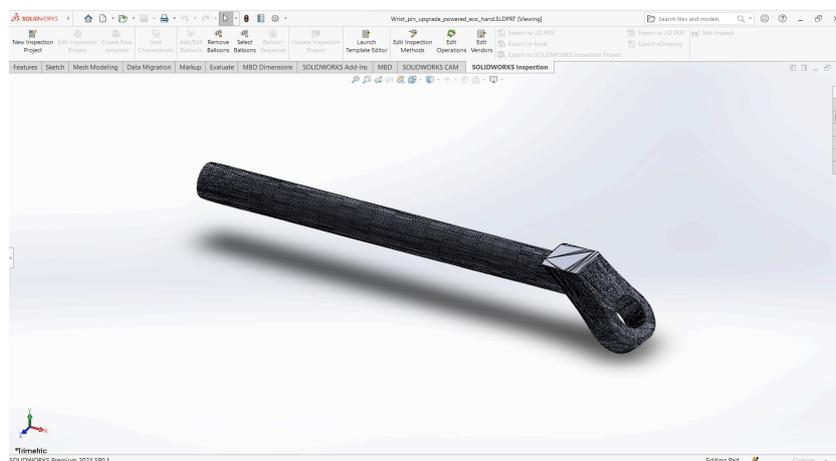
**Fig. 9.** Finger motor panel front

Figure 10 captures the intricacies of the back hand design for the right hand, emphasizing ergonomics.



**Fig. 10.** Back hand right hand

Figure 11 details the wrist pins for mobility and stability, while Figure 12 depicts the design of the wrist lock, essential for secure yet flexible connection to the user's wrist.



**Fig. 11.** Wrist pin

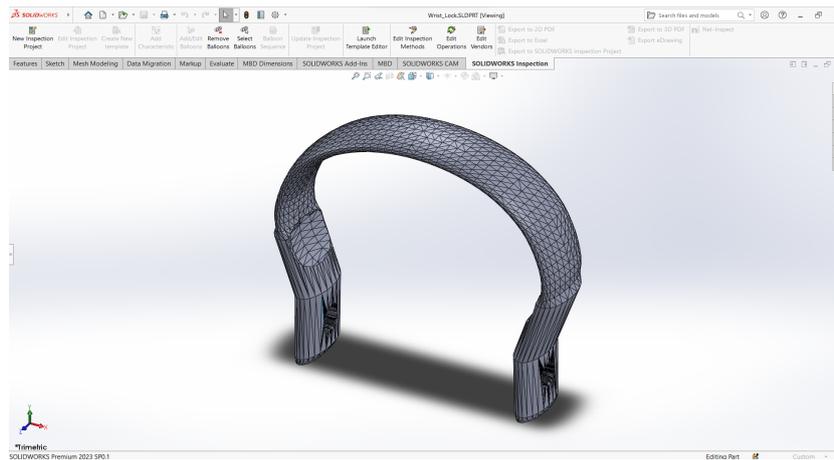


Fig. 12. Wrist lock

After completed the design, Ultimaker CURA was used to generate the G-Code for 3D printing. It provides the instructions for the 3D printer to build each layer of the physical model. Figure 13 shows one example of the 3D interface.

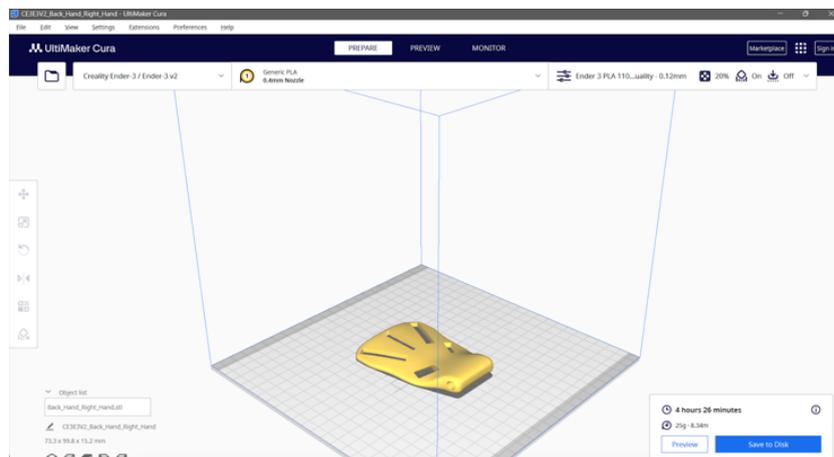
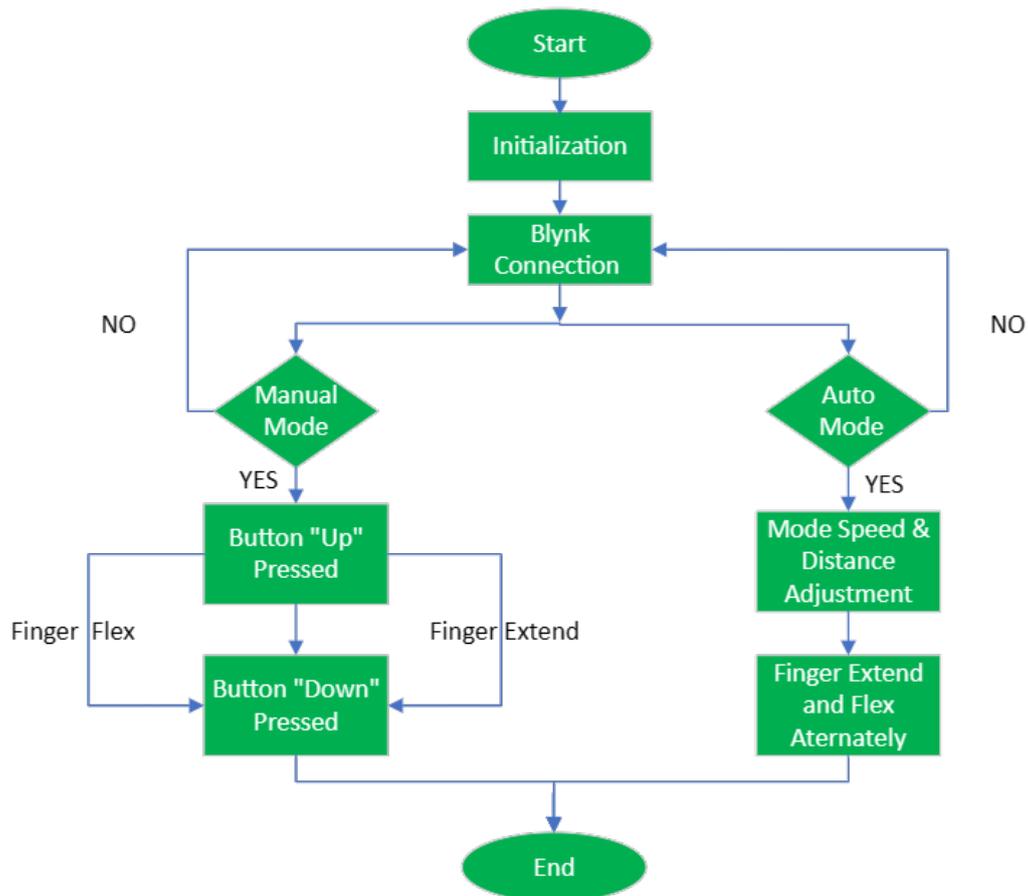


Fig. 13. 3D Printer interface

### 2.3 Flowchart

Figure 14 illustrates the flowchart of the motorized exoskeleton. The system was designed to control an N20 Motor using the L298N motor driver, with the interaction facilitated through the Blynk application. If the system is in manual mode, the “Up” button will command the N20 motor to extend the finger and “Down” button will command the N20 motor to flex the finger. If the system is not in manual mode and the “Auto” mode button is pressed, the sequence will enter automatic mode. In this mode, the N20 motor is instructed to extend and flex the finger alternately based on the motor speed and distance adjustment.



**Fig. 14.** Flowchart of the motorized finger exoskeleton

#### 2.4 Circuit, Components and Connections

In this system configuration (see Figure 15), a 9V battery is used as the main power supply. The ESP32 microcontroller is interfaced with the L298N motor driver for controlling the N20 motor. The connections from the ESP32 to the L298N include D14 to ENA (Enable A), D12 to IN1 (Input 1), D13 to IN2 (Input 2) and GND to GND, that enable the ESP32 to regulate the motor's direction and speed through the L298N. In order to facilitate the power supply and control of the motor, the L298N is connected to the N20 motor through the connections of OUT1 to the positive (+) terminal and OUT2 to the negative terminal (-). Additionally, the L298N is connected to a 9V battery, with +12V connected to the positive (+) terminal and GND to the negative (-) terminal, providing the necessary power for both the motor and the L298N motor driver. Figure 15 below shows the circuit for the motorized finger exoskeleton.

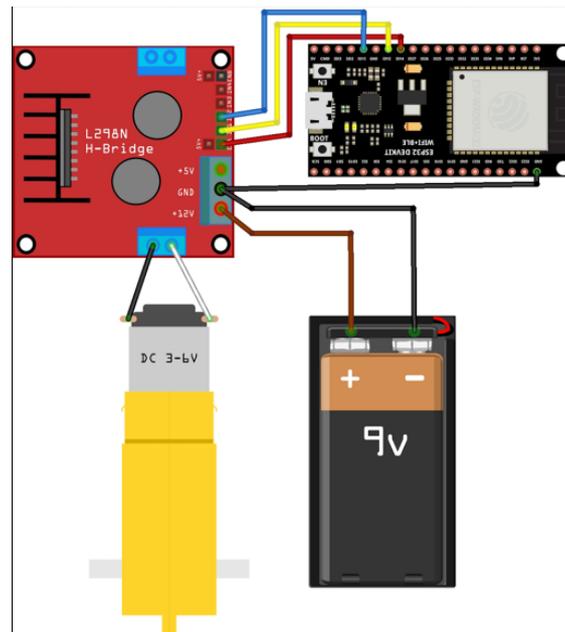


Fig. 15. Circuit connection of the system

## 2.5 Coding

Table 1 provides a principal insight into the foundational elements of the control code governing a sophisticated motorized finger exoskeleton. Developed explicitly for seamless integration with the Blynk IoT platform, this code empowers users with the capability to remotely control and monitor the intricate movements of the motorized finger. The Arduino code, intricately crafted for this project, forms the backbone of the control system. Moreover, the code presented in Table 1 is tailored for an ESP32 microcontroller, a versatile and powerful platform. It not only establishes a robust Wi-Fi connection but also harnesses the capabilities of the Blynk app, transforming it into an intuitive remote control and monitoring interface. This synergy between hardware and software ensures a dynamic and user-friendly experience.

**Table 1**

Coding of the system

| Code Segment      | Explanation  | Coding   |
|-------------------|--|--|
| Blynk Settings    | Define Blynk authentication token and Wi-Fi credentials      | <pre>char auth[] = "Your_Blynk_Auth-Token"; char ssid[] = "Your_WiFi_SSID"; char pass[] = "Your_WiFi_Password"; int motorPin = D1;</pre> |
| Motor Control Pin | Specify the pin connected to the motor.                      |  |
| Blynk Virtual Pin | Define the Blynk Virtual Pin for motor control.              | <pre>int motorControlPin = V0;</pre>   |
| Setup Function    | Initialize Blynk and attach the motor to the designated pin. | <pre>void setup() {   Blynk.begin(auth, ssid, pass);   motor.attach(motorPin); } void loop() {   Blynk.run(); }</pre>                    |
| Loop Function     | Run Blynk tasks in the loop.                                 | <pre>BLYNK_WRITE(motorControlPin) {   motor.write(param.asInt()); }</pre>  |

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|                       |  |   |
|-----------------------|--|---|
| Blynk App<br>Callback | Handle motor control data from the Blynk<br>app. | <code>Serial.println("Motor Position: " +<br/>String(param.asInt()));}</code> |
|-----------------------|--|---|

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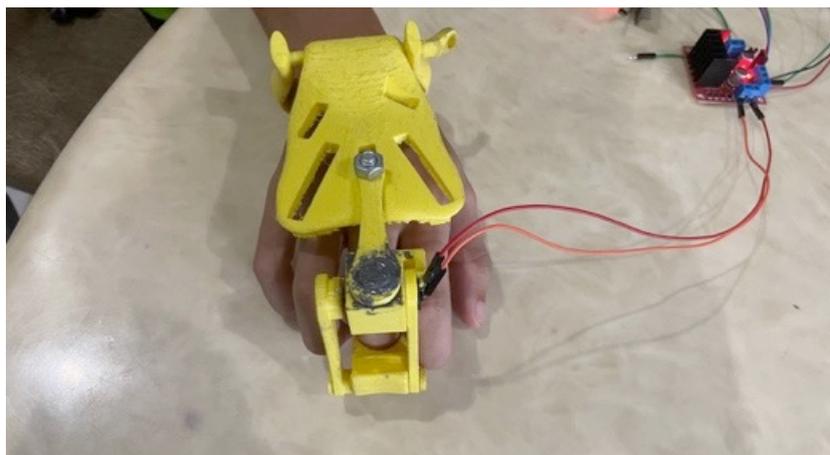
At the core of the motor control system lies the L298N motor driver, an important component directing the movements of the finger exoskeleton. Specifically, pins are defined for motor direction (IN1 and IN2) and speed control (ENA), offering precise management over the motorized finger's behaviour. The core functionality embedded in the code encompasses an array of functions designed to cater to both manual control and automated sequences. Manual movements are facilitated through dedicated functions, allowing users to direct the finger's actions with precision. Complementing this, an auto mode function facilitates a repetitive movement pattern, mimicking the natural extension and flexion of a human finger. This dual-mode capability enhances the versatility and adaptability of the motorized finger exoskeleton, positioning it as a sophisticated tool for various applications, from rehabilitation to research.

### 3. Results and Discussion

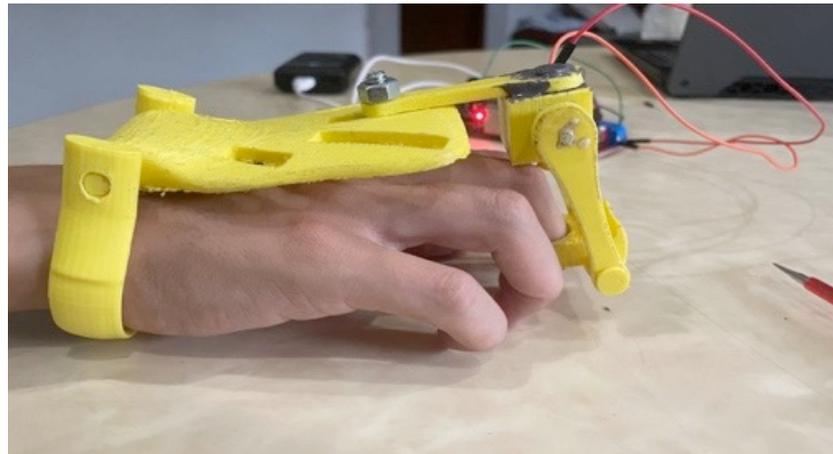
The results of the project highlight a successful achievement in the development of the motorized exoskeleton finger. The ESP32 microprocessor, L298N motor driver and a 6V 50RPM N20 metal gear motor demonstrates exceptional precision in its control mechanisms. Moreover, the seamless integration of hardware and software is achieved by leveraging Blynk for remote control through a mobile application, Ultimaker CURA for PLA 3D printing and SolidWorks for the intricacies of mechanical design.

#### 3.1 Prototype

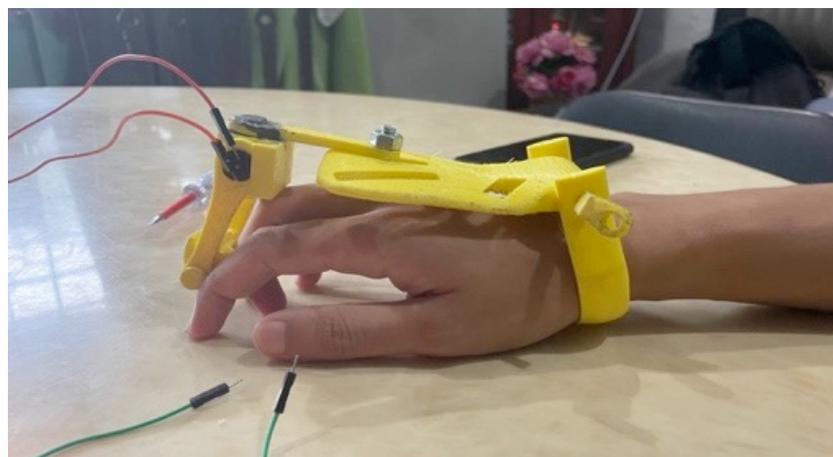
Figure 16(a), 16(b) and 16(c) shows how this exoskeleton finger is assembled. It shows each component of exoskeleton finger 1 that linked directly to the middle finger to motorize it. In contrast, a special design like base that need to put in on hand. Moreover, the pin that use to lock this device at wrist will make sure, it tightens neatly.



(a) Front view



(b) Right side view



(c) Left side view

**Fig. 16.** Prototype of developed exoskeleton

### 3.2 Performance

The prototype was tested as shown in Figure 17. The operating systems of both devices are identical. There are two interfaces to control our project which is using Blynk Web dashboard and Blynk IoT application. There is one switch including two push buttons and two types that means can control in two modes automatically and manually. Two push buttons to control lift and move down the middle finger. In mode auto, we can control the distance between middle finger can also travel its speed.



**Fig. 17.** Testing the prototype

Figure 18 and Figure 19 shows the interface of controlling the system on both mobile phone and laptop.

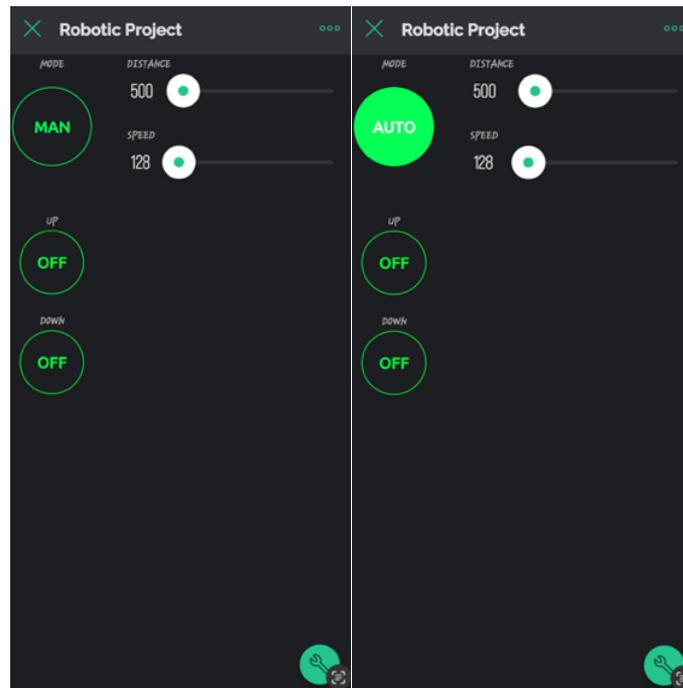


Fig. 18. Blynk IoT interface

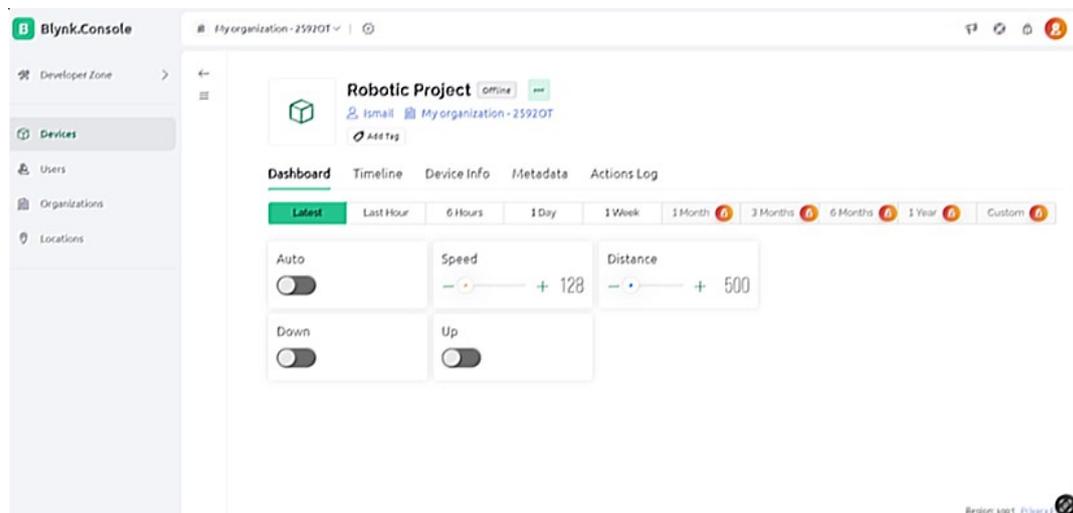


Fig. 19. Blynk web interface

### 3.3 Cost

Meanwhile, Table 2 shows the entire project cost. The overall cost for creating the exoskeleton finger is estimated to be roughly RM100. Although the cost is less expensive compared to the existing exoskeleton finger, the quality and performance of the proposed device are good enough.

**Table 2**

Project cost

| No    | Components  | Quantity | Price     |
|-------|-------------|----------|-----------|
| 1     | ESP32       | 1        | RM 28.90  |
| 2     | N20 Motor   | 1        | RM 15.00  |
| 3     | L298N Drive | 1        | RM 4.90   |
| 4     | (v Battery  | 1        | RM 3.40   |
| 5     | PLA         | 1        | RM 48.00  |
| 6     | Battery Cap | 1        | RM 0.60   |
| Total |             |          | RM 100.80 |

#### 4. Conclusions

The paper presents a significant contribution to the field of assistive rehabilitation technologies through the development of a motorized exoskeleton finger controlled by an ESP32 microprocessor, L298N motor driver and N20 motor. The integration with the Blynk app for remote control enhances user experience and adaptability. The study not only demonstrates the effectiveness of the prototype but also outlines future improvements such as adding sensors for feedback control and optimizing for user comfort. By exploring innovative sensor designs and integration techniques, developers can enhance the capabilities of the motorized exoskeleton and further advance assistive technologies for individuals with physical impairments. This research opens the door for advancements in motorized exoskeleton technology, potentially improving the quality of life for individuals with upper limb impairments.

Future recommendations for the development of motorized exoskeleton technology for assistive purposes include further exploration of advanced sensor technologies, such as inertial measurement units and pressure sensors, to enhance data collection on user finger movements and pressure exerted during interactions. This detailed data can lead to personalized adjustments and optimizations for the exoskeleton's responsiveness and support, improving user experience and functionality. Additionally, research into user comfort and the use of substitute materials can optimize the mechanical design for smoother integration into daily activities and potentially increase the exoskeleton's robustness and lifespan. By focusing on these areas, developers can advance the field of motorized exoskeleton technology and continue to improve the quality of life for individuals with upper limb impairments.

#### Acknowledgement

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