A cheap alternative for a prosthetic hand, Arthromech

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Abstract. The human hand is a component that is challenging to replicate mechanically, particularly in terms of its functionality. Most manufacturers utilize sensors to monitor electrical activity in the nerves to enable the hand to respond to the user's intentions. While this approach is reliable, it is also very expensive. Although prosthetic hands are becoming increasingly similar to real hands, the majority of individuals who need such prosthetics cannot afford them. Moreover, as many companies focus on producing highly advanced prosthetic hands, a significant gap is left in the market for affordable prosthetic solutions. This raises a critical question: Does the advancement of technology in a specific field make sense if it remains inaccessible to most people? Nevertheless, the Arthromech project is a concept of a "prosthetic hand at the price of a phone", created using Arduino, which introduces a series of innovative ideas.

1. Introduction

Prosthetics play an important role in the recovery of a person after an amputation. People after such a procedure cannot make a lot of basic tasks that they were used to do before with ease. Not only they find it hard to take care of themselves and make a living, but they also find it hard to reintegrate into society from a psychological perspective. Thus, the importance of creating a prosthetic hand accessible to a wide range of people is beyond question.

A crucial remark that made the project possible was the observation that in most cases, when we hold objects with our hands, we also move those objects in some way. For instance, when using a mop or a broom, we perform a translational motion from left to right. Similarly, when drinking a glass of water, we lift the glass and bring it closer to our mouth. Even when moving an object from one point to another, there is hand movement involved. Also, when we want to release objects we are holding, the hand is typically kept still, and the fingers are opened to let the object go.

Based on these observations, I came up with a simple idea for a prosthetic hand design. The prosthetic hand would close to grasp an object when a solid item is detected in front of it. Once the object is grasped, the hand would remain closed as long as there is detected significant movement or vibration at the hand level. Finally, the hand would open and release the object when no motion is detected for a few seconds. This concept provides a straightforward and efficient way to mimic the essential functionality of human hand movements in a prosthetic device.

2. Development of the prosthetic hand

2.1. Mechanics of the index, middle, ring and little finger

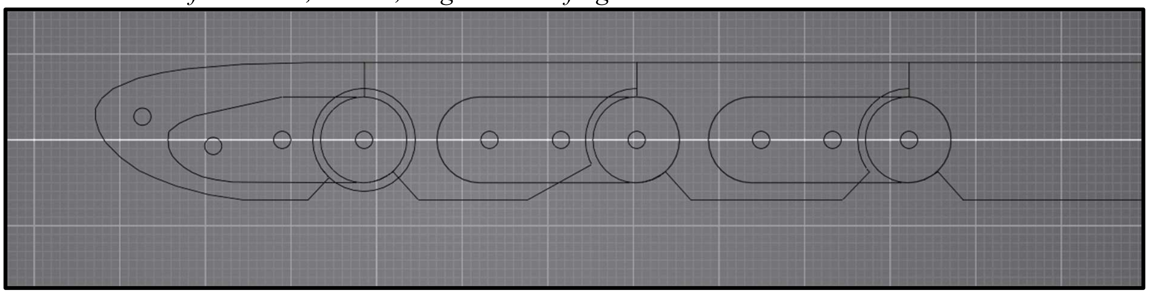

Figure 1. Design for index, middle, ring and little finger

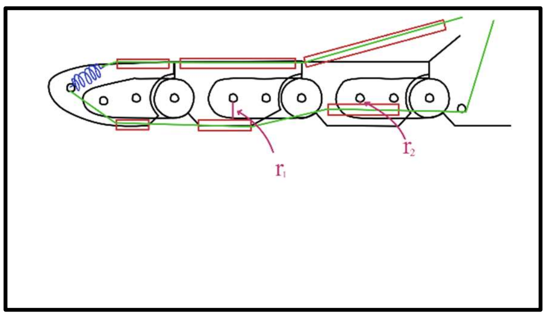

Figure 2. Opened index finger

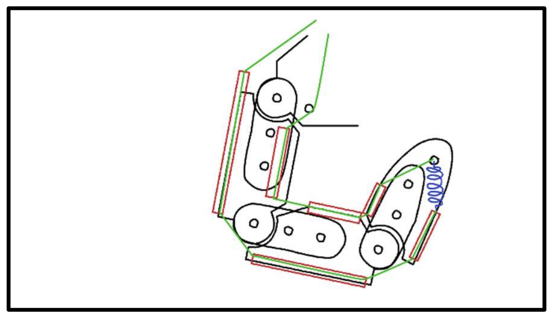

Figure 3. Closed index finger

In order to actuate the finger, the prosthetic features servomotors that pull strings that are attached to the tip of the distal phalanx. When the lower string is pulled, the upper string is simultaneously released, resulting in the closure of the finger. A critical element of this mechanism is the spring, depicted in blue in Figure 2. During the finger's closure, there is a significant likelihood that the opposing string exerts a resistance greater than the pulling capacity of the servomotor. To address this, the mechanism is designed such that the motor only needs to counteract the elastic force of the spring, which is considerably lower than the resistance imposed by the string.

As illustrated in Figure 2, the strings are routed through the cable system, with r_1 and r_2 representing the distances between the cable path and the axis on which the joints are situated. These distances correspond to the moment arm length, defined as the perpendicular distance from the axis of rotation to the line of action of the applied force. From the formula for torque:

$$\vec{\tau} = \vec{r} \times \vec{F} \tag{1}$$

where τ is the torque, *F* is the applied force, and *d* is the moment arm, it can be deduced that the length of the moment arm is inversely proportional to the force required to achieve the same torque. Consequently, increasing r_1 or r_2 reduces the force necessary for a given torque. Therefore, positioning the cables farther from the axis enhances the pulling force exerted by the finger. However, it also have a downside, increasing the distance of the cables from the axis also necessitates a greater length of string to be pulled to achieve full finger closure.

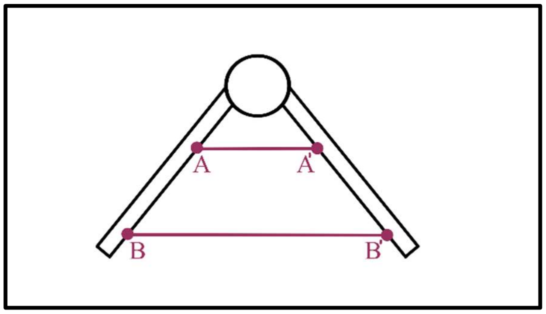

Figure 4. Hinge

This drawback can be observed in Figure 4. By positioning two points equidistant from the joint on a hinge, it can be observed that, as the distance from the joint increases, the length required to connect these two points for a joint closure also increases.

In conclusion, we need to choose those distances wisely so that we maximize the pulling force but also make sure that the finger closes. Based on extensive experimental trials, the optimal configuration was determined as follows: two of the cables are positioned at a distance r_1 from the axis, while the cable attached to the proximal phalanx is placed at a distance r_2. This arrangement achieves an effective compromise between force generation and functional range of motion.

2.2. Mechanics of the thumb finger

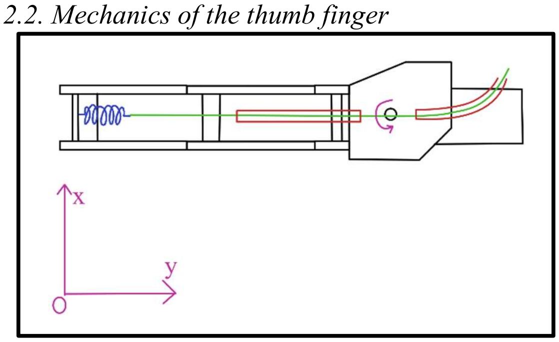

Figure 5. Thumb finger side view

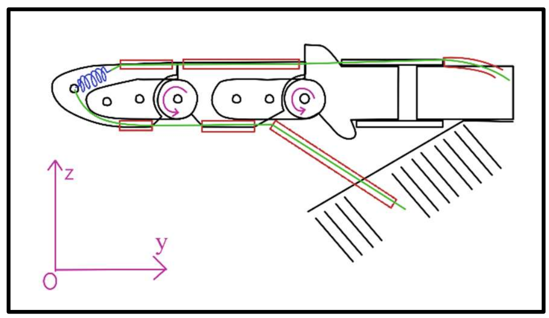

Figure 6. Thumb finger top view

The thumb operates in a manner analogous to the index finger, with the primary distinction being its ability to rotate in two different planes. When analyzed within a 3D coordinate system, as illustrated in Figure 3, it can be observed that the distal interphalangeal (DIP) and metacarpophalangeal (MCP) joints rotate within the zOy plane, while the carpometacarpal (CMC) joint rotates within the xOy plane.

2.3. Arduino components and wiring

To actuate the fingers, five MG90S servo motors were used. Object detection was facilitated using an ultrasonic sensor (HC-SR04), which offers superior adaptability compared to infrared (IR) sensors, as it functions reliably across a wide range of environmental conditions. Motion detection was implemented using an SW-420 vibration sensor, while the HC-05 module enabled Bluetooth communication between the prosthetic hand and a smartphone. The system is powered by an external phone battery, ensuring portability and convenience.

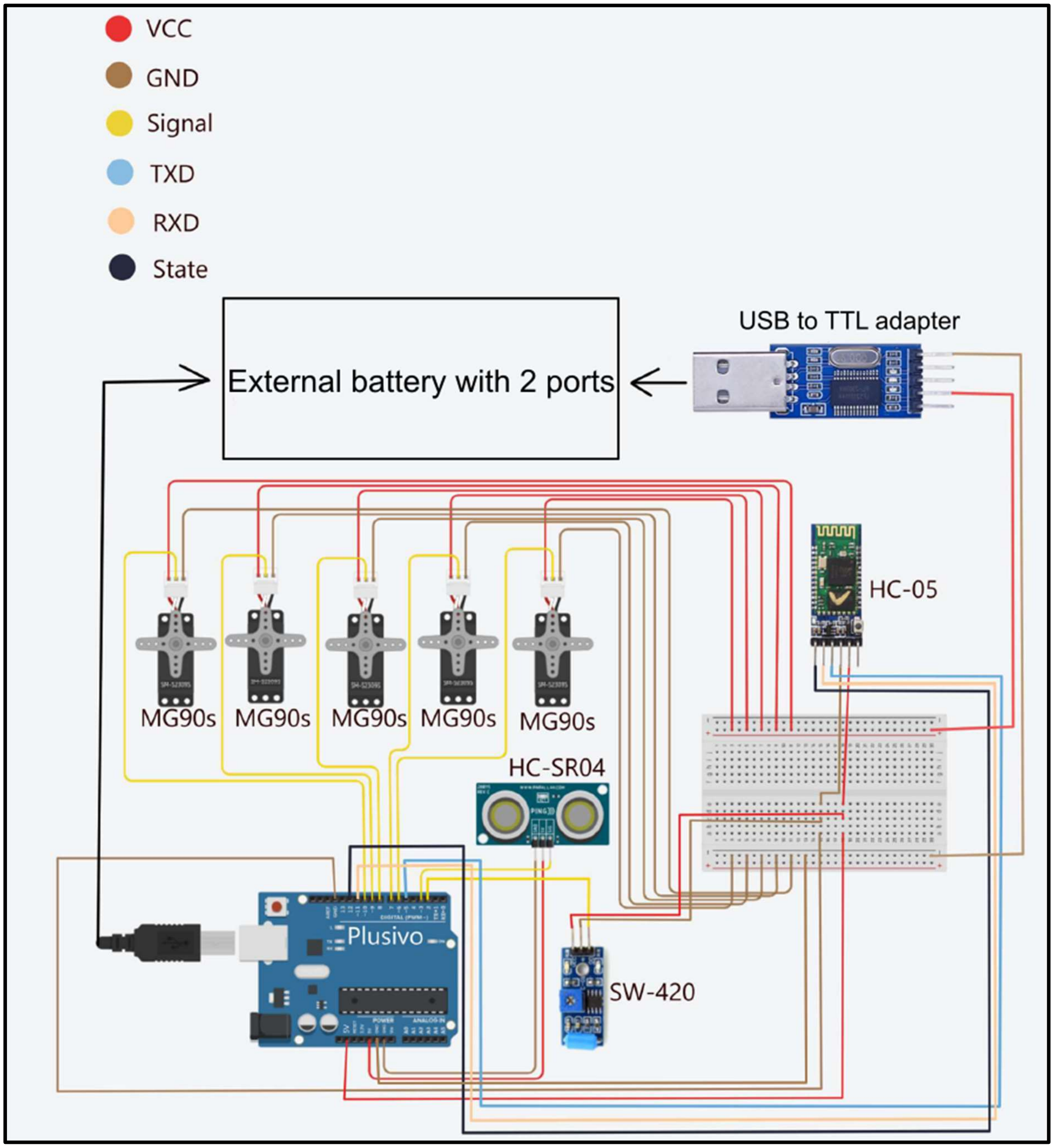

Figure 7. Wiring diagram

2.4. Arduino code

To program the Arduino board, the C++ programming language was utilized. In summary, the program processes data received from the Bluetooth module. If the received message is 1 or no information is received, the hand operates in automatic mode. If the message is 2, the hand closes, while a message of 3 prompts the hand to open. For a five-digit number, each digit corresponds sequentially to a finger, instructing it to open or close based on the respective digit's value.

In automatic mode, a counter increments continuously. If an object is detected in front of the hand, or motion or vibration is sensed, the counter resets to 0, causing the hand to close or remain closed. Conversely, if the counter surpasses a predefined threshold, the hand opens.

2.5. Phone app

Following the development of the automatic mode, potential enhancements to the prosthetic hand were evaluated with a focus on maintaining cost efficiency. It was concluded that additional functionality could be achieved by leveraging a device already widely accessible to users, the mobile phone. The mobile application was developed using Flutter, with Dart and C# as the primary programming languages.

3. Final product

The Arthromech prosthetic hand can be used both with and without the application. When not connected to the app, it operates in automatic mode. To connect the Arthromech hand via the app, the device must first be paired through Bluetooth. Once successfully paired, from the first page of the app you can connect to the hand, then the application will automatically direct the user to the primary control interface for managing the prosthetic hand.

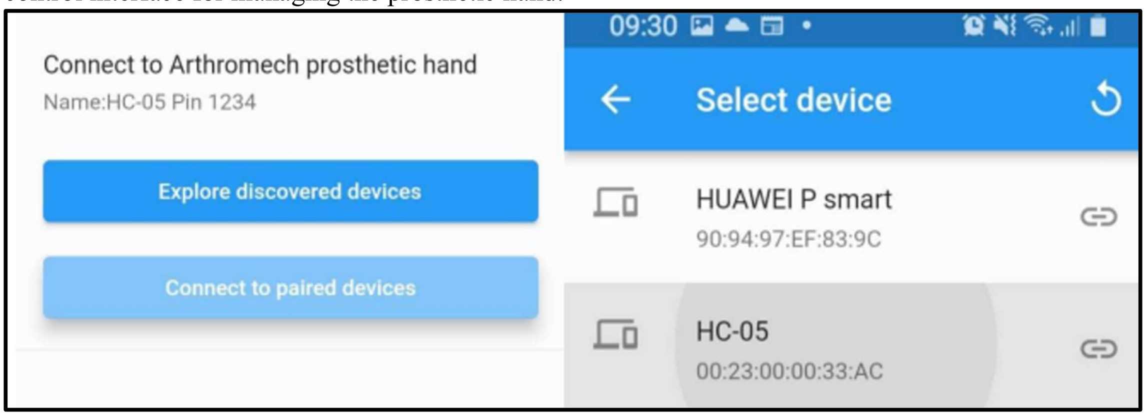

Figure 8. Phone to hand bluetooth connection interface

3.1. *Automatic mode*

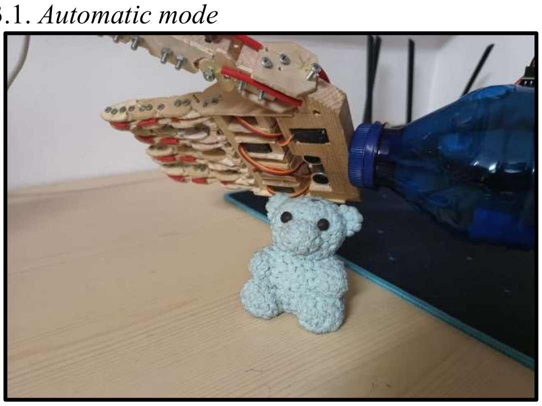

Figure 9. Hand detecting teddy bear

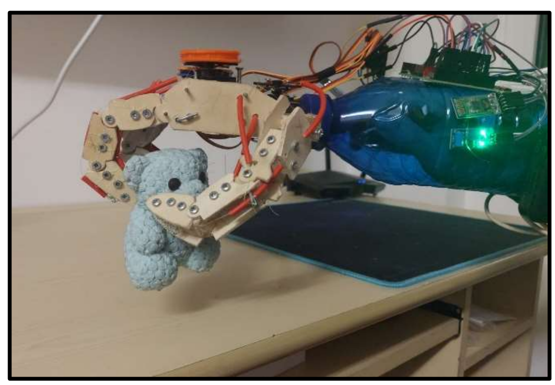

Figure 10. Hand holding teddy bear

You can select the automatic mode from the first section of the main page. This mode cannot operate concurrently with the other two. In this mode if the hand detects an object in front of it, the hand closes to grasp an object when a solid item is detected in front of it. Once the object is grasped, the hand would remain closed as long as there is detected significant movement or vibration at the hand level. When no motion is detected for a few seconds the object is released. This mode is useful for activities like brooming or taking an object from one point to another.

3.2 *Manual mode*

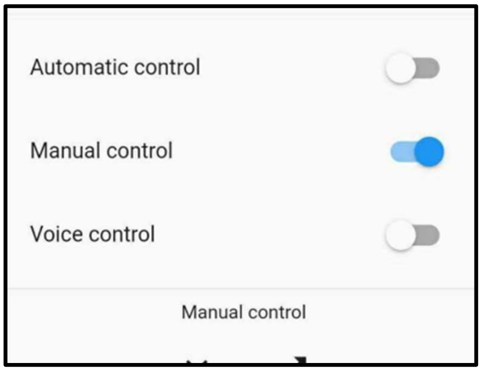

Figure 11. Selection mode section

Figure 12. Manual section

Manual mode can operate simultaneously with voice control, but not with automatic control. In this mode, the user can manually open or close the hand and control each finger individually. This is achieved by transmitting commands directly to the prosthetic via a Bluetooth connection. Manual mode is particularly useful for maintaining a secure grip on an object over extended periods, such as when holding a phone, where you don't want the device to be released when the hand is kept still.

Figure 13. Holding a phone with the hand

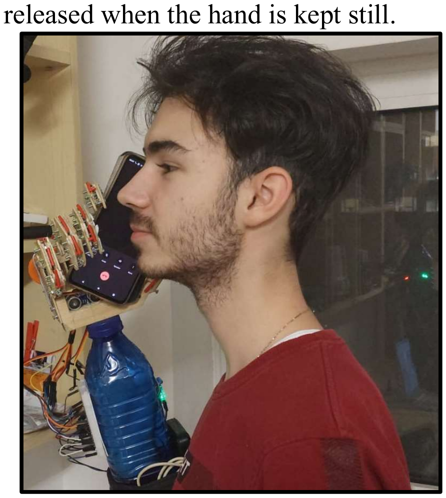

Figure 14. Using the hand for a phone call

3.3 *Voice control*

In voice control mode, the hand can be closed by saying the word "close" and opened by saying the word "open." Additionally, there is a default gesture where saying the word "look" causes the index finger to open while the other fingers close. Since the system utilizes a smartphone and an advanced speech-to-text library for Flutter, spoken words are easily detected, and the most recent words spoken are displayed beneath the microphone icon. Furthermore, the activation words and the default gesture can be modified in the dedicated voice control section. The language used for detecting words is the one that the phone is set to.

Figure 15. Voice control section

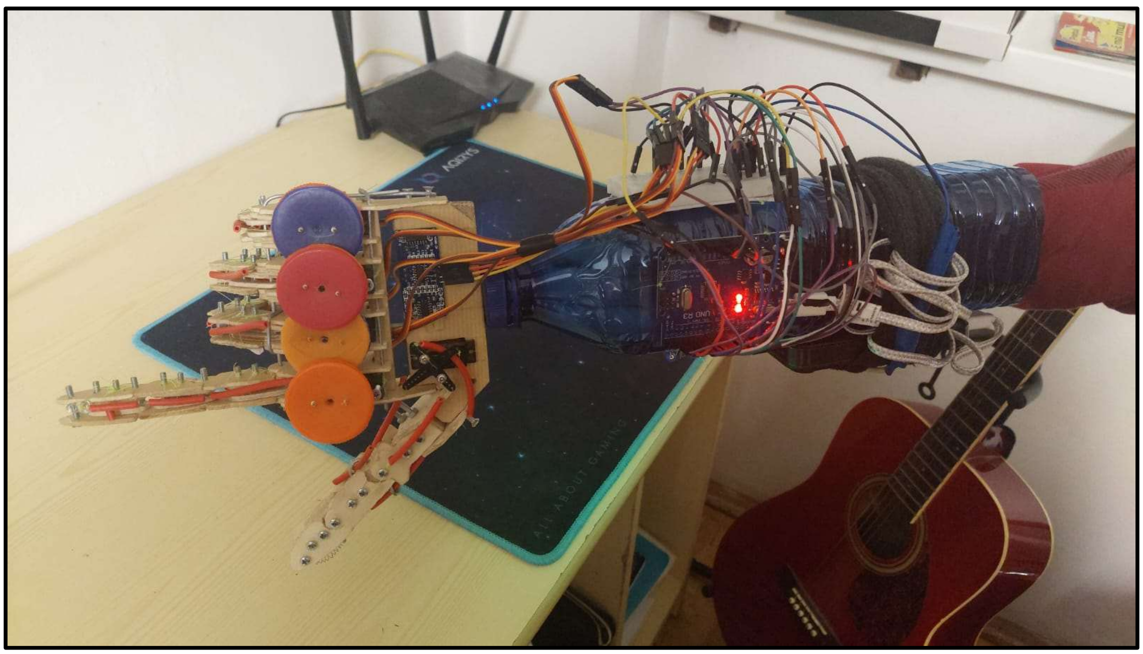

Figure 16. Hand making a gesture

4. Conclusion

The Arthromech Project is a cost-effective prosthetic hand designed specifically to address the needs of individuals with limited financial resources who may not have access to advanced prosthetic technologies. A distinguishing feature of this prosthetic is its innovative automatic mode, which plays a pivotal role in maintaining its affordability while delivering practical functionality.

The automatic mode leverages simplified yet efficient mechanisms to enable the prosthetic to perform common tasks without the need for complex or expensive components typically found in high-end prosthetics. By prioritizing accessibility and functionality, the Arthromech Project aims to empower users with an affordable solution that restores essential motor capabilities, enhancing their quality of life and enabling greater independence.