

Finger Abduction and Adduction Prosthetic Hand for Power and Precision Grasping

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I. INTRODUCTION

The human hand has 27 bones and 19 joints, and they are classified into three groups like carpals, metacarpals, and phalanges. There are eight carpals, five metacarpals, and fourteen phalanges. There is a tendon system to produce finger movements and grasping patterns in activities of daily living. With those systems, the human hand is a highly complex part of the human body that is difficult to replicate with an artificial device.

Hand amputation can happen due to various reasons, like war casualties, accidents, and neuromas. Losing a human hand through amputation ends up with mentally, physically, and socially devastating, significantly affecting the quality of life of the individual. Over the years, prosthetic hands have been developed to support hand amputees to come back to their normal lives. Different types of methods and mechanisms have been developed to replicate the human hand. However, maintaining the aesthetic view and anthropometry of the hand is challenging due to the size of the human hand. During the human hand replication, the finger movements and grasping patterns are very important. There are mainly two types of finger movements, flexion and extension (FL/EX) and abduction and adduction (AB/AD). Other than that, Retroposition and Opposition, and Bending and Flattening are some other finger movements. Using the above finger movements, the human hand is capable of different types of grasping patterns. Power, Precision, Lateral, and Extension grasps are the main grasping ranges. Power and Precision grasps cover 65% of the grasping patterns in Activities of Daily Living.

Most of the currently available prostheses are not capable of producing individual finger AB/AD motion. Due to the lack of motion patterns, the functionality of the hand prostheses is limited. The aim was to propose an abduction and adduction mechanism to fill the gap in the prosthetic hand industry. The proposed prosthetic hand is capable of individual finger AB/AD motions and covers the special grasping patterns like Tripod, Quadpod, and Squeeze, along with other common power and precision grasping patterns. The objectives of the project are to design an under-actuated finger abduction and adduction mechanism for a prosthesis. Then, develop a suitable control system to control the prosthesis and test and validate the prosthesis using experiments

II. LITERATURE REVIEW

There are different types of prosthetic hands that can be classified based on the hand amputation, like Trans radial and

Wrist Hands. However, this project mainly focuses on wrist amputees. Passive Hands, Externally Powered, Body Powered, and Hybrid versions of external and body powered are the main classifications of the prosthetic hands. Degrees of freedom (DoF), under actuation, and Shape adaptiveness are very important when selecting finger mechanisms. Different DoF mechanisms have been developed with shape-adaptive features. Prosthetic hands have been developed with various mechanisms and methods. Tendon-based systems and linkage-based systems are very common for finger mechanisms. Gear systems, pneumatic systems, fluid systems, shape memory alloy systems, and belt drive systems are some other methods and mechanisms used for prosthetic hand development. Different types of actuators have been used for prosthetic hands, like DC Brush motors, Brushless motors, Stepper motors, pneumatic artificial muscle systems, and shape memory alloy actuator systems. For controlling the prosthetic hands, basic Arduino control systems, EEG, EOG and EMG signals are used with different types of development boards like Raspberry Pi, Arduino MEGA, and Teensy.

Most of the commercial and research prosthetic hands are mainly focused on the finger flexion and extension motions. However, for the majority of the power and precision grasping patterns, finger AB/AD motion is very important. Pisa/IIT Soft Hand II[1], Dexterous Prosthetic Hand[2], TN Prosthetic Hand[3], and Adab Mora[4] Prosthetic Hands have the abduction and adduction motions. Only the TN hand has the individual finger AB/AD motions with nine linear actuators. The proposed Adab Mora 2 prosthetic hand has eight brushless DC motors and individual finger AB/AD motions as the novelty.

III. MATERIALS AND METHODS

The prosthetic hand has been designed using a 50th percentile of a human hand data set to maintain the anthropometrics of the prosthetic hand. The 1st stage of the design process was selecting existing finger FL/EX mechanisms for the fingers and designing an AB/AD mechanism for the individual AB/AD motions. A four-bar mechanism has been used for the Thumb FL/EX motion. A modified five-bar mechanism has been used for the Little, Ring, Middle, and Index fingers. The selected five-bar mechanism is a shape-adaptive and underactuated mechanism. For the AB/AD motions, Thumb has a single motor. The middle finger is considered a fixed finger and is rigidly attached to the palm. AB/AD motion of the Little, Ring, and Index fingers is covered using four systems, which are the Gear System, Clutch System, Cam System, and Spring System. The proposed gear system is a four-spur gear system with one driving gear and three driven

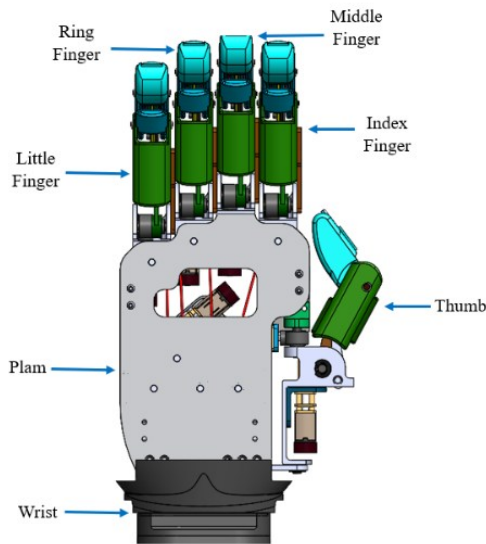


Fig. 1. Final Design of the Prosthetic Hand

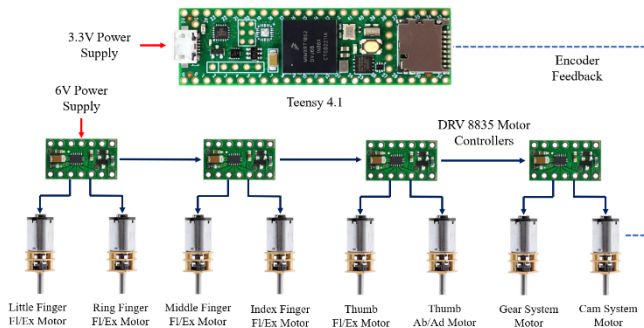


Fig. 2. Control System of the Prosthetic Hand

gears allocated for the Little, Ring, and Index fingers to run the clutch systems. Compression springs and torsion springs are used for the spring system of the hand. Each little, ring and index fingers have a separate spring to return the clutch system and fingers to their initial position. Three separate Cam parts were designed for the Little, Ring, and Index fingers. Three separate clutch parts are also allocated for the three fingers.

Eight N20 Pololu brushless DC motors have been used with four DRV8835 dual H Bridge motor controllers for the prosthetic hand control. All the motors have magnetic encoders for the position control. Each finger has one motor for FL/EX motions, and the thumb has an additional motor for AB/AD. The other three motors are allocated for the novel AB/AD mechanism. Teensy 4.1 was used for the motor control. Stainless Steel was used for the stress-critical parts after conducting the stress simulations. Aluminum and PLA plastic were used for all other parts manufacturing. For the fabrication process of the hand, CNC machining was used for the metal parts, and the 3D printing process was used for the plastic parts. Standard Screws, Miniature bearings, Worm and wheel gears are used for the final assembly of the hand.

IV. RESULTS AND DISCUSSION

The motion range of the individual fingers was measured using the Kinovea Video capturing tool. The proposed prosthetic hand covers a considerable range of motion compared to the human hand. The power and precision grasping patterns, including Sphere three-finger and Shere

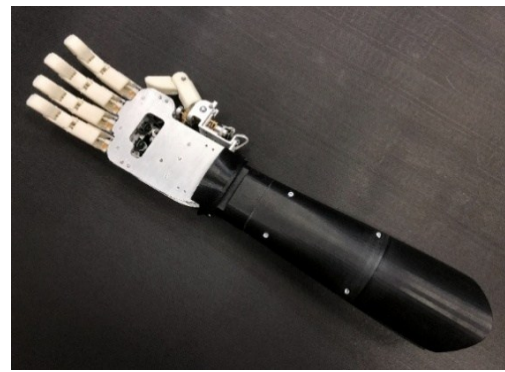


Fig. 3. Fabricated Prototype Prosthetic Hand

four-finger, were tested during the experimental validation of the hand. However, due to the practical limitations in the mechanism, the Ring and Little fingers are abducted simultaneously.

TABLE 1. RANGE OF MOTIONS OF THE HAND

Motion	Finger	Healthy Fingers (Degrees)	Developed Prosthetic Hand (Degrees)
Flexion and Extension	Little	-30 to 90	-10 to 73
	Ring	-30 to 90	-10 to 73
	Middle	-20 to 90	-10 to 73
	Index	-30 to 90	-10 to 73
	Thumb	0 to 100	30 to 90
Abduction and Adduction	Little	-25 to 20	0 to 20
	Ring	-25 to 20	0 to 20
	Middle	-25 to 20	N/A
	Index	-25 to 20	0 to 20
	Thumb	-50 to 40	0 to 90

V. CONCLUSION

The proposed prosthetic hand is an 18 DoF underactuated hand with self-adaptive fingers. Fabrication of the hand proves the anthropometric features and similarity to the natural human hand. Experimental validation of the hand for Sphere three-finger, Shere four-finger, and Squeezing proves the capability of the individual finger AB/AD motions.

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