Structural Integration and Control of Peerless Human-like Prosthetic Hand

1Ankit Dave, 2P.Muthu, 3V.Karthikraj, 4S.Latha
1,2,3 Biomedical Engineering Department, SRM Institute of Science & Technology, Kattankulathur, Chennai – 603203
4ECE Department, SRM Institute of Science & Technology, Kattankulathur, Chennai – 603203

Email: muthu.p@ktr.srmuniv.ac.in

Abstract. Limb damage can create severe disturbance in movement and operative abilities wherein the prosthetic rehabilitation has the potential to replace function and enhance the quality of life. This paper presents a humanlike prosthetic hand using such unique design concept of hand model using artificial bones, ligaments, and tendons controlled using Arduino. Amongst various platforms available, Arduino is known for its adaptability, adoration and low cost. The design of prosthetic hand has a unique structure with all carpal, metacarpal, and phalanges which are bones of the hand. These bones are attached to each other following the pattern of human hand using the polymeric rubber as a functioning ligament. Furthermore, this structure of finger is driven by tendons attached to all fingers and passes through the ligaments working as pulley resulting in more degrees of freedom. The motor can twitch the tendons to achieve the action of fingers. Thus the servos, controlled by an Arduino, are used to regulate the movement mechanism of the prosthetic hand.

Keywords: Prosthetic hand, bone, motor, Arduino, rehabilitation

1. Introduction

There are number of patients who are having disability of hand because of accidents, traumatic injury or neurological damages. In India, it has been assessed that 1.5 million people face the problem of stroke each year based upon a yearly occurrence of stroke in an average of 140 per 100,000, and 500,000 people living with stroke-related disabilities. The long-term significances of stroke on people in India, mainly in rural areas, are expected to be noteworthy. [1]. In this type of cases patient suffer from partial or total absence of hand action, eventually that can affect the daily living activities and reduces the quality of life. The high intensity and task explicit upper limb treatment comprising of active and highly tedious movement is one of the most operative method to arm and hand function refurbishment [2].

The existing technology in manufacturing of the prosthetic hand has variety such as earlier used prosthetic hand made up of fibers, iron, steel, copper, wood. While the modern era’s myoelectric prosthetic hands are made up with plastic, aluminum and composite materials to make it lighter in weight and much flexible as well as functional. But these all inventions of prosthetic hand also do not fulfill the full functionality of hand and more degree of freedom.
Several earlier research works have designed prosthetic hand with more weight, high cost and reduced degrees of freedom. Hence there is a need to research on the development of prosthetic hand in overcoming the previous numerous studies with much more limitations [3-16].

2. Methodology

2.1. Anatomy of Hand

Human hand has more degrees of freedom and so the structure of hand is very complex in nature. It has overall 27 bones comprising the primary skeleton of the hand, which are congregated into carpals, metacarpals, and phalanges [17].

The wrist forms the utmost intricate joint in the body with eight carpal bones assembled in two rows with constrained motion amongst them. The wrist joint can execute different actions including abduction and adduction. The hand has five metacarpal possessing a base, a shaft, a neck, and a head. The first metacarpal bone, thumb is a shortest and most movable. The hand comprises fourteen phalanges with each digit containing three phalanges, excluding thumb which possess two phalanges [18].

The intercarpal joints are supported by intercarpal ligaments, palmar ligaments and intrinsic ligaments. All these joints are movable and moved using the tendons. Tendons are attached to bones on one end and to muscle at other end. Muscle twitches and leads to the mobility of the fingers and wrist. The thumb pulley system consists of two annular pulleys and one oblique pulley. The oblique pulley located at the proximal phalanx between the two annular pulleys averts bowstringing of the flexor tendon [19].

2.2. Biomechanics of hand and finger

Biomechanics of hand includes Power grasp and Precision grasp. Cylindrical grip, spherical grip and hook grip involving the power grasp soothes an object against the palm. Precision grasp involves the active muscles which abduct or oppose the thumb. Proximal Transverse arch, distal transverse arch and longitudinal arch balance stability and mobility in the hand. Interestingly, the proximal transverse arch is firm, whereas other two arches are bendable, and are upheld by movement in the intrinsic muscles of hand [20].

Nasrul et al., 2014 [21] obtained the torque applied at the elbow joint for normal hand by,

\[ \sum T_{\text{elbow}} = 0 \]  
\[ \sum T_{\text{elbow}} = F \cdot \text{distance} \]  

By taking elbow joint as the origin, the summation of torque at the elbow for typical hand equals to zero. The force and torque applied for body-powered prosthesis are diverged based on the mechanism of the prosthetic which employs tautness cable and shoulder control of the body.

Similarly, Vladimir et al., 2002 [22] in their study has indicated the relation between the commands and the finger forces, attained from the neural network as a matrix equation:

\[ F = wc/n + vc \]  
\[ F = wc \]  

where \( F \) is the \((4 \times 1)\) vector of the finger forces, \( w \) is the \((4 \times 4)\) matrix of weight coefficients (the matrix models interconnections among the fingers, both peripheral connections – at the muscle-tendon level – and central), \( c \) is the \((4 \times 1)\) vector of the dimensionless neural commands (a single element of the vector represents the intensity of the command sent to a given finger), \( v \) is the \((4 \times 4)\) diagonal matrix with gain coefficients that model the input–output relations for single-digit muscles, and \( n \) is the number of fingers that are envisioned to yield force. For a given \( n \), \((4)\) can be reduced to

2.3. Materials And Assembling

The major parts in making prosthetic hand are discussed as following:
Bones: Artificial bone shaped models are being prepared as base material in order to begin fabrication of the parts. These bones could be made up using the plastic. Either using the molds of hand bone shape or by using 3d printing the artificial bones are prepared in here bone models made up in molds are used [23].

Ligaments: Artificial ligaments are made up of polymeric rubber which is elastic in nature as a ligament in human hand has property of flexibility as well as elasticity. These ligaments play the major role for establishing a joint in bones as a supporting agent [24].

Tendons: The plastic strings are used as an artificial tendon. It has property of being flexible in nature but not elastic which is similar to the human hand [25].

Pulleys: Pulley in the structure of hand are having a crucial role for holding the tendon throughout finger and another major operation of it is to make fingers capable of doing flexion. Elastic bands are used as an artificial pulley.

Stepper Motor: Bipolar stepper motor is used here for functioning of prosthetic hand. It’s a stepping motor which divides a full rotation into number of equal steps. A gear is attached in an arrangement with a shaft of stepper motor which helps in achieving multiple operations [26].

Arduino: Arduino is a microcontroller device works on an ATMEGA328P controller IC. It being programmed in its own programming environment called Arduino IDE. Arduino gives controls over the analog or digital input signal and analog or digital output signal by developing the desired program [27, 28].

Assembling: All the above mention parts are attached together and initially bones are connected together with the help of artificial ligaments which is thin polymeric rubber sheet here, this material can melt easily and forms desired shape (Fig. 1). Polymeric rubber sheet is accumulated in four layers and heated using burner to make thick artificial ligaments as similar to the human ligaments (Fig. 2).
An artificial tendons are passing under pulleys and reaches to the motor on another end. Motor leads to actual action by pulling the artificial tendon downwards.

3. Arduino Interface
The Arduino IDE software will first upload the program to drive stepper motor on Arduino Uno board. The Serial monitor in the Arduino IDE software is able to give integer input from the computer. Integer input is given to the Arduino board. According to the input signal Arduino configure the output by giving signal to the ‘L293D’ (motor driver IC) which ultimately drives stepper motor. The connection of Arduino interface in (Fig 3).

![Figure 3. Circuit Diagram](image3.png)

4. Experimental Results
Developed prosthetic arm is operated by using Arduino microcontroller. The signal in the form of integer input is given to Arduino from serial monitor in Arduino IDE software. The given signal through Arduino will trigger the motor to rotate. The setup is shown in image (Fig 4).

![Figure 4. Setup of Prosthetic Hand](image4.png)

The motor rotates and thus the tendon is being pulled. The finger of prosthetic arm gives similar motion to the hand.
As shown in (Fig. 5) above all five fingers of prosthetic hand are separately pulled through a single stepper motor. Fingers hand fingers have mimicked the flexion of the human hand and gave similar degree of freedom to human hand.

5. Conclusion

The work presents unique design concept of prosthetic hand. This approach of peerless design is light in weight and less in price compare to other traditional prosthetic hands. Also the fingers can be moved like the real finger and gives maximum degree of freedom as an anthropomorphic hand. In future, this prosthetic hand can be improved to be controlled by EMG signals and on the tips of the fingers sensors can make it tactile, also electro active polymer can be used as an artificial muscle in place of motors to pull the artificial tendons.

6. References

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