J Bionic Mem 2022; 2(1): 37-43 DOI: 10.53545/jbm.2022.15

Journal of Bionic Memory Review article

Bionic hand: A brief review

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ABSTRACT

The hand is one of the most crucial organs in the human body. Hand loss causes the loss of functionality in daily and work life and psychological disorders for the patients. Hand transplantation is best option to gain most of the hand function. However, the applicability of this option is limited since the side effects and the need for tissue compatibility. Electromechanical hand prosthesis also called bionic hand is an alternative option to hand transplantation. This study presents a quick review of bionic hand technology.

Keywords: Bionic hand, design, data acquisition, control.

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Received: 2022-03-08 / Revisions: 2022-03-17
Accepted: 2022-03-22 / Published: 2022-03-25

Introduction

The hand is one of the most active organs in the human body and is responsible for many crucial functions. The hand has a complex structure to perform those functions and the central nervous system (CNS) uses about 30% of its capacity to control this complex structure. Hence the loss of hand causes an important sensory-motor deficiency for CNS [1]. In addition, loss of hand causes crucial functionality loss in daily and work lives and this situation can bring psychological disorders.

Hand transplantation is an option that allows the regaining of most of the hand functions and attempted since 1963 [1]. Successful hand transplantation can let the person to go back a normal life. But the need for tissue compatibility and the side effects limits the applicability of this method [1, 2]. After the transplantation, several side effects lead to the reamputation with a rate of %23 [3].

The Bionic hand is another option for patients suffering from hand loss. The bionic hand is an electro-mechanical device that mimics the natural hand by using the commands from the user. The form of a bionic hand is similar to the natural hand [4]. The bionic hand can also be used by the ones who are not amputated but suffers from the loss of functionality of their hands. Although the functionality of the bionic hand is not as well as the natural hand it can increase the living standard of the patient, and even let to get back to the work in some limited cases [5]. Unfortunately, bi-directional communication with CNS is very limited. In other words, transmitting the feedback signals from the bionic hand to the CNS are very restricted. The studies on feedback signals generally focus on grasping force and touch sense [6-9].

In this paper, the methods in designing the bionic hand are considered. The design of the bionic hand consists of three steps: i) mechanical design, ii) signal acquisition, and iii) control. In the rest of the paper, the steps given above are considered under separate subsections.

Mechanical Designs

A bionic hand aims to mimic the functionality of a natural hand. As given in Figure 1, a natural hand comprises of a palm, a wrist and fingers in basic. There are 8 bones in the wrist, 5 bones in the palm, 14 finger phalanxes. The phalanxes connected by joint in each finger. The natural hand has 27 degrees-of-freedom [2, 10].

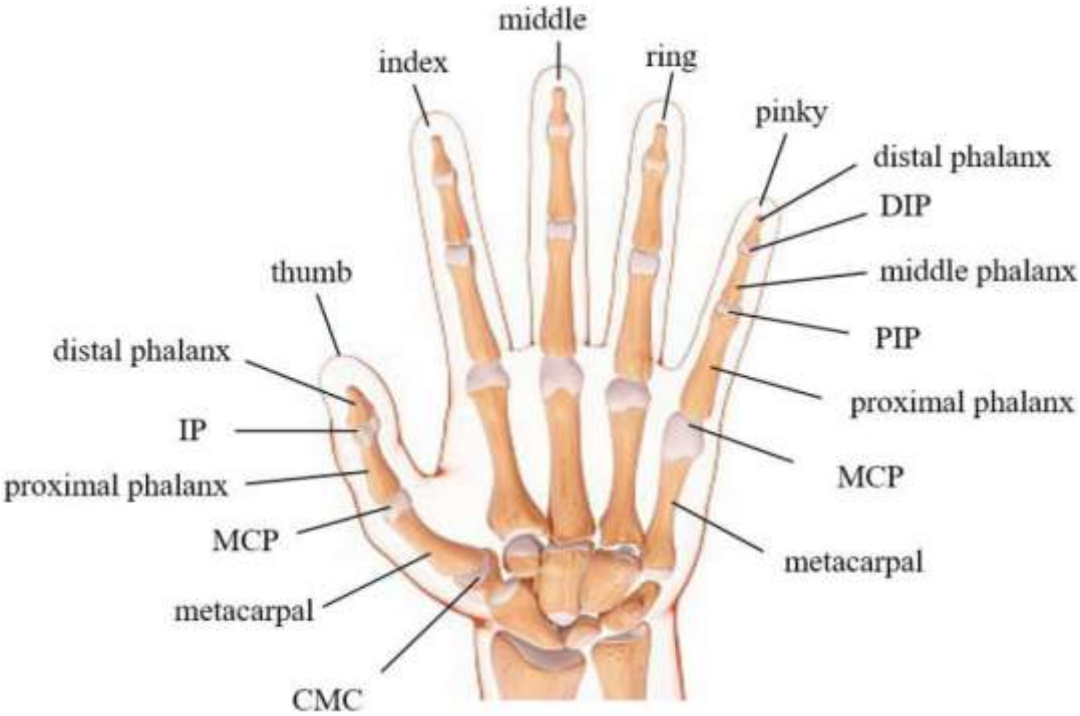

Figure 1. The structure of human hand (The figure is taken from [20]).

The bionic hands can be separated into two groups in aspect of the actuator capabilities [11]. In the first group, the underactuated hands provide simple manipulations by using actuators as few as possible. These types of bionic hands present a cost-efficient solution that provides simple grasping of the objects. In the second group, anthropomorphic designs are considered by using more actuators. The increasing number of actuators leads to more grasping strength. However, the cost of the hand also increases remarkably. The price of anthropomorphic bionic hands is as high as many people cannot have them.

There are many commercially available mechanical and mechatronic systems such as Vincent hand, bebionic hand, Michelangelo hand, I-limb hand. Some of hand types can be seen in Figure 2. A good review on prosthetic hand types can be found in [10, 12].

Aside from the commercial ones, there are many studies in the literature presenting the designs of different types of mechanical hands [10, 12-19]. Also, free 3D models for 3D printing are available on the internet to use for academic or educational purposes. In Figure 3, an example of an open source 3D printed hand is given.

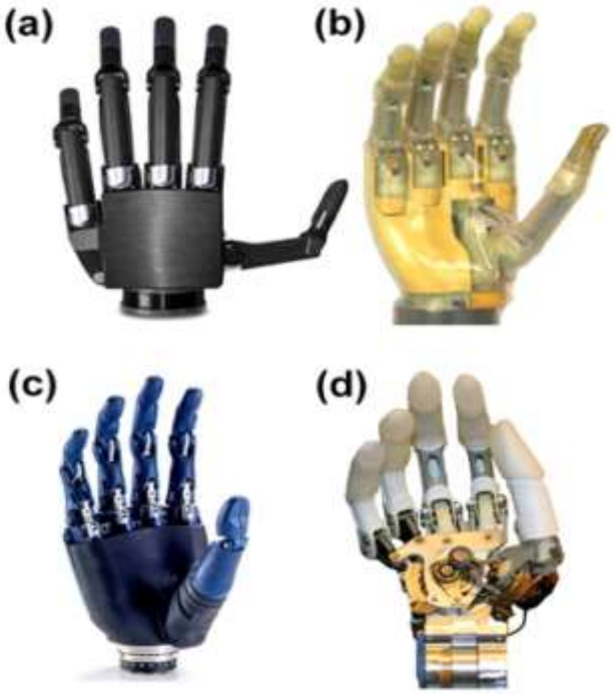

Figure 2. Hand types: a) Vincent hand by Vincent Systems, b) I-limb hand by Touch Bionics c) Bebionic hand by RSL Steeper d) Michelangelo hand by Otto Bock [12].

Figure 3. Open-source 3D hand model [10].

Signal Acquisition

In signal acquisition, the first step is collecting signals from user by using invasive or noninvasive techniques. Invasive methods use sensor array/electrode directly implanted to the nerves whereas noninvasive methods mostly use vibrotactile and electrotactile stimulations by using myoelectric sensors [1, 2, 21-24]. The sensor placements for invasive and noninvasive cases are given in Figures 4 and 5, respectively. A good list and comparison of invasive and noninvasive signal acquisition methods can be found in [2, 25].

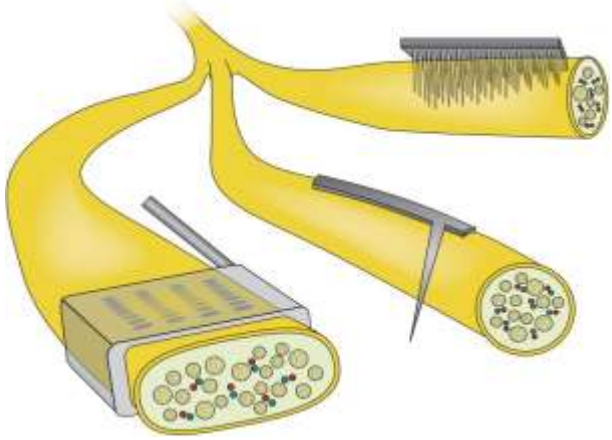

Figure 4. Placement of electrodes on the nerve (The figure is taken from [28]).

The signal acquired from the CNS is subjected to amplification, filtering, and feature extraction processes to obtain the useful features from the signal [26]. All those processes should be performed on hardware on the bionic arm to satisfy the mobility of the user. Since that high-performance microcontrollers and low noise analog devices are used. After the features are extracted, the classification methods are used to classify the features. In this way, commands from the user are defined. Then the commands are converted into continuous signals by using regression algorithms [2, 23-25, 27].

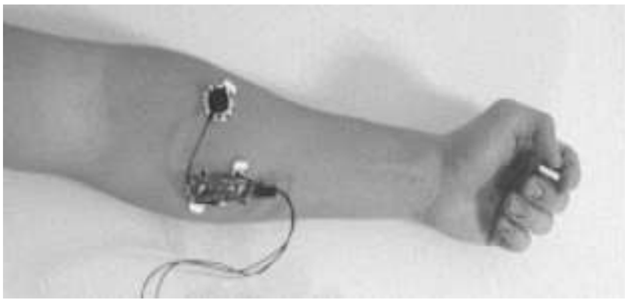

Figure 5. Placement of surface electrodes on the arm (The figure is taken from [23]).

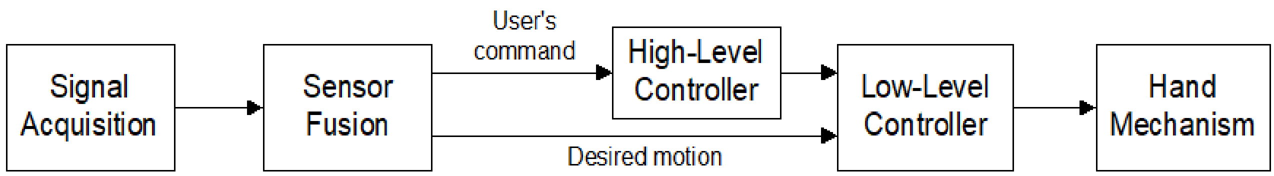

Figure 6. Bionic hand control block diagram [29].

Control Techniques

The purpose of the control is to provide the bionic hand to move in line with the user's commands by considering the mechanical limitations [29, 30]. The controller is composed of two parts: high-level controller and low-level controller. The high-level controller decides which action will be taken by using classification output. The low-level controller provides the stability of the action. For instance, the high-level controller decides the desired grasp and the low-level controller provides the stability of the grasp [2, 29, 31]. The low-level controller is also responsible for avoiding the slip or damage of the target object by using feedback signals. In the low-level controller, P, PD, or PID control methods are generally preferred because of their simple structure and efficiency [29, 31-33]. A block diagram of bionic hand control system is given in Figure 6. In the literature, there are many studies on prosthetic hands which propose different control techniques [20, 29, 31-51].

Conclusions

Hand loss causes crucial functionality loss in human life. The bionic hand has an important role to gain some of those functionalities. By developing the technology, the bionic hands continue to gain new features which increase the user's life quality. In this study, a quick review of bionic hand technology was presented. The bionic hand technology was introduced and the crucial design parts of the bionic hand which are mechanical design, signal acquisition, and control, were considered briefly.

Funding: *The author(s) received no financial support for the research, authorship, and/or publication of this article.*

Conflict of Interest: *The authors declare that they have no conflict of interest.*

Ethical statement: *Since this research is a review study, no ethics committee decision was required.*

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