

Bionic hand: A brief review

Alper Bayrak,  Erdal Bekiroglu 

Department of Electrical and Electronics Engineering, Bolu Abant Izzet Baysal University, Bolu, Turkey

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.

 Alper Bayrak, Ph.D., Associated Prof.
Department of Electrical and Electronics Engineering,
Bolu Abant Izzet Baysal University, Bolu, Turkey
E-mail: alperbayrak@ibu.edu.tr

Received: 2022-03-08 / Revisions: 2022-03-17

Accepted: 2021-03-22 / 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 phalanges. The phalanges connected by joint in each finger. The natural hand has 27 degrees-of-freedom [2, 10].

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

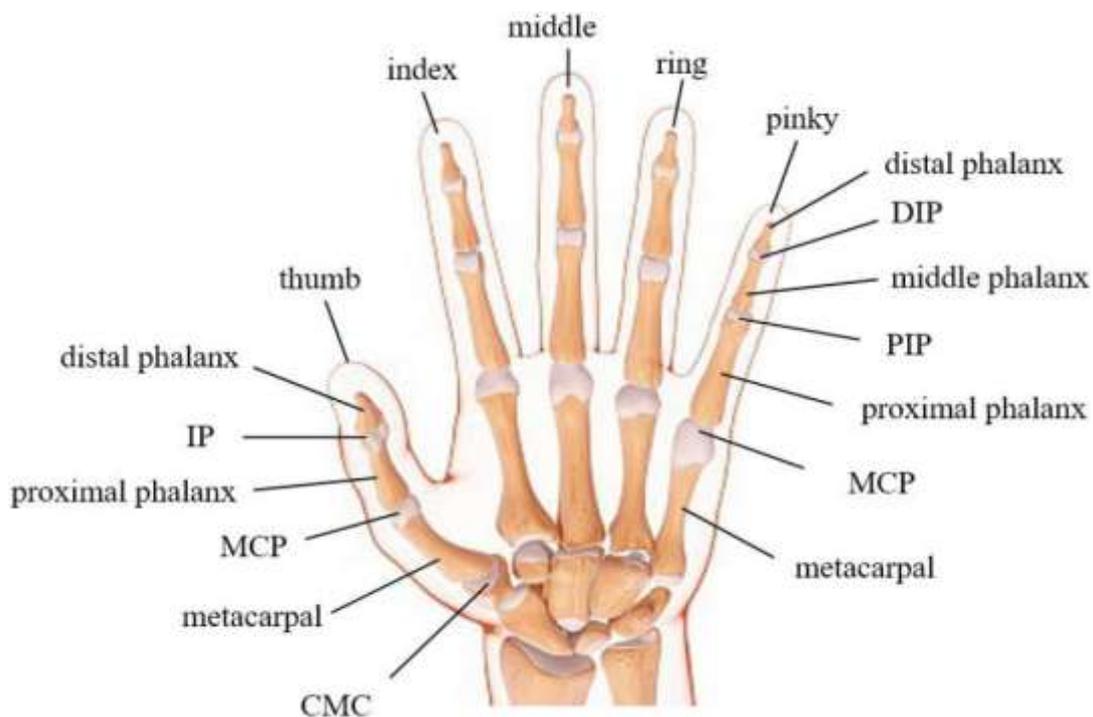


Figure 1. The structure of human hand (The figure is taken from [20]).

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

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.

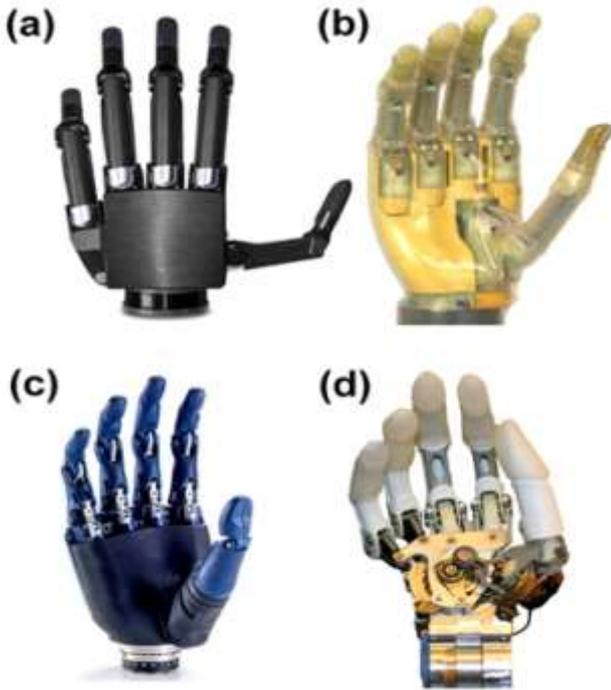


Figure 2. Hand types: a) Vincent hand by Vincent Systems, b) I-limb hand by Touch Bionics c) Bebionic hand by RSL Steeper d) Michelangelo hand by Otto Bock [12].



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].

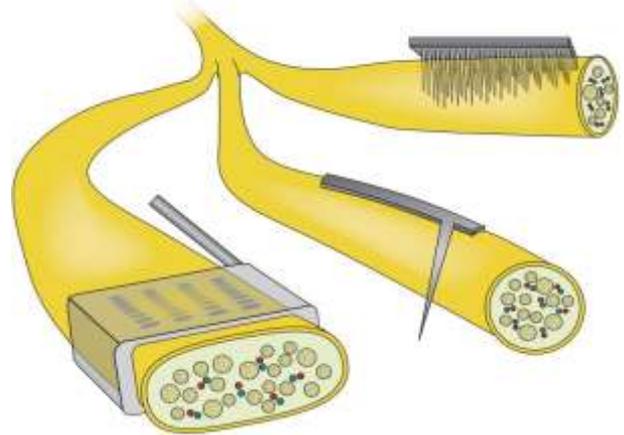


Figure 4. Placement of electrodes on the nerve (The figure is taken from [28]).

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]).

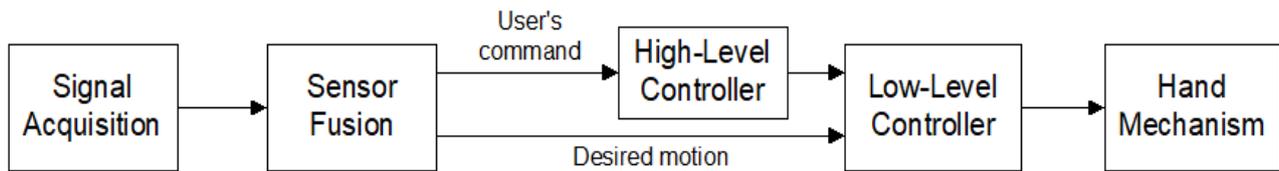


Figure 6. Bionic hand control block diagram [29].

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.

Open Access Statement

This is an open access journal which means that all content is freely available without charge to the user or his/her institution under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0>). Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles, without asking prior permission from the publisher or the author.

Copyright (c) 2021: Author (s).

References

- [1] Aman M, Sporer ME, Gstoettner C, et al. Bionic hand as artificial organ: Current status and future perspectives. *Artif Organs*. 2019;43(2):109-118.
- [2] Basumatary H, Hazarika SM. State of the art in bionic hands. *IEEE Trans Hum Mach Syst*. 2020; 50(2):116-130.
- [3] Shores JT, Brandacher G, Lee WA. Hand and upper extremity transplantation: an update of outcomes in the worldwide

- experience. *Plast Reconstr Surg.* 2015; 135(2):351-360.
- [4]Kakoty NM, Hazarika SM. A biomimetic similarity index for prosthetic hands, in: 2013 IEEE Symposium on Computational Intelligence in Rehabilitation and Assistive Technologies (CIRAT). 2013:32-39.
- [5]Jang CH, Yang HS, Yang HE, et al. A survey on activities of daily living and occupations of upper extremity amputees. *Ann Rehabil Med.* 2011;35(6); 907-21.
- [6]Abbass Y, Saleh M, Dosen S, et al. Embedded electrotactile feedback system for hand prostheses using matrix electrode and electronic skin. *IEEE Trans Biomed Circuits Syst.* 2021;15(5):912-25.
- [7]Svensson P, Wijk U, Bjorkman A, et al. A review of invasive and non-invasive sensory feedback in upper limb prostheses. *Expert Rev Med Devices.* 2017;14(6):439-47.
- [8]Schofield JS, Evans K.R, Carey JP et al. Applications of sensory feedback in motorized upper extremity prosthesis: a review. *Expert Rev Med Devices.* 2014;11(5):499-511.
- [9]Rossi M, Bianchi M, Battaglia E, et al. Hapro: A wearable haptic device for proprioceptive feedback. *IEEE Trans Biomed Eng.* 2019; 66(1):138-49.
- [10]Fourie R Mechanical design of a biologically inspired prosthetic hand, the touch hand 3. Master's thesis, University of KwaZulu-Natal, Durban, July 2017.
- [11]Jamil MFA, Jalani J, Ahmad A, et al. An overview of anthropomorphic robot hand and mechanical design of the anthropomorphic red hand a preliminary work. *Conference Towards Autonomous Robotic Systems, Springer.* 2015:13-18.
- [12]Belter JT, Segil JL, SM B. Mechanical design and performance specifications of anthropomorphic prosthetic hands: a review. *J Rehabil Res Develop.* 2013;50(5):599.
- [13]Ghanbari A, Solaimani R, Rahmani A, et al. Design and simulating finger robot hand to grasp spherical objects. *Life Sci J.* 2013;10(3):140-145.
- [14]Mamura N. Development of an articulated mechanical hand with enveloping grasp capability. *J Robot Mechatron.* 2007; 19(3):1-5.
- [15]Shahid T, Khan US. Design of a low cost multi degree of freedom hand exoskeleton. *International Conference on Robotics and Emerging Allied Technologies in Engineering, IEEE.* 2014:312-316.
- [16]Toole KTO, Grath MM. Mechanical design and theoretical analysis of a four fingered prosthetic hand incorporating embedded SMA bundle actuators. *IJMEMS.* 2007;1(2):83-90.
- [17]Zhang W, Yang Y, Sun F, et al. Mechanical design and tactile sensing in dexterous robot hands manipulation. *Cognitive Systems and Signal.* 2017; 710:52-61.
- [18]Berceanu C, Tarni D. Mechanical design and control issues of a dexterous robotic hand. *Advanced Materials Research.* 2012:463;1368-1271.
- [19]Vulliez P, Gazeau JP, Laguillaumie P, et al. Focus on the mechatronics design of a new dexterous robotic hand for inside hand manipulation. *Robotica.* 2018;36(8);1206-1224.
- [20]Teng Z, Xu G, Liang R, et al. Design of an underactuated prosthetic hand with flexible multi-joint fingers and EEG-based control. *IEEE International Conference on Cyborg and Bionic Systems.* 2018;647-651.
- [21]Bensmaia SJ. Biological and bionic hands: natural neural coding and artificial perception. *Philosophical Transactions of*

- the Royal Society B: Biological Sciences. 2015;370:1-10.
- [22] Micera S, Carrozza M, Beccai L, et al. Hybrid bionic systems for the replacement of hand function. *Proceedings of the IEEE*. 2006;94(9):1752-1762.
- [23] Russo RE, Fernandez JG, Rivera RR, et al. Revuelta, Algorithm of myoelectric signals processing for the control of prosthetic robotic hands. *Journal of Computer Science and Technology*. 2018;18(1):28-34.
- [24] Hudgins B, Parker P, Scott RN. A new strategy for multifunction myoelectric control. *IEEE Transactions on Biomedical Engineering*. 1993;40(1):82-94.
- [25] Englehart K, Hudgins B, Parker PA. Time-frequency based classification of the myoelectric signal: static vs. dynamic contractions. *International Conference of the IEEE Engineering in Medicine and Biology Society*. 2000;1:317-320.
- [26] Snajdarova M, Barabas J, Radil R, et al. Proof of concept EMG controlled prosthetic hand system-an overview. *19th International Conference Computational Problems of Electrical Engineering, IEEE*. 2018:1-4.
- [27] Englehart K, Hudgin B, Parker PA. A wavelet-based continuous classification scheme for multifunction myoelectric control. *IEEE Transactions on Biomedical Engineering*. 2001;48(3):302-311.
- [28] Bensaïa SJ, Tyler DJ, Micera S. Restoration of sensory information via bionic hands. *Nature Biomedical Engineering*. 2020:1-13.
- [29] Novak D, Riener R. A survey of sensor fusion methods in wearable robotics. *Robotics and Autonomous Systems*. 2015; 73:155-170.
- [30] Deng H, Zhong G, Li X,. Slippage and deformation preventive control of bionic prosthetic hands. *IEEE/ASME Transactions On Mechatronics*. 2016;22(2):888-897.
- [31] Cipriani C, Zaccone F, Micera S, et al. On the shared control of an EMG-controlled prosthetic hand: analysis of user prosthesis interaction. *IEEE Transactions on Robotics*. 2008;24(1):170-184.
- [32] Zhiming Y, Tian Y, Zhuojun X, et al. Co-simulation and control algorithm of intelligent bionic hands with multi-degree of freedom. *9th IEEE Conference on Industrial Electronics and Applications, IEEE*. 2014: 639-644.
- [33] Deng H, Luo H, Wang R, et al. Grasping force planning and control for tendon-driven anthropomorphic prosthetic hands. *J Bionic Eng*. 2018; 15(5):795-804.
- [34] Zhao J, Xie Z, Jiang L, et al. Hirzinger, Emg control for an fingered prosthetic hand based on wavelet transform and autoregressive model. *International Conference on Mechatronics and Automation, IEEE*. 2006:1097-1102.
- [35] Chen CH, Naidu DS. Fusion of fuzzy logic and pd control for a five fingered smart prosthetic hand. *IEEE International Conference on Fuzzy Systems*. 2011: 2108-15.
- [36] Yanagisawa T, Hirata M, Saitoh Y, et al. Real-time control of a prosthetic hand using human electrocorticography signals. *J Neurosurg*. 2011;114(6):1715-22.
- [37] Jafarzadeh M, Hussey DC, Tadesse Y. Deep learning approach to control of prosthetic hands with electromyography signals. *IEEE International Symposium on Measurement and Control in Robotics, IEEE*. 2019:1-4.
- [38] He Y, Fukuda O, Yamaguchi N, et al. Novel control scheme for prosthetic hands through spatial understanding. *International Journal of Advanced Computer Science and Applications*. 2020;11(10): 719-725.

- [39]Zhang T, Jiang L, Liu H. A novel grasping force control strategy for multi- fingered prosthetic hand. *Journal of Central South University*. 2012;19(6):1537-1542.
- [40]Li QM, Lv YP. A fuzzy PID control method for the grasping force of an underactuated prosthetic hand. *Applied Mechanics and Materials*. 2014;551:514-522.
- [41]Mangieri E, Ahmadi A, Maharatna K, et al. A novel analogue circuit for controlling prosthetic hands. *IEEE Biomedical Circuits and Systems Conference, IEEE*. 2008:81-84.
- [42]Chen CH, Naidu DS, Perez Gracia A, et al. A hybrid adaptive control strategy for a smart prosthetic hand. *Annual International Conference of IEEE Engineering in Medicine and Biology Society, IEEE*. 2009:5056-5059.
- [43]Li XF, Duan XG, Deng H. Hybrid slip detection scheme based re ex control of a prosthetic hand. *Applied Mechanics and Materials*. 2013; 433:85-92.
- [44]Li X, Huang Q, Zhu J, at al. A novel proportional and simultaneous control method for prosthetic hand. *J Mechanics Med Biol*. 2017;17(8):1750-1760.
- [45]Duan XG, Zhang Y, Deng H. A simple control method to avoid overshoot for prosthetic hand control. *IEEE International Conference on Information and Automation, IEEE*. 2014:736-739.
- [46]Yagiz N, Arslan YZ, Hacıoglu Y. Sliding mode control of a finger for a prosthetic hand. *JVC*. 2007;13(6):733-49.
- [47]Chen CH, Naidu DS, Gracia PA, et al. Hybrid control strategy for fingered smart prosthetic hand. *Proceedings of the 48h IEEE Conference on Decision and Control, IEEE*. 2009:5102-5107.
- [48]Zhu GK, Duan XG, Deng H. Adaptive fuzzy pid force control for a prosthetic hand. *Applied Mechanics and Materials*. 2013; 433:93-101.
- [49]Duan XG, Luo HX, Deng H. Multivariable fuzzy control for prosthetic hands. *International Conference on Manufacturing Science and Engineering*. 2015:471-478.
- [50]Deng XB, Duan XG, Deng H. Disturbance observer based fuzzy control for prosthetic hands. *International Conference on Intelligent Robotics and Applications*. 2015:338-347.
- [51]Luo HX, Duan XG, Deng H. An intelligent control for prosthetic hand. *International Conference on Manufacturing Science and Engineering, Atlantis*. 2015:465-470.