

## Design and Development of a Mind-controlled Prosthetic Hand Using Electroencephalography Sensor

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### Abstract

*The aim of this study is to develop a prosthetic hand in such a manner that the cost of production is drastically reduced and to make modern prosthesis available to people of third world countries. In this study, different designs are considered and compared to identify the suitable one. Also a new approach of using electroencephalography (EMG) sensor to control the prosthetic hand is introduced. This non-invasive technique allows detecting the attention level of human mind to activate the prosthetic hand and use it to grab or release an object. The possibility of eliminating surgery for prosthetic hand attachment is also investigated.*

**Keywords:** Prosthetic Hand, Electroencephalography, Brain signals, Beta wave

### 1. Introduction

Many studies have been conducted for developing the design of human prosthetic hand. The development of modern prosthetic hand began with the invention of prosthetic hook by David Dorrance in 1912. It uses body power to open and close the hand to pick up an object. Since then, many designs were proposed for better efficiency and performance. Doshi, Yeh and LeBlanc designed a gloveless endoskeletal prosthetic hand in 1998 [1]. Massa, Roccella, Carrozza and Danio developed an underactuated prosthetic hand in 2002 which proposed a better degree of freedom of the hand [2]. Laurentis and Mavroidis developed a prosthetic hand which was shape memory alloy actuated [3]. Anthropomorphic artificial hand for prosthesis was proposed by Zollo, Roccella, Guglielmelli, Carrozza and Danio in 2007 [4]. Later, Dalley, Wiste, Withrow and Goldfarb designed a multifunctional anthropomorphic prosthetic hand with extrinsic actuators [5]. Also, most studies on prosthesis were based on EMG-based control but very few studies were conducted on the use of EEG brain signals for prosthetic hand control. Gagar, Harkam, Hertnaes and Pfurtscheller proposed prosthetic control by EEG-based human-computer interface in 1999 [6]. Mahmoudi and Irfanian then developed a single-channel EEG-based prosthetic hand grasp control for amputee subjects [7]. Our study is a unique approach where the human-computer interface is not required for prosthetic hand control; rather a microcontroller-based system is used for this purpose. Again, instead of using all EEG brain signal patterns, a specific brain wave called Beta wave, which is related to the attention level of human mind, was tracked with the electroencephalography sensor. The activity level of brain is measured with the help of Beta wave and this level is used to control the prosthetic hand.

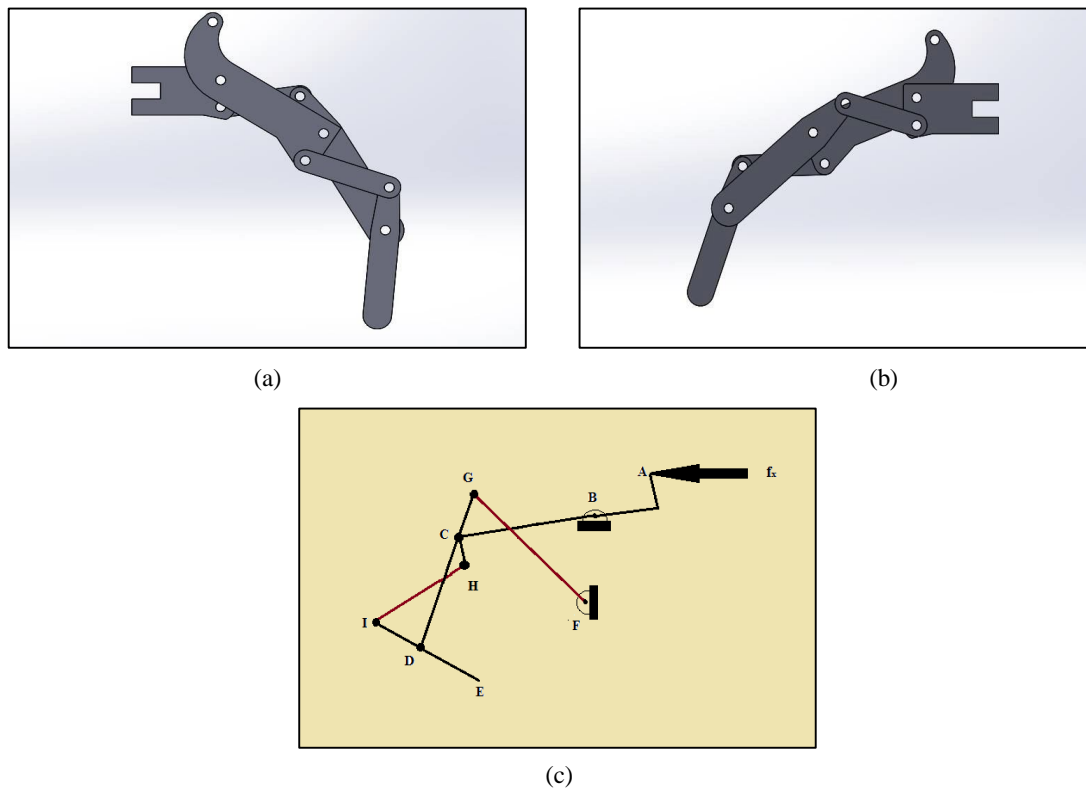
### 2. Design considerations

While developing a suitable design for prosthetic hand, the first and foremost task is to design the fingers of the hand since the design of the fingers largely influence the number of motors used in the hand, thus cost of the total project. In this project, linkage mechanisms are utilized while designing the fingers so that only one motor is required to drive each finger. This highly limits the degrees of freedom of the finger segments but it also makes reduces the cost of the hand. In our study, three different possible designs of finger are presented and compared for advantages and disadvantages.

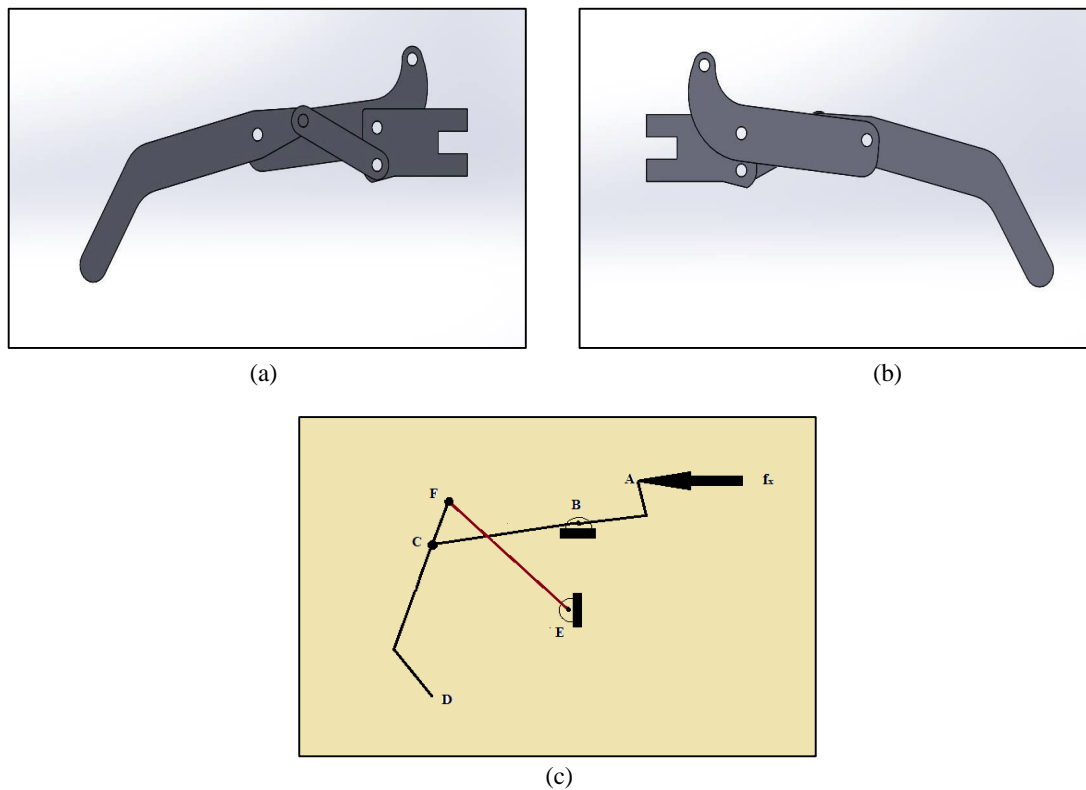
The first type of design of finger assembly with its kinematic diagram is shown in Fig. 1. From the figure, it is observed that the three finger segments ABCH, GCD and IDE are connected at points C and D. Also the three segments are interconnected with the help of two links FG and HI. These links make the movement of each segment interdependent. Thus using only one motor to apply force on extension A will allow the whole finger to create a curved shape and grab an object. So, the use of one motor for each finger is possible with this design.

The drawback of the design is that due to too many links and connections, it becomes extremely hard to avoid pressure development on the joints. Again, the design is such that one of the links is connected at a point H which is below the segment BC and CD. This extended part creates problems while grabbing an object.

To avoid this problem and keeping in mind that the topmost segment of the finger contributes very little on the overall force exerted for grabbing an object, the second type of design is suggested which is shown in Fig. 2



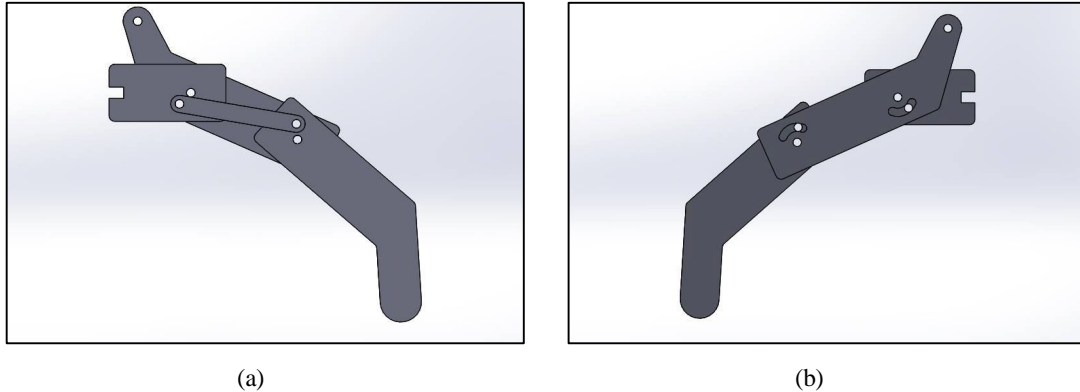
**Fig. 1.** Finger design of type 1; (a) left hand side view, (b) right hand side view, (c) kinematic diagram



**Fig. 2.** Finger design of type 2; (a) left hand side view, (b) right hand side view, (c) kinematic diagram

In this design, the second and third segments of the finger are merged to form one single segment. So the number of segments is practically reduced to two, ABC and FCD and only one link is required which is EF. This not only solves the problem of interruptions while grabbing but also improves the performance of the hand. In the first design, due to too many links the power losses are greater. But in case of second design, these losses are much less.

Finally, the third type of finger design is shown in Fig. 3. This design is almost same as that of the second type but it is more compact. This is because the use of semi-circular slide ways instead of extensions at the end of the second segment has allowed the link to be placed more close to the joint between the two segments of the finger. This design can be useful because it can reduce the weight of each finger considerably. But the major drawback of the design is that the more the links are connected close to the joints, the greater is the torque required by the motor to exert sufficient force to grab an object. This is because a large force at A will be reduced to a small force at the tip of the finger due to lever mechanism.



**Fig. 3.** Finger design of type 2; (a) left hand side view, (b) right hand side view

Considering the advantages and limitations of the three designs, the second type is assumed to be appropriate for the prosthetic hand since it is a balance between the other two designs. So, in our prosthetic hand, the finger type 2 is used.

### 3. Material selection and manufacturing

The material of the prosthetic hand needs to be lightweight but strong enough to carry the load of the object. Carbon fiber is a good choice since it has both the qualities but it is very costly. Since the aim of this study is to develop a low cost prosthetic hand, plastic is a better option as material. Plastics are also lightweight and they also exhibit good strength. Also plastics can be easily processed. In our study, we have used acrylic plastic as the material which is available in the market at low price. This plastic is usually found in the form of plates or boards of different thickness. The prosthetic hand developed in this study uses 4mm thick acrylic boards.

The acrylic boards can be easily cut to desired shape in a laser cutting machine with high amount of accuracy. The laser cutting machines are provided with the two dimensional design of the parts to be cut and the machine follows the design to the scale. The machine used here has 0.25mm dimensional error. After cutting the parts in two dimensional planes, the parts are assembled to form the prosthetic hand.

### 4. Communication establishment with electroencephalography sensor

The process of communication establishment of the electroencephalography (EEG) sensor with the prosthetic hand is done through a microcontroller-based circuit. The microcontroller receives the data sent by the sensor and makes decision to operate the motors connected with each finger. For this, precompiled codes are loaded in the microcontroller. In this study, a microcontroller-based circuit called Arduino Uno is used.

The EEG sensor used in this project is manufactured by Neurosky and it is called Mindwave Mobile. The sensor is shown in Fig. 4. This sensor is a basically a headset which has three EEG probes to be placed at three different positions; one probe must touch the forehead, another at the ear and the third one at the side of the head. With the help of these probes, the sensor can measure the frequency of Beta, Gama and Delta- three different waves associated with human mind. In this study, only the Beta wave is taken into account.

Beta wave is closely related to the activity level of brain and indicated how much attentive a person is at a particular time. The frequency of the wave ranges from 12 Hz to 32 Hz. Low frequency indicates that the brain is at relaxed condition while higher frequency indicates high attention level. Mindwave mobile is provided with an in-built chip called Thinkgear which continuously interprets the frequency of Beta wave and sends a 170 bit data depending on it via Bluetooth.

The data sent via Bluetooth is received by the microcontroller with the help of a Bluetooth module that is paired with the sensor Bluetooth. Microcontroller then determines whether the person using the prosthetic hand wants to operate the hand or not. The microcontroller is coded in such a manner that if the person concentrates on an object that he wants to grab, then the microcontroller will send signal to the servo motors connected to each of the fingers. If the person wants to release the object, the person must remove his attention from the object. There is a threshold value of attention level for which the hand is activated. This threshold value is 60%. If a person has attention level more than 60%, then the prosthetic hand will be activated and the object will be picked up by the hand. The circuit diagram of the control system is shown in Fig. 5.

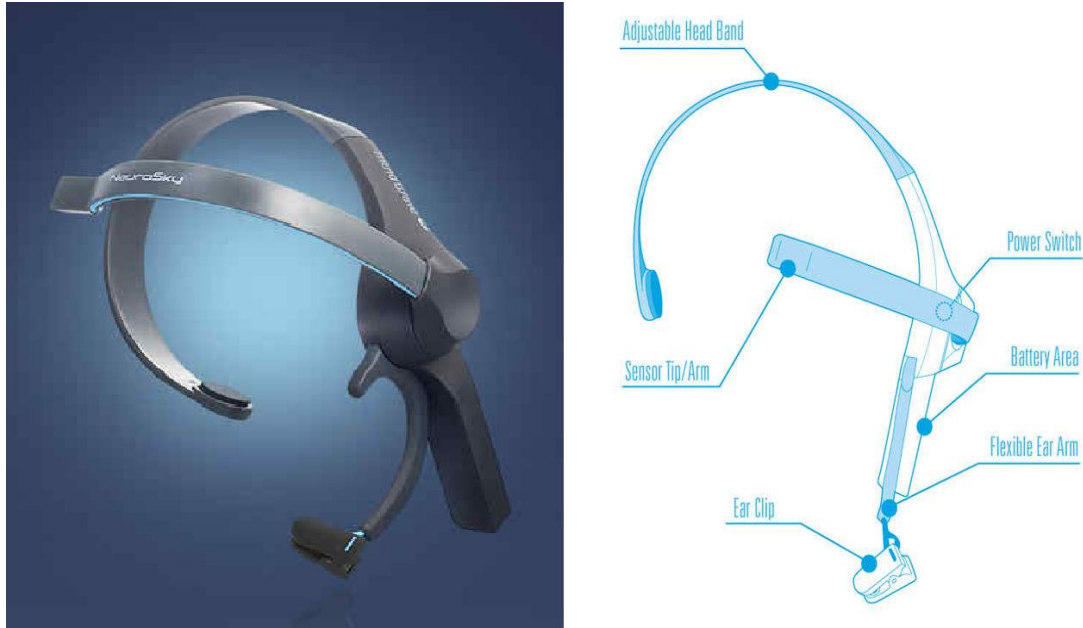


Fig. 4. EEG sensor headset

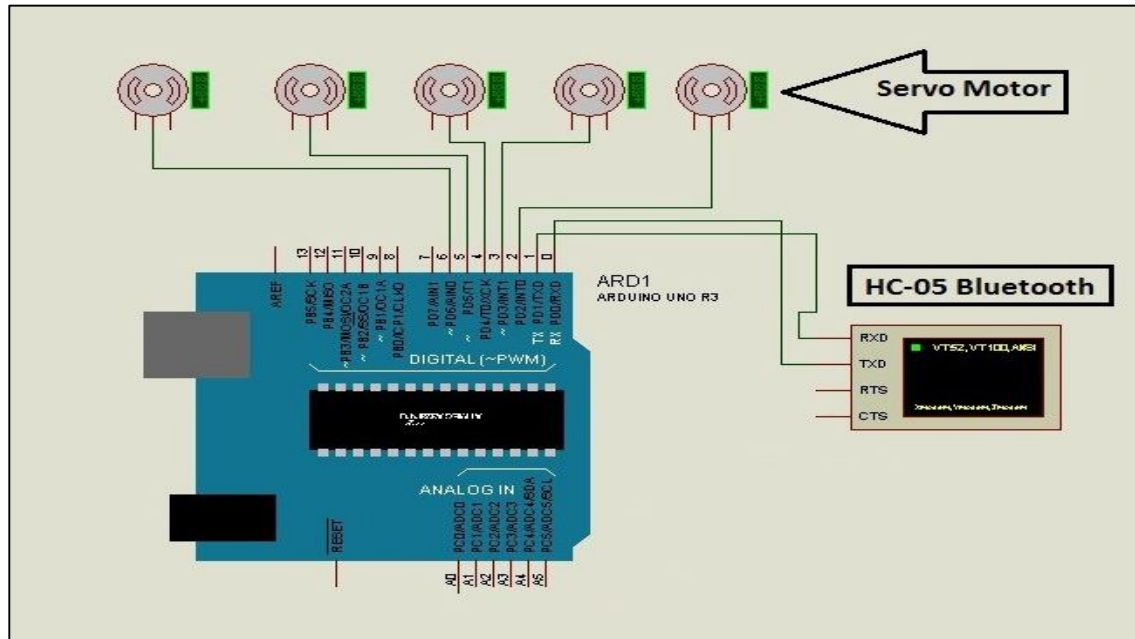
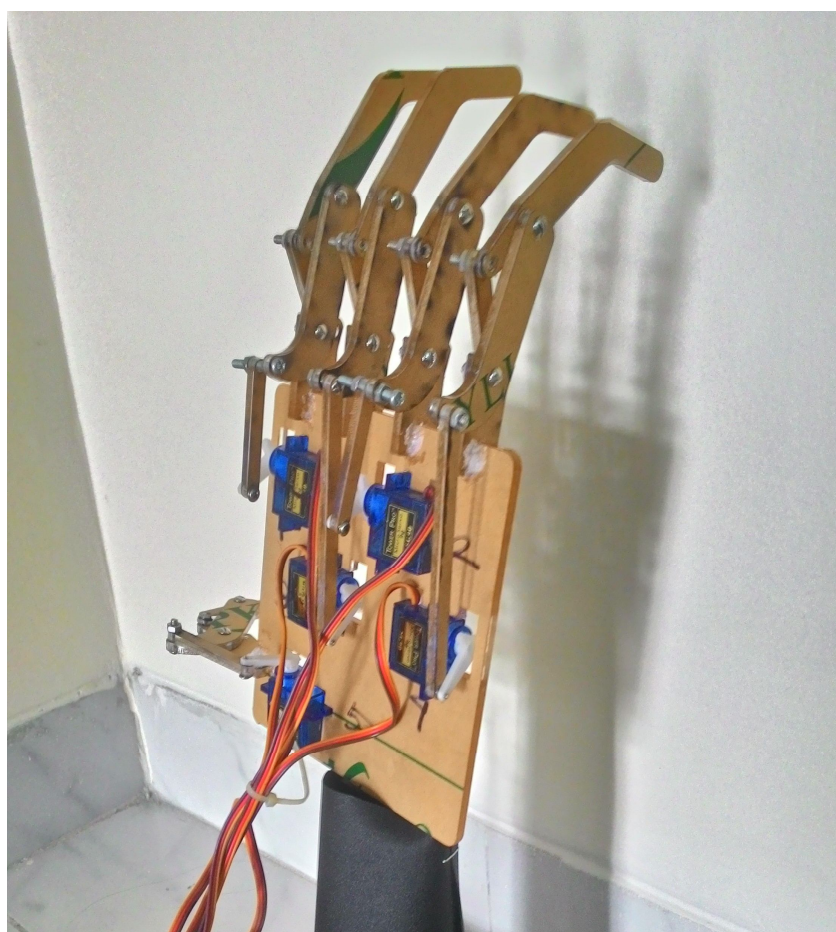


Fig. 5. Circuit diagram of the control system

The major success achieved in this study is that all the previous studies that used electroencephalography to control prosthetic hand required a human-computer interface but in our study computer has been replaced by microcontroller, thus making it portable. It has been possible since the complete EEG mapping of the brain is not done in this project to identify the EEG patterns for each movement pattern of the hand. Instead, only the attention level is measured, which reduces the amount of data to be processes, thus reducing the processor requirements. But the major drawback of this is that only one task is possible to do with the hand and that is grabbing or releasing an object. Still, the cost associated with computer interface is avoided, which makes the prosthetic hand low cost and affordable for people of third world country.

## 5. Final assembly of prosthetic hand

The fingers and motors operating the fingers are assembled together on an acrylic base. The base is cut in such a shape that there are slots for placing servo motors into specific positions. The servo motor used for each finger has a maximum torque limit of 2kg-cm. the motor horns are connected to the fingers with acrylic links. Fig. 6 shows the final assembly of the prosthetic hand.



**Fig. 6.** Final assembly of prosthetic hand

In order to connect the prosthetic hand to a person's body, a plastic structure with screws is used which is designed after taking the measurements of the person. Since EG sensor is non-invasive in nature, surgical procedures may be avoided. But this type of joint is not suitable for lifting heavy objects with the hand. So, development of the design is necessary so that it can be attached to the body permanently with surgical procedures.

The power supply of the motors and the control circuit is done with the help of four Lithium-ion batteries which are small and compact but can supply high amount of energy for a long time period. The power supply system is placed inside the plastic structure. Thus, the power supply system contributes very little to the overall weight of the assembly.

## 6. Result and conclusion

The prosthetic hand was tested on 20 persons for analyzing the performance of the hand. The sensor worked well in almost 90% cases with few exceptions. Most of the people failed to raise their concentration level high enough to activate the hand in their first trial but they were able to control the hand properly after a few more trials.

Another important thing observed is the dependence of performance of the sensor on the weather. At higher humidity or lower temperature the performance of the sensor was pretty much low.

The metal gear servo motors connected to each finger can take around 2 kg loads, but due to linked structure of the finger, almost half of the energy is lost in the mechanism. And since only four fingers mainly contribute to holding an object while the other one is for support, the prosthetic hand can lift a maximum load of 4 kg if it is permanently attached to the bones. In case of a temporary joint of the hand, it is observed that a person feels pain if he tries to lift more than half kilograms.

The use of metal gear servo motors for finger control has a major drawback. The amount of force exerted on an object cannot be varied if servo motor is used, which is the case in the prosthetic hand developed in this project. Also they take up a significant amount of space which increases the size of the hand. If the servomotors are replaced by hydraulic muscles, these problems can be solved. But use of hydraulic muscle is very costly compared to servo motors. The decision may be taken depending on the targeted people for whom the hands are manufactured.

Again the use of attention level to activate the hand has some problems since continuously concentrating on an object will not be possible if the person wants to do two things at a time. For example, after lifting a glass of water, the moment he tries to drink water, the attention on the glass will be removed, and thus the hand will release the glass. This type of situation is undesirable. To avoid this problem, the reverse design of the system can be done so that when attention is given on an object, the hand opens wide and after removing the attention the hand closes. This may be a more practical system of controlling the hand.

Finally, the major limitation of the hand is that it has only one function and that is to grab an object. But human hand can perform so much more tasks and follow so many finger patterns. But in order to achieve that, each and every pattern of brain EEG signals needs to be mapped so that the prosthetic hand can identify and follow that pattern. This will lead to high cost of the hand, thus unaffordable for people third world country. Nevertheless, further studies are required for developing a better and more human-like prosthetic hand operated by Electroencephalography.

## 7. References

- [1] R. Doshi, C. Yeh, and M. LeBlanc, "The design and development of a gloveless endoskeletal prosthetic hand", *Journal of Rehabilitation Research and Development*, Vol.35, No.4, pp. 388-395, 1998.
- [2] B. Massa, S. Roccella, M.C. Carrozza, and P. Dario, "Design and Development of an Underactuated Prosthetic Hand", *Proc. of the IEEE, International Conference of Robotics and Automation, Washington*, pp. 3374-3379, 2002.
- [3] K.J. De Laurentis, and C. Mavroidis, "Mechanical design of a shape memory alloy actuated prosthetic hand", *Technology and Health Care, IOS Press*, Vol. 10, pp. 91-106, 2002.
- [4] L. Zollo, S. Roccella, E. Guglielmelli, M.C. Carrozza and P. Dario, "Biomechatronic Design and Control of an Anthropomorphic Artificial Hand for Prosthetic and Robotic Applications", *IEEE/ASME Transactions on Mechatronics*, Vol. 12, No. 4, pp. 418-429, 2007.
- [5] S.A. Dalley T.E. Wiste, T.J. Withrow, and M. Goldfarb, "Design of a Multifunctional Anthropomorphic Prosthetic Hand with Extrinsic Actuation", *IEEE/ASME Transactions on Mechatronics*, Vol. 14, No. 6, pp. 699-706, 2009.
- [6] C Guger, W. Harkam, C. Hertnaes, and G. Pfurtscheller, "Prosthetic Control by an EEG-based Brain-Computer Interface (BCI)", *Proc. aaate 5<sup>th</sup> European Conference for the Advancement of Assistive Technology*, pp. 3-6, 1999.
- [7] B. Mahmoudi, and A. Erfanian, "Single-channel EEG-based prosthetic hand grasp control for amputee subjects", *Proc. of 2<sup>nd</sup> joint EMBS/BMES Conference*, Vol. 3, pp. 2406-2407, 2002.