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Development of a Prosthetic Hand Operated by EEG Brain Signals and EMG Muscle Signals

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Abstract: The aim of this study is to develop a low cost prosthetic hand for the people of third world countries. In most cases the prosthesis requires surgery and very costly sensors which is not feasible for poor people. So a new approach is introduced in our study where Electroencephalography sensor and Electromyography sensor is used as a combination to receive necessary brain and muscle signals respectively to operate the artificial hand. Since both types of sensors do not require any direct contact with the nerves rather skin contact only, this study has shown potential for surgery- free implantation of the hand. In our study a new linkage mechanism is utilized for controlling each finger with a single motor. Our study showed that using attention level of human mind, the prosthetic hand can be operated to grab and release objects of different size and shape within a certain weight limit. Also force exerted and finger patterns can be controlled with muscle signals.

***Keywords**:* Prosthesis; Electroencephalography; Electromyography; Brain Waves.

1. INTRODUCTION

The history of using wooden and metal hands for replacement of the original ones is very ancient. The development of the modern prosthetic hand began with the invention of prosthetic hook by David Dorrance (1912) which uses body power to open and close the hand to pick up an object. Later in 1964 Central Prosthetic Research Institution, USA which used electromyography (EMG) signals from muscles of residual limbs of a person to control the movement of the fingers. Many studies have been conducted on the use of EMG signals to control prosthetic hand since then, but the approach of using EEG signals is new. Also many studies have been conducted of developing efficient designs. Haung and Chen developed a myoelectric discrimination system for a multy degree prosthetic hand in 1999. Massa, Roccella, Carrozza and Danio developed an underactuated prosthetic hand in 2002 which proposed a better degree of freedom of the hand [2]. Boostani and Moradi studied and identified 19 EMG patterns of forearm for controlling a prosthtic hand in 2003 [3]. In 2008, used signals from position and force feedback sensors as well as myoelectric commands to control an underactuated prosthetic hand [4]. Now-a-days there are many commercially available prosthetic hands like i-limb, bebionic etc. which also utilize myoelectric signals. Our study is a combination of mind-controlled prosthesis as well as myographic prosthesis which makes it a unique approach. Again, instead of using brain signals for motor control, a specific brain wave called Beta wave, which is related to the attention of human mind is used to control the hand, which is also a new method introduced in our study.

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2. DESCRIPTIONS OF COMPONENTS

2.1. Electroencephalography (EEG) Sensor

Electroencephalography (EEG) is a non-invasive process of recording electrical activity of the brain. EEG measures voltage fluctuation due to ionic current in the neurons of the brain [5]. An EEG sensor converts these voltage fluctuations into digital output for using them in microcontroller-based or other digital circuits. There are many commercially available EEG sensors, each having different data output criteria. In this study, a commercial headset developed by Neurosky inc.(2007) named Mindwave mobile is used as the EEG sensor. This headset has three dry-type EEG electrodes which have to be in placed in specific positions of the head of a person in order to measure voltage fluctuation data of different brain waves.

Most of the brain signals observed is within the range of 1-35 Hz. These waves are subdivided into delta, theta, alpha, beta and gamma. Delta wave (<4Hz) is mostly observed during sleep. Theta wave (4-7 Hz) is seen during meditation. Alfa wave (7-14 Hz) results from relaxed condition of the brain. Beta wave (14-30 Hz) is associated with active brain and concentration. Low frequency beta wave (<22Hz) indicates active and concentrated brain while high frequency (>22Hz) indicates anxiety. The significance of Gamma wave (>32) is yet not clearly identified [6].

Figure 1: Neurosky Mindwave Mobile

Neurosky mindwave mobile is provided with a special chip called Thinkgear which uses the frequency spectrum of Theta, Alpha and Beta wave to identify the meditation, relaxation and attention level of a person and send the data continuously via Bluetooth as a data package.

2.2. Electromyography (EMG) Sensor

Electromyography (EMG) is the technique for recording and comparing electrical activities produced by muscles. EMG sensors, also called muscle sensors, detect the potential difference produced between a contracted and relaxed muscle cell [7]. These signals are converted to digital output with the help of amplifiers, comparator circuits and Analog-to-digital converter.

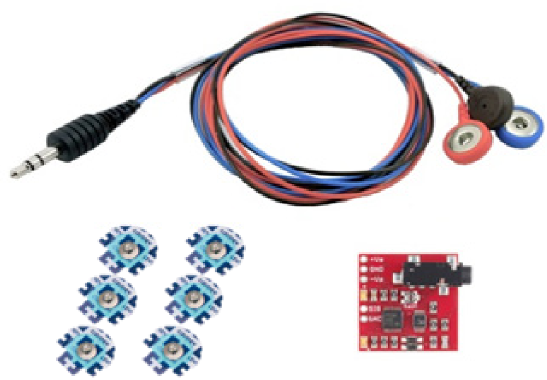

Figure 2: Muscle Sensor v3 kit

In our study, muscle sensor v3 kit manufactured by Advancer TM Technologies is used. It works under a voltage of +3.5V and gives an output ranging from 0 to 3.2V depending on the activity of the muscle. The sensor has three probes or electrodes each placed in three different positions of the forearm muscle. The values are recorded for different patterns of finger movement and these patterns are replicated in the prosthetic hand with corresponding signal.

2.3. Servo Motors for Finger Movement

In order to get precise motion of the fingers and maintain them in correct position with each instruction, servo motors are used in the prosthetic hand. The number of motors used and the size of motor were decided keeping in mind the limitation of design parameters and cost. In order to keep the cost as low as possible, only one servo motor per finger is used. In our project, metal gear servo motors are used. Each motor has operating voltage of 4.4-6V and stall torque of 1.6kg/cm. The motors have weight of approximately 9g.

Figure 3: Metal Gear Servo motor

2.4. Programmable Microcontroller-based Circuit

The data sent from both EEG and EMG sensors are of different types. EEG sensor sends a continuous stream of maximum 170 bit raw brain signal data via Bluetooth. A Bluetooth device is integrated in the headset. The data sent is a combined form of different brain wave data. To receive this data, a circuit containing Bluetooth module is required. In our study, two HT_05 Bluetooth modules are used.

On the other hand, the data of EMG sensor is potential difference and it is in the form of voltage difference from a reference value. To analyze this data, Analog-to-Digital converter is used in the circuit.

Finally, using of data received from both the sensors, it is necessary to provide instructions to the motors of the prosthetic hand to grab or release an object, which requires a programmable microcontroller. Microcontroller is a small integrated computer containing a processor core, memory, input or output pins and programmable flash memory. In our prosthetic hand, an Atmel microcontroller based development board called Arduino Uno is used for programming and control. Built-in ADC also makes it suitable for our study. The instructions are set in the microcontroller such that for a minimum attention level of mind, the prosthetic hand holds an object and at lower attention level it releases it. The patterns of the fingers to pick up objects of different shape are also specified in the code so that for a certain muscle activity, the pattern is followed by the hand. The power is supplied by four Lithium-ion batteries of 4.2V connected in series-parallel connection. The circuit diagram is shown in Figure 3.

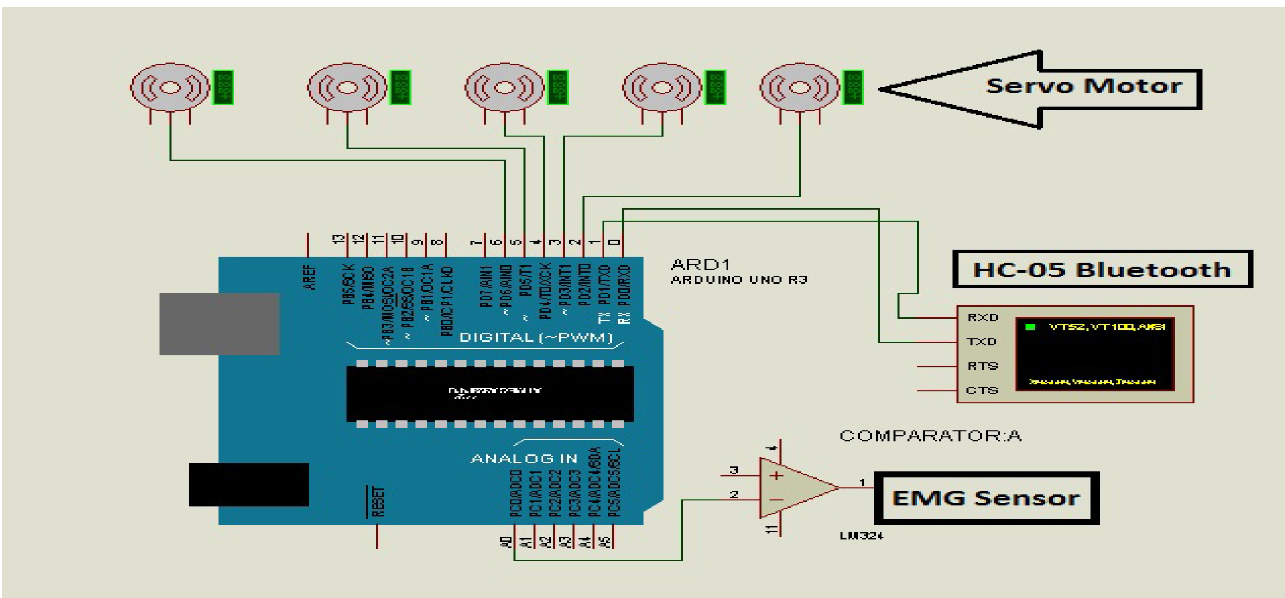

Figure 4: Circuit Diagram

3. DESIGN METHODOLOGY

3.1. Linkage mechanism of the fingers

Each finger in a human hand has three segments except for the thumb, which has two segments. The joints between these segments are hinged type and the relative motions between each segment are independent of each other. To achieve this many degree of freedom in the prosthetic hand requires use of motor in each joint, which is not cost efficient and also it will make the size of each finger very large and the prosthetic hand will be huge compared to the original size. Also this will increase the weight of the hand considerably.

To avoid this problem, the number of degree of freedom needed to be reduced. In our study, a modified design for the fingers are introduced which makes the relative motion between the segments of a finger dependent on each other in a certain proportional ratio, thus reducing degree of freedom. This makes it possible to control movement of each finger with one motor only. Figure 5 shows the design of fingers of the prosthetic hand. Figure 6 shows CAD design of the hand.

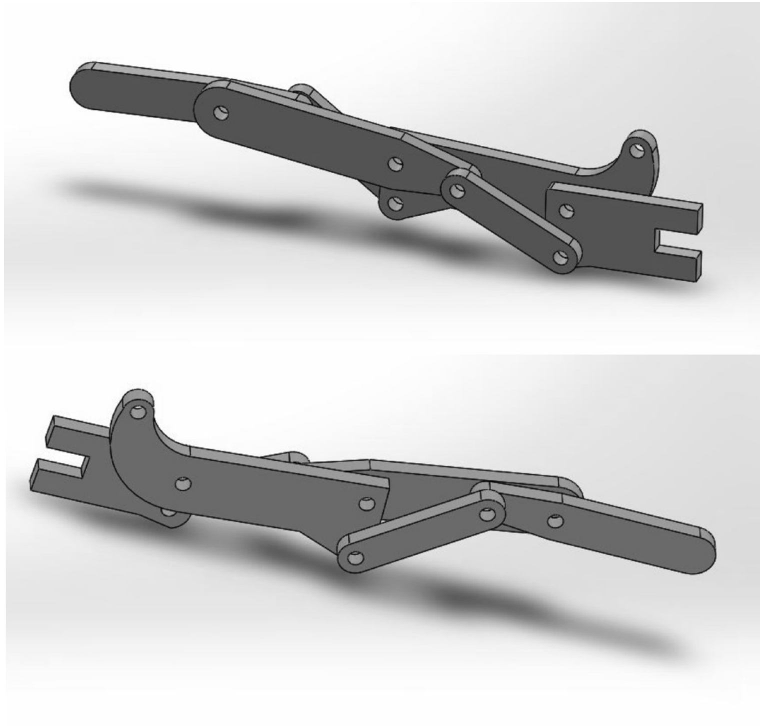

Figure 5: Finger Design

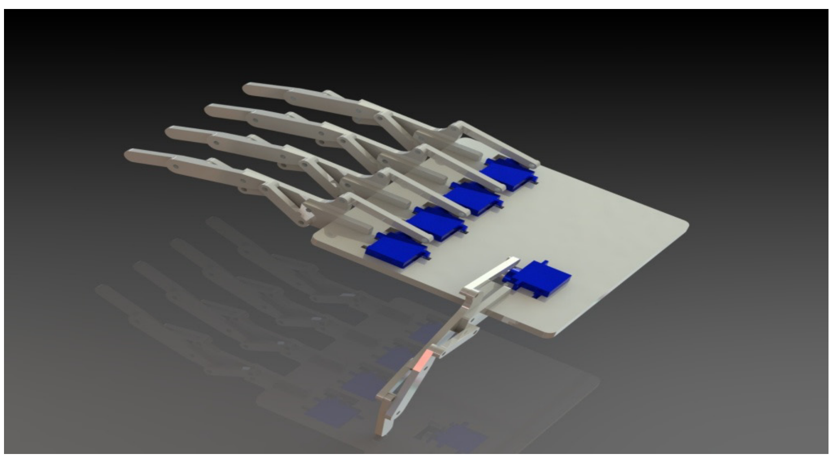

Figure 6: Total hand assembly

In Figure 5, it can be observed that with the connection between the three segments at their end points, there are two additional links in the assembly connecting the segments; one is between the base and the second segment and another is between first and third segment. These two links restrain free movement of each segment relative to one another; rather make them move in a determined ratio relative to one another. Thus, as shown in Figure 6, with a push rod connected at the end of the first segment, the total assembly can be made to create a curved shape during holding an object with one motor only.

3.2. Material Selection and Cutting Operation

Acrylic boards of different thickness are readily available in the market. In order to avoid the cost associated with mold preparation, casting process is not done in producing the parts of the prosthetic hand. The parts are designed such that they can be cut in a 2D leaser cutter and then assembled to form the total prosthetic hand. An acrylic board of 5mm thickness is taken as raw material. Then it is placed in a laser cutter where the CAD design is given as input to get desired output parts.

3.3. Final Assembly of Prosthetic Hand

The parts cut from the acrylic board are taken out from the laser cutting machine and then assembled to form the prosthetic hand. The parts cut consist of the segments of the fingers, there connecting links, push rods and a base for holding the five fingers together. First the segments of the fingers are assembled by placing smooth shafts through their common holes. After that they are connected with the servomotors with the help of push rods. The base is cut in such a way that it has hollow positions for holding the servomotors in right places. After assembling the total prosthetic hand, permanent joints are created between the base and extensions for holding the fingers with the help of acetone, which can be used to create a welded type joint between two acrylic parts. Figure 7 shows the final assembled prosthetic hand.

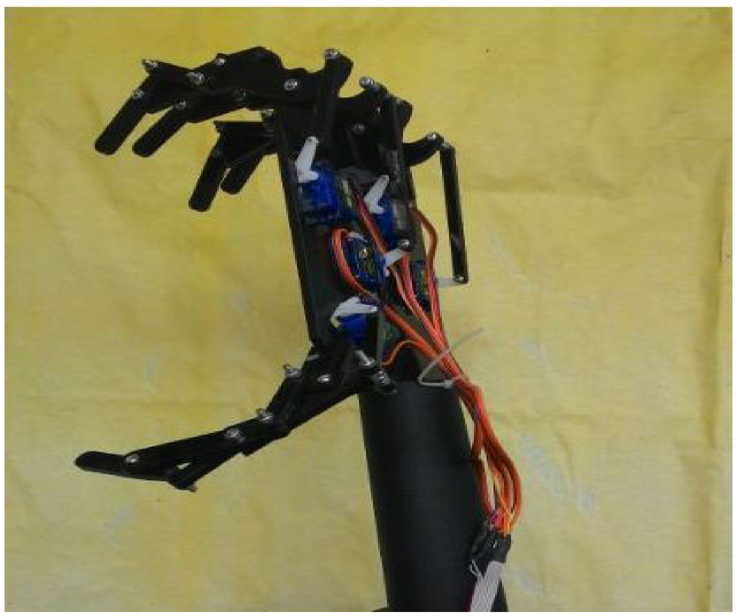

Figure 7: prosthetic hand after final assembly

3.4. Communication Establishment and Control System Working Principle

After full assembly of the hardware parts of the prosthetic hand, the EEG headset and EMG sensor need to be connected to the Arduino Uno Board. As mentioned earlier, EEG headset sends 170 bit data via Bluetooth. To receive this data, HT_05 Bluetooth module is connected to Arduino. But it is observed that due to limited memory of microcontroller, it is usually not possible to handle such a large amount of data by microcontroller. To solve this problem, a large portion of the data sent by EEG headset is rejected and only the required data is extracted from the data package. In our study, the attention level of a human mind is required to operate the prosthetic hand, thus the data corresponding to Beta Wave is received and other data is dumped. The hand is activated to grabs an object when a person focuses on the object. In the microcontroller, programming is done so that when attention level on the object is above 60%, the hand is activated.

While communication takes place between the headset and Bluetooth module of the microcontroller circuit, it is necessary that both the Bluetooth devices have same baud rate, which requires AT programming of the Bluetooth module. In order to change the AT programming, HT_05 requires some modifications.

Also To establish uninterrupted pairing between the two devices, it is necessary that any other Bluetooth device is restricted from connecting. For that AT programming is done in such a way that the headset works as a master device and HT_05 works as slave. Again only unidirectional flow of data is established between the two.

The shape and size of different objects needs different finger orientation for picking it up. Also the amount of force needed to be exerted on the object may vary depending on whether it is soft or hard. These quantities are controlled on the basis of the muscle sensor signals. The programming of the microcontroller is done for two different patterns of finger orientation in our prosthetic hand. When the muscle sensor voltage output is less than 1.5V, only three fingers are used to pick up an object, but when it is greater than 1.5V, all five fingers are used. The first orientation is for relatively smaller or softer objects and the second one is for bigger or harder objects.

4. RESULTS AND CONCLUSION

The test run of the prosthetic hand developed in our study was done on 100 normal people and 20 amputees. The EEG sensor works on almost 90% of the person both normal and amputee which means they have been able to grab and release an object successfully by giving concentration on the object and manipulating their attention level. Among them, only 20% people could do it in their first attempt and others required more than one attempt to do it. Almost no calibration is required while using it on different people. It was also observed that the characteristics of the EEG sensor is dependent of the atmospheric condition of the surrounding, that means at very low temperature or high humidity, the performance of the sensor is very poor.The EMG sensor was tested on amputee only and it is observed that for the cases where a person has lost a large portion of his forearm cannot exert enough muscle pressure on the sensor. So, this prosthetic hand is applicable for those who have lost only the hand but a significant portion of the forearm is not harmed.

In our study, it is our objective to develop a prosthetic hand which will not require any surgical procedure, thus reducing cost and making it feasible for poor people of third world country. But it is observed that because of not having any fixed joint with the bones, the hand cannot be used to lift an object of weight exceeding 5000grams, otherwise it causes discomfort of the person, sometimes serious pain. Also this limiting condition must be followed to avoid injuries and accidents. Again each motor has stall torque of 1.6kg-cm, and the horns are 2.168 cm long, again only four fingers bear nearly the total weight of the object lifted. So the accumulated theoretical maximum load that can be carried by the motors is 2.952 kg. But due to linkage mechanism and self weight of the fingers, the maximum capacity is reduced one-sixth of theoretical value. So the actual limiting value is 492grams.

The change in finger orientation does vary the amount of force exerted on the object, still it cannot ensure firm grip on a really soft object. Servo motors need to be replaced by hydraulic muscles so that the amount of force exerted can also be controlled to a desired level. Also feedback mechanism may be needed.

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