Sudan University of Science and Technology

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Prosthetic Hand Controlled Using Mind Waves

A Research Submitted in Partial fulfillment for the Requirements of the Degree of B. TECH (Honors) in Electronics Engineering.

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الأية والأستهلال

قال تعالى

((قُل لَّوْ كَانَ الْبَحْرُ مِدَادًا لِّكَلِمَاتِ رَبِّي لَنَفِدَ الْبَحْرُ قَبْلَ أَن تنفَدَ كَلِمَاتُ رَبِّي وَلَوْ جِئْنَا بِمِثْلِهِ مَدَدًا)) الكهف الاية 109

DEDICATION

To Family, Friends and our self. To Sudan University of Science and Technology community “professors, workers and colleagues”, to the spirt of D. Emad Basheer. To our beloved country, to the glory Revolutionaries and Revolution of December’s martyrs, to the all lives that pass dreaming of country with Freedom, Peace and Justice, and to you Ali Birir. We dedicate this research.

ACKNOWLEDGEMENTS

Without our Creator's -the Omniscient- felicitous, and our parent's prayers none of this would be achieved, there are no words to say except the pure gratitude to Allah and all the thankfulness to our parents.

There are plentiful people to thanks in such a bounded paragraph, so much many thanks to all those who participate in fulfilment this research in any kind of help, from engineer Zainab our savior, Boga, Awad, Mahmmoud and all Almohandis 5 staff, to Eng. Mustafa Alwahabi and our guider Eng. Essra Sati. Many thanks to SUST School of Electronic Engineering members our professors and our instructors, and an extensive thanks to Duha and Haboba Muhammad for their unconditional continuous support. Eventually we would like to express special thanks to our other family our friends for always being there.

ABSTRACT

The human hand is a part present in almost all human beings' activities and the most intriguing and versatile appendage to the human body. Amputees face variant problems during their daily tasks even the simplest ones. There were many attempts thought out history to replace the effected limps with artificial prosthesis.

This thesis introduces using NeuroSky Mobile2 headset to control a 3D printed prosthetic hand with five DoFs, using attention level and Iblink signals, servo motors are used to actuate the hand's fingers through a group of artificial tendons, the user can choose either to operate the hand or not by generating an Iblink event, and the amount of attention controls the movement of servo motors, Arduino R3 port is used as the controller. This project resulted in a prosthetic hand which can achieve three simple task which are opening/closing hand and grasping an object.

المستخلص

اليد البشرية هي جزء موجود في جميع أنشطة البشر تقريبا والأكثر إثارة للإهتمام والأكثر قابلية للارتباط بالجسم البشري. ويواجه المبتورون مشاكل متغيرة خلال مهامهم اليومية حتى أبسطها. كان هناك العديد من المحاولات على مر التاريخ التي فكرت في الاستعاضة عن الأطراف المصابة باخرى اصطناعية.

تقدم هذه الأطروحة إستخدام جهاز Mobile2 NeuroSky للتحكم في يد اصطناعية مصممة و مطبوعة بإستخدام طابعة ثلاثية الأبعاد، وباستخدام مستوى التركيز وإشارات Iblink المقصودة، تُستخدم محركات سيرفو لتحريك أصابع اليد من خلال مجموعة من الأوتار الاصطناعية ، يمكن للمستخدم أن يختار إما تشغيل اليد أو لا عن طريق توليد حدث Iblink ، ومستوى التركيز يستخدم للتحكم في حركة محركات السيرفو ، ولوح أردوينو R3 يستخدم كمعالج للنظام. وأسفر هذا المشروع عن يد اصطناعية يمكن أن تحقق ثلاث مهام بسيطة هي فتح وإغلاق اليد بالإضافة الى الأمساك بجسم ما.

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LIST OF ABBREVIATIONS

BCI	Brain Computer Interface
3D Printing	Three Dimensions Printing
DoF	Degree of Freedom
EEG	Electroencephalogram
CMC joint	Carpometacarpal joint
MCP joint	Metacarpal-phalangeal joint
IP joint	Interphalangeal joint
DIP joint	Distal Interphalangeal joint
EMG	Electro Myography
CNC	Computer Numerical Control
PWM	Pulse Width Modulation
CAD	Computer Aid Design
ABS	Acrylonitrile Butadiene Styrene
FSRs	Force Sensor Resistor
PLA	Poly Lactic Acid
Tx pin	Transmitter pin
Rx pin	Receiver pin

KEY WORDS AND DEFINITIONS

Prosthetics	An artificial Limps
NeuroSky Headset	Single Electrode EEG Sensor
Anthropomorphism	Similar to Human or Human Like
Degree of Freedom	The Amount of Free Moves that a human limp could afford

CHAPTER I

INTRODUCTION

1.1 Preface

1.2 Problem Statement

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CHAPTER I

INTRODUCTION

1.1 Preface

A robot in general is a machine designed to execute one or more tasks automatically with the adequate speed and precision [1]. By collecting data and information from its environment using sensing devices, and act upon that collected information doing specific tasks, robotic science and Robots involves in a different fields and applications, the Medical field can be considered as one of the most important fields.

Prosthetics can be considered as medical robotic devices that used as substitutes for missing parts of human body [1]. For many centuries innovators tried to replace the effected limps by manufactured devices, from the early passives devices such as the wooden leg to the mechanical and recently bionic limps [2] . By the development of science and the bionic concepts the materials had been improved, and the prosthetics arms were improved.

Brain Computer Interface is one of prosthetics controlling approaches, working by placing an array of electrodes at the surface of human skull which record and read human brain waves, this type of technology is still in its infancy but has already demonstrated disabled people controlling bionic devices with their thoughts alone.

1.2 Problem Statement

The human hand is a member present in almost all human being activities and the most intriguing and versatile appendage to the human body, although a man needs his both hands to perform and acts upon his daily life tasks in a prober way, from complex tasks to fairly simple tasks. And any lack on it leads to incompetency of the person.

1.3 Problem Solution

To design and build an anthropomorphism prosthetic robotic hand that can be controlled by human's brain waves, to replace the ordinary prostheses.

1.4 Research Objectives

I. Design an anthropomorphism robotic hand, which can replace the -ordinaries prostheses- hands and perform like the original limb.

II. Build and design a robotic hand that can be controlled by human's mind waves.

III. Make the prosthetic hand affordable and easy to use.

1.5 Research Methodology

This thesis depends on knowledge in electronic and mechanical engineering fields, basics of BCI, Solid work program and 3D printing process. The data and necessary information in this research collected by a deep survey in the fields noted above, from similar researches, specialized books, and referring to specialist on those fields.

This project was made in two sections; each one covers certain topics. The first section is the software and the system design, this field is discussing the principles of the prosthetic hand module design, determining its demotions, constructions, and other features. The equivalent system control circuit was built and simulated using Proteus program. The required control code applied using the Arduino IDE.

The second section considering on the system hardware implantation, after testing the equivalent circuit of the propose project the required component had been determined in order to achieve the proposed goals. The prosthetic hand parts have been printed using 3D printing machine. More details will be found in chapter three

1.6 Chapters Layout

1.6.1 Chapter I

Chapter one is an introduction to the basic concepts of the proposed project determining the proposed problem and the suggestion solution, and brief discuss of the methods that used to write this thesis.

1.6.2 Chapter II

Chapter two consider on general edification to the reader, from the general curriculum that will be used on this project, the history of robots and robotic science, prosthetic and prostheses, including a general view to the components used to build the proposed project, at the end of this chapter you will find some of the similar research that are related to this thesis.

1.6.3 Chapter III

Chapter three determined the principle of the proposed system design from the electronic point of view and the mechanical point of view, Specification of the project components that used are detailed too.

1.6.4 Chapter IV

Chapter four discussed the result of the hardware circuit and the simulation process, showing the scenarios of each.

1.6.5 Chapter V

Chapter five represents the final conclusion of this thesis recommendation for future studies also included.

CHAPTER II

LITERATURE REVIEW

CHAPTER II

LITERATURE REVIEW

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CHAPTER II

LITERATURE REVIEW

2.1 Preface

Chapter two is about educating the readers on the areas that will be covered in this thesis to provide them with the necessary knowledge to help understand the approaches that had been used to design and implement the proposed project.

Anatomy of the human hand and its structure were discussed briefly, explaining some basics concepts that related to this project, such as joints, number of Degree of Freedom (DOFs) etc…, also a background research in the field of prosthetics and robotics have been done presenting the state of art to each one.

Others have been explained too such like the meaning of BCI a brief history of it and how does it effect in prosthetics development, EEG signals can be considered as the base of the prosthetics that controlled by the Brain computer interface, so we focused in this chapter on EEG, its history, development, methods of use, its types and other features are explained.

A general over view of project components were declared in this chapter too including sensor device which provides the control signals to the system, DC Servo Motors in general and its specifications, Arduino ports classifications and structure, beside any knowledge would help to understand this thesis in a proper way.

A related works that will provide the readers with extra knowledge to take up with the proposed design were declared at end of this chapter.

2.2 Human Hand Anatomy

Human hand is the most complex organ in the human body if we took in consideration its dexterity, numbers of DOFs, communication, capable of preforming complex moves

Human hand consists of 27 bones, more than 30 individual muscles, and over 100 ligaments, nerves and arteries. [2], a faultless human hand formed as four fingers, thump, palm and wrist. With 187.9$_{mm}$ from top of the middle finger to the distal crease of the wrist, and 83.6$_{mm}$ from the CMC joint of the Index finger to the Little finger CMC joint for adult male [3].

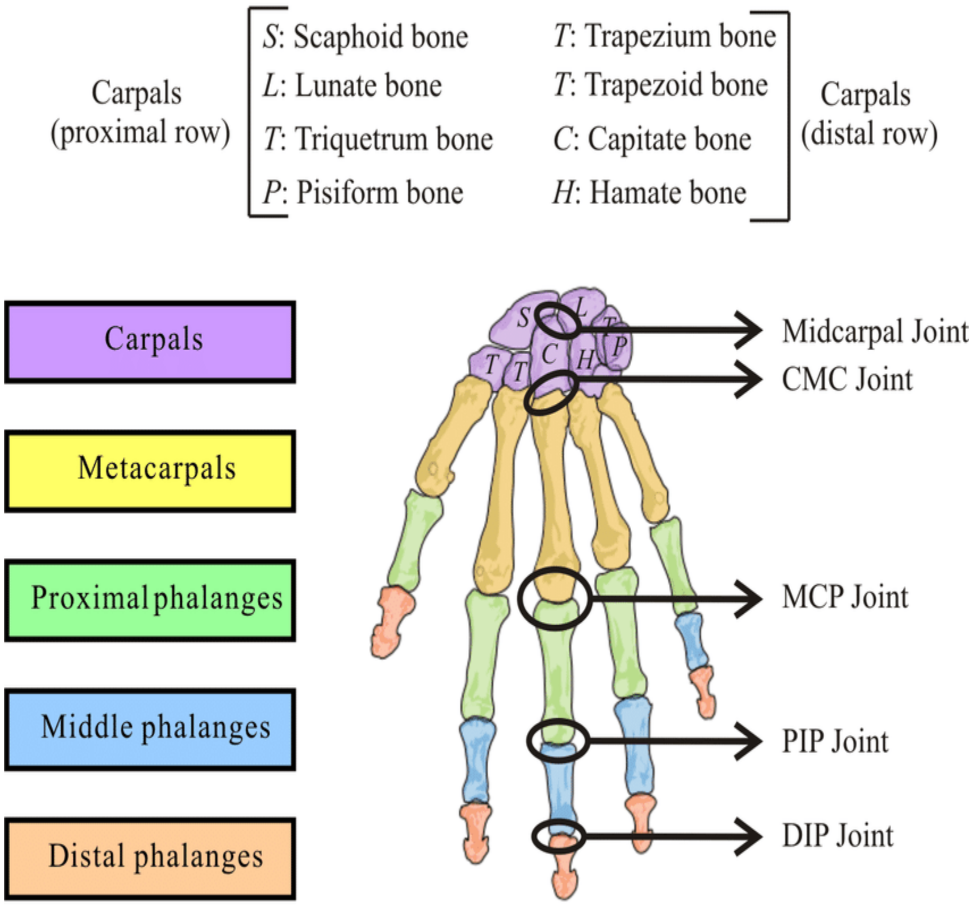

Figure 2. 1: The Skeleton of Human Hand

Figure (2.1) shows the skeleton of the human hand, composed of Thumb (t), Index (i), Middle (m), Ring (r), little (l) and palm, The wrist is located between the Forearm and the hand, consists of eight carpal bones organized in two rows, proximal and distal carpal bones, The proximal row of carpal bones from lateral to medial are the Scaphoid, Lunate, Triquetrum and Pisiform which are a moveable carpal bones, and the distal row of carpal bones from medial to lateral are the hamate, capitate, trapezoid and trapezium, which are a immoveable carpal bones.

The hand is composed of five metacarpals and five digits, the metacarpals produce a curve, so the palm is concave in the resting position. And five digits contain thumb (t) and four fingers. The thumb has two bones, proximal phalanx and distal phalanx and each finger consists of three bones, proximal phalanx, middle phalanx, and distal phalanx, joints are located between any two phalanges except the Metacarpal-phalangeal (MCP) joint which is located between metacarpal and proximal phalange bones.

Thumb contains Metacarpal-phalangeal (MCP) and interphalangeal (IP) joints, and has three DOFs (two at MCP joint and one at IP joint), each finger has four DOFs (two at MCP joint, one at PIP joint, and one at DIP joint), two DOFs at the wrist and two DOFs at the carpometacarpal (CMC) joint, produced the overall DOFs of human hand which is 23 DOFs. [4].

2.2.1 Degree of Freedoms

Degrees of freedom, in a mechanic's context, are specific, defined modes in which a mechanical device or system can move, the number of degrees of freedom is equal to the total number of independent displacements or aspects of motion.

Consider a robot arm built to work like a human arm. Shoulder motion can take place as pitch (up and down) or yaw (left and right).

Elbow motion can occur only as pitch. Wrist motion can occur as pitch or yaw. Rotation (roll) may also be possible for wrist and shoulder, such a robot arm has five to seven degrees of freedom. [5]

The human neck for example has 3 degrees of rotational freedom – we can look left/right, up/down and tilt our head sideways-. So in total a single point can have a maximum of 6 degrees of freedom (3 translational, 3 rotational). [2]

2.3 Background

A brief discussed of robots and robotics it's begging and the way it developed

2.3.1 Robot and Robotics

The earliest robots as we know them were created in the early 1950s by George C. Devol, an inventor from Louisville, Kentucky. He invented and patented a reprogrammable manipulator called "Unimate" from "Universal Automation", Unimate was the first robotic arm device had been made. In the late 1960s, the engineer businessman Joseph Engleberger acquired Devol's robot and was able to modify it into an industrial robot and form a company called Unimation to produce and market the robot. For his efforts and successes, Engleberger today is known in the industry as "The Father of Robotics".

Also in mid-1950s, the German firm Kuka developed an automated welding line for appliances as well as a multi-spot welding line for Volkswagen Company. In 1970, Stanford University developed the so-called Standard Arm, as we know it today used for small parts assembly and incorporating touch and pressure feedback.

Kuka, by 1973 had introduced the six-axis arm, which would become an industry standard. This was about the same time that fully-electric robots began to make their appearance.

2.3.2 Prosthetics

Prosthetics devices started with wood and metals without control or any moving parts, this early prosthetics consider as the first steps that lead to resampling the human limps with manmade devices, History shows that for a long time prosthetics have remained passive devices that offer little in terms of control and movement. The earliest example of a prosthesis ever discovered is not a leg, arm, or even a fake eye, it's a toe. A big toe (figure2.2), belonging to a noblewoman, was found in Egypt and dated to between 950-710 B.C.E. it's interesting that the first prosthetic ever was a toe, but the toe was important to the

Figure 2. 2: The First Prosthesis

Egyptian because it was necessary in order to wear the traditional Egyptian sandals, this mean that the prostheses mainly were made to complete the amputee’s sense of wholeness. [6].

By the developments of the designing tools and the improvement the materials, prosthetics devices improved and started incorporating hinges and pulley systems. This led to simple mechanical body powered devices such as metal hooks which can open and close as a user bends their elbow for example. [2], Among the most famous examples of early hand prosthesis was the iron hand (figure2.3) of German knight Götz von Berlichingen, designed by artisan an iron hand with digits that could be flexed and extended passively at the metacarpophalangeal, proximal interphalangeal and distal interphalangeal joints, as well as the thumb interphalangeal joint, The device was modeled as an extension of battle armor rather than a human arm.

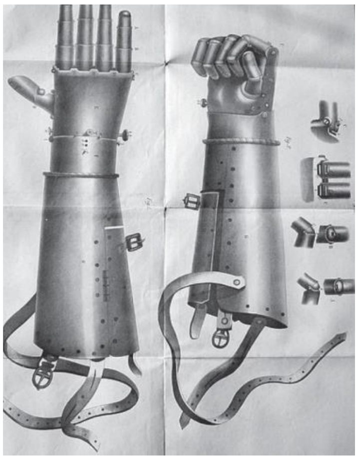

Figure 2. 3: Götz von Berlichingen Iron Hand

The concept of ‘automatic’ body-powered upper limb prosthesis was pioneered by German dentist Peter Baliff in 1818, using transmission of tension through leather straps, Baliff’s device enabled the intact muscles of the trunk and shoulder girdle to elicit motion in a terminal device attached to the amputation stump. For the first time, an amputee was able to operate his prosthesis with fluid body motions, rather than as a distinct foreign object. [7].

During the times of the American Civil War, hand prosthetics transformed from wooden pieces to cosmetic rubber. Some even had attachments that allowed for finger movement, however following World War II, most prosthetics were made from a combination of leather and wood. The Bowden cable body-powered prosthesis was introduced, replacing bulky straps with a sleek, sturdy cable.

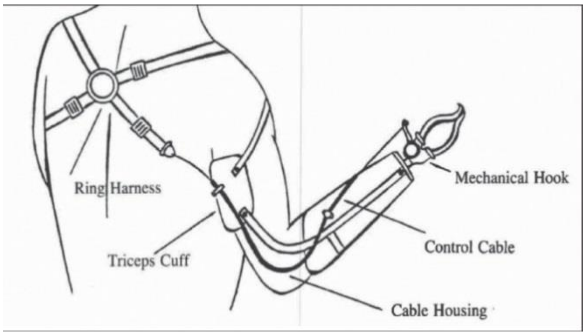

Figure 2. 4: Example of Body Powered Prostheses

Despite new materials and improved craftsmanship, today's body-powered prostheses are essentially adaptations of the Bowden design (figure 2.4).

By the 1980s, myoelectric prostheses were being used in rehabilitation centers around the world and today they are a common option for amputees (figure 2.5).

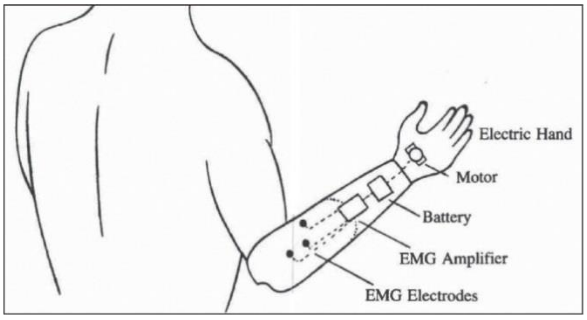

Figure 2. 5: Myoelectric Prostheses Concept

Improvement in materials has permitted lighter and more ergonomic designs, Compared with body-powered prostheses, myoelectric prostheses feature superior comfort and aesthetics [7]. However, myoelectric prostheses are externally powered and must be recharged regularly.

In August 1998 the world's first bionic arm was fitted to Robert Aird at the Princess Margaret Rose Hospital (figure 2.6). The "Edinburgh Modular Arm System" The prosthetic was created by a team of five bio-engineers at the Margaret Rose Hospital in Edinburgh, UK, while the surgical team was led by Dr. David Gow, this new bionic limb incorporated microchips, circuitry to enable engage it in different positions, and a host of tiny gears, pulleys and motors.

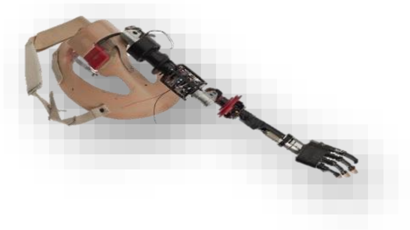

Figure 2. 6: Edinburgh Modular Arm System

Robert operated his new arm by means of a cap, which he wore all the time; this contained micro-sensors, which detected the electrical brain impulses that were being sent to the missing limb and deployed them to the bionic arm. It marked a giant step forward in prosthetics.

Of course, technology never stands still. Today, scientists are developing ever more refined prosthetics that strive to mimic the subtle complexities of limb movement or the manipulation of fingers. Modular

Prosthetic Limb, the MPL is still in research, and is likely to be for some time. But right now, genuine bionic arms – which pick up on electrical signals from the wearer's brain, are being created by means of 3D printing. And crucially, they can be manufactured for the fraction of the cost of most commercially available prosthetics. [8]

2.4 State-of-the-art

After the discussed that have been done on the history of prosthetics and their development through the time, now currently state of the modern and commercial prosthetics will be determining.

One of the most concurred prosthetics device now days is Bionic arm, it always consists of a bionic hand or partial hand and, depending on the level of amputation, may also include a powered wrist, elbow, and/or shoulder.

For example, here are the three configurations available for the Luke Arm System from Mobius Bionics:

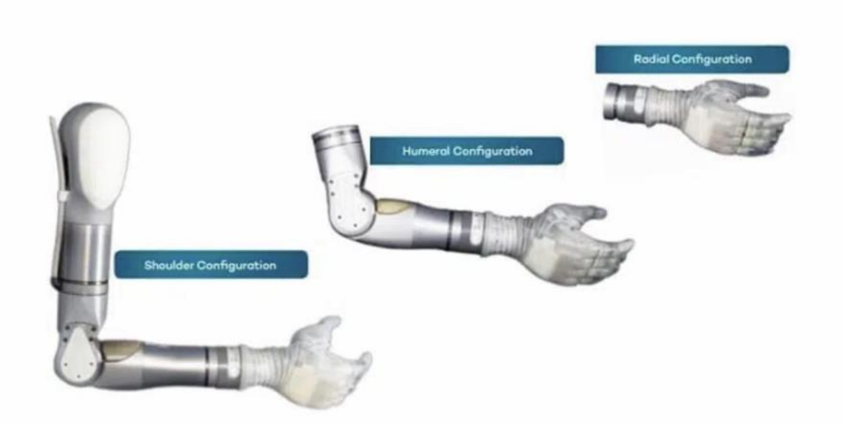

Figure 2. 7: Available Configurations for the Luke Arm System

Note, this particular line of devices always includes a powered wrist but this is optional or not available for other devices. Also, in some cases, the hand may be replaced with a powered hook or clamp.

How Bionic Hands Function

This section describes the limits of bionic hand dexterity beginning with the mechanical design of the fingers and working backward. Figure (2.8)

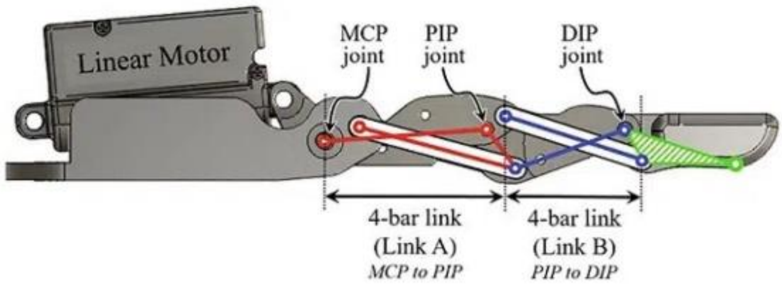

Figure 2. 8: Mechanical Design of the Bionic Hands Fingers

A battery-powered motor drives a gearing system to move the main MCP joint, which then moves the second and third joints via a bar linkage system. Note, there are many variations of this, such as using pulley systems to simulate tendons instead of bar linkage systems.

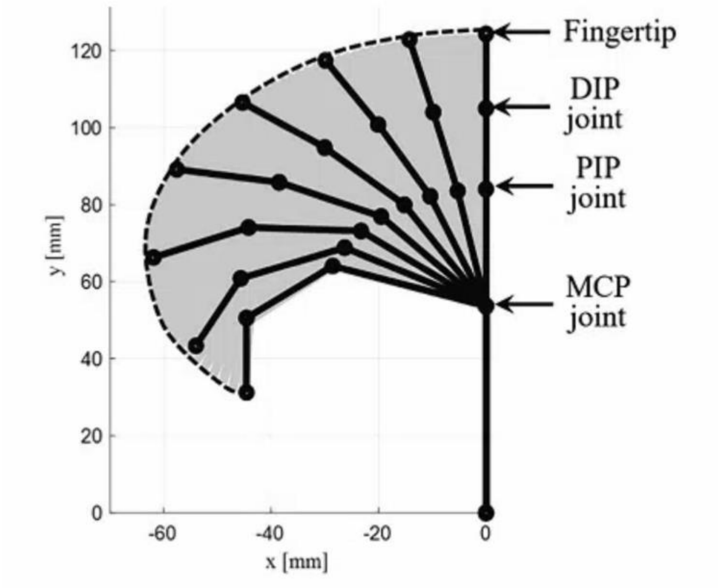

Figure 2. 9: Finger Moving Process with Main Knuckle

The key feature in this type of design is that there is only one independent joint: the MCP joint (main knuckle). The other two joints automatically follow that joint’s lead, producing the below fixed pattern of motion in figure (2.9).

By comparison, natural fingers can move the middle or PIP joint independently and the DIP joint quasi-independently. Additionally, natural fingers can spread out and twist and turn in a myriad of combinations.

The movement of a natural thumb is even more complex. In addition to opening and closing, it can rotate down and slightly outward to touch the entire underside of any finger and even parts of the palm. This allows natural hands to grasp objects of any shape.

Here is a diagram (figure 2.10) of a bionic thumb from the early work on one of the more recent entries into the bionic hand market, the Psyonic Ability Hand.

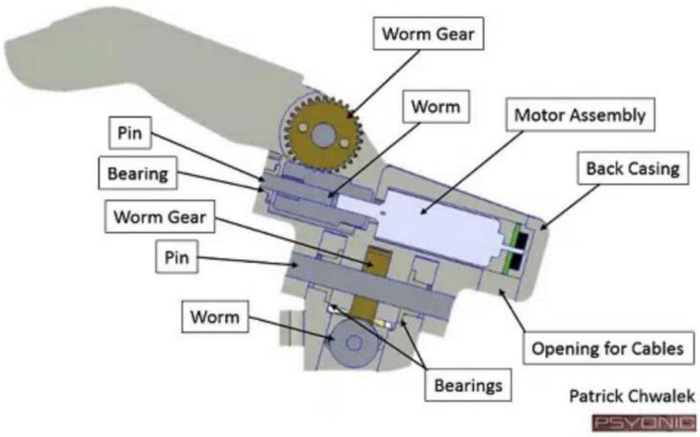

Figure 2. 10: bionic thumb from Psyonic Ability Hand.

Despite its mechanical complexity, this type of thumb still has many limitations. Yes, it can position itself to become an opposing force for many grips but it lacks the dexterity of a natural thumb.

User Control Systems

When you move a natural limb, your brain sends nerve signals to the muscles, which in turn move the limb. When a limb is amputated, the brain still sends these signals even though some of the muscles are no longer there to react to them.

The general concept behind bionic user control systems is to intercept the brain's signals and convert them into commands for the bionic.

The performance of some control systems can be significantly enhanced by surgical procedures.

i- i-LIMP Hand:

The i-LIMB Hand is the brand name of world's first commercially available bionic hand invented by David Gow and his team at the Bioengineering Centre of the Princess Margaret Rose Hospital in Edinburgh, and manufactured by Touch Bionics. The articulating prosthetic hand has individually powered digits and thumb and has a choice of grips. The i-Limb Hand offers full hand solutions in addition to partial hand solutions.

How it work

The i-LIMB Hand is controlled through the use of myoelectric signals, which uses the muscle signals in the patient's residual arm to move the i-LIMB Hand around. Electrodes are placed at two pre-determined muscle sites. The electrodes pick up the muscle signals when the patient contracts his/her muscles. These signals are then sent to a microprocessor which causes the device to move. The i-LIMB Hand has up to four different muscle triggers. The user is able to assign a grip to move the device to a certain position. These muscle triggers include:

i. **hold open';** This option uses the open signal for a certain amount of time.

ii. **double impulse';** This option uses two quick open signals once the hand is opened completely.

iii. **triple impulse'** This option uses three quick open signals once the hand is opened completely.

iv. **co-contraction'** This allows the device to contract the open and close muscles at the same time.

ii- Vanderbilt Hand:

The Vanderbilt hand use artificial tendon designs to drive finger movements instead of mechanical linkage system in commercial devices. The tendons are running through the fingers and thumb and use DC motor drive a pulley system which tensions the tendons, this tension result in closing all fingers simultaneously. When the tension is released in the tendons the implemented springs in joints return the fingers to its initial open position. [2]

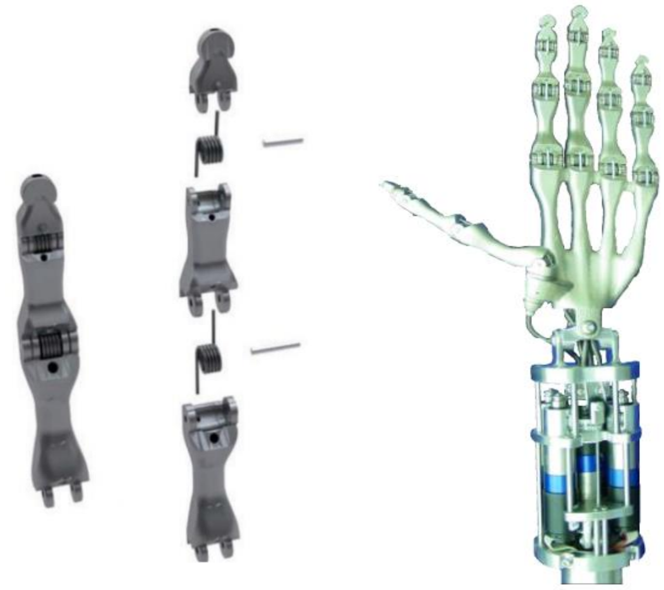

Figure 2. 11 Vanderbilt Hand.

iii- 22 Degree of Freedom APL Hand

One of the most advanced modern prosthetic arms is the 22 degree of freedom Intrinsic Hand developed at the John Hopkins Applied Physics Laboratory [15]. This hand has been developed through DARPA initiative and funding and has unmatched mechanical dexterity. To achieve such fine control designers incorporated a total of 15 miniature DC motors directly in the fingers, palm and wrist.

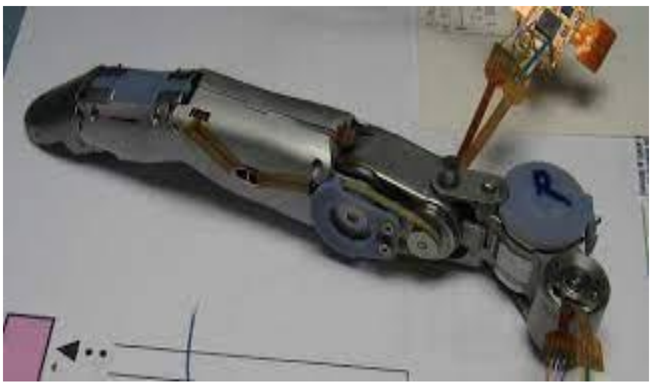

Figure 2. 12 22 Degree of Freedom APL Finger

Furthermore, this device is designed to fit to a 50th percentile female arm making it truly exceptional, in terms of its complexity and size.

The Intrinsic Hand is able to replicate almost every movement of the biological human hand. Using standard EMG sensing techniques there is no way of obtaining enough control for a user to practically use all the degrees of freedom of this device. However, DARPA is further funding the development of a prosthesis/brain neural interface to connect the user's nervous system directly to inputs in the arm. [9]

2.5 Brain Computer Interface

BCI is an emergent technology to build a direct communication channel between human brain and the computer, BCI allows reading signal waves that produced by the brain cells and translate those signals into actions and commands, which can be used to control an external device.

BCI systems can be divided into two major categories according to the measurement of bioelectrical signals, invasive and non-invasive BCI.

In case of invasive BCI the biosensors are directly placed into the brain tissue surface during a Neurosurgery, the main advantage of this type, it provides more accurate readings.

The other type which is easier to implement and operate, the non-invasive BCI in this case the electrodes are placed somewhere on the scalp, at the skull surface, it’s safer and doesn’t need any surgical operations, also there is other type of BCI which can be considered as a hybrid of the two previous types, the half-invasive or partial-invasive in the case of this type the biosensors are placed underneath the scalp, creating slightly better signal.

Non-invasive BCI systems are preferred, because it’s have the most safety and less complexity comparing with the others types. [9] [10].

2.6 EEG Signals

Mind-Waves or brain signals in general are very low amplitude signals varies from 1_{uV} to 100_{uV} in normal adults, and low frequency signals which are very sensitive to disturbance, and require a very sophisticated environment so it can be acquired and processed, the EEG is a method in which we can detect record and display those signals. [11] [12].

Electroencephalogram (EEG) in basic is a traditional lab-based recordings of the brain signals in which

Figure 2. 13 First EEG Signal Record

the person wears a cap with many electrodes glued on the scalp for accurate signal reading. The EEG since it was discovered in the early 1900s by Hans Berger (figure 2.13); German psychiatrist has been one of the most commonly used techniques for neurological and psychological assessments. [10] [9].

The EEG has two types of montage, meaning it has two ways to detect and display the Mind-Wave signals, mono-polar and bi-polar. The mono-polar montage collects signal at the active site and compares them with a common reference electrode. The common electrode should be in a location so that it would not be affected by cerebral activity, and the bi-polar montage compares signals between two active scalp sites. Any activity in common with these sites is subtracted so that only difference in activity is recorded. [12] [13]

This method of recording human brain signals use a multiple electrodes typically 32, 64, 128 or even more usually embedded in a stretch-lycra electrode cap or pasted directly to the scalp, the traditional EEG is not convenient uncomfortable to use and way more expensive with prices ranging from $5,000 to $50,000. [9] [13].

There are two more concepts about EEG that will be discussed too, the rule that concur the electrodes placement, and the types of the frequency patterns that EEG produced.

2.6.1 Electrode Placement

Attached electrodes to the skull of human body depend on the 10-20 electrode placement system, which is an internationally recognized method to describe and apply the location of scalp electrodes in the context of EEG signal acquisition.

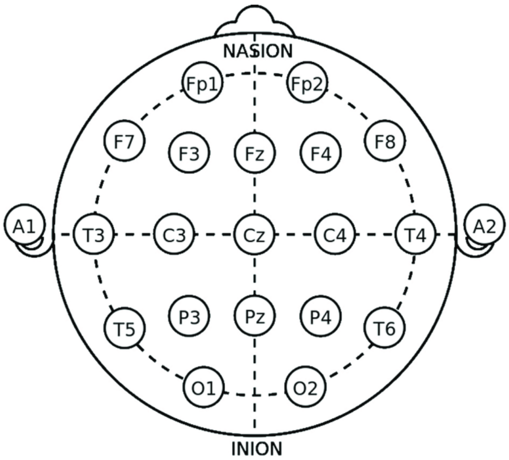

Figure 2. 14 Electrodes Placement Locations

This system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front-back or right-left distance of the skull. [11]

Each electrode placement location is identified with a combination of a letter which denotes the lobe and a number to identify the hemisphere location (figure 2.14).

The letters used to identify the various lobes on the skull such as frontal (F), temporal (T), central (C), parietal (P), and occipital (O). Even numbers are dedicated to electrode placements on the right hemisphere, and odd numbers are dedicated to the electrode placements on the left hemisphere. In addition “A”, “Pg”, and “Fp” identify the earlobes, nasopharyngeal and frontal polar sites respectively. [11]

2.6.2 EEG Frequency Patterns

Electroencephalogram signals combined of five different patterns with different frequency range to describe the human brain mental state. Each pattern provides us with the necessary information to determine which mental state the human brain is currently in. Table below shows EEG Patterns, there frequency and mental state that.

Table 2. 1: EEG FREQUENCY PATTERNS

Frequency Patterns	Frequency Range	Mental states and condition
Delta	0.1Hz to 3Hz	Deep, dreamless sleep, non-REM sleep, unconscious
Theta	4Hz to 7Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8Hz to 12Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	12Hz to 15Hz	Formerly SMR, relaxed yet focused, integrated
Midrange Beta	16Hz to 20Hz	Thinking, aware of self & surroundings
High Beta	21Hz to 30Hz	Alertness, agitation

2.7 Sensor Device

A sensor is often defined as a “device that receives and responds to a signal or stimulus”. This definition is broad. In fact, it is so broad that it covers almost everything from a human eye to a trigger in a pistol, the sensor device can be defined as “Electronic device which convert non-electronic signals into electronic signals”.

This world is divided into natural and man-made objects. The natural sensors, like those found in living organisms, usually respond with signals having electrochemical character; that is, their physical nature is based on ion transport, like in the nerve fibers. In man-made devices, information is also transmitted and processed in electrical form, through the transport of electrons. Any sensor is an energy converter. No matter what you try to measure, you always deal with energy transfer between the object of measurement to the sensor.

The process of sensing is a particular case of information transfer, and any transmission requires transmission energy, and it can be flow in both ways from the object to sensor, or backward from sensor to the object. [14]

2.8 DC Motor Devices

Electric motor can be defined as a device which converts an electrical energy into kinetic energy; Motor can move linearly or spin in axis. Electrical motors can be divided into two main groups, DC (Direct-current) motors and AC (Alternating current) motors and a few can operate on both. In this thesis we focus only on DC types of motor.

DC motor is another main type of electrical motor, which Operate on direct current only, and often used in applications where precise, speed and control are required, it is easier to control its speed by only varying the power supply.

There is some sort of modified motors that can be considered as types of DC motors called special motors.

2.9.1 Special Motors

There are several types of special electric motors that are the modified versions of other motor designed for special purposes. Some of these electric motors are given below:

i. **Direct Drive**

Direct drive motor or also known as torque motor is another type of motor that produces high torque at low speed even when it is stalling. The payload is directly connected to the rotor thus eliminating the use of gearbox, belts, speed reducers etc. It is a brushless permanent magnet synchronous motor with no commutators & brushes. Since there is no mechanical wear & tear, it reliable & has a long lifetime. The fact that it has less mechanical parts means it require less maintenance and low cost.

ii. **Linear Motors**

The linear motor has an unrolled stator & rotor that offers a linear force instead of rotational force. If you slice any motor & lay it flat on a surface, you will get a linear motor.

The armature windings are designed in a linear fashion which carries 3 phase current to generate a magnetic field. The magnetic field does not rotate but instead moves in a straight line. The magnetic field interacts with the magnetic field generated by the flat permanent magnet lying below it. The interaction between them generates a linear force upon each other, thus the armature moves forward or backward.

It is an AC powered motor with a controller such as in servo motor. The power is supplied to the primary part of the motor that contains windings. It generates its own magnetic field whose polarity depends on the phase of the AC supply. The secondary part of the motor is permanent magnet whose magnetic field interacts with the magnetic field of the primary part & as a result attracts & repels it by generating a linear force. The amount of current determines the force while the rate of change of current determines the speed of the primary part. Linear motors are used in robotics, medical device & factory automation etc.

iii. **Stepper Motor**

A stepper motor or a stepping motor is a brushless DC motor whose full rotation is divided into a number of equal steps. Such motor rotates in steps (fixed degrees) instead of rotating continuously. Such stepping movement offers great precision which is utilized is robotics.

The stepper motor operates on pulses. Each pulse moves the motor by one step. The precision of the motor depends on the number of steps per revolution. The steps size is determined during its design. However, the speed of the motor can be controlled by applying the pulse train of variable frequency. The controller inside the servo motor moves forward or backward the rotor by one step upon each pulse.

It is used for its accurate & precise positioning. It offers full torque at standstill. It has less maintenance requirement due to brushless design. Thus they are very reliable & has long lifetime.

Stepper motor due to its precise positioning is used in industrial machines used for automatic manufacturing of products, CNC based machines. It also found applications in medical instruments & machinery as wells as in security cameras. Stepper is widely used in electronic gadgets & other smart electronic systems.

iv. **Universal Motor**

The Universal motor is a special type of motor that can run on AC as well DC power supply. It is a brushed series wound motor where the field windings are connected in series with the armature windings. They offer maximum starting torque with a high operating speed.

Since the windings are connected in series, the direction of the current through both windings remains the same even if the current direction reverses multiple times in a second.

v. **Servo Motors**

Servo motor is a special type of motor used for pushing/Pulling lifting or rotating an object at some specific angle. Servo motor can be designed to run on AC as well as DC power supply. Servo motor that runs on DC supply is called DC servo motor while that runs on AC is called AC servo motor. It is a simple motor with a controller & multiple gears to increase its torque.

These motor are rated in kg/cm (kilogram per centimeter). It specifies much weight the servo can lift at a specific distance. E.g. a servo rated 3kg/cm can lift a load of 3kg that is at 1cm away from its shaft. The weight lifting capacity decreases with an increase in the distance.

The servo motor has a gear assembly, controller, a sensor and a feedback system. The gear assembly is used to decree se the speed & increase its torque significantly. The controller is used for comparing the input signal (desired position) & signal from the sensor (actual position of the servo) which is acquired through the feedback system. The controller compares these two signals & eliminated the error between them by rotating the motor shaft.

Servo motors has three wires. Two of them are used for providing the power supply while the third one is used for controlling the servo’s position. It is controlled by providing a pulsating signal thorough a microcontroller using PWM (pulse width modulation).

The servo can rotate 90° in either direction making it a total of 180° rotations. Neutrally it is in the middle position at 90°. It can rotate by varying the pulse width between 1ms & 2ms where 1ms corresponds to 0°, 1.5ms corresponds to 90° while 2ms corresponds to 180° angle of the shaft.

2.10 Microcontrollers

We can define microcontroller as a highly integrated chip that contains all the components of the computer, typically this include (CPU, RAM, I/O PORT, some form of ROM, and Timers) all this components are built in one chip (figure 2.10). [16]

A microcontroller was developed in 1971 by Intel Corporation in the United States. That was the 4-bit microcontroller called i4004. It was ordered by a Japanese company BUSICOM for calculators. Later, the contract was changed and it was sold as a general-purpose microcontroller with success.

After that, Intel Corp. developed a 16-bit microcontroller '8086,' following the 8 bit microcontrollers such as 'i8008', 'i8080A,' and 'i8085.' After developing several microcontrollers, they continued to develop the CPUs used in the current personal computers. [17]

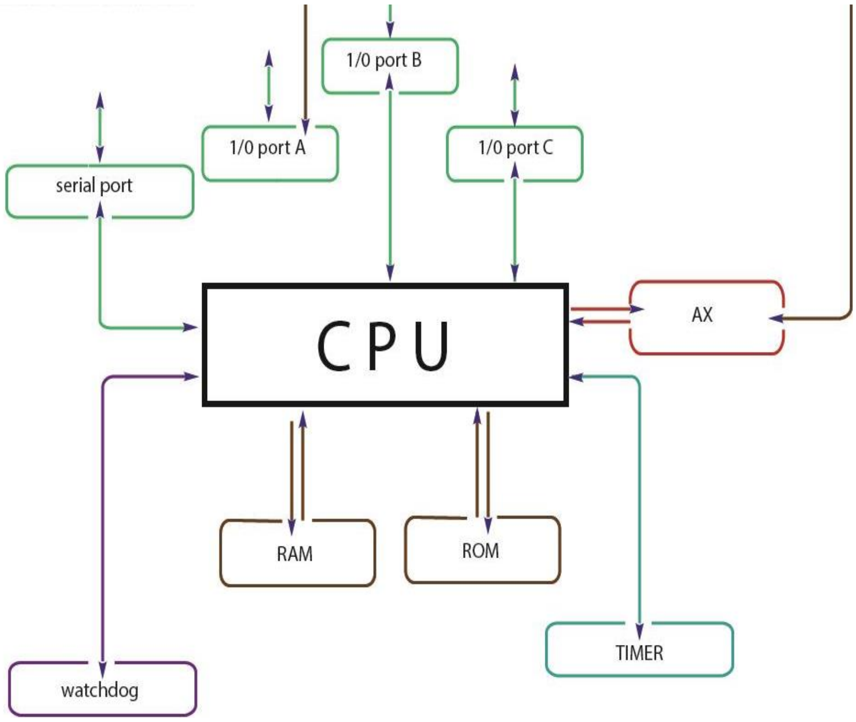

Figure 2. 15 Microcontrollers Architecture

2.10.1 Microcontroller Classifications

Microcontroller can be classified upon various principles, according to its memory devices instruction set and other specifications discussed below. [16]

a) Classification according to the number of bits

b) Classification according to Memory Device

c) Classification According to Instruction Set

d) Classification According to Memory Architecture

e) Classification According to Family

2.11 Arduino Ports

Arduino is an open-source platform consists of both a physical programmable circuit board (Microcontroller) and a piece of software IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board. [18]

Arduino also can be defined as a small microcontroller board with a USB plug to connect to computer and a number of connection sockets that can be Wired up to external electronics, such as motors, relays, light sensors, laser diodes, loudspeakers, microphones, etc. [19]

2.11.1 Brief History

In 2005, building upon the work of Hernando Barragán (creator of Wiring), Massimo Banzi and David Cuartielles created Arduino who developed the Arduino software, before long, Gianluca Martino and Tom Igoe joined the project, and the five are known as the original founders of Arduino.

They selected the AVR family of 8-bit microcontroller (MCU or μC) devices from Atmel and designed a self-contained circuit board with easy-to-use connections, wrote boot-loader firmware for the microcontroller, and packaged it all into a simple integrated development environment (IDE) that used programs called “sketches.” The result was the Arduino.

Since then the Arduino has grown in several different directions, with some versions getting smaller than the original, and some getting larger. Each has a specific intended niche to fill. The common element among all of them is the Arduino runtime AVR-GCC library that is supplied with the Arduino development environment, and the on-board boot-loader firmware that comes preloaded on the microcontroller of every Arduino board [18]

2.11.2 Types of Arduino

Over the years the designers at Arduino.cc have developed a number of board designs, with each passing year new types of Arduino boards appear and they can all be programmed from the same Arduino development software, so what is listed here is just a few examples. Table below shows some types of Arduino [19] [18]

Table 2. 2: ARDUINO TYPES

Board Name	***Year***	***Microcontroller***
Diecimila	*2007*	*ATmega168V*
Lily Pad	*2007*	*ATmega168V/ATmega328V*
Nano	*2008*	*ATmega328/ ATmega168*
Mini	*2008*	*ATmega168*
Mini Pro	*2008*	*ATmega328*
Duemilanove	*2008*	*ATmega168/ ATmega328*

Mega	*2009*	*ATmega1280*
Board Name	***Year***	***Microcontroller***
Mega 2560	*2010*	*ATmega2560*
Uno R3	*2010*	*ATmega328P*
Ethernet	*2011*	*ATmega328*
Mega ADK	*2011*	*ATmega2560*
Leonardo	*2012*	*ATmega32U4*
Esplora	*2012*	*ATmega32U4*
Micro	*2012*	*ATmega32U4*

Here are some extra specifications of the most common types of Arduino:

- **Arduino LilyPad**

The LilyPad was designed for wearable a8nd e-textile applications. It is intended to be sewn to fabric and connected to other sew able components using conductive thread. This board requires the use of a special FTDI-USB TTL serial programming cable.

Figure 2. 16 Arduino LilyPad port

- **Arduino Nano**

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 or ATmega168It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one.

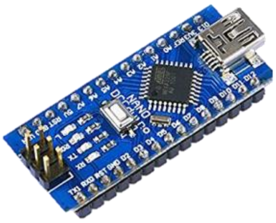

Figure 2. 17 Arduino Nano port

- **Arduino Mega**

The Mega is the second most commonly encountered version of the Arduino family. The Arduino Mega is like the Arduino Uno's beefier older brother. It boasts 256 KB of memory (8 times more than the Uno). It also had 54 input and output pins, 16 of which are analog pins, and 14 PWM pins. However, all of the added functionality comes at the cost of a slightly larger circuit board.

Figure 2. 18 Arduino Mega port

2.12 Related Works

The author in [2] designed affordable 3D printed prosthetic hand which is controlled by EMG sensor, EMG stand for Electromyography, the EMG can detect the signals that produced by contracting muscles. those signals had been used as controlling signals for the prosthetic hand movements. An 8-bit microcontroller from the Microchip PIC18F series has been used as the central computer for this system and programmed using C programming language. DC servo motors had been as actuators, and The artificial tendons were used as actuation methods

The author used CAD software to design the prosthetic hand module, and printed using 3D printer with ABS plastic material.

The prosthetic hand has six DoFs, and consists of thirty-six individual 3D printed components, which present in four fingers, thump, palm, wrist, arm, elbow and an arm socket.

The authors in [13] designed driving system of a car; controlled by signals acquired from brain's skull using EEG sensor, DC motors as actuators and Arduino IDE to create the controlling functions. Arduino UNO used as microcontroller. The authors targeted attention, meditation and Iblink to be the controlling signals which determine the car movement.

The values of each signal had been detected by single electrode Mindlink Mind Wave Headset, a HC-05 Bluetooth module used to receive the EEG values from the head set and send them to the Arduino controller by the serial port and displayed on Arduino serial monitor, after the processes that done on the received value the authors chose their acceptable values of meditation, attention and Iblink that match their needs to control the system.

The authors in [12] designed Robotic Arm controlled with Brain Computer Interfacing using an EMOTIV EPOC EEG Headset.

The system consists of five stages:

First: Signal Acquisition:

Signal acquisition is done by EMOTIV EPOC Headset, which has 14 electrodes, one electrode for each channel and it is powered by rechargeable lithium battery.

Second: Digital Filtering;

it uses sequential sampling method for sampling, the EEG output will be in the range of 0.2Hz to 45Hz, and it contains filter to reject and remove the noise from the power supply

Third: Training comparison:

The system is trained based on the signals acquired from the EEG Headset. The EEG signals corresponding to the various thoughts for movements. Those signals were recorded and analyzed in the EMOTIV CONTROL PANEL

Forth: Translational Algorithm:

EMOKEY is the software that enables execution of the translational algorithm. Rules will be defined for different features that have been extracted in the EMOTIV CONTROL PANEL. The system will behave according to these rules in a virtual environment.

Fifth: robotic Arm Control:

The output from the signal processing and the translational algorithm stage is in virtual reality of robotic arm real life system with the help of interfacing software called HYPERTERMINAL. Hyper terminal interacts with ARDUINO UNO R3 which is the Robotic arm controller via serial port where the characters are converted into blocks of four bits in parallel for transmission. ARDUINO development board can be programmed in such a way that whenever a particular keystroke has been received in the serial data pin then the controller should actuate that particular joint of the robotic arm so that the user intent is accomplished

CHAPTER III

SYSTEM DESIGN AND METHODOLOGY

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3.1 Preface

Chapter three provide readers with detailed specifications about design steps for the proposed system from the hardware point of view and the software point of view. And the characteristics of the components that had been used including electronic and mechanical components, the flow chart and the flow diagram of system were determined.

3.2 System Flow Diagram

The system flow diagram that is illustrated below in figure (3.1), shows the steps that the system goes through, from gathering data that produced by the head set to actuate motors and moves the hand fingers.

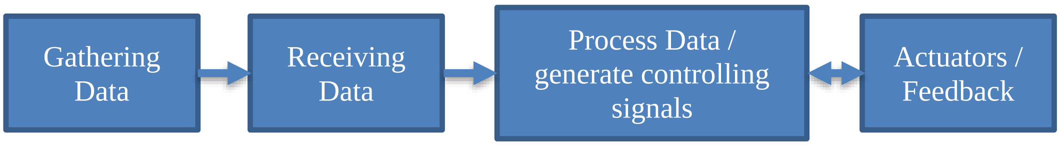


Figure 3. 1: SYSTEM FLOW DIAGRAM

3.2.1 Data Gathering

Data gathering means the process of detecting brain waves, preprocess and transmitting it.

This process is done by the NeuroSky mind wave mobile head set, NeuroSky headset send the acquired data via Bluetooth communication protocol, in the form of raw data which consist of the equivalent values of Attention level, Meditation level, Quality of data and the EEG frequency spectrums.

3.2.2 Receiving Data

A HC-05 Bluetooth module used to connect the NeuroSky head set with the system's CPU which is represent by Arduino UnoR3 controller, the HC-05 is act as an intermediate between those two, in which it receives the raw data from the NeuroSky and bypassing it into Arduino by serial port (USART).

3.2.3 Process Data / Generate Controlling Signals

The system CPU receives the raw data and start to particularizing it in order to determine the required values only, by using a special Arduino library produced by NeuroSky programming team -which is built in C programming language-, and in this proposed project's system only the values of Attention and Quality of data will be considered.

After obtaining the values of Attention and Quality of data, the system to compare their values to the preassigned constants, and depends on this comparing process the controlling signals will be afforded.

Beside of the raw data, Arduino microcontroller receive a signal from the feedback sensor indicates hand grasping situation and generate controlling signals upon it.

3.2.4 Actuators / Feedback

MG996r servo motors, artificial tendons are representing the actuating system, which take the responsibility of hand movement.

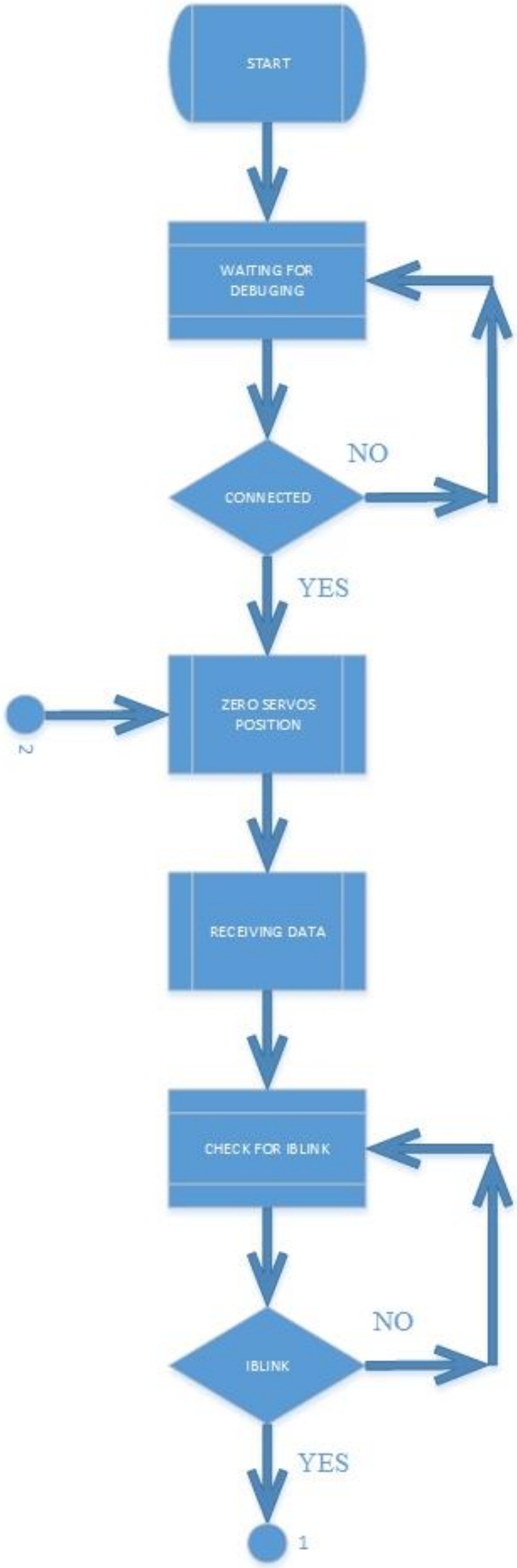
The servo motors receive the controlling signals through PWM pins at the Arduino port, according to the received signals motors will move and tension the artificial tendons in which it will cause a finger move.

A pressure sensors placed in fingertip provide a feedback signal to Arduino to indicate if the hand had grasped an object.

3.3 System Flow Chart

System flow chart presenting in figure (3.2), demonstrates the sequence of steps for the proposed system work, from a programming point of view. First the system will wait for the connection to headset, after receiving the raw data form NeuroSky headset the system will start to classify it determining Attention level and the Iblink event signal.

In addition, the pressure sensor is use to indicate the grasping state, according to the feedback pressure sensor signal, and both the Attention level and the Iblink signal the system will decide which action it will perform.


START
WAITING FOR DEBUGING
CONNECTED
NO
YES
ZERO SERVOS POSITION
2
RECEIVING DATA
CHECK FOR IBLINK
IBLINK
NO
YES
1

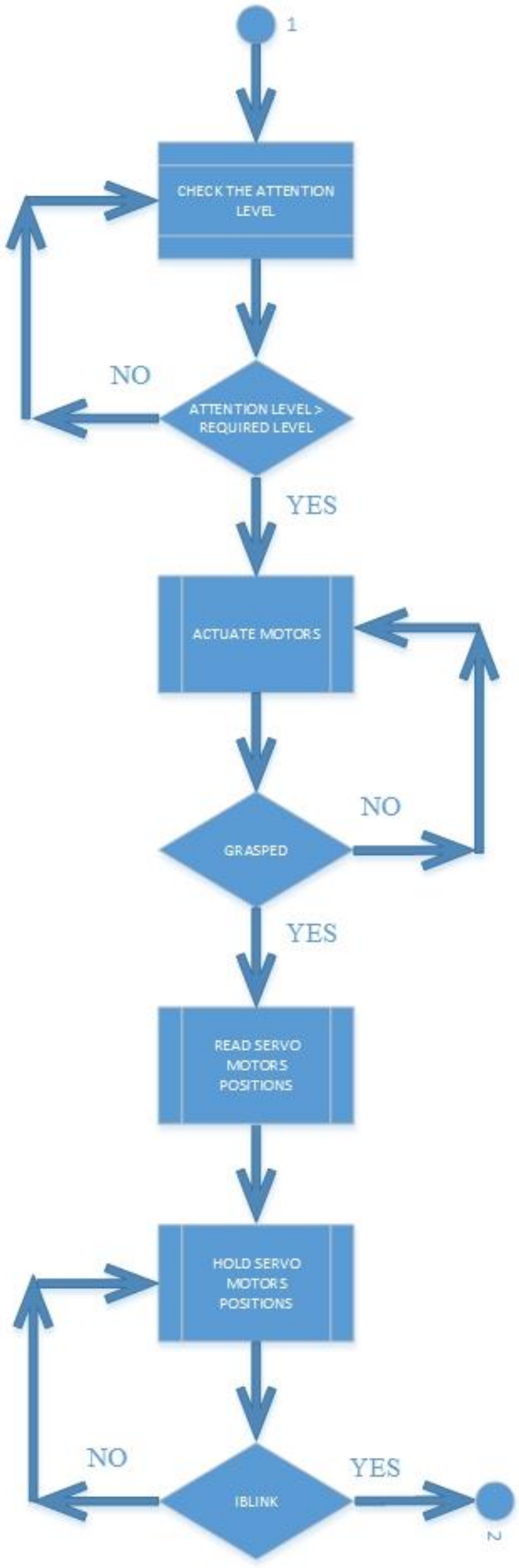


Figure 3. 2: SYSTEM FLOW CHART

3.4 Electronic Hardware Design

In this part of chapter three the electronic hardware components of the proposed project had been discussed including their characteristics and necessary specifications of each.

Hardware circuit components mean, all the electrical and electronic components that had been used in this project to achieve the ultimate goal, and it can be listed as following:

3.4.1 NeuroSky Headset

In 2004 the NeuroSky Company developed a new kit to replace the traditional EEG recording; NeuroSky Headset reads brain activity signals, where the signals are realized by only one dry electrode attached to the headset. The function of the electrode is to sense the changes on the electric field due to the neural activities in the different lobes of the brain, when one of the body part moves. These field changes can also be sense even when to think soft moving one of this particular body parts without moving it actually, just through imagination. [12] [15]

More probably, the range of brainwaves is from 0.5_{Hz} to 40_{Hz}. The EEG data captured with sampling rate 512Hz.By using a single electrode to detect the brain’s waves, this means understandably that the result will be thinner or smaller in comparison when using multiple electrodes for measuring the signal. [12] [15]

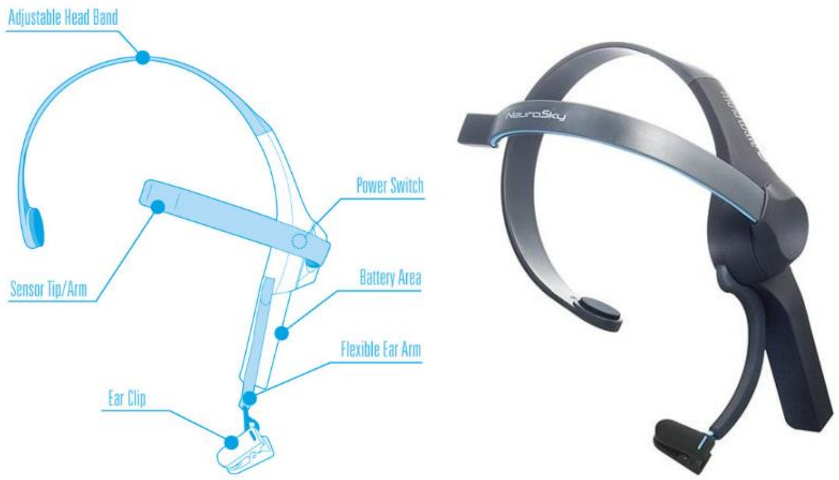


Figure 3. 3: NEUROSKY MINDWAVE MOBILE 2

The NeuroSky headset works on 3.3$_{V}$ and uses a dry sensor technology, meaning that there is no physical preparation to apply the electrode on the head. The headset integrates TGAM, ThinkGear ASIC Module, single chip EEG sensor, which is placed in the headset, to receive EEG signals, filter out the noise, amplify and convert to digital power.

3.4.1.1 NeuroSky Component

The NeuroSky headset mobile dimensions are (9.19x15.49x22.48) $_{cm.}$ And weight (86.18 $_{grams}$). Consisting of the following:

1. Dry Electrode:

Consist of single metal act as conductor between the skin and the electrode, this material is usually stainless steel. The dry electrode in the NeuroSky dives most be placed exactly at the FB1 location on the 10-20 system.

2. ThinkGear**:**

ThinkGear Connector is a middle component that receives EEG signals through an open socket. The technology is placed on the headset to read EEG signals, amplify it, translate it to binary raw data and send further through the ThinkGear Connector to present them to the developer by using its API. [15]

Through ThinkGear Stream Parser the developer can get the information, not just about the raw data, but also information about the subject's mood, attention and meditation, when receiving the EEG signal the ThinkGear uses an algorithm which calculates the signals and present the mood, or frequency band, or raw data that developer is asking for. Possible outputs are presented as following:

i. Poor Signal Level: integer value in range 0-100 indicating the quality level of the signal. If 0 the signal is good, if 100 indicate that the subject doesn't wear the headset.

ii. Raw EEG: the raw data that is either an integer or floating value. The raw data is actually a signed 16-bit integer, where the value can be in the range from -2048 to 2047. Streaming communication is at 57 600 baud rates.

iii. eSense: is a package representing meditation or attention levels based on the integer values, ranging from 1 to 100. Meditation levels correspond to integer values found in the first half of the interval 1- 100, and attention in the second half of the same interval:

- Attention- increased attention gives higher integer value.
- Meditation- increased meditation gives smaller integer value.

iv. EEG Power: is a package containing 8 different EEG frequency bands. The output is represented with eight 4- byte floating point numbers

- Delta: (0.5- 2.75) Hz
- Theta: (3.5- 6.75) Hz
- Low-Alpha: (7.5 – 9.25) Hz
- High-Alpha: (10- 11.75) Hz
- Low-Beta: (13- 16.75) Hz
- High-Beta: (18- 29.75) Hz

- **ThinkGear Packet Structure**

ThinkGear packet structure consists of three parts: Packet Header, Packet Payload and Payload Checksum, as presented in Table (3.1). The Header part is divided in two sync packet values (SYNC) and one packet length value (PLENGTH). The PLENGTH tell us the number of bytes (the length) of data payload. The (PAYLOAD) data can be up to 169 bytes long. The checksum packet (CHKSUM) is one byte long and is calculating the checksum to verify the validity of data payload packet parsing. [15]

Table 3. 1 ThinkGear packet structure

Header	Payload	Checksum
[SYNC] [SYNC] [PLENGTH]	[PAYLOAD]	[CHKSUM]

3) AAA Battery:

A triple ‘A’ battery is standard size of dry cell battery, have 44.5mm in the length and 10.5mm in diameter, weight around 11.5grams. A zinc-carbon battery in this size is designed by IEC as R03, and this type commonly used in low-drain portable electronic devices.

3.4.2 HC-05 Bluetooth Module

HC05 Bluetooth Module is an easy to use (Serial Port Protocol) module, designed for transparent wireless serial connection setup. which makes an easy way to interface with controller or PC.

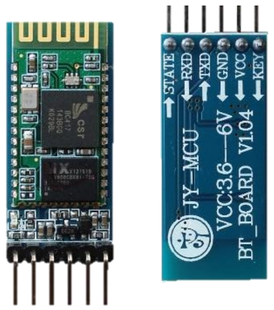


Figure 3. 4: HC-05 BLUETOOTH MODULE

HC05 Bluetooth module provides switching mode between master and slave which means it able to use Neither receiving nor transmitting data.

The Bluetooth module is using 3.3V or 5V logic, has 6 pins, 2 for power, 2 to establish connection, to enter configuration mode and the other to know the connection state. Table (3.2) shows HC-05 module specifications and table (3.3) shows pins definition.

Table 3. 2 : Specifications of the HC-05

Module	HC-05
Input voltage	3.3V / 5V DC
Communication method	Serial Communication
Master and slave mode	Switched

Table 3. 3 : HC-05 pins definition

Pin	Function
VCC	*Connect to +5v or 3.3v, providing the module with the required logic level*
GND	*Connect to Ground*
Tx	*Connect with the MCUs RXD PIN, use to transmitting data from the module*
Rx	*Connect with the MCUs TXD PIN, present the entry pin for incoming data*
Enable	Use to indicate the mode of the module
State	The state pin is connected to on board LED, it can be used as a feedback to check if Bluetooth is working properly
Button	Used to control the Enable pin to toggle between data and command mode.
LED	Indicated the status of module, entered command mode, waiting for connection, successfully paired and entered data mode

3.4.3 Arduino UNO R3

Is a microcontroller board based on the ATmega328, The Arduino Uno has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started, the most common version of Arduino is the Arduino Uno. [18]

Figure 3. 5: ARDUINO UNO R3 PORT

Arduino UNO R3 specifications presenting on the table (3.2) below:

Table 3. 4 Arduino UNO R3 specifications

Microcontroller	ATmega328P-AU
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6 pins
DC Current per I/O Pin	40 Ma
DC Current for 3.3V Pin	50 Ma
Flash Memory	32 KB and 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz
Maximum Length and Width	6.9 Length and 5.5 Width (mm)

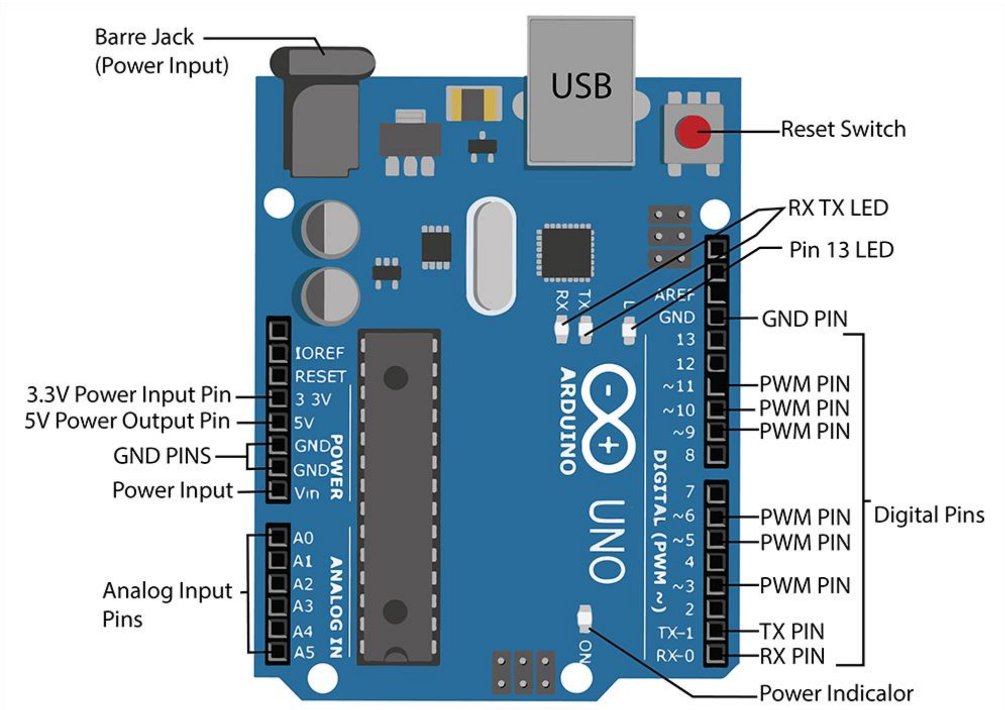


Figure 3. 6: ARDUINO UNO R3 PINS

3.4.4 MG996R Servo Motor

The MG996R is a metal gear servo motor with a maximum stall torque of 11Kg/cm, stable and shock proof double ball bearing design. like other RC servos the motor rotates from 0 to 180 degree based on the duty cycle of the PWM wave supplied to its signal pin. MG996R servo

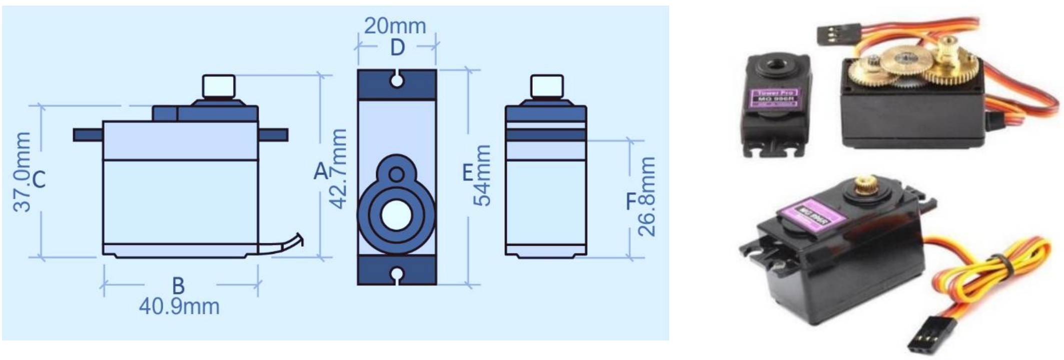


Figure 3. 7: MG996R SERVO MOTOR

motor features illustrated in the table (3.5) below:

Table 3.5: MG996R servo motor features

Operating voltage	**4.8V - 7.2V**
Running Current	**500Ma**
Stall Current	**1400Ma**
Operating Speed	**0.17s/60̊ (4.8V) or 0.14s/60̊ (6V)**
Stall Torque	**9.4Kg/cm (4.8V) or 11Kg/cm (6V)**
Dead Band Width	**5µs**
Weight	**55g**
Dimensions	**40.7×19.7×42.9 mm approximately**

3.4.5 Pressure Sensor

Force Sensing Resistors, or FSRs, are robust polymer thick film (PTF) devices that exhibit a decrease in resistance with increase in force applied to the surface of the sensor. This force sensitivity is optimized for use in human touch control of electronic devices such as automotive electronics, medical systems, and in industrial and robotics applications.

Features and Benefits

1. Actuation Force as low as 0.1N and sensitivity range to 10N.
2. Easily customizable to a wide range of sizes

3. Highly Repeatable Force Reading; As low as 2% of initial reading with repeatable actuation system
4. Cost effective
5. Ultra-thin; 0.45mm
6. Robust; up to 10M actuations
7. Simple and easy to integrate

Table 3. 5: FSRs Specifications

Actuation force	0.1 Newtons	
Force sensitivity range	0.1-10.0 Newtons	
Force repeatabilty (singal part)	2%	
Force resolution	Continuous	
Force repeatabilty (part to part)	6%	
Non-Actuated Resistance	10M W	
Size	18.28mm diameter	
Thickness Range	0.2-1.25 mm	
Stand-off Resistance	>10m ohms	Unloaded, unbent
Swith Travel (Tipical)	0.05 mm	Depends on design
Hysteresis	+10%	(R –R)/R
Device Rice Time	<3 microseconds	Measured w/steel ball
Long Term Drift	<5% per log (time)	35 days test ,1kg load

Temp Operating Range (Reconnended)	-30-+70 C	
Number off Actuations (Life time)	10 Million tested	Without failure

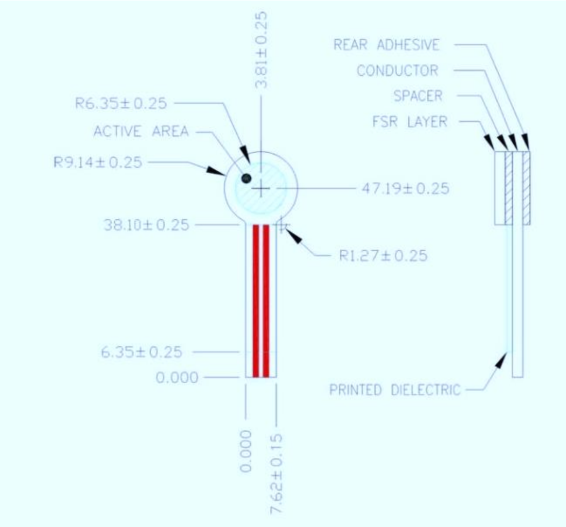


Figure 3. 8: PRESSURE SENSOR FSRs

3.4.6 Power Supply

Having an electronic circuit requires by definition some sort of power supply to make it work, and there are many types power supplies. Since the proposed design is for a portable system, so a small size with the compatible range of power should be chosen.

While servo motors consume large amount of current even when they are in idle mode beside the voltage that required to operate Arduino.

Relating to this two reasons the amount of the voltage and current the battery could provide in addition with the small size and weight should be in consideration.

A portable rechargeable power supply had been chosen for the proposed project, with 5 volts output with 20000mAh capacity. This battery is use to energize Servo motors; a 9-volt replaceable lithium battery is used to operate the Arduino port.

3.5 Mechanical Design

The basic design of the hand module was inspired by inMoov, inMoov is a website concerning in the robotics field generally, which provide robotic parts designs designed by Computer Aid Design programs (CAD), able to be fabricated using 3D printer.

The hand module consists of four fingers made up with similar design concept, one thump, palm, wrist, and arm which consider as a holder for the electrical and electronic components.

All of the hand parts were printed in CREALITY 3D printing machine using PLA material.

3.5.1 Finger Design

Because all the fingers were made with the same design concept, and have the same number of joints, mechanism of actuate and the number of degree of freedom, so only one finger design will be discussed.

Each finger printed in three individual parts proximal phalanx, middle phalanx, and distal phalanx, each part is assembling with the other by using polypropylene pin, the link point between any two part or between the distal phalanx and the palm represent finger joint. So each finger has three joints two between the finger parts and one joint between the finger and palm.

Artificial tendons extended inside each finger, from the servo motor placed in the arm to the fingertip, use to drive the actuation caused by the servo motor, then force the joints to rotate depending on the amount of rotation in the servo motor and causing a motion to fingers.

3.5.2 Thumb

The Thump have operation mechanism similar to fingers mechanism, because the Thump considered as the most complex part in human hand architecture, also it plays a significant role at the process of grasping and manipulating objects, so most commercial and research prosthetic hands aim to provide at least two degrees of freedom in the thumb. This thumb however only provides a single degree of freedom – it can only open/close in a single way.

3.5.3 Palm

Act as a holder for the hand fingers and the thump, printed in four individual parts; one for the little finger MCB joint, one for the Ring finger MCB, one for the other two fingers MCB and the last one is Thump MCB, attached to the palm with 3D printed pins.

3.5.4 Forearm

Forearm have no moving parts it used as a holder for the circuit components, which provide a holder for Arduino and power supply, servo motors table and tendons path holes. After the complete forearm section was designed it had to be split into separate components which could then be assembled with screws, this will enable you to attach the circuit components easily.

3.6 Over All System

Over all system design discusses the assembling process of the hand components, the servo motors torque calculations, fingers moving speed, hand lifting/holding capacity and calculate the needed power for the entire system to operate.

3.6.1 Assembling Process

The assembling process of the hand parts is complex and quite challenging and consuming a lot of time, also it requires several tools to be accomplish. Extending the tendons through their path holes and adjustment the servo motors movements require precision and patience.

Super glue, screws and polypropylene pins were used to attached hand parts together, for the fingers and thump a 3_{mm} drill may be used to improve diameter accuracy, polypropylene pins were applied between the joints and a drop of the super glue poured on it.

The tendons of each finger are spread through the finger, palm, wrist to the finger's servo motor horn figure $_{(3.9)}$, carefully so that they don't cross over each other.

Figure 3. 9: SPREADING TENDONS THROUGH FINGERS

For the forearm the two large part of it were aligned and glued together, servo bed and the Arduino holder were attached on their position, servo motors arrayed on the servo bed and screwed after passing their wires inside the wires holes, figure $_{(3.10)}$. The Arduino port glued on its holder after it screwed in the forearm.

Figure 3. 10: ATTACHING SERVO MOTORS AT THE FOREARM

Furthermore, the tendons were attached on the servo motors horn each on its corresponding servos, fingers were placed on their opening position and the edge of their tendons are well tied.

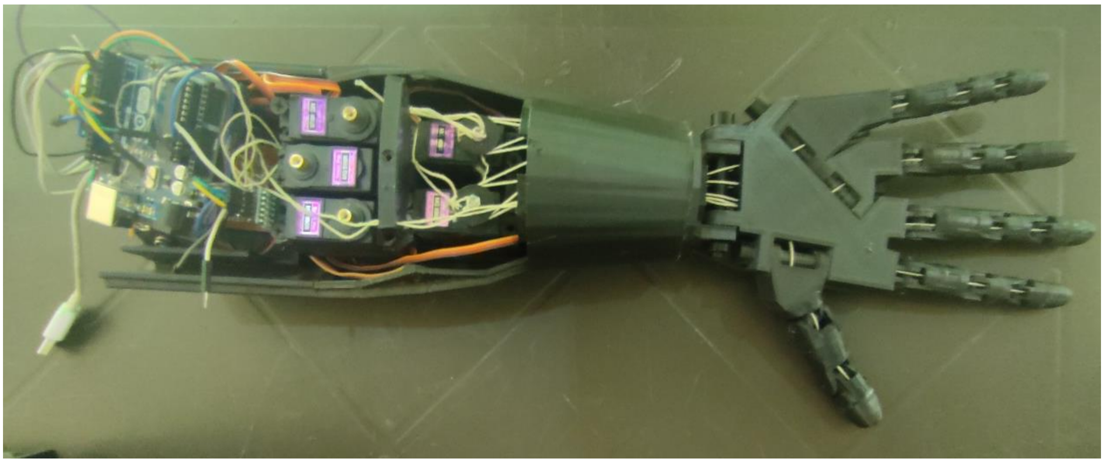


Figure 3. 11: THE FINAL FORM OF THE MODULE

3.6.2 Servo Motors Calculations

Includes the servo motors power consumption, and for how long does the battery stand before it need to be recharged, the amount of torque for each finger, and the possible total lifting/holding loads. Beside the finger actuation speed.

- **Servo Motors Power Consumption**

Assume that each servo need at least 500mA to operate, so the minimum amount of current the power supply should provide to supplies all 5 motors is equal to 2500mA.

Known that the stall torque of the servo motor is 1400mA, the stall torque current is the amount of current that the servo consuming it while holding or lifting loads, then total current that consumed while the hand is grasping or lifting an object is equal to 7000mA.

With system's power supply that have 20000mAh capacity, the hand will operate for a total of 8-hours, equation and can grasp one object for almost 3-hour continually before the battery need to be recharge.

- **The Amount of Torque for Each Finger**

Each servo motor has a proximity 9.4 Kilograms per each centimeter torque (0.95N/m) while the 5V power supply is used.

the index finger had been choosing to calculate the maximum lift-able load, assume that the finger is full extension, the lift-able load can be calculated as:

let,

$F_1 \equiv$ tension force in the tendons, $F_2 \equiv$ the force in the finger tip

$D_1 \equiv$ MCP radius, $D_2 \equiv$ distance from the center of MCP to the finger tip

F_1 = servo motor Torque × servo motor horn radius……

$F_1 = 0.95 \times 10 = 9.5$ N

$F_1 \times D_1 = F_2 \times D_2$, from Newton 3d low …

so $F_2 = (9.5 \times 7.5) \div 85 = 0.84$ N

or the maximum amount of lift-able load that one finger can handle when fully extension is 84 grams, in the normal hand moves when try to grasped or lift an object the fingers curl on in this object, so when the finger curls the distance between the fingertip and the center of the MCP will decreased to 30_{cm}, increasing the amount of lift-able load per finger to almost 287 grams, producing 1_{Kg} of total lift-able load.

- **Servo Motors Rotation Speed**

The MG996R servo has an operating speed of 0.15sec/60̊. A full finger rotation from open hand up to closing hand position (160̊) therefore takes 0.4s.

3.7 System Simulation Design

The system simulation discusses the equivalent controlling circuit of the proposed system which explaining the way the proposed system will work, build using Proteus8 professional program.

Proteus circuit simulation software use to design, test and debug embedded projects, it has various libraries for the different electronic and electrical components. [21]

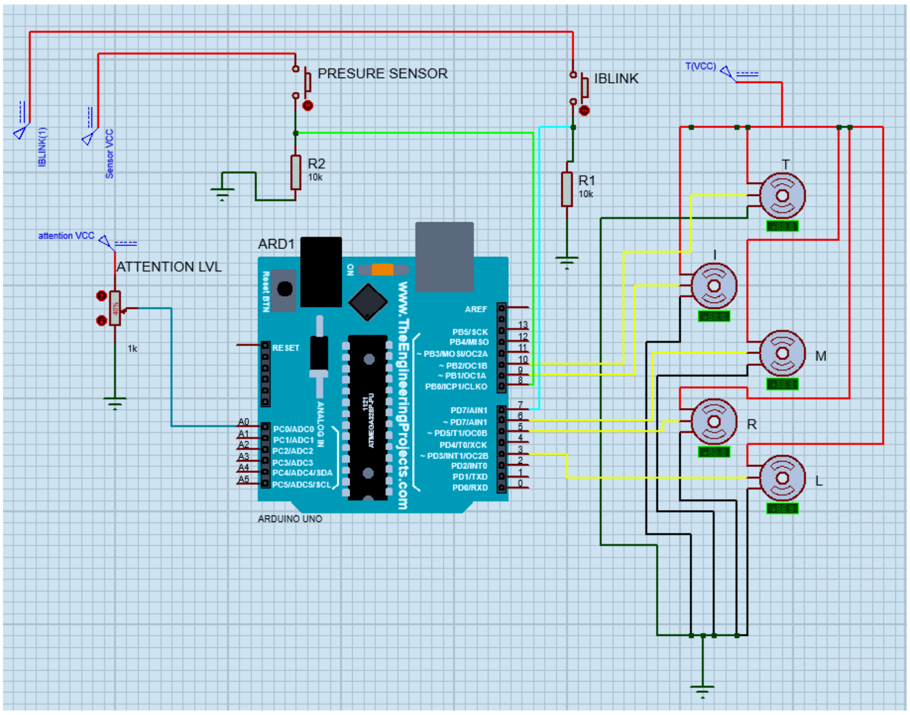


Figure 3. 12: EQUIVALENT SYSTEM CONTROL CIRCUIT

Despite of the varied libraries the Proteus software has, the NeuroSky headset cannot be represented on the simulation circuit during to some kind of deprivation, so a potentiometer was used instated, figure (3.9) illustrate the equivalent circuit which consist of five servo motors have a rotation range from 0° to 180° representing the actuation system.

Servo motors were energized by a 6V DC power supply in parallel connection, and linked to Arduino port by the PWM pins as shown in the above figure and as discussed before.

Two push buttons were used to overcome the deprivation in the software, one to replace the Iblink event signal that comes from NeuroSky headset, and the other is to indicate the grasping signal instead of pressure sensor, each one of them was supplied by 5V DC current and connected to the Arduino at pin 11, pin 12 respectively.

The main signal that is responsible of actuate the motors comes from the potentiometer which is represent the attention level. The potentiometer ranges from 1023 to 0 ohms. The potentiometer linked through pin A_0 to Arduino port.

Arduino Uno R3 represent the main CPU in the proposed project, which receives the input signals from the potentiometer and the two push buttons, generating controlling pulses in order to move servos according to functions and commands that had been loaded inside it's microcontroller.

3.8 System Implementation Design

After the compatible electronic components had been chose according to the system needs, and assembling the hand parts and placing the components as discussed in the previous sections of this thesis, and cover all the needed knowledge to complete implementing those components, the electronic circuit had built as following:

First, after the Arduino was placed and screwed in the forearm, a 9V battery attached and supplied the port through the barre jack as external power supply.

Then, HC-05 Bluetooth module configured in cross-way with Arduino port as figure (3.10) by connecting the Tx pin of the Bluetooth with the Rx of the Arduino, and the Rx of the module with the Tx of the Arduino, in order to receive the data from the head set. The VCC of the module connected to 3.3V pin and the ground to the Arduino GND pin.

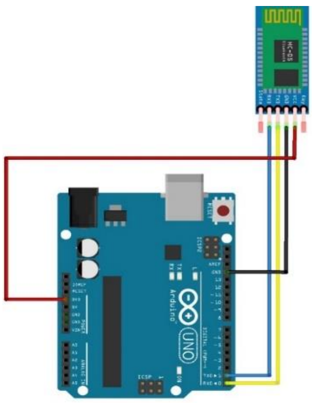


Figure 3. 13: BLUETOOTH - ARDUINO CONFIGURATION

As been discussed before, a rechargeable regulated external power supply had been used to energized the servo motors, the power and the natural lines of the battery soldered on a Printed circuit board, servo motors power and natural lines connected to the power supply in parallel. And the signal wires of servos were connected to the PWM pins as showing below.

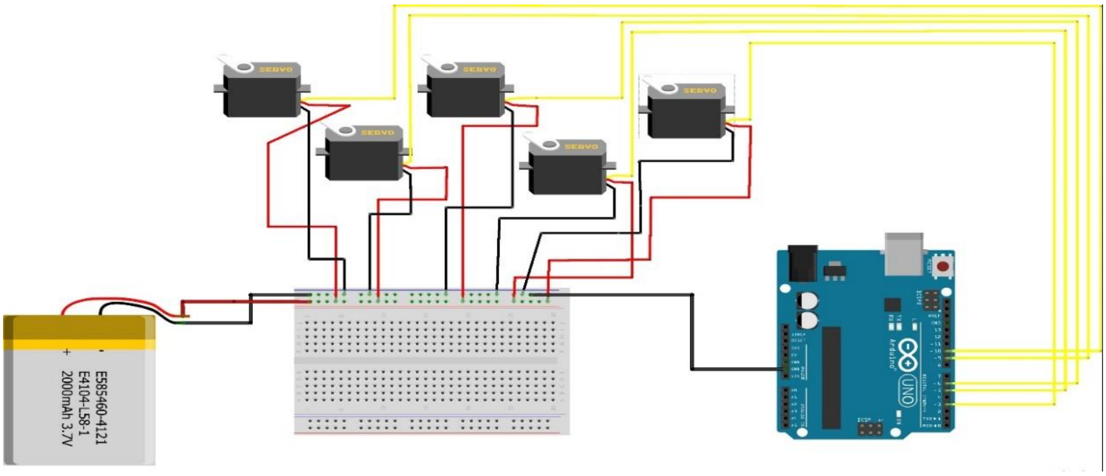


Figure 3. 14: SERVO MOTORS – ARDUINO CONFIGURATION

The pressure sensor attached to the finger tip of the prosthetic hand module, energized from the 5V pin of the Arduino port

3.9 Methodology

Discuss the way in which the system will work, including the simulation equivalent circuit and the implemented hardware circuit, providing the expected results for both.

The way that the servo motors will be actuated and causing hand movements depends on the response of Arduino microcontroller to the signals that it will receive either from the NeuroSky headset or the pressure feedback sensor.

A pair of mind wave signals that detectable by NeuroSky headset had been chose to represent the controlling signals of the proposed prosthetic hand, which are attention level and Iblink.

Several experiments have been done on ten subjects from both gender with a range of ages between 21 to 56 years, in order to determine the appropriate attention level, the subjects result as following:

```
15:45:47.600 -> the signal quality level is..
15:45:47.645 -> 88
15:45:48.630 -> the attention level is..
15:45:48.630 -> 64
15:45:48.630 -> the signal quality level is..
15:45:48.630 -> 88
15:45:49.593 -> the attention level is..
15:45:49.593 -> 64
15:45:49.593 -> the signal quality level is..
15:45:49.637 -> 88
15:45:50.629 -> the attention level is..
15:45:50.629 -> 64
15:45:50.629 -> the signal quality level is..
15:45:50.629 -> 75
15:45:51.630 -> the attention level is..
15:45:51.630 -> 60
```

Figure 3. 15: 56 YEARS OLD FEMALE ATTENTION AND IBLINK READINGS

Figure (3.12) shows the attention and the signal quality for a 56 years old female, the maximum amount of attention the user could handle is 64 and this is in her first time using the device, the signal quality with the value 88 was provided by one Iblink and with the value 75 was provided by two Iblinks.

Figure (3.13) display the recorded values of attention and Iblink for a 29 years old female, as shown the values of attention varied between 75 and 88 and for one time reach 100. The Iblink is the same for booth subjects.

```
15:28:35.630 -> the attention level is..
15:28:35.630 -> 75
15:28:35.630 -> the signal quality level is..
15:28:35.630 -> 100
15:28:36.599 -> the attention level is..
15:28:36.647 -> 100
15:28:36.647 -> the signal quality level is..
15:28:36.647 -> 100
15:28:37.629 -> the attention level is..
15:28:37.629 -> 88
15:28:37.629 -> the signal quality level is..
15:28:37.629 -> 100
15:28:38.646 -> the attention level is..
15:28:38.646 -> 88
15:28:38.646 -> the signal quality level is..
15:28:38.646 -> 75
15:28:39.629 -> the attention level is..
15:28:39.629 -> 84
15:28:39.629 -> the signal quality level is..
15:28:39.629 -> 100
```

Figure 3. 16: 29 YEARS OLD FEMALE ATTENTION AND IBLINK READINGS

From the results that illustrated above, the appropriate level of attention and convenient to be used had been found in range of 68% to

75% of its final value. And the 70% from the attention final value had been chosen as the required level of attention to move the motors.

The level of attention is use to control servo motors rotation, as the attention level increase and reach the required level of concentration the rotation degree of motors increase.

Iblink means the intentionally movement of an eye by closing and opening it. In order to detect the Iblink event the NeuroSky electrode most placed in the FP1 location at the forehead according to 10-20 electrode placement system, near to the eyebrow.

The ThinkGear Connector ignore the unintentionally Iblink sending only the intentionally ones, which appear as poor signal level (signal quality) in Arduino serial monitor.

The signal quality ranged from 0% to 100%, zero percent means the user is not wiring the headset properly, and hundred percent means a good signal quality. The intentionally Iblink reduces the quality of signal depending on the strength and the amount of Iblink itself, one Iblink reduce the signal quality to 81% and two Iblink reduce it to 74%, this is the range of the Iblink that had been used.

As declared above the attention level could be increased only by increasing concentration or even focusing in specific thought. Therefore, Iblink had been used as an operation condition for the system, so that the attention level shall not take any effect on moving servo motors unless Iblink was detected at the specific determined level.

For the simulation circuit the NeuroSky headset had been replaced with a potentiometer to represent attention levels and a push button to indicate Iblink event, and a second push button to indicate the hand grasping state as declared in figure (3.7).

Arduino microcontroller receive the values of the potentiometer, mapped it in range between 0 to 180 which understandable by the servo motors, these mapped values represent the rotation degrees and passes to the servos if and only if a high level signal occurred in the pin 11 representing the Iblink level and the hand is not in grasping mode, the grasping mode indicated by high level signal in pin 12 passed by another push button represent the feedback sensor.

When initiate the simulation Arduino start by reading the state of each Iblink push button and feedback sensor push button, according to their values the Arduino operate one of the below scenarios:

The first one if Iblink was high it will keep reading the value of the potentiometer mapping it and then write the mapped values to the servo motors, the Arduino microcontroller keep repeating these three commands while the is no signal indicate that the hand entered the grasping mode.

When a high level signal came from the feedback sensor push button, and the hand had grasped an object, the Arduino microcontroller will read the position of the Index finger servo motor and write it to the all servos and keep writing it, holding the object the user decides to release the object by generating Iblink, when Iblink became a high, Arduino microcontroller write zero to all servos releasing the object.

For the implemented hardware circuit, the HC-05 module act as intermediate between the NeuroSky headset and Arduino port, which receives the EEG data and upload it to Arduino microcontroller through Tx and Rx pins.

The system will start by checking the connection between Arduino port and the NeuroSky head set after the connection is established, Arduino start to classifying the received data and choose signal quality (which determine the Iblink events) and attention level as the mind wave controlling signals.

Preset values for booth attention and Iblink -had been stored in the Arduino microcontroller- which determine the required level of attention in order to move the hand and the system operate condition as the Iblink.

After the connection is established and the system start to receiving data, the microcontroller will wait for Iblink event to present, when the user produces an Iblink the system will execute on of the following scenarios:

If the received attention value was below the required level the system will keep checking the received values until they reach the preset level, when it became in or above the required level of concentration, and the hand was not in grasping mode, the Arduino microcontroller will start to move servo motors from their zero position to full closing hand, or until the feedback sensor indicate that the hand already had grasped an object.

If a high level signal was generated by the feedback sensor, the microcontroller will stop the servos from moving and start to read the index and thump servos position, and keep holding those two values for the all other fingers servos, these ensure that the servos will not move and the hand shall hold tied on the grasped object, regardless of the attention level in this state.

In order to release the grasping object, the user need to produce anther Iblink, when Arduino receives an Iblink while the hand is in grasping mode, it will state for returning all servos to their zero positions, the fingers will start to open and releasing the grasped object.

CHAPTER IV

RESULT AND DISCUSSION

CHAPTER IV

RESULT AND DISCUSSION

4.1 **Preface**

4.2 **Simulation Result**

4.3 **Implementation Result**

4.4 **Prosthetic Hand Specifications**

CHAPTER IV

RESULT AND DISCUSSION

4.1 Preface

The final system result as a bionic hand controlled by the amount of the attention that the user provides, plus the sensory feedback which help in the process of grasping objects.

After the process of designing, programming and implementing, this hand provides one DOF for each finger and one DOF for the thump, with total of five degree of freedoms that result in opening and closing in addition to grasping.

In the fourth chapter of this thesis the result of the simulation design and the result of the implemented system had been discussed, including the specification of the bionic hand.

4.2 Simulation Result

The equivalent circuit worked and preformed exactly as it designed to, the motors moved to the corresponding value of the potentiometer input if there was an Iblink event. Figure (4.1)

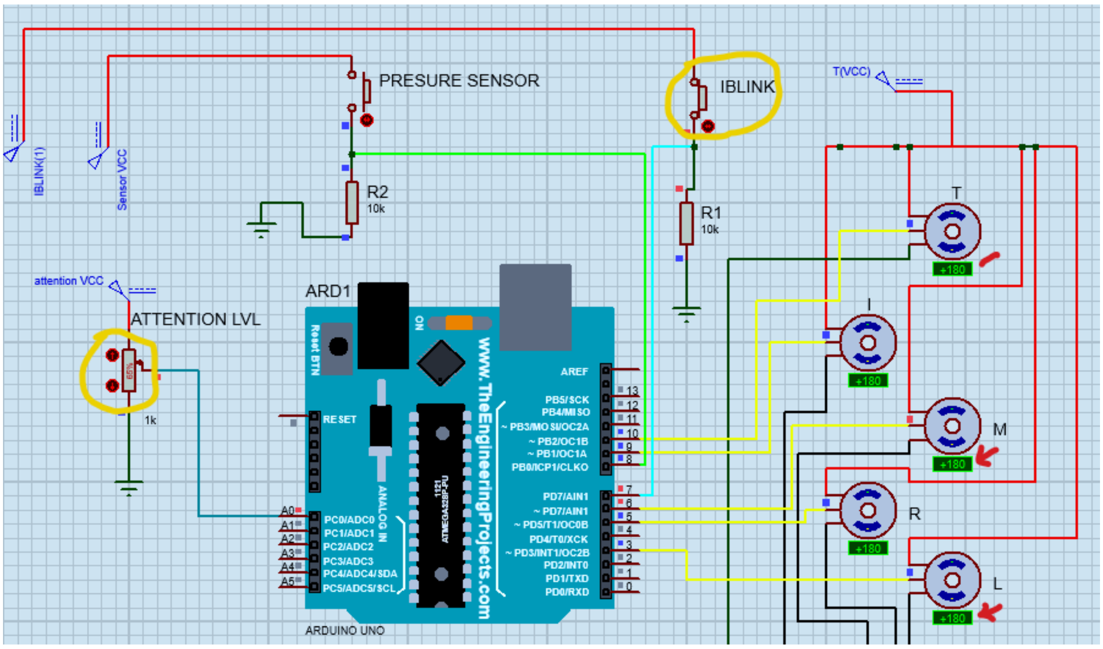


Figure 4. 1: EQUIVALENT CIRCIUT SIMULATION RESULT

As showing in the figure (4.2), regardless of the change in the attention level the servos rotation degree will not change until an Iblink activated.

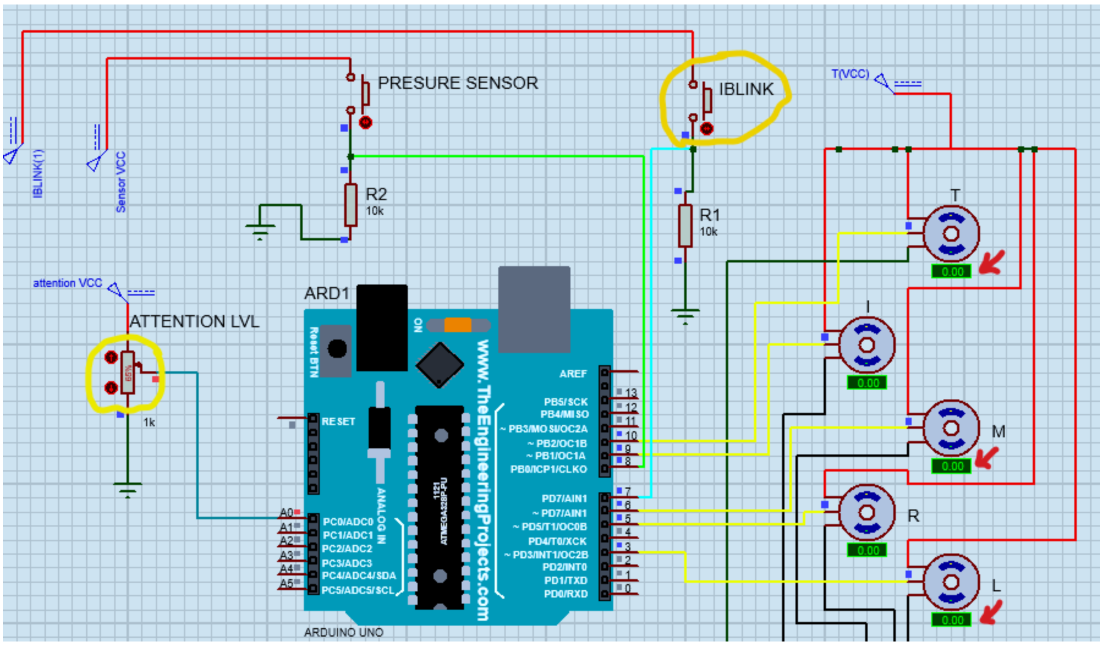


Figure 4. 2: EQUIVALENT CIRCIUT SIMULATION RESULT DEPENDING ON IBLINK VALUE

When the feedback sensor push button pressed, Arduino hold the last position of servo motors and keep writing this position on them which is representing the grasping process.

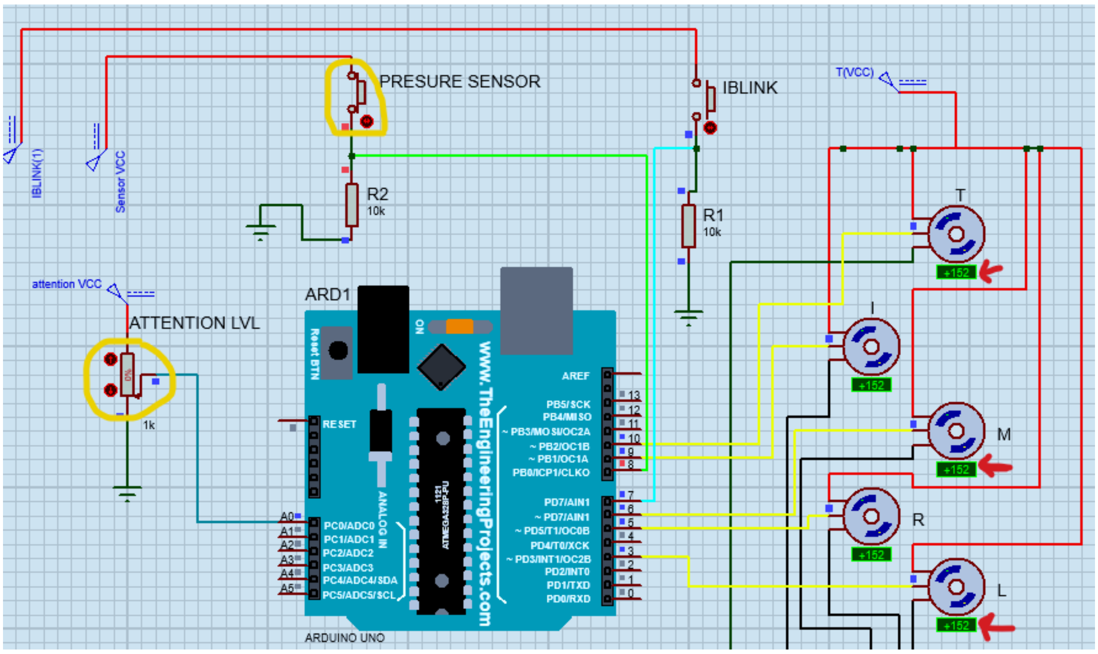


Figure 4. 3: EQUIVALENT CIRCIUT SIMULATION ENTERING GRASPING MODE

As showing in the figure (4.3) above when the feedback sensor is high indicating that the hand is grasping an object, Arduino enter grasping mode saving the last servos position, despite of the amount of attention that received the servo will remain still.

In order to release the object, the Iblink push button is pressed, when press the Iblink while the servos are in grasping mode, Arduino returns all servos to their zero position, and the system will standby be waiting for anther Iblink to start the sequence all over again.

4.3 Implementation Result

The final result of this project arises as an anthropomorphism prosthetic hand capable to do three simple moves, depending on the controlling signals it receives.

The first move is closing the hand, known that the normal position of the hand is opened, so after the user generate an Iblink and the attention level exceed the required level the servo motors start to move clockwise and tension the tendons which move the fingers in turn.

The fingers move were acceptable and the joints response to the tension was smooth, the servos keep turning until the hand is full closed, or the feedback sensor generate a signal indicate that the hand had grasped an object this situation leads to the next stage which is grasping object.

The servo motors response to the feedback sensor signal was reasonable take in consideration the delay time that the Arduino take to process this signal. And the hand keep holding the object.

After the user decide to release the object and generate an Iblink, the servos start to move counter clockwise slowly slipping the grasped object until they reach their zero position producing hand opening stage

4.4 Prosthetic Hand Specifications

For the final prosthetic hand after implement the component, running the system and testing it, had resulted in a five degree of freedom hand, in which each finger is actuated individually with eight hours' battery life. Table $_{(4.1)}$ illustrates more specifications about the prosthetic hand. And table $_{(4.2)}$ shows the parts cost.

Table 4. 1: PROSTHETIC HAND SPECIFICATIONS

Hand Specification	Description
Type	Right Prosthetic Hand
Dimensions $_{(cm)}$	50 × 16.5 × 10
Actuator	5 MG996r Servo Motors
Artificial Tendons	0.55 $_{mm}$ waxed Thread
Microcontroller	Arduino UNO R3
Number of Degree of Freedom	Five Degree of Freedom
EEG Sensor	NeuroSky Mobile 2
Power Source	9v Disposable battery for Arduino and a rechargeable 5v with 20,000$_{mA}$ capacity battery for Servos

Table 4. 2: PROSTHETIC HAND COST

Part	Cost
3D Printing	**134$**
Arduino R3 port	**32.4$**
HC-05 Bluetooth module	**3$**
Power Supplies	**47.6$**
Tendons	**1$**
Electronic Tools	**3.5$**
MG996R Servo motors	**16.5$**
Total Cost	**238$**

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

5.2 Recommendations

5.1 CONCLUSION

The final design of this project had achieved most of its academic goals, in which the hand module is similar to the adult human hand in shape and dimensions, the control actions that the user have to produce in order to operate the hand are simple, represented in the amount of concentration and the intentional Iblink, which provide an easy use of the hand, the ease of using hand increase by the time the user spent in using it, so he/she will learn to control his/her attention level in better way.

The designed prosthetic hand is able to provide three basic moves which are opining the hand, closing the hand and grasp an object, which are more than simple compering to the moves that the human hand is capable of.

The final design of the hand module suffers from some flaws due to some circumstances as describing below:

1. **Limited Data Gathering**

The system use NeuroSky headset to detect the EEG signals from the brain, the NeuroSky use single electrode to detect those signals, due to the sensing capability of a single electrode the amount and the accuracy of the gathered data are bounded.

2. The Impact of Environmental Conditions

Since the NeuroSky headset is a non-invasive BCI approach, the electrode of the NeuroSky is placed at the forehead skin, so the stability of the electrode reading will be effected by the environment situation that the user is in, for example sweating will effect electrode placement. Note that this impact has limited influence in the system efficiency compering with the others.

3. The Usability of the Module

This hand module is usable by amputees who lost his right upper limp from the elbow or a little below the elbow, and the only moving parts are the fingers, so this module have a large non required space, this non required space is used to carry or as a holder for the electronic components and the actuating system (servo motors), beside this space the size of the electronic components effected on the total weight of the module.

5.2 Recommendations

In order to enhanced the overall system efficiency and to detraction the impact of the flaws that discussed above, some of the following recommendations could be used:

1. **Increasing the Number of Electrodes**

   By using a multi electrode EEG device measuring the brain signals from different locations in the skull increase the accuracy and amount of gathering data that can be used for the control functions.

2. **Use the Half-Invasive BCI**

   In half invasive BCI, the electrodes are placed underneath the scalp, creating slightly better signal gathering and it will not be directly affected by the environmental conditions.

3. **Enhanced the Electronic Circuit**

   Enhancing the electronic circuit can be done for example by using a custom servo motors that can be fit inside the palm instead of the big size MG996r motor, and instead of Arduino Uno port a Microcontroller or a Microprocessor can be used, this changes will reduce the unused part of the hand and decrease its weight.

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