**Palestine Polytechnic University**

**College of Engineering**


# Design and Implementation of a Bionic Hand Controlled by Hand Gestures

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Submitted to the College of Engineering
in partial fulfillment of the requirements for the
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**Palestine Polytechnic University**
**College of Engineering**
**Electrical Engineering Department**

# Design and Implementation of a Bionic Hand Controlled by Hand Gestures

**Project Designer:**

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**Based on the system of the College of Engineering and Technology, and by the guidance of project supervisor and by the approval of the members of the examining committee, this project was submitted to the department of electrical engineering to meet the requirements of a bachelor's degree in Biomedical Engineering.**

**Project Supervisor Signature**

……..

**Committee Signature**

…… ……

**Department Headmaster Signature**

…….

**جامعة بوليتكنك فلسطين**
**كلية الهندسة**
**دائرة الهندسة الكهربائية**

# تصميم وتنفيذ يد آلية حيوية (بيونيك) يتم التحكم بها بواسطة إيماءات اليد البشرية

**منفذ المشروع:**

بيان نصار

**بناء على نظام كلية الهندسة والتكنولوجيا ومتابعة المشرف على المشروع وموافقة أعضاء اللجنة الممتحنة، تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية، وذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة الأجهزة الطبية.**

**توقيع المشرف**

.....

**توقيع اللجنة الممتحنة**

..... .....

**توقيع رئيس الدائرة**

.....

# الإهداء

قال لامية ابن الوردي:

أطلبُ العِلمَ ولا تكسَلْ فما *** أبعدَ الخيرَ على أهلِ الكَسَلْ

واحتفلْ للفقهِ في الدِّين ولا *** تشتغلْ عنهُ بمالٍ وخَوَلْ

واهجرِ النَّومَ وحصِّلهُ فمنْ *** يعرفِ المطلوبَ يحقرْ ما بَذَلْ

لا تقلْ قد ذهبتْ أربابُهُ *** كلُّ من سارَ على الدَّربِ وصلْ

في ازديادِ العلمِ إرغامُ العِدى *** وجمالُ العلمِ إصلاحُ العملْ

إلى طلاب العلم

إلى أصحاب الهمم

إلى ذوي الأفق الواسع

إلى الحريصين على التطور المستمر

إلى الباحثين عن المعرفة بشتى مصادرها

إلى الراغبين في الإبداع أهدي هذا الكتاب

# Abstract

The human hand is one of the complex organs in biomechanical perspective, it consists of 27 skeleton bones and allows up to 30 degrees of freedom (DOF).

Attempts to imitate the human hand movements were very expensive or cumbersome, so the studies carried out in order to model the human hand motions have found link between the various joints of finger, the human usually cannot bend the top joint of the finger without bending the joint next to it.

Using this knowledge the model is built, that allows 15 degree of freedom related to each other and therefore can be activated using 6 actuators only.

The hand gesture controlled bionic hand is a project which can be used in many of applications, it use as humanoid robotic hand to train the hands of those who suffer from weakness of the muscles of their hands as a result of amputation or as a result of a stroke which in this case is used as a support structure for rehabilitation, treatment by using right hand to help improper hand and in the places unsafely of human which exist in it and as surgical arm.

The project includes the idea of sending signals from normal hand which contain many of sensors into bionic hand which simulate normal hand in some movements by using wireless technology where contains actuators and these operations are controlled by using microcontroller.

There are humanoid robots which mimic many of the human movement( face, arm, legs, eyes and so on), in this project the goals have been dramatically increased to design a bionic hand which mimic the normal hand in rotational motion of wrist and flexion and extension of fingers.

# ملخص المشروع


اليد البشرية هي واحدة من الأعضاء المعقدة في المنظور الحيوي الميكانيكي، وتتكون من 27 عظمة من الهيكل العظمي لجسم الإنسان وتسمح عادة بالتحرك لغاية 30 من إمكانيات الحركة (درجات الحرية).

كانت محاولات تقليد حركات اليد البشرية مكلفة جدا أو مرهقة، لذلك الدراسات التي أجريت من أجل إيجاد نموذج يحاكي حركات اليد البشرية وجدت صلة بين مختلف المفاصل من الإصبع، والبشر عادة لا يمكنهم أن يحنوا أعلى مفصل من الإصبع دون إنحاء المفصل الذي يليه.

باستخدام هذه المعرفة تم بناء النموذج لهذا المشروع، الذي يسمح بالتحرك لغاية15 درجة من الحرية متعلقة ببعضها البعض، وبالتالي يمكن تفعيل هذه اليد الآلية باستخدام 6 من المحركات فقط.

مشروع اليد الآلية المتحكم بها عن طريق الإيماءات الحيوية التي يصنعها الإنسان تستخدم في العديد من المجالات، في المجال الطبي كذراع جراحي و لإعادة التأهيل وتدريب أيادي الذين يعانون من ضعف بعضلات أيديهم نتيجة البتر أو نتيجة إصابتهم بجلطة. في هذه الحالة لإعادة النشاط لأيدهم يمكن الاستعانة باليد السليمة وتدريب اليد الغير سليمة على الحركة، كما ويمكن استخدام اليد الآلية في الأماكن الخطرة على الإنسان التواجد فيها وجعل تلك اليد تتحرك في هذه الأماكن والتحكم بها لاسلكيا عن بعد.

يشتمل هذا المشروع على فكره إرسال إشارات من اليد الطبيعية التي في هذه الحالة مجهزة بالعديد من المجسات الحركية إلى اليد الآلية التي تحاكي بعض حركات اليد الطبيعية باستخدام تقنية الاتصال اللاسلكي حيث تحتوي هذه اليد على المحركات لتحريك المفاصل بحيث يتم التحكم بهذه العمليات باستخدام متحكم برمجي.

هناك روبوت كانسان آلي, الذي يحاكي العديد من حركات الإنسان (الوجه،الأذرع،الأرجل،العيون والعديد من الحركات)،في هذا المشروع الأهداف حددت لتصميم يد آلية تحاكي اليد الطبيعية في حركات الأصابع انحناء واسترخاء، حركة الرسغ الدورانية.

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# Abbreviations

**LED**: Light Emitting Diode

**RF**: Radio Frequencies

**Rx**: Receiver

**Tx**: Transmitter

**FTDI**: Future Technology Devices International

**DOF**: Degree Of Freedom

**PWM**: Pulse Width Modulation

**DOUT**: Data Output

**DIN**: Data Input

**PLA**: Polylactide

**MC**: Microcontroller

# List of Pieces

| Component | Quantity | Cost (NIS) |
|---|---|---|
| **Servo Motor** | 6 | 240 |
| **Bending Sensor** | 6 | 476 |
| **Xbee Module** | 2 | 170 |
| **Xbee Explorer Regulated** | 2 | 110 |
| **Xbee Explorer USB** | 1 | 85 |
| **Print hand parts** | 40 | 600 |
| **Op amp, Resistors, Capacitors** | 30 | 10 |
| **Total Cost** | 1691 NIS | |

# Chapter One

# Introduction

**1.1 Project Overview**

**1.2 Project Objectives**

**1.3 Literature Review**

**1.4 Project Importance**

**1.5 Task Time Schedule**

**1.6 Project Content**

## 1.1 Project Overview

Human movements have been studied intensively by engineering for several reasons [1] with cooperation with doctors [2][3]. Rehabilitation, treatment, and analogy are among the interesting motivations.

An example of the analogy is the humanoid robot. The research in this area has been dramatically increased on how the robot can mimic the human from several aspects such as walking, running, action-reaction response[4], In this project, the hand movements be studied to design a bionic hand which can be used in many fields such as to help people which suffer from weakness in hand muscles.

There are many bionic hands that are attached to people. But, the main problem is that they can't control that bionic hand, so they need the ability to control and move these limbs. The natural hand gestures can be utilized to move the bionic hand and control it.

The expression "Bionic" is one of the branches of engineering where engineers try to imitate nature to solve engineering problems such as the study of the wing of birds led to solve the problem of flying through the design of the wing of the plane, so it infers the mix of the fields Biology and Electronics to design vital models that benefit humans such as bionic hand, bionic man, bionic eye and bionic leg.

To design a bionic hand that copies the movement and gesture of the human hand wirelessly. The control of this hand is done through amount number of electric bending sensors sewed into each finger of a glove and at wrist joint, and these sensors senses the movement of finger and palm, and the output of these sensor is transmitted to the bionic hand. The bionic hand simulate the natural hand, which is contain joints have to be bend as human fingers bend.

Also, this hand can be applied in other places such as the places that dangerous on human, because of humans cannot have direct contact with everything; many of materials can cause harm to the human body, such as toxins, radioactive material [5] and could be applied in surgical field and control for a distance with some developments on it.

## 1.2 Project Objectives

The main objective of the project is to design and implementation of a bionic hand to be controlled by hand movements in order to create a useful system that works efficiently to translate the hand gesture into movement of the bionic hand. Which is the microcontroller programmed to eventually move the bionic hand as a natural hand, and to use wireless technology between transmitter and receiver circuits.

**The project objectives can be summarized in the following:**

1) Construction the glove for captures the hand movements.
2) Design a Bending sensor circuit to convert the bending motion of bending sensors into rotational motion of servomotors (transmitter circuit).
3) Design a processing circuit of signals that is taken from sensor.
4) Implement a processing module for controlling in signals.
5) Implement a communication module for transfer signals from transmitter circuit to receiver circuit.
6) Design and building of a light weight, prototype 3D robotic hand to simulate The working of bionic hand using servo motors.

## 1.3 Literature Review

The following are some studies that have been published in several of international papers and journals.

- **Study #(1):**

  **Research title:** Real-time speech recognition system for prosthetic arm control.

**Made by:** Piyush Samant and Ravinder Agarwal, EIED, Thapar University Patiala, India, Int. J. Sensing, Computing & Control ,Vol. 5, No. 1, pp. 39-46, 2015.

In this study, the prosthetic arm is designed and implemented by 3D printer technology and controlled by voice, a voice recognition unit was used to control the arm movement using five from voice commands. This prosthetic hand with two degrees of freedom in elbow and palm is designed with the help of gear DC motor, which has the ability of simply picking up and placing the objects.

- **Study #(2):**

  **Research title:** Gesture controlled robotic surgical arm (GCRSA).

**Made by:** Jayaramaraja B, Meiyappan AN, Naveen Lakshman Land RamanathanS Department of Electronics and Communication Engineering, St. Joseph's College of Engineering, Old Mamallapuram Road, Semmencherry, Chennai 600 119.

This research paper primarily focuses on Arduino controlled Humanoid arm which can be used in surgical processes that operated by surgeon, this Humanoid arm will be a substitute for those experts at their proximity. The fine movement in the finger movements are sensed by the Accelerometric sensor and flex sensor whose actions are replicated by servos. In this study, accelerometer sensor is used to determine the direction the arm, also flex sensor is used to copy the movement of the surgeon into the arm, by this method, the surgical arm controlled by surgeon gestures. This arm has 6 DOF at elbow, wrist, and shoulder.

**Results from previous studies:**

After studying the numerous methods in which an artificial hand could be controlled by different methods. It can control in it through voice, biomedical signals such as brain signal and muscle signal, smart devices work on android system, in this project the objectives were set so as to control the bionic hand to simulate natural hand in movements using gestures by bend sensors and motors due to their inexpensive nature and ease of interface with the microcontrollers.

## 1.4 Project Importance

The project is very important, because it can serves not only people who are paralyzed by hand, it can work in medicine field as telesurgical robotic hand if we work and develop some tasks on bionic hand that use for performing the surgery by surgeon at a remote site.

**The project importance can be summarized in the following:**

- The wireless hand could be found useful in environments where it is dangerous for humans. In space or places such as hazardous radioactive environments is where the robotic hand would be useful.

- The bionic hand can also be helpful to physically disabled patients who have limited locomotory capabilities. According to a study in the United States, it is found that approximately 1 in 50 people or 5,596,000 people suffer from paralysis [6].

- The wireless artificial hand could be used as a surgical device. The surgeon can be able to control its movement using the sensors and the hand performs surgery on the patient.

- People who are paralyzed by hand to re-strengthen the muscles of their hands can use the right hand to return activity to the paralyzed hand

## 1.5 Task Time Schedule

In this section of the project, the automatic distribution of tasks needed to implement the project during the year is shown in the following tables.

**Table1.1 Tasks Scheduled Table (First Semester)**

| Time(Weak) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project Definition | | | | | | | | | | | | | | |
| Collecting data | | | | | | | | | | | | | | |
| Analysis | | | | | | | | | | | | | | |
| Theoretical Calculation | | | | | | | | | | | | | | |
| Documentation | | | | | | | | | | | | | | |

**Table1.2 Tasks Scheduled Table (Second Semester)**

| Time(Weak) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Collecting components | | | | | | | | | | | | | | |
| Building and testing the system | | | | | | | | | | | | | | |
| Analysis | | | | | | | | | | | | | | |
| Documentation | | | | | | | | | | | | | | |
| Prepare for presentation | | | | | | | | | | | | | | |

## 1.6 Project Content

The content of the documentation of the project is divided into six chapters; each is briefly explained as following:

### Chapter 1: Introduction

This chapter presents overview, literature review, objectives, importance of project and project scheduling.

### Chapter 2: Description of Hand Movement and Applications of robot

This chapter includes knowledge about: the hand structure, biomechanical movement of hand at freedom, applications of robotic system (industrial robot, medical robot "da vinci robot").

### Chapter 3: Project System Design and Analysis

This chapter contains the project components, General block diagram of the project were discussed and features between components were introduced.

### Chapter 4: Project Implementation and Simulation

This chapter explains the principle of operation of each of the system and simulation of each circuit.

### Chapter 5: Results and Analysis

This chapter discusses the results corresponded with this project.

### Chapter 6: Recommendations and Challenges

This chapter discusses the challenges that included in the project and recommendations for future improvement which related with the project.

# Chapter Two

# Description of Hand Movement and Applications of Robot

## 2.1 Introduction

The human locomotor system is very important because without it no human can move or do any work. So, the upper and lower limbs of human. It is important to move and pick up things. Therefore, the hand can not be considered as a higher limb only, but rather part of the upper limb involves (shoulder region, arm, forearm, hand).

The human hand is a grasping tool. It is quickly adaptable to perform various complex functions. So, hand is part of upper limb.

There are several functions of the human hand:

- Pick up the things that surround about human.
- Make human able to realize things around it through the sense of touch.
- Hand gestures have a large meanings can use to communicate with others.

In this chapter, study of human movements are discussed and how these gestures can be used in control of other things

## 2.2 Hand Structure [7]

The important structures of the hand can be divided into several categories. These include:

- bones and joints
- ligaments and tendons
- muscles
- nerves
- blood vessels

❖ **Bones and Joints**: There are 27 bones within the wrist and hand. The wrist itself contains eight small bones, called carpals. The joint is to connect bones with some.

The carpals join with the two forearm bones, the *radius* and *ulna*, forming the Wrist joint. Further into the palm, the carpals connect to the *metacarpals*. There are five

metacarpals forming the palm of the hand. One metacarpal connects to each finger and thumb. Small bone shafts called *phalanges* line up to form each finger and thumb [7]. See Figure (2.1)

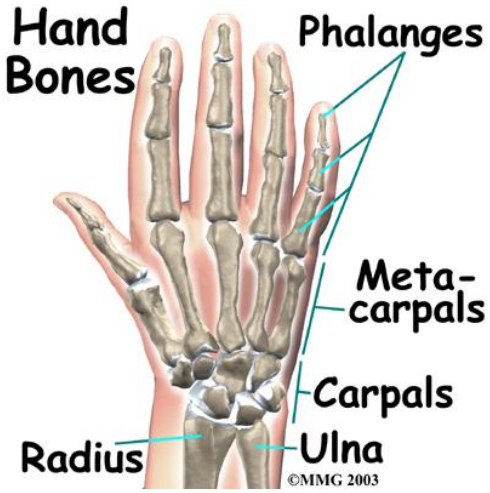



**Figure 2.1: Bones and Joints of Human Hand [7]**

- **Ligaments and tendons**: are tough bands of tissue that connect bones together and exist at every joint and these joints all are movable.
- **Muscles, Nerve and blood vessels**: muscles that control the hand movement start at the elbow or forearm. These muscles contract and extend when nervous signals come it so, the bending or straightening of the hand occurs. Blood vessels to supply the hand with blood and reach oxygen and food into tissues [7]. See Figure (2.2)

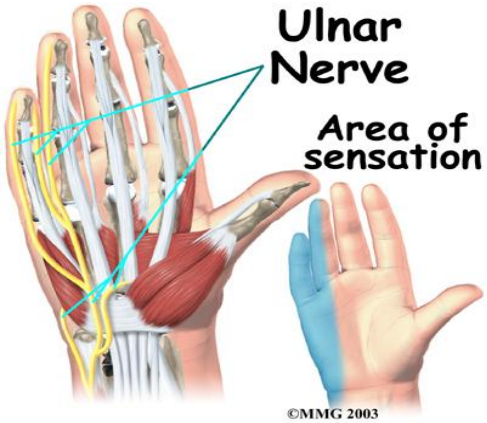



**Figure 2.2: Nerves and Muscles of Human Hand [7]**

## 2.3 Description of Movement for Hand

The hand gesture has signs and meanings that have been studied over time since ancient times. They were used to communicate between humans and to interpret several meanings before learning to speak. In this project, these gestures will be used to control an artificial hand to move fingers, wrist in hand as the normal hand moves.

There are many of movements that describe the movement of hand include the following:

- **Flexion and Extension**

  Flexion: is bending movement in which a relative angle decreases. The relative angle is the included angle between two adjacent segments.

  Extension: is a straighten movement in which relative angle increases, as the segment return to original situation.

- **Abduction and Adduction**

  Abduction: movement away from the mid line of the body and equivalent lateral.

  Adduction: the movement toward the mid line of the body and equivalent medial

  And these the movements of the hand can be seen as in Figure (2.3)

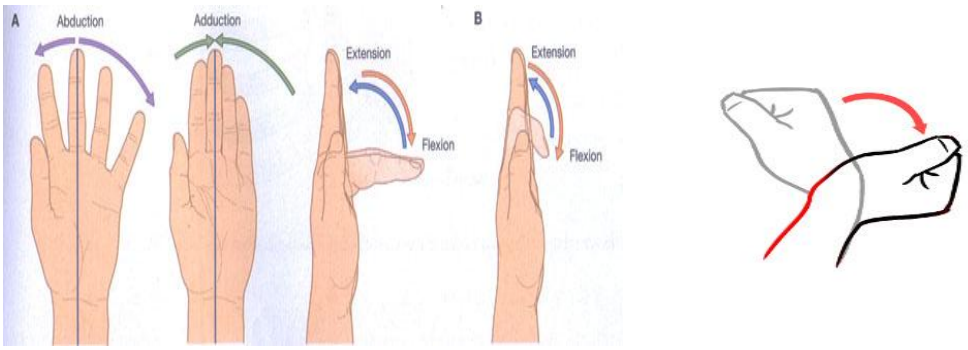



**Figure 2.3: Movement Description of Hand [8][9]**

## 2.4 Introduction of Robots

**Definition of Robot:**

Robot is simply a smart electromechanical machine that works by automatic programming by through direct control of the human and often used by the computer software to do some tasks which is performed manually. The activities that human can work to be performed are usually hard Such as the search for mines and outer space and the cleaning of waste generated in nuclear reactors. More precisely, the robot is not merely a machine to replace man but performs functions that require:

- High accuracy especially in surgical field, doctor can feel tired during the operation and with using robotic arm and control far away in this robot can be good working.
- Repetition as in industrial field such as (packaging, removal of spoilages).
- To perform difficult and unsafe tasks of human as radioactive material.

## 2.5 Application of Robotic system

### 2.5.1 Robot in Industry

Robot is an important tool in supporting production, development, quality and productivity because the robot is doing all its tasks such as transportation, welding, assembly and quality inspection sophisticated motor system and advanced software technologies, the tasks performed are accurate, quality.

### 2.5.2 Medical Robot

Robot systems help disabled people. Scientists have been able to invent a robotic arm that senses nerve impulses from the brain with the necessary movement so that a person can live a natural life; also as medical robot is telesurgical robot that similar this project.

### 2.5.2.1 Da vinci Robot (Telesurgical Robot)

Is surgical robot can use to perform the surgery under controlling of surgeon doctor and this control can be performed by using hand gestures of doctor, and this is one of the greatest advances in medicine. In this type of modern technical operation, surgical procedures and devices are used computer and three-dimensional digital high-definition imaging to see doctor the operation at a distance and the use of internet devices where the doctor surgeon performs the procedures by remote control. See figure (2.4)

Thus avoiding vibrations of the surgeons because they feel tired during an accurate surgery, which represents a significant risk of patients during surgery.

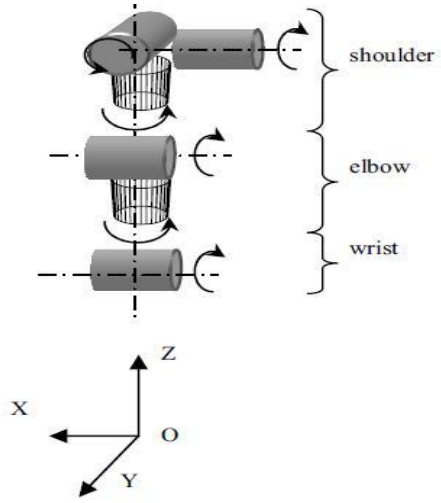



Fig. 2 The model of humanoid robot arm

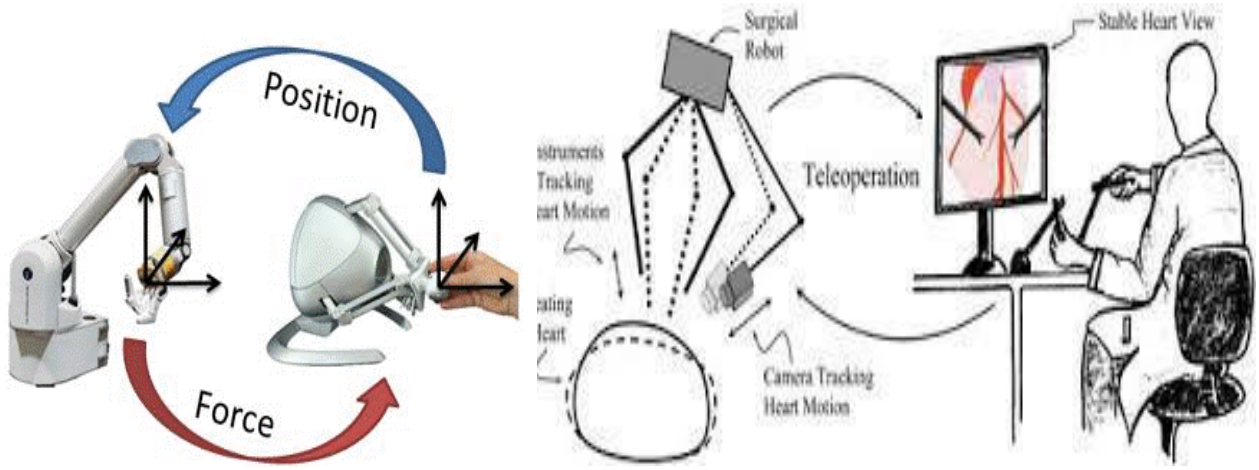
**Figure 2.4: The Model of Surgical Arm [10]**

### 2.5.2.2 The Mechanism of Da vinci Robot

Da vinci robot is not like the other robots, it is a sophisticated technology in the world of surgery offering high quality and effective features.
Da vinci robot is not independent and does not work alone and can not perform surgery alone. It is not a doctor it is telesurgical device which can be moved remotely and is undergo to the supervision and management of the specialist doctor.

It is a sophisticated mechanism in the hands of the surgeon where the movement of the hand is made by a specific doctor and the robot doing the same movement and if the doctor removed his hand stops the work of the robot so, this robot can simulate the movement of doctor hands. See Figure (2.5)

This robot is a very sophisticated technology and was manufactured by American company (Intuitive Surgical) in 2000 year.




**a.** Surgical Arm **b.** Imitation Movement

**Figure 2.5: Da vinci Robot and Transfer Movement from Hand of Doctor into Arm[10][11]**

### 2.5.2.3 Features and Benefits

Da vinci robot has a many of advantages and features that is made work in surgical fields and these features as following:

- ❖ The Da Vinci Robot has many features in terms of image, accuracy and motion, besides the three-dimensional image that doctor can see the place of operation it conveys and the improved hand movement by the computer and this computer can take hand movement and programming this movement to be transferred to robotic arms at patient.

- It can enter difficult places within the human body during normal surgeries.
- The surgery is characterized by this robot by less palm and aesthetic results better and does not work cracks and large wounds as in the normal surgeries.
- The patient does not need to be in bed and stay in hospital for a longer period because he recovers quickly because cracks and wounds are less.
- The control in this robot through hand gesture of doctor makes it easy.

Despite of the many of the advantages of this robot, there are some disadvantages and these as following:

- The cost of this robot is very high and up to three million dollars so, the hospitals can not have it.
- It takes a very large place in the operations room.
- The cost of maintenance and equipments is great.

# Chapter Three

# Project System Design

**3.1 Introduction**

**3.2 General Block Diagram for Project**

**3.3 Transmitter Circuit and Receiver Circuit**

**3.4 Hardware Components for Project**

- **3.4.1 Bending sensor**
- **3.4.2 Control Glove**
- **3.4.3 Microcontroller Board**
- **3.4.4 Xbee Module**
- **3.4.5 Xbee Explorer Regulated**
- **3.4.6 Servo Motor**
- **3.4.7 Xbee Explorer Board (USB)**

**3.5 Power Supply System**

**3.6 Design of Bionic Hand**

**3.7 System Flowchart**

## 3.1 Introduction

In order to design the electronic circuit, it is necessary to identify the most important components of the circuit, so through this chapter the most important components used in the project and its features are discussed.

The comparison between components exists to explain the best to be used.

## 3.2 General Block Diagram

The description of system components for building a model to simulate hand is shown in the following Figure (3.1) that contains general block diagram of the project.

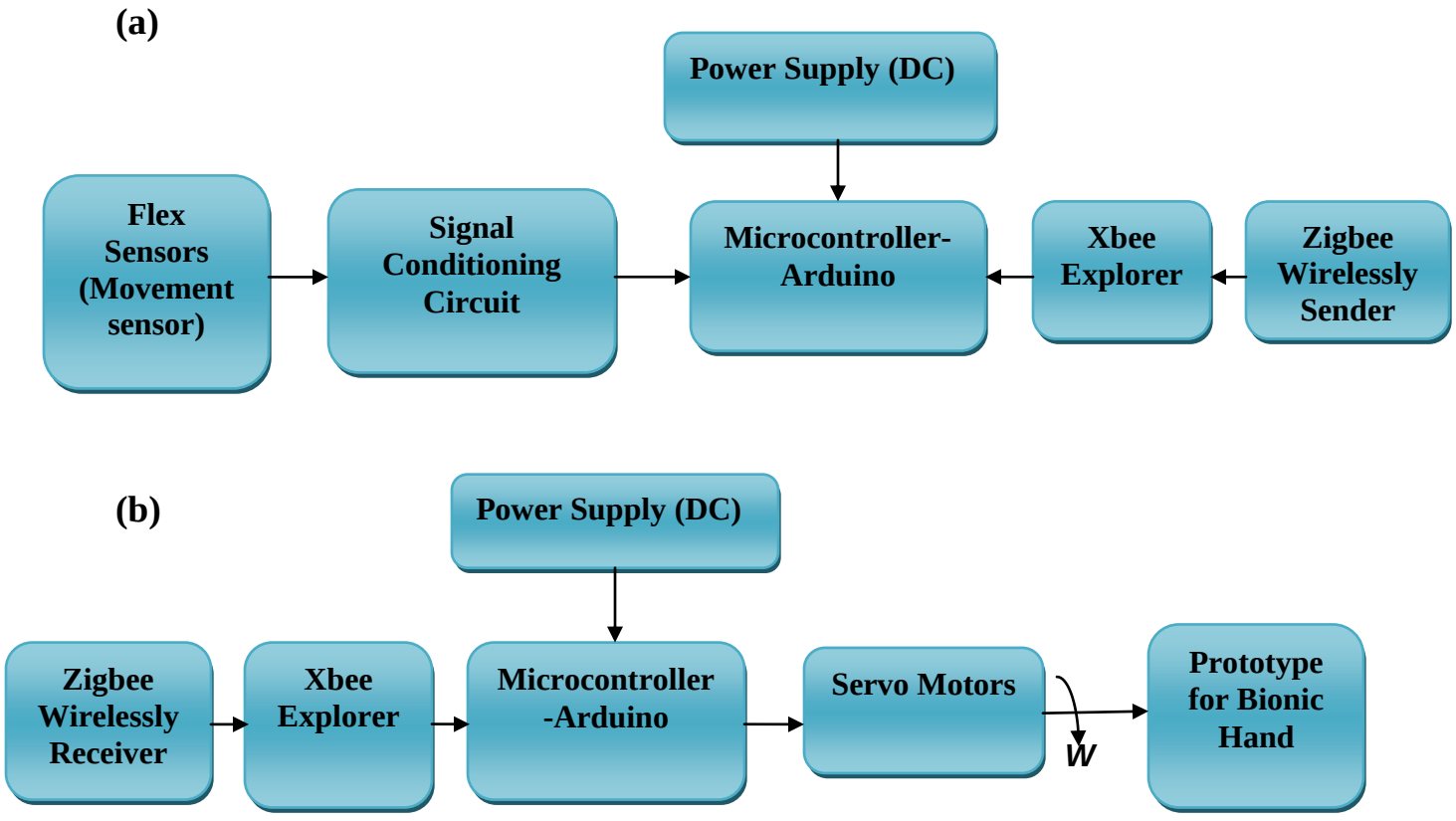



**Figure 3.1: General Block Diagram (a) Transmitter Circuit (Sensing Circuit), (b) Receiver Circuit (Actuator Circuit)**

## 3.3 Transmitter circuit and receiver circuit

- **The Transmitter Circuit (SENSOR):**

The transmitter circuit is mounted on a control glove that is worn at the right end of the hand. This glove contains the sensors, these sensors are called electric bending sensors sewed into each finger of a glove and sewed at wrist joint, and these sensors senses the movement of finger and palm, each sensor has the ability to know the angle to flex the finger and the output of these sensor gives the change in resistance.

After taking the change in resistance through sensors, the change in voltage is required so that these sensors are connected with the voltage divider circuit to take the voltage that corresponds to the change in the angle of the fingers and wrist flexion. This voltage that is taken through sensors does not DC voltage perfect, there some noise that can affect on signals so processing of these signals are performed on two stages.

The first stage is amplification of signal to be able of programming through arduino board. The second stage is noise reduction circuit that through it the noise that affect into signals is removed.

Then signals are transformed from transmitter circuit to receiver circuit wirelessly by using zigbee technology for large range up to 100 meters.

- **The Receiver Circuit (ACTUATOR)**

The receiver circuit is mounted on prototype 3D bionic hand that is simulating the hand movement. After sending the signals through zigbee module at transmitted part there another zigbee module at received part to receive the signals from wide range and then these signals are programmed and processed through microcontroller.

There many of controllers that have ability to give PWM (pulse width modulation) such as arduino, PIC, AVR, FPGA, etc to use the easiest slice to be programmed so, the choosing is arduino ATmega.

After arduino is programming the signals that come from transmitter circuit, it able to give specific PWMs that have duty cycle different from another according the voltage signals that is transmitted.

These PWM signals are used to move servo motors that are mounted on prototype 3D bionic hand for movements. Servo motor have good feature and this feature is that it does not need into any another signal for control in angle change only need to PWM signal to change the angle.

Servo motors will move and as a result of this wrist joint will rotate and hand will move and simulate the same natural hand at real time of hand movements.

Each finger module contains on one servo motor to convert the rotational motion into linear motion to flex fingers.

All the previous operations in both transmitter circuit and receiver circuit controlled using advanced microcontroller, which acts as the brain of the system and control each component synchronously in a parallel process without any time delay, since it contains timers make it work with extraordinary processing speed.

### 3.4 Hardware Components for Project

Through this section of chapter all hardware components used in the project are discussed, so that features and specifications are discussed.

#### 3.4.1 Bending Sensor

The project needs into six flex sensors, each flex sensor is sewed into each finger from glove that user will wear it and sixth sensor is sewed into wrist joint region.

- **Flex Sensor:** is a mechanical passive resistive element that gives the change in resistance depending on the bending at joints, these sensors convert the change in bend into change in electrical resistance and the value of this resistance is varied either increasing or decreasing depending on the type of sensor to be used, the extent of the deflection is proportional to the force of the bending moment [12]. See Figure (3.2).

There are two types of flex sensor, see figure (3.3) the features of these sensor are shown as Table (3.1).

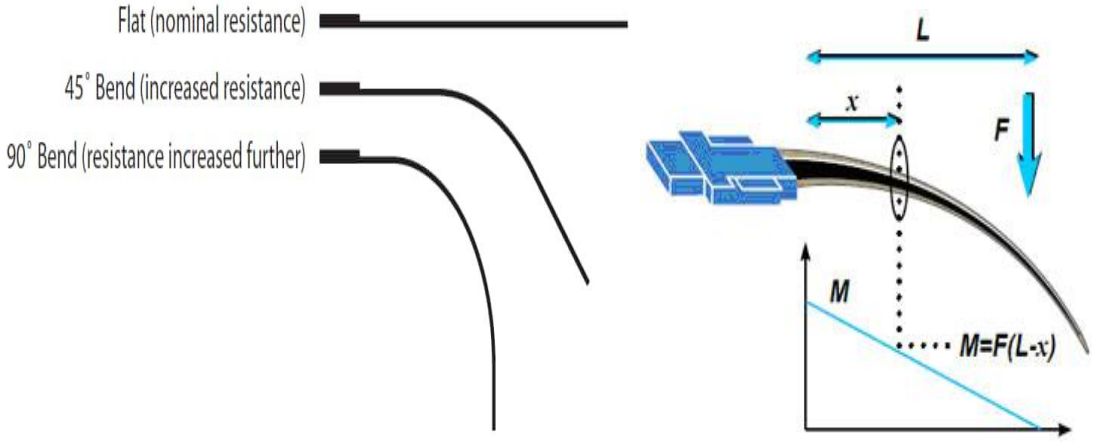



**Figure 3.2: Flex Sensor and the Relationship between Moment and Force [13]**


**a.** Flexpoint Sensor(Bidirection) **b.** Bend Sensor(Unidirection)

**Figure 3.3: Types of Flex Sensors [14][15]**

There several of sensors which are used to capture hand movement and could be fixed at joints and these as following:

- ✓ Strain gauges sensor can be used for measuring the flexion of a joint.
- ✓ Optical sensors, in which the amount of light transmitted or reflected by a bent optical fiber is a measure of the bending degree. They are made of plastic optical fiber, which at one end is LED that is transmitting light, and at the other end, has a photodetector like photodiode or phototransistor to receive light. The bending results in a loss in light transmission, which translates into a reduction in the detected voltage or an increase in resistance if used photoresistor.
- ✓ Hall sensors and magnets can be placed on human hand to give change in voltage.
- ✓ Displacement sensors placed for measuring flexion and extension of the joints.
- ✓ 3D gyroscopes, accelerometers, magnetometers. Each can provide information about the relative position of the segments of the human body [16].
- ✓ The last which will be used in this project is bending sensor (flex sensor) because it is has a several of features as following:

**Features of Flex Sensor:**

- Flexiable and Non-refractable.
- Wide Range.
- It is able to provide more accurate data.
- Its shape and design fits the hand.
- Medium cost.

The table below shows a comparison between distinct two types of sensor in several features, according to the design bending sensor is selected.

**Table 3.1: Bending Sensor Specifications [17]**

| **Characteristic** | **Bending Sensor** | **Flexpoint Sensor** |
|---|---|---|
| **Operating Voltage** | NA | 5V to 12V DC |
| **Temperature Range** | -35°C to 80°C | -35°C to 80°C |
| **Flat Resistance** | 25KΩ | 100 to 500 KΩ |
| **Resistance Tolerance/Nonlinearity** | 30% | NA |
| **Bend Resistance Range** | 45K to 125KΩ | 1.5K to 40KΩ |
| **Resolution** | Less than 1 degree | Less than 1 degree |

### 3.4.2 Control Glove

The control glove acts as a human hand where sensing circuit is mounted on it to capture the movements of user hand from fingers and wrist joints and translates into specific signals to be processed and controlled.
Choosing this glove to wear it the user is easier for work the activities instead of mounting the sensors on direct fingers and wrist join, so to modify glove, 6 sensors were inserted into the glove each sensor measures the degree of bending in the joint to which it is connected.

### 3.4.3 Microcontroller Board

The arduino ATmega 2560 is a microcontroller which has on its board microcontroller ATmega 2560, the project needs into two arduino Atmega 2560, the first arduino takes the processed signals from sensing circuit and processing it to give specific digital signals according the voltages, the second arduino is programmed to take the signals through Zigbee module and convert the signals into pwm signals to move actuators, two arduino are programmed by the arduino software, see Figure(3.4)

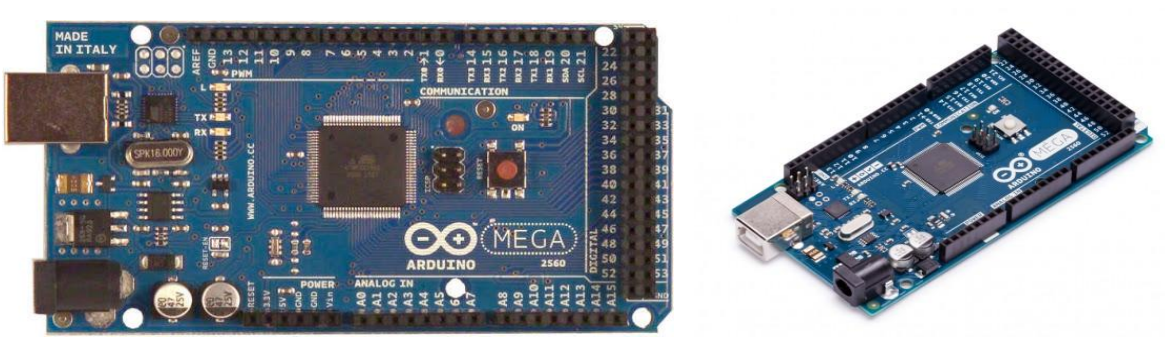



**Figure 3.4: Arduino Microcontroller [18]**

- **Arduino characteristics:**

  There are many of microcontrollers available for many of using ,and could give PWM signals with specific duty cycle such as FPGA, PIC,AVR, and many others offer similar functionality.

  Arduino simplifies the process of working with microcontrollers, it offers some advantages that made it easy to use such as the arduino software is published as open source and simple, clear programming environment which is easy to use also inexpensive [19].

Many types of arduino boards exist, such as UNO, DUE, MEGA, each has features differ from others, see table (3.2). Some applications requires high speed but others not, so the selection of the type of arduino board depends on the application and its features.

**Table 3.2: Arduino Specifications**

| **Microcontroller** | **ATmega2560** |
|---|---|
| **Operating Voltage** | 5Vdc |
| **Input Voltage (recommended)** | 7-12Vdc |
| **Input Voltage (limits)** | 6-20Vdc |
| **Digital I/O Pins** | 54 (of which 15 can be used as PWM outputs) |
| **Analog Input Pins** | 16 |
| **DC Current per I/O Pin** | 40 mA |
| **DC Current for 3.3V Pin** | 50 mA |
| **Flash Memory** | 256 KB (ATmega2560) of which 8 KB used by bootloader |
| **SRAM** | 8 KB (ATmega2560) |
| **EEPROM** | 4 KB (ATmega2560) |
| **Clock Speed** | 16 MHz |
| **Length** | 101.98 mm |
| **Width** | 53.4 mm |
| **Weight** | 25 g |

### 3.4.4 Zigbee Module

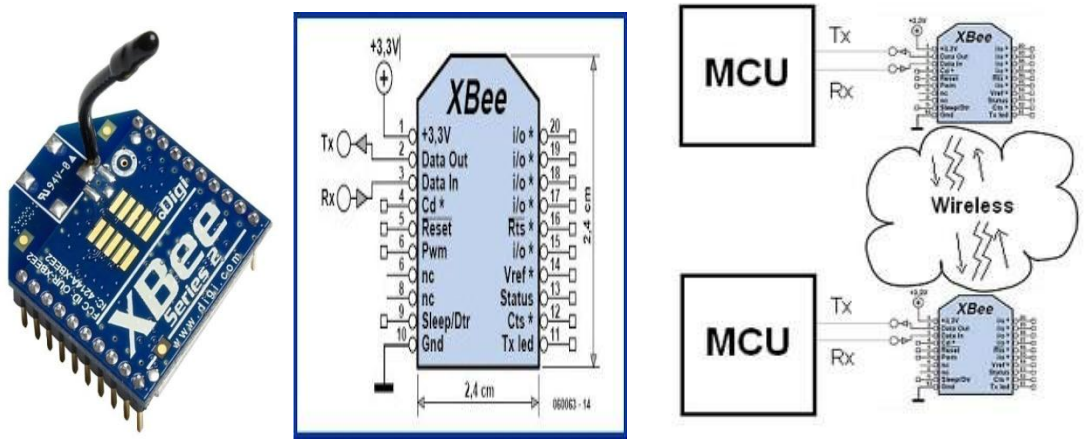
The actuators on 3D printable hand coupled with sensors in transmitter circuit through XBee-S2 (2.4 GHz). In order to allow wireless communication between the two microcontroller and control in movement of hand from far distance, two Xbee modules are used, it has a very small antenna placed above it as shown in Figure (3.5), the zigbee at transmitter circuit receive the voltage value serially from microcontroller through connect Rx pin of zigbee into Tx pin of microcontroller.

In this method data was serially sent to the Rx pin of zigbee module, this data will be sent wirelessly to zigbee at receiver circuit. Xbee-S2 at receiver part will receive the data wirelessly and these values were sent serially to the second microcontroller through connect Tx pin of zigbee into Rx pin of microcontroller see figure (3.5 c).

Zigbee is using for communication between point-to-point, point to network, point to mesh in this project is used to send signals from one point to another.

Before using zigbee-series2 module for wireless communication, it is must firstly configure it for communication and then is used for wireless communication, so X-CTU software is used.

X-CTU is the program is used to configure two xbees for communication, baud rate will be changed to 9600 because the xbees can only talk at their configured baud rate, so setting the same number for two xbees through the program in order to ensure that will be no other xbee or RF devices interfering with two xbee module which are used [20].




**a.** Xbee Module **b.** Xbee Pin Configuration **c.** Xbee Connection

**Figure 3.5: XBee Module [21]**

There are many of wireless communication devices which are used for transmitting and receiving the data from place to another as shown in table (3.3), some applications require speed in transmitting and receiving and others need to transmit the data for very wide range, so the selection of type depends on features and application, zigbee module is chosen for advantages following:

- ❖ Richer communication and flexibility.
- ❖ The transmission of signals will not be blocked in a long distance and even by a well.
- ❖ No need to consume power highly.
- ❖ Very wide rang can send the data at 1000 meter.

**Table 3.3: Wireless Devices Features [22]**

| Characteristic | Zigbee(802.15.4) | Bluetooth(802.15.1) | Wi Fi(802.11b) |
|---|---|---|---|
| **Battery Life (days)** | 100-1000 | 1-7 | 1-5 |
| **Band Width (kbps)** | 20-250 | 720 | 11Mb/s |
| **Range (meters)** | 1-100+ | 1-10 | 1-100 |
| **Specifications** | Low power,Cost ,effective | Cost | Speed |

### 3.4.5 XBee Explorer Regulated

Xbee module can not attach directly onto microcontroller, so Xbee explorer is used which allow an Arduino board to communicate with Zigbee module through it as shown in Figure (3.6).Thus two Xbee explorer are used in this project; one for transmitter and other for receiver xbee module.

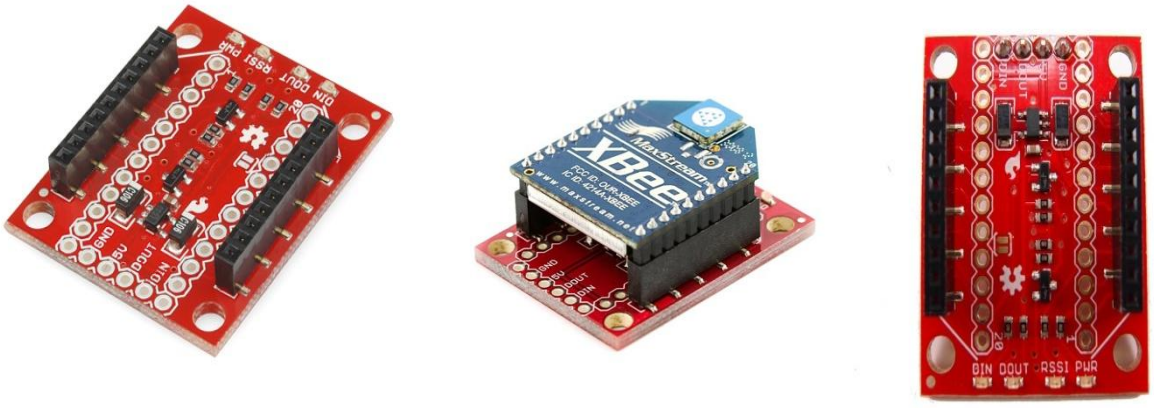



**Figure 3.6: Xbee Explorer Regulated[23]**

Zigbee explorer module has a 250mA, 3.3V regulator and is fed by 5Vdc, xbee module needs into power supply 3.3Vdc and this voltage is provided directly by zigbee explorer module into xbee module without using another regulator.

### 3.4.6 Servo Motor

Is using  as actuator in this project, the actuator is turns the electrical energy into kinetic energy which is the reverse sensor, so to move the joints in the hand, micro servo motors are using as an actuator which gives a precise control of velocity, angular position and torque see figure(3.8). Servo motor gives different angles for various duty cycles, through this variation, angular bending of the fingers and wrist rotation is different according the duty cycle of signal which coming from the microcontroller to the  servo motor see figure(3.7).

With using this motor for achieving the movements of wrist and hand, smooth movement is achieved.

Bending the sensors at joints are analyzed by microcontroller at transmitter part and this data is send to another part via serial communication, so microcontroller at receiver part generates PWM signals to control in angle change of servo motors.
Servo motor no need into external motor driver circuit to drive it because of deriver circuit exist inside it.

Also, servo motor has a gear system inside it which is used to alter the speed/torque of the motor by reducing the speed and increasing the torque, so the power consumption by servo motor is low.

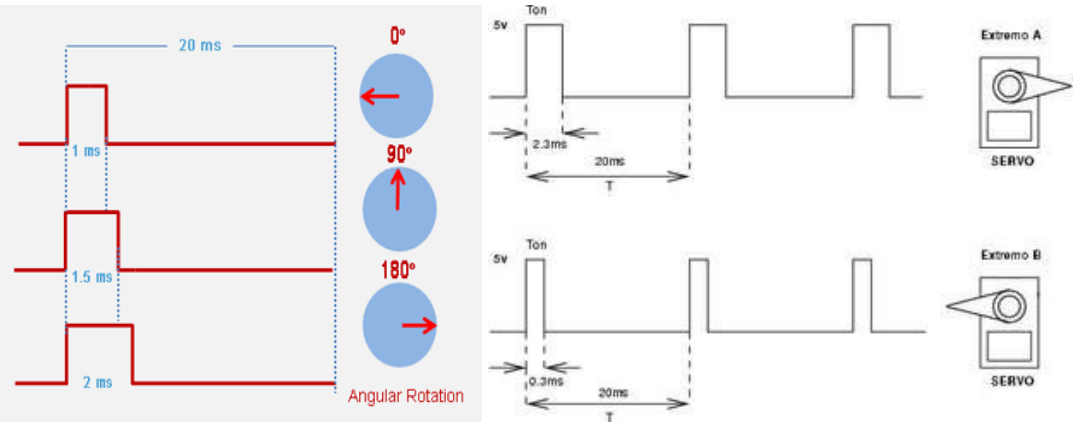
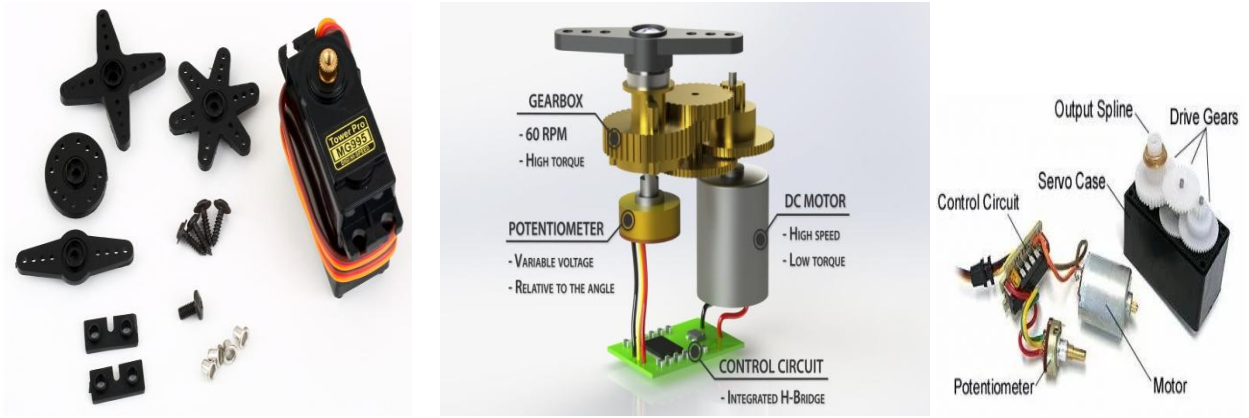



**Figure 3.7: Controlling in Direction of Servo Motor by PWM Signal [24]**




**a.** Servo Motor **b.** Features of Internal Structures **c.** Internal Structure

**Figure 3.8: Micro Servo motor and Internal Structure [25][26][27]**

The table below displays a comparison between three types of dc motor which can be used in this project, so the selection of motor type depends on features and application, servo motor is chosen according to the table (3.4).

**Table 3.4: Motor Types Comparison**

| **Characteristic** | **Servo Motor** | **Stepper Motor** | **Micro Gear Motor** |
|---|---|---|---|
| **Operating Voltage** | 4.8-6VDC | 5VDC | 6VDC |
| **Torque** | 11Kg.cm | 3.2kg.cm | 5.5Kg.cm |
| **Speed** | 0.16sec/60º | 200-400 Steps/rev | 13RPM |
| **Weight** | 55 gram | 350 gram | 10.5 gram |
| **Cost** | Medium | High | High |

Servo motor requires a pulse signal with 50/60 Hz (about 20ms or 30ms travel wave), so pulse width vary from 1ms, 2ms, a pulse with 20ms works well for most servo motor with maximum pulse width 2ms will make servo rotate at the end of rotation (maximum rotation), so arduino has software commands in language to generate these signals and any microcontroller can be programmed to generate these pulses.

### 3.4.7 Xbee Explorer Board (USB)

This module is using to program and configure the xbee module for communication using computer by USB port using X-CTU software see figure (3.9).

**Figure 3.9: Xbee Explorer Board (USB) [28]**

## 3.5 Power Supply

The project needs two batteries as a system power, supplies the required current for the electrical circuit and loads, the first battery 9VDC is placed at transmitter circuit to feed the components in it and the second battery 12VDC portable rechargeable to feed the components at receiver circuit which are needing into large effort and current with charger to charge it see figure (3.10).

**a.**9 VDC Battery(Transmitter Circuit) **b.**12VDC Portable Rechargeable Battery

**Figure 3.10: Power Supply System [29][30]**

## 3.6 Design of Bionic Hand

Artificial hand is the most important part in the project which is a printable bionic hand with the same size of human hand. The design points of bionic hand are: ability to grip, suitable size, and mechanical simplicity.

So, to print the bionic hand using 3D printer Technology, hand and wrist parts should be available until they are printed.

So, all the parts of hand and wrist are taken from inmoov design.

InMoov is the first Open Source 3D printed life-size robot [31].See figures below.
All parts of hand and rotational wrist are designed by catia software.
By using fishing lines to connect hand parts with servo motors, which is replacement of tendon for human fingers, it is strong artificial tendon to flex fingers in bionic hand see figure (3.13).

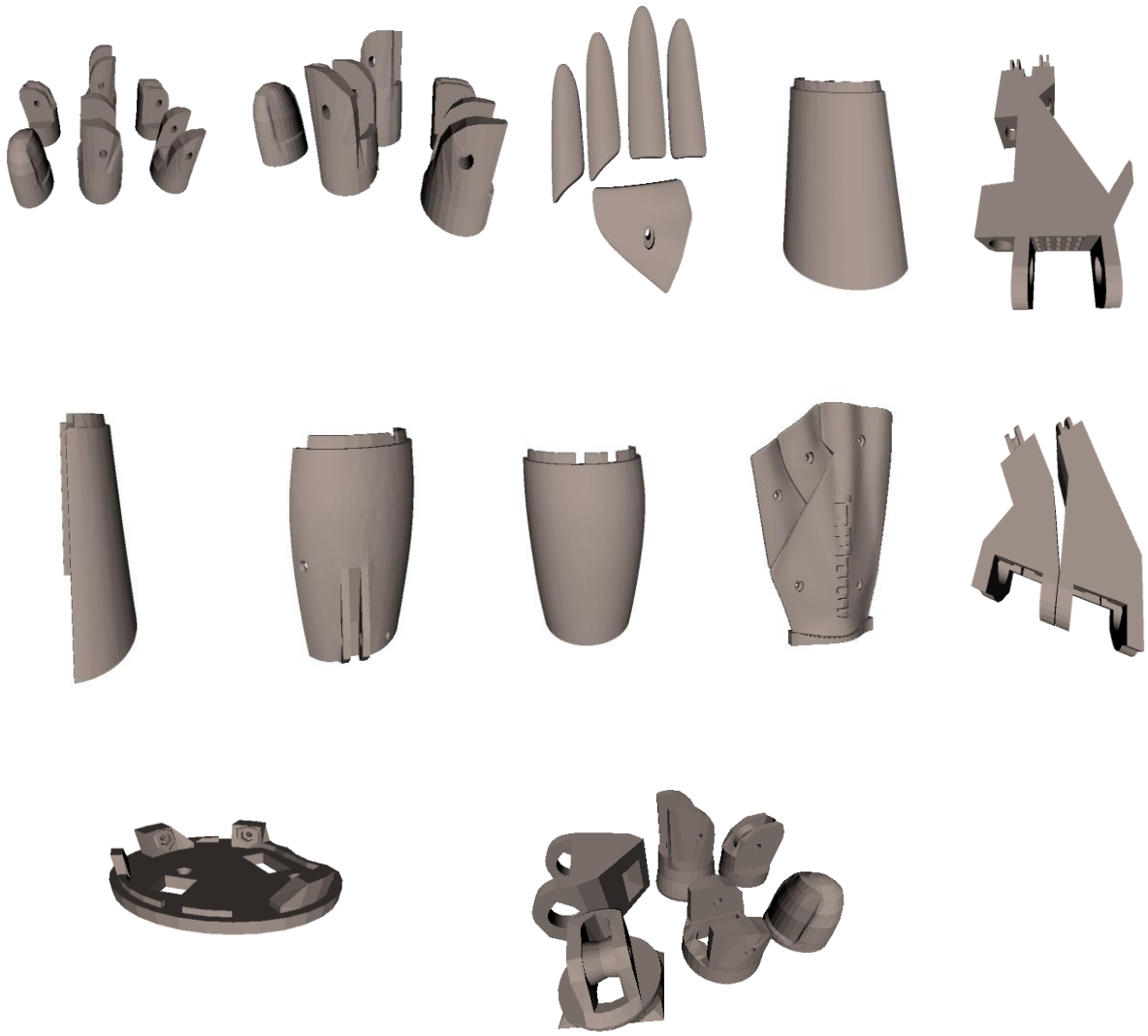


**Figure 3.11: Hand and Forearm Parts [31]**

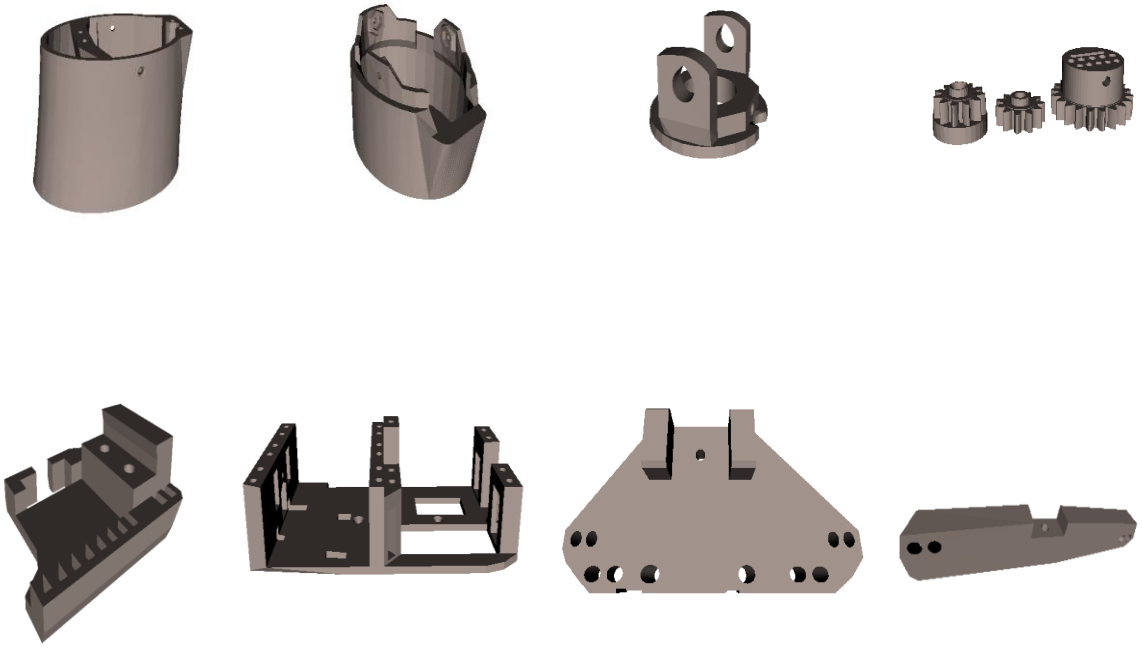


**Figure 3.12: Rotational Wrist and Servo Bed Parts [31]**

**Figure 3.13: Fishing Lines [32]**

## 3.7 System Flowchart

Figure 3.14 represents the flowchart of system activity.

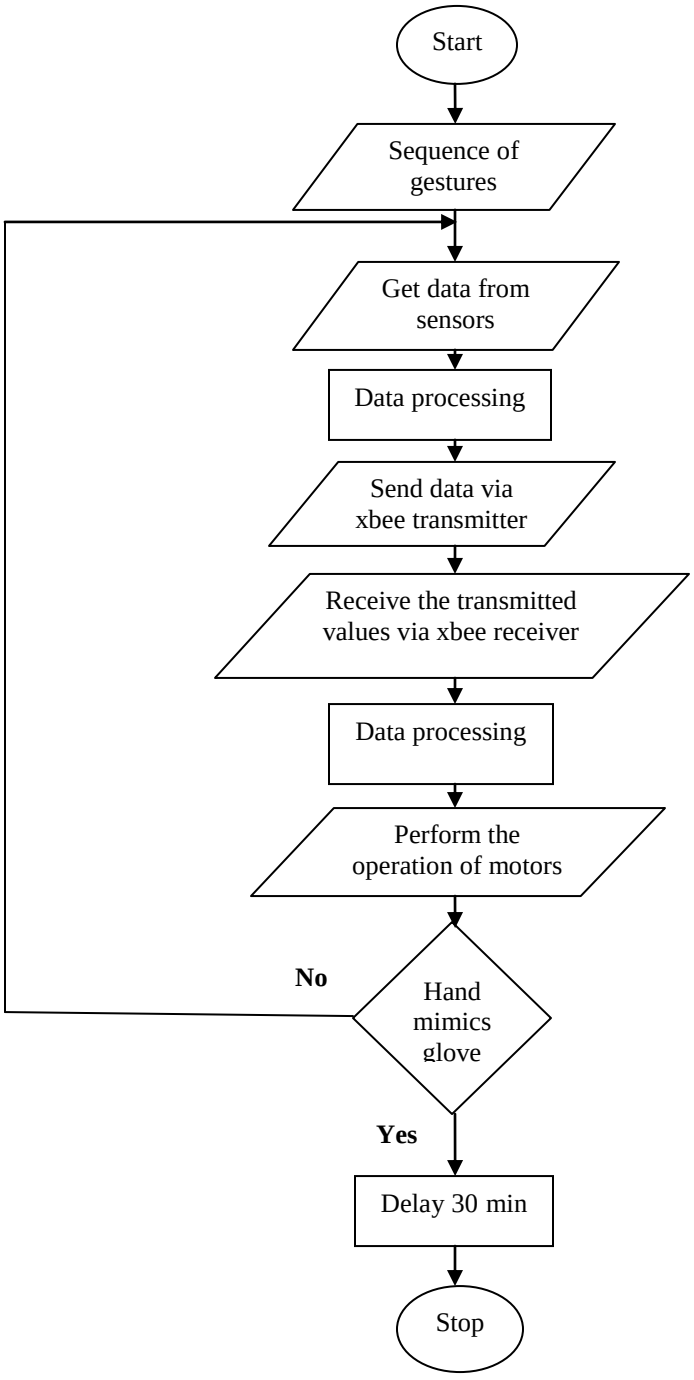



**Figure 3.14: System Flowchart**

# Chapter Four

# System Implementation

**4.1 Introduction**

**4.2 Transmitter Circuit Design**

**4.2.1 Conditioning Circuit for Sensing Devices**

**4.2.2 Wireless Communication**

**4.3 Receiver Circuit Design**

**4.4 Power Supply Circuit**

**4.5 Final System Schematic**

## 4.1 Introduction

This chapter explains in details the electrical circuits which are required for each stage to implement the final schematic diagram for system and description of working principle.

Also, all the calculations are performed to obtain suitable values to connect the components with arduino board.
The software which is used to simulate the electrical circuits is Proteus Program.

## 4.2 Transmitter Circuit Design

This circuit contains sensor devices, microcontroller and xbee transmitter module.

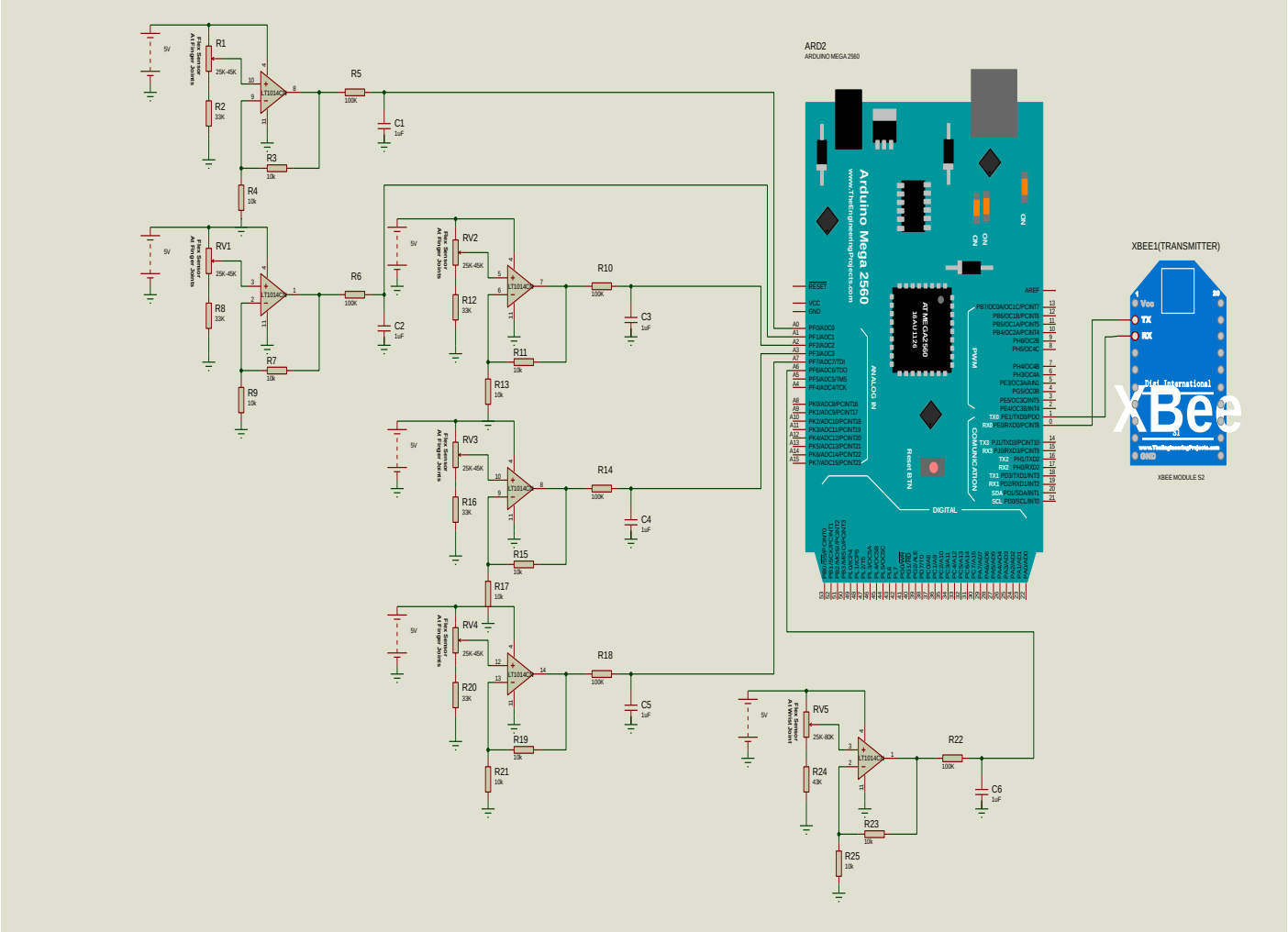



**Figure 4.1: Transmitter Circuit**

### 4.2.1 Conditioning Circuit for Sensing Devices

Conditioning circuit consists of two stages, the first stage is amplification of the signal from voltage divider circuit which includes bending sensor and the second stage is noise reduction by using passive filter. See figure (4.2)

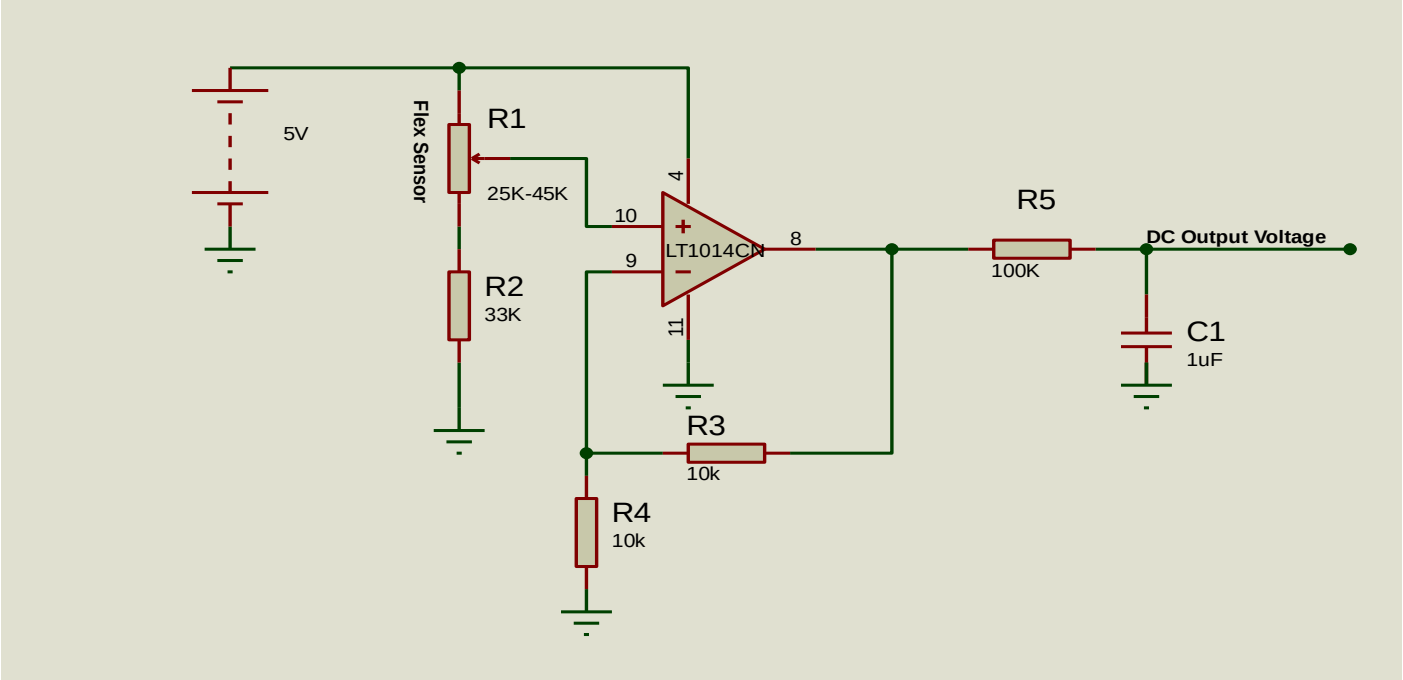



**Figure 4.2: Signal Conditioning Circuit**

The output from the voltage divider configuration of the bending sensor goes into the non inverting op amp. It then outputs a signal with twice the amplitude into first order passive low pass filter according the relationship:

$$v_{out} = (1+\frac{R3}{R4})\, v_{in} = (1+\frac{10K}{10K})\, v_{in} = 2v_{in} \qquad (4.1)$$

High frequency noise was found in this output signal, which produced undesired signals, so in order to read the analog signal by the microcontroller, noise reduction circuit is used. Because of the oscillating signal causes the arduino to output random commands, so resistor R5 and capacitor C1 were implemented into the circuit to form a low pass filter, with $f_C = \frac{1}{2\pi R5C1} = \frac{1}{2x3.14x100kx1.5\square} = 1\,Hz$ to attenuate any noise signal may be connected to the sensor signal.

There are two reasons for choosing 1Hz cut off frequency. The first was because the exact frequencies range unknown. Ideally, a DC signal specifications were required. The low pass filter was to remove as many oscillating components from the output as possible. Only signals approaching a DC characteristic (less than 1Hz in frequency) were allowed to pass through. The second reason, cut-off frequency too close to the actual frequency of the noise can result in poor filtering. Because of real filters do not have perfect signal attenuation at the cut-off region [33].

This circuit will be used into all sensors which are used in the project.
The $R_{ref}$ in voltage divider circuit with sensors can be calculated using equation (4.2) this equation has the derivation in the appendices, review the appendices:

$$R_{ref} = \sqrt{R_{sensor\_max} * R_{sensor\_min}} \quad (4.2)$$

So, for sensors which are responsible for capturing the fingers motion,
$R_{sensor\_max} = 40K\Omega,\ R_{sensor\_min} = 25K\Omega$ then,
$R_{ref} = \sqrt{R_{sensor\_max} * R_{sensor\_min}} = 33.541K\Omega$, $R_{ref}$ Chosen 33kΩ according a standard values.
Also, for sensor which are responsible for capturing the wrist joint motion,
$R_{sensor\_max} = 80K\Omega,\ R_{sensor\_min} = 25K\Omega$ then,
$R_{ref} = \sqrt{R_{sensor\_max} * R_{sensor\_min}} = 44.721K\Omega$, $R_{ref}$ Chosen 43kΩ according a standard values.

### 4.2.2 Wireless Communication

To implement the wireless communication between two arduino, two xbee are used, in order to make the xbee at transmitter able to communicate with xbee at receiver, two xbee are programmed by x-ctu software which has the ability of setting up xbee modules for communication. See figures (4.3), (4.4), (4.5).
So, before connect xbee module with microcontroller, it need to be programmed and setting up into communication, there are two ways to connect xbee with computer in order to enable it into communication. The first way is to use xbee explorer board (USB) where xbee is installed on it. The second way is to use arduino board (UNO) with remove the microcontroller from a board, when the microcontroller is removed from an arduino board, it works as an FTDI board

(Future Technology Devices International) [34]. In this case Rx from xbee is connected into Rx from arduino, and Tx from xbee is connected into Tx from arduino, this connection only for configuration, so in this project xbee explorer board (USB) is used.

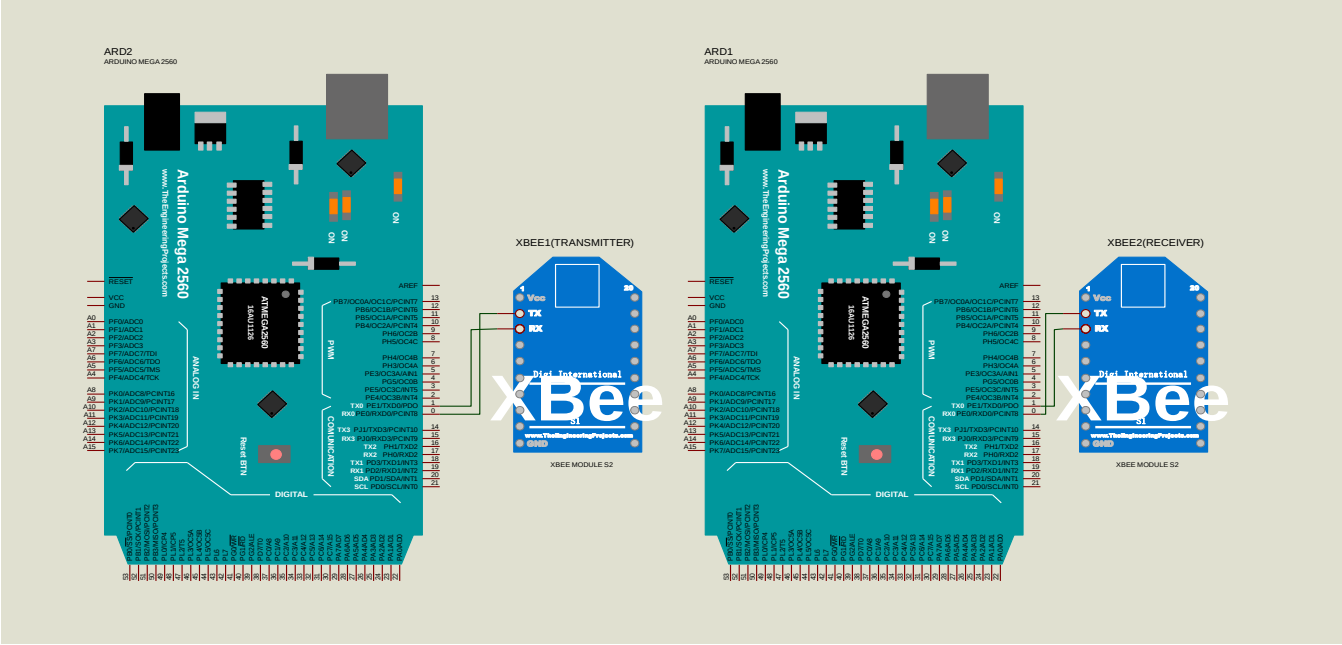



**Figure 4.3: Circuit Diagram for Communication between Two Arduino by Zigbee Technology**

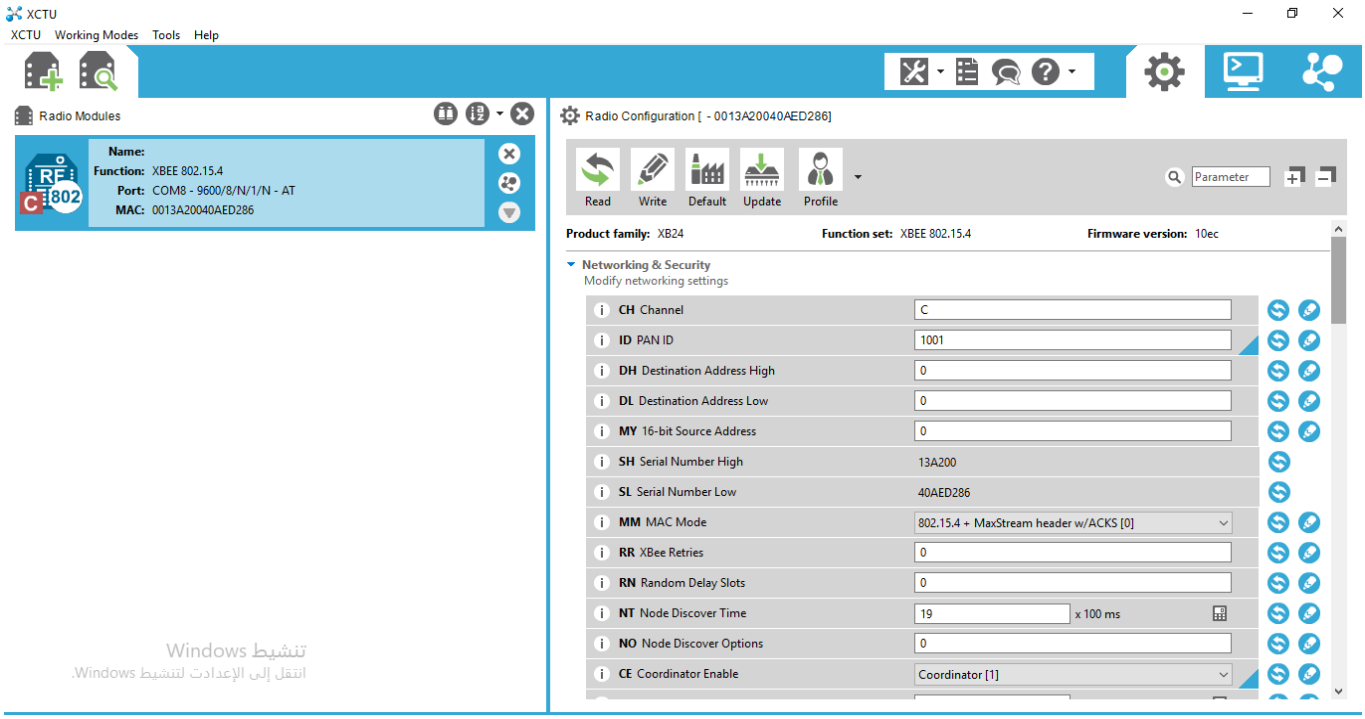



**Figure 4.4: Setting up Xbee Transmitter Module for Communication**

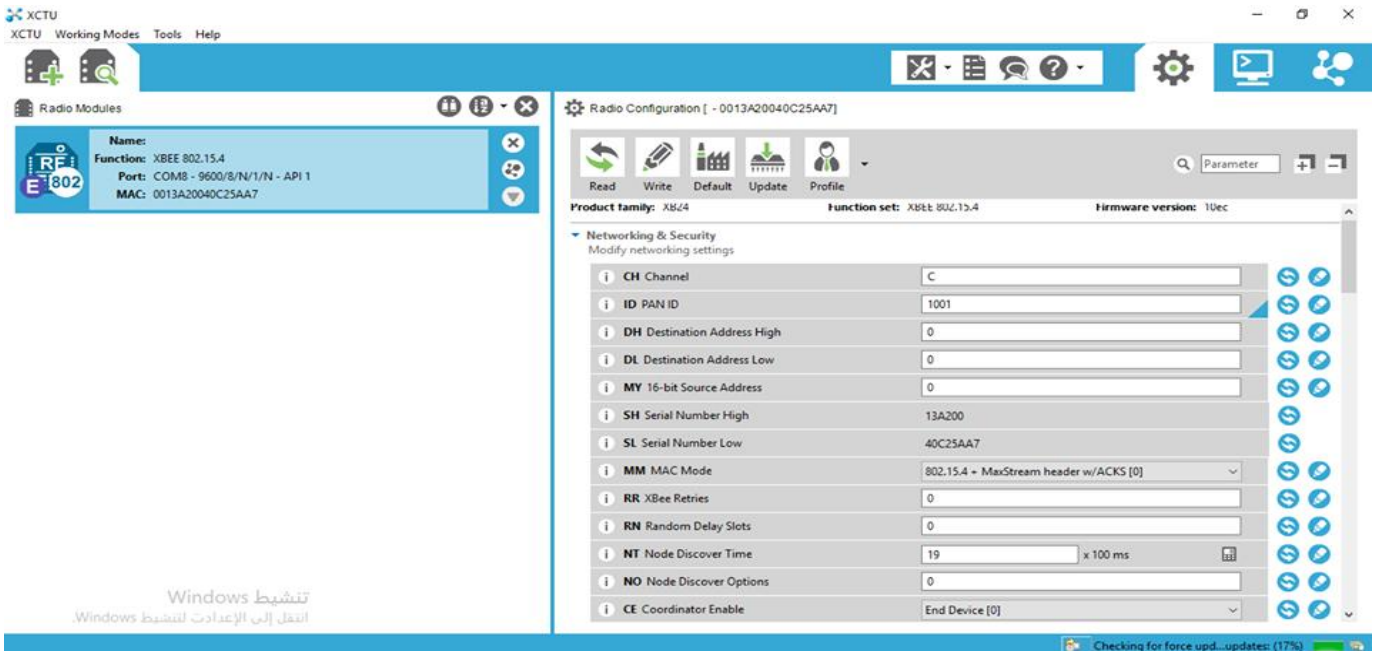



**Figure 4.5: Setting up Xbee Receiver Module for Communication**

By setting up a first xbee as coordinator (transmitter), and a second xbee as endpoint (receiver) and the same channel and ID for both xbee, then it connected with a microcontroller.

## 4.3 Receiver Circuit Design

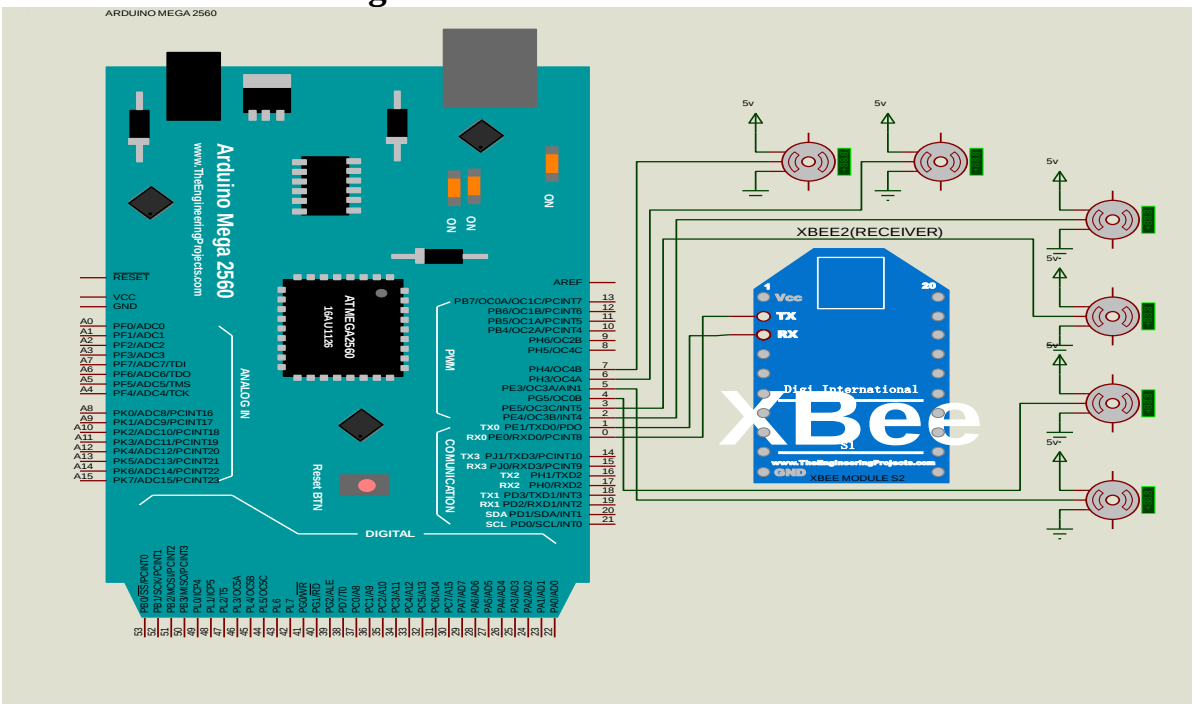



**Figure 4.6: Receiver Circuit**

In this circuit, six servo motors exist, the first for wrist joint movement and the other into fingers movements.
Servo motor has 3 edges, the first edge connected into supply voltage (5 Volt DC), The second edge connected into ground and third edge represents voltage control (PWM signal from microcontroller).
Inside the servo motor exists control circuit which contains driver circuit (H_bridge) that control the direction of servo motor (CCW or CW) and speed.

### 4.4 Power Supply Circuit

As mentioned previously, the project needs into two batteries (9Vdc, 12Vdc), some of components need into 5Vdc, 3.3Vdc and others need into 9Vdc, 12Vdc which are fed directly from source, 9Vdc is used as power supply to provide the energy into the components in the transmitter circuit, the components require 5Vdc are fed from 5Vdc pin in arduino board.
12Vdc is used as power supply to provide the energy into the components in the receiver circuit, the components require 5Vdc are fed by using 7805 regulator, for xbee requires 3.3Vdc is fed indirectly from xbee explorer regulated which contains inside it on 3.3V regulator, see figure(4.7)

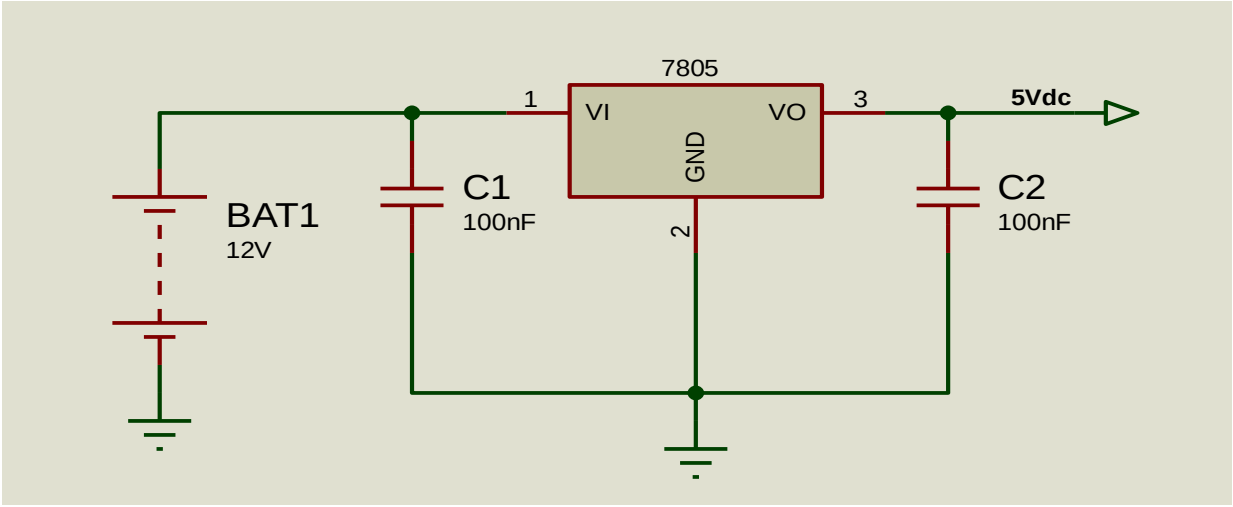



**Figure 4.7: Power Supply Circuit**

The aim of adding C1 and C2, in order to decrease the effect of wire resistance (High input impedance to ensure no drop in voltage).

## 4.5 Final System Schematic

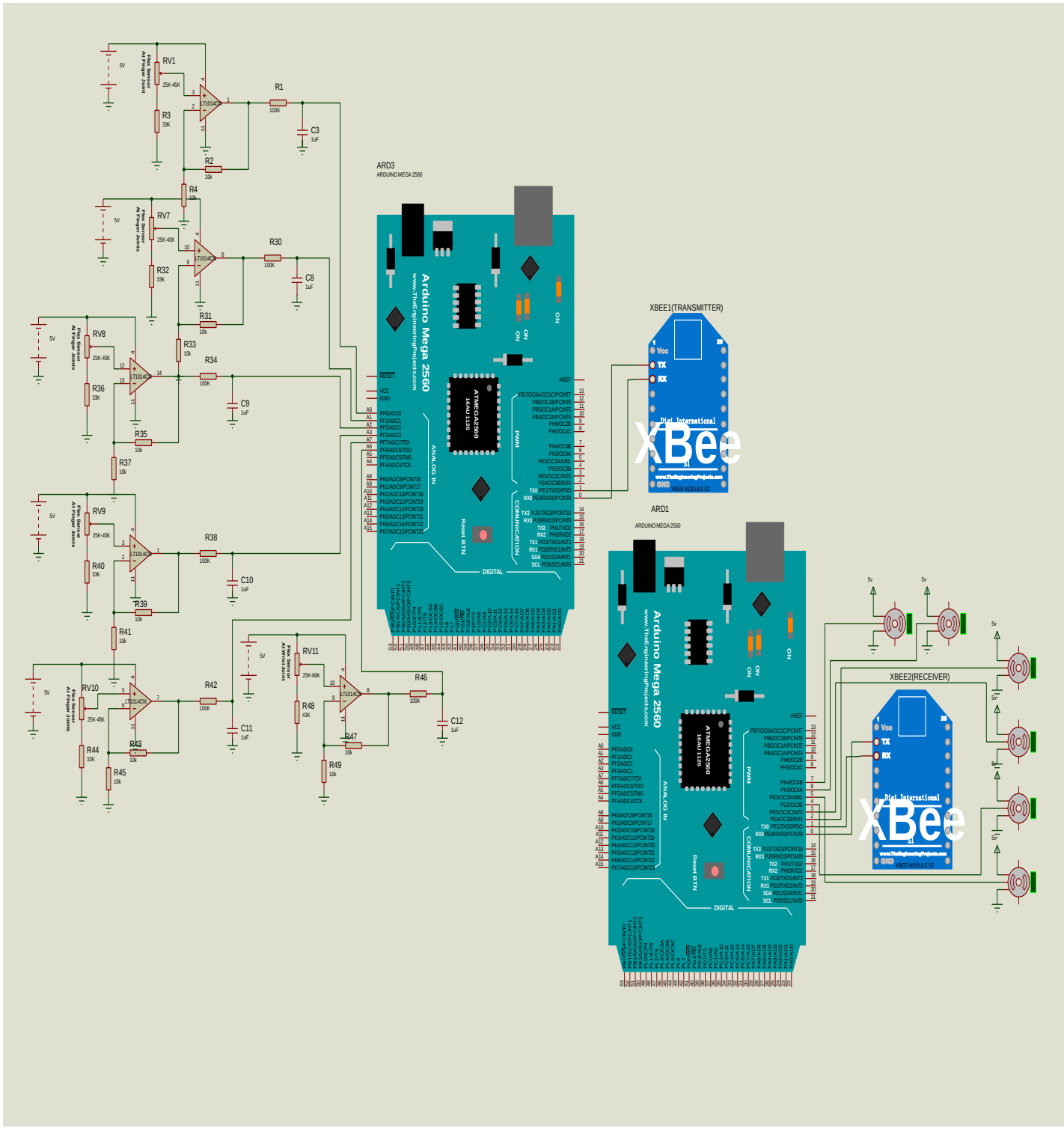



**Figure 4.8: Project Circuit**

# Chapter Five

# Results and Analysis

**5.1 Introduction**

**5.2 Results of system circuits**

**5.2.1 Signal Conditioning Circuit**

**5.2.2 Wireless Communication**

**5.2.3 Bionic Hand Design**

**5.3 Final Project Testing**

## 5.1 Introduction

After implementing the system hardware, the results obtained during the system testing are discussed in this chapter.

## 5.2 Results of system circuits

Since the project's system consists of three main tasks (linearity of sensors, wireless test and hand formation with motors), each task was implemented and tested individually.

### 5.2.1 Signal Conditioning Circuit

To verify the linear relationship between the deflection angle and resistance for bending sensitive resistor, The testing obtained for bending sensor using digital multimeter device, so the results was as following (Table 5.1 and Figure 5.1):

**Table 5.1: Outputs for Bending Sensor**

| Angle[°] | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|---|---|---|
| Resistance[kΩ] | **26.4** | **27** | **27.8** | **28.1** | **30.3** | **35.1** | **38.02** | **40** | **46** |

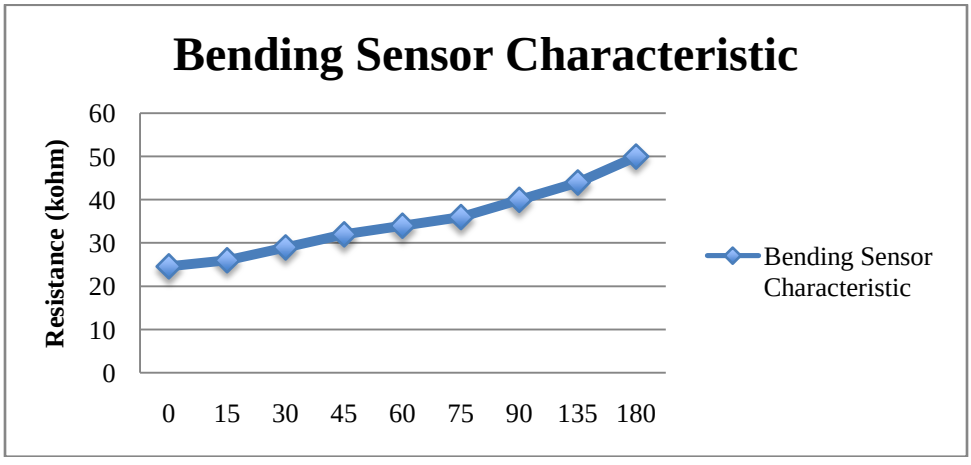



**Figure 5.1: Characteristic Curve for Bending Sensitive Sensor**

After taking all the readings from the sensors, the first result was that the voltage signal variation range varies from sensor to sensor, this is related by manufacturing technology, also another result is that maximum bending angle for each sensor depends on the joint which it is applied it, so for these two results it was necessary to choose in designing the non_inverting amplifier (level shift), voltage divider in order to make the signals for all the sensors fit with the input range of a microcontroller(0-5volt) without any problem.

So, in order to verify that the output voltage from sensing circuit is located in allowable range for microcontroller, it used for testing two sensing circuit.

The first reading for sensor which is responsible for capturing the rotational wrist motion, and the second reading for any sensor which is responsible for capturing the motion at joints for fingers.

- First Reading: the measured voltage from wrist sensor circuit

With flat resistance ($\boldsymbol{R_{sensor\_min} = 26.6k\Omega}$), and bending resistance ($\boldsymbol{R_{sensor\_max} = 76.4k\Omega}$), so $\boldsymbol{R_{ref} = 43k\Omega}$.

| $\boldsymbol{R_{ref}}$ | $\boldsymbol{V_{min}}$ | $\boldsymbol{V_{max}}$ |
|---|---|---|
| $\boldsymbol{43k\Omega}$ | **1.75 v** | **3.16 v** |

- Second Reading: the measured voltage from finger joint sensor circuit with flat resistance ($\boldsymbol{R_{sensor\_min} = 25k\Omega}$), and bending resistance ($\boldsymbol{R_{sensor\_max} = 45k\Omega}$), so $\boldsymbol{R_{ref} = 33k\Omega}$.

| $\boldsymbol{R_{ref}}$ | $\boldsymbol{V_{min}}$ | $\boldsymbol{V_{max}}$ |
|---|---|---|
| $\boldsymbol{33k\Omega}$ | **2.12 v** | **2.84 v** |

With these values of the voltage, the sensor has a suitable range from the voltages between minimum and maximum.

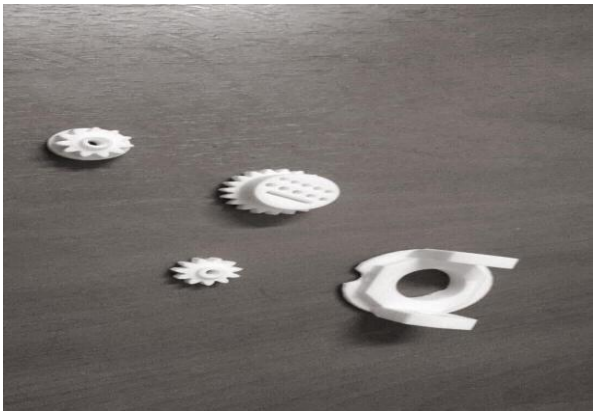
### 5.2.2 Wireless Communication

After implementing the programming for two xbees, both xbee modules are connected with xbee explorer regulated, so to test the communication between them, DOUT and DIN LED on board turned on as a sign of communication success. The results appear in figure (5.2) below.

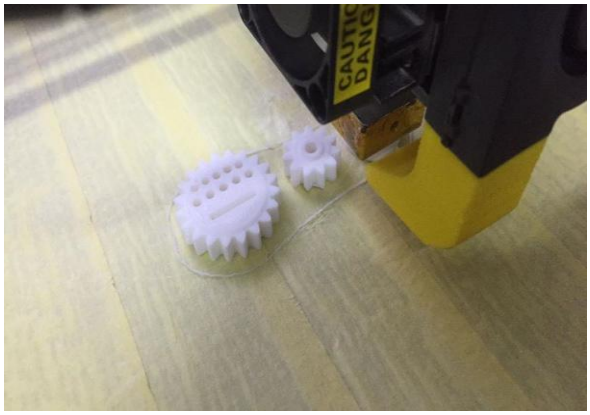

**Figure 5.2: XBEE Modules Connection Test**

### 5.2.3 Bionic Hand Design

After printing the rotational wrist parts, forearm parts and hand parts by using 3D printer, all parts are collected together to form the final shape of hand. All of parts are printed with high resolution for rotational wrist, forearm and hand.
The material which is used to form printed parts for hand is PLA (Polylatic Acid or Polylactide) which is thermoplastic that can be formed by heat at 180°c and 220°c. This type of polymers is bioplastic, biodegradable and bioactive.

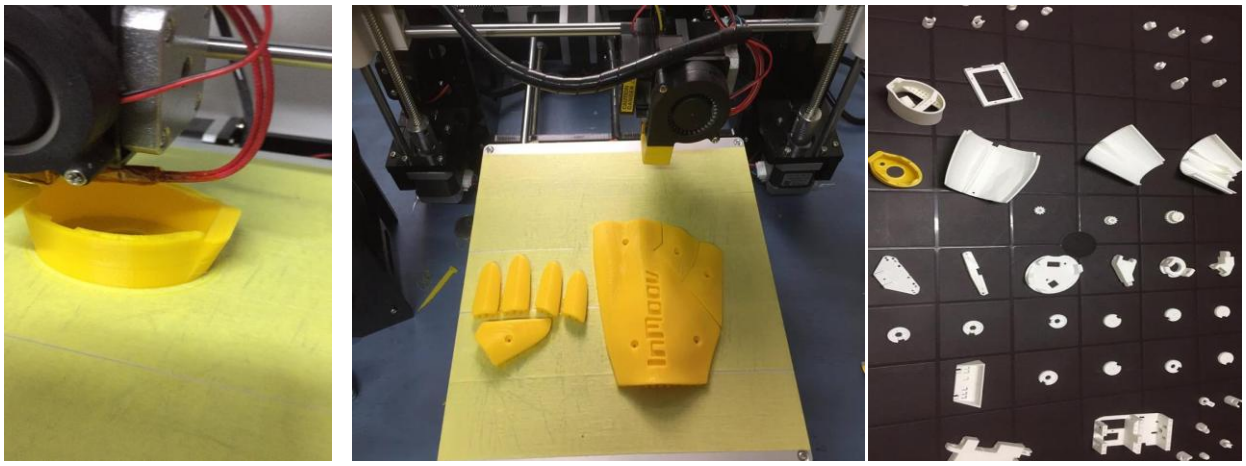


**a.** Wrist Joint and gears



**b.** Formation Phase

**Figure 5.3: Printed Gears for Rotational Wrist**



**a.** Formation Phase **b.** Hand Cover Formation **c.** Hand Parts

**Figure 5.4: All Printed Parts to Form Hand**

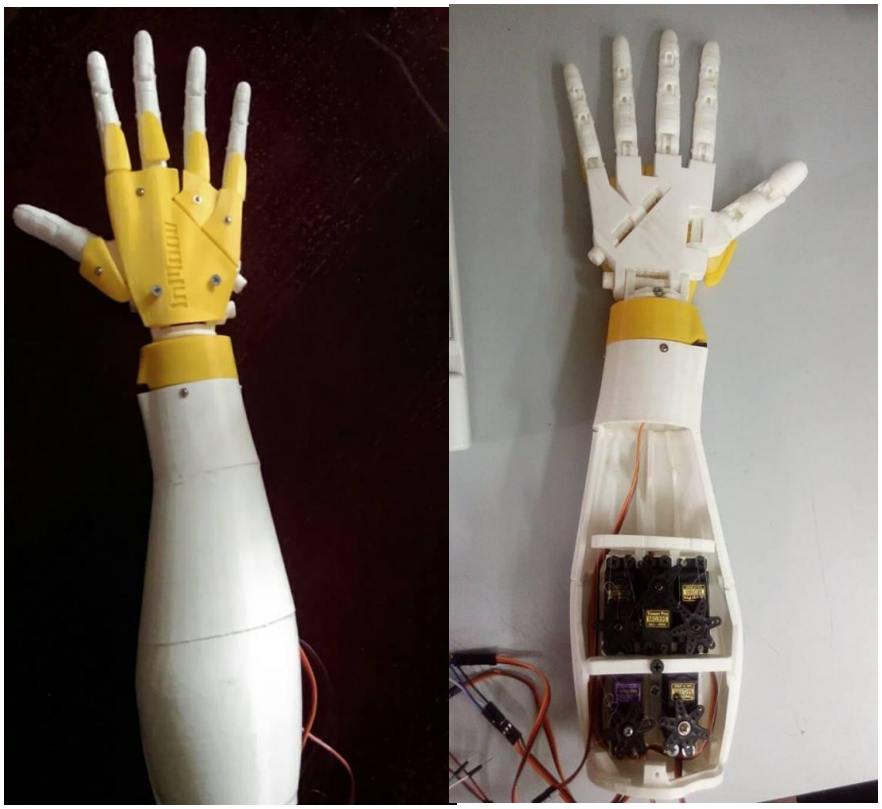


**Figure 5.5: Final Hand**

## 5.3 Final Project Testing

After obtaining successful results from each task, transmitter and receiver circuits combined together by wireless communication channel to form an integrated system capable of simulating human hand, the following figures show results

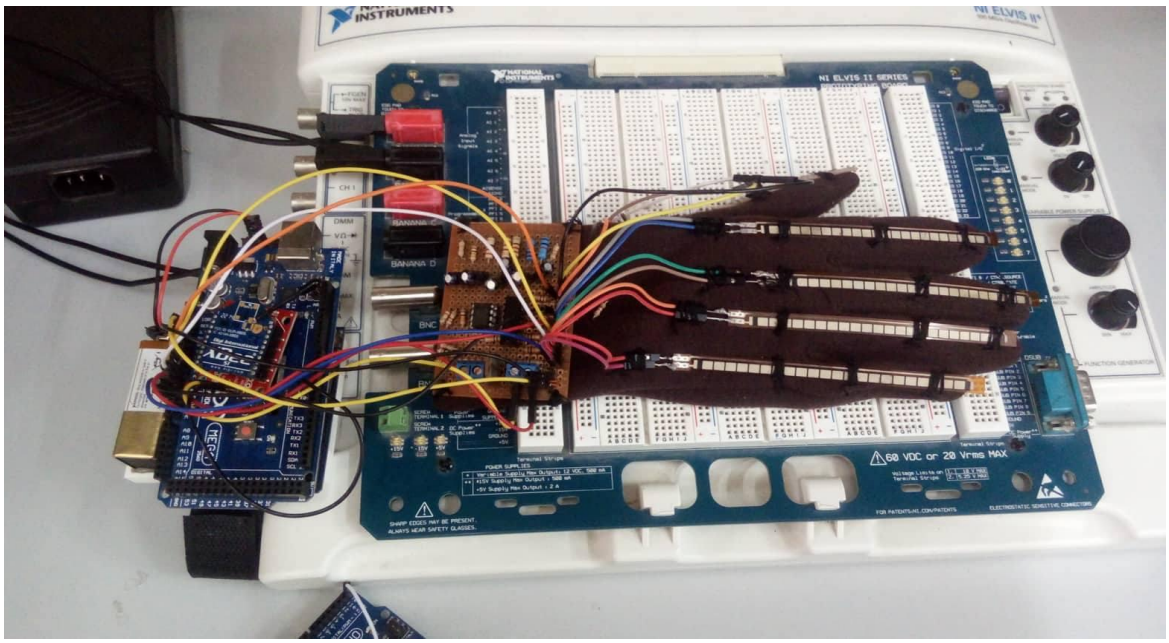



**Figure 5.6: Control Glove(Transmmitter)**

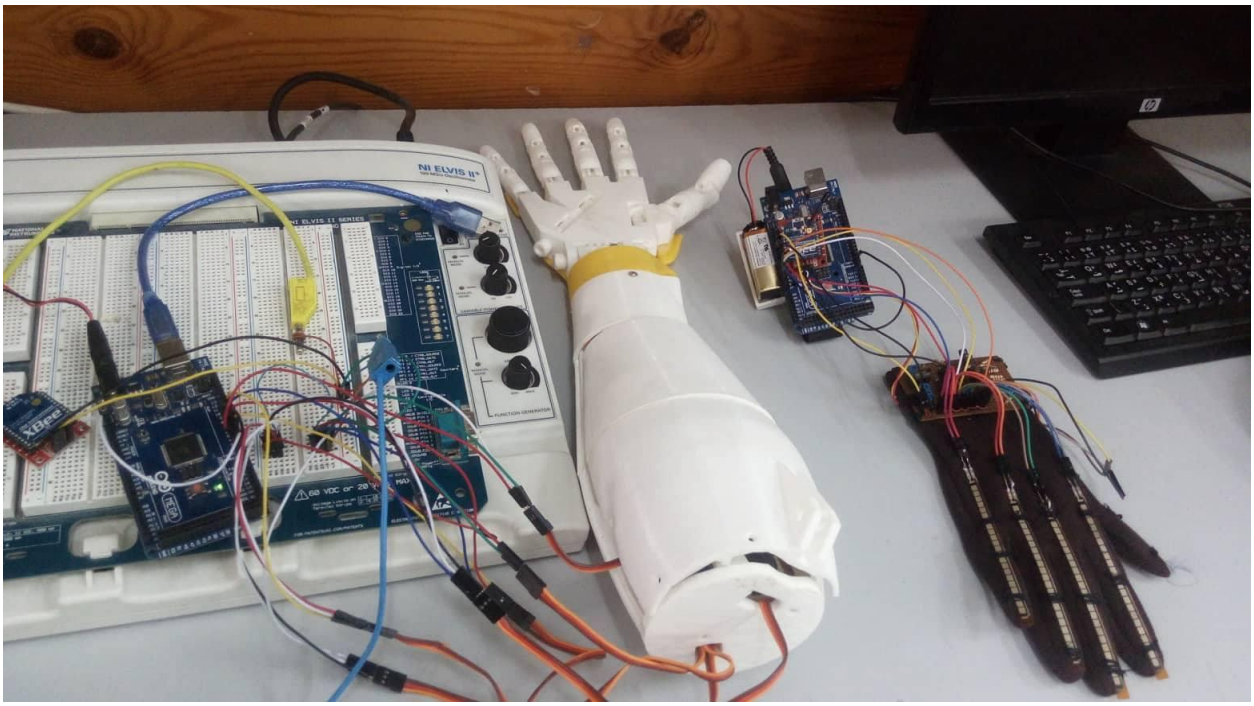



**Figure 5.7: Final Design**

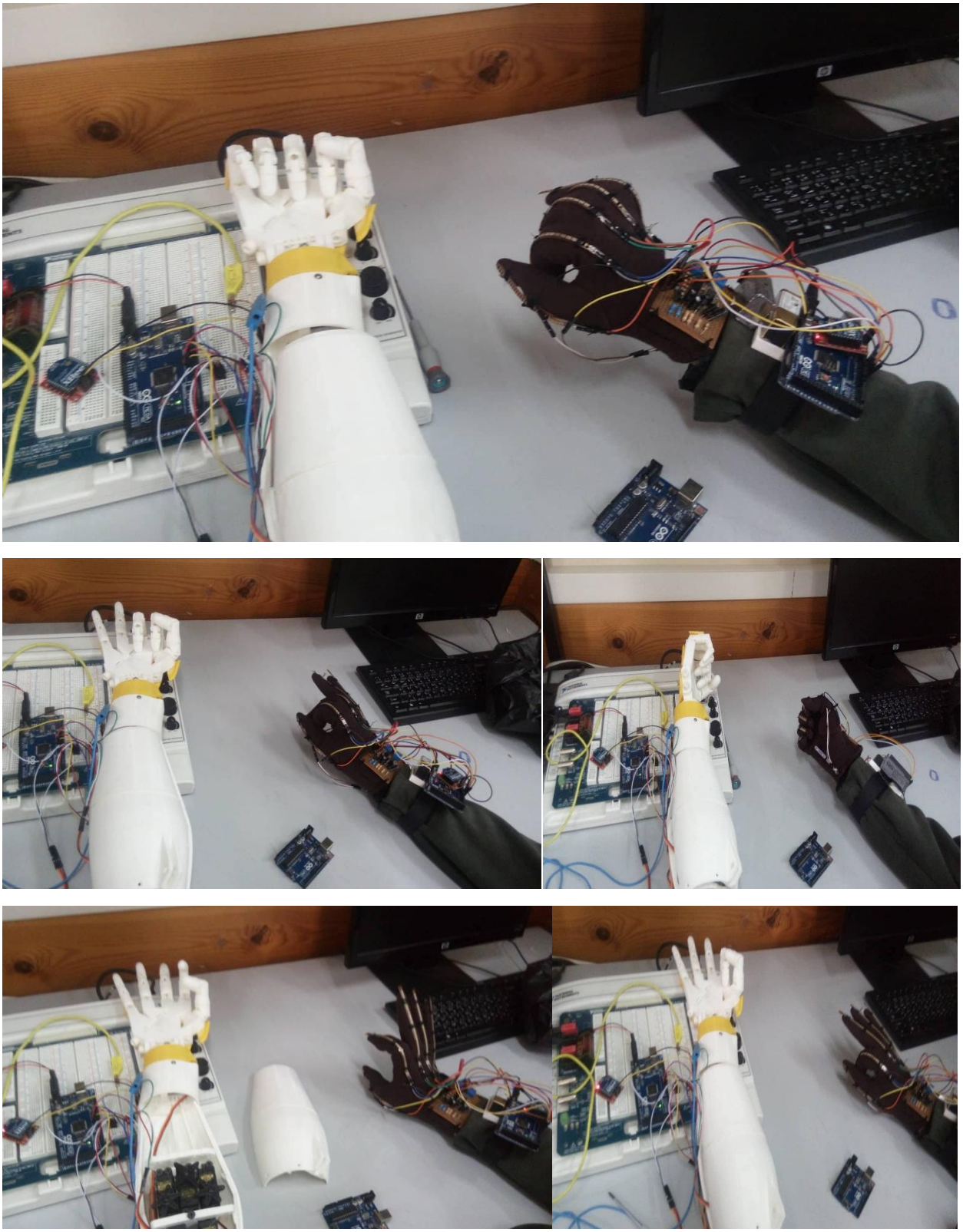


**Figure 5.8: Final Project Test(Simulation Test)**

# Chapter Six

# Challenges and Conclusions

**6.1 Introduction**

**6.2 Conclusions**

**6.3 Challenges**

**6.4 Recommendations**

## 6.1 Introduction

The main challenges occurred during the design process, some recommendations for further development and conclusions are mentioned in this chapter.

## 6.2 Conclusions

**1.** Use of the zigbee technology facilitated the control in hand for a distance.

**2**. The microcontroller was the brain in this project, which is used to control the movement of motors based on the extracted signals.

**3.** Use plastic material to print the hand; it makes the hand sufficient for using instead of using the metal.

## 6.3 Challenges

**1.** The bionic hand in the local Palestinian market is not available, so it was printed with long time to complete.

**2.** Installation for gear at wrist joint.

**3.** The use of servo motors require into enough current to move without vibration, so at the beginning of the project 9Vdc battery is used to feed the motors, but all motors are vibrated, with no load servo motor drawing about 7 to 12 mA, so 12Vdc is used without vibration.

**4.** The sensitivity of sensors are high which any force located on the sensors, motors are working automatically.

## 6.4 Recommendations

The following points can be implemented to improve the system:

**1.** Use many sensors for capturing the force, position and use camera to photograph the place to use this arm in surgical process with high motors (very torque) at each joint in arm to mimic the doctor hand with very accurately.

**2.** Use short flex sensor at each joint in hand instead of using one sensor as in the project to make the movement of fingers very accuracy with much micro motors in bionic hand.

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# Appendices

**Derivation:**

Each sensor has the following voltage divider:

$$\frac{Vi}{Vcc}=\frac{R_{sensor}}{R_{sensor}+R_{ref}} \quad \textbf{(1)}$$

So, after a maximum bending:

$$\frac{\Delta Vi}{Vcc}=\frac{R_{sensor\_max}}{R_{ref}+R_{sensor\_max}}-\frac{R_{sensor\_min}}{R_{ref}+R_{sensor\_min}} \quad \textbf{(2)}$$

Where $R_{sensor\ \_min}$ corresponds to 0° angle, and $R_{sensor\ \_max}$ to maximum angle which depend on joints which applied it, whereas **Δ**Vi to voltage variation between maximum and minimum.

In order to take the maximum signal sweep with the maximum allowed flection degrees, $R_{ref}$ for voltage divider can be yield from partial derivative according the equation (3):

$$\frac{\partial\frac{\Delta Vi}{Vcc}}{\partial R_{ref}}=\frac{R_{sensor\_max}}{(R_{ref}+R_{sensor\_max})^2}-\frac{R_{sensor\_min}}{(R_{ref}+R_{sensor\_min})^2}=0 \quad \textbf{(3)}$$

To obtain:

$$R_{ref}=\sqrt{R_{sensor\_max}*R_{sensor\_min}} \quad \textbf{(4)}$$

**Software Code:**

**/* transmitter circuit */**

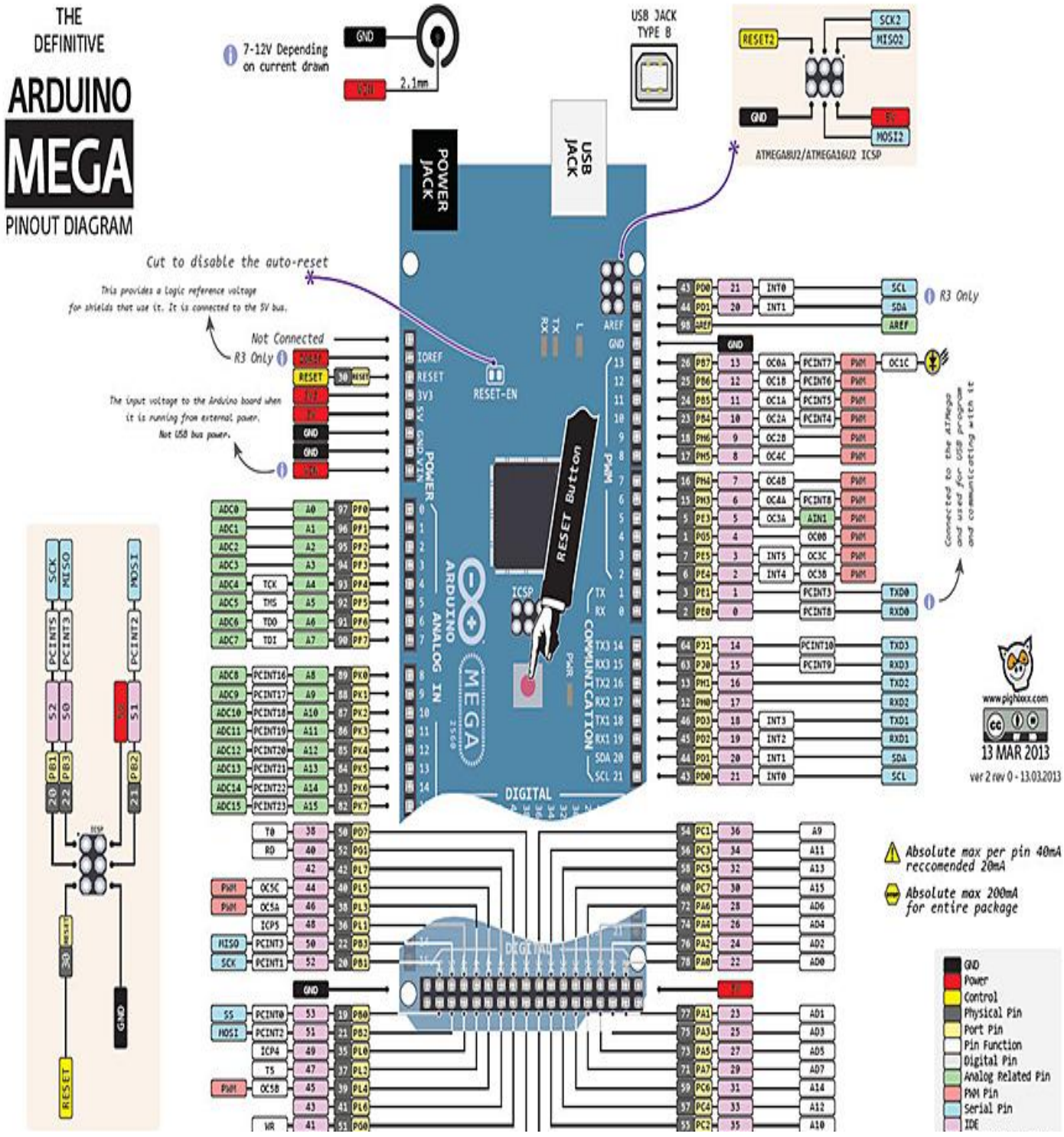
```
//Constants:
const int sensor1Pin = A0; //sensor at Arduino A0 pin
const int sensor2Pin = A1;
const int sensor3Pin = A2;
const int sensor4Pin = A3;
const int sensor5Pin = A4;
const int sensor6Pin = A5;
//Variables:
int value1 ; int value2 ; int value3 ; int value4 ; int value5 ; int value6 ; //Value from sensor
void setup() {
  //Start the serial communication
  Serial.begin(9600); //Baud rate must be the same as is on xBee module
```

```
}
void loop() {
   //Read the analog value from sensor and store it to "value" variable
    value1 = analogRead(A0);
    value2 = analogRead(A1);
    value3 = analogRead(A2);
    value4 = analogRead(A3);
   value5 = analogRead(A4);
    value6 = analogRead(A5);

    value1 = map (value1, 130, 450, 30, 180);
    value2 = map (value2, 589, 919, 30, 180);
    value3 = map (value3, 589, 919, 30, 180);
    value4 = map (value4, 614, 1023, 0, 180);
    value5 = map (value5, 614, 1023, 0, 180);
    value6 = map (value6, 614, 1023, 0, 180);

  //Send the message:
  Serial.print('<');  //Starting symbol
  Serial.print(value1);
  Serial.print(value2);
  Serial.print(value3);
  Serial.print(value4);
  Serial.print(value5);
  Serial.print(value6);
  Serial.println('>');//Ending symbol}
```

**/*receivor circuit */**

```
#include <Servo.h>   // Library needed to use function for servomotors
Servo Servo1, Servo2,        // Viene assegnato un nome a ciascun servomotore.
Servo3, Servo4, Servo5,Servowrist;

byte start; // Variable that will contain the character of start package set in the GloveTX sketch, "<"

int sensor1= 0;    // Variables with the values for the servomotors (between 0 and 180)
int sensor2= 0;int sensor3= 0;int sensor4= 0;int sensor5 = 0;int sensorwrist= 0;

void setup()
```

```
{
  Serial.begin(9600); // Serial communication is activated at 9600 baud/s.

  Servo1.attach(11);  // The servomotors are asigned to the pins of the Arduino board.
  Servo2.attach(10);
  Servo3.attach(9);
  Servo4.attach(6);
  Servo5.attach(5);
  Servowrist.attach(3);

  Serial.println("Ready to receive.");
}

void loop()
{
  if(Serial.available()) {    // Witing for data incoming from the other XBee module

    start = Serial.read(); // The first value will be "<", the other are assigned to the finger
    sensor1   = Serial.read();
    sensor2   = Serial.read();
    sensor3 = Serial.read();
    sensor4 = Serial.read();
    sensor5  = Serial.read();
   sensorwrist = Serial.read();

    if(start == '<'){   // Verifying that the first value is "<"

      ServoThumb.write(sensor1);    // The servomotors rotates of the assigned degrees
      ServoIndex.write(sensor2);
      ServoMiddle.write(sensor3);
      ServoAnnular.write(sensor4);
      ServoPinky.write(sensor5);
      Servowrist.write(sensor6);
    }
  }
  delay(30); // a delay to make the servomotors working correctly
}
```


THE
DEFINITIVE
ARDUINO
MEGA
PINOUT DIAGRAM
7-12V Depending on current drawn
GND
VIN
2.1mm
USB JACK TYPE B
POWER JACK
USB JACK
RESET2
SCK2
MISO2
GND
MOSI2
ATMEGA8U2/ATMEGA16U2 ICSP
Cut to disable the auto-reset
This provides a logic reference voltage for shields that use it. It is connected to the 5V bus.
Not Connected
R3 Only
The input voltage to the Arduino board when it is running from external power. Not USB bus power.
RESET-EN
RESET Button
ICSP
POWER
ANALOG IN
DIGITAL
PWM
COMMUNICATION
ARDUINO
MEGA
R3 Only
Connected to the ATMega and used for USB program and communicating with it
www.pighixxx.com
13 MAR 2013
ver 2 rev 0 - 13.03.2013
Absolute max per pin 40mA reccomended 20mA
Absolute max 200mA for entire package
GND
Power
Control
Physical Pin
Port Pin
Pin Function
Digital Pin
Analog Related Pin
PWM Pin
Serial Pin
IDE