Palestine Polytechnic University

Designing And Controlling 1DOF Robot Arm Using EEG Signals For People With Special Needs

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According to the direction of the project supervisor and by the agreement from the entire committees members. This project was submitted to department of electrical engineering in college of engineering and technology to partially fulfill of the B.Sc requirements.

Supervisor Signature

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Testing Committee Signature

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Chair of the Departement Signature

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Abstract

This system discussed a brain controlled robot based on Brain computer interfaces (BCI). BCIs are systems that can bypass conventional channels of communication to provide direct communication and control between the human brain and physical devices by translating different patterns of brain activity into commands in real time. With these commands a robot arm can be controlled. The intention of the project work is to develop a robot that can assist the disabled people in their daily life to do some work independent on others. This done by three parts : mechanical part, Biomedical (EEG), processing and decision making.

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Chapter One

1.1 Overview

Many people suffer from paralysis or cutting in the right arm, as a result of some disease or accident exposure to it in their life. That make them face a big challenge for doing basic functions that every normal people do it. For this reason and to make this group of people practiced their life partly as a normal people, a robot arm has been designed that take its controlling commands from patients brain .

This project based on brain computer interface (BCI) technology, that includes a human subject, a brain signals capturing device, a specific brain signal recognition software, a robot interface, a robot, and a feedback (usually visual) to the subject.

We picked up the brain waves by placing electrodes on the surface of the skull, without the need for any surgical intervention (Non-Invasive). Then electrodes transmit data to amplification circuit, in order to process these signals by amplifying and filtering it from Jamming or any signals that generated from sources other than the brain.

Then we inserted these signals into microcomputer (raspberry pi) that consist of software to complete signal processing, extract the features of the signal and classify it. Then transfer the output from raspberry pi to microcontroller (arduino) that responsible for provide a signal to the motor that specified in classification step at raspberry pi.

We used Aluminum metal for each link of the arm in order to get one similar to the human arm, and for each joints we used a servo motor and gears for the gripper.

1.2 Brain Computer Interface (BCI)

(BCIs) Advances in cognitive neuroscience and brain imaging technologies have started to provide us with the ability to interface directly with the human brain. This ability is made possible through the use of sensors that can monitor some of the physical processes that occur within the brain that correspond with certain forms of thought. Researchers have used these technologies to build brain-computer interfaces (BCIs), communication systems that do not depend on the brain's normal output pathways of peripheral nerves and muscles. In these systems, users explicitly manipulate their brain activity instead of using motor movements to produce signals that can be used to control computers or communication devices.[1]

Brain computer interface(BCI) is a fast growing emergent technology, where researchers aim to build a direct channel between the human brain and the computer, which allows a human to control a computer, peripheral, or other electronic device with thought.

It does so by using electrodes to detect electric signals in the brain which are sent to a computer. The computer then translates these electric signals into data which is used to control a computer or a device linked to a computer. Figure 1.1 shows the BCI block diagram.

A brain computer interface(BCI) is collaboration in which a brain accepts and controls a mechanical device as a natural part of it is representation of the body.

A brain computer interfaces are designed to restore sensory information to the brain, or stimulate the brain through artificially generated electrical signals.

Figure 1.1 : BCI block diagram

1.3 Project Objectives

1. To build a robotic arm that will be used for amputees .

2. To introduce a new technology for the domestic market.

3. To get a new product with low cost and high quality .

1.4 Problem statement

This project based on the principle of using Electroencephalograph (EEG) to help people with disabilities kinetics or cutting in there right hand arm, by capturing signals from the brain and make a series of process in these signals, in order to get a material that the microcontroller can understand it. And we can program this microcontroller in order to controlling a robot arm that connects to the patient body, and by sending his thought signal to the arm, he can use it to capture objects , moving it without any feedback tell him how hardness of it or its temperature or any physical characteristic of it. The feedback will be just by eyes .

1.5 Conceptual Design

It is desired to design and produce an electro-mechanical system that relies on EEG signals to control it. The process starts when the electrodes on the patient brain cortex detect signals, and translate it as an electrical signals. These electrodes are connected to Amplification circuit to process it, and transmitted it to microcomputer (Raspberry Pi) then to microcontroller (Arduino) that represents the robot arm brain. The patient can now deal with the arm as a normal arm that he can use it to carrying objects , shifting it from place to another and using it in eating or drinking. The block diagram of the whole system is shown in Figure 1.2.

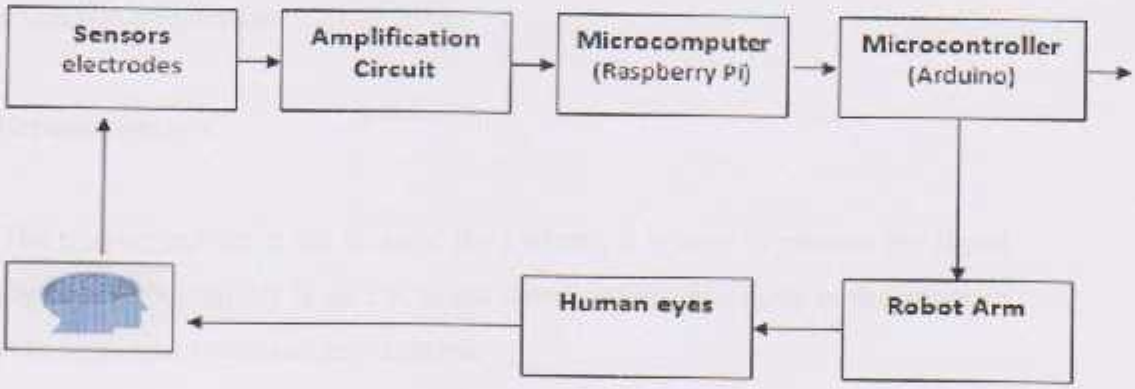


Figure 1.2: Block diagram for the whole system

1.6 Functional Specification :

In this section, more details are given for each system with its related blocks in Figure 1.2.

1.6.1 Sensors (electrodes)

In bio-signal recordings, electrodes are the initial elements which are used for converting biopotential signals due to biopotential sources into electrical signals. Where EEG electrodes transform ionic currents from cerebral tissue into electrical currents used in EEG preamplifiers . EEG electrodes are usually made of metal and are produced as cup-shaped, disc, needle, or microelectrode to measure intra-cortex potentials. In the EEG system, as a non-invasive application, the electrodes are placed on the scalp, and a sufficient number of electrodes may be 1 to 256 placed on EEG cap for easy application.[2]

1.6.2 Amplification circuit :

The EEG signal is very small signal and it have other signals from other sources that appear as noise on the signal . So that at this stage, we used many electronic device to amplify and eliminate this noise from the signal such as: instrumentation preamplifier with a specific gain, band reject filter to reject the noise that create from line power source with 50 or 60 Hz frequency , Band pass filter to bypass a specific frequencies.

1.6.3 Microcomputer :

The microcomputer is the brain of the system , it is used to process the signal to classify it. Microcomputer is an electronic device which functions as the program language to sending a command into arduino.

1.6.4 Controller :

Controller is an electronic device which functions as sending a pulse signal into servo motor to control the position of the pulse of servo motor. Controller usually comes with required program which can be controlled by computer or PIC circuit .

1.6.5 Robot Arm

A robotic arm is a robot manipulator, usually programmable, with similar functions to a human arm. The links of such a manipulator are connected by joints allowing either rotational motion (such as in an articulated robot) or translational (linear) displacement. The links of the manipulator can be considered to form a kinematic chain. The business end of the kinematic chain of the manipulator is called the end effectors and it is analogous to the human hand. [3]

1.7 Previous Studies

1-Emulating "Iron Man":

Iniguez made a mechanical arm and for controlling this arm he use a BCI headset. The mechanical arm, attached to a person's arm, could be used by someone who has lost strength in their arm or has paralysis. and it could make them 10 times stronger.[4]

2-Truly brain-controlled prosthetic arm uses electrodes attached to nerves and muscles :

This project developed by Swedish researchers to help amputees to control an artificial limb in a very similar way as their own biological hand or arm, The robotic prosthesis mounted to the bone and controlled by thoughts is connected directly to the person's own nerves and remaining muscles. [5]

3-Brain-Robot Interaction:

Byron Galbraith, Max Versace and Sean Lorenz develop an EEG-based brain-machine interface (BMI) for controlling an adaptive mobile agent . Using EEG signals, subjects will be tasked with navigating the robot to a desired location in a room, orienting the camera to fixate upon a target object, and picking up the attended object with the robotic arm.[7]

1.8 Project Cost

Table 1.1: Hardware Cost

Main Components	Cost
Amplification Circuit	93$
Analog To Digital Converter	20$
Microcontroller	75$
Microprocessor	75$
Servo Motors	450$
Mechanical Elements	5$

1.9 Scheduling Table

Table 1.2: Timing schedule of the first semester

Task\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Choosing the project																
Collect information																
Basic Design																
System Analysis																
Writing documentation																

Table 1.3: Timing schedule of the second semester

Task\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Collect information																
Design of project																
Documentation																
Advanced Features																

CHAPTER TWO

THEORETICAL BACKGROUND

2.1 Introduction

This chapter introduces a detailed description of the human brain, brain wave and robot parts and the other components will be used in this project, the parts have different types and shapes with different properties , our selection must be compromise between these properties to achieve the required shape and performance without affecting safety of patient .

First Part

2.2 Human Brain

The brain is a complex organ, which is made up of billions of brain cells called neurons, which use electricity to communicate with each other . The combination of millions of neurons sending signals at once produces an enormous amount of electrical activity in the brain, which can be detected using sensitive medical equipment (such as an EEG), that measuring electricity levels over areas of the scalp. The combination of electrical activity of the brain is commonly called a Brainwave pattern.[8]

2.2.1 Parts of the Brain

The brain is composed of the cerebrum, cerebellum and brainstem, as in figure(2.1).

- The cerebrum is the largest part of the brain, divided into left and right hemispheres. Carries out higher thought processes involved with language, learning, memory, and voluntary body movements.

- The cerebellum means "little brain" Smaller structure under the base at the back of the brain. Responsible for balance and coordination.

- The brain stem is extending from the base of the brain; this continues into the spinal cord, made up of the pons and medulla oblongata. Relays signals between the brain and spinal cord [9]There is other Functions of the brain stem include automatic functions, like breathing, the beating of the heart, and blood pressure.

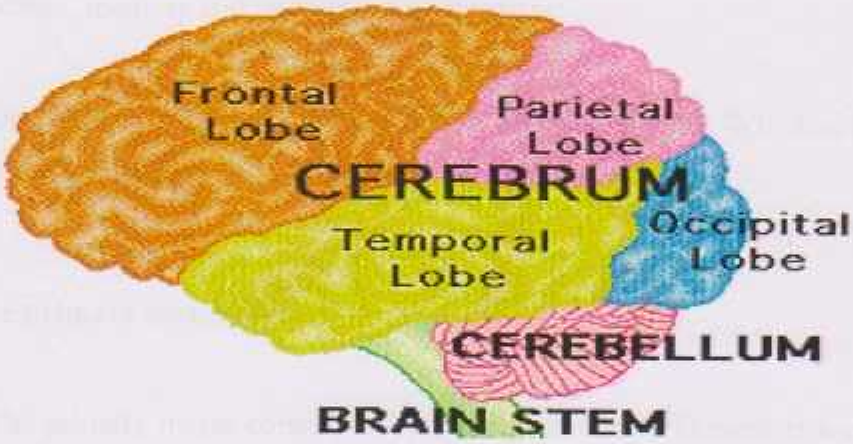


Figure 2.1: Human brain.[8]

The brain's hemispheres have matching elements. The right hemisphere controls the left side of the body, while the left hemisphere controls the right side.

2.2.2 Lobes of the brain

The cerebral hemisphere have distinct fissures, which divide the brain into lobes. Each hemisphere has four lobes: frontal, temporal, parietal and occipital. Each lobe may be divided, into areas that serve very specific functions, it is important to understand that each lobe of the brain does not function alone. There is are very complex relationships between the lobes of the brain and between the right and left hemisphere.[10]

Cerebral lobes:

- Frontal lobe: Located in the front of the brain. Which is responsible for conscious thought, behavior, emotion, planning, personality, organizing, problem solving.

- Parietal lobe: Located in the middle top of the brain. Which is responsible for Integrations of sensory information from primary sensory areas such as perception, arithmetic, spelling, manipulation of objects.

- Temporal lobe: Located in the Temple region. Which is responsible for Senses of smell and sound, as well as processing of complex stimuli like faces and scenes, memory and understanding language.

- Occipital lobe: Located in the Extreme back of the brain. Which is responsible for Sense of sight[10].

2.2.3 The primary motor cortex

The primary motor cortex is a brain region that in humans is located in the posterior portion of the frontal lobe. It works in association with other motor areas including premotor cortex, the supplementary motor area, posterior parietal cortex, and several subcortical brain regions as shown in figure (2.2), to plan and execute movements. Primary motor cortex is defined anatomically as the region of cortex that contains large neurons.

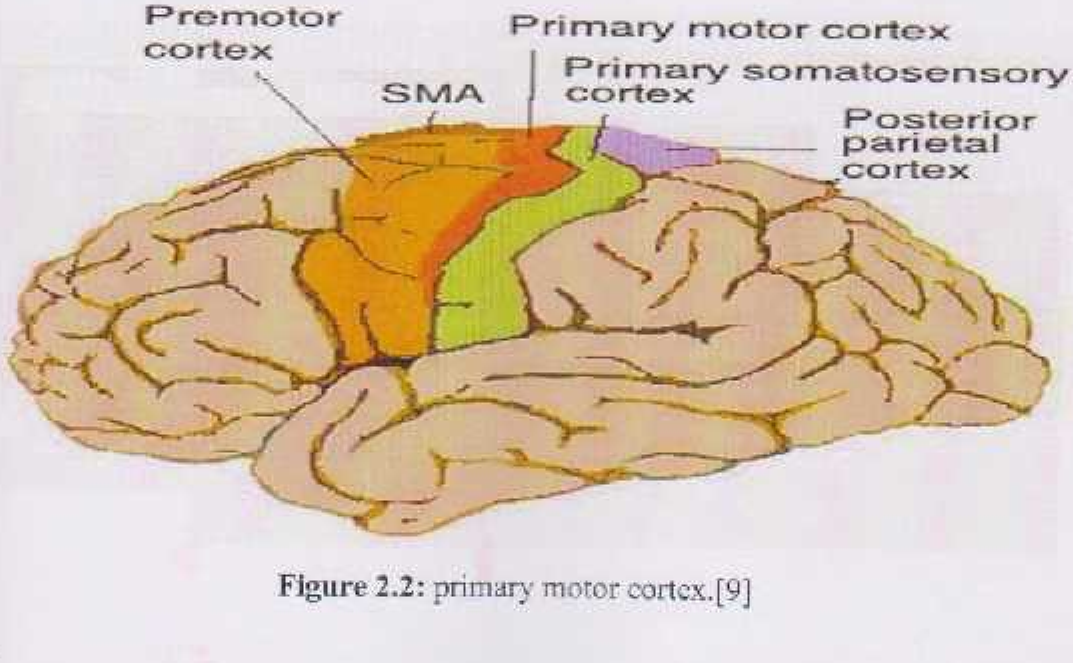


Figure 2.2: primary motor cortex.[9]

2.3 Electroencephalograph

Electroencephalograph (EEG) is a recording of the electrical activity of the brain, by suitably placing surface electrodes on the scalp.

EEG describing the general function of the brain activity, is the superimposed wave of neuron potentials operating in a non-synchronized manner in the physical sense.[11]

EEG signals picked up by the surface electrodes are usually small as compared with the ECG signals. They may be several hundred microvolts, but 50 microvolts peak to peak is the most typical. The brain waves, unlike the electrical activity of the heart , do not represent the same pattern over and over again .Therefore, brain recordings are made over a much longer interval of time in order to be able to detect any kind of abnormalities.[11]

The brain generates rhythmical potentials which originate in the individual neurons of the brain. these potentials get summated as millions of cell discharge synchronously and appear as a surface waveform, the recording of which is known as the electroencephalogram, as shown in figure(2.3).[11]

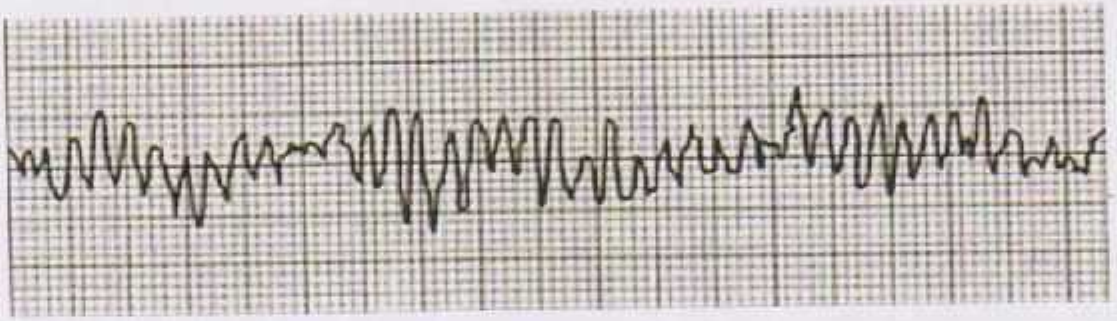


Figure 2.3: Typical EEG signal waveform[11]

2.3 Brain Rhythms

Many brain disorders are diagnosed by visual inspection of EEG signals. The clinical experts in the field are familiar with manifestation of brain rhythms in the EEG signals. For example, in healthy adults, the amplitudes and frequencies of such signals change from one state of a human to another, such as wakefulness and sleep. The characteristics of the waves also change with age. There are five major brain waves distinguished by their different frequency ranges: alpha (α), theta (θ), beta (β), delta (δ), and gamma (γ),as shown in figure(2.5).[12]

Gamma Brain Waves (+40 Hz): are the waves highest in frequency at above 40Hz. They also tend to be the lowest in amplitude. Gamma waves are present in whole brain functioning and are associated with bursts of insight and information processing related to "super-learning" and peak performance.[13]

Beta Brain Waves (13-40 Hz): are lower in frequency than Gamma waves with slightly higher amplitude. They usually dominate in normal, waking consciousness, when processing information or engaged in activity or conversation. They are associated with analytical thinking, a state of alertness, anxiety and stress.[13]

Alpha Brain Waves (8-12.9 Hz): are lower still than Beta waves, with even higher amplitude. They are active when the eyes are closed, or when the brain is not actively processing information. They are indicative of a relaxed, calm state of mind.[13]

Theta Brain Waves (4-7.9 Hz): are slower than Gamma, Beta or Alpha waves and are typically of even greater amplitude. They are active during light sleep, and deep meditation.[13]

Delta Brain Waves (0.2-3.9 Hz): are the slowest in frequency and the highest in amplitude. They are active in deep sleep, dreamless sleep and in very deep, transcendental meditation where awareness is completely detached.[13]

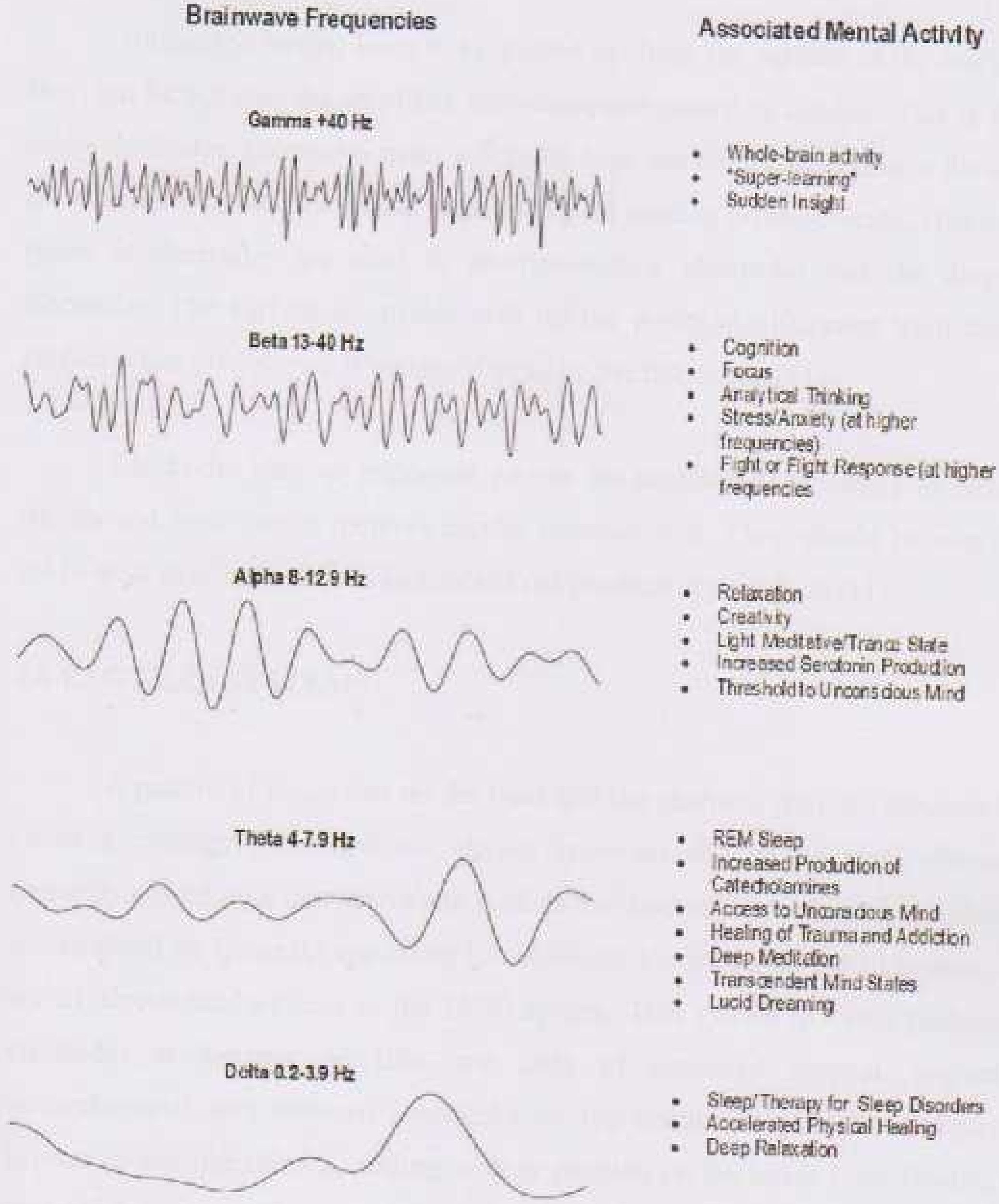


Figure 2.5: brain rhythms[13]

2.5 EEG Electrodes

Bioelectric events have to be picked up from the surface of the body before they can be put into the amplifier for subsequent record or display. This is done by using electrodes. Electrodes make a transfer from the ionic conduction in the tissue to the electronic conduction which is necessary for making measurements. There are two types of electrodes are used in practice-surface electrodes and the deep-seated electrodes. The surface electrodes pick up the potential difference from the tissue surface when placed over it without damaging the live tissue.[11]

Electrodes play an important part in the satisfactory recording of bioelectric signals and their choice requires careful consideration. They should be comfortable for to wear over long periods and should not produce any artifacts.[11]

2.6 EEG LEAD SYSTEMS

A pattern of electrodes on the head and the channels they are connected to is called a montage. Montages are always symmetrical. The reference electrode is generally placed on a non-active site such as the forehead or earlobe. EEG electrodes are arranged on the scalp according to a standard known as the 10/20 system. There are 21 electrodes locations in the 10/20 system. This system involves placement of electrodes at distance of 10% and 20% of measured coronal, sagittal and circumferential arcs between landmarks on the cranium as shown in figure(2.6). Electrodes are identified according to their position on the head: F for frontal, C for central, P for parietal, T for temporal and O for occipital. Odd numbers refer to electrodes on the left side of the head and even numbers represent those on the right while Z denotes midline electrodes.[11]

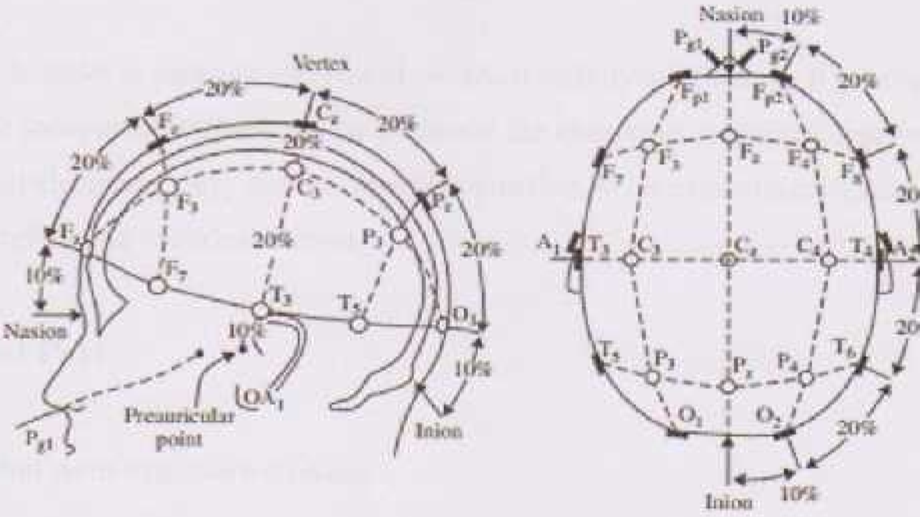
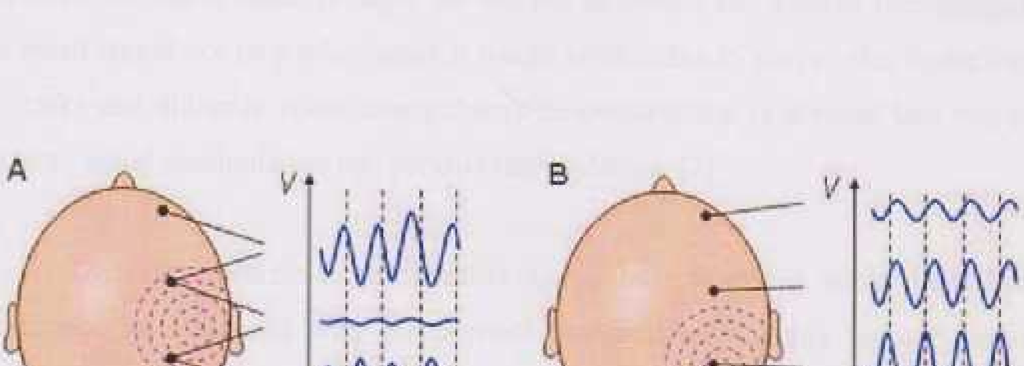


Figure 2.6: The international 10-20 system seen from left and above the head.[12]

EEG may be recorded by picking up the voltage difference between an active electrode on the scalp with respect to a reference electrode on the ear lobe or any other part of the body. This type of recording is called Monopolar recording . However, Bipolar recording is more popular wherein the voltage difference between two scalp electrodes is recorded as shown in figure(2.7). Such recordings are done with multi-channel electroencephalographs. [12]



bipolar montages ***unipolar montages***

Figure 2.7:(A) Bipolar and (B) Unipolar measurements.[14]

2.7 Electrodes

In order to measure and record electrical activity of the brain, it is necessary to provide some interface between the brain and the electronic measuring apparatus, bio-potential electrodes carry out this interface function. Where the electrodes convert the ionic current into electrical current.

Second Part

2.8 Robot Arm Structure Options

In this section the structure design of the arm have been discuss to be adapted in such an application , the robot itself, the controller , the actuators and the gripping mechanism .

2.8.1 Manipulator design :

Robot manipulator is a set of links connects to each other throw joints ,the first is fixed called base and the last which tool or gripper connects is called end effectors. the manipulator produce the motion to robot , so without the manipulator the robot would not be a robot since it would not be able to move . due to the variety of tasks and duties in robot manipulators its construction is divided into two main classes : serial manipulators and parallel manipulators. [2]

The only obstacle of the parallel manipulator is that it suffer from limited workspace as compared with serial robot manipulators. In this project the serial manipulator has been chosen.

Most manipulators arms at the present time have five or fewer DOF. These manipulators are usually classified kinematically on the basis of the first three joints of the arm, with the wrist being described separately. The majority of these manipulators fall into one of five geometric types: articulated (RRR), Cartesian (PPP), cylindrical (RPP), or spherical (RRP). [1]Each of these four manipulator arms are serial link robots.

2.8.1.1 Articulated manipulator (RRR)

The articulated manipulator shown in figure (2.9) is also called a revolute, is the most common , these robot are often referred to as anthropomorphic because their movements closely like the human arm. The revolute configuration has several advantages.

It is the most varied configuration and provides a larger work envelope than the Cartesian, cylindrical, or spherical configurations.[15]It also more flexible than the other configurations, it ideally suited to do many tasks. because of these the articulated configuration is our choice in the design of this project. A disadvantages to the revolute configuration is that it requires a very complicated controller, and programming is more complex than the other three configurations.

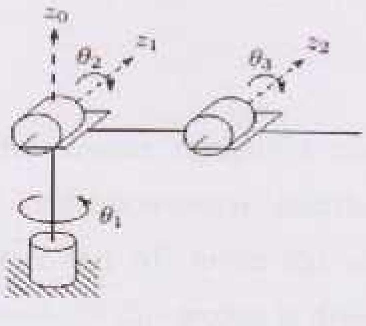


Figure 2.8: The Articulated manipulator.[15]

2.9 Gripper

Generally used to hold an objects and place it from place to another ,it can be classified into mechanical, vacuum, pneumatic or even electrical gripper .many properties must the gripper achieves like light weight, small size, accuracy and fast action in this project an electro-mechanical gripper shown in Figure (2.13) will be used in design .

It consist of two fingers close against the object with sufficient mechanical force to hold the object against gravity and movement forces. The force should not however be too severe and cause damage to the component. The grippers powered by servo motor .

Figure 2.12: Gripper

2.10 Motors And Actuators

Motor is a device that creates motion; it usually refers to either an electrical motor or an internal combustion engine. electric motor includes DC motor that is driven by direct current and AC motor that runs on alternating current electricity. The selection of motor for this project is depending on the DOF of the robotic arm includes weight, arm link length and power or current. There are a number of different types of motors that can be used: dc, stepper and servo motors.

2.10.1 Servo Motor:

Of the three motors, the servo motors offers the smoothest and greatest control. They can be told to rotate to a specific point, making them ideal for applications that require precise movement.

RC servo is small actuators designed remotely operating model vehicles such as cars, airplanes, and boats. Today, RC servos are become popular in robotic arm, creating humanoid robot, biologically inspired robot, and robotic arm. This is because its ability to rotate and maintain certain location, position or angle according to control pulse from a single wire.

Inside a typical RC servo contains a small motor and gearbox to do the work, a potentiometer to measure the position of the output gear, and an electric circuit that control the motor to make the output gear move to the desired position. Because all of these components are packed into a compact, low-cost unit, RC servos are great actuator for this robotic arm project. Figure 2.15 show the picture of the RC servo motor.

Figure 2.14: RC servo motor.

Servos are controlled by sending them a pulse of variable width. The signal wire is used to send this pulse. The parameters for this pulse are that it has a minimum pulse, a maximum pulse, and repetition rate. Given the rotation constraints of the servo, neutral is defined to be the position where the servo exactly the same amount of potential rotation in the clockwise direction as it does in the counter clockwise direction. It is important to note that different servos will have different constraints on their rotation.

2.12 Raspberry pi Model B+ :

Figure 2.16: Raspberry pi Model B+

The Model B+ shown in figure 2.17 uses the same BCM2835 application processor as the Model B. It runs the same software, and still has 512MB RAM; But More GPIO. The GPIO header has grown to 40 pins, while retaining the same pin out for the first 26 pins as the Model B. More USB. We now have 4 USB 2.0 ports, compared to 2 on the Model B, and better hot plug and over current behavior. Micro SD. The old friction-fit SD card socket has been replaced with a much nicer push-push micro SD version. Lower power consumption. By replacing linear regulators with switching ones we've reduced power consumption by between 0.5W and 1W. Better audio. The audio circuit incorporates a dedicated low-noise power supply.

Raspberry Pi Model B+ Featuring :

700MHZ Broadcom BCM2835 processor with 512MB RAM ,40 pin extended GPIO ,Full size HDMI, 4USB ports ,Micro SD slot, More energy efficiency (less power required), Improved power management, New 4-pole connector replaces the existing analogue and composite video port on the Model B.

2.13 Arduino

An Arduino is a single-board microcontroller and a software suite for programming. It is designed for an Atmel AVR processor and features on-board I/O support. The software consists of a standard programming language and the boot loader that runs on the board. We are using ArduinoDue microcontroller board.

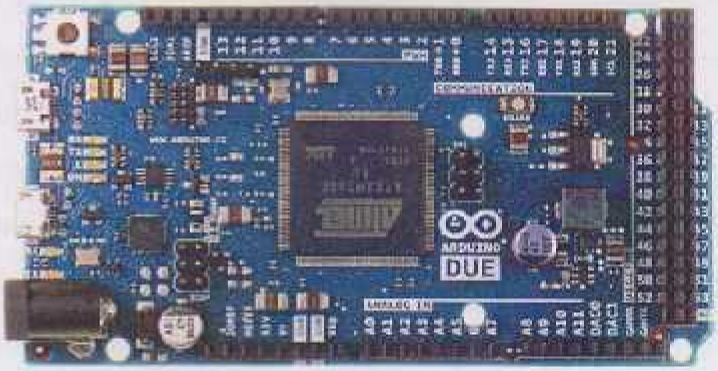


Figure 2.17: Arduino Due

Table 2.1: ArduinoDue specifications

Microcontroller	AT91SAM3X8E
Operating Voltage	3.3V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-16V
Digital I/O Pins	54 (of which 12 provide PWM output)
Analog Input Pins	12
Analog Output Pins	2(DAC)
Total DC Output Current on all I/O lines	130mA
DC Current per 3.3V Pin	800 mA
DC Current for 5V Pin	800 mA
Flash Memory	512 KB all available for the user applications
SRAM	96 KB(two banks:64KB and 32KB)
Clock Speed	84 MHz

CHAPTER THREE

SYSTEM DESIGN

3.1 Introduction to acquiring system design

EEG signal is acquired by electrodes. The EEG signal is very small and exist in level of ambient noise. The amplification circuit must amplify this small signal without any distortion and suppress any noise in it.

3.2 Signal processing system design

This section talks about EEG signal processing such as amplification and filtration. Figure(3.1) depicts the main components of the hardware system. The electrodes will be used to transform ionic current in tissue of the brain to electrical current. Pre-Amplifier circuit amplify the differential signal and reduce the common mode voltage. Band Pass Filter allows a specific range of frequencies to pass, while blocking lower and higher frequencies and Inverting amplifier to amplify the signal.

Figure 3.1: block diagram of EEG system

3.2.1 Electrodes

The EEG recording electrodes and their proper function are critical for acquiring appropriately high quality data for interpretation. Many types of electrodes exist, often with different characteristics. For multichannel montages, electrode caps are preferred, with number of electrodes installed on its surface . Commonly used scalp electrodes consist of Ag-AgCl disks, 1 to 3 mm in diameter, with long flexible leads that can be plugged into an amplifier. AgCl electrodes can accurately record also very slow changes in potential .Needle electrodes are used for long recordings and are invasively inserted under the scalp.[16]

Ag/AgCl electrode is chosen because of its very low half-cell potential of approximately 220 mV and its ease of manufacture ability. Ag/AgCl electrodes are non polarized electrodes ,they allow current to pass across the interface between the electrolyte and the electrode. Non polarized electrodes are better than polarized electrodes in terms of their rejection of motion artifacts and their response to defibrillation currents[17].

3.2.2 Instrumentation Amplifier (INA)

The AD620 INA has been used, as in figure (3.3), because it is:

- Easy to use.
- High common mode rejection ratio.
- Low power consumption.
- Low internal noise.
- High input impedance.

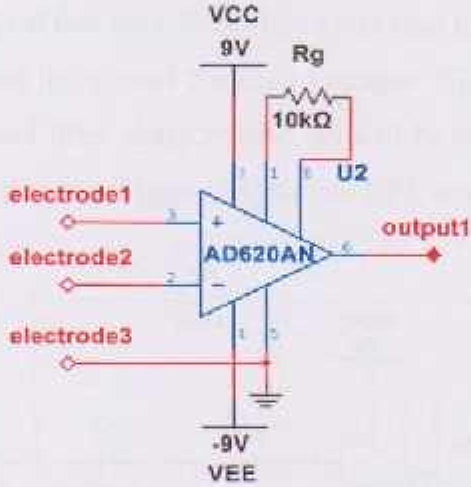


Figure 3.3 : AD620 INA

From data sheet of AD620, the gain is illustrated in Eq(3.9):

$$A = \frac{49.9K\Omega}{Rg} + 1 \qquad (3.9)$$

Where:

A : INA voltage gain.

Rg : External resistance added to achieve a determined voltage gain.

So, the gain that needed in this stage is 6 because there is DC offset voltage, so can't amplifying the signal more than 6 to prevent the saturation, by using Eq(3.9) the value of Rg is approximately 10 KΩ.

3.2.3 Band-Pass Filter

A Band Pass Filter (BPF) allows a specific range of frequencies to pass, while blocking lower and higher frequencies.

3.2.3.1 High-Pass Filter

An optimum high pass filter (HPF) will be designed to passes high frequency signals but attenuate the signal that have frequencies less than high cutoff frequency (F_h). Since this signals far exceed the size of the EEG voltages. Higher order pass filters are required to sharpen a desired filter characteristic, so will be uses 2nd order (Sallen-Key Butterworth Filter) for this purpose. Figure(3.4) shown HPF circuit.

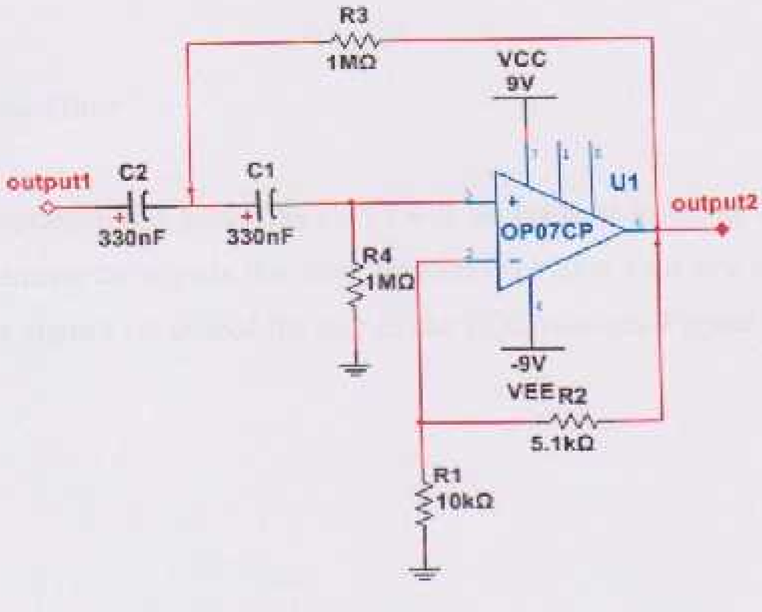


Figure 3.4: Second order HPF circuit.

Eq(3.10) illustrated high critical frequency:

$$F_h = \frac{1}{2\pi\sqrt{R_3R_4C_1C_2}} \quad (3.10)$$

$$A_2 = 1 + \frac{R_2}{R_1} \quad (3.11)$$

Quality factor

$$Q = \frac{1}{3 - A_v} \quad (3.12)$$

The high cutoff frequency that required in this project is $0.5Hz$. (Q=0.71) in Butterworth coefficients filter[19]. So A=1.5 .

Let $C_1 = 330nF$ and $C_2 = C_1 = 330nF$.

by using Eq(3.10):

$R_3 = R_4 = 1M\Omega$.

Since the gain of this stage equal 1.5 , so by using Eq(3.11), let $R_1 = 10K\Omega$, so $R_2 = 5.1K\Omega$.

3.2.3.2 Low Pass Filter

An optimum low pass filter (LPF) will be designed to passes low-frequencies signals but attenuate the signals that have frequencies higher than low cutoff frequency (F_l). Since this signals far exceed the size of the EEG voltages. Figure(3.5) shown LPF circuit.

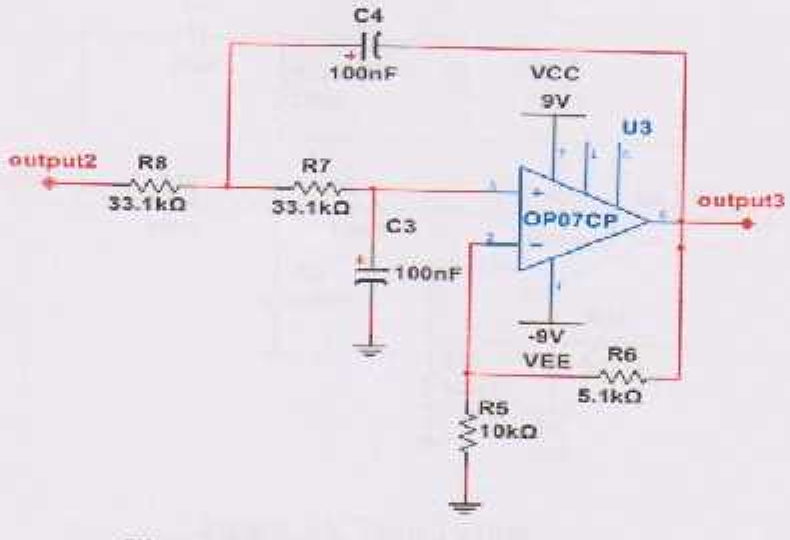


Figure 3.5: Second order LPF circuit.

Eq(3.13) illustrated low critical frequency :

$$F_l = \frac{1}{2\pi\sqrt{R_7 R_8 C_3 C_4}} \qquad (3.13)$$

The low cutoff frequency that required in this project is 48Hz.

Let $C_3 = C_4 = 100nF$

By using Eq(3.13):

$R_8 = R_7$ =33.1KΩ.

Since the gain (A_3) of this stage equal 1.51 , so by using Eq(3.11), let $R_5 = 10K\Omega$, so $R_6 = 5.1K\Omega$.

3.2.4 Notch Filter

In previous section, the common voltage attenuated by high and low circuit, but there is residual common mode voltage that created from power line are still combined with the EEG signal. So notch filter will be used to reject the residual common mode voltage. The Twin-T circuit will be used since it is provides a large degree of rejection at a particular frequency. Figure(3.6) shown the Twin-T filter circuit.

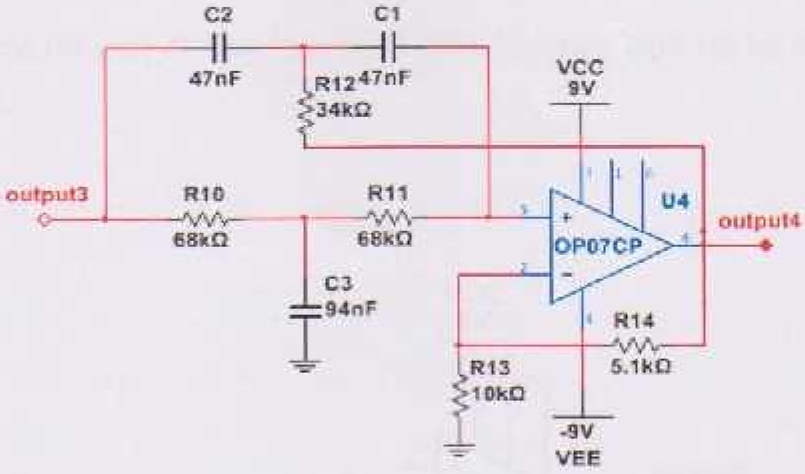


Figure 3.6: Twin-T Filter.

To calculate the values of resistors and capacitor for the notch filter, will be used Eq(3.15).

$$F_{notch} = \frac{1}{(2\pi RC)} \qquad (3.15)$$

$R_{10} = R_{11} = 2R_{12}$

$C_1 = C_2 = C_3/2$

$F_{notch} = 50Hz$

Let $C_1 = 47nF$ so $C_2 = 47nF and C_3 = 94nF$.

By using Eq(3.15):

$R_{10} = 68K\Omega so R_{11} = 68K\Omega and R_{12} = 34K\Omega$.

Since the gain (A_4) of this stage equal 1.51 , so by using Eq(3.11), let $R_{13} = 10K\Omega$, so $R_{14} = 5.1K\Omega$.

3.2.5 Inverting Amplifier

After filtration the signal from common mode voltage, now we can amplify this signal since it is very small signal in (microvolt). Inverting amplifier will be use for this purpose as shown in fig(3.7). Eq(3.16) illustrated the gain of this filter.

$$A_5 = -\frac{R_2}{R_1} \qquad (3.16)$$

Since the gain of this stage equal -200, by using Eq(3.16) let $R_1 = 1K\Omega$, so $R_2 = 200K\Omega$.

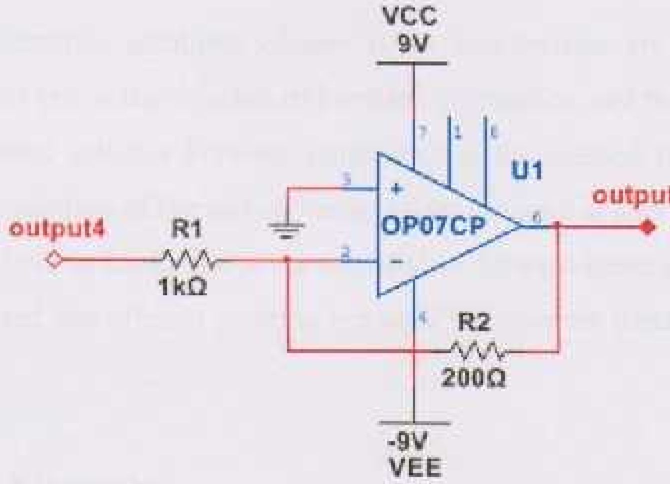


Figure 3.7: Inverting amplifier.

In this project the OP07 Op-Amps have been used since it have the following characteristic:

- Power supply $\pm 9V$.
- Low internal noise.

3.2.6 Power Supply

Power supply has been used to supply a power to electrical component. Since the product of this project is portable so also we need portable power supply such as Battery with 9V.

3.3 Introduction to robot kinematics

Kinematics is the description of motion without regard to the forces that cause it. It deals with the study of position, velocity, acceleration, and higher derivatives of the position variables[20].

The kinematics solutions of any robot manipulator are divided into two solution, the first one is the solution of Forward kinematics, and the second one is the inverse kinematics solution Forward kinematics is the method for determining the orientation and position of the end -effector ,given the joint angles and link lengths of the robot arm .Inverse kinematic is the opposite of forward kinematics , it used when we have a desired end effector position but need to know the joint angles required to achieve it.

3.3.1 Forward Kinematics

The forward kinematic equations, describe the functional relationship between the joint variables and the position and orientation of the end-effector. If a robot has i links, the joints and links numbered from 1 to i and 0 to i respectively. The joint variables are denoted by q_i . In the case of prismatic joint, d_i represents the displacement, similarly θ_i represent the angle of rotation for the revolute joint.[21]
To obtain the forward kinematic equations the following steps should be done :

A)The DH parameters :

To describe the kinematics of any robot, four parameters are given for each link $a_i, \alpha_i, d_i, \theta_i$ where two of them described the link, and the others describe the connection with other links. this four parameters are generally given the names : link length, link twist , joint offset, and joint angle respectively [15].figure (3.8) show the frame assignment for the robot manipulator where frame 1 is the shoulder frame and frame G is the gripper frame. then we can set the DH parameters of these links as follow [22]:

Table 3.1: DH Parameters

Link	Joint	a_i	α_i	d_i	θ_i
0	1	0	α_1	d_1	θ_1
1	2	a_2	0	0	θ_2
2	3	a_3	0	0	θ_3
3	4	a_4	α_4	0	θ_4
4	5	0	0	d_5	θ_5

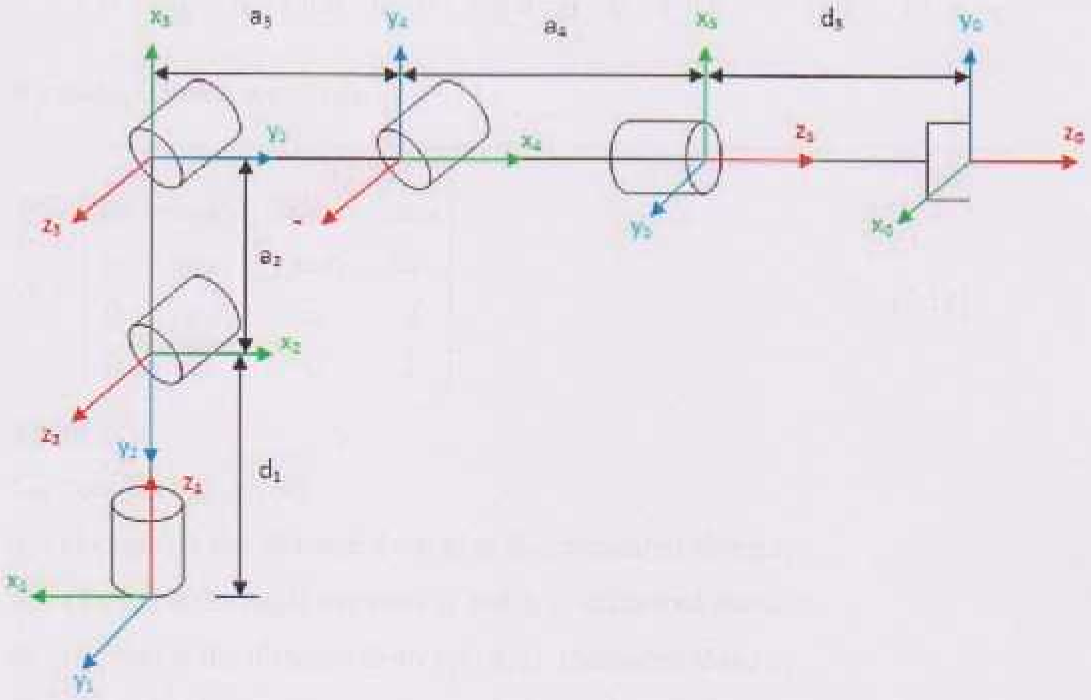


Figure 3.8: frame assignment for the robot manipulator

B) The transformation matrices of each link :

Once the DH coordinate system has been established for each link , a homogeneous transformation matrix can easily be developed depending on the number of the DOF. The homogeneous transformation matrix for each joint from joint 1 to the joint i can be calculated as[21][15]:

$$A_i = Rot(z,\theta_i)Trans(z,d_i)Trans(x,a_i)Rot(x,\alpha_i) \tag{3.17}$$

This transformation consists of four basic transformations as shown in equation above ,where the notation $Rot(z,\theta_i)$ stands for rotation about z_i axis by θ_i, $Trans(z,d_i)$ is translation along z_i axis by a distance d_i, $Trans(x,a_i)$ is translation along x_i axis by a distance a_i, $Rot(x,\alpha_i)$ is rotation about x_i by α_i .Then in terms of the full matrices :

$$A_i = \begin{bmatrix} C_{\theta i} & -S_{\theta i} & 0 & 0 \\ S_{\theta i} & C_{\theta i} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C_{\alpha i} & -S_{\alpha i} & 0 \\ 0 & S_{\alpha i} & C_{\alpha i} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

By multiplication we obtain :

$$A_i = \begin{bmatrix} C_{\theta i} & -S_{\theta i}C_{\alpha i} & S_{\theta i}S_{\alpha i} & a_iC_{\theta i} \\ S_{\theta i} & C_{\theta i}C_{\alpha i} & -C_{\theta i}S_{\alpha i} & a_iS_{\theta i} \\ 0 & S_{\alpha i} & C_{\alpha i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.18)$$

where :

$C_{\theta i}$: cos θi, $S_{\theta i}$: sin θi

a_i : (Length) is the distance from z_i to z_{i+1} measured along z_i .

α_i : (Twist) is the angle between z_i and z_{i+1} measured about x_i.

d_i : (Offset) is the distance from x_i to x_{i+1} measured along z_i .

θi : (Angle) is the angle between x_i and x_{i+1} measured about z_i .

and by substituting in equation (3.18) for each link we get :

$$A_1 = \begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3.19)$$

$$A_2=\begin{bmatrix} c_2 & -s_2 & 0 & a_2c_2 \\ s_2 & c_2 & 0 & a_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.20}$$

$$A_3=\begin{bmatrix} c_3 & -s_3 & 0 & a_3c_3 \\ s_3 & c_3 & 0 & a_3s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.21}$$

$$A_4=\begin{bmatrix} c_4 & 0 & -s_4 & a_4c_4 \\ s_4 & 0 & c_4 & a_4s_4 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.22}$$

$$A_5=\begin{bmatrix} c_5 & -s_5 & 0 & 0 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.23}$$

c) Obtain the manipulator transformation matrix T_i^0:

After the homogeneous matrix has been defined for each link of the robot manipulator, we find the total homogeneous matrix for robot manipulator with 5-joints by multiplying all the transformation matrices from A_1^0 to A_5^4 as describe in equation(3.24)[15][21]:

$$T_5^0 = A_1^0 \times A_2^1 \times A_3^2 \times A_4^3 \times A_5^4 \tag{3.24}$$

then using matlab and write this code:

```
c1=sym('c1'); % to creates symbolic variable
c2=sym('c2');
c3=sym('c3');
c4=sym('c4');
```

```
c5=sym('c5');
s1= sym('s1');
s2= sym('s2');
s3= sym('s3');
s4= sym('s4');
s5= sym('s5');
a2=sym('a2');
a3=sym('a3');
a4=sym('a4');
d1=sym('d1');
d5=sym('d5');

A1=[c1 0 s1 0;s1 0 -c1 0;0 1 0 d1;0 0 0 1]
A2=[c2 -s2 0 a2*c2;s2 c2 0 a2*s2;0 0 1 0;0 0 0 1]
A3=[c3 -s3 0 a3*c3;s3 c3 0 a3*s3;0 0 1 0;0 0 0 1]
A4=[c4 0 -s4 0;s4 0 c4 a4*s4;0 -1 0 0;0 0 0 1]
A5=[c5 -s5 0 0;s5 c5 0 0;0 0 1 d5;0 0 0 1]

T1=A1
T2=T1*A2
T3=T2*A3
T4=T3*A4
T5=T4*A5
```

we can get in the work space the following :

$$T_1^0 = A_1 = \begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.25}$$

$$T_2^0 = A_1 A_2 = \begin{bmatrix} c_1c_2 & -c_1s_2 & s_1 & a_2c_1c_2 \\ c_2s_1 & -s_1s_2 & -c_1 & a_2c_2s_1 \\ s_2 & c_2 & 0 & d_1 + a_2s_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.26}$$

$$T_3^0 = T_2^0 A_3 = \begin{bmatrix} c_1c_2c_3 - c_1s_2s_3 & -c_1c_2s_3 - c_1c_3s_2 & s_1 & a_2c_1c_2 - a_3c_1s_2s_3 + a_3c_1c_2c_3 \\ c_2c_3s_1 - s_1s_2s_3 & -c_2s_1s_3 - c_3s_1s_2 & -c_1 & a_2c_2s_1 - a_3s_1s_2s_3 + a_3c_2c_3s_1 \\ c_2s_3 + c_3s_2 & c_2c_3 - s_2s_3 & 0 & d_1 + a_2s_2 + a_3c_2s_3 + a_3c_3s_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3.27)

$$T_4^0 = T_3^0 A_4 = \begin{bmatrix} \begin{array}{c} c_4(c_1c_2c_3 - c_1s_2s_3) \\ -s_4(c_1c_2s_3 + c_1c_3s_2) \end{array} & -s_1 & \begin{array}{c} -c_4(c_1c_2s_3 + c_1c_3s_2) \\ -s_4(c_1c_2c_3 - c_1s_2s_3) \end{array} & \begin{array}{c} a_2c_1c_2 - a_4s_4(c_1c_2s_3 + c_1c_3s_2) \\ -a_3c_1s_2s_3 + a_3c_1c_2c_3 \end{array} \\ \begin{array}{c} c_4(c_2c_3s_1 - s_1s_2s_3) \\ -s_4(c_2s_1s_3 + c_3s_1s_2) \end{array} & c_1 & \begin{array}{c} c_4(c_2s_1s_3 + c_3s_1s_2) \\ -s_4(c_2c_3s_1 - s_1s_2s_3) \end{array} & \begin{array}{c} a_2c_2s_1 - a_4s_4(c_2s_1s_3 + c_3s_1s_2) \\ -a_3s_1s_2s_3 + a_3c_2c_3s_1 \end{array} \\ \begin{array}{c} c_4(c_2s_3 + c_3s_2) \\ +s_4(c_2c_3 - s_2s_3) \end{array} & 0 & \begin{array}{c} c_4(c_2c_3 - s_2s_3) \\ -s_4(c_2s_3 + c_3s_2) \end{array} & \begin{array}{c} d_1 + a_2s_2 + a_3c_2s_3 + a_3c_3s_2 \\ +a_4s_4(c_2c_3 - s_2s_3) \end{array} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3.28)

$$T_5^0 = T_4^0 A_5 \tag{3.29}$$

$$
= \begin{bmatrix}
\begin{array}{l} c_5(c_4(c_1c_2c_3 - c_1s_2s_3) \\ -s_4(c_1c_2s_3 + c_1c_3s_2)) \\ -s_1s_5 \end{array} &
\begin{array}{l} -c_5s_1 - s_5(c_4(c_1c_2c_3 - c_1s_2s_3) \\ -s_4(c_1c_2s_3 + c_1c_3s_2)) \end{array} &
\begin{array}{l} -c_4(c_1c_2s_3 + c_1c_3s_2) \\ -s_4(c_1c_2c_3 - c_1s_2s_3) \end{array} &
\begin{array}{l} a_2c_1c_2 - d_5(c_4(c_1c_2s_3 + c_1c_3s_2) \\ +s_4(c_1c_2c_3 - c_1s_2s_3)) \\ -a_4s_4(c_1c_2s_3 + c_1c_3s_2) \\ -a_3c_1s_2s_3 + a_3c_1c_2c_3 \end{array} \\
\begin{array}{l} c_5(c_4(c_2c_3s_1 - s_1s_2s_3) \\ -s_4(c_2s_1s_3 + c_3s_1s_2)) \\ +c_1s_5 \end{array} &
\begin{array}{l} c_1c_5 - s_5(c_4(c_2c_3s_1 - s_1s_2s_3) \\ -s_4(c_2s_1s_3 + c_3s_1s_2)) \end{array} &
\begin{array}{l} c_4(c_2s_1s_3 + c_3s_1s_2) \\ -s_4(c_2c_3s_1 - s_1s_2s_3) \end{array} &
\begin{array}{l} a_2c_2s_1 - d_5(c_4(c_2s_1s_3 + c_3s_1s_2) \\ +s_4(c_2c_3s_1 - s_1s_2s_3)) \\ -a_4s_4(c_2s_1s_3 + c_3s_1s_2) \\ -a_3s_1s_2s_3 + a_3c_2c_3s_1 \end{array} \\
\begin{array}{l} c_5(c_4(c_2s_3 + c_3s_2) \\ +s_4(c_2c_3 - s_2s_3)) \end{array} &
\begin{array}{l} -s_5(c_4(c_2s_3 + c_3s_2) \\ +s_4(c_2c_3 - s_2s_3)) \end{array} &
\begin{array}{l} c_4(c_2c_3 - s_2s_3) \\ -s_4(c_2s_3 + c_3s_2) \end{array} &
\begin{array}{l} d_1 + a_2s_2 \\ +d_5(c_4(c_2c_3 - s_2s_3) \\ -s_4(c_2s_3 + c_3s_2)) + a_3c_3s_2 \\ +a_3c_2s_3 + a_4s_4(c_2c_3 - s_2s_3) \end{array} \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

d) Calculate the position and orientation of the end-effector.

The homogeneous representation given in previous equation can be denote in terms of matrices takes the form :

$$T = \begin{bmatrix} R_{3\times3} & d_{3\times1} \\ f_{1\times3} & s_{1\times1} \end{bmatrix} = \begin{bmatrix} Rotation & Translation \\ Prespective & Scale\ factor \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & x \\ r_{21} & r_{22} & r_{23} & y \\ r_{31} & r_{32} & r_{33} & z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3.30)

This equation is the end effector transformation matrix and it consists of two main components: the rotation matrix and the position vector of the end-effector . The 3×3 rotation matrix provides the orientation of frame i with respect to the base frame and the position vector d represents the desired position from the origin O_0 to the origin O_i expressed in the frame $O_0X_0Y_0Z_0$ [15]

equation (3.30) can also be expressed by 12 equation by substituting equation (3.29) into it as :

$$r_{11} = c_5(c_4(c_1c_2c_3 - c_1s_2s_3) - s_4(c_1c_2s_3 + c_1c_3s_2)) - s_1s_5 = c_1c_5c_{234} - s_1s_5$$
$$r_{21} = c_5(c_4(c_2c_3s_1 - s_1s_2s_3) - s_4(c_2s_1s_3 + c_3s_1s_2)) + c_1s_5 = c_1(c_5 + c_{234}s_1)$$
$$r_{31} = c_5(c_4(c_2s_3 + c_3s_2) + s_4(c_2c_3 - s_2s_3)) = c_5s_{234}$$

$$r_{12} = -c_5s_1 - s_5(c_4(c_1c_2c_3 - c_1s_2s_3) - s_4(c_1c_2s_3 + c_1c_3s_2)) = -c_{234}c_1s_5 - c_5s_1$$

$$r_{22} = c_1c_5 - s_5(c_4(c_2c_3s_1 - s_1s_2s_3) - s_4(c_2s_1s_3 + c_3s_1s_2)) = c_1c_5 - c_{234}s_1s_5$$

$$r_{32} = -s_5(c_4(c_2s_3 + c_3s_2) + s_4(c_2c_3 - s_2s_3)) = -s_5s_{234}$$

$$r_{13} = -c_4(c_1c_2s_3 + c_1c_3s_2) - s_4(c_1c_2c_3 - c_1s_2s_3) = -c_1s_{234}$$

$$r_{23} = c_4(c_2s_1s_3 + c_3s_1s_2) - s_4(c_2c_3s_1 - s_1s_2s_3) = -s_1s_{234}$$

$$r_{33} = c_4(c_2c_3 - s_2s_3) - s_4(c_2s_3 + c_3s_2) = c_{234}$$

$$\begin{aligned} x &= a_2c_1c_2 - d_5(c_4(c_1c_2s_3 + c_1c_3s_2) + s_4(c_1c_2c_3 - c_1s_2s_3)) - a_4s_4(c_1c_2s_3 + c_1c_3s_2) - a_3c_1s_2s_3 + a_3c_1c_2c_3 \\ &= a_3c_1c_{23} + a_2c_1c_2 + d_5c_1s_{234} + a_4c_1c_{234} \end{aligned}$$

$$\begin{aligned} y &= a_2c_2s_1 - d_5(c_4(c_2s_1s_3 + c_3s_1s_2) - s_4(c_2c_3s_1 - s_1s_2s_3)) - a_4s_4(c_2s_1s_3 + c_3s_1s_2) - a_3s_1s_2s_3 + a_3c_2c_3s_1 \\ &= a_2c_2s_1 + a_3c_{234}s_1 + d_5s_1s_{234} + a_4c_{23}s_1 \end{aligned}$$

$$\begin{aligned} z &= d_1 + a_2s_2 + d_5(c_4(c_2c_3 - s_2s_3) - s_4(c_2s_3 + c_3s_2)) + a_3c_2s_3 + a_3c_3s_2 + a_4s_4(c_2c_3 - s_2s_3) \\ &= a_2s_2 + d_5c_{234} + a_4s_{234} + a_3s_{23} \end{aligned}$$

3.3.2 Inverse kinematics

Inverse Kinematics (IK) analysis determines the joint angles for desired position and orientation in Cartesian space. The solution of inverse kinematic is more difficult than forward kinematics . The transformation matrix $T_{end\ effector}^{base}$ will be used to calculate the inverse kinematics equations as follow[15],[22],[21]:

To determine the inverse kinematics solution for the first joint θ_1 as a function of the known elements of T_5^0 we multiplied the link transformation inverses as shown in equation

$$\left[A_1^0\right]^{-1} T_5^0 = \left[A_1^0\right]^{-1} \times A_1^0 \times A_2^1 \times A_3^2 \times A_4^3 \times A_5^4 \tag{3.31}$$

where :

$\left[A_1^0\right]^{-1} \times A_1^0 = I$, I is identity matrix . using matlab the above equation can be written in form of full matrices as follow :

$$\begin{bmatrix} c_1 r_{11} + r_{21} s_1 & c_1 r_{21} + r_{22} s_1 & c_1 r_{31} + r_{23} s_1 & c_1 x + s_1 y \\ r_{31} & r_{32} & r_{33} & z - d_1 \\ r_{11} s_1 - c_1 r_{21} & r_{21} s_1 - c_1 r_{22} & r_{31} s_1 - c_1 r_{23} & s_1 x - c_1 y \\ 0 & 0 & 0 & 1 \end{bmatrix} = \tag{3.32}$$

$$\begin{bmatrix} \begin{matrix} c_5(c_4(c_2c_3 - s_2s_3) \\ -s_4(c_2s_3 + c_3s_2)) \end{matrix} & \begin{matrix} -s_5(c_4(c_2c_3 - s_2s_3) \\ -s_4(c_2s_3 + c_3s_2)) \end{matrix} & \begin{matrix} -c_4(c_2s_3 + c_3s_2) \\ -s_4(c_2c_3 - s_2s_3) \end{matrix} & \begin{matrix} a_2c_2 - d_5(c_4(c_2s_3 + c_3s_2) + s_4(c_2c_3 - s_2s_3)) \\ + a_3c_2c_3 - a_3s_2s_3 - a_4s_4(c_2s_3 - c_3s_2) \end{matrix} \\ \begin{matrix} c_5(c_4(c_2s_3 + c_3s_2) \\ +s_4(c_2c_3 - s_2s_3)) \end{matrix} & \begin{matrix} -s_5(c_4(c_2s_3 + c_3s_2) \\ +s_4(c_2c_3 - s_2s_3)) \end{matrix} & \begin{matrix} c_4(c_2c_3 - s_2s_3) \\ -s_4(c_2s_3 + c_3s_2) \end{matrix} & \begin{matrix} a_2s_2 + d_5(c_4(c_2c_3 - s_2s_3) - s_4(c_2s_3 + c_3s_2)) \\ + a_3c_3s_2 + a_3c_2s_2 + a_4s_4(c_2c_3 - s_2s_3) \end{matrix} \\ -s_5 & -c_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.33}$$

From equation(3.32), (3.33) we find [23]:

$$s_1 x - c_1 y = 0$$

$$r_{11} s_1 - c_1 r_{21} = -s_5$$

$$r_{21} s_1 - c_1 r_{22} = -c_5$$

$$r_{31} s_1 - c_1 r_{23} = 0$$

then : $\theta_1 = A\tan 2(x, y)$ (3.34)

$\theta_5 = A\tan 2(s_5, c_5)$ (3.35)

From elements (1,2) and (2,2) we get :

$$c_1 r_{21} + r_{22} s_1 = -s_5 c_4 c_{23} - s_5 s_4 s_{23}$$

$$r_{32} = -s_5 c_4 s_{23} - s_5 c_4 c_{23}$$

then :

$\theta_4 = A\tan 2(s_4, c_4)$ (3.36)

where $s_4 = \dfrac{c_1 r_{12} + s_1 r_{22} + s_5 c_4 c_{23}}{s_5 s_{23}}$

$c_4 = \dfrac{r_{32} + s_4 s_5 c_{23}}{s_5 s_{23}}$

Similarly we can solve the other angles as the same way :

$\theta_2 = A\tan 2(s_2, c_2)$ (3.37)

and

$\theta_3 = A\tan 2(s_3, c_3)$ (3.38)

3.4 Servo Motor Modeling

The servo motor is used widely in control systems for analytical purpose, it is necessary to establish mathematical models for servo motors. Servo motor converts the electrical energy to mechanical energy. The motor directly has a rotary motion, and when combined with mechanical part it can provide translation motion for the desired link.

The equivalent circuit of servo motor shown in figure(2.1) [24].The armature is modeled as a circuit with resistance R_a connected in series with an inductance L_a and a voltage source $e_a(t)$. $V_b(t)$ representing the back electromotive force (EMF) in the armature when the rotor rotates.

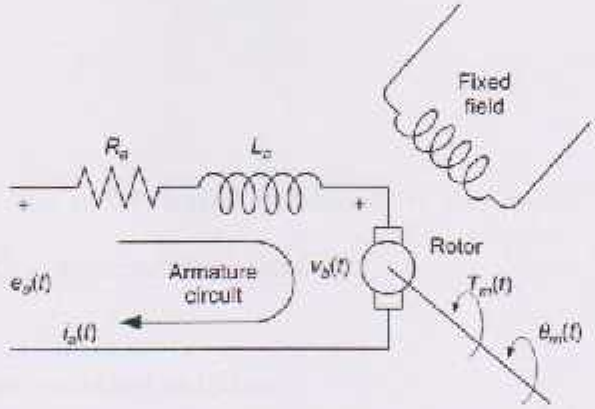


Figure 3.9: equivalent circuit of servo motor[24]

If we apply the KVL equation for the circuit in figure (3.9)[24][23] :

$$R_a i_a(t) + L_a \frac{di_a(t)}{dt} = v_a(t) - v_b(t) \tag{3.39}$$

This motion induces the back EMF by the angular speed of the motor shaft as follows:

$$V_b(t) = K_b \omega_m(t) = K_b \frac{d\theta(t)}{dt} \tag{3.40}$$

where $V_b(t)$ is the back EMF , and ω_m is the shaft velocity of the motor. The

mechanical equation (Newton law of motion) is obtained as follows :

$$\tau_m(t) = J_m \frac{d^2\theta(t)}{dt^2} + B_m \frac{d\theta(t)}{dt}$$
$$= J_m \ddot{\theta}(t) + B_m \dot{\theta}(t) \tag{3.41}$$

where J_m is the moment of inertia of the motor and B_m is the motor friction coefficient .

Based on the previous two equations when the input voltage $V_a(t)$ is applied, the armature current i_a (t) goes through resistance R_a and inductance L_a , producing magnetic flux and causing the motion of the rotor according to the motor torque as illustrated in equation

$$\tau_m(t) = K_t i_a(t) \tag{3.42}$$

where $\tau_m(t)$ is the motor torque produced by the motor shaft , $i_a(t)$ the armature current ,and K_t is a proportional constant.

The equations are combined as follow :

$$L_a \frac{di_a(t)}{dt} + R_a i_a(t) = v_a(t) - K_b \frac{d\theta(t)}{dt} \tag{3.43}$$

$$J_m \frac{d^2\theta(t)}{dt^2} + B_m \frac{d\theta(t)}{dt} = K_t i_a(t) \tag{3.44}$$

Transforming the above two equations using Laplace transformation, we obtain the two equations as follows:

$$L_a sI(s) + R_a I(s) = V_a(s) - K_b s\theta(s) \tag{3.45}$$

And

$J_m s^2\theta(s) + B_m s\theta(s) = K_t I(s)$ (3.46)

Substituting (3.45) in (3.46) gives the motor speed as follows

$$G_{speed}(s) = \frac{\dot{\theta}(s)}{V(s)} = \frac{K_t}{J_m L_a s^2 + (L_a B_m + R_a J_a)s + K_t K_b} \tag{3.47}$$

In addition, the transfer function of the motor position is determined by multiplying the transfer function of the motor speed by the term $\frac{1}{s}$:

$$G_{position}(s) = \frac{\theta(s)}{V(s)} = \frac{K_t}{s[J_m L_a s^2 + (L_a B_m + J_m R_a)s + K_t K_b]} \tag{3.48}$$

The block diagram of servo motor shown in Figure (3.10) This block diagram represents an open loop system, and the motor has built-in feedback EMF, which tends to reduce the current flow[25].

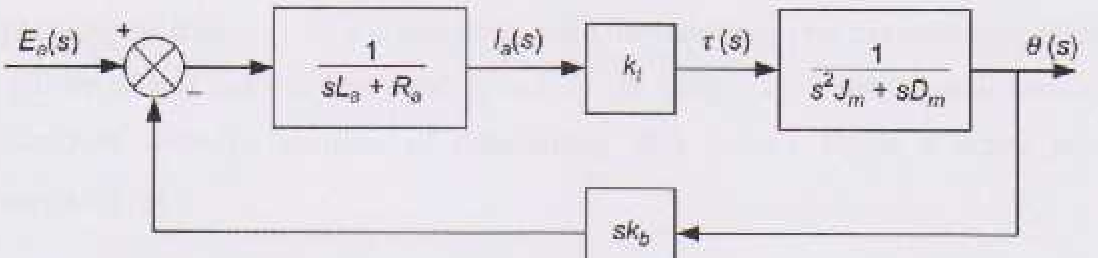


Figure 3.10: The block diagram of servo motor[25]

3.5 Gear Ratios and Torque :

When a series of gears is used to transmit power from a motor to a link, the gear connected to the motor is called the driver or input gear, and the gear connected to the link is called the driven or output gear.

The gear ratio is the ratio of the number of teeth on the output gear(the one connected to the link) to the number of teeth on the input gear(connected to the motor).

Equivalently, it is the ratio of the circumference of the output gear to the circumference of the input gear, because the number of teeth on each gear is proportional to the gear's circumference C. Also, since the formula for circumference is $C = \pi D$ and diameter (D) is twice the radius (R) we can write :

$$GR = \frac{\pi D_o}{\pi D_i} = \frac{R_o}{R_i}$$

The gear ratio expresses the ratio of the output torque to the input torque. Thus, we can multiply the torque supplied at the motor shaft (the input) by the gear ratio to find the torque at the output.

output torque = motor torque × $\frac{R_o}{R_i}$

3.6 Trajectory planning

The problem of this section is to find a trajectory that connects the initial and final configuration while satisfying other specified constraints at the endpoints (e.g., velocity and/or acceleration constraints).Without loss of generality, we will consider planning the trajectory for a single joint, since the trajectories for the remaining joints will be created independently and in exactly the same way. Thus, we will concern ourselves with the problem of determining $\theta(t)$,where $\theta(t)$ is a scalar joint variable.[15].

We suppose that at time t_0 the joint variable satisfies

$$\theta(t_0)=\theta_0 \quad (3.49)$$

$$\dot{\theta}(t_0)=\theta_0 \quad (3.50)$$

and we wish to obtain the values at t_f

$$\theta(t_f)=\theta_f \quad (3.51)$$

$$\dot{\theta}(t_f)=\theta_f \quad (3.52)$$

Figure (3.11) shows a suitable trajectory for this motion. In addition, we want to specify the constraints on initial and final accelerations. In this case, we have two additional equations

$$\ddot{\theta}(t_f)=a_0 \quad (3.53)$$

$$\ddot{\theta}(t_f)=a_f \quad (3.54)$$

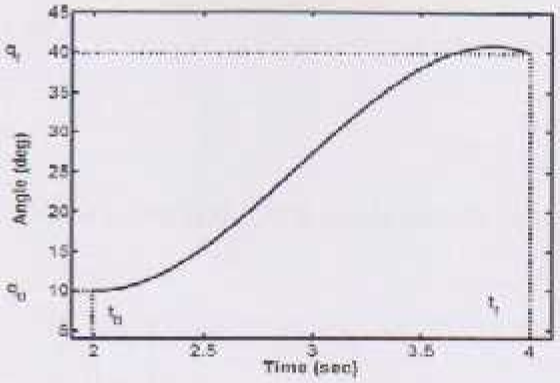


Figure 3.11: joint space trajectory[15]

Here we illustrate two types of trajectories:

3.6.1 Cubic Polynomial Trajectories

We wish to generate a trajectory between two configurations, and we wish to specify the start and end velocities for the trajectory. In order to generate a smooth curve such as that shown in Figure (3.10) is to use a polynomial function of t. If we have four constraints to satisfy, then we need at minimum a polynomial with four independent coefficients that can be chosen to satisfy these constraints. Thus, we consider a cubic trajectory of the form[15]

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \tag{3.55}$$

Then, if we derive equation (3.55) we get the desired velocity

$$\dot{\theta}(t) = a_1 + 2a_2 t + 3a_3 t^2 \tag{3.56}$$

and the second derivative of equation (3.55) is the desired acceleration :

$$\ddot{\theta}(t) = 2a_2 + 6a_3 t \tag{3.57}$$

Combining equations (3.55) and (3.56) with the four constraints we get four equations with four unknowns

$$\theta_0 = a_0 + a_1 t_0 + a_2 t_0^2 + a_3 t_0^3$$

$$v_0 = a_1 + 2a_2 t_0 + 3a_3 t_0^2$$

$$\theta_f = a_0 + a_1 t_f + a_2 t_f^2 + a_3 t_f^3$$

$$v_f = a_1 + 2a_2 t_f + 3a_3 t_f^2$$

These four equations can be combined into a single matrix equation

$$\begin{bmatrix} \theta \\ v_0 \\ \theta_f \\ v_f \end{bmatrix} = \begin{bmatrix} 1 & t_0 & t_0^2 & t_0^3 \\ 0 & 1 & 2t_0 & 3t_0^2 \\ 1 & t_f & t_f^2 & t_f^3 \\ 0 & 2t_f & 2t_f & 3t_f^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} \quad (3.58)$$

This equation always has a unique solution provided a nonzero time interval is allowed for the execution of the trajectory .

3.6.2 Quintic Polynomial Trajectories

As can be seen in Figure (3.12)[15], a cubic trajectory gives continuous positions and velocities at the start and finish points times but discontinuities in the acceleration. The derivative of acceleration is called the jerk. A discontinuity in acceleration leads to an impulsive jerk, which may excite vibration modes in the manipulator and reduce tracking accuracy[15].

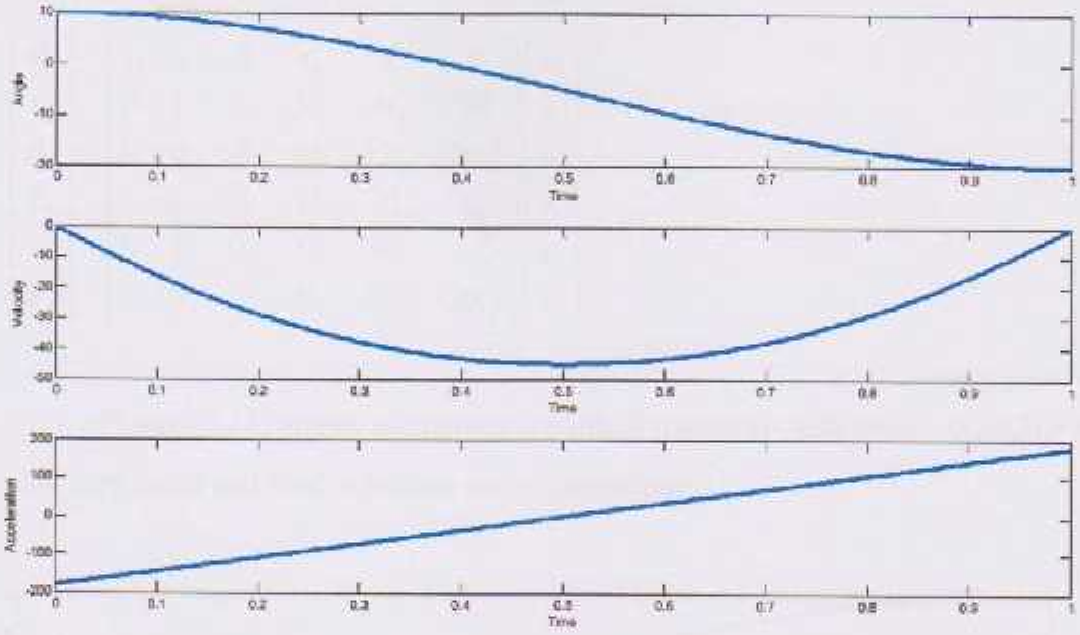


Figure 3.12: Cubic Polynomial Trajectories for position, velocity, and acceleration

For this reason, one may wish to specify constraints on the acceleration as well as on the position and velocity. In this case, we have six constraints (one each for initial and final configurations, initial and final velocities, and initial and final accelerations). Therefore, we require a fifth order polynomial[15]

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \qquad (3.59)$$

Using equations (3.49) - (3.54) and taking the appropriate number of derivatives, we obtain the following equations

$$\theta_0 = a_0 + a_1 t_0 + a_2 t_0^2 + a_3 t_0^3 + a_4 t_0^4 + a_5 t_0^5$$

$$v_0 = a_1 + 2a_2 t_0 + 3a_3 t_0^2 + 4a_4 t_0^3 + 5a_5 t_0^4$$

$$a_0 = 2a_2 + 6a_3 t_0 + 12a_4 t_0^2 + 20a_5 t_0^3$$

$$\theta_f = a_0 + a_1 t_f + a_2 t_f^2 + a_3 t_f^3 + a_4 t_f^4 + a_5 t_f^5$$

$$v_f = a_1 + 2a_2 t_f + 3a_3 t_f^2 + 4a_4 t_f^3 + 5a_5 t_f^4$$

$$a_f = 2a_2 + 6a_3 t_f + 12a_4 t_f^2 + 20a_5 t_f^3$$

and in the form of matrices we can write the previous equations as :

$$\begin{bmatrix} \theta_0 \\ v_0 \\ \alpha_0 \\ \theta_f \\ v_f \\ \alpha_f \end{bmatrix} = \begin{bmatrix} 1 & t_0 & t_0^2 & t_0^3 & t_0^4 & t_0^5 \\ 0 & 1 & 2t_0 & 3t_0^2 & 4t_0^3 & 5t_0^4 \\ 0 & 0 & 2 & 6t_0 & 12t_0^2 & 20t_0^3 \\ 1 & t_f & t_f^2 & t_f^3 & t_f^4 & t_f^5 \\ 0 & 1 & 2t_f & 3t_f^2 & 4t_f^3 & 5t_f^4 \\ 0 & 0 & 2 & 6t_f & 12t_f^2 & 20t_f^3 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} \tag{3.60}$$

Figure (3.13) shows a quintic polynomial trajectory with $\theta(0) = 0$, $\theta(2) = 40$ with zero initial and final velocities and accelerations .

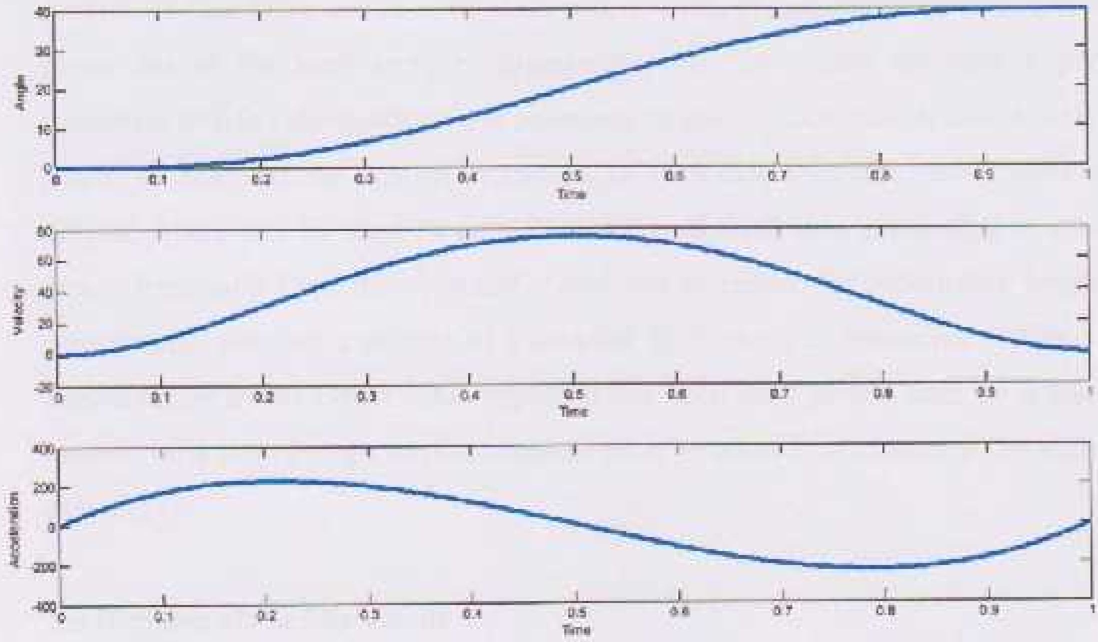


Figure 3.13:quintic polynomial trajectory with velocity and acceleration profiles[15] .

3.7 Acquiring signal system

After brain signal processing in hardware processing circuit, the signal still have a noise, so we build a digital filter to obtain the signal with very low level of noise.

3.8 Digital processing system

Information content of EEG signals is essential for detection of many problems of the brain and in connection with analysis of magnetic resonance images it forms one of the most complex diagnostic tools. To extract the most important properties of EEG observations it is necessary to use efficient mathematical tools to enable reliable and fast enough processing of very extensive data sets in most cases .Digital filters can be used in the initial stage of EEG data processing to remove power frequency from the observed signal and to reduce its undesirable frequency components. presents a sample of a selected EEG channel comparing results of its segmentation by an expert. This approach has been used in this case for a selected channel only even though further channels must be taken into account in the real case as well.[1]

3.9 Decision of the Movement

The robot arm have a one servo motors and gripper. each servo motor have two movements, each movement have one interval of a reference signal.

The servo motor receive signal from PWM (pulse with modulation) pin of the microcontroller as pulse signal.

The next flow chart represent the project step by step.

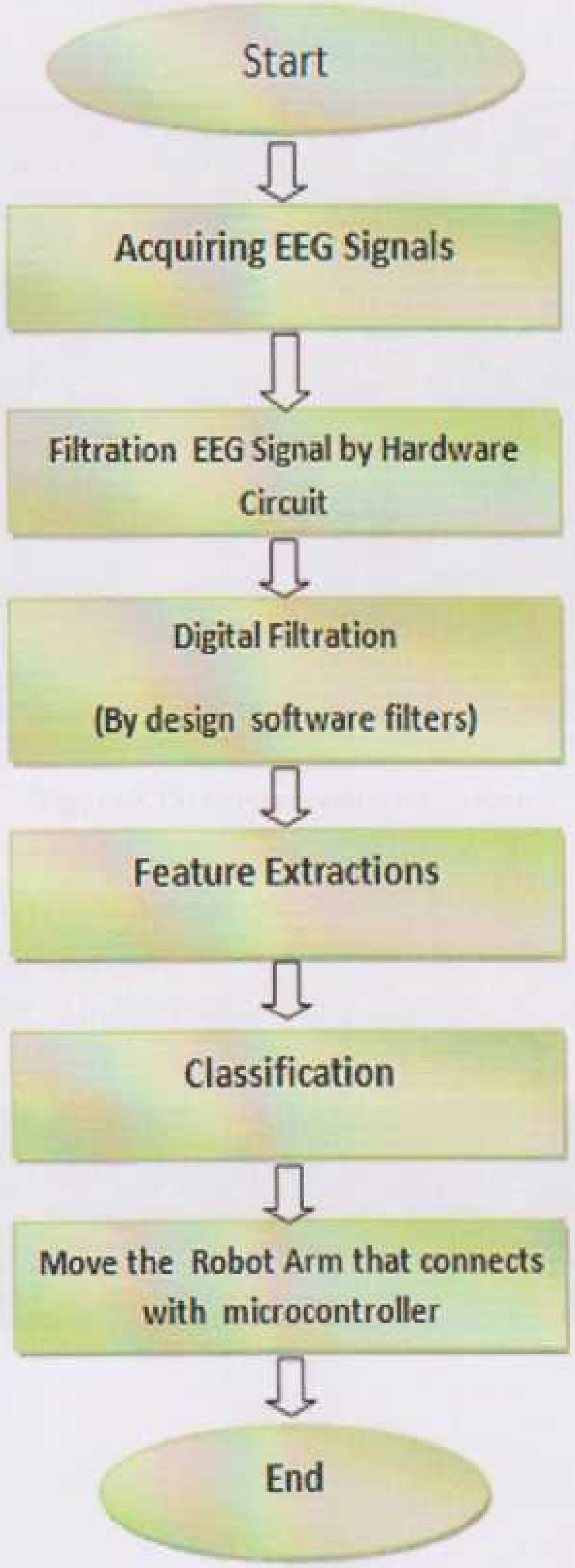


Figure 3.14: flow chart of whole system

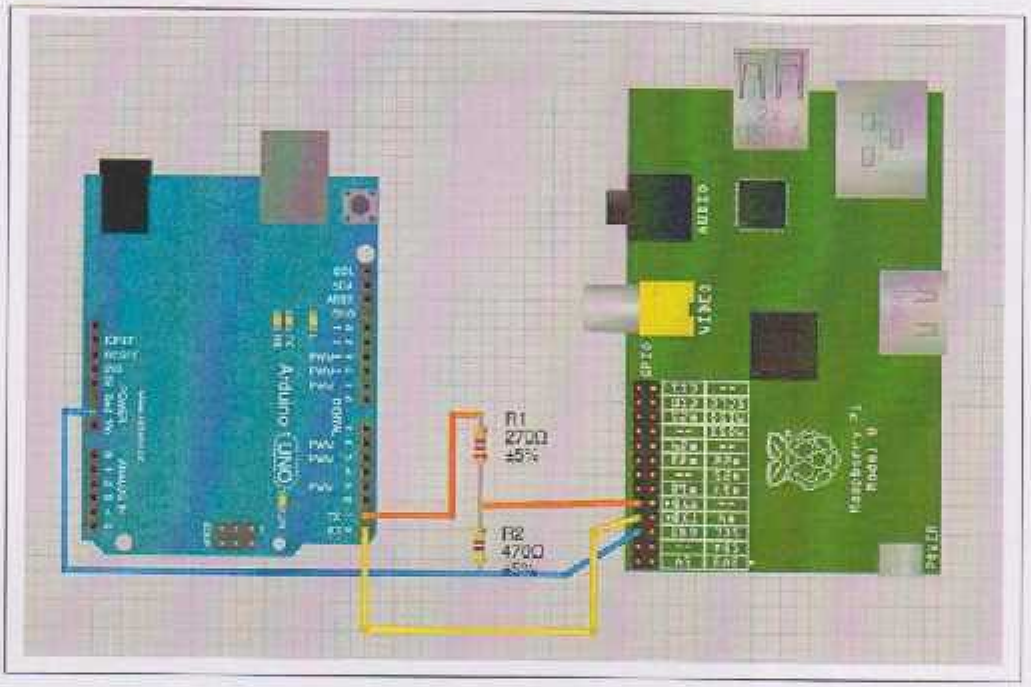
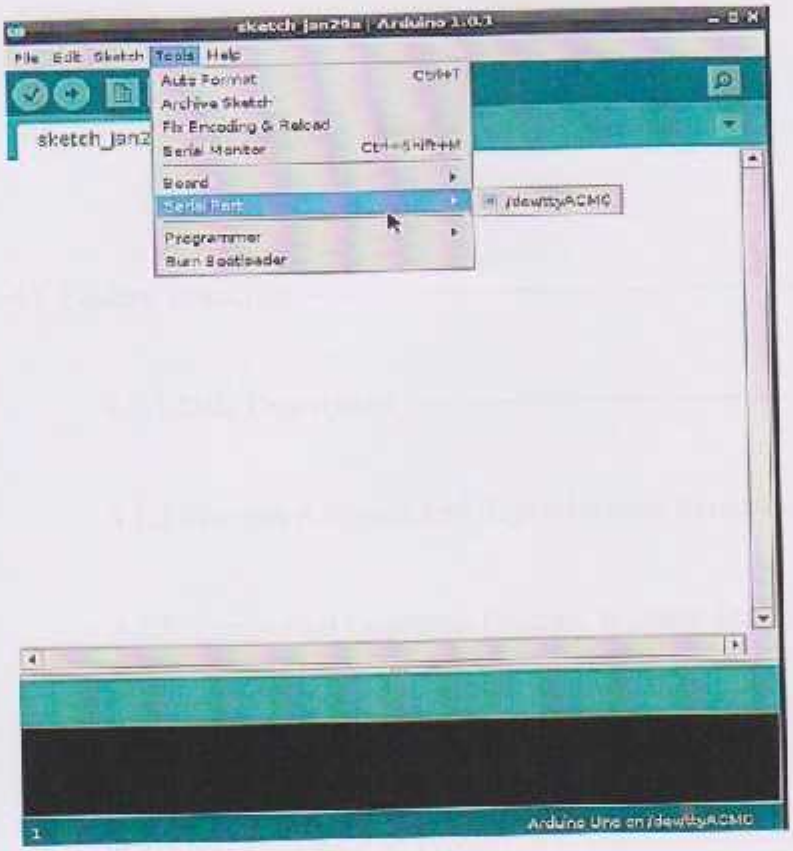


Figure 3.15: internal design for system

To connect RasbperryPi with Arduino :-

```
sudo apt-get install -y arduino
sudo apt-get install -y python-serial
```

```
pi@raspberrypi ~ $ ls /dev/tty*
/dev/tty    /dev/tty19  /dev/tty3   /dev/tty40  /dev/tty51  /dev/tty62
/dev/tty0   /dev/tty2   /dev/tty30  /dev/tty41  /dev/tty52  /dev/tty63
/dev/tty1   /dev/tty20  /dev/tty31  /dev/tty42  /dev/tty53  /dev/tty7
/dev/tty10  /dev/tty21  /dev/tty32  /dev/tty43  /dev/tty54  /dev/tty8
/dev/tty11  /dev/tty22  /dev/tty33  /dev/tty44  /dev/tty55  /dev/tty9
/dev/tty12  /dev/tty23  /dev/tty34  /dev/tty45  /dev/tty56  /dev/ttyACM0
/dev/tty13  /dev/tty24  /dev/tty35  /dev/tty46  /dev/tty57  /dev/ttyAMA0
```


File Edit Sketch Tools Help
Auto Format Ctrl+T
Archive Sketch
Fix Encoding & Reload
Serial Monitor Ctrl+Shift+M
Board
Serial Port
Programmer
Burn Bootloader
/dev/ttyACM0
Arduino Uno on /dev/ttyACM0

Chapter4

Feature Extraction And Classification

Before we extract the features from the EEG signals , we need to filter signals to take pure data for every movements ,we design some filters to this level as notch filter and bandpassfilter ,we design code by Matlab language to test the result then we write another code in Python language to set it on RaspberryPi . (Appendix A)

4.1 Feature extraction

In machine learning, feature extraction starts from an initial set of measured data and builds derived features intended to be informative, non redundant, facilitating the subsequent learning and generalization steps.

When the input data to an algorithm is too large to be processed and it is suspected to be redundant, then it can be transformed into a reduced set of features (also named features vector).The extracted features are expected to contain the relevant information from the input data, so that the desired task can be performed by using this reduced representation instead of the complete initial data.

Feature extraction involves reducing the amount of resources required to describe a large set of data. When performing analysis of complex data one of the major problems stems from the number of variables involved. Analysis with a large number of variables generally requires a large amount of memory and computation power or a classification algorithm which over fits the training sample and generalizes poorly to new samples.

Feature extraction of EEG signals is core issues on EEG based brain mapping analysis. The classification of EEG signals has been performed using features extracted from EEG signals. Many features have proved to be unique enough to use in all brain related medical application. EEG signals can be classified using a set of features like Auto-regression, Energy Spectrum Density, Energy Entropy, and Linear Complexity. However, different features show different discriminative power for different subjects or different trials.

Analysis of brain signals that provides direct communication between the brain and a body can help patients who suffer from ill health and several psychic problems and severe motor impairments to improve their living quality . The mental decision and reaction into control commands by analyzing the bioelectrical brain activity. A kind of analysis brain computer interface system based on analysis of EEG. Generally, the EEG has poor spatial resolution and low signal-to-noise ratio (SNR) of any evoked response embedded within ongoing background activity. To distinguish signals of interest from the background activity various feature extraction methods have been applied, including autoregressive models , phase , entropy, spatial filter , wavelet transform , etc. It is known that EEG signals under appropriate well designed experimental paradigms allow a subject to convey her/his intentions by e.g. motor imagery or executing specific mental tasks. Once the intentions have manifested themselves in brain activity and have been measured by EEG, the scene is set for advanced signal processing and machine learning technology.

Feature vectors need to be extracted from the EEG signals, then this feature vectors are translated by machine learning techniques like linear discriminate analysis or neural networks or k nearest neighbor. It's helpful for classification that the EEG-features are extracted such that they hold the most discriminative information for a chosen paradigm.

4.1.1 Data Description

EEG signals are extracted from sophisticated machines in highly secured and de-noised labs are prone to artifacts and several other type of non-separable noise. EEG signal when analyzed has a very low frequency in the range of hertz. These EEG signals can be classified based on their frequency bands. feature extraction is a special form of dimensionality reduction. When the input data to an algorithm is too large to be processed and it is suspected to be notoriously redundant (much data, but not much information) then the input data will be transformed into a reduced representation set of features (also named features vector).

Transforming the input data into the set of features is called feature extraction. If the features extracted are carefully chosen it is expected that the features set will extract the relevant information from the input data in order to perform the desired task using this reduced representation instead of the full size input. Feature extraction involves simplifying the amount of resources required to describe a large set of data accurately. When performing analysis of complex data one of the major problems stems from the number of variables involved. Analysis with a large number of variables generally requires a large amount of memory and computation power or a classification algorithm which over fits the training sample and generalizes poorly to new samples. Feature extraction is a general term for methods of constructing combinations of the variables to get around these problems while still describing the data with sufficient accuracy.

With regard to the brain signal There are several ways for feature extraction, including the : Short Time Fourier transform ,Fast Fourier transform, principle component analysis and Wavelet Transform .

The autocorrelation, wavelets, and Principal Component Analysis (PCA) were the types of the processing used. We applied these methods on the brain signal and the best way with the result accurate in respect of this project; PCA is used to reduce the dimensionality of the EEG signal. Finally, wavelet analysis is used as a classifier prior to the KNN. The aim of this work is to calculate the EEG waves (delta, theta, alpha, and beta) using Discrete Wavelet Transforms (DWT) followed by discrete Fast Fourier Transform (FFT).,Discrete Wavelet Transform (HAAR),wavelet transform use for feature extraction and EEG signal segments classification.[1]

4.1.2 Wavelet Analysis And Signal Feature Extraction

Wavelet transform forms a general mathematical tool for signal processing with many applications in EEG data analysis well. Its basic use includes time-scale signal analysis, signal decomposition and signal compression.[1]

4.1.3Theoretical Concepts: Discrete Wavelet Transforms(DWT)

The DWT means choosing subsets of the scales (a) and positions (b) of the wavelet mother ψ (t).

$$\psi_{(a,b)}(t) = 2^{\frac{a}{b}}\psi(2^{-\frac{a}{b}}(t-b)) \qquad 4.1$$

Choosing scales and positions are based on powers of two.which are called dyadic scales and positions { j a = 2−;b j kj k− 2− , } (j and k integers). Equation (1) shows that it is possible to built a wavelet for any function by dilating a function ψ (t) with a coefficient 2^j , and translating the resulting function on a grid whose interval is proportional to 2^(-j).

Contracted (compressed) versions of the wavelet function match the high-frequency components, while dilated(stretched) versions match the low-frequency components .Then, by correlating the original signal with wavelet functions of different sizes, the details of the signal can be obtained at several scales. These correlations with the different wavelet functions can be arranged in a hierarchical scheme called multi-resolution decomposition. The multi-resolution decomposition algorithm separates the signal into "details" at different scales and a coarser representation of the signal named "approximation"

The algorithm of the DWT decomposition and reconstruction can be summarized by following procedure

Given a signal "s" of length n. Starting from s, the first step produces two sets of coefficients: approximation coefficientscA1, and detail coefficients cD1. These vectors are obtained by convolving s with the low-pass filter Lo_D for approximation, and with the high-pass filter Hi_D for detail ,followed by dyadic decimation. This is shown in Fig. (1.a).The length of each filter is equal to 2N. If n = length (s), the signals F and G are of length n + 2N - 1, and then the coefficients cA1 and cD1 are of length

Floor((n-1/2)) + N)

Floor means that the length of the coefficients rolled to the nearest integer.

• The next step splits the approximation coefficients cA1into two parts using the same scheme, replacing s by cA1 and producing cA2 and cD2 as shown in Fig. (1.b), and so on. So, the wavelet decomposition of the signal s analyzed at level I has the following structure: [cAi, cDi... cD1].

• The structure in Fig. 2 contains i= 3, as shown in the terminal of the tree.

• Conversely, starting from cAi and cDi, the inverse discrete wavelet transform (IDWT) reconstructs cAi-1, inverting the decomposition step by inserting zeros and convolving the results with the reconstruction filters.

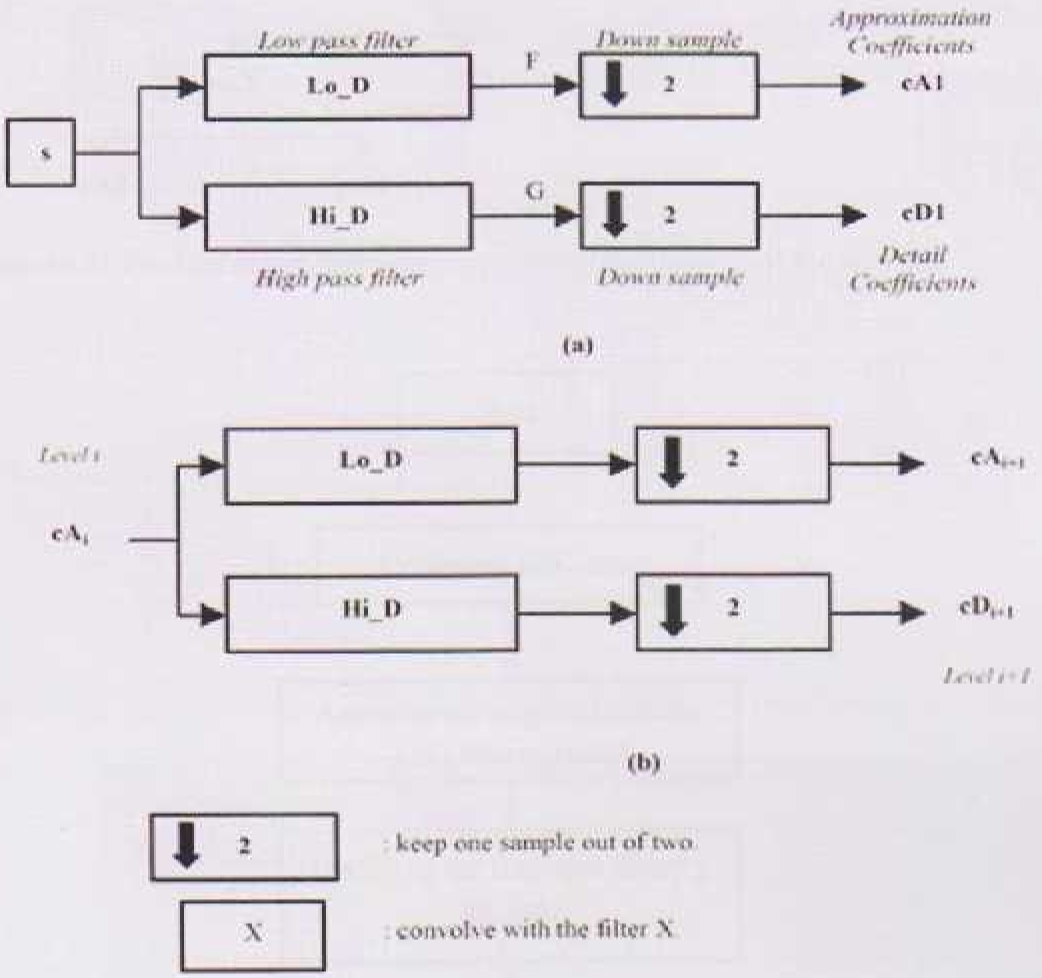


Figure4.1: The algorithm of the DWT, (a) one decomposition of the signal s, (b) decomposition at each level

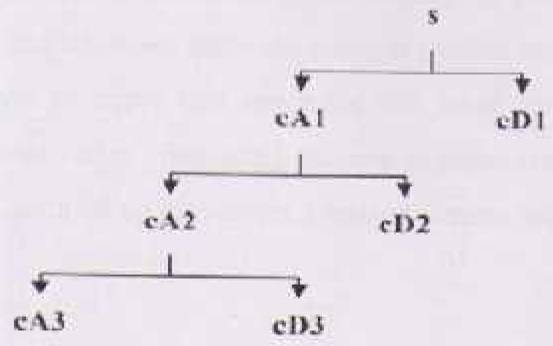


Figure4.2: The tree of the multi-decomposition (multi-level) of the signals

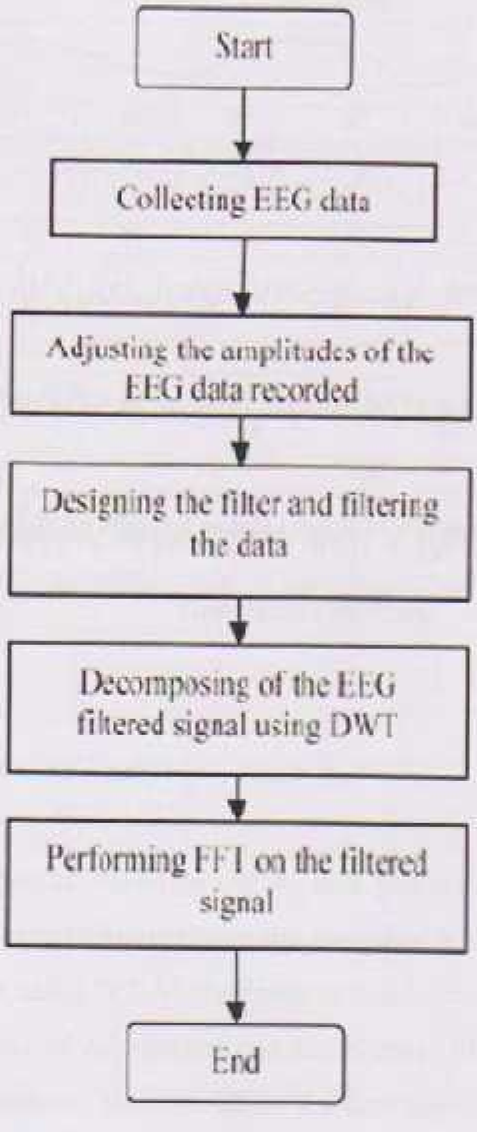
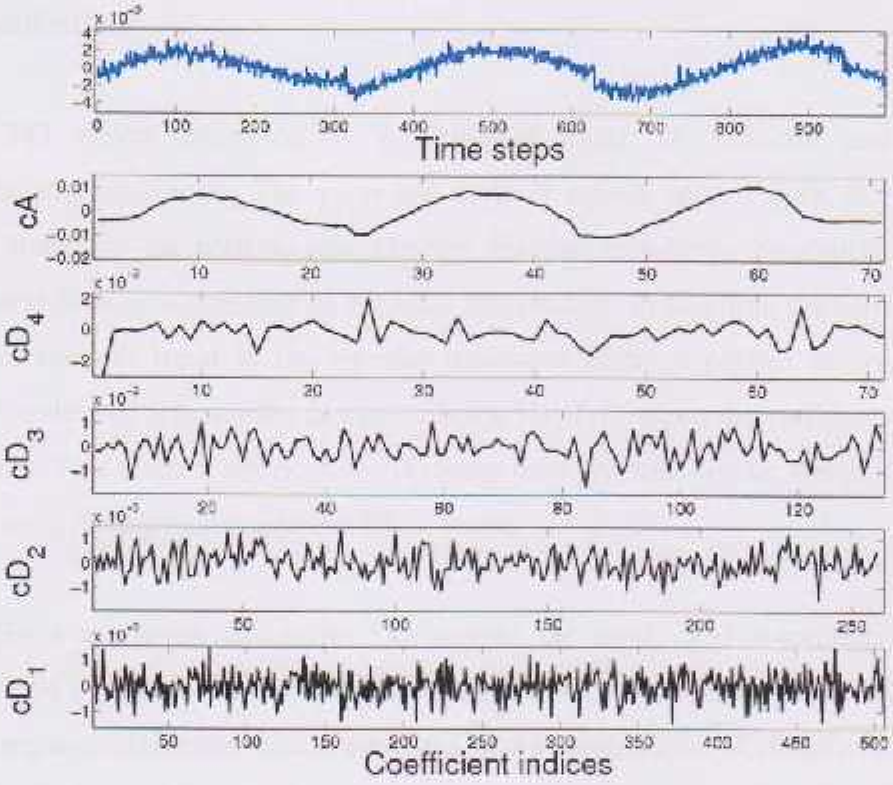


Figure4.3:- Flowchart Display The Steps Of Feature Extraction

Finally;

The code use to do this level and display the result we write matlab code to test the result and then we write the code in python code to save it on RasbperryPi, we do five level to arrive best result for this level ,every EEG signal that special to up movement after five level discrete wavelet transform (haar) it's the same results almost ,each 20 up movement almost the same result in digital data .



4.1.4 Principal Component Analysis:-

Principal Component Analysis (PCA) is a powerful tool used to reduce the dimensionality of the features maintaining the variation in information. If the number of features e.g 30 after using "PCA" the features number reduce to e.g 3 .thy way to reduce features by steps of calculation and sometimes PCA combination some of features with another features. How to reduce the dimensionality?

4.1.5 PCA: Steps and Properties:-

1)The samples should be normalized by calculate Mean.

2) Covariance Matrix.

3) Find the Eigen Values/ Eigen Vectors of Matrix .

After PCA we reduce the number of features from the EEG signals .

4.2 Classification:

EEG waves classification is achieved using an accurate and highly distinguishable technique. The proposed method makes use of both the discrete wavelet transform as well as the discrete Fourier transform. Specially, wavelet transform is used as a classifier of the EEG frequencies. In addition, the filtered EEG data were used as input to the wavelet transform offers a perfect success in the rejecting undesired frequencies and permits the DWT levels to discriminate the EEG waves only. This method offers more efficiency than previous works, which it can be easily distinguished between EEG. waves

There are many categories that covers the most used algorithms in BCI classification systems, and they are: linear classifiers, nonlinear Bayesian classifiers, nearest neighbor classifiers, neural networks, and a combination of classifiers:-

1. K-Nearest Neighbor (KNN)

K-Nearest Neighbor classifier is one of the simplest classifiers. To classify a new data sample, we compute its distance to all of its k nearest neighbors. This sample is assigned to the class in which most of these k neighbors are located. By distance we refer to Euclidean distance.

2.Linear Discriminate Analysis (LDA)

In this method, the main idea is to find a hyper plane which separates data of two classes and maximize between class distances and minimize inter class distances. Thus, the optimized separation is guaranteed.

In LDA, data distribution is assumed to be Gaussian with equal covariance matrices for both classes. Middle and inner class scattering are obtained from the following formulas.

$S_w = \sum_j p_j \times (cov_j)$

$S_b = \sum_j(\mu_j \times \mu_3) \times (\mu_j \times \mu_3)^T$

Where S_w is the within-class scatter and S_b is the between-class scatter, p_j is prior probability, cov_j is the covariance of class j.

μ is the total average of classes and μ_j is the average of class μ_j. The aim is to find a measure which maximize the between class scatter and minimize the within class scatter which is defined as Equation 4.4 .

criterion= $inv^6(S_w) \times S_b$

Thus, LDA tries to maximize this criterion.

3. Support Vector Machine (SVM)

Supporting Vector Machine is a classifying method proposed .This method is a powerful tool in solving different problems. The main idea of this method is mapping the nonlinear input vectors to a high dimensional feature space in which a hyper plane exists that separates features linearly. Let $\{(\chi_i, y_i) \mid i = 1,\ldots,l\}$ be the training data. x_i is a train sample and $\cdot y_i\{-1,1\}$ is the label of sample i.

A hyper plane can be defined as follows.

w.x b = 0

Where w is a vector perpendicular to the hyper plane, x is one point on the hyper plane and b is the bias. If $w.\chi_i+b \geq +1$, x_i is assigned to class +1 and if $w.\chi_i-b \leq -1$, xi is assigned to class -1. The optimized hyper plane is the one which maximize the margin value. The optimized margin is the one with this property that all samples of class -1 are located on one side of it and all samples in class 1 are located on the other side. As we have m = 2/|w| (where m stands for margin), so |w| should be decreased to produce an optimized hyper plane .

There are many theories that perform classification operation .In this project the K-Nearest Neighbor is used to divide the signal pattern into classes .this class is iterated as a single class.

4.2.1 K-Nearest Neighbor (KNN)

K-Nearest Neighbors (KNN) is known as a simple but robust classifier and is capable to produce high performance results even for complex applications . The KNN uses a distance of features in a data set to determine which data belongs to which group. A group is formed when the distance within the data is close while many groups are formed when the distance within the data is far. In Electroencephalogram (EEG) research, KNN is widely used as a classifier to classify the EEG signals. For example, KNN was used to classify epileptic and normal brain activities through EEG signals .In another example, KNN was used to classify ten samples of EEG signals for individual biometric purposes.

K-Nearest Neighbor Advantages: Simple ,Powerful ,Requires no training time. Disadvantage : Memory intensive ,Classification/estimation is slow.

The way for calculation this method ;calculate the mean(center) for the sample and then measure Centroid , and by Euclidean distance between the sample and the Nearest Neighbor .

$$\sqrt{(p_x - q_x)^2 + (p_y - q_y)^2}$$

$$\sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \dots\dots\dots + (p_n - q_n)^2}$$

Another Classifier can we use in this project : Naïve Bayes Classifier. The Naive Bayes Classifier technique is a probabilistic approach based on the so-called Bayesian theorem.

Figure 4.4: General Block Diagram For The Classification Level.

Next code ;we write it by Matlab to testing then we write the classification code by python , in test code the accuracy in matlab 80% , but in actual code by python code is 65-70%.

```
%%%

k=3;%k for KNN
n=5; %number of samples in each class
v=1000;
x=[40 50 20 40];

class1=[1 2 3 4; 2 1 4 7; 10 4 2 10; 8 9 12 3; 11 3 2 7];
class2=[40 17 60 20; 20 50 40 70; 70 80 45 63; 40 60 55 33;77 22 44 33];

dist1=zeros(1,n);
dist2=zeros(1,n);

D1=zeros(1,k);
D2=zeros(1,k);

num1=0;
num2=0;

for i=1:n
   dist1(i)=sqrt(sum((x-class1(i)).^2));
```

```
end

for i=1:n
   dist2(i)=sqrt(sum((x-class2(i)).^2));
end

for i=1:k
  [m,index]=min(dist1);
   D1(i)=m;
   dist1(index)=v;
end

for i=1:k
   [m,index]=min(dist2);
   D2(i)=m;
   dist2(index)=v;
end

d=[D1 D2];

for i=1:k
   [m,index]=min(d);
   D2(i)=m;
   dist2(index)=v;
   if index>k
      num2=num2+1;
   else
      num1=num1+1;
   end
end

if num1>num2
   class=1;
else
   class=2;
end
```

Chapter Five

Experiments and Results

5.1 Acquiring circuit of EEG signal:

5.1.1 Electrodes

Acquiring the EEG signal from electrodes C1,C3,Cz that set in motor cortex area which is responsible on right hand movement.

5.1.2 Instrumentation Amplifier(INA)

Is the first step in the processing circuit, figure5.1 shows the INA circuit.

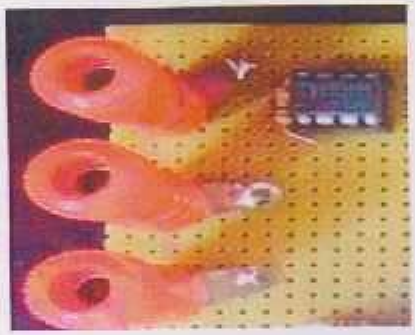


Figure5.1: AD620 circuit

5.1.3 High Pass Filter

Is the second step in the processing circuit, figure5.2 show the 2nd order HPF. Table 5.1 show the result of test of HPF.

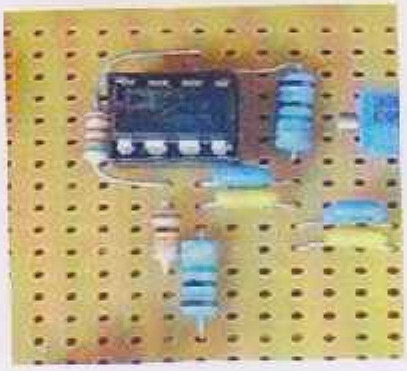


Figure5.2 : 2nd order HPF circuit

Table 5.1: the result of test of HPF.

V_{in}	*Frequency*	V_{out}
1 v_{p-p}	0.2 *Hz*	440 *mV*
1 v_{p-p}	0.5 *Hz*	1 *V*
1 v_{p-p}	0.8 *Hz*	1.4 *V*
1 v_{p-p}	1.2 *Hz*	1.52 *V*
1 v_{p-p}	2 *Hz*	1.5 *V*
1 v_{p-p}	5 *Hz*	1.5 *V*
1 v_{p-p}	50 *Hz*	1.5 *V*
1 v_{p-p}	60 *Hz*	1.5 *V*
1 v_{p-p}	100 *Hz*	1.5 *V*
1 v_{p-p}	200 *Hz*	1.5 *V*
1 v_{p-p}	280 *Hz*	1.5 *V*
1 v_{p-p}	330 *Hz*	1.5 *V*
1 v_{p-p}	400 *Hz*	1.5 *V*
1 v_{p-p}	511 *Hz*	1.5 *V*

5.1.4 Low Pass Filter

Is the third step in the processing circuit, figure5.3 show the 2nd order LPF. Table5.2 show the result of test of LPF.

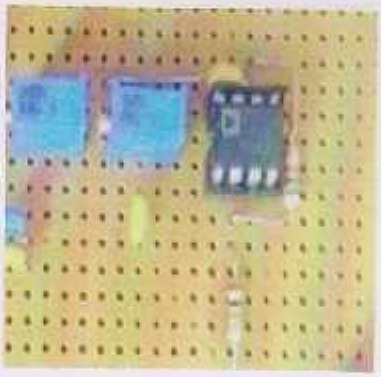


Figure5.3: 2nd order LPF circuit

Table 5.2: The result of test of LPF.

V_{in}	*Frequency*	V_{out}
1 v_{p-p}	6 *Hz*	1.58*V*
1 v_{p-p}	10 *Hz*	1.58 *V*
1 v_{p-p}	20 *Hz*	1.56 *V*
1 v_{p-p}	30 *Hz*	1.48 *V*
1 v_{p-p}	40 *Hz*	1.36 *V*
1 v_{p-p}	45 *Hz*	1.26 *V*
1 v_{p-p}	48 *Hz*	1.20 *V*
1 v_{p-p}	55 *Hz*	1 *V*
1 v_{p-p}	65 *Hz*	840 *mV*
1 v_{p-p}	75 *Hz*	700 *mV*
1 v_{p-p}	90 *Hz*	540 *mV*
1 v_{p-p}	100 *Hz*	460 *mV*
1 v_{p-p}	120 *Hz*	340 *mV*
1 v_{p-p}	150 *Hz*	260 *mV*

5.1.5 Notch Filter

Is the fourth stage in, to eliminate the 50Hz effect from the signal, figure5.4 show the notch filter. Table 5.3 show the result of test of notch filter.

Figure5.4: notch filter

Table 5.3: The result of test of notch filter.

V_{in}	*Frequency*	V_{out}
1 $v_{p\text{-}p}$	5 *Hz*	1.52 *V*
1 $v_{p\text{-}p}$	10 *Hz*	1.5 *mV*
1 $v_{p\text{-}p}$	20 *Hz*	1.36 *V*
1 $v_{p\text{-}p}$	30 *Hz*	1.12 *V*
1 $v_{p\text{-}p}$	40 *Hz*	640 *mV*
1 $v_{p\text{-}p}$	50 *Hz*	140 *mV*
1 $v_{p\text{-}p}$	60 *Hz*	680 *mV*
1 $v_{p\text{-}p}$	70 *Hz*	880 *mV*
1 $v_{p\text{-}p}$	80 *Hz*	1.02 *V*
1 $v_{p\text{-}p}$	90 *Hz*	1.12 *V*
1 $v_{p\text{-}p}$	100 *Hz*	1.26 *V*
1 $v_{p\text{-}p}$	110 *Hz*	1.30 *V*
1 $v_{p\text{-}p}$	120 *Hz*	1.34 *V*
1 $v_{p\text{-}p}$	1 *KHz*	1.54 *V*

5.1.6 Inverting Amplifier

The next stage in the processing circuit to amplify a filtered signal, figure5.5 show the inverting amplifier.

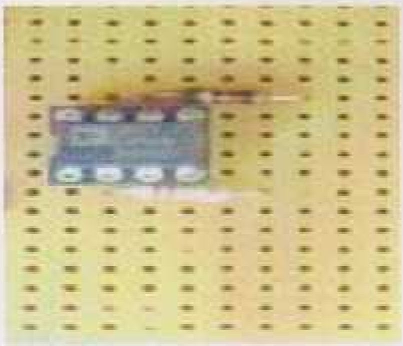


Figure5.5: inverting amplifier.

Figure 5.6 show the whole processing circuit of our project.

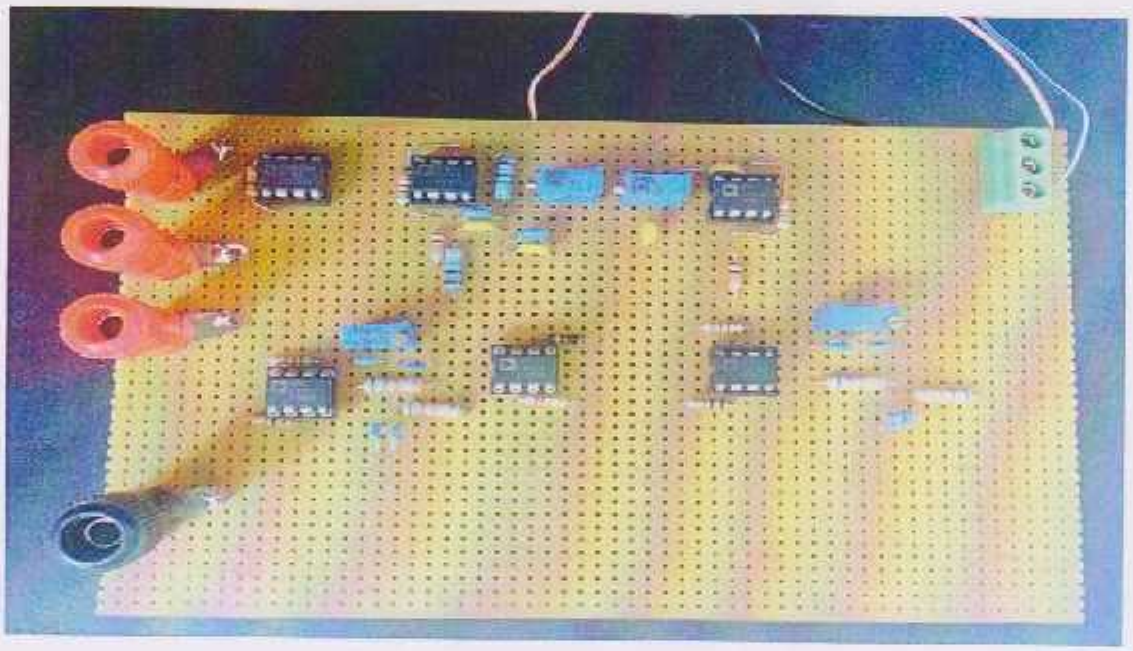


Figure 5.6: The whole processing circuit of our project.

5.2 Robot arm testing

Our robot is an articulated manipulator RRR, with 5 rotational joints. The robot mounted with moving gripper at the end of the chain. Figure 5.7 shows the robot arm.

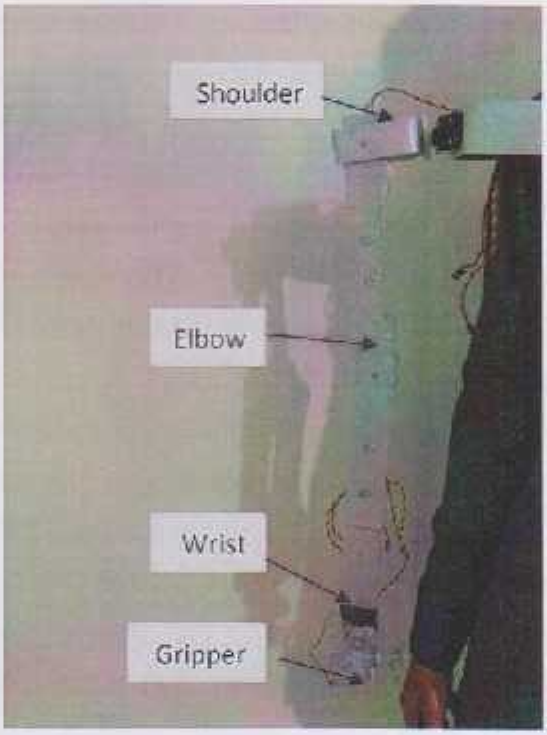


Figure 5.7: Robot Arm

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Appendix

%Notch filter(50 hertz):

```
[a b]=butter(4,[.3891 .3922],'stop');
signal =filter(a,b,data);
```

```
figure(2), plot(signal);

%Bandpass filter(0_48 hertz):
[c d]=butter(4,[0.00000000001 .38],'bandpass');
s=abs(filter(c,d,signal));
figure(3), plot(s);

%Wavelet Code:
[C,L] = wavedec(s,5,'haar');
A3 = wrcoef('a',C,L,'haar',5);
figure(4), plot(A3);

%Convert Matrix To Vector:
vector = A3(:);
```