Palestine Polytechnic University

College of Engineering & Technology
Electrical & Computer Department

Graduation Project

Sign Language Coach

Project Team:

Hanan Ahmad Shroukh

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Project Supervisor

Eng. Hiba Tamimi

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جامعة بوليتكنك فلسطين

الخليل- فلسطين

كلية الهندسة والتكنولوجيا

دائرة الهندسة الكهربائية والحاسوب

اسم المشروع:

Sign Language Coach

أسماء الطلبة:

حنان أحمد الشروخ　　هبه موسى الدبابسه　　تحرير قاهر محمد

بناء على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة أنظمة الحاسوب

توقيع المشرف

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توقيع اللجنة الممتحنة

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توقيع رئيس الدائرة

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Abstract

The Sign Language Coach (SLC) is an embedded system that translates the movement of the fingers that represent the American Sign Language (ASL) into letters.

ASL is a visual language, meaning that the information is expressed not with combination of sound but with combination of hand shapes, palm orientations, movements of the hands, arms and body, location in relation to the body, and facial expressions.

The system was implemented using statistical approach which called nearest neighbor algorithm, and it uses a glove to recognize the hand positions and outputs letters onto LCD.

The goal is achieved and the system was able to recognize 26 letters at PC phase.

الملخص

معلم لغة الاشارة هونظام يقوم بترجمة حركة الاصابع الممثلة بلغة الاشارة الامريكية الى حروف.

لغة الاشارة الامريكية هي عبارة عن لغة مرئية وهذا يعني ان المعلومات لا يعبر عنها بالصوت وانما يعبر عنها بحركة اليد وشكلها ودوران الكف وحركة الذراع والجسم ، وموقع الكف بالنسبة للجسم، وتعابير الوجه.

تم تمثيل النظام باستخدام طريقة احصائية تسمى خوارزمية الجار الاقرب ، ويستخدم كف للتعرف على مواقع اليد ويخرج النتيجة على LCD.

الهدف من النظام تحقق؛ فالنظام قادرعلى التعرف على 26 حرف في مرحلة الكمبيوتر.

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List of Abbreviations

ASL	American Sign Language
DC	Direct Current
EEPROM	Electrically Erasable Programmable Read Only Memory
LCD	Liquid Crystal Display
LABVIEW	Laboratory Virtual Instrument Engineering workbench
MCU	Microcontroller Unit
MSSP	Managed Security Service Provider
OpAmp	Operational Amplifier
PC	Personal Computer
PGSI	Power Glove Serial Interface
PIC	Peripheral Interface Controller
SLC	Sign Language Coach
SVM	Support Vector Machine
SRAM	Static Random Access Memory
USART	Universal Synchronous Asynchronous Receiver Transmitter
T	Task

CHAPTER

1

INTRODUCTION

Introduction

General idea about project and its importance

Project objectives

Literature review

Time plane / project schedule

Estimated cost and budget break down

Project risk management

Report contents

Chapter one
Introduction

1.1 Introduction

This chapter presents the general idea about project, its importance, literature review and estimated cost.

1.2 General idea about project and its importance

Sign Language Coach (SLC) is an embedded system that translates the movement of the fingers of a glove into the American Sign Language (ASL).The system is portable and stands alone.

This system consists of an ordinary glove and movement sensors, a microcontroller unit (MCU). The system outputs letters on an LCD.

1.2.1 Importance of project

1. Help deaf people to explain what they need in their society.
2. The Sign Language Coach (SLC) helps people to understand the American Sign Language(ASL) by translating the sign into letters.

1.3 Project objectives

1. Create a glove that senses a user's finger position.
2. Translate the American Sign Language into letters that appear on the LCD.
3. Match each sign with the appropriate letter.

1.4 Literature review

This section mentions previous projects that done in this domain.

- **The AcceleGlove [1]**

  The AcceleGlove is a portable system, designed as an assistive device that translates hand and gesture based languages into written and spoken language. The AcceleGlove consists of a group of sensors and accelerometers that are strapped to the hand, arm and shoulder and a set of algorithms that decipher and categorize the movements of the hand and arm. The accuracy of this system is 89%.

- **Arabic Sign Language recognition using an instrumented Glove[2]**

  This system recognizes Arabic Sign Language using an instrumented glove as interfacing device and the support vector machine algorithm as classification Algorithm, this instrumented glove is the power glove. The accuracy of this system is 85%.

- Mehdi and Khan proposed a glove. It used a seven sensors form 5 dimensions and a multi-layer perception neural network to recognize the alphabet of the American Sign Language (ASL).

The glove that used provides only measurements for the bend of each finger and measures the tilt and the rotation of the hand. The neural network that used had 7 neurons in the input layer, 54 neurons in the hidden layer and 26 neurons in the output layer. The system was able to achieve an accuracy of around 88% [3].

- Yoon and Jo designed a vision-based system for recognizing the Korean Sign Language alphabet, which consists of 16 consonants and 14 vowels. The system consists of a video camera connected to a computer with an image capturing board

To aid the system in extracting the hand shape form images, the user of the system wears gloves with different colors for each hand. Moment invariance was used for recognition and experiments with one person showed a recognition rate of 97% [4]

1.5 Time plane / project schedule

The project time needed is 32 weeks.

1.5.1. The main activities in this project:

T: Task.

T1: Collecting information and theoretical issues.

At the beginning; the requirements collected from the stakeholders and then a feasibility study will be written.

T2: Analyzing and specifying the concepts.

In this activity the requirements will be analyzed very well to make decisions regarding what the new system will be according to users and stakeholders defining user and system requirements.

T3: System modeling and design.

After collecting the requirements and writing the feasibility study, the system modeled .

T4: Learning American Sign Language.

In this task the designer will learn how to represent the letters using American Sign Language.

T5: System implementation.

T6: System testing.
T7: System documentation.

The following tables display the duration of each task

Table (1.1): The tasks duration for first semester

Activities (Tasks)	Symbol	Duration(week)
Collecting information and theoretical issues	T1	8
Analyze the concepts.	T2	6
System modeling and design	T3	6
Learning American sign Language	T4	6
System documentation.	T7	15

Table (1.2): The tasks duration for the second semester

Activities(Tasks)	Symbol	Duration(week)
System implementation.	T5	8
System testing	T6	7
System documentation.	T7	15
Final project		32 week

The time chart of each semester is shown below:

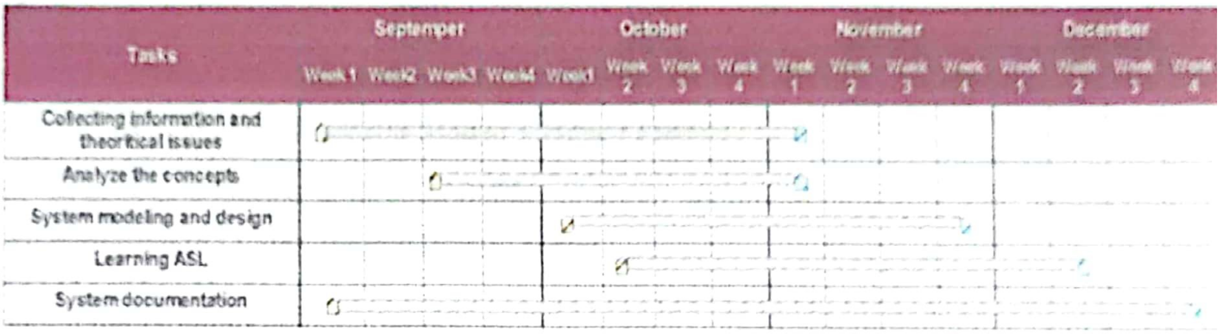

Figure1.1. Project scheduling & time plan (First semester)

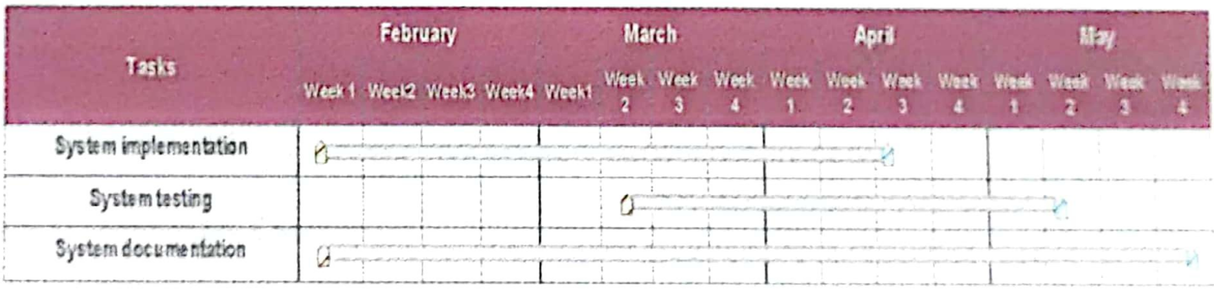

Figure1.2. Project scheduling & time plan (second semester)

1.5.1 Project management

This section presents the members of the project and their job.

1.5.1.1 Allocation of rules of system developers

- Collecting information and theoretical issues (T1)→Tahreer + Hanan+Hiba.
- Analyzing and specifying of the concepts (T2)→Hanan.
-System modeling and design (T3)→Hiba.
-Learning American Sign Language (T4)→Hanan+Hiba+Tahreer.
-System implementation (T5)→ Hanan + Hiba +Tahreer.
-Testing (T6)→ Hanan + Hiba +Tahreer.
-Documentation (T7)→ Hanan+Hiba+Tahreer.

1.6. Estimated cost

This section presents the hardware cost and the software cost.

1.6.1. Hardware Component

This section mentions the cost of hardware components.

Table (1.3): Hardware cost

Component	Cost
Accelerometer sensor(ADXL202AQC) (#5)	153$
LCD 2X16	10$
Capacitor 0.1MF(# 5) + 0.47MF(# 10)	2$
Resistor (25K +100k)(#5)	1$
Board	15$
LM358	3(1)$
Wires	20$
Regulator 7807	1$
PC	--
DAQ	--

1.6.2. Software Component

This section mentions the cost of software components.

Table (1.4): Software cost

Component	Cost
Flash memory	15$
PIC 18f4550	20$

1.6.3. Human Development Resources

The development of project will be implemented by a team of 3 developers.

Human resources cost estimation

The project team works through 32 week, 5 days per week, and 5 hours a day.

Total number of hours:

32 week*5 days*5 hour=800hour.

800 hour*$10=$8000 per individual

Total human cost=$8000*3=$24000

Internet:

Total internet cost=7week*5hour*$1=$ 35

1.6.4. Total cost

The following table shows the total cost of the whole component:

Table (1.5): Total cost

Resource	Estimated cost
Hardware	203$
Software	35$
Human	24000$
Internet	35$

1.7. Project risk management

In this project the team may faces the following risks:

- Some activities may not be made on time for some reasons, such as one of the team members might become ill.
- The system may fail in the operation stage.
- Political situation may affect the time schedule like suspensions in university.

Nonfunctional risks:

- Project component may not found.

Functional risks:

- Some requirements might be changed.

Operational risk:

- Appearance of new requirement after or during development stage.

1.8.Report contents

The report consists of seven chapters; this is a brief description of the main topics of each chapter.

Chapter (2): Introduces and illustrates the idea of the project, describes the component used in the project, software component and hardware component.

Chapter (3): Introduces the design concepts, the project objectives, and the general block diagram of the system and explains how system works.

Chapter (4): Outlines formal procedure for design, and the overall system design.

Chapter (5): Contains the software.

Chapter (6):Contains the system implementation and testing.

Chapter (7): Contains the conclusion and future work.

CHAPTER

2

THEORETICAL BACKGROUND

Introduction.

Theoretical background of the project.

Hardware and Software component.

Project integrity.

Chapter two
Theoretical background

2.1 Introduction

This chapter focuses on theoretical subjects related to the main idea of the project, and information about the components used in the project.

2.2 Theory

Sign language can be represented using different sign languages such as Arabic sign Language, British Sign Language, and American Sign Language (ASL). This project deals with American Sign Language (ASL).

2.2.1 American Sign Language (ASL)

ASL is a natural language contains semantic, syntax and pragmatics just like spoken language.

It is a manual language or visual language, meaning that the information is expressed not with combination of sound but with combination of hand shapes, palm orientations, movements of the hands, arms and body, location in relation to the body, and facial expressions.

While spoken language are produced by the vocal cords only, and can thus be easily written in linear pattern, ASL uses the hands, head and body, with constantly changing movements and orientation. ASL is used natively and predominantly by the deaf and hard-of-hearing.

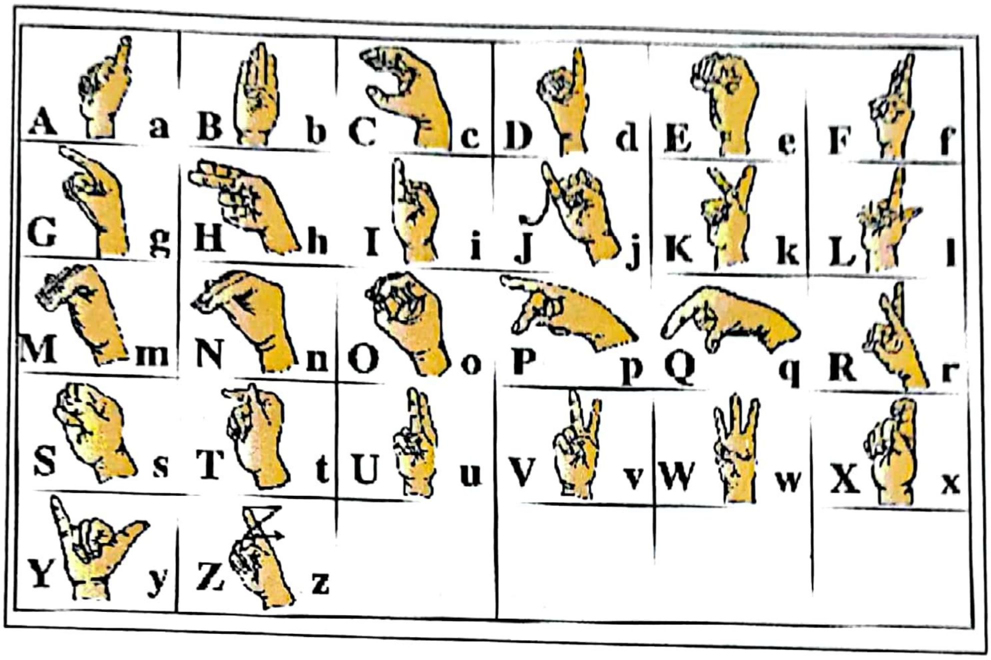

Figure 2.1: ASL (letters and its associated sign using one hand) [5]

2.3 Components

There are two kinds of components hardware component and software component.

2.3.1 Hardware Component

This section mentions and explains the hardware that are used in this project

2.3.1.1 Accelerometer sensor

Piezo- electric crystals are man made or naturally occurring crystals that produce a charge output when they are compressed, flexed or subjected to shear forces, the word piezo is a corruption of the Greek word for squeeze.

In a piezo –electric accelerometer a mass is attached to a pizo –electric crystal, which is in turn mounted to the case of the accelerometer.

When the body of the accelerometer is subjected to vibration the mass mounted on the crystal wants to stay in space due to inertia and so compresses and stretches the pizo electric crystal. This force causes a charge to be generated and due to Newton low F=ma (F: force, m: mass, a: acceleration) this force is in turn proportional to acceleration.

The charge output is either converted to a low impedance voltage output by the use of integral electronic or made available as a charge output.

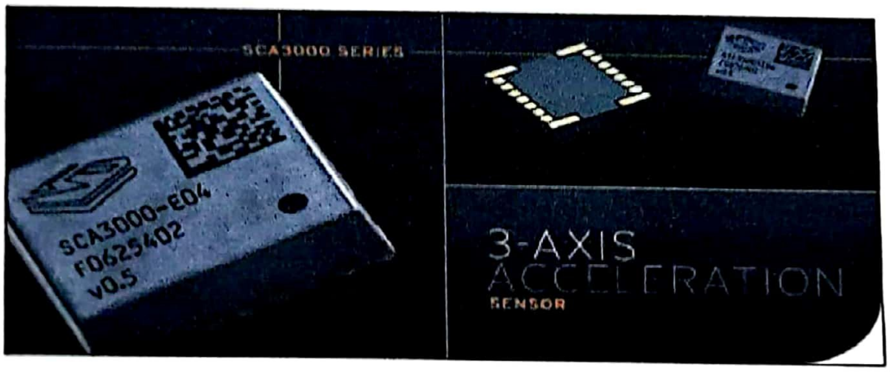

Figure 2.2 Accelerometer sensors [6]

2.3.1.1.1 ADXL202 AQC

The ADXL202 is low cost, low power, complete 2_axis accelerometer with a measurement range of either +-2g/+-10g. It can measure both dynamic acceleration (e.g vibration) and static acceleration (e.g gravity).

The outputs are digital signals whose duty cycles (ratio of pulse-width to period) are proportional to the acceleration in each of the 2 sensitive axes. These outputs may be measured directly with a microprocessor counter, requiring no A/D converter . The output period is adjustable from 0.5 ms to 10 ms via a single resistor (Rset). If a voltage output is desired, a voltage output proportional to acceleration is available from the Xfilt and Yfilt pins, or may be reconstructed by filtering the duty cycle outputs.

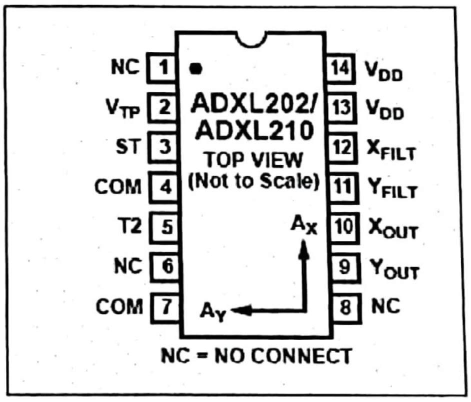

Figure 2.3: ADXL202AQC Pin configuration [7]

Features:

- 2_axis acceleration sensor on a single IC chip measures static acceleration as well as dynamic acceleration.
- Duty cycle output with used adjustable period .

- Low power <0.6mA.
- Faster response than electrolytic, mercury or thermal tilt sensors.
- Bandwidth adjustment with a single capacitor per axis .
- 5mg resolution at 60 Hz bandwidth.
- +3v to +5.25v single supply operation.

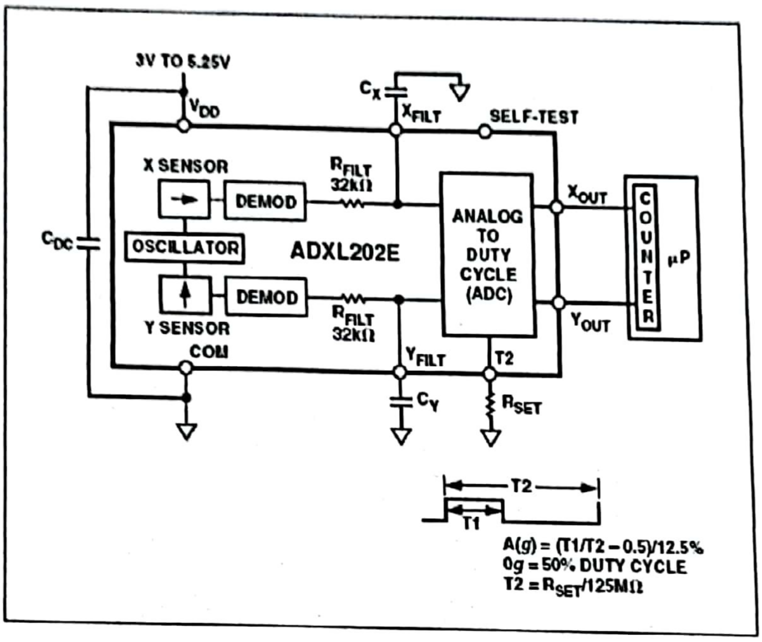

Figure 2.4:ADXL202AQC Functional block diagram [8]

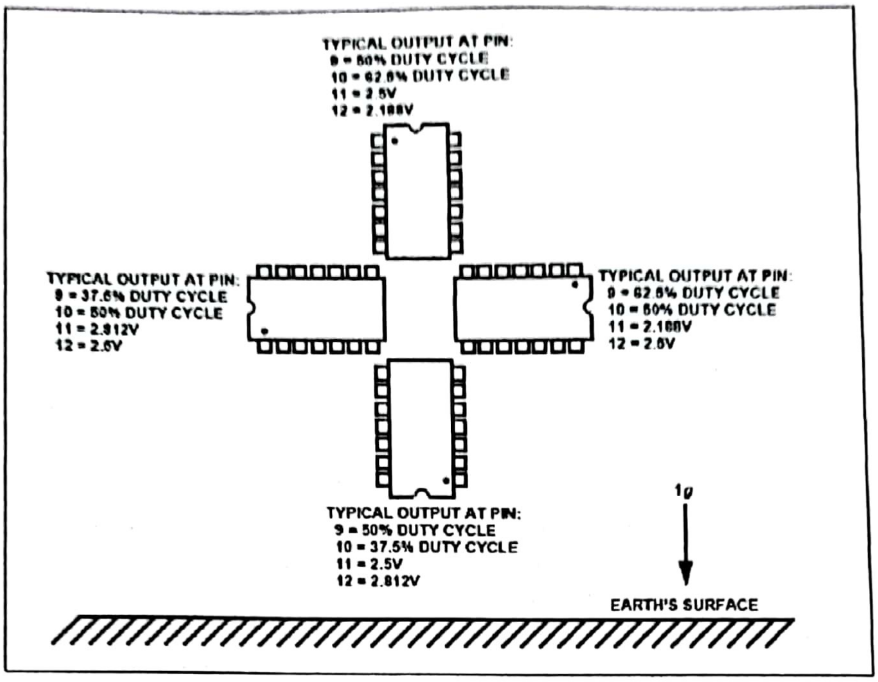

Figure 2.5: Earth Orientations [9]

Application

- 2_axis tilt sensing.
- Computer peripherals.
- Inertial navigation.
- Seismic monitoring.
- Vehicle security systems.
- Battery powered motion sensing.

In this project the designer uses the analog output, because the system needs five of these sensors and if the designer uses the digital output (which appears as duty cycle pulse), he needs counter to count the number of pulses and the PIC18f4550 has only one pin for counter and also the Data Acquisition(DAQ) which uses to enter data to the computer has only two . So the designer chooses the analog output because the DAQ has 16 channels for analog input, and PIC18f4550 has 12 channels.

2.3.1.2 LM358 Operational Amplifier

LM358 consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Features

Internally frequency compensated for unity gain

- Large dc voltage gain: 100 dB
- Wide bandwidth (unity gain): 1 MHz
- (temperature compensated)
- Wide power supply range:
  - Single supply: 3V to 32V
  - or dual supplies: ±1.5V to ±16V
- Very low supply current drain (500 μA)—essentially independent of supply voltage
- Low input offset voltage: 2 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing: 0V to V+– 1.5V

Advantages

- Two internally compensated op amps
- Eliminates need for dual supplies
- Allows direct sensing near GND and VOUT also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation
- Pin-out same as LM1558/LM1458 dual op amp.

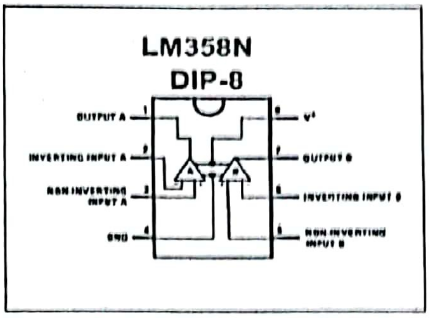

Figure 2.6: LM358 Pin Diagram[10]

2.3.1.3 2X16 LCD

This project needs this 2X16 LCD to show the output letters of this system. This LCD can show 32 chars which are enough for this product which needs to appear 26 letters. Also 2X16 LCD is suitable to use with the glove because of its size which is small.

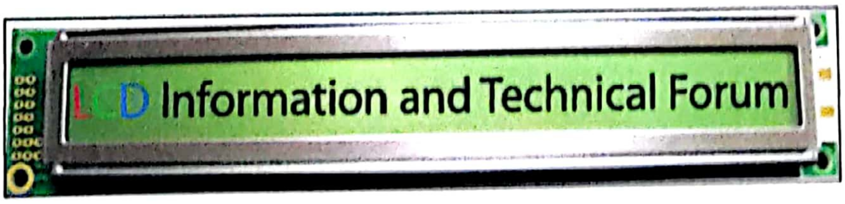

Figure 2.7:2X16 LCD [11]

2.3.1.4 Data Acquisition (DAQ)

This device is used for acquiring, analyzing, output data.
DAQ characteristics:

- 16 channels for analog input.
- 8 bit digital input
- Max voltage entered =+,- 10 volts

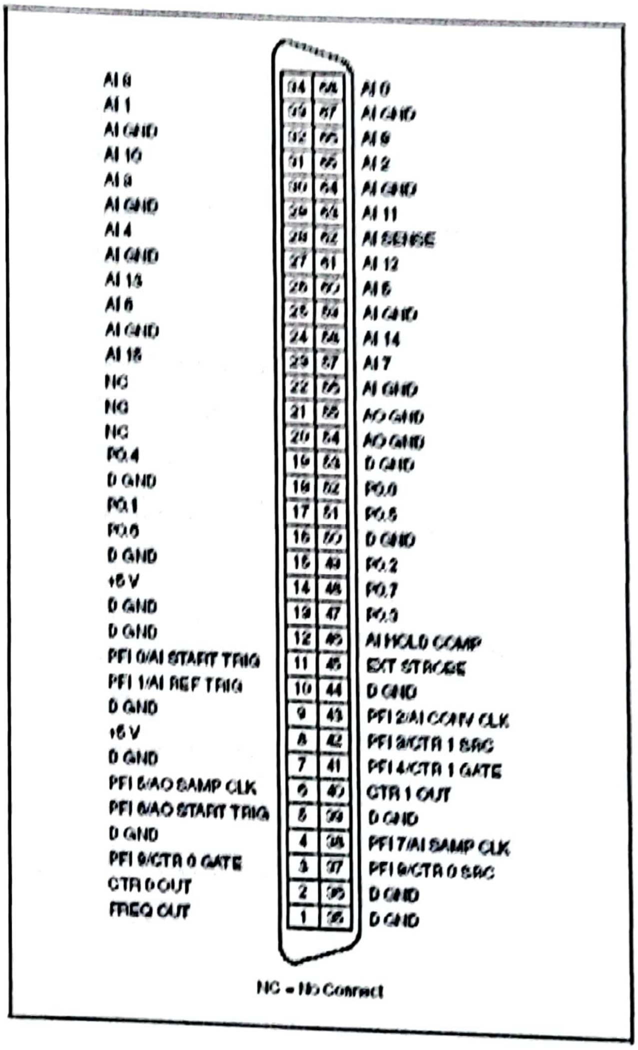

Figure 2.8: Pin diagram of 6034E [12]

2.3.2 Software Components

This section contains the software components that used in this system.

2.3.2.1 PIC Microcontroller (PIC18f4550)

Microcontroller is a device which integrates a number of the components of a microprocessor system onto a single microchip and optimized to interact with the outside world through on-board interfaces.

It is a little gadget that house a microprocessor, ROM, RAM, I/O, and various other specialized circuits all in one package.

The PIC that used in this project is PIC18f4550, the designer chooses this type because it has the feature that is suitable for this product such that:

- It contains 256 byte data EEPROM, 2kbyte SRAM byte,32k flash byte; this system needs to store 26 letter so it enough(26letter * 5sensor * 8 bit).
- It has 32 I/O lines to the PIC I/O ports so it suitable.
- 8 bit Microcontroller.
- Non volatile program and data memory.
- High performance, low power.
- High speed Flash/EEPROM technology.
- 12 channel 10 bit A/D.

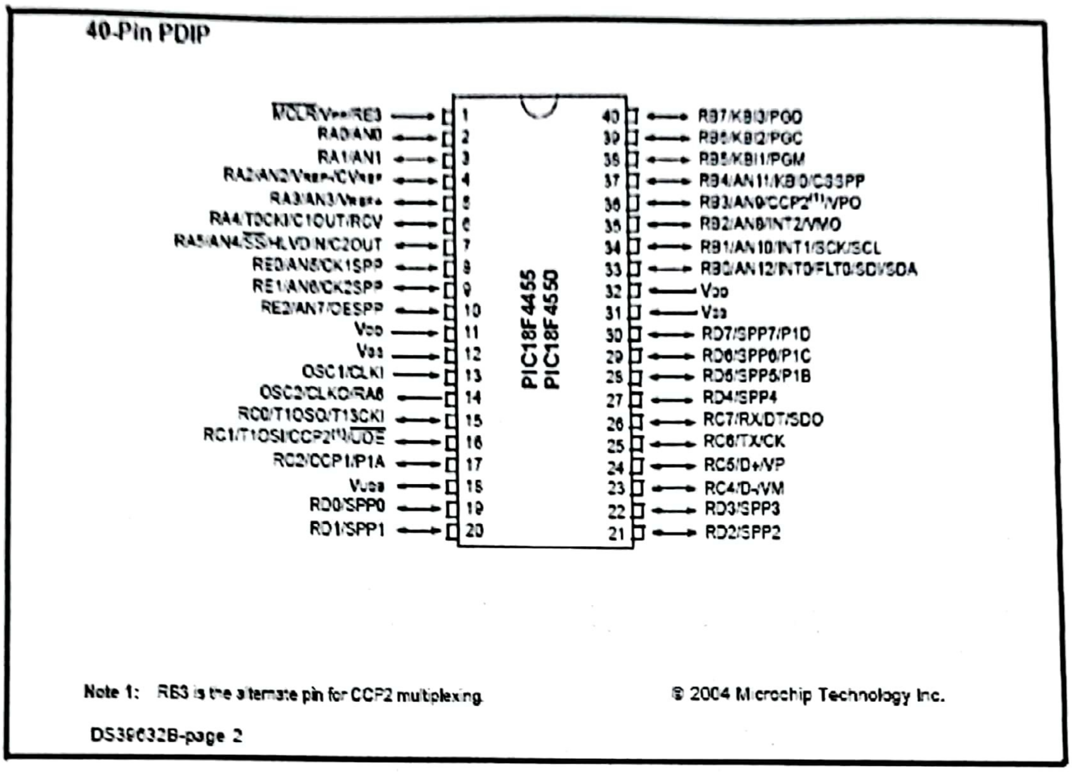

Figure 2.9: PIC18F4550 Pin Diagram[13]

2.4 Project integrity

This system does not cause any problem either for the human or for the environment, on the opposite it has humanistic helpful.

CHAPTER

3

PROJECT CONCEPTUAL DESIGN

Introduction

Detailed project objectives.

Design options.

Project design block diagram.

Project interaction with the surrounding environment.

Design realization approach.

Chapter three
Project conceptual design

3.1 Introduction

This chapter shows the design concepts and the block diagram of the system.

3.2 Objectives

- Read the movement of the fingers.

This is done by fixing a movement sensor on the glove; one for each finger. This sensor can sense the movement of each finger.

- Matching each movement with its associated letter.

The value of the movement and its associated letter will be stored in the EPROM of the MCU and when the user represents a letter in ASL, this value and its letter will be matched from those that previously stored in the EEPROM.

3.3 Design options

Depending on the requirements of the system there are various options for the design as the following.

- The designer can use potentiometer instead of the flex sensor but it is costly because the designer must use one for each knuckle.
- The designer can use camera to take photo for each sign and this photo will interpret into its associated letter but this will make the design not portable..

- The designer can use P5 glove(Power of five) , but this will make the design not portable because it has a receiver and it does not work without it.
- The designer can use Arabic Sign Language, but there is a problem (there is no Arabic LCD).
- The designer can use British Standard Sign Language but this language uses 10 fingers and this will be costly because it needs 10 sensor while American Sign Language uses 5 fingers (so it needs 5 sensor).

3.4 Project design block diagram

This system works on two phases ; computer phase and MCU phase.

3.4.1 Computer phase:

This phase composed of three units:

- Glove unit: This unit reads the value of hand movement and this value enters to the DAQ unit.
- DAQ unit: This unit used to read the signals that come from the sensors through analog channels and enter these signals into computer.
- PC unit: This unit used to process the signals that come from the DAQ unit, and the result will appear on the computer screen.

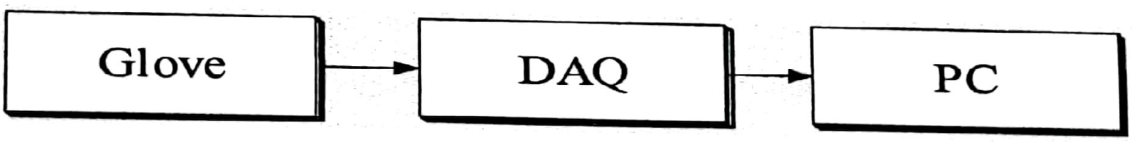

Figure 3.1: Block diagram of the system in computer phase

3.4.2 MCU phase:

This system composed of three units:

- Glove unit: This unit reads the value of hand movement and this value enters to the MCU.
- MCU unit: This unit reads this value and makes match between this value and its associated letter.
- LCD unit: This unit displays the letter that matched.

Glove → MCU → LCD

Figure 3.2: Block diagram of the system in MCU phase

3.5 Project interaction with the surrounding environment

The input of this system comes from a movement sensor (Accelerometer) fixed on the glove that will sense the movement of the fingers, and the output will appear on LCD.

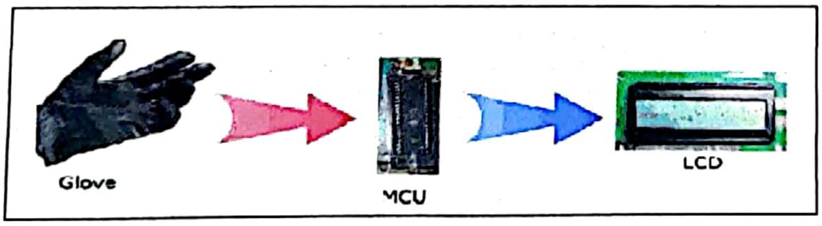

Figure 3.3: Interaction with the surrounding environment [14]

3.6 Design realization approach

This section contains the details of the system. The glove unit contains accelerometer sensor and accelerometer sensor circuit.

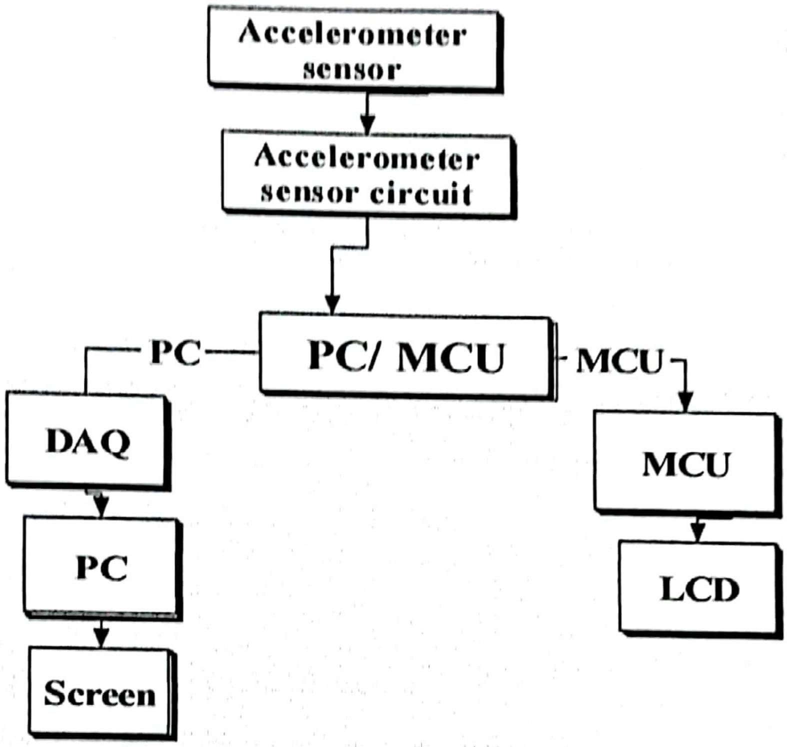

Figure 3.4: Detailed system flowchart

When the designer represents the signal of the letter in ASL, a movement will happen and an acceleration results from this movement, and this acceleration will change to voltage .

The output which comes from the sensor circuit is analog, so analog to digital converter will be used and the value that comes from it compared with the database that stored in the EEPROM to make match. LCD used to interface with the user.

CHAPTER

4

DETAILED TECHNICAL PROJECT DESIGN

Introduction

Detailed descriptions of the project phases.

Subsystem detailed design (characteristics, specifications).

Overall system design (schematic diagram).

User system interface (hardware, software).

Chapter four

Detailed technical project design

4.1 Introduction

This chapter outlines formal procedure for design and the overall system design.

4.2 Detailed description of the project phases

This system works in two modes, train mode and operational mode.

- Train mode: In this mode the user trains the MCU ASL using hand gestures.

To prevent data corruption A/D converter outputs and the associated user specified alphabet are saved in EEPROM.

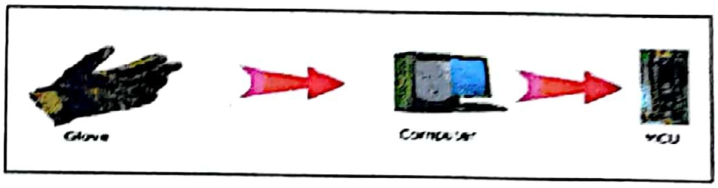

Figure 4.1: Train mode [15]

- Operational mode: In this mode the user chooses a letter and represents it and so the MCU compares between the value of this representation and the database stored in the EEPROM to make match.

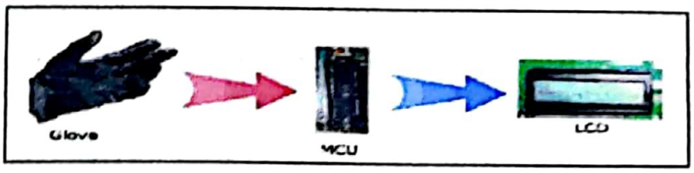

Figure 4.2: Operational mode [16]

4.3 Subsystem detailed design

This section contains detailed description of the subsystems.

4.3.1 ADXL202 connections

The circuit consists of five modules one for each finger, each module contained an accelerometer sensor. The output of each module is a voltage

The following figure shows the accelerometer sensor circuit, this module is repeated to each finger.

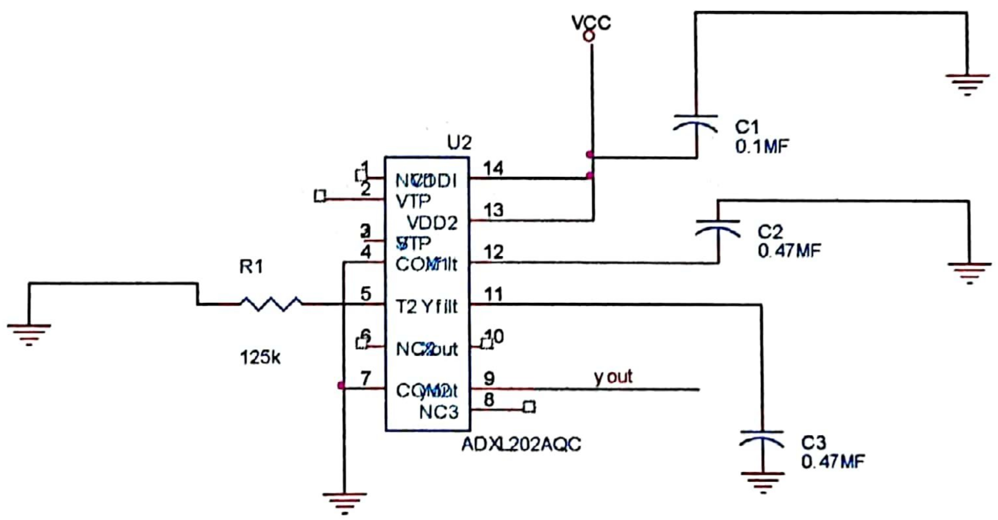

Figure 4.3: ADXL202AQC sensor circuit

- 0.1MF capacitor will decouple the accelerometer from signal and noise on the power supply, this capacitor will be placed between VDD and COM.

- Pin4 and pin7: These two pins are commons and they should be connected directly together and pin7 grounded.
- Pin 12 analog output for x axis.
- Pin 11 analog output for y axis.
- 125k (Reset): It will set the duty cycle repetition rate to approximately 1 kHZ, or 1ms.

Note: Reset should always be included, even if only an analog output is desired.

4.3.2 MCU Connection

The output of the accelerometer sensor is analog signal; these signals are entered into the MCU which contains Analog to Digital converter (A/D) to convert the analog signals into digital signals.

Also it contains EEPROM that used to store the value of voltage for each letter in train mode so that the value of the voltage in operational mode will compare with the values that are stored in train mode in this memory.

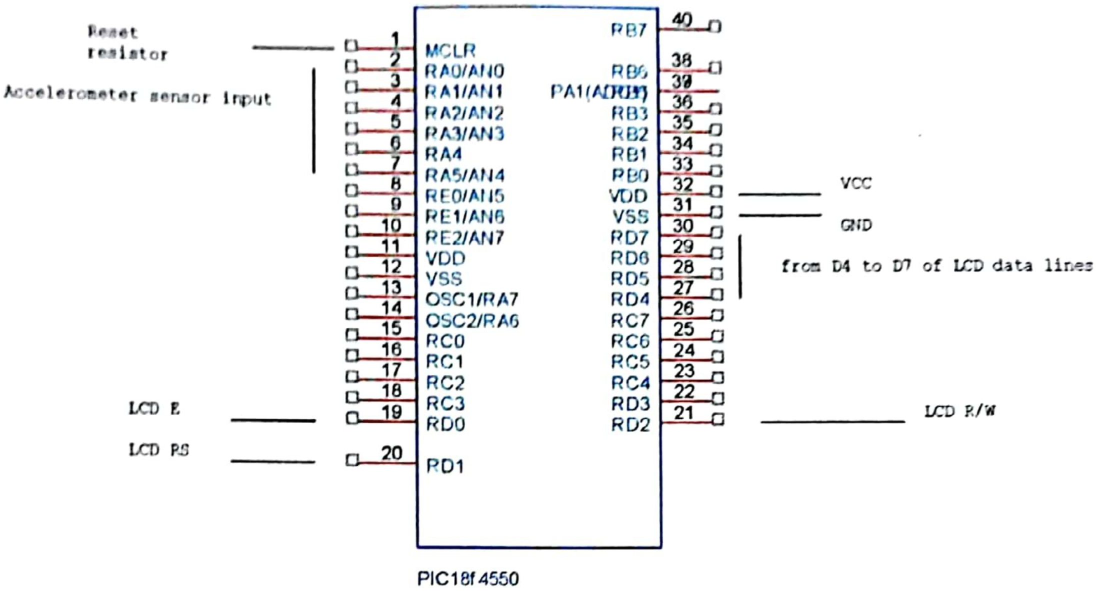

Figure 4.4: MCU connection

1.3.3 Operational amplifier connection

The output of the accelerometer sensor is analog signal; these signals are entered nto PIC18f4550 which needs at least current in milliampere(mA), and accelerometer has urrent in microampere(MA) at most so the PIC cant read this analog input so the designer eeds an operational amplifier circuit to make the current larger.

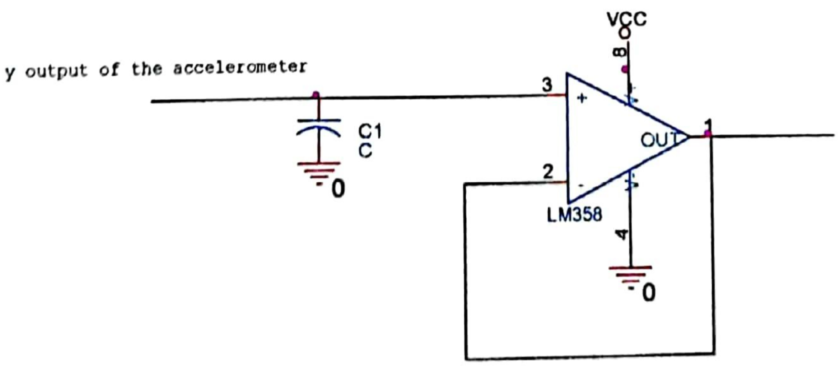

Figure 4.5: Operational amplifier connection

4.4 Overall system design

The system design is shown in the following figure:

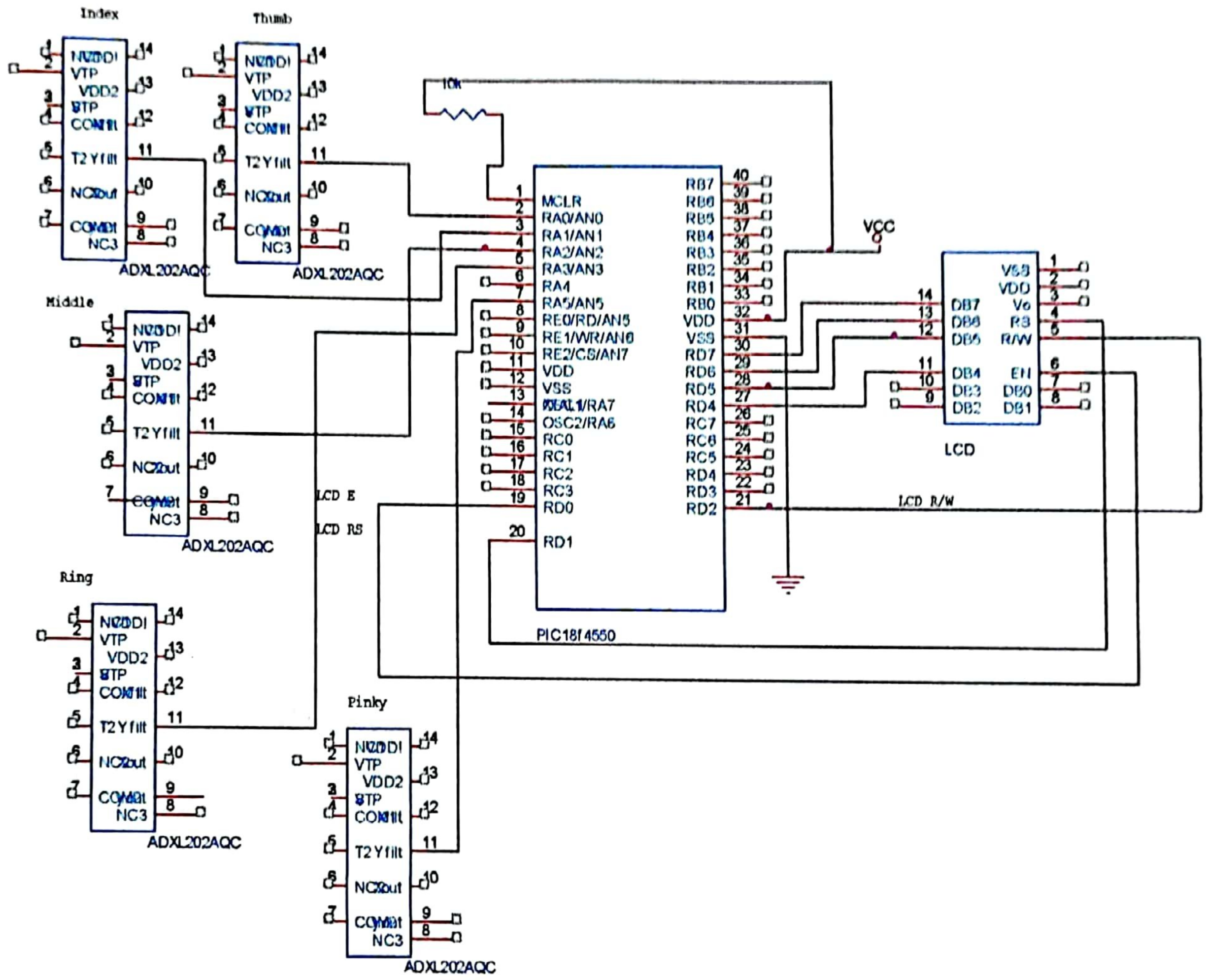

Figure 4.6: Overall system design

4.5 User System interface

This section contains the hardware and the software used for the interface.

4.5.1 Hardware

The following components will be used:

- The movement sensors called Accelerometer sensor.
- The LCD is 2X16 LCD.
- The glove is an ordinary glove used just to fix the sensors on it, but the designer must choose one that is durable.

4.5.2 Software

The user uses MPLAB C18 program to program the PIC in the different hand positions of the alphabet in MCU phase, and LABVIEW program in PC phase.

CHAPTER

5

PROJECT SOFTWARE

Introduction

Software needed for the Project.

Algorithms and Flowcharts.

Chapter five

Project software

5.1 Introduction

This chapter contains the software needed for the design and the flow charts of the system.

5.2 Software needed for the project

The language that will use in this project is C language because it is very familiar language and easy to use and program, also this language can be used to program PIC18f4550, this will be used in MCU phase while the computer phase will use the LABVIEW.

5.3 Algorithms and Flowcharts

1. **Train mode**

```
for(i=0 to 26)  // number of letters
for(j=0 to 20)  // number of samples for each letter
//  Choose a letter and represent it .
for(k=0 to 5)  // number of fingers
// Read the output of accelerometer sensor  and store it in array [20][5]  for each letter .
for (j=0 to 20)
for (k=0 to 5)
```

```
array1[j][k]=array[k];
// calculate the mean of the 20 samples
for(j=0 to 20)
for(k=0 to 5)
mean[k]=array1[j][k]/20;
// store the mean for each letter in array[26][5] called sign
for(i=0 to 26)
for(k=0 to 5)
sign[i][k]=mean[k];
```

2. Operational mode

```
for(i=0 to 26)
Choose a letter and represent it in ASL.
for (i=0 to 5).
Read the output of the accelerometer sensor.
Compare between the values that is read and those that are stored in sign[26][5] depends on
nearest neighbor algorithm .
if match
   Display the matched letter.
```

5.3.1 Computer phase:

This section contains the system flowcharts and LABVIEW blocks description.

5.3.1.1 System flowcharts

This section talks about the flowcharts of the system phases train and operation, the following are the symbols used in the flowcharts.

CountL: represents the counter that counts the letters.

CountS: represents the counter that counts the samples.

Va : represents the voltage of accelerometer sensor.

Vavg : represents the average voltage.

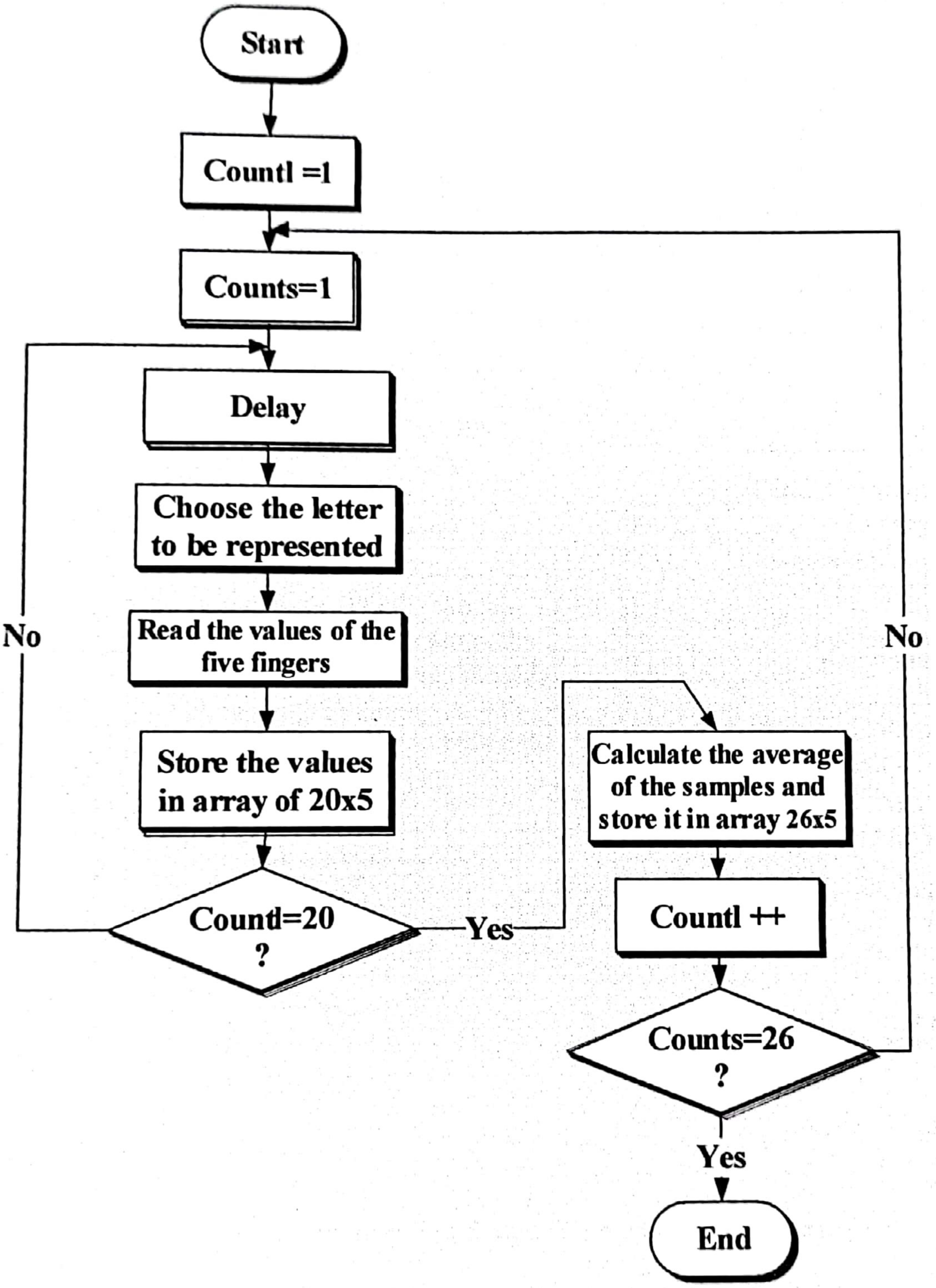

Figure 5.1: Train mode flow chart in computer phase

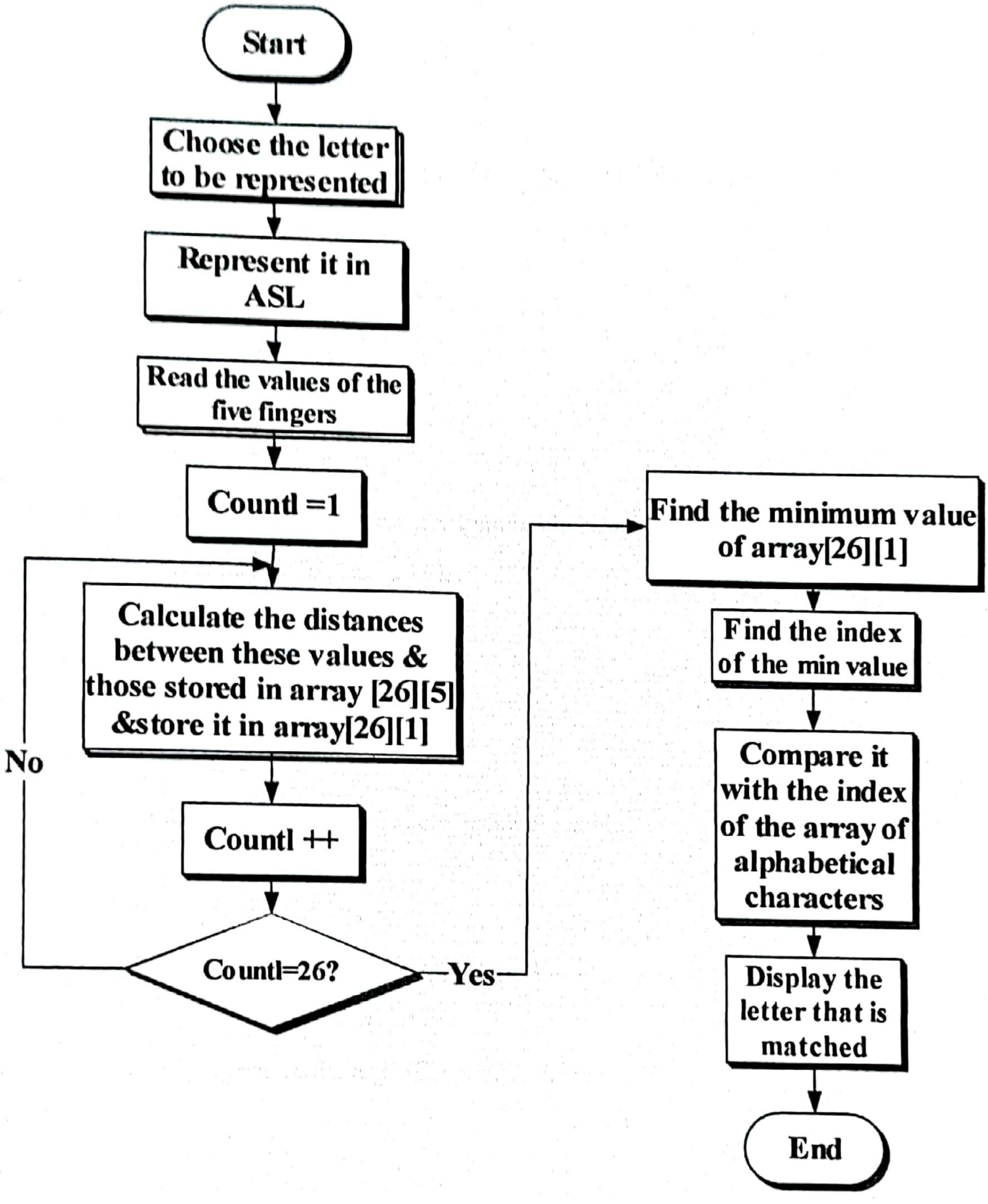

Figure 5.2: Operational mode flow chart in computer phase

5.3.2 MCU phase

- Train mode: The values of train mode are taken and stored statically through array [26][5].
- Operational mode:

```
for(i=0 to 26)
// Choose a letter and represent it.
for(j=0 to 5)
// Read the output of the accelerometer sensor for thumb, index, middle, Ring, Pinky;
Calculate_N(thumb, index, middle, Ring, Pinky);
Nearest_N(distance);
match( index);
LCD_display(letter);
```

The following section explains the methods that are called above.

5.3.2.1 Calculate_N(arg1,arg2,arg3,arg4,arg5) method

```
arg1=thumb, arg2=index, arg3=middle, arg4=Ring, arg5=Pinky.
for(i=0 to 26)
for(j=0 to 5)
D=sqrt(pow(thumb-sign[i][0],2)+ pow(thumb-sign[i][1],2)+ pow(thumb-sign[i][2],2)+
pow(thumb-sign[i][3],2) + pow(Pinky-sign[i][4]),2));
Distance[i]=D;
```

To know more go to the code in the appendices

5.3.2.2 Nearest _N(arg) method

```
arg=distance[26];
min=distance[0];
for(i=0 to 26)
if(distance[i]<min)
min=distance[i];
count=i;  // the index of the minimum value
```

To have more details go to the code in the appendices.

5.3.2.3 Match (arg) method

```
arg=count // index of the minimum values.
Letter=Character[count];
```

To have more information go to the code in the appendices.

5.3.2.4 LCD_display(arg) method

```
arg=letter
lcd_init();
lcd_gotoyx(1,1);
lcd_putc(letter);
```

To have more information go to the code in the appendices.

CHAPTER

6

SYSTEM IMPLEMENTATION AND TESTING

Introduction.

Implementation.

Testing .

Chapter six

System implementation and testing

6.1 Introduction

This chapter introduces the system implementation and component testing, subsystem testing and integrated testing related to SLC system.

6.2 Implementation

In this section the circuits was built and the code was built.

6.2.1 Sensor circuit

The ADXL202AQC sensor circuit which mentions in chapter 4 was built .This circuit is repeated for the five fingers.

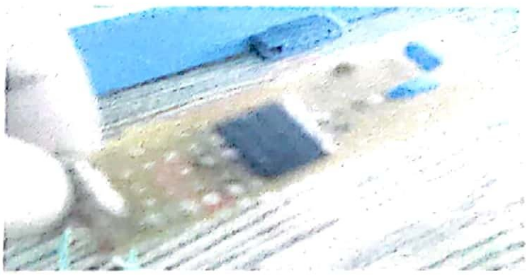

Figure 6.1: Sensor circuit for each finger.

6.2.2 Sensor circuit for the five fingers

The circuit shown in figure 6.1 was repeated for the five fingers, the five modules for the five fingers are connected together through VCC and GND.

The following figure represents the sensor circuit for all the glove.

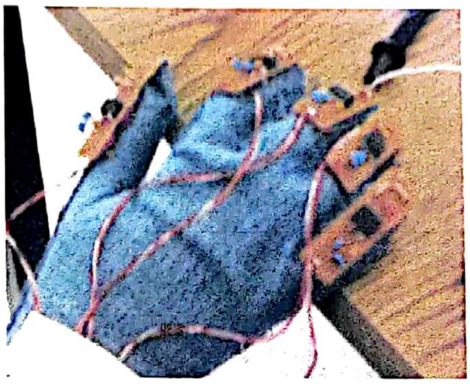

Figure 6.2: The created glove

6.2.3 PC phase train mode

The glove are connected to the PC through DAQ and the letters are represented in ASL and the result are stored in array[20][5]{ 20:number of samples for each letter, 5:number of fingers}.

Figure 6.3: Glove connected to PC through DAQ.

6.2.4 PIC phase

This section mentions the circuits that used for LCD section, ADC section.

6.2.4.1 LCD implementation

There are two modes in LCD connection, the first mode uses 4 data lines for data and the data are transfer in two phases and the designer uses this mode in this system in order to use less data lines, and the second mode uses 8 data lines for data, and so the data are transfer in one phase.

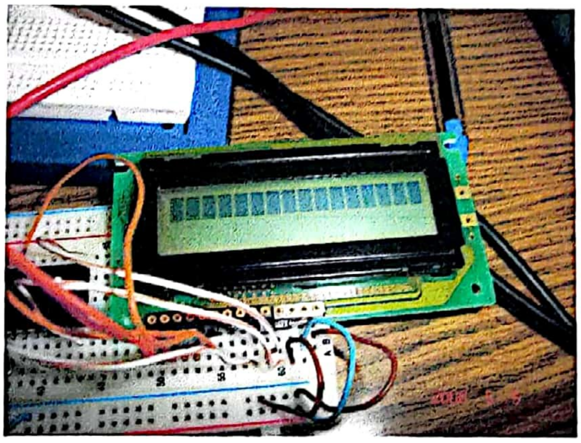

Figure 6.4: LCD connected in PIC mode.

6.3 Testing

This section contains the result of the circuits that are implemented in the previous section.

6.3.1 Sensor circuit result

The circuit which shown in figure 6.1 is tested on the oscilloscope, it tested for its digital output x and y (pin9 and pin10) and the result was as follow:

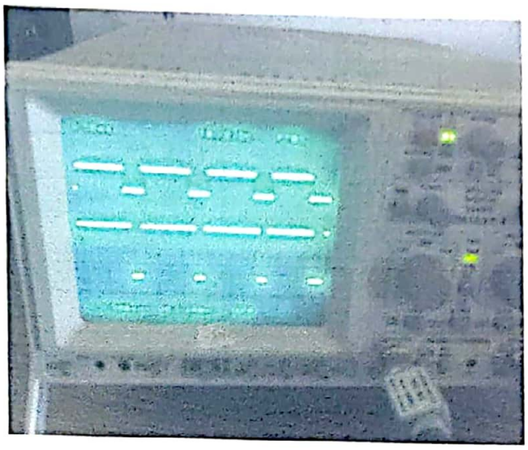

Figure 6.5 : Result of x and y on pin9 and pin10.

6.3.2 Sensor circuit result for all hand

The letters are implemented in ASL and the results for the five fingers are taken from five digital multimeter at the first time.

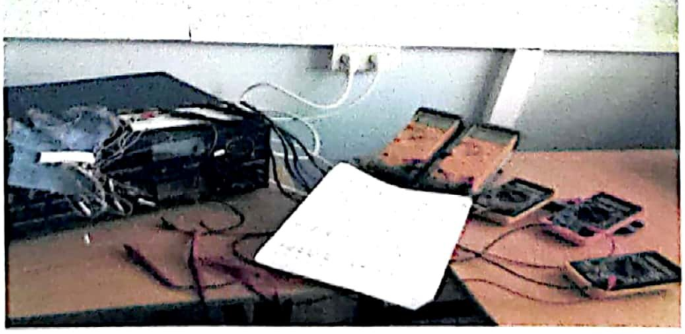

Figure 6.6 :Voltages of letters represented in ASL using five digital multimeter.

The result which the designer took it from the five digital multimeter for the 26 letter are shown in the following table.

Table (6.1): Voltage values for the letters measured using 5 digital multimeter.

Letter	Thumb	Index	Middle	Ring	Pinky
A	2.14	2.95	2.52	2.93	1.96
B	2.27	2.50	2.08	2.41	2.2
C	2.28	2.77	2.34	2.67	1.95
D	2.39	2.53	2.37	2.42	2.11
E	2.55	2.74	2.41	2.82	1.97
F	2.21	2.70	2.10	2.53	2.02
G	2.43	2.66	2.41	2.59	2.22
H	2.46	2.59	2.15	2.92	2.19
I	2.40	2.96	2.57	2.81	2.35
J	2.50	2.89	2.43	2.41	2.15
K	2.26	2.51	2.07	2.42	2.9
L	2.16	2.48	2.54	2.87	2.86
M	2.47	2.87	2.61	2.92	2.22
N	2.48	3.23	2.50	2.76	2.67
O	2.41	3.91	2.45	2.67	2.32
P	2.70	2.91	2.58	2.46	2.42
Q	2.71	3	2.23	2.91	1.9
R	2.46	2.55	2.04	2.82	1.7
S	2.32	2.96	2.58	2.41	1.86
T	2.27	2.73	2.53	2.43	1.98
U	2.32	2.48	2.06	2.42	1.96
V	2.30	2.48	2.06	2.63	2.2
W	2.34	2.49	2.11	2.92	2.582
X	2.57	2.70	2.48	2.44	2.43
Y	2.14	2.93	2.55	2.45	2.53
Z	2.55	2.62	2.47	2.66	2.6

6.3.3 PC train mode

Figure 6.3 was implemented for each letter and this section contains the values of train mode for each letter.

The code of train mode was implemented and the letters was implemented in ASL.

The values for each finger stored in array[20][5].

The following figure represents the values of 20 samples for representation of A letter in ASL.

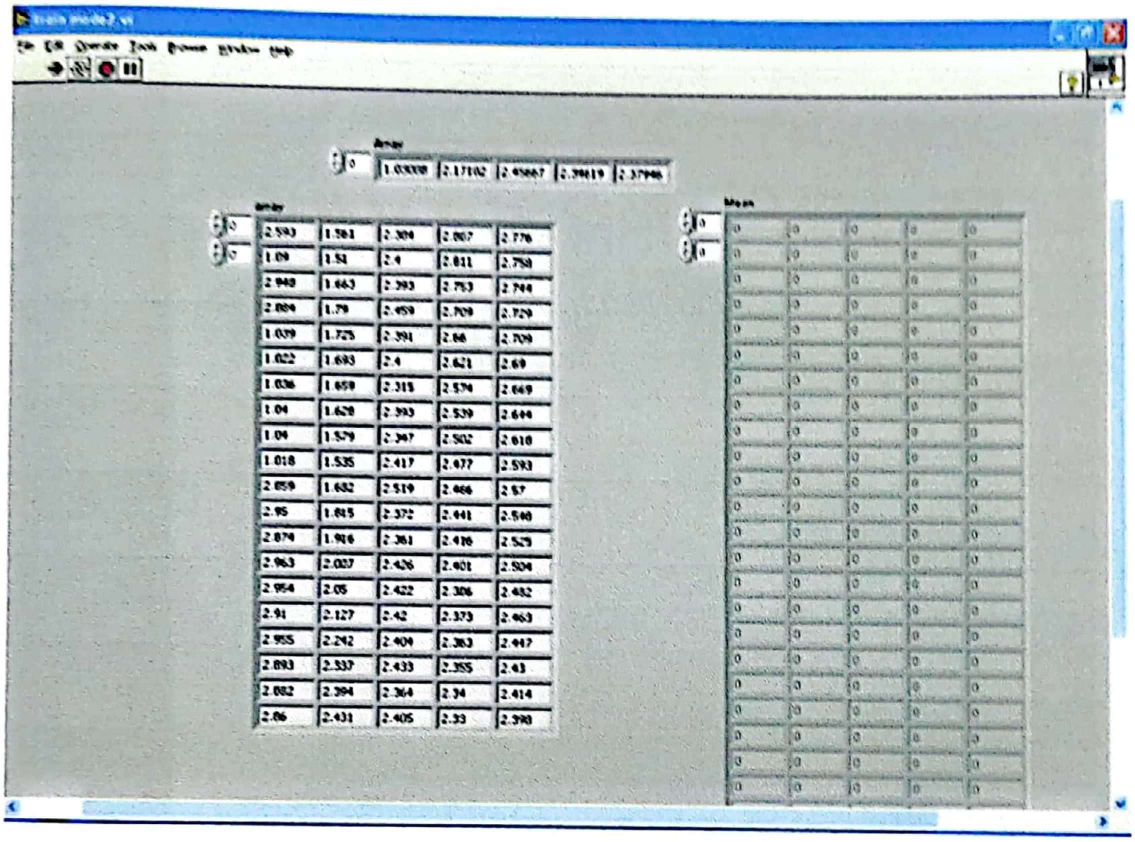

Figure 6.7: A letter train mode at PC phase.

'he following figure shows the representation of letter A in ASL.

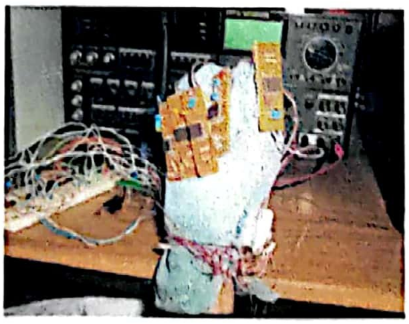

Figure 6.8: Representation of A letter in ASL.

The following figure represents the values of 20 samples for representation of B letter in ASL.

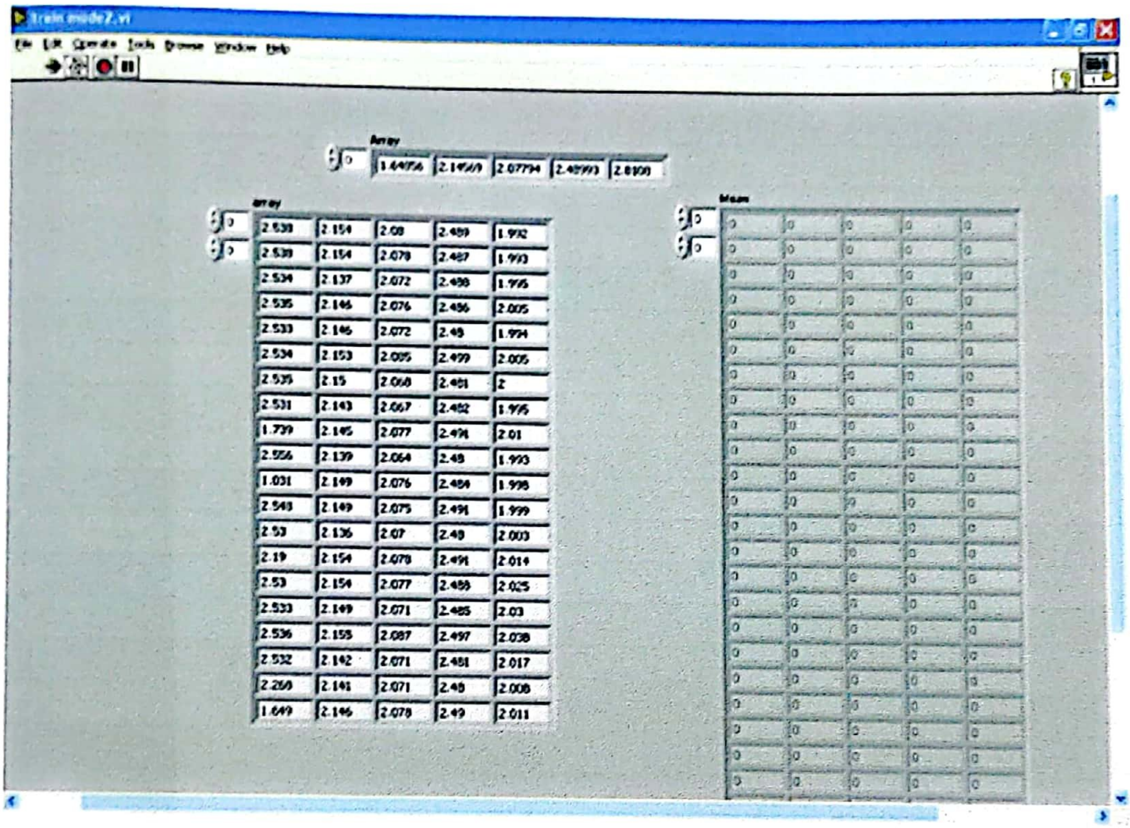

Figure 6.9: B letter train mode at PC phase.

The following figure shows the representation of B letter in ASL.

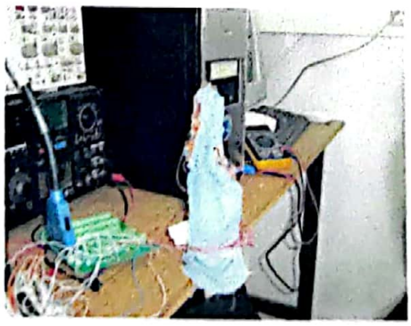

Figure 6.10: Representation of B letter in ASL.

The following figure represents the values of 20 samples for representation of C letter in ASL.

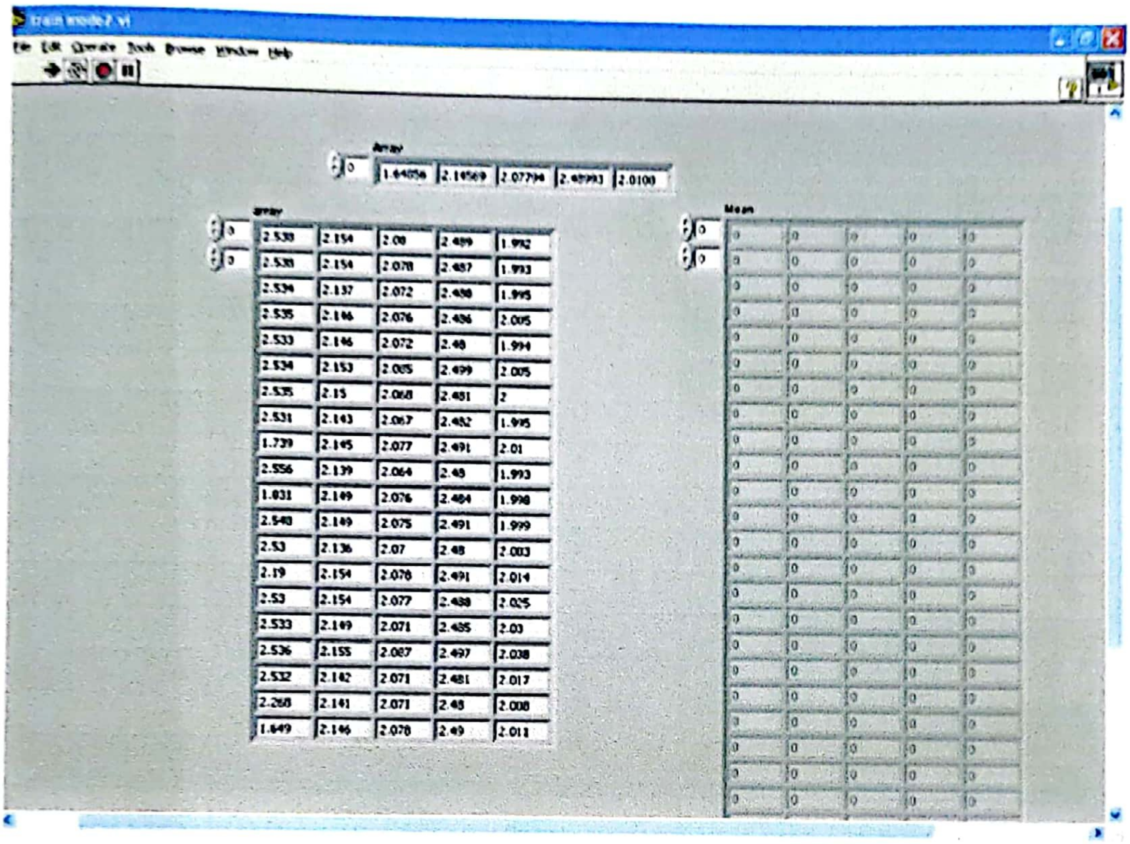

Figure 6.11: C letter train mode at PC phase.

The following figure shows the representation of C letter in ASL.

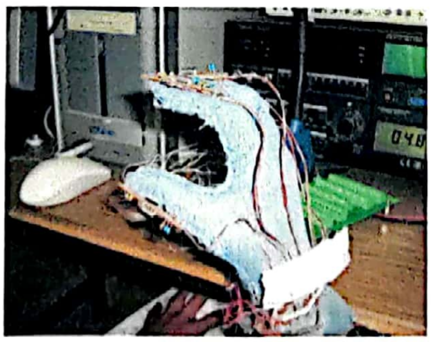

Figure 6.12: Representation of C letter in ASL.

The following figure represents the values of 20 samples for representation of D letter in ASL.

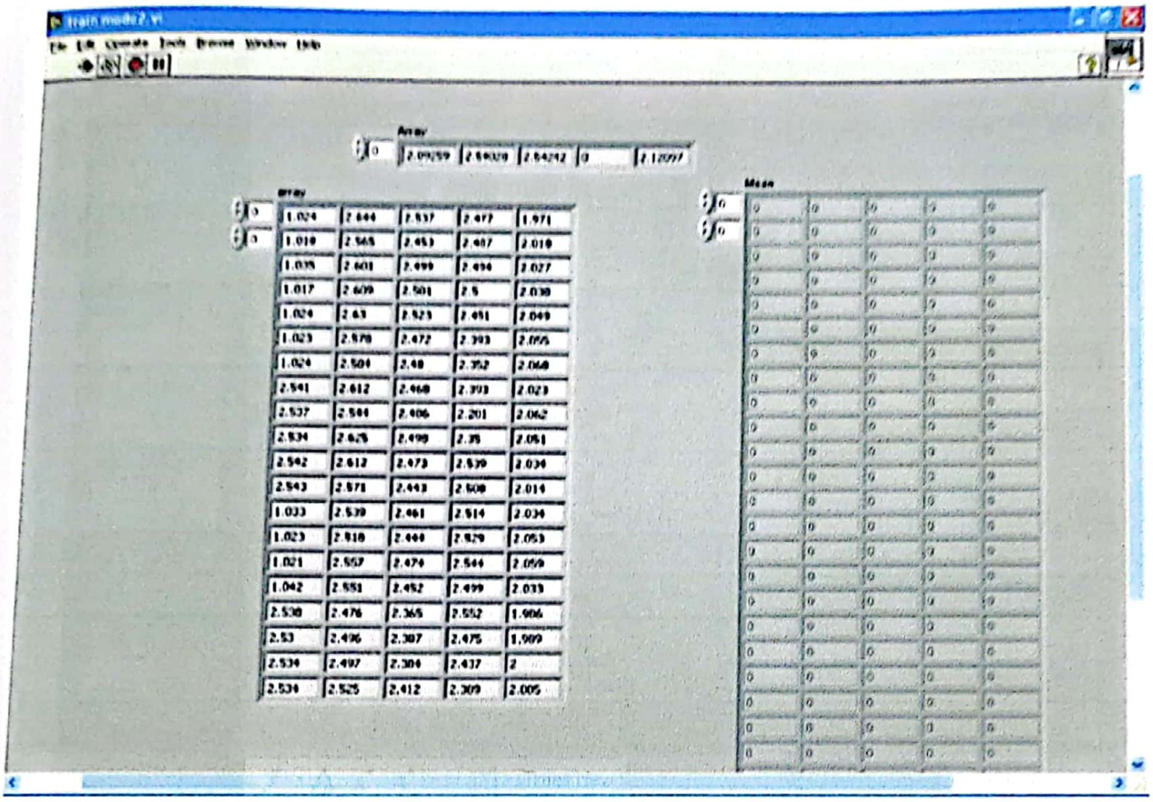

Figure 6.13: D letter train mode at PC phase.

The following figure shows the representation of D letter in ASL.

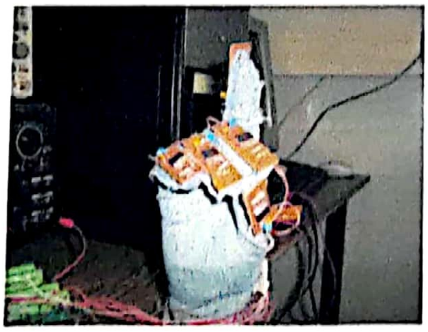

Figure 6.14: Representation of D letter in ASL.

The following figure represents the values of 20 samples for representation of E letter in ASL.

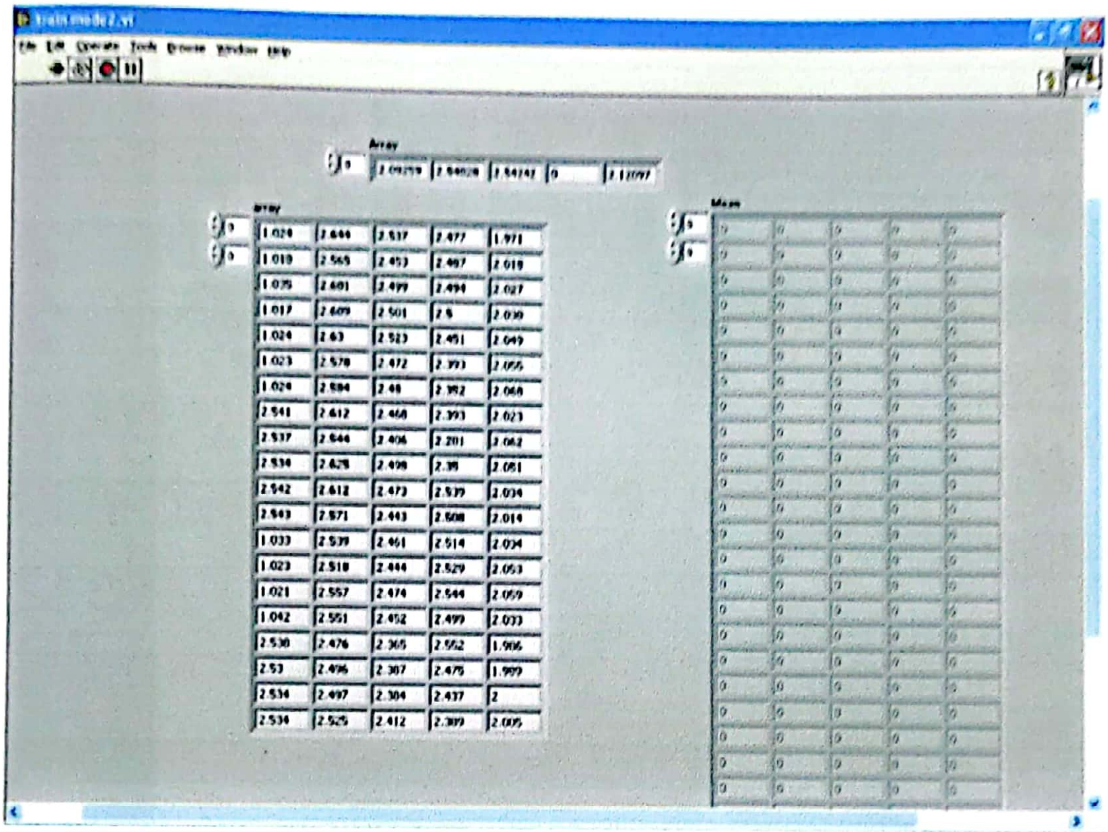

Figure 6.15: E letter train mode at PC phase.

The following figure shows the representation of E letter in ASL.

Figure 6.16: Representation of E letter in ASL.

The following figure represents the values of 20 samples for representation of F letter in ASL.

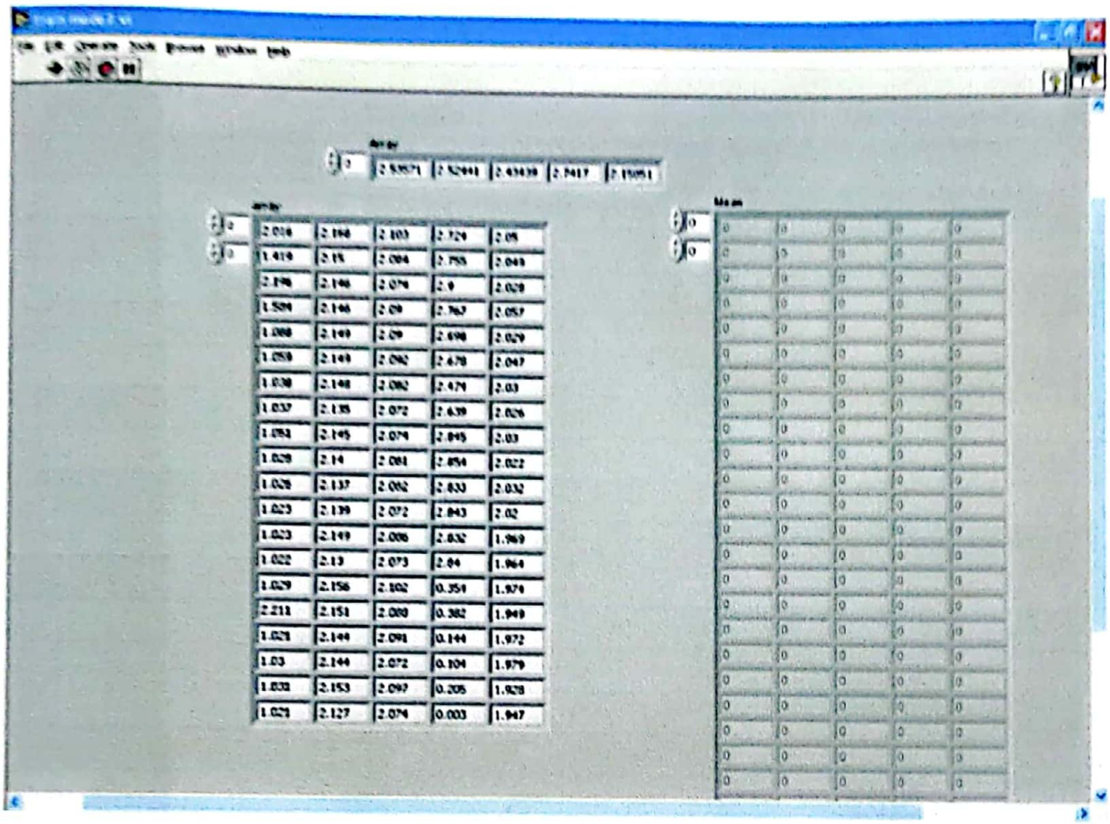

Figure 6.17: F letter train mode at PC phase.

The following figure shows the representation of F letter in ASL.

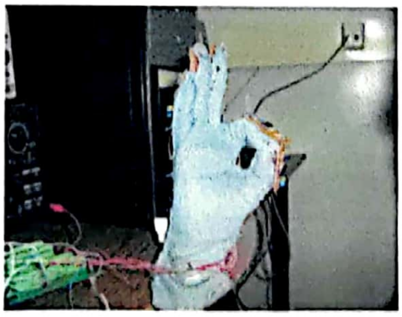

Figure 6.18: Representation of F letter in ASL.

The following figure represents the values of 20 samples for representation of G letter in ASL.

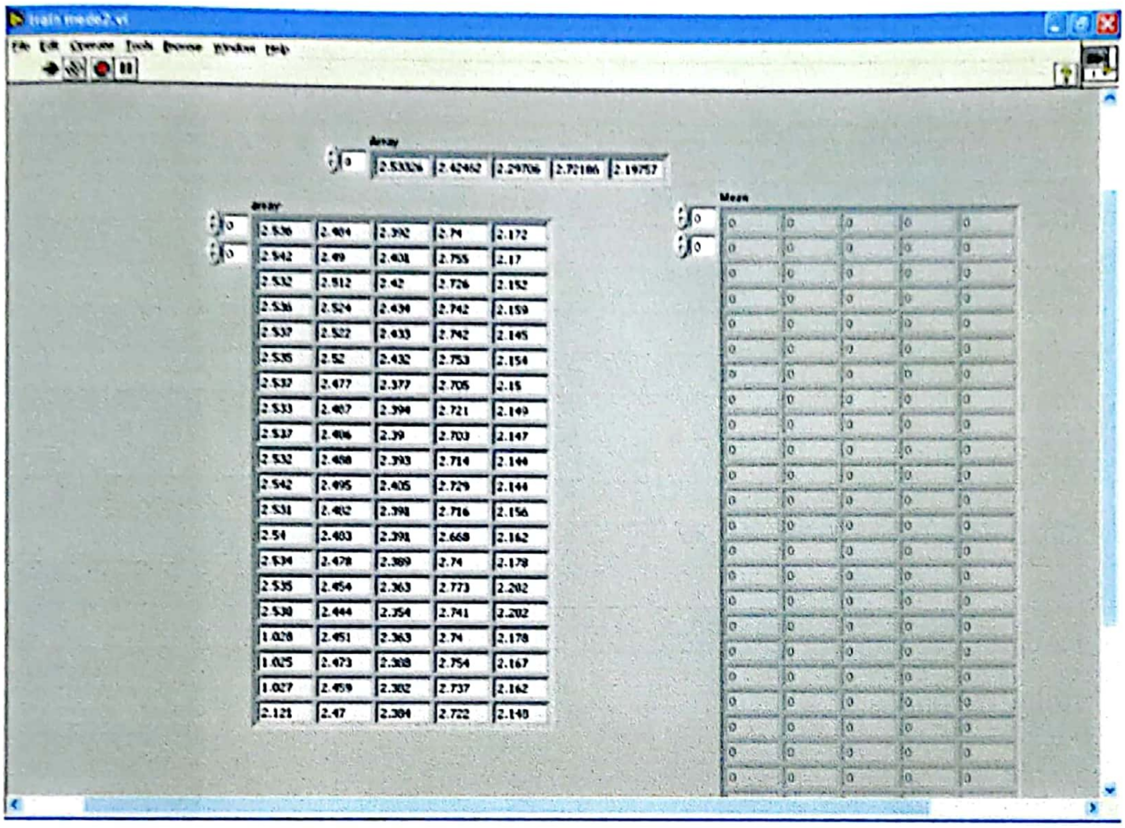

Figure 6.19: G letter train mode at PC phase.

The following figure shows the representation of G letter in ASL.

Figure 6.20: Representation of G letter in ASL.

The following figure represents the values of 20 samples for representation of H letter in ASL.

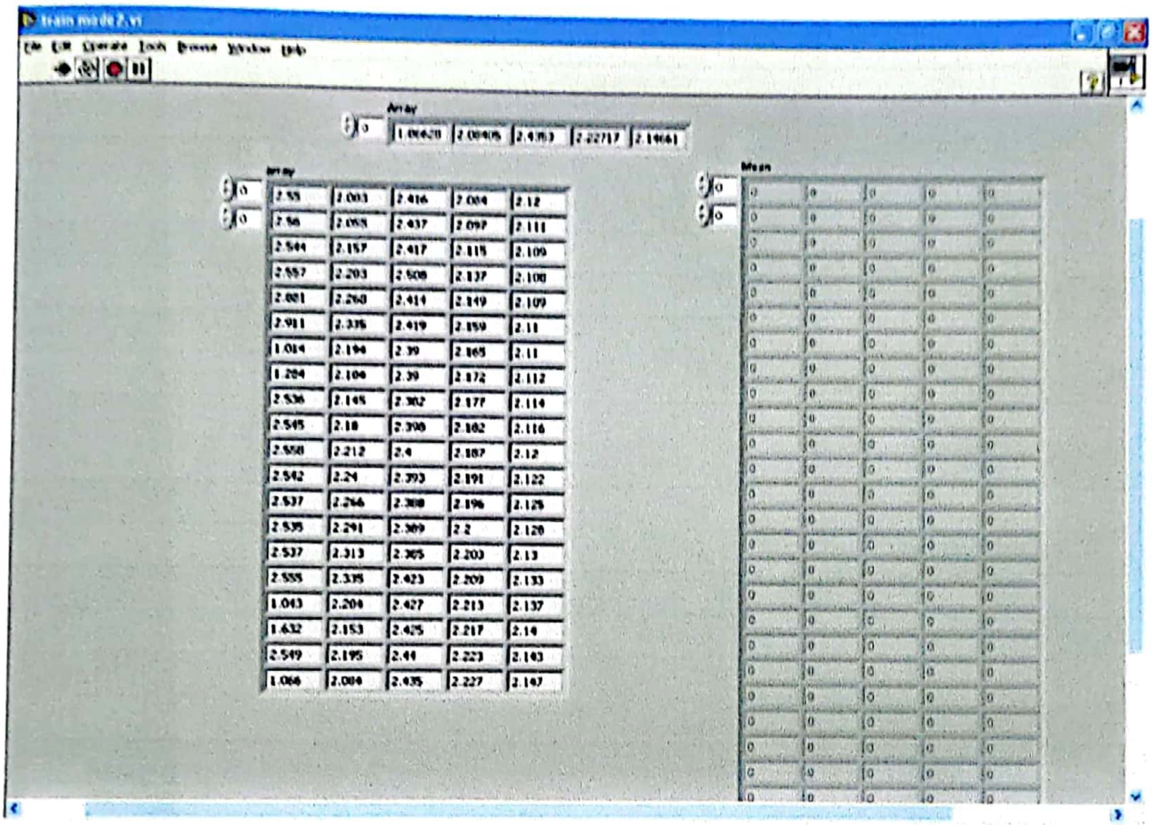

Figure 6.21: H letter train mode at PC phase.

'he following figure shows the representation of H letter in ASL.

Figure 6.22: Representation of H letter in ASL.

The following figure represents the values of 20 samples for representation of I letter in ASL.

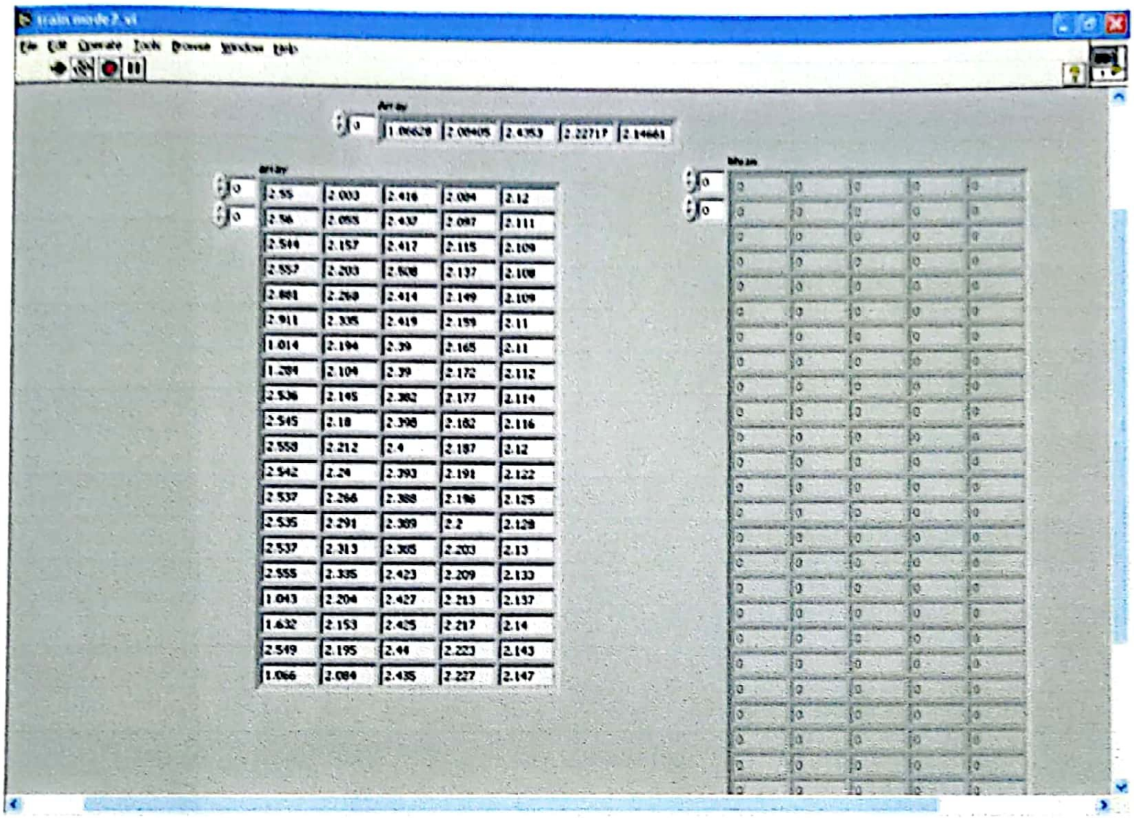

Figure 6.23: I letter train mode at PC phase.

'he following figure shows the representation of I letter in ASL.

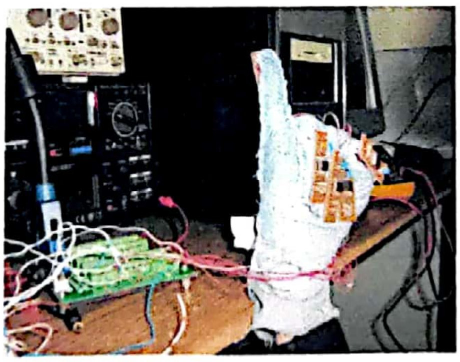

Figure 6.24: Representation of I letter in ASL.

The following figure represents the values of 20 samples for representation of J letter in ASL.

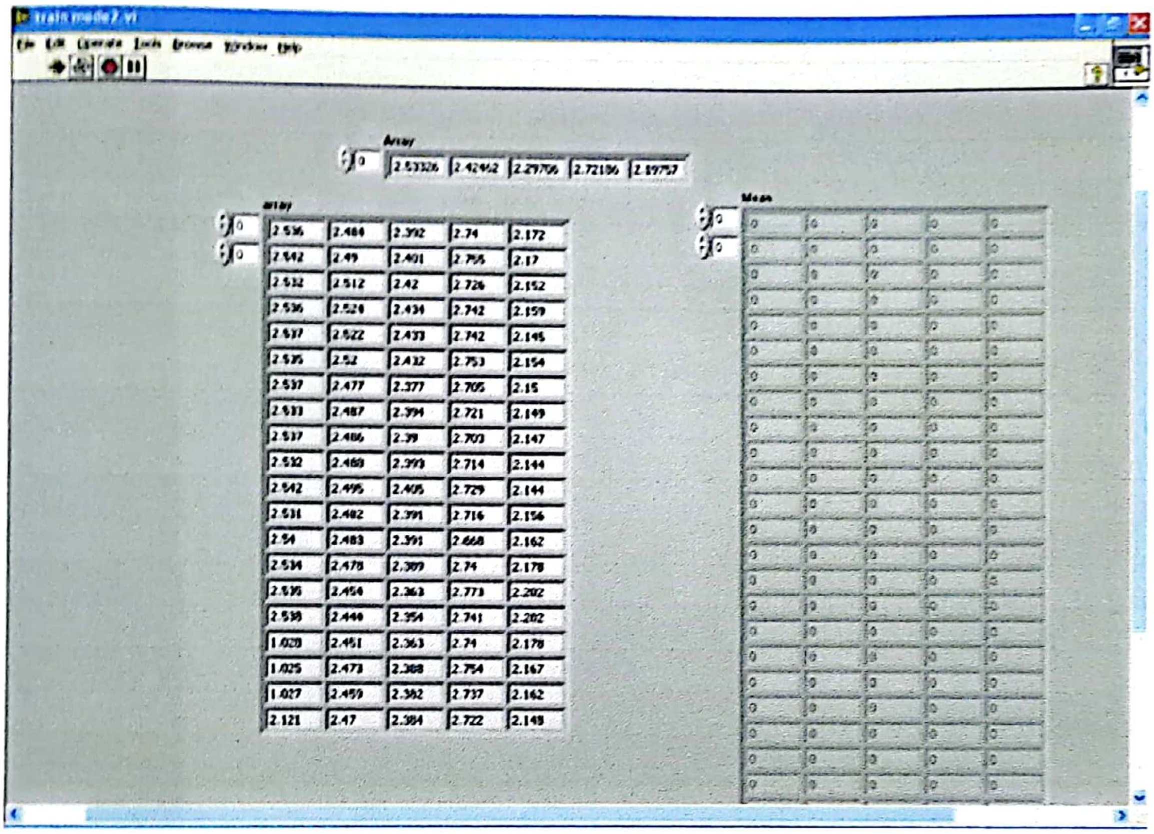

Figure 6.25: J letter train mode at PC phase.

'he following figure shows the representation of J letter in ASL.

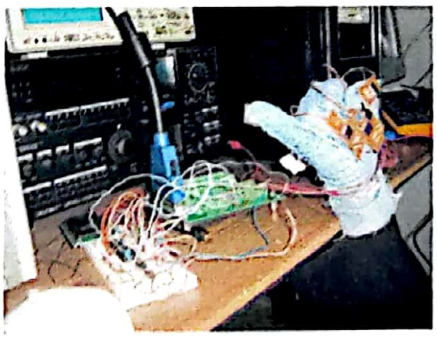

Figure 6.26: Representation of J letter in ASL.

The following figure represents the values of 20 samples for representation of K letter in ASL.

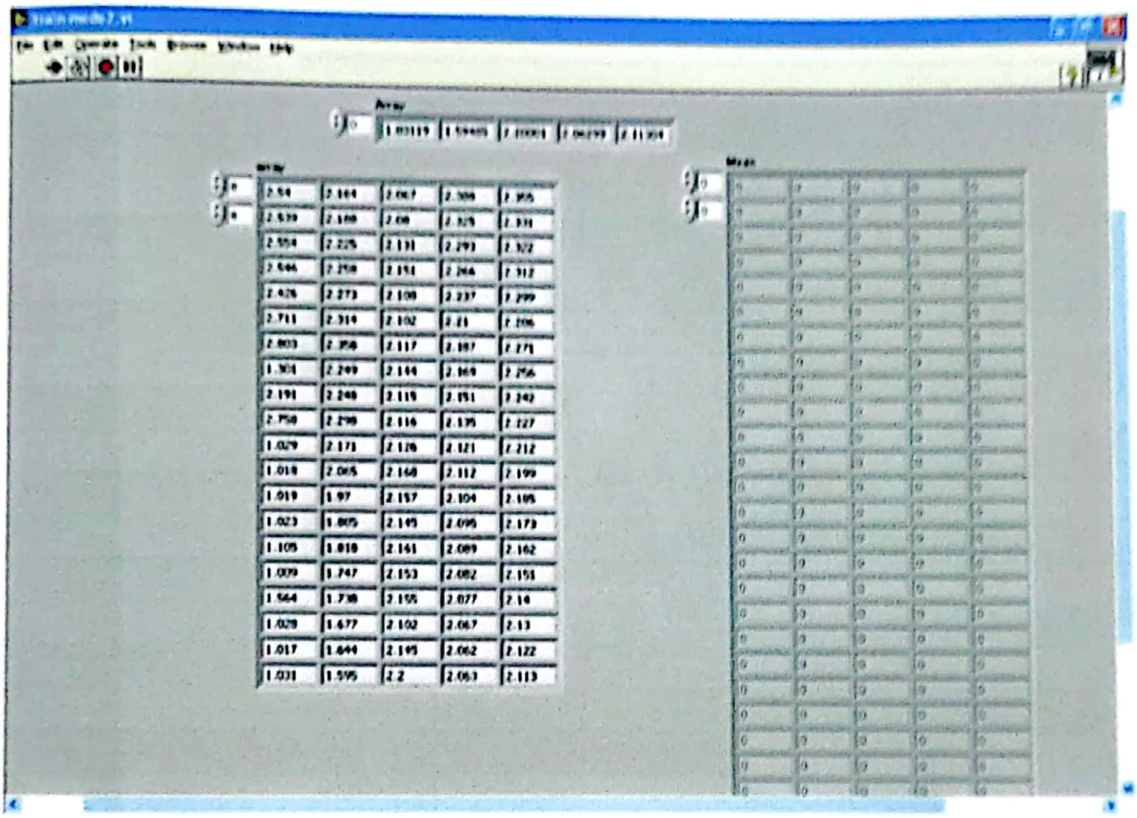

Figure 6. 27: K letter train mode at PC phase.

The following figure shows the representation of K letter in ASL.

Figure 6.28: Representation of K letter in ASL.

The following figure represents the values of 20 samples for representation of L letter in ASL.

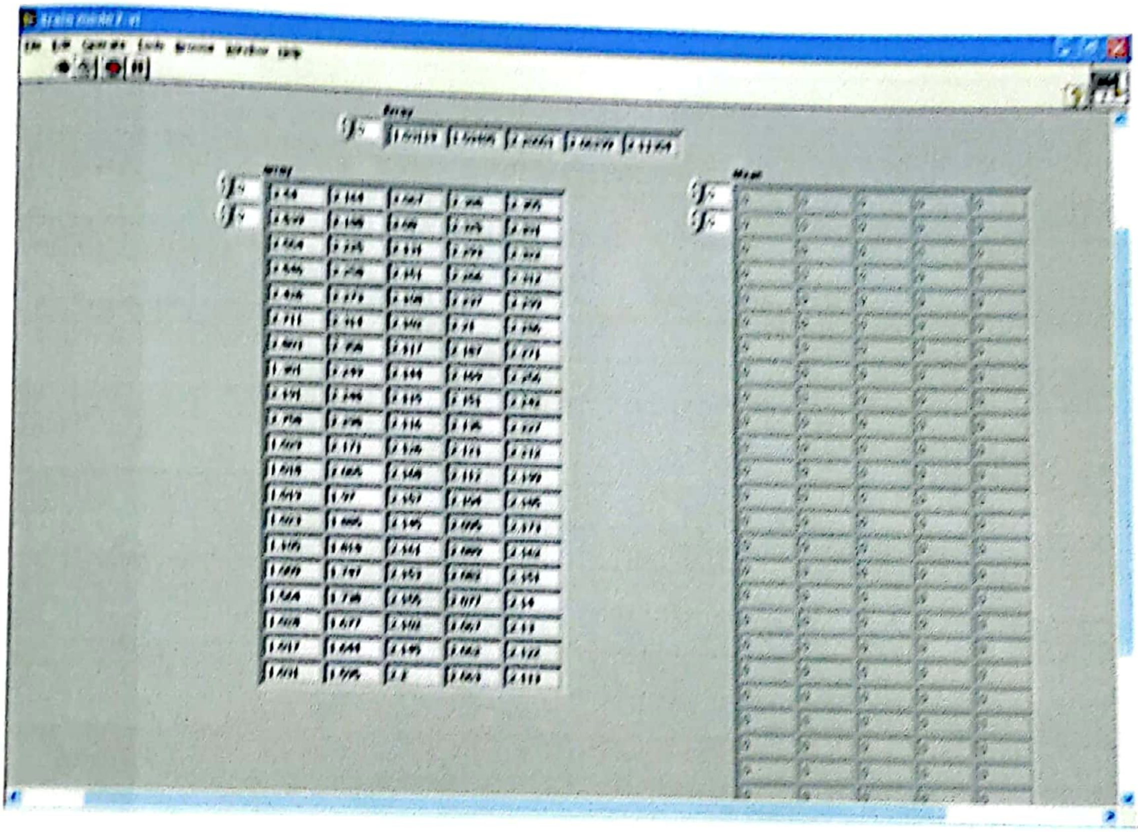

Figure 6.29: L letter train mode at PC phase.

The following figure shows the representation of L letter in ASL.

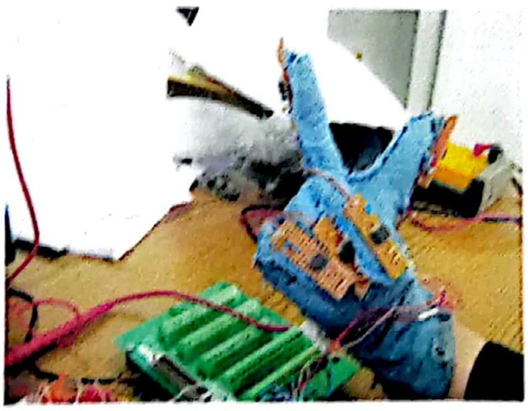

Figure 6.30: Representation of L letter in ASL.

The following figure represents the values of 20 samples for representation of M letter in ASL.

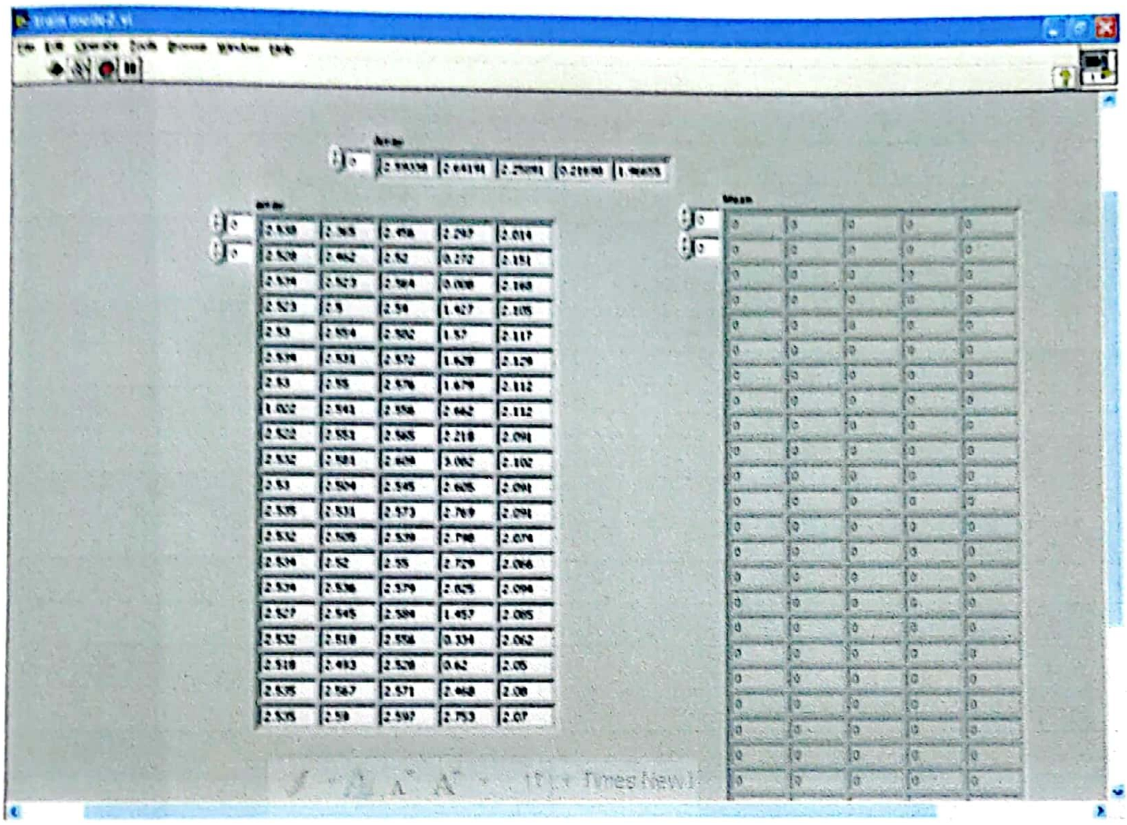

Figure 6.31: M letter train mode at PC phase.

'he following figure shows the representation of M letter in ASL.

Figure 6.32: Representation of M letter in ASL

The following figure represents the values of 20 samples for representation of O letter in ASL.

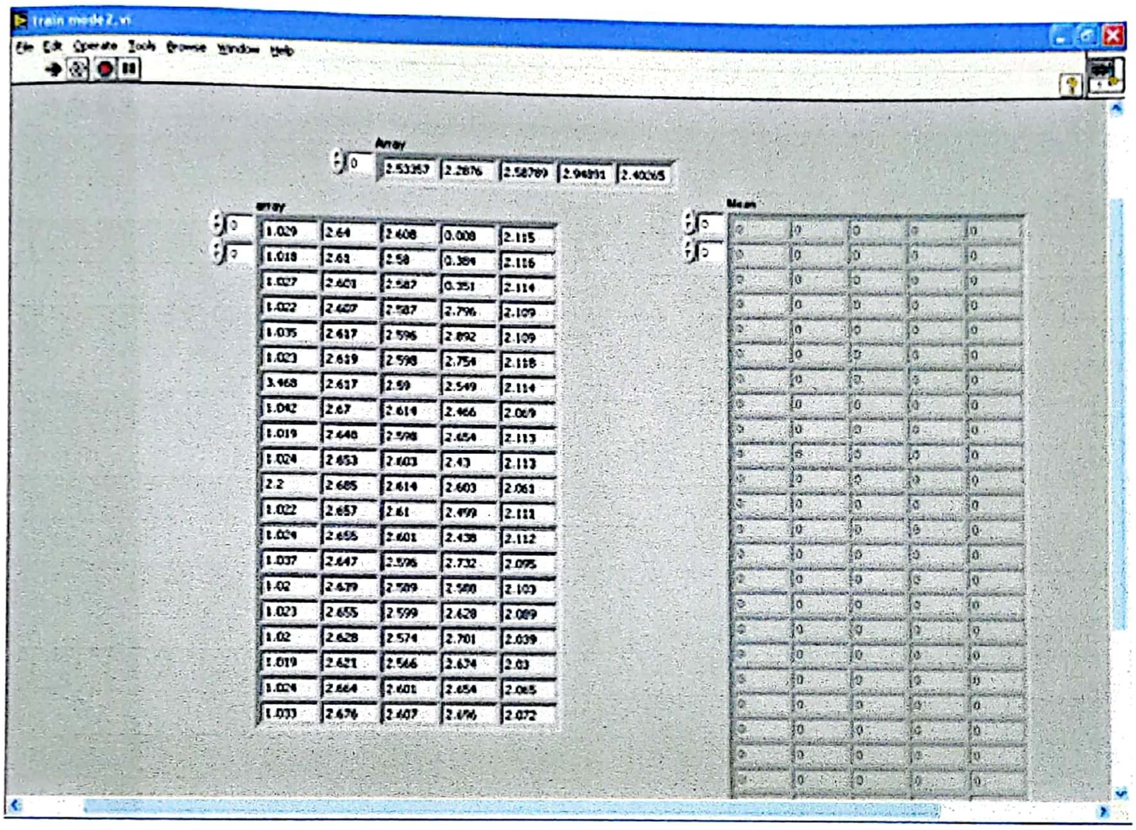

Figure 6.35: O letter train mode at PC phase.

The following figure shows the representation of O letter in ASL.

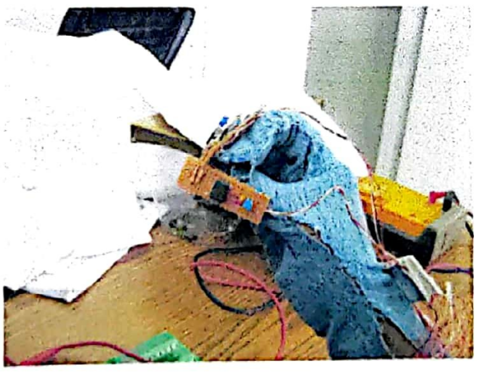

Figure 6.36: Representation of letter O in ASL

The following figure represents the values of 20 samples for representation of P letter in ASL.

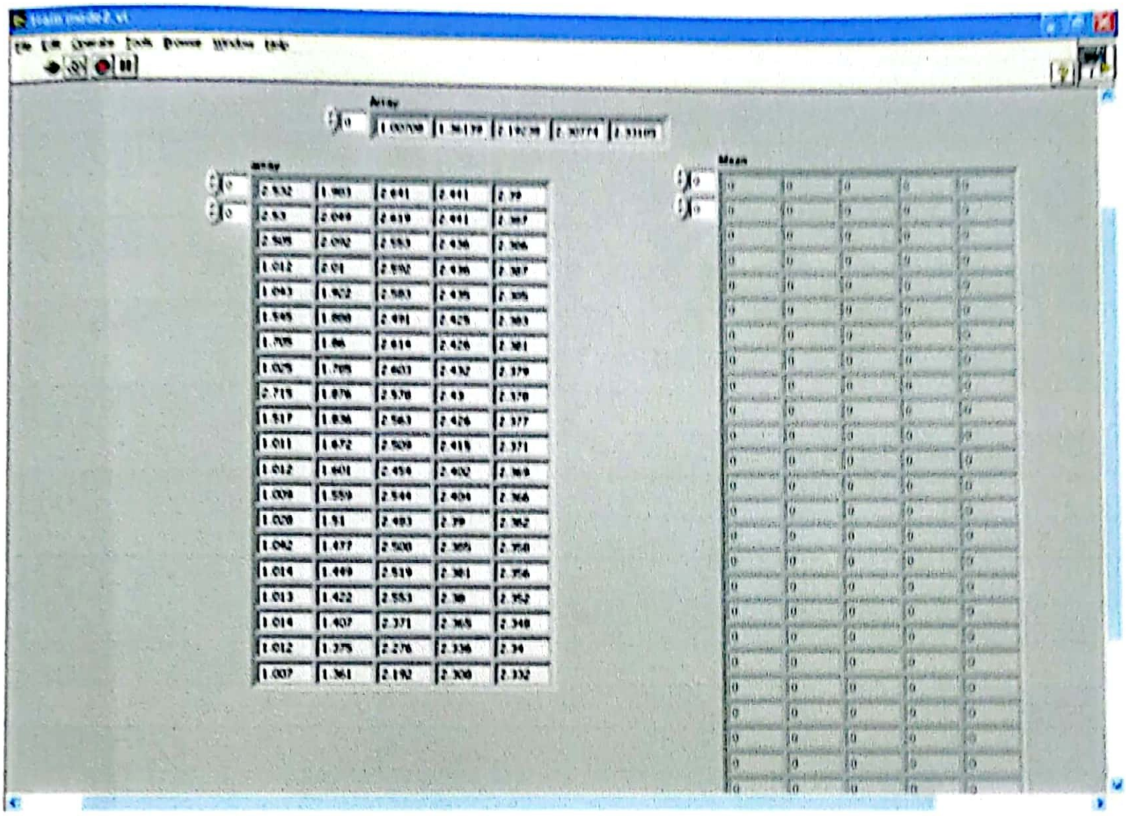

Figure 6.37: P letter train mode at PC phase.

The following figure shows the representation of P letter in ASL.

Figure 6.38: Representation of letter P in ASL

The following figure represents the values of 20 samples for representation of R letter in ASL.

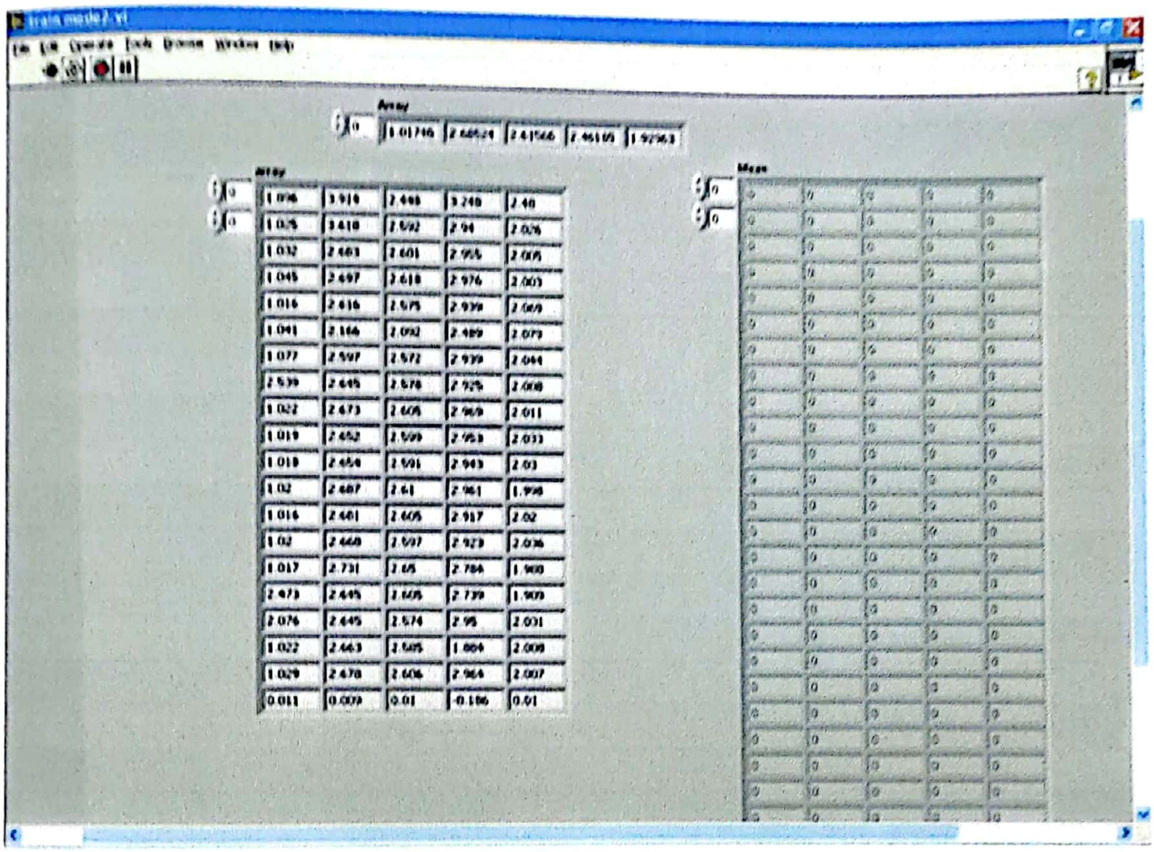

Figure 6.41: R letter train mode at PC phase.

The following figure shows the representation of R letter in ASL.

Figure 6.42: Representation of letter R in ASL

The following figure represents the values of 20 samples for representation of T letter in ASL.

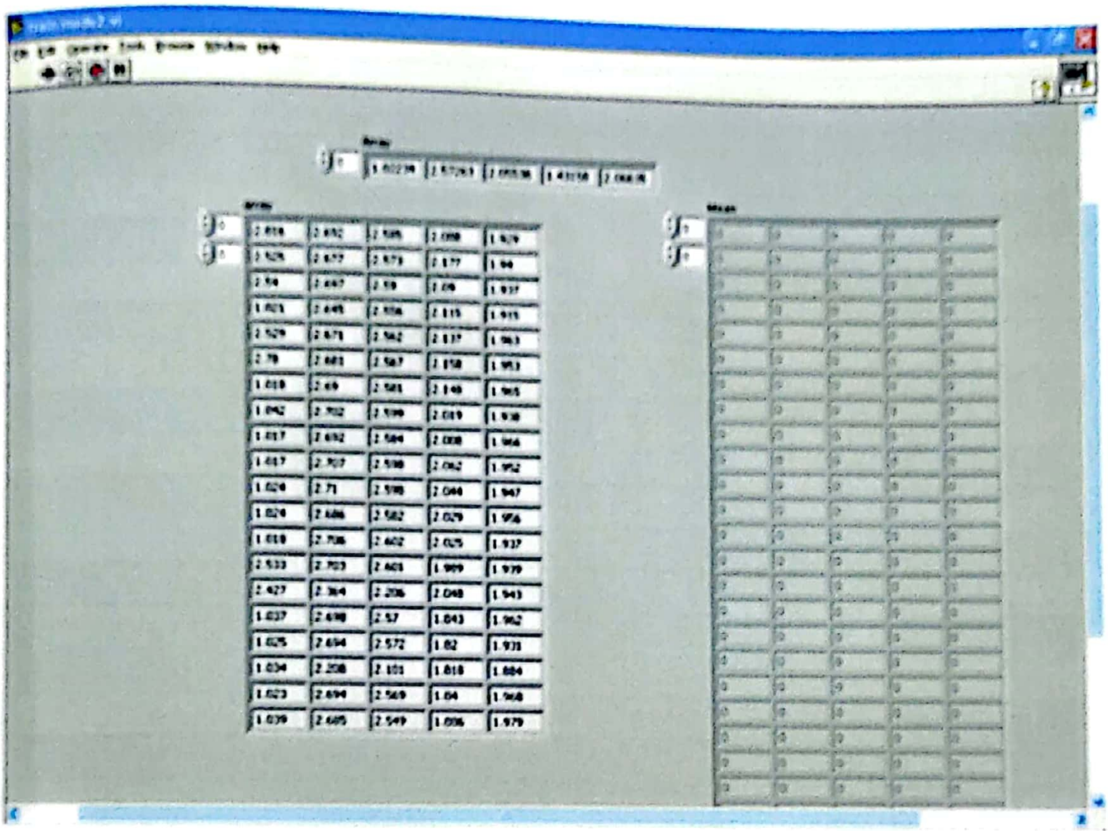

Figure 6.45: T letter train mode at PC phase.

The following figure shows the representation of T letter in ASL.

Figure 6.46: Representation of letter T in ASL

The following figure represents the values of 20 samples for representation of U letter in ASL.

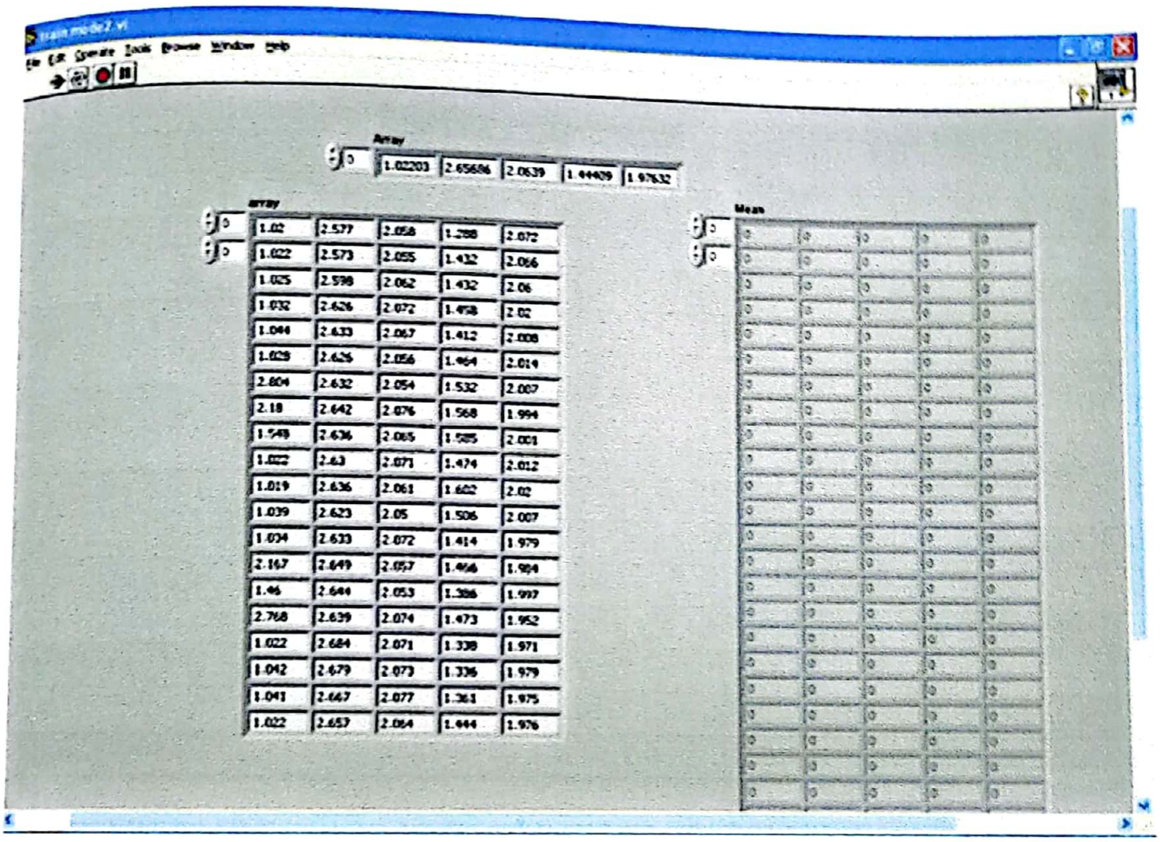

Figure 6.47: U letter train mode at PC phase.

: following figure shows the representation of U letter in ASL.

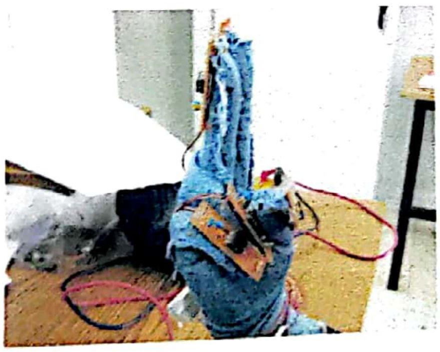

Figure 6.48: Representation of letter U in ASL

The following figure represents the values of 20 samples for representation of V ı ASL.

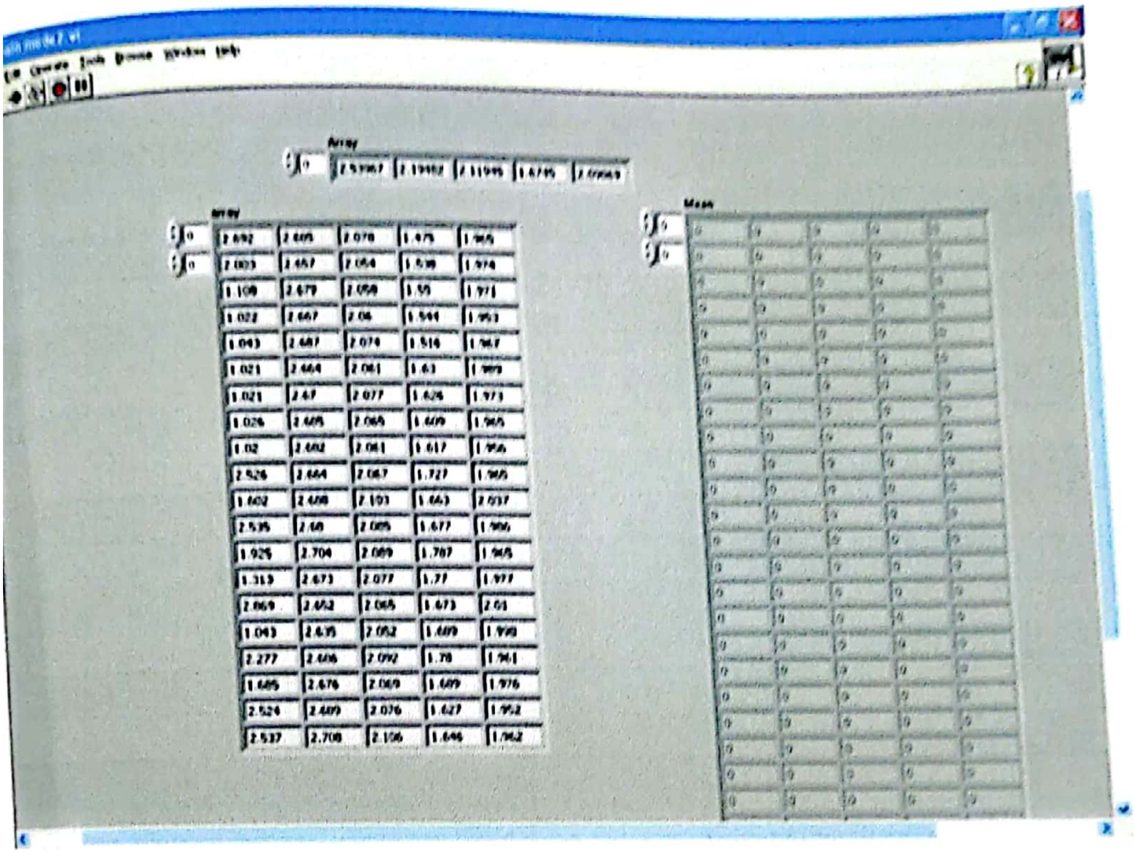

Figure 6.49: V letter train mode at PC phase.

he following figure shows the representation of V letter in ASL.

Figure 6.50: Representation of letter V in ASL

The following figure represents the values of 20 samples for representation of W letter in ASL.

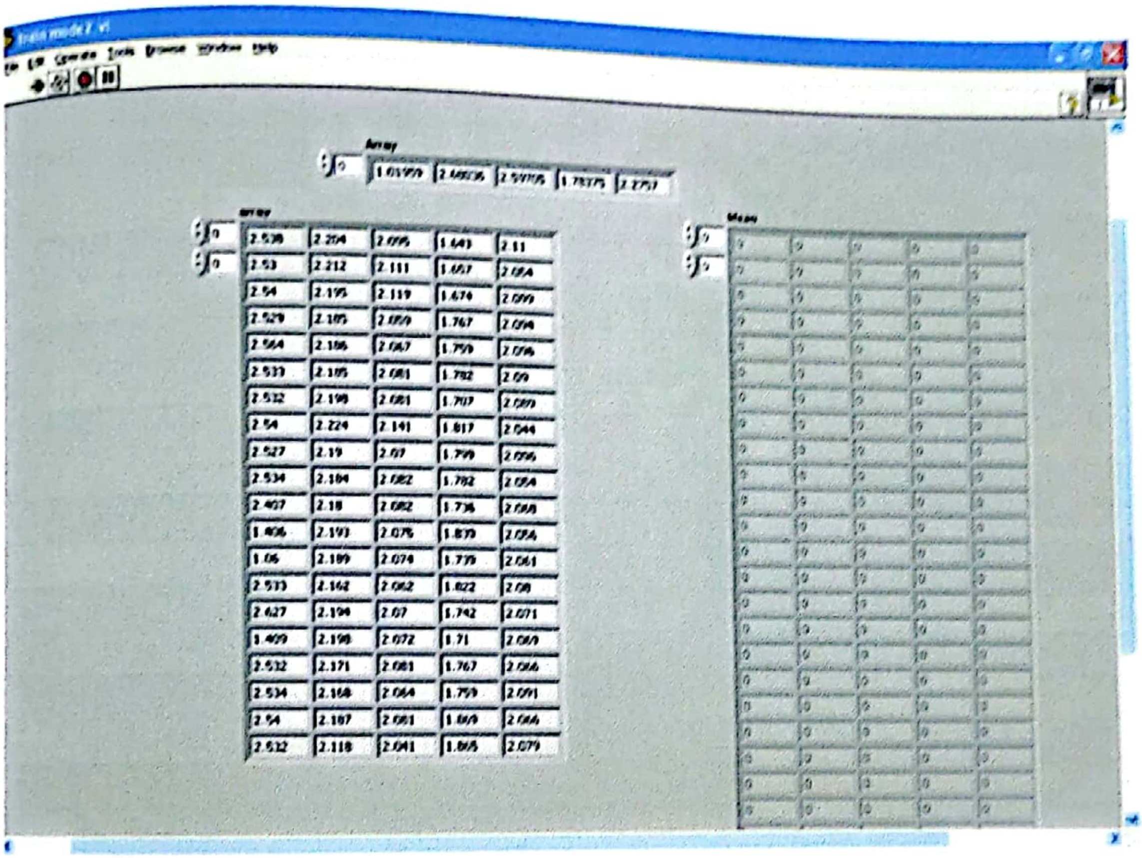

Figure 6.51: W letter train mode at PC phase.

The following figure shows the representation of W letter in ASL.

Figure 6.52: Representation of letter W in ASL

The following figure represents the values of 20 samples for representation of X letter in ASL.

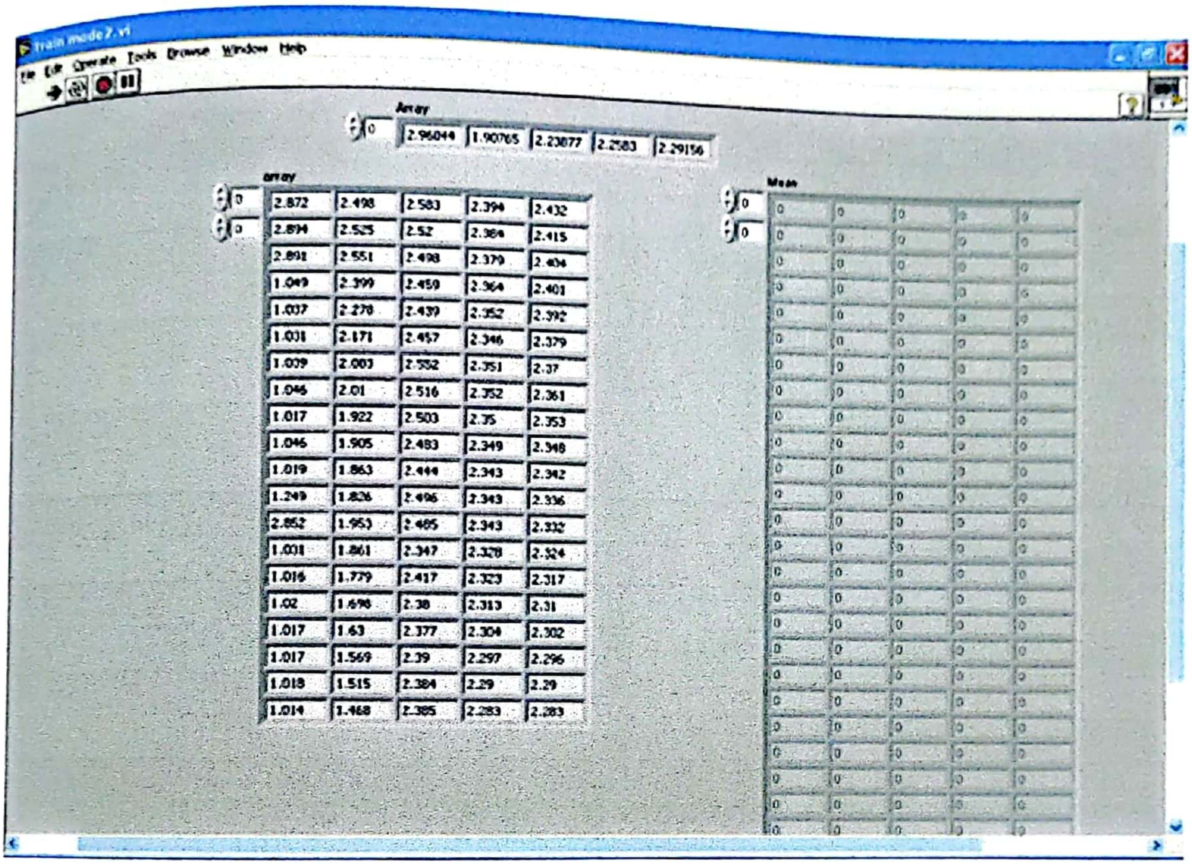

Figure 6.53: X letter train mode at PC phase.

The following figure shows the representation of X letter in ASL.

Figure 6.54: Representation of letter X in ASL

The following figure represents the values of 20 samples for representation of Y letter in ASL.

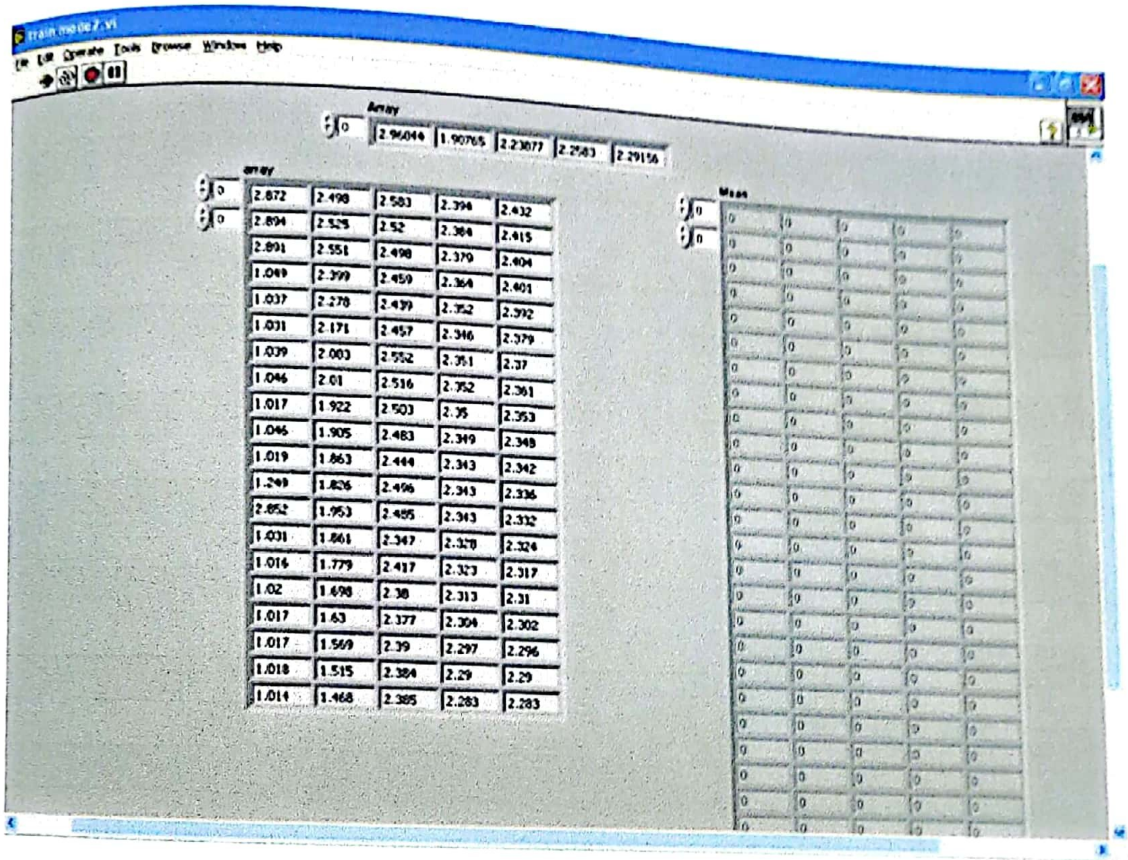

Figure 6.55: Y letter train mode at PC phase.

The following figure shows the representation of Y letter in ASL.

Figure 6.56: Representation of Y letter in ASL.

The following figure represents the values of 20 samples for representation of Z letter in ASL.

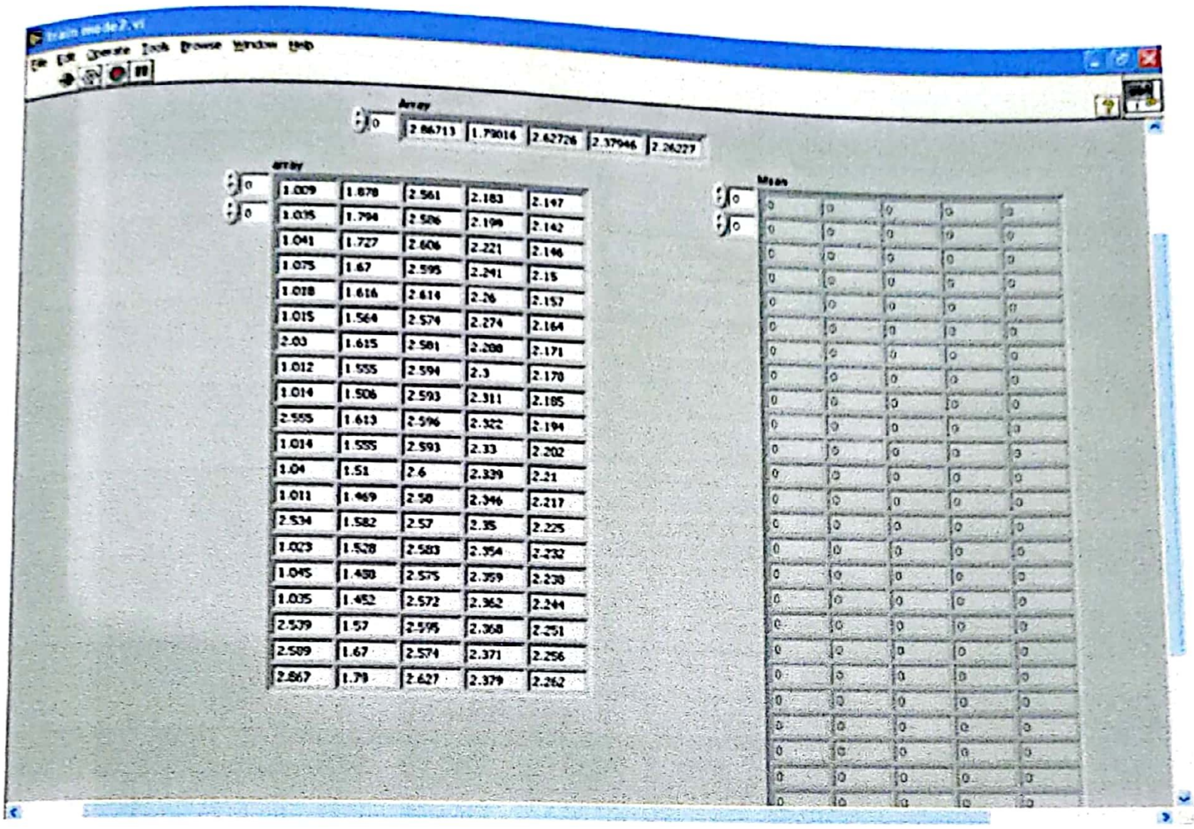

Figure 6.57: Z letter train mode at PC phase.

The following figure shows the representation of Z letter in ASL.

Figure 6.58: Representation of letter Z in ASL

...ay[26][5] which is shown below:

2.4459	2.6866	2.57955	2.93905	1.88685
2.41885	2.11345	2.0359	2.41275	1.9606
2.45195	2.3901	2.39135	2.67875	2.0656
2.4144	2.5141	2.42895	2.4276	1.95315
2.43955	2.47165	2.4384	2.8213	2.11445
2.58205	2.198	2.1276	2.53565	1.97155
2.4517	2.4902	2.39375	2.5915	2.067
2.41115	2.45335	2.23915	2.59835	2.12775
2.4292	2.68045	2.59145	2.9275	1.9798
2.4502	2.55015	2.47965	2.81405	2.24485
2.41145	2.63505	2.112	2.4098	1.8946
2.4246	2.6878	2.5908	2.42215	1.9003
2.4884	2.55505	2.5541	2.8784	2.07025
2.51845	2.662	2.5366	2.92965	2.05905
2.42735	2.43015	2.33595	2.7098	1.9946
2.537	2.44885	2.65175	2.76695	2.45215
2.5852	2.3282	2.27575	2.6758	2.4787
2.4661	2.6482	2.06225	2.46085	2.01085
2.4517	2.6838	2.5855	2.917	1.95645
2.47825	2.6685	2.5746	2.82895	1.86825
2.4754	2.66815	2.05315	2.4152	2.02605
2.4963	2.5478	2.0659	2.4353	1.9637
2.49155	2.1272	2.03825	2.4259	2.07045
2.42995	2.64965	2.55155	2.6318	2.2821
2.4848	2.68175	2.58825	2.9234	1.86935
2.4086	2.66585	2.5768	2.44525	2.0743

6.3.4 PC test mode

After the train mode was done the designer test the system, and the system was able to recognize to all the letters.

This section contains the results of the test mode for all letters.

The following figure shows the A letter after it was tested successfully on the PC phase.

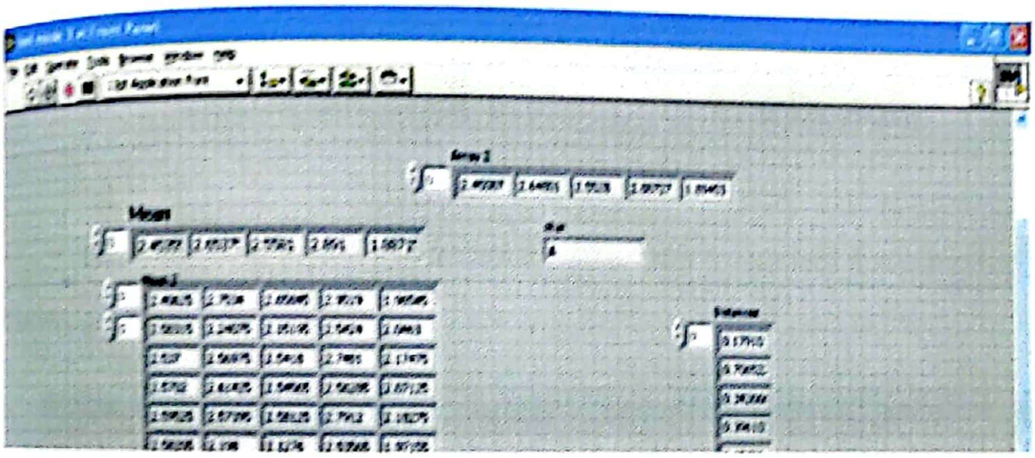

Figure 6.60: A letter test mode at PC phase.

The following figure shows the B letter after it was tested successfully on the PC phase.

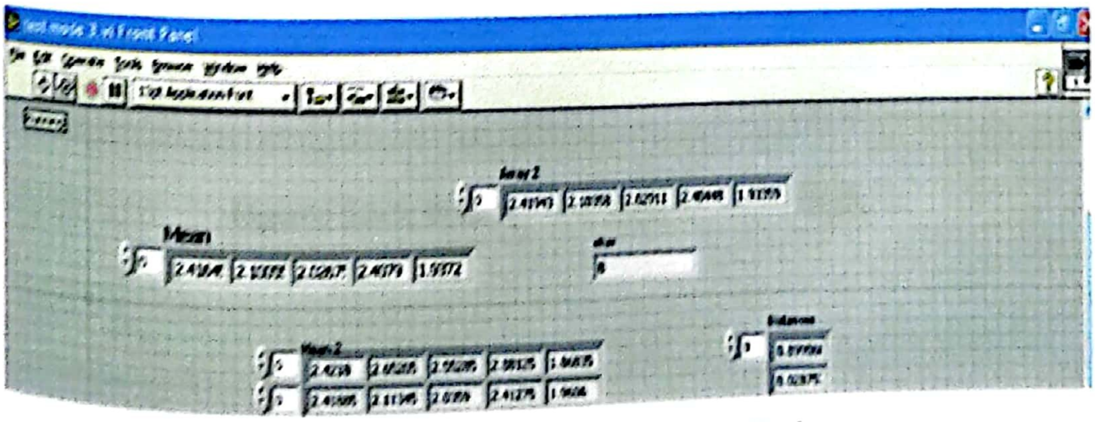

Figure 6.61: B letter test mode at PC phase.

The following figure shows the C letter after it was tested successfully on the PC phase.

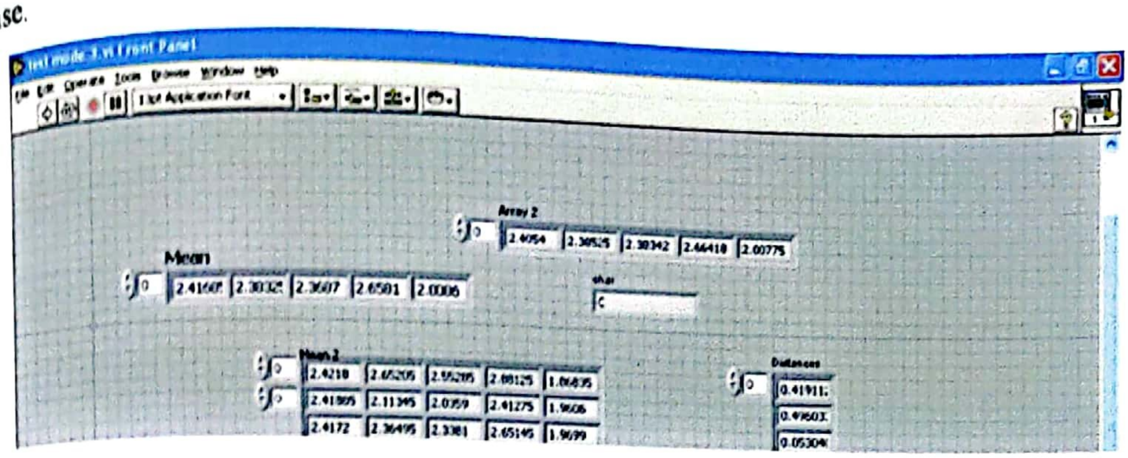

Figure 6.62: C letter test mode at PC phase.

The following figure shows the D letter after it was tested successfully on the PC phase.

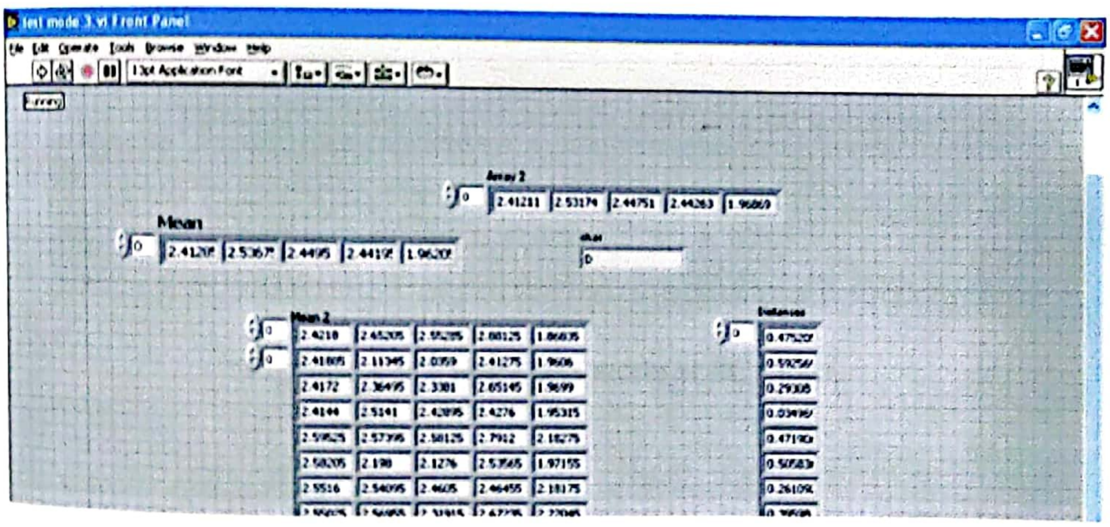

Figure 6.63: D letter test mode at PC phase.

The following figure shows the E letter after it was tested successfully on the PC phase.

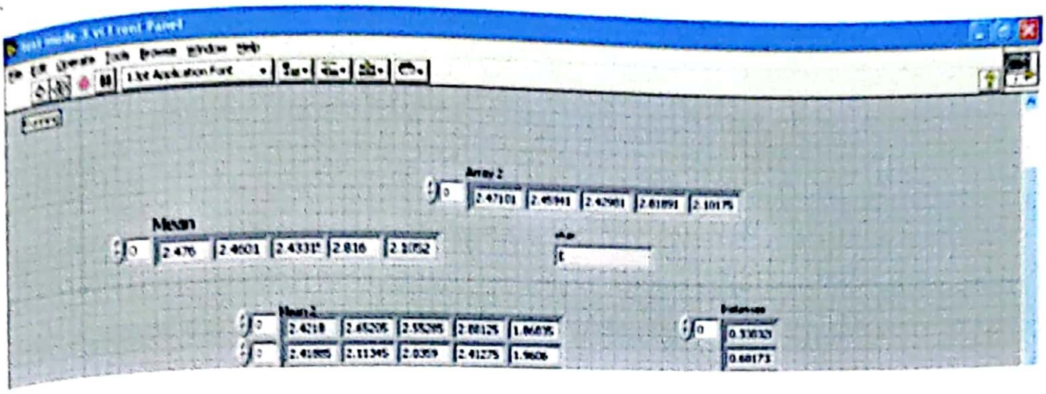

Figure 6.64: E letter test mode at PC phase.

The following figure shows the F letter after it was tested successfully on the PC phase.

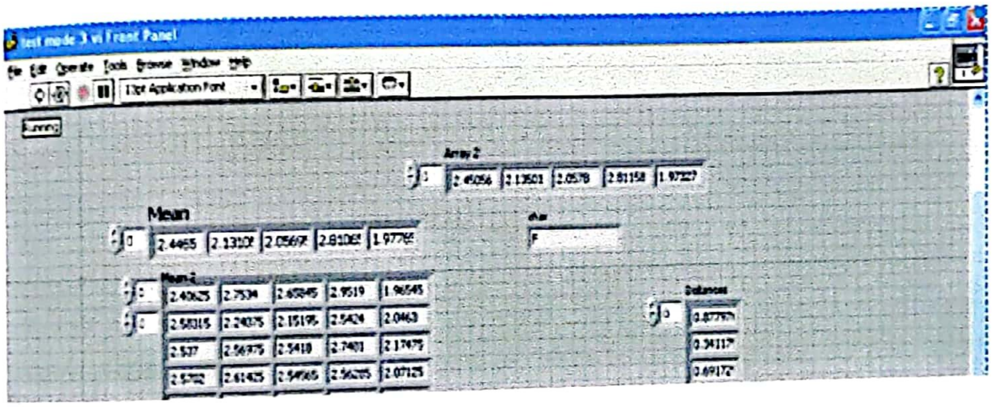

Figure 6.65: F letter test mode at PC phase.

The following figure shows the G letter after it was tested successfully on the PC phase.

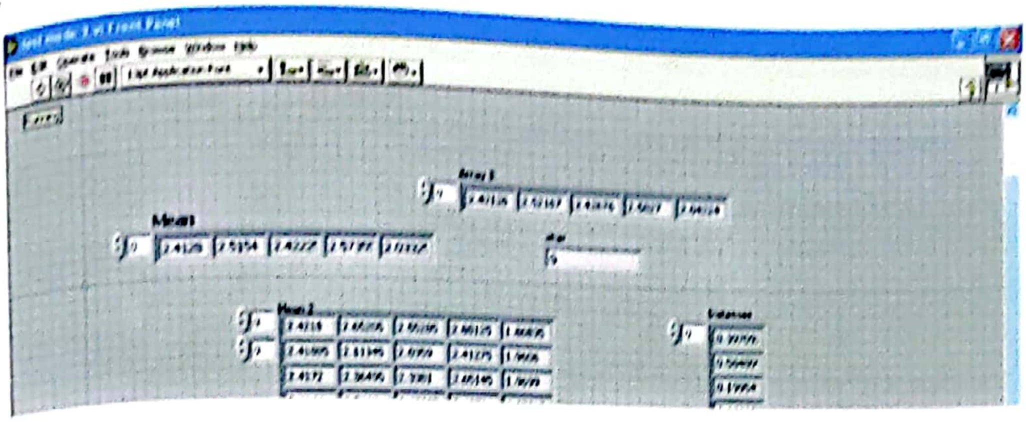

Figure 6.66: G letter test mode at PC phase.

The following figure shows the H letter after it was tested successfully on the PC phase.

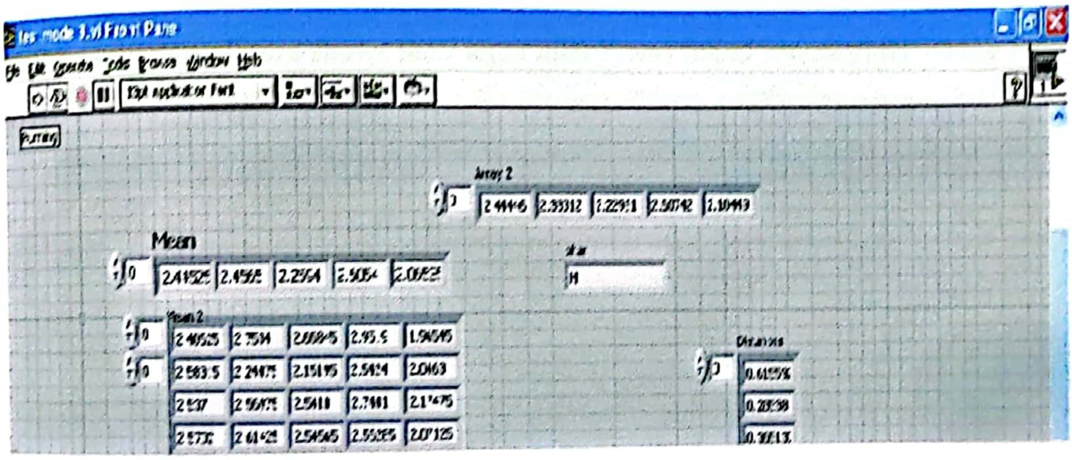

Figure 6.67: H letter test mode at PC phase.

The following figure shows the I letter after it was tested successfully on the PC se.

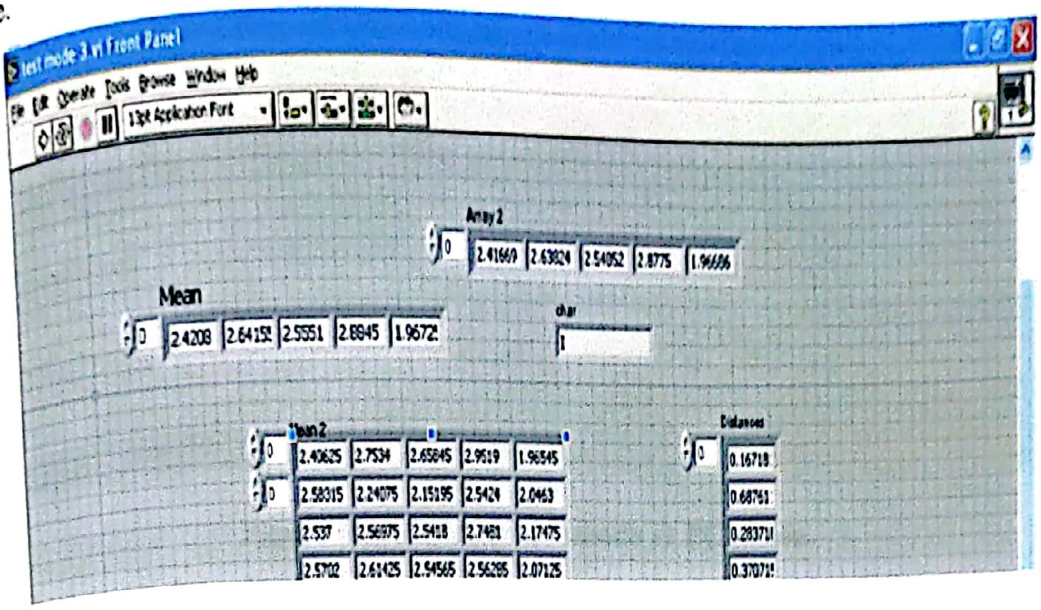

Figure 6.68: I letter test mode at PC phase.

The following figure shows the J letter after it was tested successfully on the PC phase.

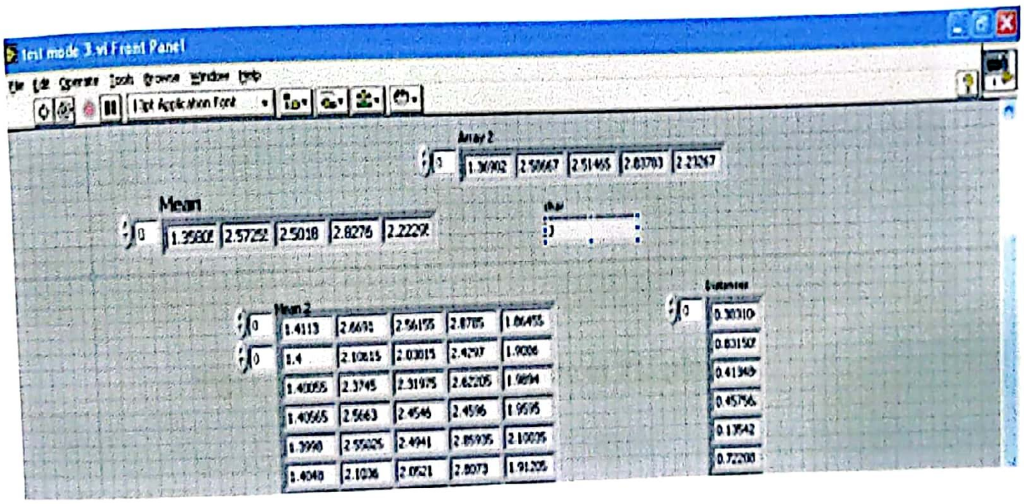

Figure 6.69: J letter test mode at PC phase.

The following figure shows the K letter after it was tested successfully on the PC phase.

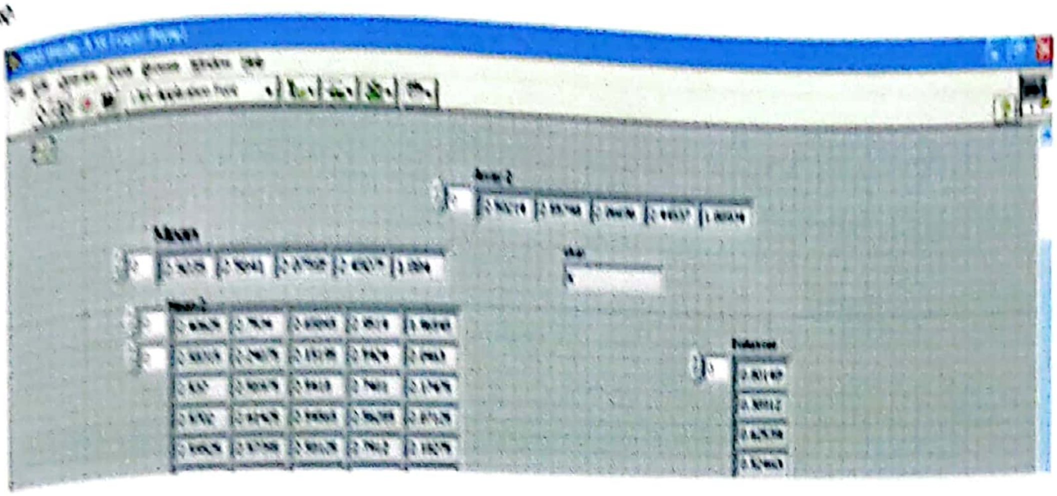

Figure 6.70: K letter test mode at PC phase.

The following figure shows the L letter after it was tested successfully on the PC phase.

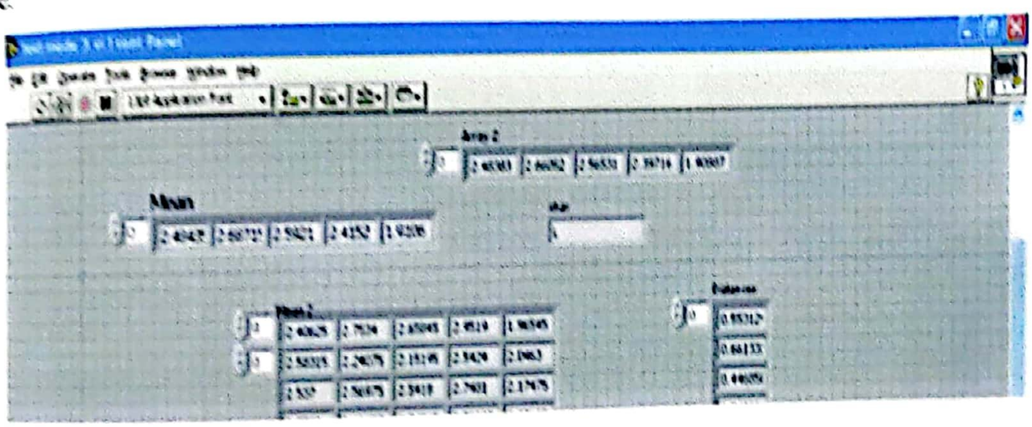

Figure 6.71: L letter test mode at PC phase.

The following figure shows the M letter after it was tested successfully on the PC

se.

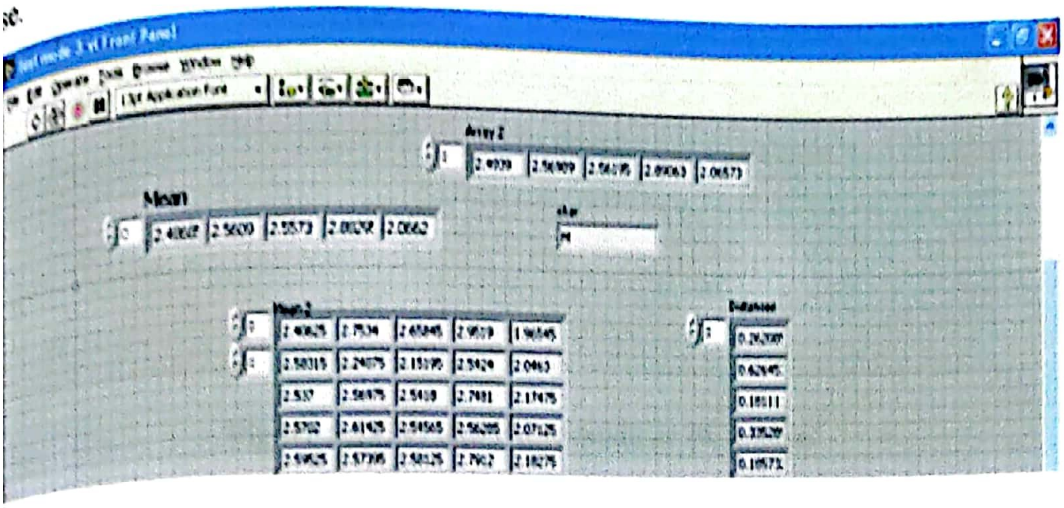

Figure 6.72: M letter test mode at PC phase.

The following figure shows the N letter after it was tested successfully on the PC

se.

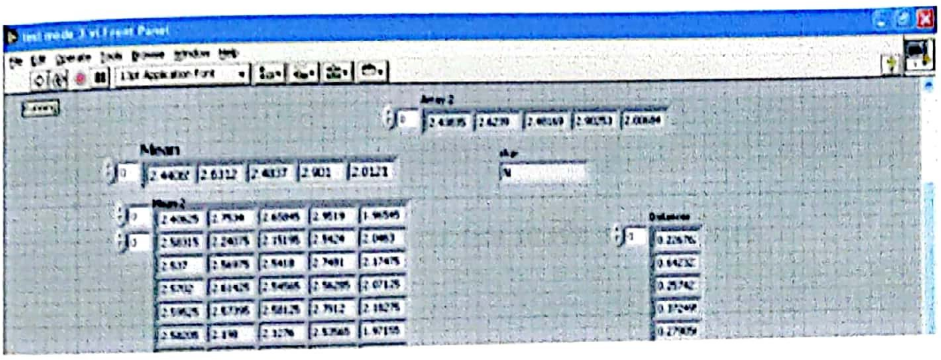

Figure 6.73: N letter test mode at PC phase.

The following figure shows the O letter after it was tested successfully on the PC phase.

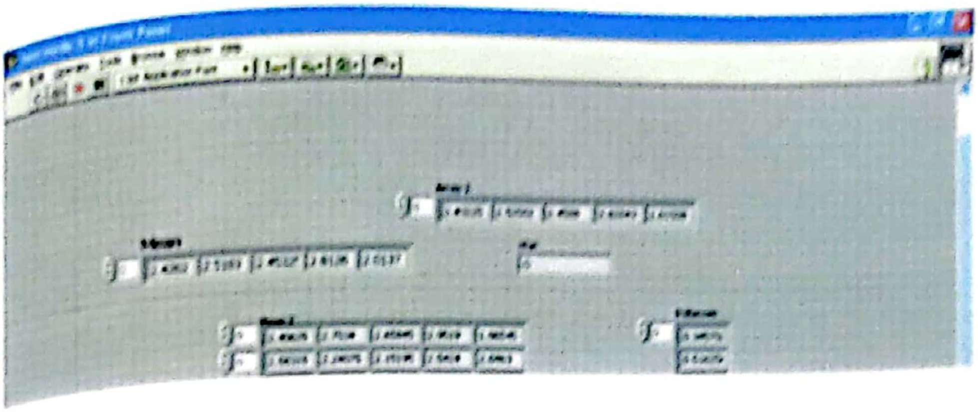

Figure 6.74: O letter test mode at PC phase.

The following figure shows the P letter after it was tested successfully on the PC phase.

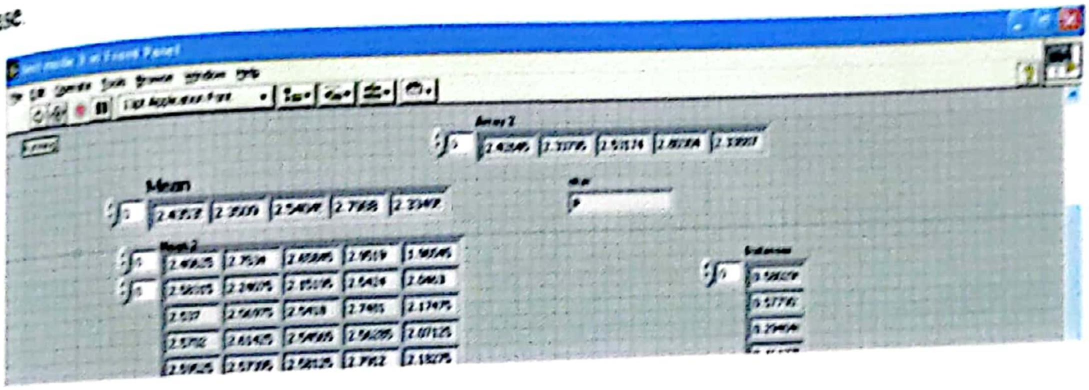

Figure 6.75: P letter test mode at PC phase.

The following figure shows the Q letter after it was tested successfully on the PC phase.

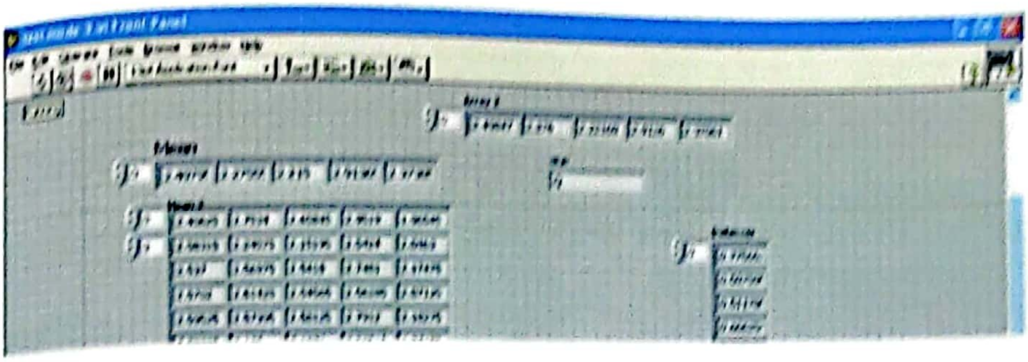

Figure 6.76: Q letter test mode at PC phase.

The following figure shows the R letter after it was tested successfully on the PC phase.

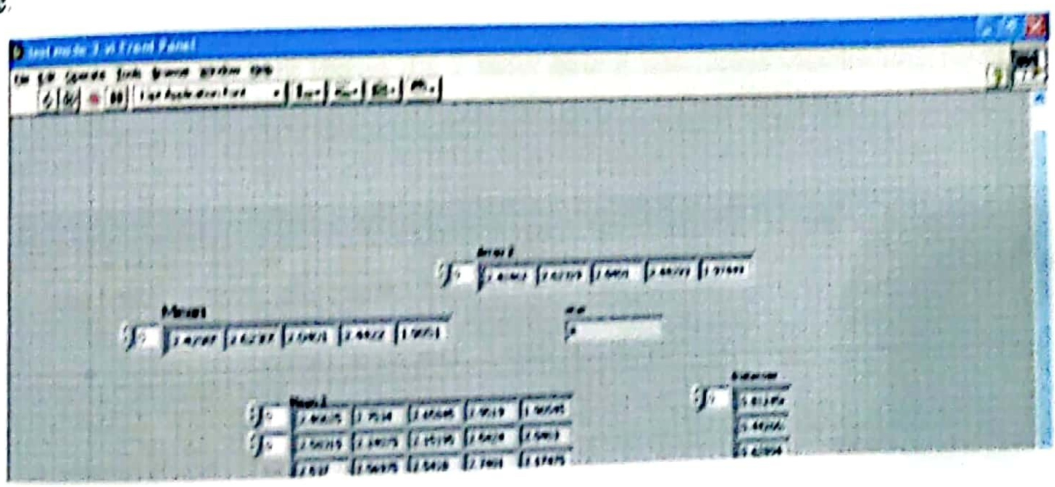

Figure 6.77: R letter test mode at PC phase.

The following figure shows the U letter after it was tested successfully on the PC phase.

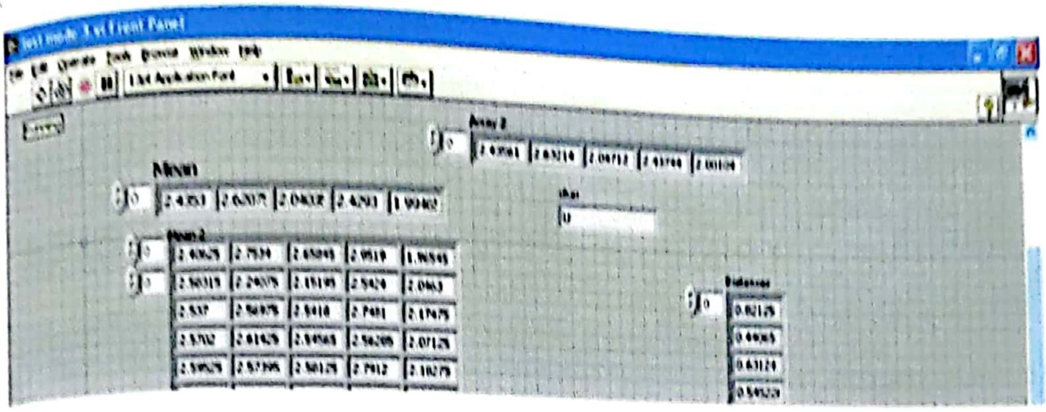

Figure 6.80: U letter test mode at PC phase.

The following figure shows the V letter after it was tested successfully on the PC phase.

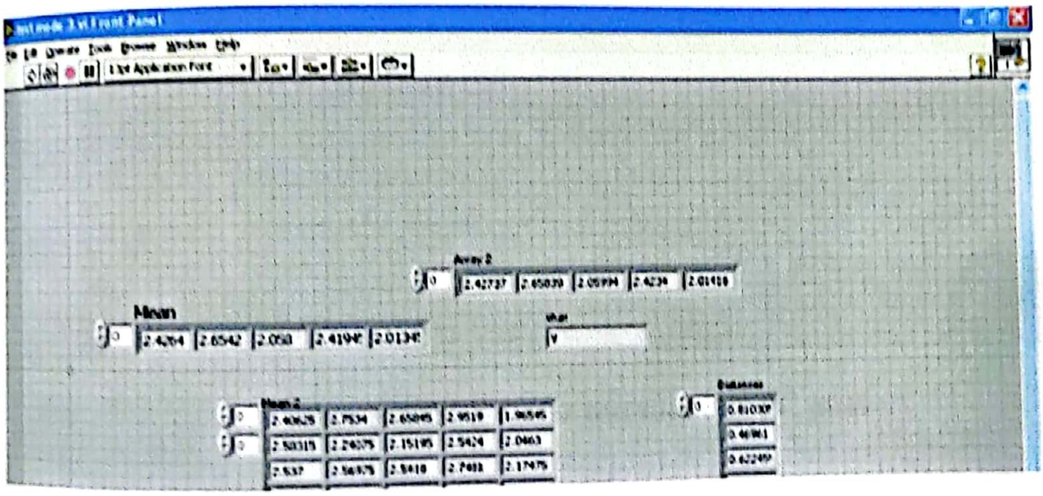

Figure 6.81: V letter test mode at PC phase.

The following figure shows the W letter after it was tested successfully on the PC phase.

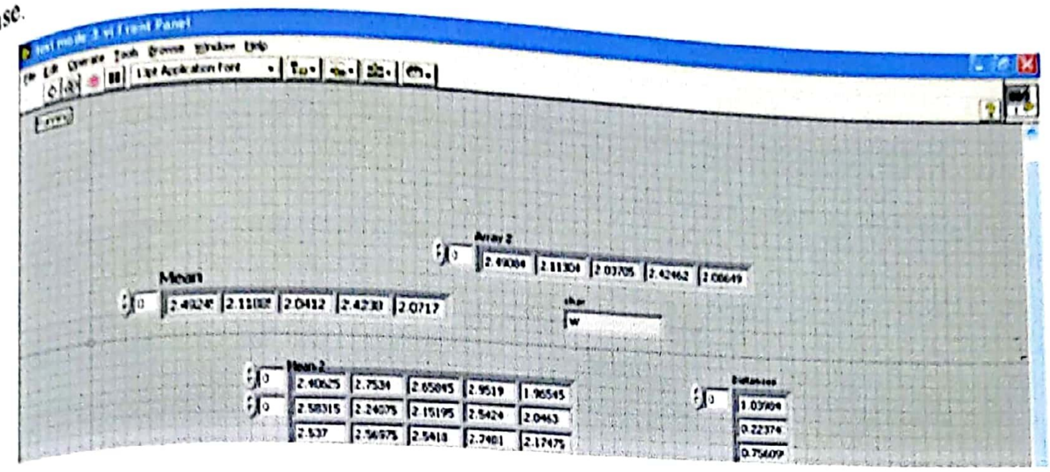

Figure 6.82: W letter test mode at PC phase.

The following figure shows the X letter after it was tested successfully on the PC phase.

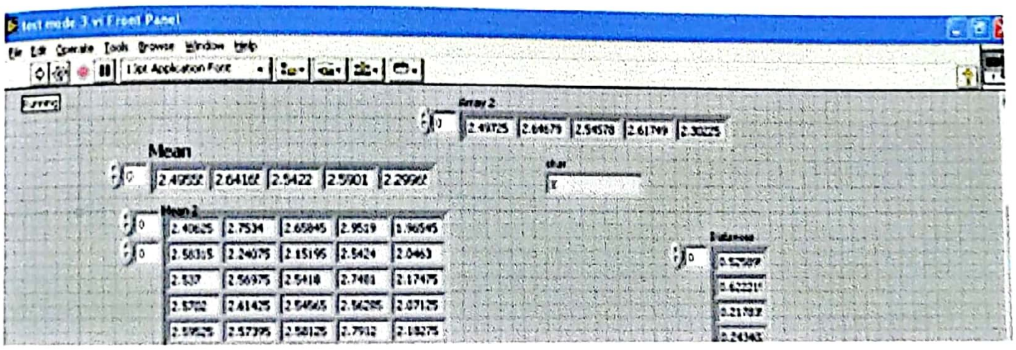

Figure 6.83: X letter test mode at PC phase.

The following figure shows the Y letter after it was tested successfully on the PC phase.

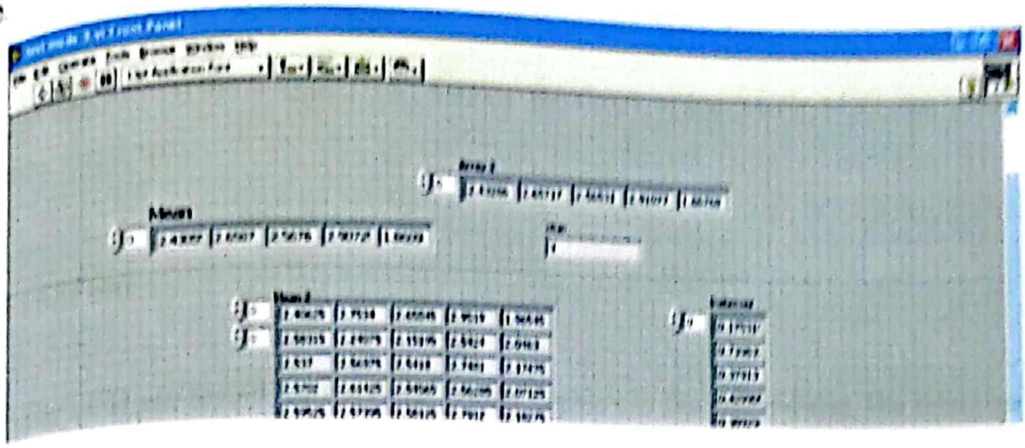

Figure 6.84: Y letter test mode at PC phase.

The following figure shows the Z letter after it was tested successfully on the PC phase.

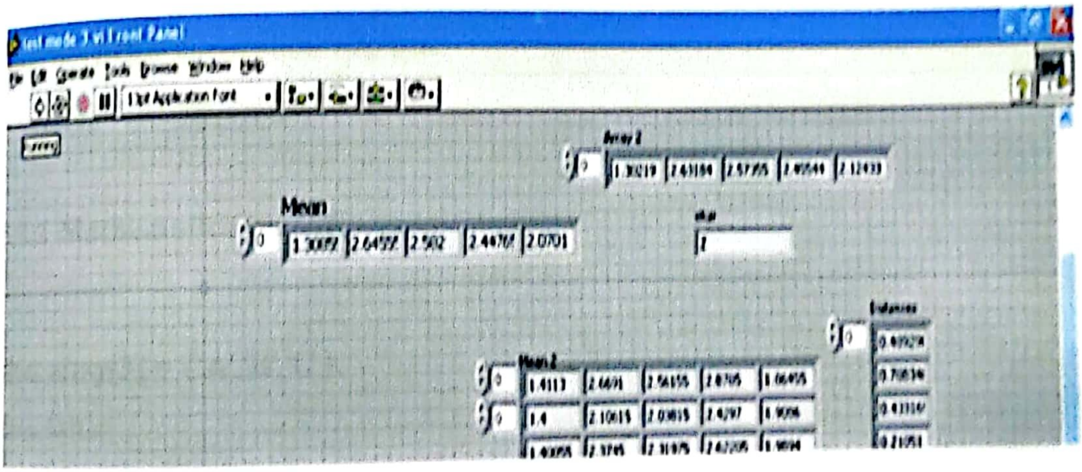

Figure 6.85: Z letter test mode at PC phase.

6.3.5 PIC phase

In this section the designer will display the result of test LCD, ADC, the whole system.

6.3.5.1 LCD test

The LCD are tested for the code which appears in the appendices, the designer stored 3 letters in array of char, he supposed values for voltage for the five fingers and stored them in array[3][5] ,and he stored values as constant in thumb, index, middle, ring, pinky variables instead of reading these values from sensors.

The designer made calculations using nearest neighbor algorithm and he expected that the LCD will display A , and after he tested the LCD, it displayed A, so the code was true and the LCD connection was true.

6.3.5.1.1 Mathematical proof

```
char array[3] = {'A','B','C'};
char letter;
float sign_values[3][5];
sign_values[3][5]={{1.1,1.2,1.3,1.4.1.44},{1.1,1.3,1.4,1.44,1.5},{1.2,1.35,1.5,1.45,
2.5}};

float thumb=1.12;
float index= 1.3;
float middle=1.1;
```

```
float ring=1.6;
float pinky=1.5;

float distance[3];
```

Note: the values which stores in 2 dimension array are stored in alphabetical order, this means that the first row is for A letter, the second for B and so on.

Steps of the nearest neighbor algorithm:

- Calculate the distance between the first point(thumb, index , middle, ring, pinky) and the rows of the 2 dimension array.

```
For(i=0;i<3;i++)
D=sqrt(pow(thumb-sign[i][0],2)+ pow(thumb-sign[i][1],2)+ pow(thumb-sign[i][2],2)+
pow(thumb-sign[i][3],2) + pow(Pinky-sign[i][4]),2));
```

Substitute in the above formula.

D1=(((1.12)-(1.1))^2 + (1.3-1.2)^2+(1.1-1.3)^2+(1.6-1.4)^2+(1.5-1.44)^2)^(1/2)=0.306594194.

D2 =(((1.12)-(1.1))^2 + (1.3-1.3)^2+(1.1-1.4)^2+(1.6-1.44)^2+(1.5-1.5)^2)^(1/2)=0.340587727.

D3 =(((1.12)-(1.2))^2 + (1.3-1.35)^2+(1.1-1.5)^2+(1.6-1.45)^2+(1.5-2.5)^2)^(1/2)=1.091512712

- Find the minimum value.

D1 is the minimum, so A is the nearest neighbor and the LCD must display A.

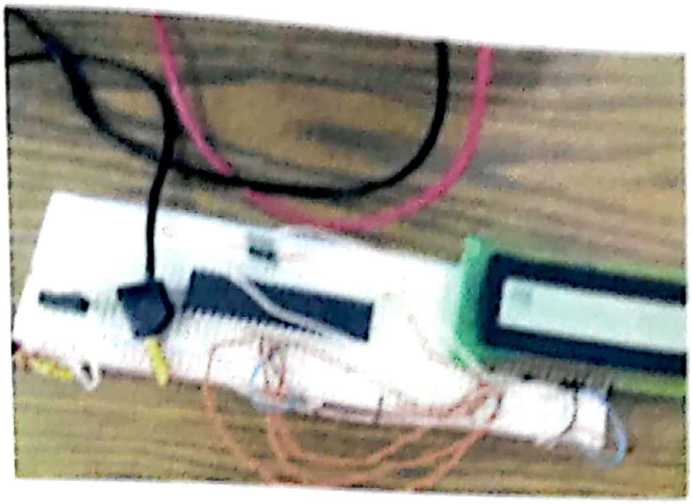

Figure 6.86: LCD displays letter A.

6.3.5.2 ADC code test

The code of analog to digital converter was tested on the PIC, but in the first the designer took the input from VCC and GND and connected it to channel zero of port A of the PIC which is used for analog input.

The result was displayed on LCD, when connected to GND it displayed 0 and when connected to VCC it displayed 1023.

The following figure shows the analog input when connected to GND and it displayed 0.

Figure 6.87: ADC tested through connecting analog input to GND.

The following figure shows the analog input when connected to VCC and it displayed 1023.

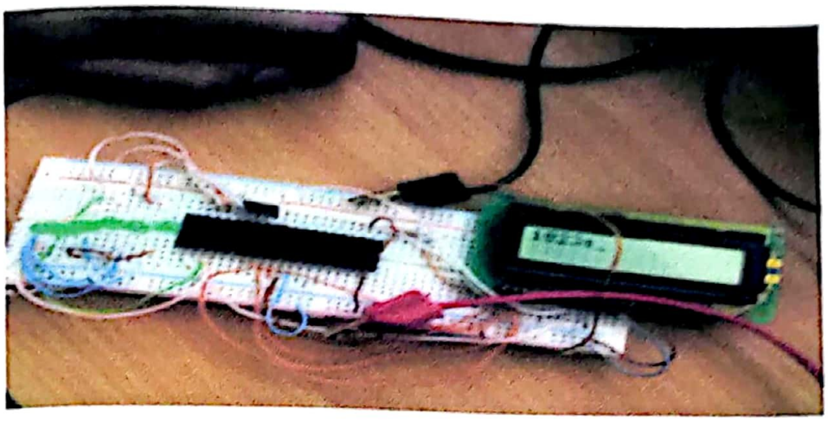

Figure 6.88: ADC tested through connecting analog input to VCC.

When the designer used the input from the sensor, the PIC was unable to read from the sensor because the signal was so small and it displayed only either 0 or 1023 (the values of VCC and GND) , so the designer used Operational amplifier to make the signal larger and after that the PIC was able to read from sensor.

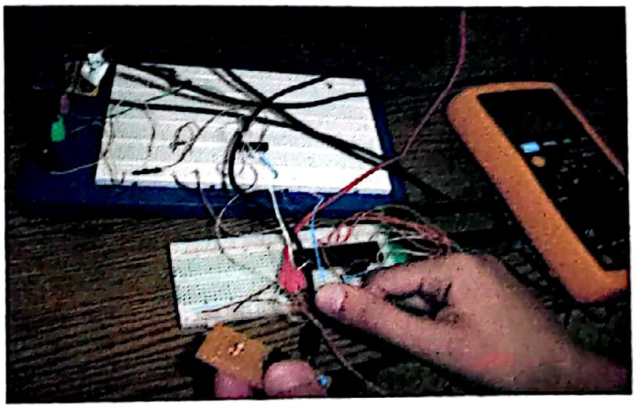

Figure 6.89: ADC tested through connecting sensor to the analog input.

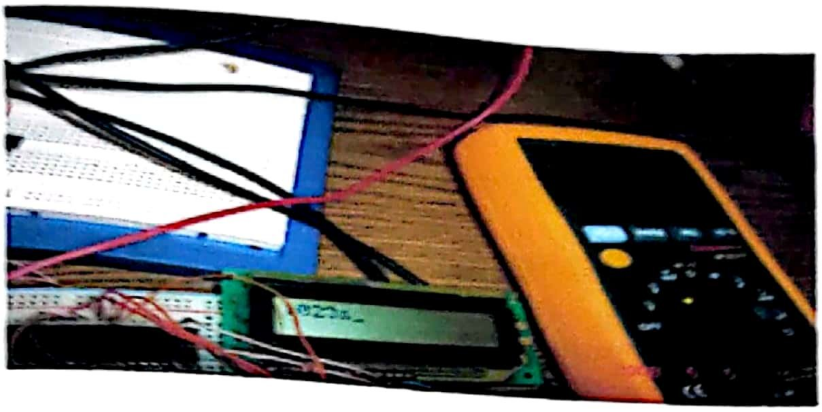

Figure 6.90: ADC tested through connecting sensor to analog input without using operational amplifier.

In the previous figure the PIC was unable to read from the accelerometer sensor without using operational amplifier, while in the following figure the PIC was able to read from accelerometer sensor after using operational amplifier.

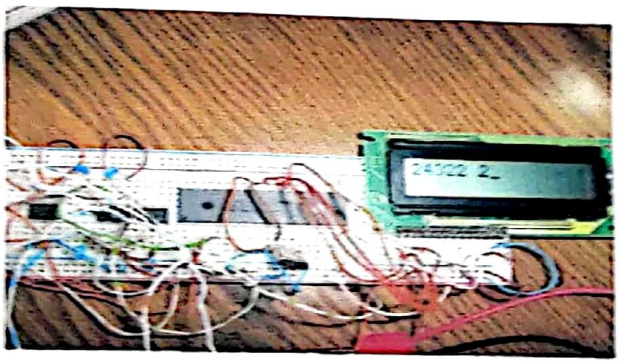

Figure 6.91: ADC tested through connecting analog input to sensor using operational amplifier.

6.3.5.3 Nearest neighbor algorithm code test

In this section the code for the nearest neighbor was tested on C language before it was applied on the MPLAB C18 which used to program the PIC .

The code was tested for the following methods:

- Calculate_N().
- Nearest_N().
- Match().
- LCD_display().

The designer entered constant array with values which were supposed from the designer, and he entered values through using scanf() for thumb, index, middle, ring, pinky; and so the code was tested successfully.

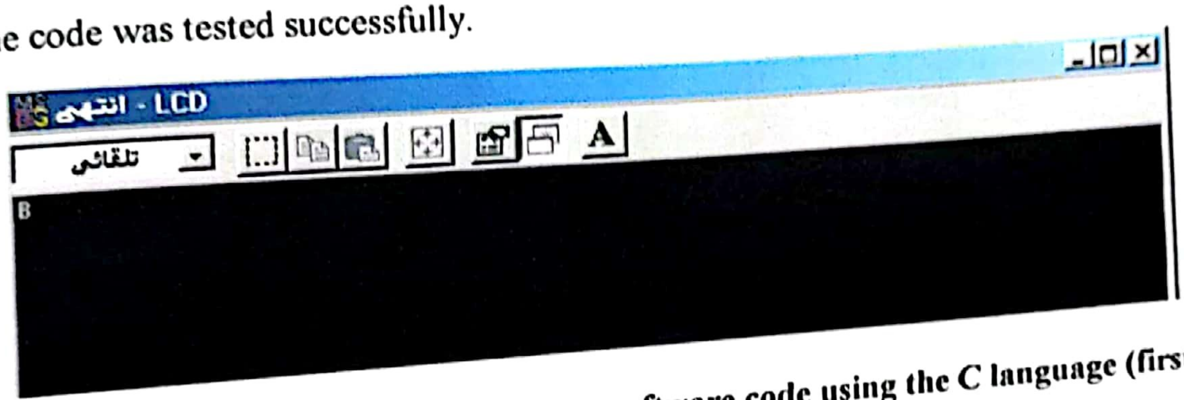

Figure 6.92: The output of testing the software code using the C language (first trial displayed B letter).

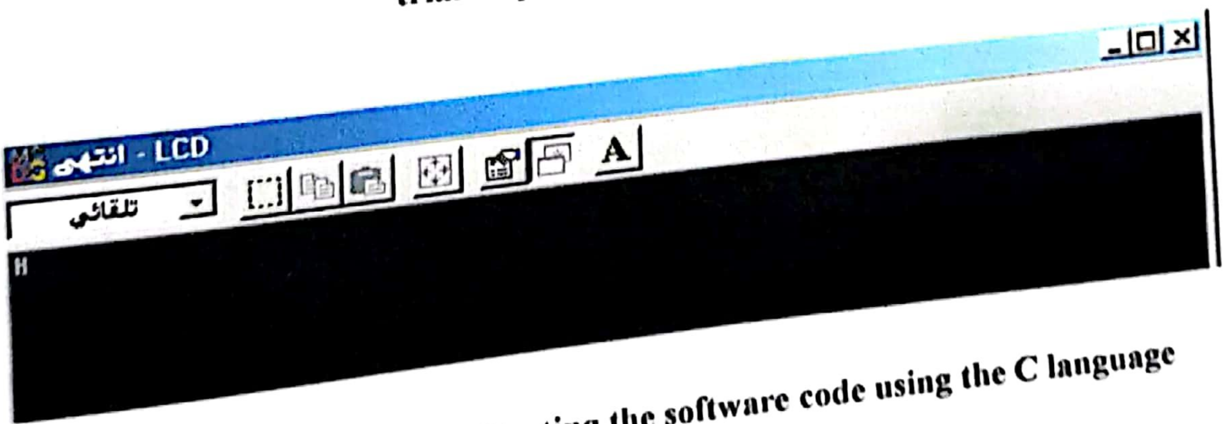

Figure 6.93: The output of testing the software code using the C language (second trial displayed H letter).

6.3.5.4 PIC train mode

The 26th letters were represented using ASL (10 trials for each letter and then the average was calculated), and the values of voltage were read from LCD after the train mode code was put on the PIC.

Note : the value of voltage is multiplying by 5000.

Table (6.2): The displayed values of all letters in train mode at PIC phase.

A letter	T	I	M	R	P
	9625	7625	19300	18750	89250
	9274	7675	19225	18700	87250
	9350	7600	19125	18750	87250
	9250	7650	19150	18775	87255
	9274	7725	19225	18600	87000
	9299	7650	19350	18600	87000
	9250	7874	19250	18575	88255
	9299	7650	19300	18575	86495
	10450	7650	19225	18675	86755
AVG	9452.333	6909.9	17315	16800	78651
B letter	T	I	M	R	P
	9025	8075	19425	18900	89250
	9325	7725	19200	18650	87500
	9375	7725	19350	18625	87505
	9425	7675	19350	18650	87500
	9250	7725	19175	18700	87500
	9274	7625	19175	18600	87250
	9250	7700	19300	18600	87250
	9325	7924	19275	18600	87500
	9274	7700	19250	18550	87250
	9274	7700	19200	18700	87000
Avg	9279.7	7757.4	19270	18657.5	87550.5
C letter	T	I	M	R	P
	8024	5675	20150	19800	73240
	7299	5899	20125	19425	69005
	7249	5875	20125	19425	68505
	7249	5875	20125	19400	68750
	7224	5875	20100	19400	68500
	7224	5875	20050	19400	68500
	7400	6024	19925	19575	66995
	7249	5875	20100	19425	68505

	T	I	M	R	P
	7224	6875	20075	19375	68505
	7400	6999	19925	19550	66990
Avg	7354,2	6884,7	20070	19477,5	68749,5
D letter	T	I	M	R	P
	8600	6900	19425	19050	77000
	8575	6875	19400	19150	77990
	8700	6649	19375	19050	81750
	8700	6800	19625	18860	78240
	8600	6875	19625	19000	77500
	8750	6875	19525	19000	75500
	8700	6900	19500	18950	80500
	8750	6950	19325	18925	79995
	8750	7025	19500	18925	77505
Avg	8680,556	6872.111	19477.78	18990	78442.22
E letter	T	I	M	R	P
	8875	7000	19425	19050	85250
	8825	7125	19550	18775	98995
	8675	6975	19400	18925	85505
	8800	7075	19550	18750	78740
	8675	6975	19375	18850	75750
	8649	6975	19325	18925	77005
	8700	6950	19300	18750	78990
	8825	7050	19450	18900	85000
	8825	6950	19325	18875	84255
avg	8761	7008,333	19411,11	18866,67	83276,67
F Letter	T	I	M	R	P
	9625	7374	19700	19175	83505
	8700	6975	19400	18875	78745
	8649	6900	19425	19050	78490
	8675	6950	19450	19000	75000
	8675	6925	19600	18800	79240
	8649	6925	19450	18850	79740
	8825	7149	19525	18900	77740
	8675	6925	19350	18750	77990
	8775	6850	19600	19050	79490
	8800	7050	19600	18775	85005
Avg	8804.8	7002.3	19510	18922.5	79494.5
G Letter	T	I	M	R	P
	9625	7249	19800	19075	85255
	8750	7025	19600	18675	83505
	8875	6925	19550	18950	77000
	8800	6875	19375	19000	77000

	8700	6850	19350	19025	85005
	8825	6800	19475	19000	75500
	8850	7125	19400	19025	77745
	8800	7149	19500	18950	77740
	8775	7174	19500	18950	82500
	8800	6975	19300	18850	77500
Avg	8880	7014.7	19485	18950	79875
H letter	T	I	M	R	P
	9625	7400	19650	19000	88250
	8925	7000	19600	19000	85250
	8825	7025	19625	18775	78995
	8775	7075	19600	18925	85255
	8900	7050	19450	18800	79740
	8775	7025	19600	19025	79495
	8775	7025	19450	18950	80750
	8850	7000	19650	18900	80750
	8875	6925	19375	18825	77505
	8750	7025	19575	18775	84005
Avg	8907.5	7055	19557.5	18897.5	81999.5
I letter	T	I	M	R	P
	9625	7400	19575	19175	86495
	8850	7050	19450	18850	86000
	8900	6950	19400	18800	78990
	8775	6925	19425	18850	81500
	8775	7224	19325	18900	77990
	8675	6925	19450	18900	77990
	8775	7149	19525	18650	84000
	8750	7100	19400	18850	78740
	8725	7149	19500	18750	79990
	8850	7050	19575	18825	79745
Avg	8870	7092.2	19462.5	18855	81144
J letter	T	I	M	R	P
	7750	7000	19675	18975	88505
	8950	7125	19425	18675	83005
	8875	6900	19350	19025	79245
	8900	7025	19450	18775	80505
	8750	6900	19225	18675	79245
	8850	6875	19375	18750	78240
	8800	7050	19500	18650	81250
	8900	7224	19400	18800	79240
	8800	7224	19450	18875	77745
	8900	7025	19375	18700	78990

Avg	8747.5	7034.8	19422.5	18790	80597
K Letter	T	I	M	R	P
	8675	7475	19575	19150	87250
	8975	7174	19450	18775	86755
	8900	6950	19525	18950	81250
	8875	7075	19475	19000	79490
	8900	7274	19600	18900	80750
	8875	7050	19575	18800	79990
	8900	7125	19400	18700	79240
	8800	7075	19500	18925	81755
	8900	7050	19300	18950	78990
	8825	7274	19375	18625	85255
Avg	8862.5	7152.2	19477.5	18877.5	82072.5
L letter	T	I	M	R	P
	8975	7075	19575	189000	85250
	8925	7025	19475	18825	85255
	8850	7050	19425	19000	85250
	9000	7100	19425	18775	83255
	8825	7299	19500	18825	81005
	8975	6900	19550	18825	84755
	9000	7100	19650	18825	85005
	8875	7075	19375	18900	81750
	8900	7149	19375	18900	85250
Avg	8925	7085.889	19483.33	37763.89	84086.11
M Letter	T	I	M	R	P
	9625	7525	19550	19000	87250
	9025	7224	19300	18875	84255
	8925	7174	19300	19075	84505
	9000	7224	19375	18850	84250
	9000	7149	19350	18750	83750
	8975	7224	19400	18900	84250
	8975	7249	19325	18650	84500
	8975	7100	19375	18825	85505
	9000	7450	19450	18750	84000
	9025	7450	19225	18675	85505
Avg	9052.5	7276.9	19365	18835	84777
N letter	T	I	M	R	P
	9625	7650	19600	18950	87750
	9050	7349	19350	18700	87250
	9100	7249	19550	18750	85500
	8975	7224	19325	18775	85005
	9050	7274	19300	18850	85000
	9000	7199	19350	18725	85005

	9000	7100	19300	18625	86255
	9125	7100	19450	18700	84250
	9000	7249	19275	18650	84500
	8975	7274	19325	18725	84755
Avg	9090	7200.6	19362.5	18765	85527
O letter	T	I	M	R	P
	9625	7525	19450	18900	87500
	9050	7274	19325	18925	85255
	9050	7274	19350	18650	85750
	9050	7500	19475	18700	86000
	9125	7249	19450	18700	85250
	9050	7274	19300	18625	85255
	9075	7274	19450	18725	85005
	9125	7075	19325	18700	85000
	9025	7299	19300	18800	85250
	9075	7249	19450	18700	85000
Avg	9125	7299.3	19387.5	18762.5	85526.5
P letter	T	I	M	R	P
	8725	7899	5575	18900	88500
	9200	7625	5475	18750	86250
	9175	7575	5500	18575	87505
	9150	7575	5525	18575	86495
	9125	7550	5449	18650	86250
	9200	7774	5500	18575	85755
	9100	7575	5424	18725	85255
	9150	7525	5449	18550	85500
	9005	7799	5449	18700	85500
	9100	7450	5449	18675	85505
Avg	9093	7634.7	5479.5	18667.5	86251.5
Q letter	T	I	M	R	P
	18900	69250	20050	19925	25450
	18925	67505	20325	19925	25474
	19000	68750	20075	19875	25600
	19000	68750	20100	19875	25474
	19050	68750	20075	20050	25474
	18900	67240	20125	19925	25400
	19075	69005	20050	20050	25525
	18900	69250	20100	20000	25474
	19000	69000	20100	19875	25500
Avg	18972.22	68611.11	20111.11	19944.44	25485.67
R letter	T	I	M	R	P
	9150	7274	19425	18700	86250

	9200	7274	19350	18850	86000
	9075	7249	19225	18850	85500
	9075	7274	19475	18750	86000
	9050	7125	19275	18700	85000
	9050	7500	19200	18625	86495
	9050	7174	19275	18550	87000
	9150	7324	19425	18650	85500
	9025	7249	19275	18800	85750
Avg	9091.667	7271.444	19325	18719.44	85943.89
S letter	T	I	M	R	P
	9625	7500	19450	18900	88250
	9125	7374	19275	18675	85755
	9200	7349	19425	18700	85500
	9125	7324	19425	18650	85500
	9075	7324	19225	18800	85500
	9100	7425	19275	18600	86750
	9050	7274	19250	18550	85250
	9025	7324	19175	18825	85255
	9050	7324	19200	18775	85505
	9075	7500	19175	18625	85255
Avg	9145	7371.8	19287.5	18710	85852
T letter	T	I	M	R	P
	9625	7600	5575	18775	87755
	9225	7675	5500	18425	86255
	9299	7650	5475	18575	86495
	9175	7650	5475	18600	86490
	9200	7675	5475	18500	87250
	9200	7600	5475	18625	86255
	9150	7675	5475	18675	87005
	9175	7725	5475	18600	86490
	9125	7625	5475	18300	86750
	9150	7849	5449	18725	86255
Avg	9232.4	7672.4	5484.9	18580	86700
U letter	T	I	M	R	P
	9625	7625	19500	18900	89500
	9125	7525	19325	18700	87250
	9125	7274	19450	18725	85505
	9050	7274	19450	18725	85255
	9050	7274	19400	18650	85000
	9075	7274	19450	18725	84755
	9100	7249	19450	18725	84755
	9000	7249	19275	18800	84250

	9000	7274	19325	18825	84050
	9100	7199	19475	18850	84750
Avg	9125	7321.7	19410	18762.5	85507
V letter	T	I	M	R	P
	9625	7475	19450	18750	86250
	8975	7224	19325	18725	8505
	9100	7174	19475	18850	84750
	9025	7149	19325	18750	84500
	8975	7224	19350	18725	86255
	8950	7199	19375	18900	83500
	8975	7174	19225	18750	82750
	8900	7025	19400	18600	85250
	8925	7174	19350	18775	79995
	8925	7050	19450	18900	82500
Avg	9037.5	7186.8	19372.5	18772.5	76425.5
W letter	T	I	M	R	P
	8825	7299	19600	19150	87500
	8975	7374	19425	18825	83255
	8875	7174	19450	18900	85250
	8925	7125	19600	18825	85005
	8875	7025	19525	18825	85255
	8850	7075	19600	18950	84500
	8775	7025	19350	18800	84250
	8925	7299	19300	18800	79240
	8800	7174	19450	18700	77990
	8775	7000	19500	18850	81750
Avg	8860	7157	19480	18862.5	83399.5
letter	T	I	M	R	P
	9625	7400	19600	19000	87000
	8850	6950	19400	18750	83500
	8800	7249	19400	189745	79245
	8900	7075	19425	18725	81505
	8850	7050	19350	18750	80750
	8950	7050	19550	18725	84005
	8900	7249	19375	18950	78990
	8875	7174	19425	18850	81000
	8775	6975	19450	19000	79490
	88900	7249	19450	18925	85005
Avg	16942.5	7142.1	19442.5	35942	82049
Y letter	T	I	M	R	P
	9625	7450	5525	19175	87755

	8950	7374	5449	18725	86755
	8925	7299	5424	18925	83755
	8950	7349	5424	18875	84005
	8900	7274	5424	18875	80755
	8900	7349	5449	18925	81505
	8875	7299	5399	18925	83505
	9000	7274	5424	18875	80505
	8825	7299	5374	18850	81500
	8850	7199	5424	18850	84750
Avg	8980	7316.6	5431.6	18900	83479
Z letter	T	I	M	R	P
	9625	7620	19325	18675	87255
	9274	7425	19300	18600	86000
	9250	7725	19275	18600	86490
	9200	7575	19200	18700	87500
	9200	7525	19150	18575	86255
	9225	7774	19200	18550	88500
	9250	7575	19250	18575	86755
	9299	7500	19300	18600	86750
	9225	7700	19150	18750	87000
	9325	7899	19300	18650	87500
Avg	9287.3	7631.8	19245	18627.5	87000.5

The previous trials was able to recognize only one letter (C letter) , so the designer repeat the train mode.

The 26th letters were represented again using ASL (10 trials for each letter and then the average was displayed on the LCD), then the averages were read from LCD after the train mode code was put on the PIC, the averages were in the following table.

Table (6. 3): displayed values for the letters taken from the LCD (10 trials for each letter) .

Letter	Thumb	Index	Middle	Ring	Pinky
A	772	229	817	810	249
B	778	229	821	815	251
C	777	232	822	813	248

D	776	229	819	816	251
E	776	233	821	813	250
F	775	234	820	813	251
G	776	234	821	813	251
H	773	231	817	811	251
I	777	234	821	814	251
J	777	244	205	818	257
K	776	232	821	815	255
L	770	825	826	192	1017
M	771	233	817	812	255
N	775	232	819	815	254
O	775	234	821	813	252
P	776	233	820	814	255
Q	773	233	817	811	253
R	777	236	821	814	253
S	775	234	818	814	254
T	777	235	821	812	253
U	773	234	817	810	253
V	777	235	821	811	253
W	772	236	817	810	254
X	773	235	818	811	254
Y	776	235	821	815	256
Z	773	249	206	816	262

Note: the previous values were taken and stored statically in array in test mode code, and after the letters were tested, the PIC was able to recognize only 4 letters from 26(A, K,L and C letters).

So the designer repeated the previous work and took 20 trials for each letter.

Table (6.4): displayed values for the letters taken from the LCD(20 trials for each letter) .

Letter	Thumb	Index	Middle	Ring	Pinky
A	775	230	1020	8250	8250
B	778	227	1019	8289	8289
C	778	226	1017	8277	1077
D	777	227	1019	8299	7299
E	771	825	1015	1895	1017
F	768	824	1015	1905	1016
G	776	232	1020	8310	8310
H	777	230	1018	8278	7278
I	775	226	1013	8253	8253
J	778	226	1016	8286	8286
K	777	227	1018	8278	7278
L	775	226	1014	8244	7244
M	778	228	1019	8309	8309
N	775	226	1015	8255	8255
O	778	228	1019	8279	7279
P	778	228	1018	8288	8288
Q	777	225	1015	8295	9295
R	777	227	1018	8288	7288
S	779	224	1016	8296	8296
T	779	227	1019	8299	8299
U	778	225	1018	8298	7298
V	777	227	1018	8278	7278
W	773	827	1015	1895	1017
X	778	230	1018	8298	9298
Y	775	227	1013	8263	8263
Z	771	830	1016	1916	1917

6.3.5.5 PIC test mode

This section contains the result of test mode for the letters after they tested on the PIC in the second trial.

The following figure shows the K letter after it was tested successfully in PIC phase.

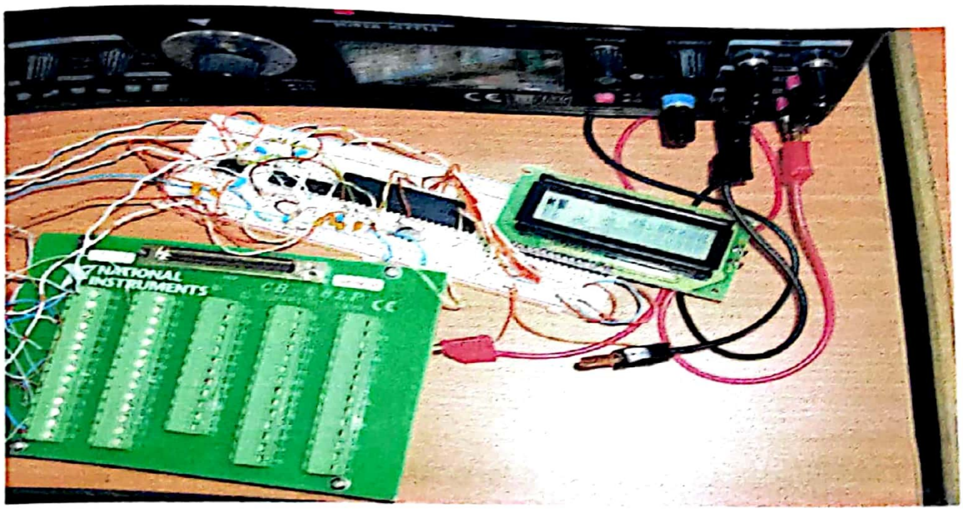

Figure 6.94: K letter test mode at PIC phase.

The following figure shows the L letter after it was tested successfully in PIC phase.

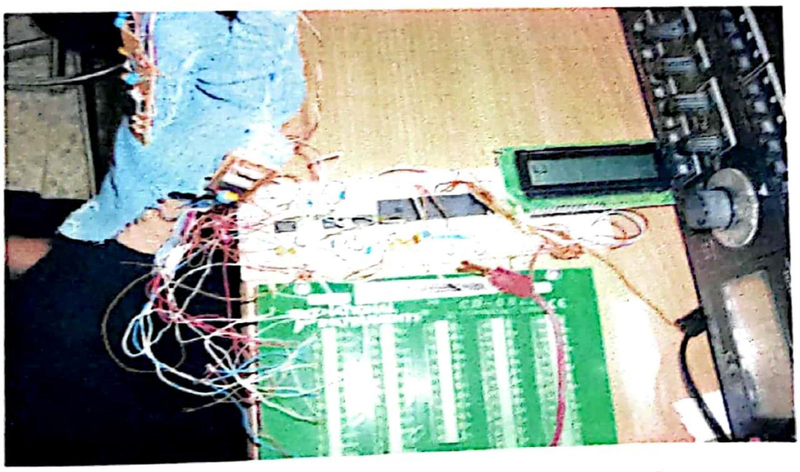

Figure 6.95: L letter test mode at PIC phase.

The following figure shows the J letter after it was tested successfully in PIC phase.

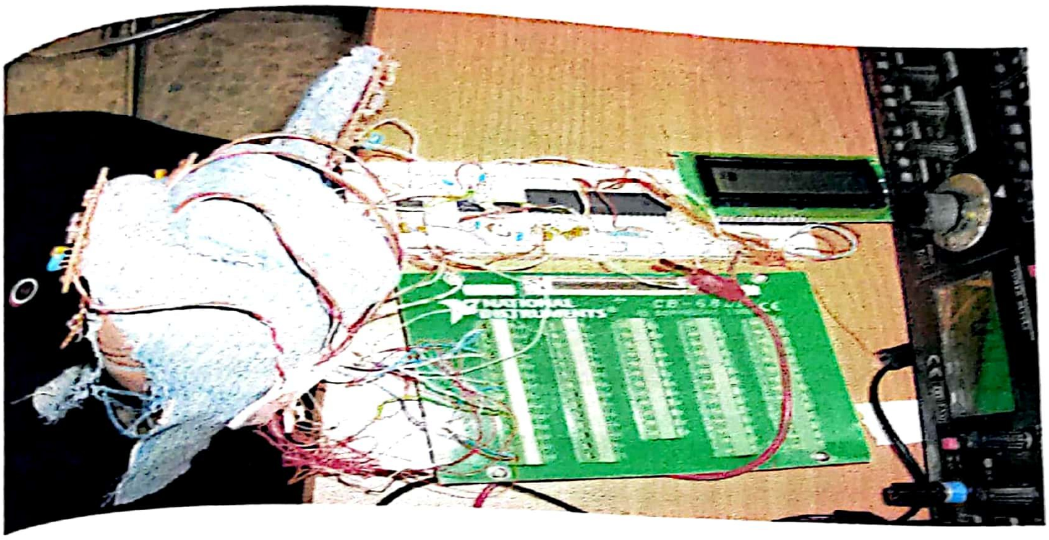

Figure 6.96 J letter test mode at PIC phase.

The following figure shows the F letter after it was tested successfully in PIC phase.

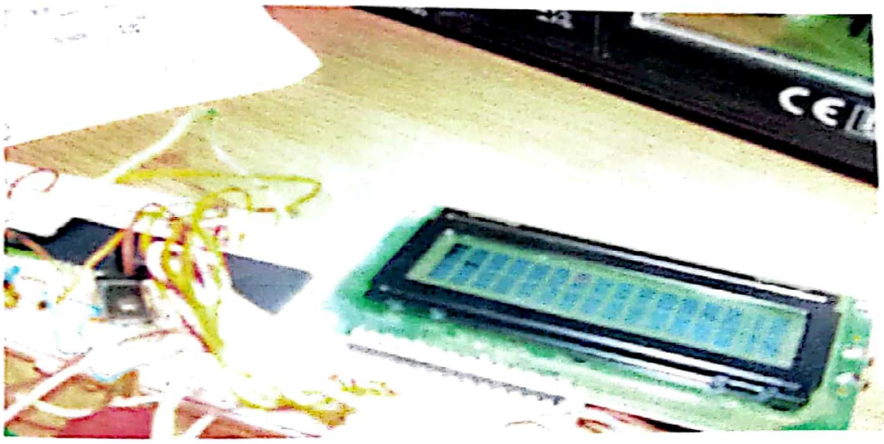

Figure 6.97 F letter test mode at PIC phase

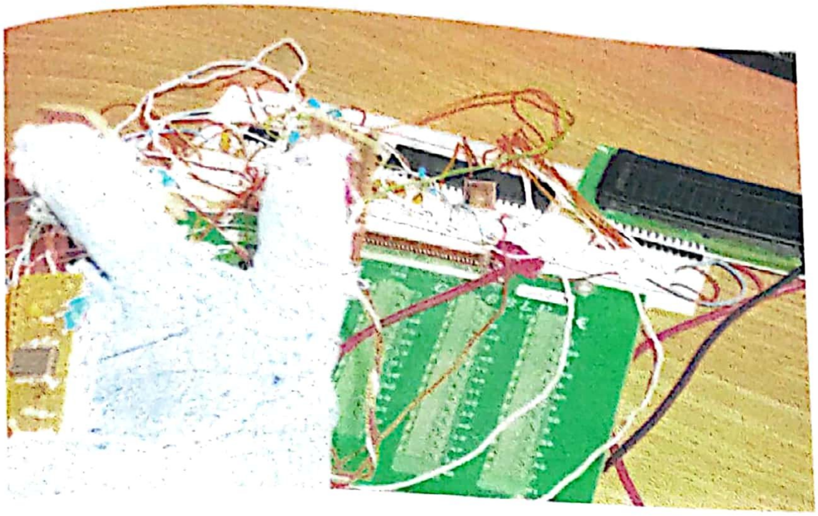

Figure 6.98 V letter test mode at PIC test mode

The following figure shows the V letter after it was tested successfully in PIC phase.

Figure 6.99 V letter at PIC test mode

CHAPTER

7

CONCLUSION AND FUTURE WORK

Introduction.

Conclusion.

Future works.

Chapter Seven
Conclusion and future work

7.1 Introduction

This chapter represents the future works and conclusions related to the SLC system.

7.2 Conclusions

In this system many conclusions that are concluded after working with this project and in this section a description of the resulted conclusions will be pointed:

- The SLC system recognizes 26 letters at computer phase.
- Working on this system increases the knowledge of PIC programming.
- Working on this system increases the knowledge of sign language.
- Working on this system increases the knowledge of working with a new sensor called accelerometer sensor (new technology).
- In test mode the designer must represent the letter in the same way he did in train mode from the side of hand position.
- If the designer stores an array statically in ROM he can retrieve any value depends on the index in the same way as if it was stored in ram.
- If the designer stores an array dynamically at runtime in ROM and he tries to retrieve value depends on index this will return 0, so to solve this problem the designer uses external EEPROM to write on it at runtime and after that to read from it.

7.3 Future work

This system could be improved and modified, and the following points can be implemented as future work:

1. The system could be improved so that it becomes able to implement sound by using speaker to pronounce the sound of each letter.
2. The system could be improved so that it becomes able to implement words instead of letters, by using PIC with larger memory like AVR PIC microcontroller.

Resources

Books:

- S.Mehdi and Y.khan,"Sign Language recognition using sensors gloves" in Proceeding of the 9th international conference in neural information processing.(ICONIP'02),2002,pp,2204_22_6.
- Y.Yoon and k.Jo " hand shape recognition using moment invariant for the Korean sign language recognition" in proceedings of the 7th korea_Russia international symposium,KORUS,2003,pp,308_313.
- Barbara Bernstein Fant, Betty Miller, Lou Fant "The American Sign Language phrase book" ISBN 0071497137/9780071497138,format paperback,416 pages, 2003.

Papers:

- Omar Al_Jarrah, Alaa Halawani, "Recognition of gestures in Arabic Language using neuro_fuzzy systems", Artifical Inteligence ,133(2001) 117_138.

Links:

[1]:http://www.gwu.edu/~research/ac
cele.htm.
Research at George Washington University.
By jose Hernandez_Rebollar.

[2]: A thesis presented to the deanship of graduate studies
King Fahd University of petroleum and minerals.
By Salah Mohammad Saeed Al_Buraiky,
Master of science in electrical engineering,
September 2004.

[3]:S.Mehdi and Y.khan,"Sign Language recognition using sensors gloves" in
Proceeding of the 9th international conference in neural information processing.
(ICONIP'02),2002,pp,2204_22_6.

[4]: Y.Yoon and k.Jo " hand shape recognition using moment invariant for the Korean sign language recognition" in proceedings of the 7th korea_Russia international symposium,KORUS,2003,pp,308_313.

[5]:http://en.wikipedia.org/wiki/American_Manual_Alphabet.

[6]:http://www.vti.fi/en/products_solutions/products/accelerometers/sca3000_accelerometers/.
[7]:http://www.futurlec.com/AnalogDevices/ADXL202AQCa.shtml.
[8]:http://www.futurlec.com/AnalogDevices/ADXL202AQCa.shtml.
[9]:http://www.futurlec.com/AnalogDevices/ADXL202AQCa.shtml.
[10]: http://www.national.com/pf/LM/LM358.html[lm358].
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[12]:http://www.mines.edu/Academic/courses/physics/phgn317/labview06/6034E_and_6035E_User_Manual.pdf.
[13]: http://ww1.microchip.com/downloads/en/DeviceDoc/39632D.pdf
[14]:http://home.gwu.edu/~jreboll/news.htm.
[15]:http://home.gwu.edu/~jreboll/news.htm.
[16]:http://home.gwu.edu/~jreboll/news.htm.

APPENDIX A

DATA SHEET

ANALOG DEVICES

Low Cost ±2 g/±10 g Dual Axis iMEMS® Accelerometers with Digital Output

ADXL202/ADXL210

FEATURES
- 2-Axis Acceleration Sensor on a Single IC Chip
- Measures Static Acceleration as Well as Dynamic Acceleration
- Duty Cycle Output with User Adjustable Period
- Low Power <0.6 mA
- Faster Response than Electrolytic, Mercury or Thermal Tilt Sensors
- Bandwidth Adjustment with a Single Capacitor Per Axis
- 5 mg Resolution at 60 Hz Bandwidth
- +3 V to +5.25 V Single Supply Operation
- 1000 g Shock Survival

APPLICATIONS
- 2-Axis Tilt Sensing
- Computer Peripherals
- Inertial Navigation
- Seismic Monitoring
- Vehicle Security Systems
- Battery Powered Motion Sensing

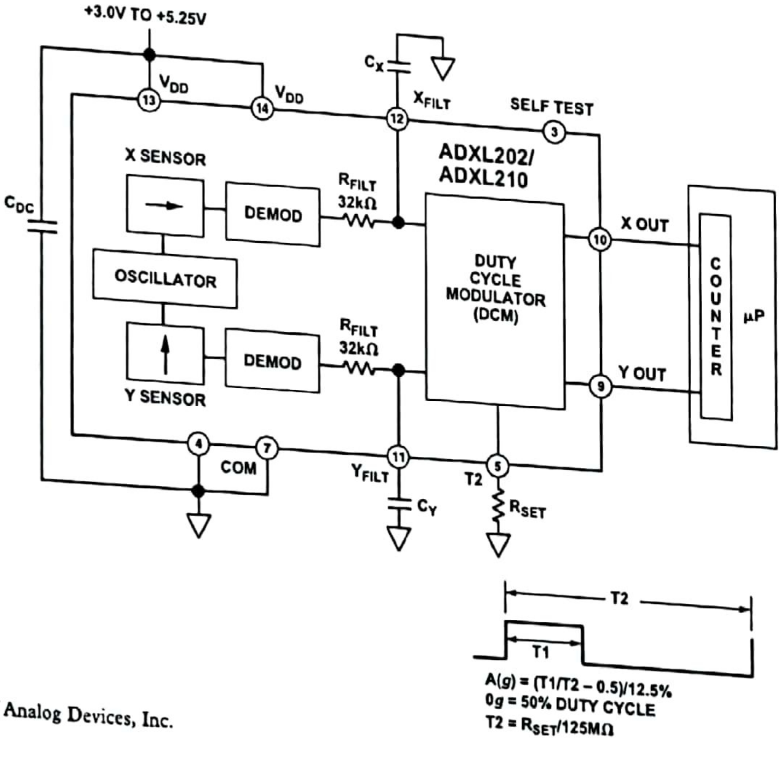
GENERAL DESCRIPTION
The ADXL202/ADXL210 are low cost, low power, complete 2-axis accelerometers with a measurement range of either ±2 g/±10 g. The ADXL202/ADXL210 can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity).

The outputs are digital signals whose duty cycles (ratio of pulse-width to period) are proportional to the acceleration in each of the 2 sensitive axes. These outputs may be measured directly with a microprocessor counter, requiring no A/D converter or glue logic. The output period is adjustable from 0.5 ms to 10 ms via a single resistor (R_{SET}). If a voltage output is desired, a voltage output proportional to acceleration is available from the X_{FILT} and Y_{FILT} pins, or may be reconstructed by filtering the duty cycle outputs.

The bandwidth of the ADXL202/ADXL210 may be set from 0.01 Hz to 5 kHz via capacitors C_X and C_Y. The typical noise floor is 500 $\mu g/\sqrt{Hz}$ allowing signals below 5 mg to be resolved for bandwidths below 60 Hz.

The ADXL202/ADXL210 is available in a hermetic 14-lead Surface Mount CERPAK, specified over the 0°C to +70°C commercial or –40°C to +85°C industrial temperature range.

FUNCTIONAL BLOCK DIAGRAM



iMEMS is a registered trademark of Analog Devices, Inc.

REV. B

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781/329-4700 World Wide Web Site: http://www.analog.com
Fax: 781/326-8703

ADXL202/ADXL210–SPECIFICATIONS

($T_A = T_{MIN}$ to T_{MAX}, $T_A = +25°C$ for J Grade only, $V_{DD} = +5$ V, $R_{SET} = 125$ kΩ, Acceleration = 0 *g*, unless otherwise noted)

Parameter	Conditions	ADXL202/JQC/AQC Min	Typ	Max	ADXL210/JQC/AQC Min	Typ	Max	Units
SENSOR INPUT	Each Axis							
Measurement Range[1]		±1.5	±2		±8	±10		*g*
Nonlinearity	Best Fit Straight Line		0.2			0.2		% of FS
Alignment Error[2]			±1			±1		Degrees
Alignment Error	X Sensor to Y Sensor		±0.01			±0.01		Degrees
Transverse Sensitivity[3]			±2			±2		%
SENSITIVITY	Each Axis							
Duty Cycle per *g*	T1/T2 @ +25°C	10	12.5	15	3.2	4.0	4.8	%/*g*
Sensitivity, Analog Output	At Pins X_{FILT}, Y_{FILT}		312			100		mV/*g*
Temperature Drift[4]	Δ from +25°C		±0.5			±0.5		% Rdg
ZERO *g* BIAS LEVEL	Each Axis							
0 *g* Duty Cycle	T1/T2	25	50	75	42	50	58	%
Initial Offset			±2			±2		*g*
0 *g* Duty Cycle vs. Supply			1.0	4.0		1.0	4.0	%/V
0 *g* Offset vs. Temperature[4]	Δ from +25°C		2.0			2.0		m*g*/°C
NOISE PERFORMANCE								
Noise Density[5]	@ +25°C		500	1000		500	1000	µ*g*/√Hz
FREQUENCY RESPONSE								
3 dB Bandwidth	Duty Cycle Output		500			500		Hz
3 dB Bandwidth	At Pins X_{FILT}, Y_{FILT}		5			5		kHz
Sensor Resonant Frequency			10			14		kHz
FILTER								
R_{FILT} Tolerance	32 kΩ Nominal		±15			±15		%
Minimum Capacitance	At X_{FILT}, Y_{FILT}	1000			1000			pF
SELF TEST								
Duty Cycle Change	Self-Test "0" to "1"		10			10		%
DUTY CYCLE OUTPUT STAGE								
F_{SET}	$R_{SET} = 125$ kΩ		125 MΩ/R_{SET}			125 MΩ/R_{SET}		kHz
F_{SET} Tolerance		0.7		1.3	0.7		1.3	
Output High Voltage	I = 25 µA	V_S – 200 mV			V_S – 200 mV			mV
Output Low Voltage	I = 25 µA			200			200	mV
T2 Drift vs. Temperature			35			35		ppm/°C
Rise/Fall Time			200			200		ns
POWER SUPPLY								
Operating Voltage Range		3.0		5.25	2.7		5.25	V
Specified Performance		4.75		5.25	4.75		5.25	V
Quiescent Supply Current			0.6	1.0		0.6	1.0	mA
Turn-On Time[6]	To 99%		160 C_{FILT} + 0.3			160 C_{FILT} + 0.3		ms
TEMPERATURE RANGE								
Operating Range	JQC	0		+70	0		+70	°C
Specified Performance	AQC	–40		+85	–40		+85	°C

NOTES
[1] For all combinations of offset and sensitivity variation.
[2] Alignment error is specified as the angle between the true and indicated axis of sensitivity.
[3] Transverse sensitivity is the algebraic sum of the alignment and the inherent sensitivity errors.
[4] Specification refers to the maximum change in parameter from its initial at +25°C to its worst case value at T_{MIN} to T_{MAX}.
[5] Noise density (µ*g*/√Hz) is the average noise at any frequency in the bandwidth of the part.
[6] C_{FILT} in µF. Addition of filter capacitor will increase turn on time. Please see the Application section on power cycling.
All min and max specifications are guaranteed. Typical specifications are not tested or guaranteed.
Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS*

Acceleration (Any Axis, Unpowered for 0.5 ms) . . . . . . 1000 *g*
Acceleration (Any Axis, Powered for 0.5 ms) . . . . 500 *g*
$+V_S$ . . . . –0.3 V to +7.0 V
Output Short Circuit Duration
(Any Pin to Common) . . . . Indefinite
Operating Temperature . . . . –55°C to +125°C
Storage Temperature . . . . –65°C to +150°C

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Drops onto hard surfaces can cause shocks of greater than 1000 *g* and exceed the absolute maximum rating of the device. Care should be exercised in handling to avoid damage.

PIN FUNCTION DESCRIPTIONS

Pin	Name	Description
1	NC	No Connect
2	V_{TP}	Test Point, Do Not Connect
3	ST	Self Test
4	COM	Common
5	T2	Connect R_{SET} to Set T2 Period
6	NC	No Connect
7	COM	Common
8	NC	No Connect
9	Y_{OUT}	Y Axis Duty Cycle Output
10	X_{OUT}	X Axis Duty Cycle Output
11	Y_{FILT}	Connect Capacitor for Y Filter
12	X_{FILT}	Connect Capacitor for X Filter
13	V_{DD}	+3 V to +5.25 V, Connect to 14
14	V_{DD}	+3 V to +5.25 V, Connect to 13

PACKAGE CHARACTERISTICS

Package	θ_{JA}	θ_{JC}	Device Weight
14-Lead CERPAK	110°C/W	30°C/W	5 Grams

PIN CONFIGURATION

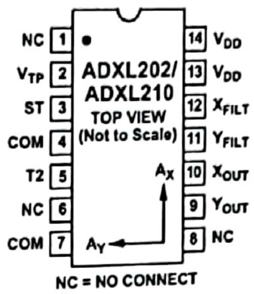


Figure 1 shows the response of the ADXL202 to the Earth's gravitational field. The output values shown are nominal. They are presented to show the user what type of response to expect from each of the output pins due to changes in orientation with respect to the Earth. The ADXL210 reacts similarly with output changes appropriate to its scale.

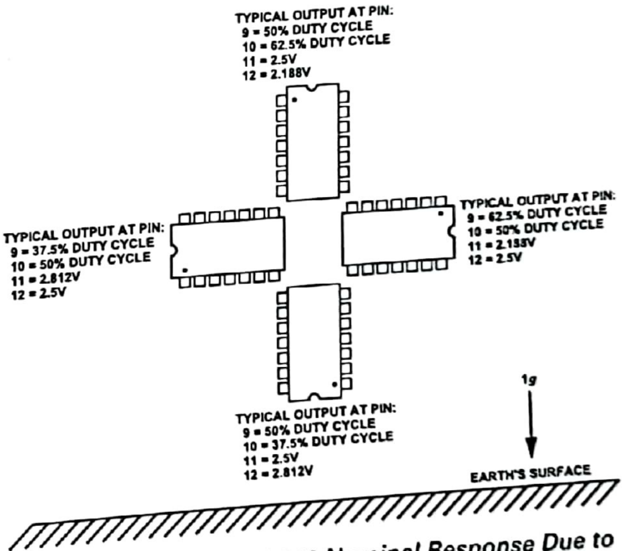


Figure 1. ADXL202/ADXL210 Nominal Response Due to Gravity

ORDERING GUIDE

Model	*g* Range	Temperature Range	Package Description	Package Option
ADXL202JQC	±2	0°C to +70°C	14-Lead CERPAK	QC-14
ADXL202AQC	±2	–40°C to +85°C	14-Lead CERPAK	QC-14
ADXL210JQC	±10	0°C to +70°C	14-Lead CERPAK	QC-14
ADXL210AQC	±10	–40°C to +85°C	14-Lead CERPAK	QC-14

CAUTION
ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADXL202/ADXL210 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

TYPICAL CHARACTERISTICS (@ +25°C R_{SET} = 125 kΩ, V_{DD} = +5 V, unless otherwise noted)

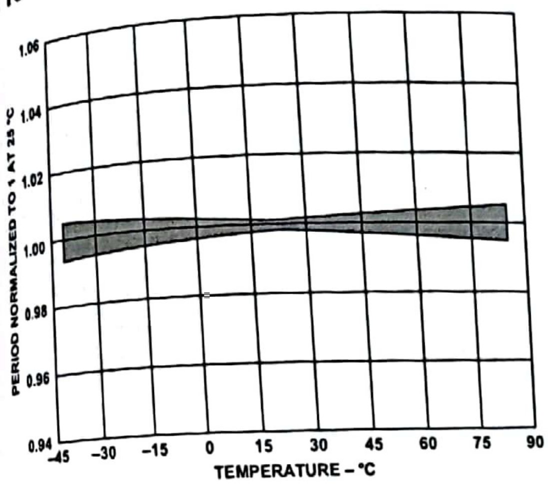


Figure 2. Normalized DCM Period (T2) vs. Temperature

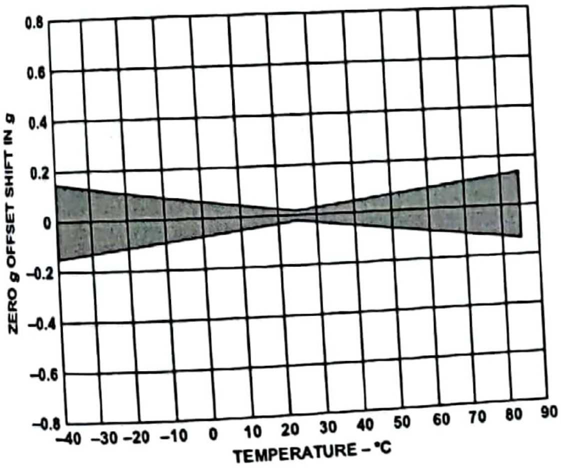


Figure 3. Typical Zero g Offset vs. Temperature

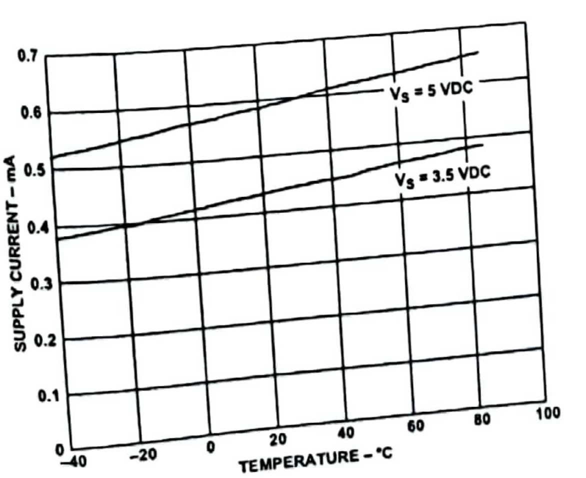


Figure 4. Typical Supply Current vs. Temperature

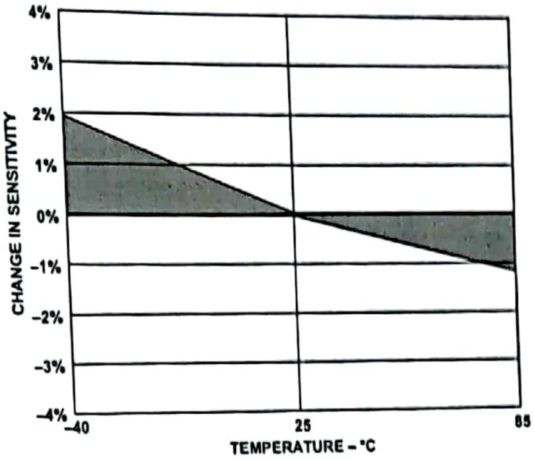


Figure 5. Typical X Axis Sensitivity Drift Due to Temperature

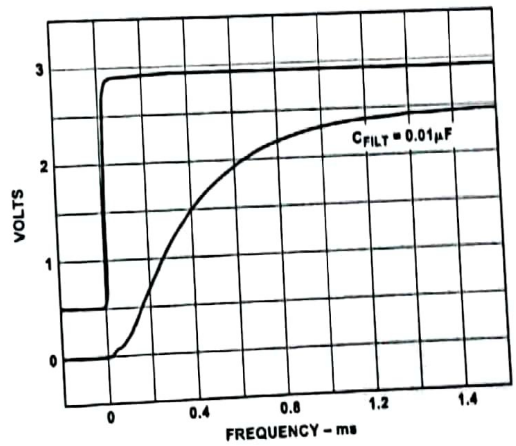


Figure 6. Typical Turn-On Time

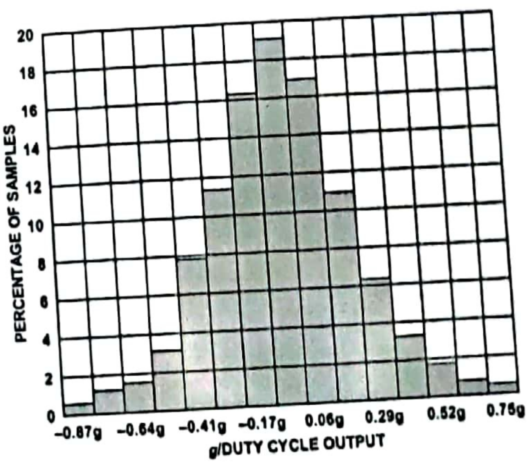


Figure 7. Typical Zero g Distribution at +25°C

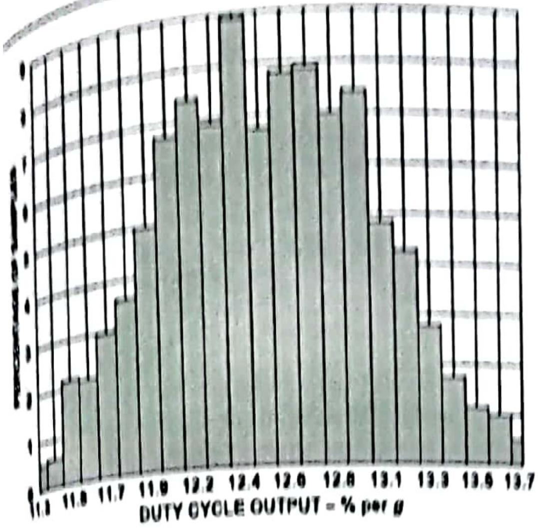


Figure 8. Typical Sensitivity per g at +25°C

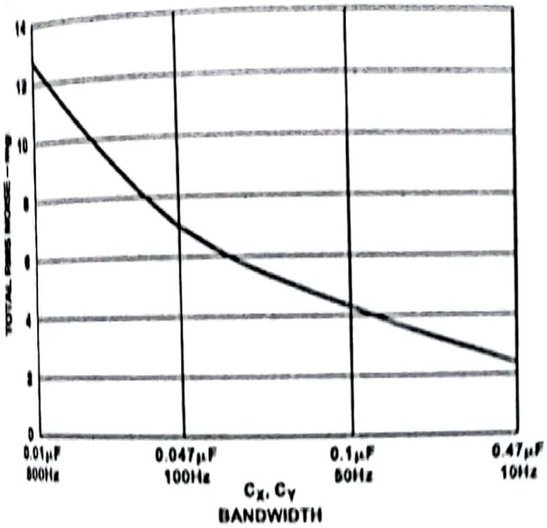


Figure 9. Typical Noise at X_{FILT} Output

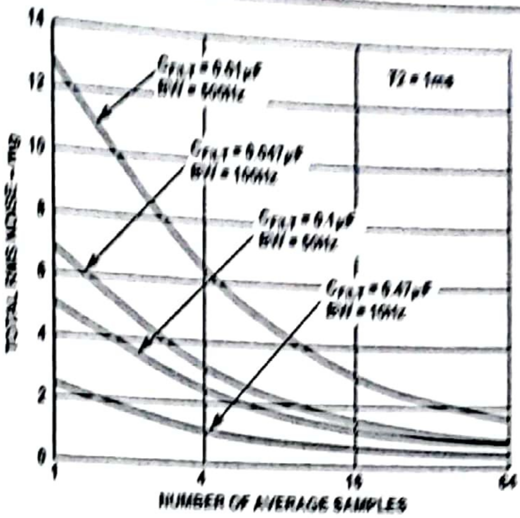


Figure 10. Typical Noise at Digital Outputs

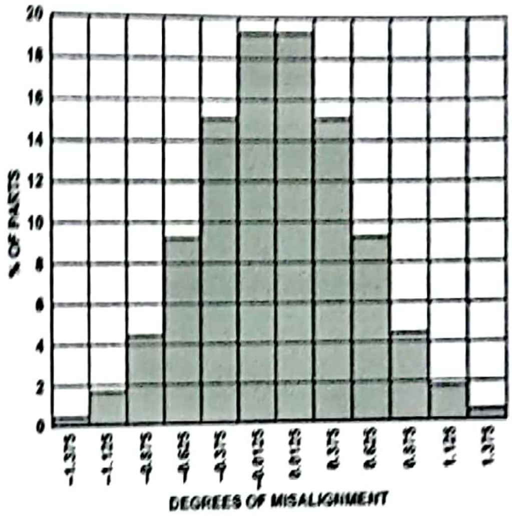


Figure 11. Rotational Die Alignment

NITIONS

Length of the "on" portion of the cycle.

Length of the total cycle.

Cycle Ratio of the "on" time (T1) of the cycle to the total cycle (T2). Defined as T1/T2 for the ADXL202/ ADXL210.

width Time period of the "on" pulse. Defined as T1 for the ADXL202/ADXL210.

ORY OF OPERATION

ADXL202/ADXL210 are complete dual axis acceleration urement systems on a single monolithic IC. They contain a licon surface-micromachined sensor and signal condition- rcuitry to implement an open loop acceleration measure- architecture. For each axis, an output circuit converts the g signal to a duty cycle modulated (DCM) digital signal an be decoded with a counter/timer port on a micropro- r. The ADXL202/ADXL210 are capable of measuring positive and negative accelerations to a maximum level of or ±10 g. The accelerometer measures static acceleration s such as gravity, allowing it to be used as a tilt sensor.

sensor is a surface micromachined polysilicon structure on top of the silicon wafer. Polysilicon springs suspend the ture over the surface of the wafer and provide a resistance st acceleration forces. Deflection of the structure is mea- d using a differential capacitor that consists of independent d plates and central plates attached to the moving mass. The d plates are driven by 180° out of phase square waves. An leration will deflect the beam and unbalance the differential acitor, resulting in an output square wave whose amplitude roportional to acceleration. Phase sensitive demodulation niques are then used to rectify the signal and determine the ction of the acceleration.

output of the demodulator drives a duty cycle modulator M) stage through a 32 kΩ resistor. At this point a pin is lable on each channel to allow the user to set the signal dwidth of the device by adding a capacitor. This filtering roves measurement resolution and helps prevent aliasing.

er being low-pass filtered, the analog signal is converted to a y cycle modulated signal by the DCM stage. A single resistor the period for a complete cycle (T2), which can be set be- en 0.5 ms and 10 ms (see Figure 12). A 0 g acceleration duces a nominally 50% duty cycle. The acceleration signal be determined by measuring the length of the T1 and T2 ses with a counter/timer or with a polling loop using a low t microcontroller.

analog output voltage can be obtained either by buffering the nal from the X_{FILT} and Y_{FILT} pin, or by passing the duty cycle nal through an RC filter to reconstruct the dc value.

e ADXL202/ADXL210 will operate with supply voltages as v as 3.0 V or as high as 5.25 V.

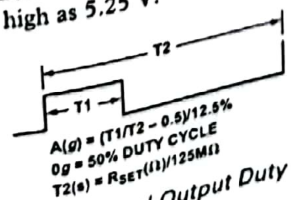


Figure 12. Typical Output Duty Cycle

APPLICATIONS

POWER SUPPLY DECOUPLING

For most applications a single 0.1 µF capacitor, C_{DC}, will adequately decouple the accelerometer from signal and noise on the power supply. However, in some cases, especially where digital devices such as microcontrollers share the same power supply, digital noise on the supply may cause interference on the ADXL202/ ADXL210 output. This is often observed as a slowly undulating fluctuation of voltage at X_{FILT} and Y_{FILT}. If additional decoupling is needed, a 100 Ω (or smaller) resistor or ferrite beads, may be inserted in the ADXL202/ADXL210's supply line.

DESIGN PROCEDURE FOR THE ADXL202/ADXL210

The design procedure for using the ADXL202/ADXL210 with a duty cycle output involves selecting a duty cycle period and a filter capacitor. A proper design will take into account the application requirements for bandwidth, signal resolution and acquisition time, as discussed in the following sections.

V_{DD}

The ADXL202/ADXL210 have two power supply (V_{DD}) Pins: 13 and 14. These two pins should be connected directly together.

COM

The ADXL202/ADXL210 have two commons, Pins 4 and 7. These two pins should be connected directly together and Pin 7 grounded.

V_{TP}

This pin is to be left open; make no connections of any kind to this pin.

Decoupling Capacitor C_{DC}

A 0.1 µF capacitor is recommended from V_{DD} to COM for power supply decoupling.

ST

The ST pin controls the self-test feature. When this pin is set to V_{DD}, an electrostatic force is exerted on the beam of the accelerometer. The resulting movement of the beam allows the user to test if the accelerometer is functional. The typical change in output will be 10% at the duty cycle outputs (corresponding to 800 mg). This pin may be left open circuit or connected to common in normal use.

Duty Cycle Decoding

The ADXL202/ADXL210's digital output is a duty cycle modulator. Acceleration is proportional to the ratio T1/T2. The nominal output of the ADXL202 is:

0 g = 50% *Duty Cycle*

Scale factor is 12.5% Duty Cycle Change per g

The nominal output of the ADXL210 is:

0 g = 50% *Duty Cycle*

Scale factor is 4% Duty Cycle Change per g

These nominal values are affected by the initial tolerance of the device including zero g offset error and sensitivity error.

T2 does not have to be measured for every measurement cycle. It need only be updated to account for changes due to temperature, (a relatively slow process). Since the T2 time period is shared by both X and Y channels, it is necessary only to measure it on one channel of the ADXL202/ADXL210. Decoding algorithms for various microcontrollers have been developed. Consult the appropriate Application Note.

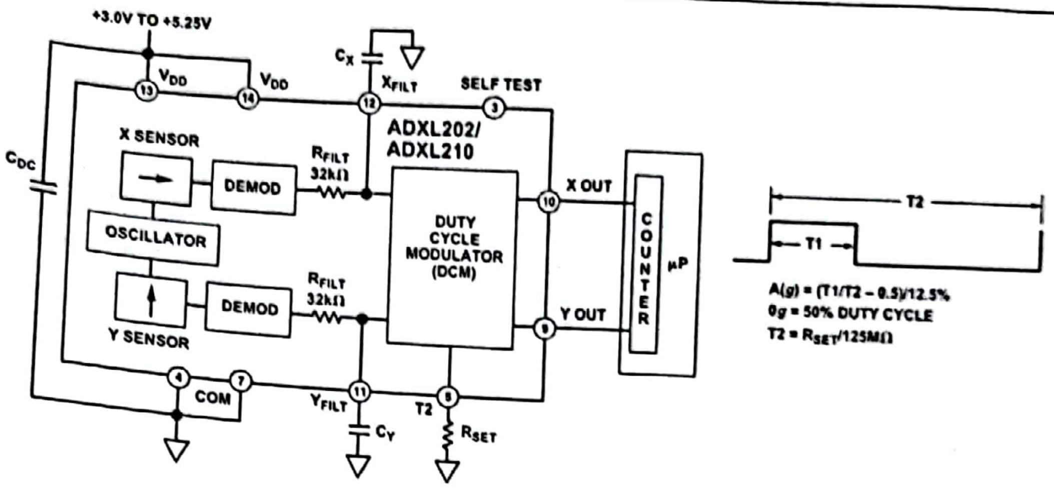


Figure 13. Block Diagram

Setting the Bandwidth Using C_X and C_Y

The ADXL202/ADXL210 have provisions for bandlimiting the X_{FILT} and Y_{FILT} pins. Capacitors must be added at these pins to implement low-pass filtering for antialiasing and noise reduction. The equation for the 3 dB bandwidth is:

$$F_{-3\,dB} = \frac{1}{\left(2\pi(32\,k\Omega) \times C(x,y)\right)}$$

or, more simply, $F_{-3\,dB} = \dfrac{5\,\mu F}{C_{(X,Y)}}$

The tolerance of the internal resistor (R_{FILT}), can vary as much as ±25% of its nominal value of 32 kΩ; so the bandwidth will vary accordingly. A minimum capacitance of 1000 pF for $C_{(X,\,Y)}$ is required in all cases.

Table I. Filter Capacitor Selection, C_X and C_Y

Bandwidth	Capacitor Value
10 Hz	0.47 µF
50 Hz	0.10 µF
100 Hz	0.05 µF
200 Hz	0.027 µF
500 Hz	0.01 µF
5 kHz	0.001 µF

Setting the DCM Period with R_{SET}

The period of the DCM output is set for both channels by a single resistor from R_{SET} to ground. The equation for the period is:

$$T2 = \frac{R_{SET}\,(\Omega)}{125\,M\Omega}$$

A 125 kΩ resistor will set the duty cycle repetition rate to approximately 1 kHz, or 1 ms. The device is designed to operate at duty cycle periods between 0.5 ms and 10 ms.

Table II. Resistor Values to Set T2

T2	R_{SET}
1 ms	125 kΩ
2 ms	250 kΩ
5 ms	625 kΩ
10 ms	1.25 MΩ

Note that the R_{SET} should always be included, even if only an analog output is desired. Use an R_{SET} value between 500 kΩ and 2 MΩ when taking the output from X_{FILT} or Y_{FILT}. The R_{SET} resistor should be place close to the T2 Pin to minimize parasitic capacitance at this node.

Selecting the Right Accelerometer

For most tilt sensing applications the ADXL202 is the most appropriate accelerometer. Its higher sensitivity (12.5%/*g* allows the user to use a lower speed counter for PWM decoding while maintaining high resolution. The ADXL210 should be used in applications where accelerations of greater than ±2 *g* are expected.

MICROCOMPUTER INTERFACES

The ADXL202/ADXL210 were specifically designed to work with low cost microcontrollers. Specific code sets, reference designs, and application notes are available from the factory. This section will outline a general design procedure and discuss the various trade-offs that need to be considered.

The designer should have some idea of the required performance of the system in terms of:

Resolution: the smallest signal change that needs to be detected.

Bandwidth: the highest frequency that needs to be detected.

Acquisition Time: the time that will be available to acquire the signal on each axis.

These requirements will help to determine the accelerometer bandwidth, the speed of the microcontroller clock and the length of the T2 period.

When selecting a microcontroller it is helpful to have a counter timer port available. The microcontroller should have provisions for software calibration. While the ADXL202/ADXL210 are highly accurate accelerometers, they have a wide tolerance for initial offset. The easiest way to null this offset is with a calibration factor saved on the microcontroller or by a user calibration for zero *g*. In the case where the offset is calibrated during manufacture, there are several options, including external EEPROM and microcontrollers with "one-time programmable" features.

DESIGN TRADE-OFFS FOR SELECTING FILTER CHARACTERISTICS: THE NOISE/BW TRADE-OFF

The accelerometer bandwidth selected will determine the measurement resolution (smallest detectable acceleration). Filtering can be used to lower the noise floor and improve the resolution of the accelerometer. Resolution is dependent on both the analog filter bandwidth at X_{FILT} and Y_{FILT} and on the speed of the microcontroller counter.

The analog output of the ADXL202/ADXL210 has a typical bandwidth of 5 kHz, much higher than the duty cycle stage is capable of converting. The user must filter the signal at this point to limit aliasing errors. To minimize DCM errors the analog bandwidth should be less than 1/10 the DCM frequency. Analog bandwidth may be increased to up to 1/2 the DCM frequency in many applications. This will result in greater dynamic error generated at the DCM.

The analog bandwidth may be further decreased to reduce noise and improve resolution. The ADXL202/ADXL210 noise has the characteristics of white Gaussian noise that contributes equally at all frequencies and is described in terms of µg per root Hz; i.e., the noise is proportional to the square root of the bandwidth of the accelerometer. It is recommended that the user limit bandwidth to the lowest frequency needed by the application, to maximize the resolution and dynamic range of the accelerometer.

With the single pole roll-off characteristic, the typical noise of the ADXL202/ADXL210 is determined by the following equation:

$$Noise\,(rms) = \left(500\ \mu g/\sqrt{Hz}\right) \times \left(\sqrt{BW \times 1.5}\right)$$

At 100 Hz the noise will be:

$$Noise\,(rms) = \left(500\ \mu g/\sqrt{Hz}\right) \times \left(\sqrt{100 \times (1.5)}\right) = 6.12\ mg$$

Often the peak value of the noise is desired. Peak-to-peak noise can only be estimated by statistical methods. Table III is useful for estimating the probabilities of exceeding various peak values, given the rms value.

Table III. Estimation of Peak-to-Peak Noise

Nominal Peak-to-Peak Value	% of Time that Noise Will Exceed Nominal Peak-to-Peak Value
2.0 × rms	32%
4.0 × rms	4.6%
6.0 × rms	0.27%
8.0 × rms	0.006%

The peak-to-peak noise value will give the best estimate of the uncertainty in a single measurement.

Table IV gives typical noise output of the ADXL202/ADXL210 for various C_X and C_Y values.

Table IV. Filter Capacitor Selection, C_X and C_Y

Bandwidth	C_X, C_Y	rms Noise	Peak-to-Peak Noise Estimate 95% Probability (rms × 4)
10 Hz	0.47 µF	1.9 *mg*	7.6 *mg*
50 Hz	0.10 µF	4.3 *mg*	17.2 *mg*
100 Hz	0.05 µF	6.1 *mg*	24.4 *mg*
200 Hz	0.027 µF	8.7 *mg*	35.8 *mg*
500 Hz	0.01 µF	13.7 *mg*	54.8 *mg*

CHOOSING T2 AND COUNTER FREQUENCY: DESIGN TRADE-OFFS

The noise level is one determinant of accelerometer resolution. The second relates to the measurement resolution of the counter when decoding the duty cycle output.

The ADXL202/ADXL210's duty cycle converter has a resolution of approximately 14 bits; better resolution than the accelerometer itself. The actual resolution of the acceleration signal is, however, limited by the time resolution of the counting devices used to decode the duty cycle. The faster the counter clock, the higher the resolution of the duty cycle and the shorter the T2 period can be for a given resolution. The following table shows some of the trade-offs. It is important to note that this is the resolution due to the microprocessors's counter. It is probable that the accelerometer's noise floor may set the lower limit on the resolution, as discussed in the previous section.

Table V. Trade-Offs Between Microcontroller Counter Rate, T2 Period and Resolution of Duty Cycle Modulator

T2 (ms)	R_{SET} (kΩ)	ADXL202/ ADXL210 Sample Rate	Counter-Clock Rate (MHz)	Counts per T2 Cycle	Counts per *g*	Resolution (*mg*)
1.0	124	1000	2.0	2000	250	4.0
1.0	124	1000	1.0	1000	125	8.0
1.0	124	1000	0.5	500	62.5	16.0
5.0	625	200	2.0	10000	1250	0.8
5.0	625	200	1.0	5000	625	1.6
5.0	625	200	0.5	2500	312.5	3.2
10.0	1250	100	2.0	20000	2500	0.4
10.0	1250	100	1.0	10000	1250	0.8
10.0	1250	100	0.5	5000	625	1.6

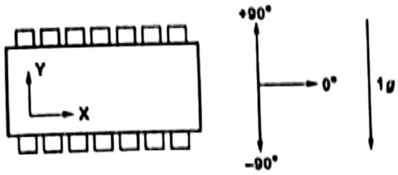
STRATEGIES FOR USING THE DUTY CYCLE OUTPUT WITH MICROCONTROLLERS

Application notes outlining various strategies for using the duty cycle output with low cost microcontrollers are available from the factory.

USING THE ADXL202/ADXL210 AS A DUAL AXIS TILT SENSOR

One of the most popular applications of the ADXL202/ADXL210 is tilt measurement. An accelerometer uses the force of gravity as an input vector to determine orientation of an object in space.

An accelerometer is most sensitive to tilt when its sensitive axis is perpendicular to the force of gravity, i.e., parallel to the earth's surface. At this orientation its sensitivity to changes in tilt is highest. When the accelerometer is oriented on axis to gravity, i.e., near its +1 *g* or –1 *g* reading, the change in output acceleration per degree of tilt is negligible. When the accelerometer is perpendicular to gravity, its output will change nearly 17.5 m*g* per degree of tilt, but at 45° degrees it is changing only at 12.2 m*g* per degree and resolution declines. The following table illustrates the changes in the X and Y axes as the device is tilted ±90° through gravity.



X AXIS ORIENTATION TO HORIZON (°)	X OUTPUT (g)	Δ PER DEGREE OF TILT (mg)	Y OUTPUT (g)	Δ PER DEGREE OF TILT (mg)
	X OUTPUT		Y OUTPUT (g)	
–90	–1.000	–0.2	0.000	17.5
–75	–0.966	4.4	0.259	16.9
–60	–0.866	8.6	0.500	15.2
–45	–0.707	12.2	0.707	12.4
–30	–0.500	15.0	0.866	8.9
–15	–0.259	16.8	0.966	4.7
0	0.000	17.5	1.000	0.2
15	0.259	16.9	0.966	–4.4
30	0.500	15.2	0.866	–8.6
45	0.707	12.4	0.707	–12.2
60	0.866	8.9	0.500	–15.0
75	0.966	4.7	0.259	–16.8
90	1.000	0.2	0.000	–17.5

Figure 14. How the X and Y Axes Respond to Changes in Tilt

A DUAL AXIS TILT SENSOR: CONVERTING ACCELERATION TO TILT

When the accelerometer is oriented so both its X and Y axes are parallel to the earth's surface it can be used as a two axis tilt sensor with a roll and a pitch axis. Once the output signal from the accelerometer has been converted to an acceleration that varies between –1 *g* and +1 *g*, the output tilt in degrees is calculated as follows:

$$Pitch = ASIN\,(Ax/1\,g)$$
$$Roll = ASIN\,(Ay/1\,g)$$

Be sure to account for overranges. It is possible for the accelerometers to output a signal greater than ±1 *g* due to vibration, shock or other accelerations.

MEASURING 360° OF TILT

It is possible to measure a full 360° of orientation through gravity by using two accelerometers oriented perpendicular to one another (see Figure 15). When one sensor is reading a maximum change in output per degree, the other is at its minimum

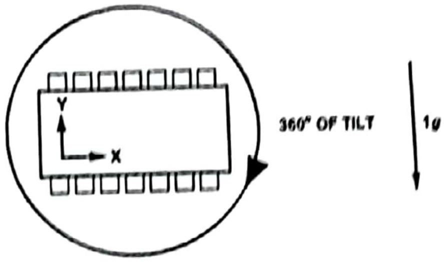


Figure 15. Using a Two-Axis Accelerometer to Measure 360° of Tilt

USING THE ANALOG OUTPUT

The ADXL202/ADXL210 was specifically designed for use with its digital outputs, but has provisions to provide analog outputs as well.

Duty Cycle Filtering

An analog output can be reconstructed by filtering the duty cycle output. This technique requires only passive components. The duty cycle period (T2) should be set to 1 ms. An RC filter with a 3 dB point at least a factor of 10 less than the duty cycle frequency is connected to the duty cycle output. The filter resistor should be no less than 100 kΩ to prevent loading of the output stage. The analog output signal will be ratiometric to the supply voltage. The advantage of this method is an output scale factor of approximately double the analog output. Its disadvantage is that the frequency response will be lower than when using the X_{FILT}, Y_{FILT} output.

X_{FILT}, Y_{FILT} Output

The second method is to use the analog output present at the X_{FILT} and Y_{FILT} pin. Unfortunately, these pins have a 32 kΩ output impedance and are not designed to drive a load directly. An op amp follower may be required to buffer this pin. The advantage of this method is that the full 5 kHz bandwidth of the accelerometer is available to the user. A capacitor still must be added at this point for filtering. The duty cycle converter should be kept running by using R_{SET} <10 MΩ. Note that the accelerometer offset and sensitivity are ratiometric to the supply voltage. The offset and sensitivity are nominally:

0 *g* Offset = $V_{DD}/2$	2.5 V at +5 V
ADXL202 Sensitivity = (60 mV × V_S)/*g*	300 mV/*g* at +5 V, V_{DD}
ADXL210 Sensitivity = (20 mV × V_S)/*g*	100 mV/*g* at +5 V, V_{DD}

USING THE ADXL202/ADXL210 IN VERY LOW POWER APPLICATIONS

An application note outlining low power strategies for the ADXL202/ADXL210 is available. Some key points are presented here. It is possible to reduce the ADXL202/ADXL210's average current from 0.6 mA to less than 20 μA by using the following techniques:

1. Power Cycle the accelerometer.
2. Run the accelerometer at a Lower Voltage, (Down to 3 V).

Power Cycling with an External A/D

Depending on the value of the X_{FILT} capacitor, the ADXL202/ADXL210 is capable of turning on and giving a good reading in 1.6 ms. Most microcontroller based A/Ds can acquire a reading in another 25 μs. Thus it is possible to turn on the ADXL202/ADXL210 and take a reading in <2 ms. If we assume that a 20 Hz sample rate is sufficient, the total current required to take 20 samples is 2 ms × 20 samples/s × 0.6 mA = 24 μA average current. Running the part at 3 V will reduce the supply current from 0.6 mA to 0.4 mA, bringing the average current down to 16 μA.

The A/D should read the analog output of the ADXL202/ADXL210 at the X_{FILT} and Y_{FILT} pins. A buffer amplifier is recommended, and may be required in any case to amplify the analog output to give enough resolution with an 8-bit to 10-bit converter.

Power Cycling When Using the Digital Output

An alternative is to run the microcontroller at a higher clock rate and put it into shutdown between readings, allowing the use of the digital output. In this approach the ADXL202/ADXL210 should be set at its fastest sample rate (T2 = 0.5 ms), with a 500 Hz filter at X_{FILT} and Y_{FILT}. The concept is to acquire a reading as quickly as possible and then shut down the ADXL202/ADXL210 and the microcontroller until the next sample is needed.

In either of the above approaches, the ADXL202/ADXL210 can be turned on and off directly using a digital port pin on the microcontroller to power the accelerometer without additional components. The port should be used to switch the common pin of the accelerometer so the port pin is "pulling down."

CALIBRATING THE ADXL202/ADXL210

The initial value of the offset and scale factor for the ADXL202/ADXL210 will require calibration for applications such as tilt measurement. The ADXL202/ADXL210 architecture has been designed so that these calibrations take place in the software of the microcontroller used to decode the duty cycle signal. Calibration factors can be stored in EEPROM or determined at turn-on and saved in dynamic memory.

For low *g* applications, the force of gravity is the most stable, accurate and convenient acceleration reference available. A reading of the 0 *g* point can be determined by orientating the device parallel to the earth's surface and then reading the output.

A more accurate calibration method is to make a measurements at +1 *g* and –1 *g*. The sensitivity can be determined by the two measurements.

To calibrate, the accelerometer's measurement axis is pointed directly at the earth. The 1 *g* reading is saved and the sensor is turned 180° to measure –1 *g*. Using the two readings, the sensitivity is:

Let A = Accelerometer output with axis oriented to +1 g
Let B = Accelerometer output with axis oriented to –1 g then:

$$Sensitivity = [A - B]/2\,g$$

For example, if the +1 *g* reading (A) is 55% duty cycle and the –1 *g* reading (B) is 32% duty cycle, then:

$$Sensitivity = [55\% - 32\%]/2\,g = 11.5\%/g$$

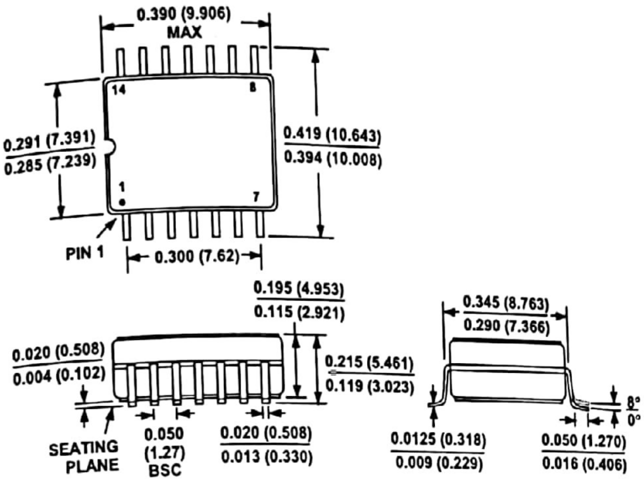
These equations apply whether the output is analog, or duty cycle.

Application notes outlining algorithms for calculating acceleration from duty cycle and automated calibration routines are available from the factory.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

14-Lead CERPAK (QC-14)



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NI 6034E/6035E/6036E Family Specifications

This document lists the I/O terminal summary and specifications for the devices that make up the NI 6034E/6035E/6036E family of devices. This family includes the following devices:

- NI PCI-6034E
- NI PCI-6035E
- NI DAQCard-6036E
- NI PCI-6036E

I/O Terminal Summary

Note With NI-DAQmx, National Instruments revised its terminal names so they are easier to understand and more consistent among NI hardware and software products. The revised terminal names used in this document are usually similar to the names they replace. For a complete list of Traditional NI-DAQ (Legacy) terminal names and their NI-DAQmx equivalents, refer to *Terminal Name Equivalents* of the *E Series Help*.

Table 1. I/O Terminals

Terminal Name	Terminal Type and Direction	Impedance Input/ Output	Protection (V) On/Off	Source (mA at V)	Sink (mA at V)	Rise Time (ns)	Bias
AI <0..15>	AI	100 GΩ in parallel with 100 pF	25/15	—	—	—	±200 pA
AI SENSE	AI	100 GΩ in parallel with 100 pF	25/15	—	—	—	±200 pA
AI GND	—	—	—	—	—	—	—
AO 0†	AO	0.1 Ω	Short-circuit to ground	5 at 10	5 at −10	—	—
AO 1†	AO	0.1 Ω	Short-circuit to ground	5 at 10	5 at −10	—	—
AO GND	—	—	—	—	—	—	—
D GND	—	—	—	—	—	—	—

NATIONAL INSTRUMENTS™

Table 1. I/O Terminals (Continued)

Terminal Name	Terminal Type and Direction	Impedance Input/ Output	Protection (V) On/Off	Source (mA at V)	Sink (mA at V)	Rise Time (ns)	Bias
+5 V	—	0.1 Ω	Short-circuit to ground	1 A fused	—	—	—
P0.<0..7>	DIO	—	V_{CC} + 0.5	13 at (V_{CC} – 0.4)	24 at 0.4	1.1	50 kΩ pu
AI HOLD COMP	DO	—	—	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
EXT STROBE*	DO	—	—	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 0/ (AI START TRIG)	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 1/ (AI REF TRIG)	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 2/ AI CONV CLK)*	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 3/ CTR 1 SOURCE	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 4/CTR 1 GATE	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
CTR 1 OUT	DO	—	—	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 5/ (AO SAMP CLK)*	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 6/ (AO START TRIG)	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 7/ (AI SAMP CLK)	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 8/ CTR 0 SOURCE	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
PFI 9/ CTR 0 GATE	DIO	—	V_{CC} + 0.5	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu
CTR 0 OUT	DO	—	—	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu

Table 1. I/O Terminals (Continued)

Terminal Name	Terminal Type and Direction	Impedance Input/ Output	Protection (V) On/Off	Source (mA at V)	Sink (mA at V)	Rise Time (ns)	Bias
FREQ OUT	DO	—	—	3.5 at (V_{CC} – 0.4)	5 at 0.4	1.5	50 kΩ pu

* Indicates active low.
† NI 6035E/6036E only.
AI = Analog Input   DIO = Digital Input/Output   pu = pull-up
AO = Analog Output   DO = Digital Output
Note: The tolerance on the 50 kΩ pull-up resistors is large. Actual value might range between 17 kΩ and 100 kΩ.

Specifications

The following specifications are typical at 25 °C unless otherwise noted.

Analog Input

Input Characteristics

Number of channels........................ 16 single-ended or 8 differential (software-selectable per channel)

Type of A/D converter (ADC)........ Successive approximation

Resolution.. 16 bits, 1 in 65,536

Max sampling rate .... 200 kS/s guaranteed

Input signal ranges

Range (Software-Selectable)	Bipolar Input Range
20 V	±10 V
10 V	±5 V
1 V	±500 mV
100 mV	±50 mV

Input coupling .... DC

Max working voltage (signal + common mode) .... Each input should remain within ±11 V of ground

Overvoltage protection

Signal	Powered On (V)	Powered Off (V)
AI <0..15>, AI SENSE	±25	±15

FIFO buffer size

NI DAQCard-6036E .... 1,024 samples (S)

NI 6034E, NI 6035E, NI PCI-6036E .... 512 S

DMA (PCI only)

Channels.......................................1

Data sources/destinations............ Analog input, analog output, counter/timer 0, or counter/timer 1

Data transfers.................................. Direct memory access (DMA)[1], interrupts, programmed I/O

DMA[1] modes.................................. Scatter-gather (single transfer, demand transfer)

Configuration memory size .... 512 words

[1] DMA is not available on the NI DAQCard-6036E.

Accuracy Information (NI 6034E, NI 6035E, NI PCI-6036E Only)

Nominal Range at Full Scale (V)	Absolute Accuracy							Relative Accuracy Resolution (µV)	
	% of Reading		Offset (µV)	Noise + Quantization (µV)		Temp Drift (%/°C)	Absolute Accuracy at Full Scale (mV)		
	24 Hours	1 Year		Single Pt.	Averaged			Single Pt.	Averaged
±10	0.0546	0.0588	±1601	±933	±82.4	0.0010	7.56	1,085	108.5
±5	0.0146	0.0188	±811	±467	±41.2	0.0005	1.79	542	52.24
±0.5	0.0546	0.0588	±100	±56.2	±5.04	0.0010	0.399	66.3	6.630
±0.05	0.0546	0.0588	±28.9	±28.2	±2.75	0.0010	0.0611	36.2	3.616

Note: Accuracies are valid for measurements following an internal E Series calibration. Averaged numbers assume dithering and averaging of 100 single-channel readings. Measurement accuracies are listed for operational temperatures within ±1 °C of internal calibration temperature and ±10 °C of external or factory-calibration temperature. NI recommends a one-year calibration interval. The Absolute Accuracy at Full Scale calculations were performed for a maximum range input voltage (for example, 10 V for the ±10 V range) after one year, assuming 100 points of averaged data. Go to `ni.com/info` and enter info code `rdspec` for example calculations.

Accuracy Information (NI DAQCard-6036E Only)

Nominal Range at Full Scale (V)		Absolute Accuracy							Relative Accuracy Resolution (µV)	
Positive Full Scale	Negative Full Scale	% of Reading		Offset (µV)	Noise + Quantization (µV)		Temp Drift (%/°C)	Absolute Accuracy at Full Scale (mV)		
		24 Hours	1 Year		Single Pt.	Averaged			Single Pt.	Averaged
+10	−10	0.0549	0.0591	2,602.05	1,500.21	137.329	0.0010	8.653	1,808.17	180.82
+5.0	−5.0	0.0149	0.0191	1,311.53	750.10	68.665	0.0005	2.337	904.08	90.408
+0.5	−0.5	0.0549	0.0591	150.053	84.319	7.782	0.0010	0.454	102.463	10.246
+0.05	−0.05	0.0549	0.0591	33.905	32.779	3.204	0.0010	0.067	42.191	4.219

Note: Accuracies are valid for measurements following an internal E Series calibration. Averaged numbers assume dithering and averaging of 100 single-channel readings. Measurement accuracies are listed for operational temperatures within ±1 °C of internal calibration temperature and ±10 °C of external or factory-calibration temperature. NI recommends a one-year calibration interval. The Absolute Accuracy at Full Scale calculations were performed for a maximum range input voltage (for example, 10 V for the ±10 V range) after one year, assuming 100 points of averaged data. Go to `ni.com/info` and enter info code `rdspec` for example calculations.

Transfer Characteristics

Integral nonlinearity (INL)

NI DAQCard-6036E .... ±3 LSB typ, ±6 LSB max

NI 6034E, NI 6035E, NI PCI-6036E .... ±1.5 LSB typ, ±3.0 LSB max

Differential nonlinearity (DNL)

NI DAQCard-6036E .... ±1 LSB typ, +4 LSB, −2 LSB max

NI 6034E, NI 6035E, NI PCI-6036E .... ±0.5 LSB typ, ±1.0 LSB max

No missing codes

NI DAQCard-6036E .... 15 bits

NI 6034E, NI 6035E, NI PCI-6036E .... 16 bits

Offset error

Pregain error after calibration .... ±1.0 μV max

Pregain error before calibration

NI DAQCard-6036E .... ±3.0 mV max

NI 6034E, NI 6035E, NI PCI-6036E .... ±28.8 mV max

Postgain error after calibration

NI DAQCard-6036E .... ±0.20 mV max

NI 6034E, NI 6035E, NI PCI-6036E .... ±157 μV max

Postgain error before calibration

NI DAQCard-6036E .... ±50.1 mV max

NI 6034E, NI 6035E, NI PCI-6036E .... ±40 mV max

Gain error (relative to calibration reference)

After calibration (gain = 1)

NI DAQCard-6036E .... ±77 ppm of reading max

NI 6034E, NI 6035E, NI PCI-6036E .... ±74 ppm of reading max

Before calibration

NI DAQCard-6036E .... ±19,800 ppm of reading max

NI 6034E, NI 6035E, NI PCI-6036E .... ±18,900 ppm of reading max

Gain ≠ 1 with gain error adjusted to 0 at gain = 1 .... ±200 ppm of reading max

Amplifier Characteristics

Input impedance

Normal powered on .... 100 GΩ in parallel with 100 pF

Powered off .... 820 Ω

Overload .... 820 Ω

Input bias current

NI DAQCard-6036E .... ±800 pA

NI 6034E, NI 6035E, NI PCI-6036E .... ±200 pA

Input offset current .... ±100 pA

Common-mode rejection ratio (CMRR), DC to 60 Hz

Range	Bipolar
20 V	85 dB
10 V	85 dB
1 V	96 dB
100 mV	96 dB

Dynamic Characteristics

Bandwidth

Signal	Bandwidth
Small (−3 dB)	413 kHz
Large (1% THD)	490 kHz

Settling time for full-scale step[1]

NI DAQCard-6036E

Range 100 mV, 1 V, 20 V .... ±4.5 LSB, 5 μs typ

Range 10 V .... ±2 LSB, 5 μs typ

NI 6034E, NI 6035E, NI PCI-6036E

Range 100 mV .... ±4 LSB, 5 μs typ

Range 1 to 20 V .... ±2 LSB, 5 μs max

System noise (LSB_{rms}, including quantization)

NI DAQCard-6036E

Range 10 V, 20 V 1.5

Range 1 V 1.7

Range 100 mV 7.0

[1] Accuracy values are valid for source impedances <1 kΩ. Refer to *Multichannel Scanning Considerations* of the *E Series Help* for more information.

NI 6034E, NI 6035E, NI PCI-6036E

Range 10 to 20 V 0.8

Range 1 V 1.0

Range 100 mV 6.2

Crosstalk ....DC to 100 kHz

Adjacent channels.............................–75 dB

Other channels...................................–90 dB

Stability

Recommended warm-up time

NI DAQCard-6036E ....30 minutes

NI 6034E, NI 6035E,
NI PCI-6036E ....15 minutes

Offset temperature coefficient

Pregain ....±20 µV/°C

Postgain..±175 µV/°C

Gain temperature coefficient...........±20 ppm/°C

Analog Output (NI 6035E/6036E Only)

Output Characteristics

Number of channels........................2 voltage

Resolution

NI DAQCard-6036E,
NI PCI-6036E.............................16 bits, 1 in 65,536

NI 6035E ....12 bits, 1 in 4,096

Max update rate

DMA[1] ....10 kHz, system-dependent

Interrupts ....1 kHz, system-dependent

Type of D/A converter (DAC)........Double buffered, multiplying

FIFO buffer size.............................None

Data transfers ....DMA, interrupts, programmed I/O

DMA modes....................................Scatter-gather (single transfer, demand transfer)

Accuracy Information

Device	Nominal Range at Full Scale (V)	Absolute Accuracy					
		% of Reading			Offset (µV)	Temp Drift (%/°C)	Absolute Accuracy at Full Scale (mV)
		24 Hours	90 Days	1 Year			
NI DAQCard-6036E	±10	0.0091	0.0111	0.0133	1.22	0.0005	2.547
NI 6035E	±10	0.18	0.02	0.022	5.93	0.0005	8.127
NI PCI-6036E	±10	0.009	0.011	0.013	1.1	0.0005	2.417

Note: Accuracies are valid for measurements following an internal E Series calibration. Averaged numbers assume dithering and averaging of 100 single-channel readings. Measurement accuracies are listed for operational temperatures within ±1 °C of internal calibration temperature and ±10 °C of external or factory-calibration temperature. NI recommends a one-year calibration interval. The Absolute Accuracy at Full Scale calculations were performed for a maximum range input voltage (for example, 10 V for the ±10 V range) after one year, assuming 100 points of averaged data. Go to `ni.com/info` and enter info code `rdspec` for example calculations.

[1] DMA is not available on the NI DAQCard-6036E.

Transfer Characteristics

INL, after calibration

NI DAQCard-6036E, NI PCI-6036E	±2 LSB max
NI 6035E	±0.3 LSB typ, ±0.5 LSB max

DNL .... ±1.0 LSB max

Monotonicity

NI DAQCard-6036E, NI PCI-6036E	16 bits, guaranteed after calibration
NI 6035E	12 bits, guaranteed after calibration

Offset error

After calibration

NI DAQCard-6036E, NI PCI-6036E	±305 µV max
NI 6035E	±1.0 mV max

Before calibration

NI DAQCard-6036E	±60 mV max
NI 6035E	±200 mV max
NI PCI-6036E	±44 mV max

Gain error (relative to internal reference)

After calibration

NI DAQCard-6036E, NI PCI-6036E	±30.5 ppm
NI 6035E	±100 ppm

Before calibration

NI DAQCard-6036E, NI PCI-6036E	±0.50%
NI 6035E	±0.75%

Voltage Output

Range	±10 V
Output coupling	DC
Output impedance	0.1 Ω max
Current drive	±5 mA max
Protection	Short-circuit to ground

Power-on state (steady state)

NI DAQCard-6036E	±60 mV
NI 6035E	±200 mV
NI PCI-6036E	±44 mV

Initial power-up glitch

Magnitude

NI DAQCard-6036E	±1.6 V
NI 6035E	±1.1 V
NI PCI-6036E	±2.2 V

Duration

NI DAQCard-6036E	545 ms
NI 6035E	2.0 ms
NI PCI-6036E	42 µs

Power reset glitch

Magnitude

NI DAQCard-6036E	±1.6 V
NI 6035E, NI PCI-6036E	±2.2 V

Duration

NI DAQCard-6036E	545 ms
NI 6035E	4.2 µs
NI PCI-6036E	42 µs

Dynamic Characteristics

Settling time for full-scale step

NI DAQCard-6036E	5 µs to ±4.5 LSB accuracy
NI 6035E	10 µs to ±0.5 LSB accuracy
NI PCI-6036E	5 µs to ±1 LSB accuracy

Slew rate

NI DAQCard-6036E	5 V/µs
NI 6035E	10 V/µs
NI PCI-6036E	15 V/µs

Noise

NI DAQCard-6036E	160 μV_{rms}, DC to 400 kHz
NI 6035E	200 μV_{rms}, DC to 1 MHz
NI PCI-6036E	110 μV_{rms}, DC to 400 kHz

Mid-scale transition glitch (NI 6035E and NI PCI-6036E only)

Magnitude

NI 6035E	±12 mV
NI PCI-6036E	±10 mV

Duration

NI 6035E	2.0 µs
NI PCI-6036E	1.0 µs

Stability

Offset temperature coefficient
- NI DAQCard-6036E ....±150 µV/°C
- NI 6035E......................................±50 µV/°C
- NI PCI-6036E ....±35 µV/°C

Gain temperature coefficient
- NI DAQCard-6036E ....±8 ppm/°C
- NI 6035E......................................±25 ppm/°C
- NI PCI-6036E ....±6.5 ppm/°C

Digital I/O

Number of channels..........................8 input/output

Compatibility....................................5 V TTL/CMOS

Digital logic levels on P0.<0..7>

Level	Min	Max
Input low voltage	0 V	0.8 V
Input high voltage	2.0 V	5.0 V
Input low current (V_{in} = 0 V)	—	–320 µA
Input high current (V_{in} = 5 V)	—	10 µA
Output low voltage (I_{OL} = 24 mA)	—	0.4 V
Output high voltage (I_{OH} = –13 mA)	4.35 V	—

Power-on state ....Input (high-impedance), 50 kΩ pull-up to +5 VDC

Data transfers....................................Programmed I/O

Transfer rate (1 word = 8 bits)[1] ....50 kwords/s, typ

Constant sustainable rate[1]................1 to 10 kwords/s, typ

Timing I/O

Number of channels
- Up/down counter/timers 2
- Frequency scaler 1

Resolution
- Up/down counter/timers ....24 bits
- Frequency scaler ....4 bits

Compatibility....................................5 V TTL/CMOS

Digital logic levels

Level	Min	Max
Input low voltage	0.0 V	0.8 V
Input high voltage	2.0 V	5.0 V
Output low voltage (I_{out} = 5 mA)	—	4.35 V
Output high voltage (I_{out} = –3.5 mA)	0.4 V	—

Base clocks available
- Up/down counter/timers............20 MHz, 100 kHz
- Frequency scaler.........................10 MHz, 100 kHz

Base clock accuracy........................±0.01%

Max external source frequency up/down counter/timers ....20 MHz

External source selections..............PFI <0..9>, RTSI <0..6> (except DAQCard), analog trigger, software-selectable

External gate selections ....PFI <0..9>, RTSI <0..6> (except DAQCard), analog trigger, software-selectable

Min source pulse duration..............10 ns in edge-detect mode

Min gate pulse duration ....10 ns in edge-detect mode

Data transfers
- PCI up/down counter/timer ....DMA[2] (scatter-gather), interrupts, programmed I/O
- DAQCard up/down counter/timer ....Interrupts, programmed I/O

Frequency scaler ....Programmed I/O

---

[1] Not guaranteed on the NI DAQCard-6036E.

[2] DMA is not available on the NI DAQCard-6036E.

Triggers

Digital Trigger

Purpose

- Analog input ..... Start, reference, and pause trigger, sample clock
- Analog output ..... Start and pause trigger, sample clock
- Counter/timers ..... Source, gate

External sources ..... PFI <0..9>, RTSI <0..6> (except DAQCard)

Compatibility ..... 5 V TTL

Response ..... Rising or falling edge

Pulse width ..... 10 ns min

RTSI (PCI Only)

Trigger lines 7

Calibration

Recommended warm-up time

- PCI ..... 15 minutes
- DAQCard ..... 30 minutes

Interval ..... 1 year

External calibration reference ..... Between 6 and 10 V

Onboard calibration reference

- Level ..... 5.000 V (±3.5 mV) (over full operating temperature, actual value stored in EEPROM)
- Temperature coefficient ..... ±5.0 ppm/°C max
- Long-term stability ..... ±15.0 ppm/ $\sqrt{1{,}000 \text{ h}}$

Power Requirement

PCI ..... +5 VDC (±5%) at 0.9 A

DAQCard ..... +5 VDC (±5%) at 0.3 A

Note Excludes power consumed through +5 V available at the I/O connector.

Power available at I/O connector

- PCI ..... +4.65 to +5.25 VDC at 1 A
- DAQCard ..... +4.65 to +5.25 VDC at 0.75 A

Physical

Dimensions

- PCI (not including connectors) ..... 17.5 cm × 10.6 cm (6.9 in. × 4.2 in.)
- DAQCard ..... Type II PC Card

Weight

- NI DAQCard-6036E ..... 32 g (1.1 oz)
- NI PCI-6034E ..... 152 g (5.3 oz)
- NI PCI-6035E ..... 165 g (5.8 oz)
- NI PCI-6036E ..... 114 g (4.0 oz)

I/O connector

- PCI ..... 68-pin male SCSI-II type
- DAQCard ..... 68-position female VHDCI

Maximum Working Voltage

Maximum working voltage refers to the signal voltage plus the common-mode voltage.

Channel-to-earth ..... ±11 V, Installation Category I

Channel-to-channel ..... ±11 V, Installation Category I

Environmental

Operating temperature ..... 0 to 55 °C

Storage temperature ..... –20 to 70 °C

Relative humidity

- NI DAQCard-6036E ..... 10 to 90%, noncondensing
- NI 6035E, NI PCI-6036E ..... 10 to 90%, noncondensing

Safety

NI PCI-6034E/6035E/6036E

The device meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1
- CAN/CSA-C22.2 No. 61010-1

Note For UL and other safety certifications, refer to the product label or visit `ni.com/certification`, search by model number or product line, and click the appropriate link in the Certification column.

NI DAQCard-6036E

The device meets the requirements of the following standards for safety and electrical equipment for measurement, control, and laboratory use:

- IEC 60950, EN 60950
- UL 1950, UL 60950
- CAN/CSA-C22.2 No. 60950

Note For UL and other safety certifications, refer to the product label, or visit `ni.com/certification`, search by model number or product line, and click the appropriate link in the Certification column.

Electromagnetic Compatibility

Emissions	EN 55011 Class A at 10 m FCC Part 15A above 1 GHz
Immunity	EN 61326:1997 A2:2001, Table 1

CE, C-Tick, and FCC Part 15 (Class A) Compliant

Note For EMC compliance, you must operate this device with shielded cabling.

CE Compliance

This product meets the essential requirements of applicable European Directives, as amended for CE marking, as follows:

Low-Voltage Directive (safety)	73/23/EEC
Electromagnetic Compatibility Directive (EMC)	89/336/EEC

Note Refer to the Declaration of Conformity (DoC) for this product for any additional regulatory compliance information. To obtain the DoC for this product, visit `ni.com/certification`, search by model number or product line, and click the appropriate link in the Certification column.

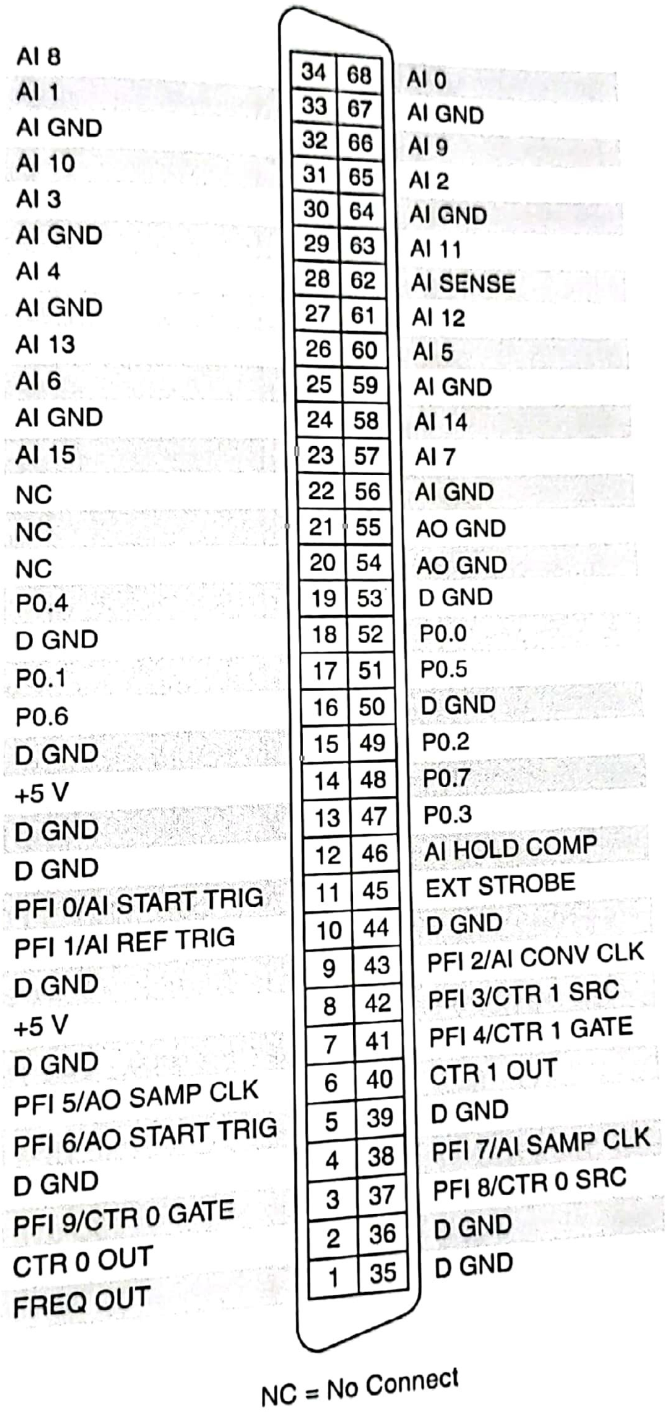


Figure 1. NI 6034E Pinout

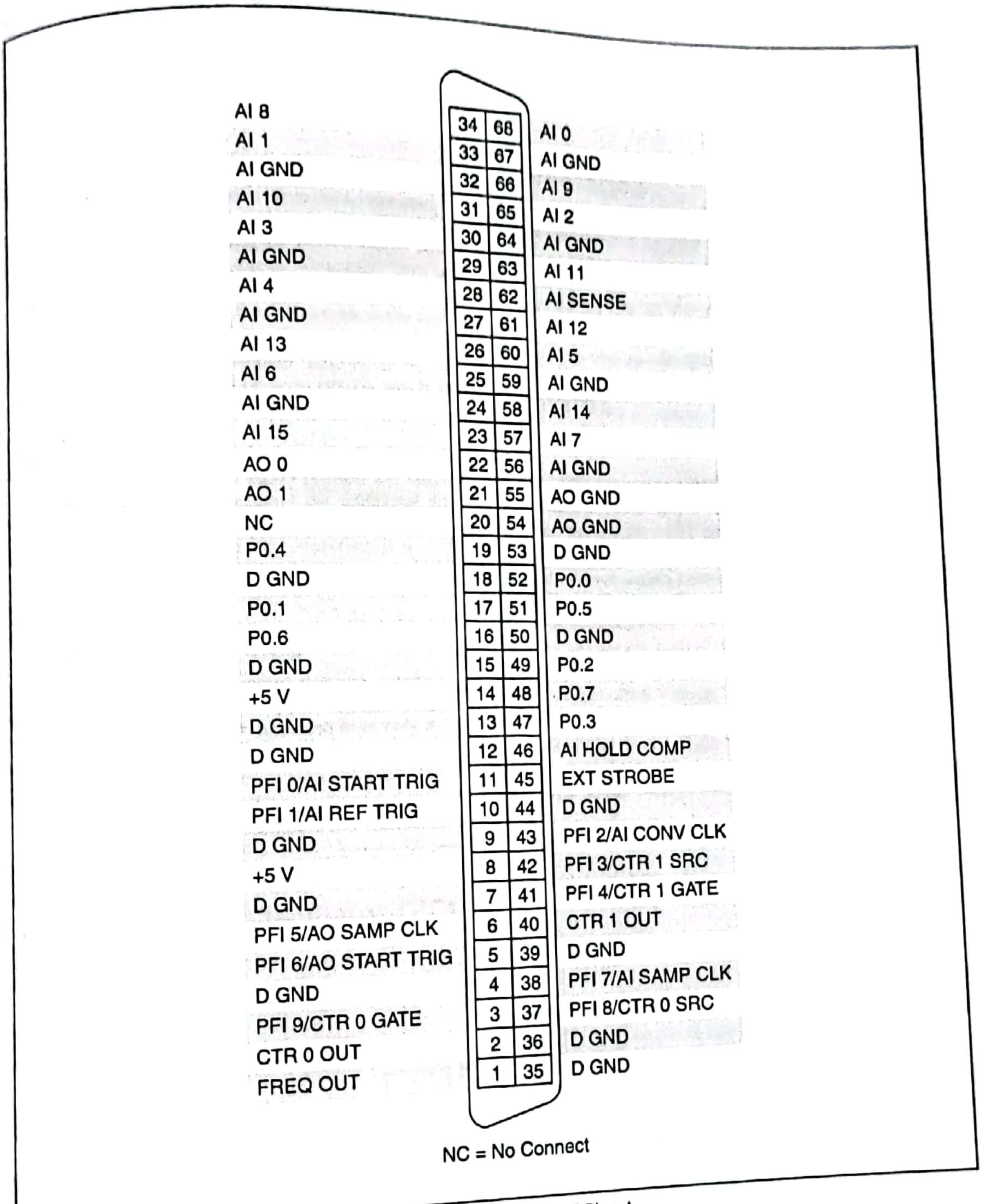


Figure 2. NI 6035E/6036E Pinout

370721C-01 Dec05

General Description

consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, dc gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the ated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.
- The unity gain cross frequency is temperature compensated.
- The input bias current is also temperature compensated.

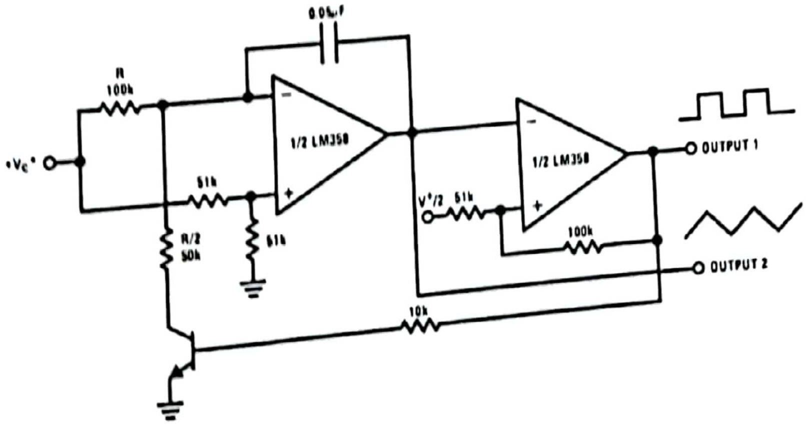
Advantages

- Two internally compensated op amps
- Eliminates need for dual supplies
- Allows direct sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation
- Pin-out same as LM1558/LM1458 dual op amp

Features

- Internally frequency compensated for unity gain
- Large dc voltage gain: 100 dB
- Wide bandwidth (unity gain): 1 MHz (temperature compensated)
- Wide power supply range:
  - — Single supply: 3V to 32V
  - — or dual supplies: ±1.5V to ±16V
- Very low supply current drain (500 µA)—essentially independent of supply voltage
- Low input offset voltage: 2 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing: 0V to V^{+}− 1.5V

Voltage Controlled Oscillator (VCO)



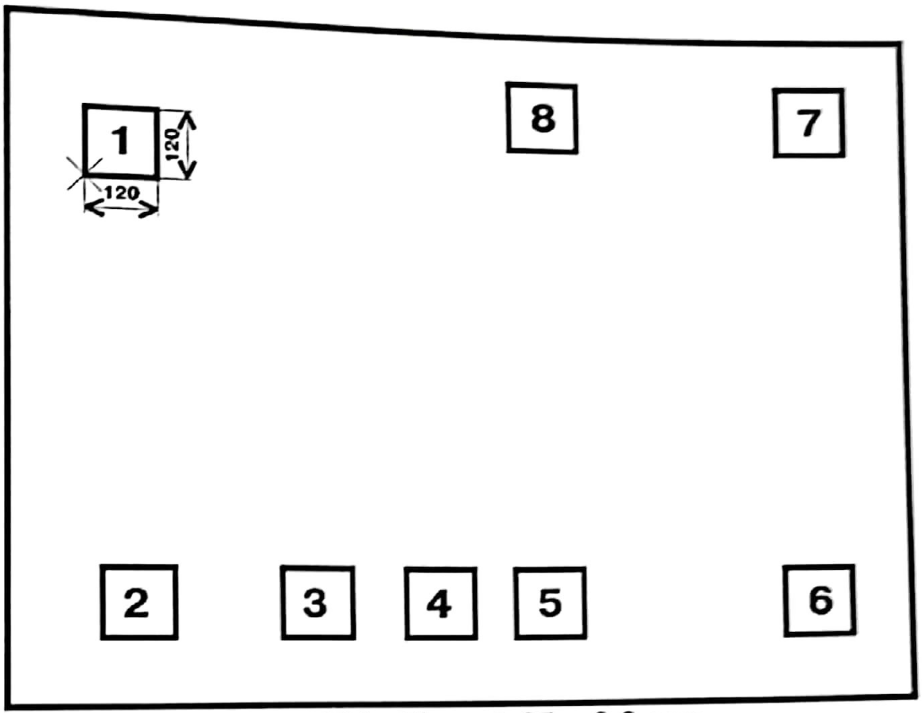
Wing Shing Computer Components Co., (H.K.)Ltd.
Homepage: http://www.wingshing.com
Tel:(852)2341 9276 Fax:(852)2797 8153
E-mail: wsccltd@hkstar.com

electrical characteristics at specified free-air temperature, Vcc = 5 V (unless otherwise noted)

PARAMETER	TEST CONDITIONS*		LM358 MIN	LM358 TYP	LM358 MAX	UNIT
V_{IO} Input offset voltage	Vcc = 5 V to MAX, V_{IC} = V_{ICR} min, Vo=1.4 V	25 °C		3	7	mV
		Full range			9	
αV_{IO} Average temperature coefficient of input offset voltage		Full range		7		μV/°C
I_{IO} Input offset current	Vo=1.4 V	25 °C		2	50	nA
		Full range			150	
αI_{IO} Average temperature coefficient of input offset current		Full range		10		pA/°C
I_{IB} Input bias current	Vo=1.4 V	25 °C		-20	-250	nA
		Full range			-500	
V_{ICR} Common-mode input voltage range	Vcc = 5 V to MAX	25 °C	0 to Vcc-1.5			V
		Full range	0 to Vcc - 2			
V_{OH} High-level output voltage	$R_L \geq 2$ kΩ	25 °C	Vcc-1.5			V
	Vcc = MAX, R_L=2 kΩ	Full range	26			
	Vcc = MAX, $R_L \geq 10$ kΩ	Full range	27	28		
V_{OL} Low-level output voltage	$R_L \geq 10$ kΩ	Full range		5	20	mV
A_{VD} Large-signal differential voltage amplification	Vcc = 15 V, Vo=1V to 11 V, $R_L \geq 2$ kΩ	25 °C	25	100		V/mV
		Full range	15			
CMRR Common-mode rejection ratio	Vcc = 5 V to MAX, V_{IC} = V_{ICR} min	25 °C	65	80		dB
k_{SVR} Supply voltage rejection ratio ($\Delta Vcc/\Delta V_{IO}$)	Vcc = 5 V to MAX	25 °C	65	100		dB
Vo1 /Vo2 Crosstalk attenuation	f=1 kHz to 20 kHz	25 °C		120		dB
Io Output current	Vcc = 15 V, V_{ID}=1 V, V_O= 0	25 °C	-20	-30		mA
		Full range	-10			
	Vcc = 15 V, V_{ID} = - 1 V, Vo = 15 V	25 °C	10	20		
		Full range	5			
	V_{ID} = - 1 V, Vo =200 mV	25 °C	12	30		μA
I_{OS} Short-circuit output current	Vcc at 5 V, GND at -5 V, Vo=0	25 °C		±40	±60	mA
I_{CC} Supply current (two amplifiers)	Vo - 2.5 V, No load	Full range		0.7	1.2	mA
	Vcc = MAX, Vo = 0.5Vcc, No load	Full range		1	2	

* All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified. «MAX» V_{CC} for testing purposes is 30 V. Full range is 0 °C to 70 °C.

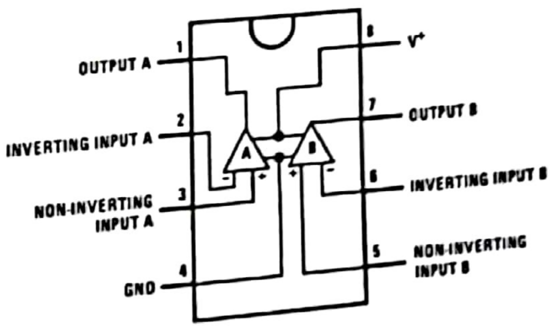
Pad Location



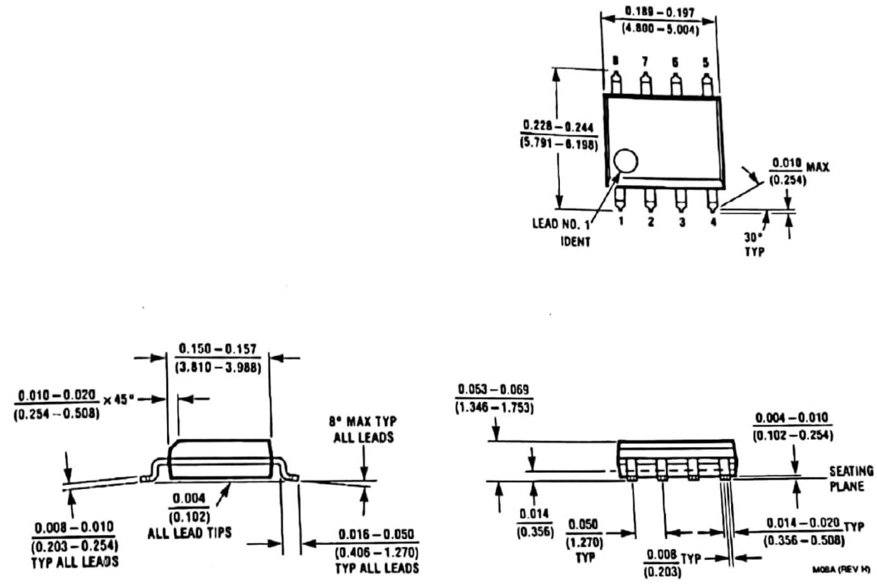
Chip Size: 1.65 x 0.9 mm

Pad N	Pad Name	Coordinates, mkm	
		X	Y
1	#1 OUT	85	625
2	#1 IN-	182	88
3	#1 IN+	518	88
4	GND	845	88
5	#2 IN+	1045	88
6	#2 IN-	1381	88
7	#2 OUT	1478	625
8	V_{CC}	909	720

Connection Diagrams



Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

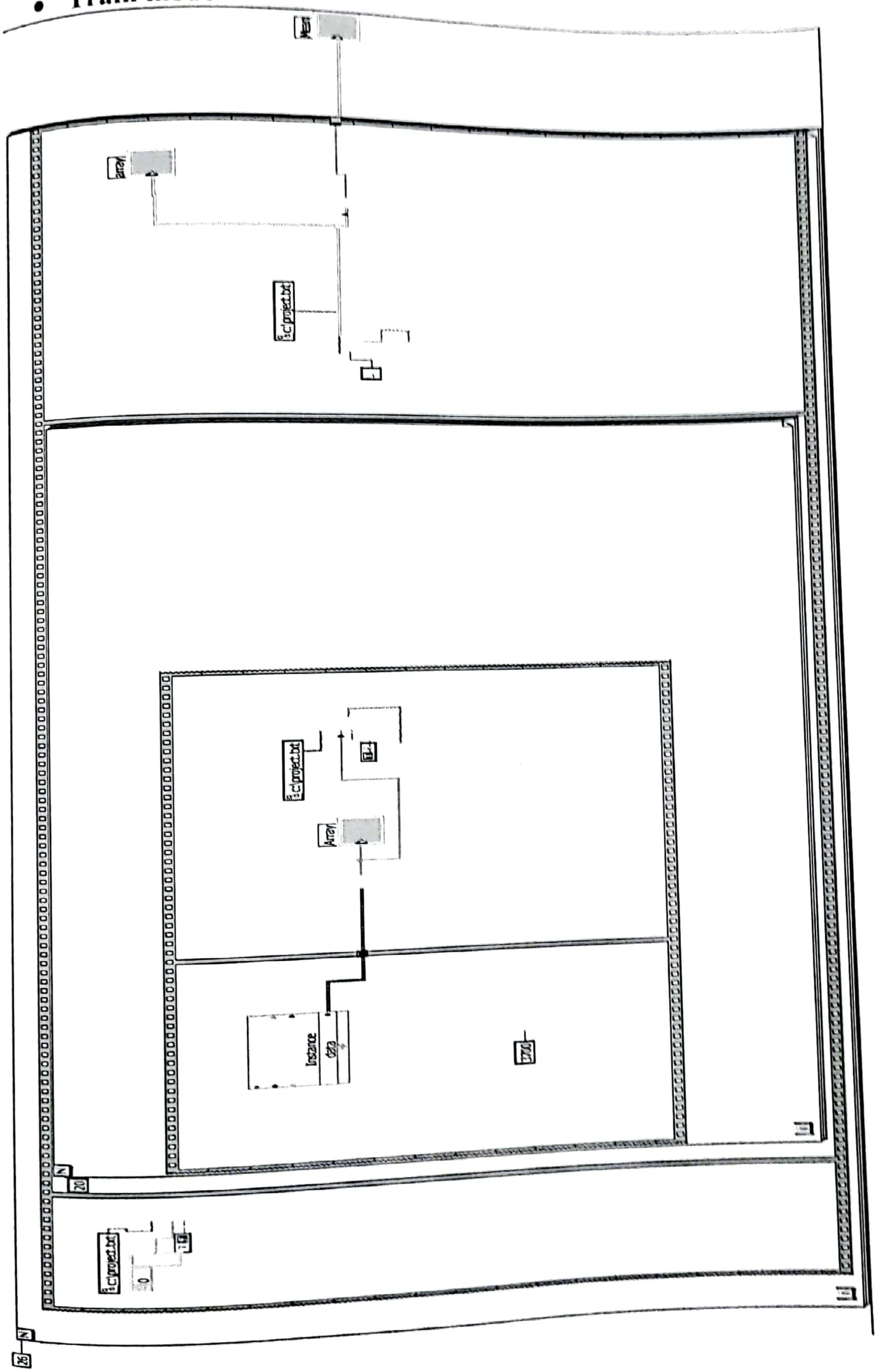


APPENDIX B

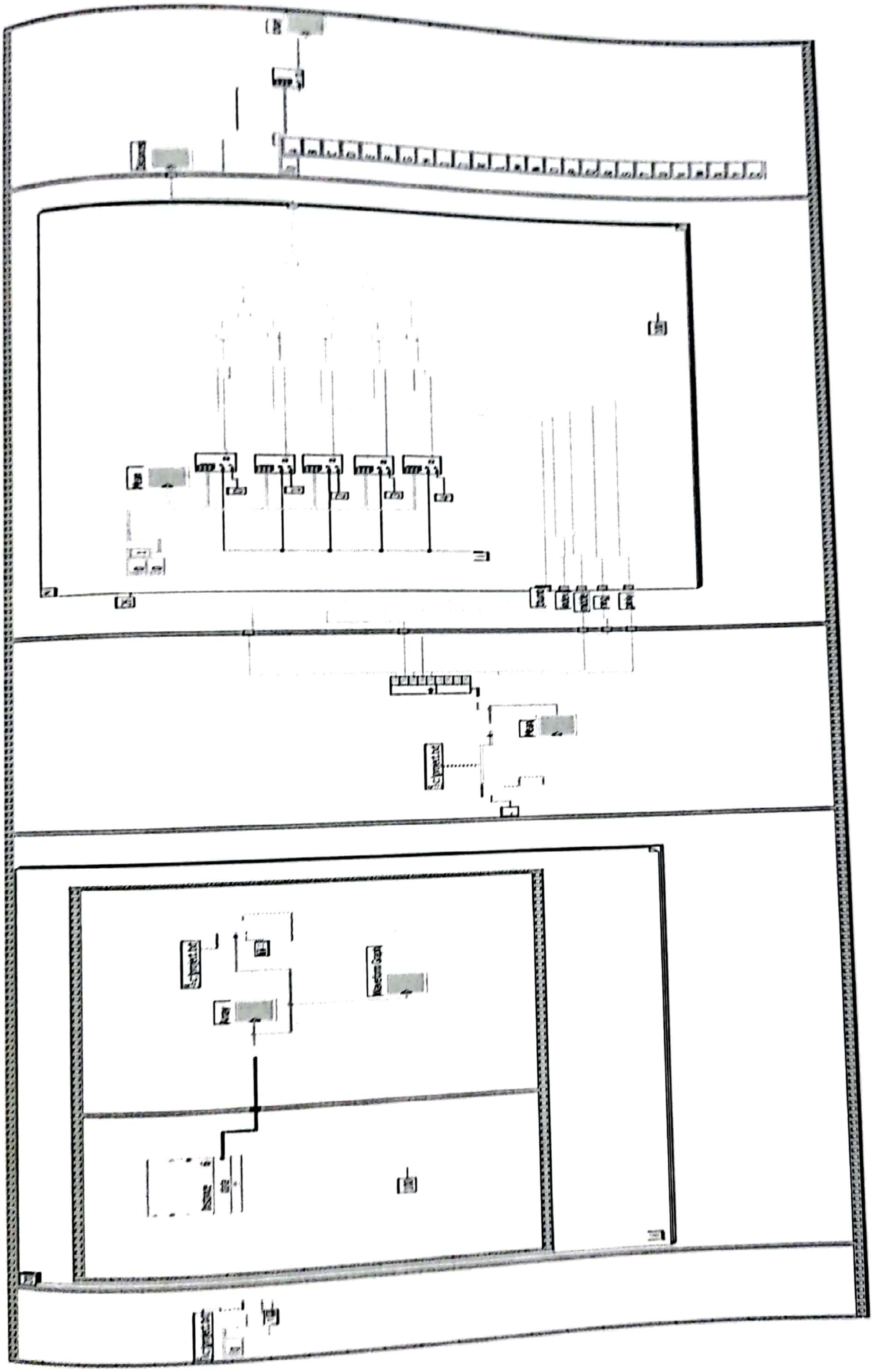
SOURCE CODE

LAVBIEW software

- **Train mode**



2. Test mode



Train mode of PIC

```
#include<p18f4550.h>
#include<adc.h>
#include<delays.h>
#include<math.h>
#include"gamelcd_v3.h"

//#include<timers.h>
#pragma config WDT=OFF
#pragma config LVP=OFF
#pragma config DEBUG=OFF
#pragma config PWRT=OFF

int thumb,index,middle,Ring,Pinky;
int  sumT,sumI,sumM,sumR,sumP;

int T,I,M,R,P;
int i;
int Array[5];
char chararray[5]={'T','I','M','R','P'};


void main(void)
{
TRISA=1; //input
TRISD=0; // output
//TRISC=0;  //output
ADCON1=0x00; // all  channels works as analoge

        sumT=0.0;
                        sumI=0.0;
                sumM=0.0;
                        sumR=0.0;
                        sumP=0.0;




            // A/D converter
                // read the value of the first finger


    OpenADC(ADC_FOSC_64 & ADC_RIGHT_JUST & ADC_2_TAD,
ADC_CH0 & ADC_INT_OFF & ADC_REF_VDD_VSS,00);
```

```
for(i=0;i<20;i++)

{

// read the value of the second finger


SetChanADC(ADC_CH0 );
ConvertADC();
while(BusyADC());
thumb=ReadADC();



// read the value of the second finger

SetChanADC(ADC_CH1 );

ConvertADC();
while(BusyADC());
index=ReadADC();


// read the value of the third finger


SetChanADC(ADC_CH2 );
ConvertADC();
while(BusyADC());
middle=ReadADC();


// read the value of the fourth finger
SetChanADC(ADC_CH3 );

ConvertADC();
while(BusyADC());
Ring=ReadADC();


// read the value of the fifth finger

SetChanADC(ADC_CH4 );
```

```
        ConvertADC();
        while(BusyADC());
        Pinky=ReadADC();
        CloseADC();


    sumT+=thumb;
                    sumI+=index;
            sumM+=middle;
                    sumR+=Ring;
                    sumP+=Pinky;


        } // for




    T=sumT/20;
    I=sumI/20;
    M=sumM/20;
    R=sumR/20;
    P=sumP/20;

    Array[0]=T;
    Array[1]=I;
    Array[2]=M;
    Array[3]=R;
    Array[4]=P;


// LCD


 lcd_init();
  for(i=0; i<5; i++)
   {
    lcd_gotoyx(1,1);
    lcd_putc(chararray[i]);
    lcd_putc(' ');
    lcd_puti(Array[i]);
    Delay10KTCYx(500);

 } // for



     Delay10KTCYx(500);
```

```
// calculate the nearest neighor

} // main
```

PIC Test mode

```
#include<p18f4550.h>
#include<adc.h>
#include<delays.h>
#include<math.h>
#include"gamelcd_v3.h"

//#include<timers.h>
#pragma config WDT=OFF
#pragma config LVP=OFF
#pragma config DEBUG=OFF
#pragma config PWRT=OFF

int thumb,index,middle,Ring,Pinky;
 float x ,D;
      int i ,j;
  int T,I,M,R,P;

int sumT,sumI,sumM,sumR,sumP;

rom  int
sign_values[26][5]={{45,14,58,51,81},{43,12,46,46,66},{44,13,47,47,77},{48,18,24,
51,11},
{43,12,46,46,66},{49,20,26,53,13},{45,14,48,48,88},{44,13,47,47,77},
{49,20,26,53,13},{44,14,47,47,77},{43,13,46,46,66},
{43,12,46,46,66},{47,18,25,51,11},{43,13,46,46,66},{43,12,46,46,66},
{45,14,48,48,88},{43,13,46,46,66},{45,14,48,48,88},{49,20,26,53,13},
{47,18,24,51,11},{48,19,25,52,12},{46,15,49,49,99},{44,13,47,47,77},
{45,14,48,48,88},{43,14,46,47,77},{44,14,47,47,77}};


rom char
characters[26]={'A','B','C','D','E','F','G','H','I','J','k','L','M','N','O','P','Q','R','S','T','U','V','
W','X','Y','Z'};
 float distance[26];

void calculate_N(float thumb,float index,float middle,float Ring,float Pinky);
void nearest_N(float distance[]);
void match(int count);
```

```
void LCD_display(char letter);


void main(void)
{
TRISA=1; //input
TRISD=0; // output
//TRISC=0;  //output
ADCON1=0x00; // all  channels works as analoge


  for(j=0;j<2;){

                    sumT=0.0;
                    sumI=0.0;
              sumM=0.0;
                    sumR=0.0;
                    sumP=0.0;

        for(i=0;i<10;i++)


         {  // for


        // A/D converter
           // read the value of the first finger


         OpenADC(ADC_FOSC_64 & ADC_RIGHT_JUST & ADC_2_TAD,
ADC_CH0 & ADC_INT_OFF & ADC_REF_VDD_VSS,00);


         ConvertADC();
         while(BusyADC());
         thumb=ReadADC();




         // read the value of the second finger

          SetChanADC(ADC_CH1 );

         ConvertADC();
         while(BusyADC());
         index=ReadADC();
```

```
// read the value of the third finger

SetChanADC(ADC_CH2 );
ConvertADC();
while(BusyADC());
middle=ReadADC();

// read the value of the fourth finger
SetChanADC(ADC_CH3 );
ConvertADC();
while(BusyADC());
Ring=ReadADC();

// read the value of the fifth finger

SetChanADC(ADC_CH4 );

ConvertADC();
while(BusyADC());
Pinky=ReadADC();
CloseADC();

sumT+=thumb;
sumI+=index;
sumM+=middle;
sumR+=Ring;
sumP+=Pinky;

} // for

T=sumT/10;
```

```
I=sumI/10;
M=sumM/10;
R=sumR/10;
P=sumP/10;

                    if (j=0)j++;
                         else {

   // calculate the nearest neighor

   calculate_N( T,I, M, R,P);
   nearest_N(distance);
    }

}// outer for

} // main

// calculate of distance b/w points

void calculate_N(float thumb , float index, float middle,float Ring,float Pinky)
  {

    for(i=0;i<26;i++) //row
     {

        x=pow((thumb-sign_values[i][0]),2);
        x += pow((index-sign_values[i][1]),2);
                          x+= pow((middle-sign_values[i][2]),2);
        x+=pow( (Ring-sign_values[i][3]),2 );
        x+=pow((Pinky-sign_values[i][4]),2 );
        D=sqrt(x);

    distance[i]=D;

    } // outer for

  }// method
```

```
// to find the nearest neighbors
//...........................................................................
void nearest_N(float distance[])
 {
   float min;
  int i, count=0;
  min=distance[0];

    for(i=0;i<26;i++)
     {
      if(distance[i]< min)
        {
          min=distance[i];
          count=i;
        } // if
     } // for

    match(count);
  }// function

//  ...........................................................................

void match(int count)
 {

   char letter;


        letter=characters[count];


   LCD_display(letter);
 } //function

//  ...........................................................................

 void LCD_display(char letter)

   {
    lcd_init();
    lcd_gotoyx(1,1);
    lcd_putc(letter);
    while(1);

   } // function


//  ...........................................................................
```