Bluetooth Based Data Acquisition System

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Thesis

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by

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2015

Dedicated to

My Parents

National Institute of Technology Rourkela

CERTIFICATE

This is to certify that the thesis entitled, **" Bluetooth Based Data Acquisition System"** submitted by **Suresh Gurjar** in partial fulfillment of the requirements for the award of Bachelor of Technology and Master of Technology Dual Degree in **Electrical Engineering** with specialization in **Electronic Systems and Communication** during 2014-2015 at the National Institute of Technology Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree.

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"If you don't have time to read, you don't have the time (or the tools) to write. Simple as that."

∼ Stephen King

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Abstract

Data acquisition systems are devices used to collect information to document or analyze some physical phenomenon such as voltage, force or temperature. Data acquisition systems available in the market are very expensive, bulky and power hungry. However, PC based data acquisition system offers a lot of benefit in terms of processing speed, display resolution and connectivity capabilities. The Project aims at designing and implementing a portable, economical and power efficient real-time data acquisition system. The proposed system comprises of a hardware circuitry and a Graphical User Interface (GUI) based on MATLAB environment. The hardware device consist of an 8-bit microcontroller interfaced with a serial ADC chip and a Bluetooth serial module. The Bluetooth HC-05 module is used to provide a wireless connectivity between the hardware and the PC. For testing purpose, the sampling rate of ADC is set to 833 Hz, capturing 50 values per 0.06 second. Whereas on the PC side, the GUI receives the sampled values transmitted by the hardware device and plots the real-time signal waveform. It has been found that the GUI plots the signal waveform with good quality and efficiency. The proposed system can be deployed in number of industrial application such as remote device controlling and ECG data acquisition with some adjustments in the hardware. The wireless connectivity reduces the complexity of cables and probability of occurrences of the accidents in industrial areas.

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Chapter 1

INTRODUCTION

1.1 Overview

Data acquisition systems are devices utilized to gather information to record or analyze any physical phenomenon such as voltage, force or temperature. Data acquisition plays a very important role in industries. Data acquisition available in the market are very expensive, power hungry and complex. Also these devices are not easily available except in electronics laboratory. In todays world computer, which has become very common now-a-days, have become a vital component in the data acquisition system. PC based DAQ system have many advantages over standalone DAQ system. DAQ system can be easily connected with PC providing high speed processing power, productivity, display, and connectivity capabilities [1].

The project aims at developing an economical, portable, wireless, low power data acquisition system. The designed prototype can be used with any Bluetooth enabled laptop or PC with ease. For controlling the acquisition process, a standalone GUI is developed. GUI has many control options along with the display of important signal parameters. While designing the prototype, due care has been taken on the cost, speed and complexity issues. The designed system is equipped with the low power Bluetooth wireless technology. Bluetooth provides a working signal range of 9 meters. Bluetooth is picked over other wireless technologies since it provides better overall characteristics, discussed in detail in chapter 3, required for this project. Replacement of cables by Bluetooth technology has opened up a whole new range of applications. Further it makes the overall system more flexible, portable, stable and trouble free. The standalone application can be installed in any computer which helps to establish the communication with the hardware subsystem. The designed system will also work efficiently with an input signal from any transducer or sensor.

1.2 Objective and scope of the project

The aim of the project work is to design an economical, low power and portable prototype of a PC based data acquisition. The work aims to obliterate the physical cabled connection between a data acquisition system. The proposed design is equipped with the Bluetooth technology to make it a portable and flexible system. The software subsystem consists of a standalone GUI application for the display of analyzed results. The main focus of the work is make the system as compact and economical as possible and at the same time it should be user friendly.

The scope of this project is limited to simple data acquisition since the sampling rate is fixed at 833 Hz. The sampling rate can be increased with the change in parameter in the microcontroller code and with the use high sampling rate ADC chip. The system can be utilized in number of industrial and indoor aspects for devices control and ECG data acquisition with a small adjustments in hardware circuitry. The system can also be operated with battery. Multiple systems can be used to form a network of wireless distributed data acquisition and control system.

1.3 Motivation for the work

The basic operation of DAQ is to acquire signal from a sensor and to analyze and display the results on the screen. Unfortunately, these devices are too bulky and are not readily available except high electronics laboratories. For simple data acquisition, where sampling rate requirement is not high, these bulky DAQ are uneconomical and more complex. So the main motivation for this work is to overcome the above shortcomings. The final aim is to have the following attributes for the designed prototype:

- Low complexity
- User friendly
- Wireless system to enhance the portability of the system
- Economical
- Modular

1.4 Literature Review

Portable DAQ available in the market are highly priced, power hungry and also have low resolution waveform display. The substitution of serial cabled networks by a wireless network offers a lot of benefits obtained from the removal of the cables. Other advantages are that the placement of the whole network becomes much more flexible, quick and trouble-free.

There are many types of wireless technologies available in the market. Bluetooth serial module provides an easy and quick solution for interconnecting the whole system wirelessly. Bluetooth is a personal area network which operates in 2.4 to 2.485 GHz unlicensed ISM band. It uses frequency hopping spread spectrum (FSSS) and delivers a gross data rate of 1 Mbps [2]. Bluetooth master pairs with other seven slave devices to form a star network known as piconet and the devices have a maximum working distance range of 100 m, based on the class of the Bluetooth module. At the MAC layer, the Bluetooth device uses a polling based protocol that provides support for both real-time and asynchronous traffic management [18]. Bluetooth low energy technology is very power efficient and consumes less power than WLANs. As compared to Zigbee , Bluetooth technology offers more data rate. Bluetooth's spread spectrum extends over a frequency bandwidth of 79 MHz whereas ZigBee operates in a bandwidth of 4.5 MHz. This makes Bluetooth more resilient against interference. Bluetooth also provides an adaptive frequency hopping mechanism which helps bandwidth spectrum from being influenced by the interference.

Many applications based on Bluetooth have been studied in recent years. Paper [2] describes an *independent embedded platform for a wireless distributed data acquisition and control system*, and discusses its application in the context of controlling the data processing and communication between sensors and actuators of an autonomous flying robot. The hardware circuit consists of low power Texas instruments MSP430 micrcontroller. ConnectBlue OEM serial adapter devices are employed for wireless connectivity. Related work based on the design of remote device controlling and data acquisition system is studied in [3].

The capability of a Bluetooth device to get paired with other Bluetooth enabled devices have simulated the the interest of networking association. A prototype system [4] has been realized for indoor networking. A number of studies have been conducted on the use of Bluetooth technology in indoor positioning system [5]. Data Acquisition based on ARM (LPC2142) microcontroller were also proposed in [6] [7]. The designed prototype differs from other designs in the fact that it has attained the wireless data transmission after the A/D conversion. It also claims to be straightforward in the circuit, robust in integration, interference resistant, mobile and can be easily used in complicated location such as industrial field.

The paper [8] proposed mobile health (*mHealth*) system for remote acquisition of patient data using Bluetooth technology. The goal of the proposed design is to enhance chronic disease administration using economical mobile phones. A PIC microcontroller and a Bluetooth module (RN-41) are used as components of mHealth.

The paper [9] presents the design and implementation of a low cost, portable, light weight; low power, dual-channel oscilloscope, consisting of a hardware device and a software program. The connection between the hardware and android(OS) phone is provided using Bluetooth technology.

1.5 Thesis Outline

The remaining part of the thesis from here is summarized in this section. The second chapter discusses basics of data acquisition system. The components of DAQ are explained in details. Third chapter focuses on the wireless Bluetooth technology. The fundamental and technical specification are analyzed. Comparison of Bluetooth technology with other standard wireless technology is done in this chapter. In chapter four, we study the design aspects of the developed prototype. The chapter five explains the details of software subsystem of the prototype i.e. code algorithms for microcontroller and graphical user interface (GUI). The experimental test outcomes are examined in chapter six. The thesis is concluded with a conclusion and future work.

Chapter 2

DATA ACQUISITION SYSTEM

2.1 Introduction to Data Acquisition System

In todays world digital electronics instruments dominate many varieties of information systems including data acquisition system. Digital data offers a lot of advantages over analog signal: a digital data can be stored in a memory device for further analysis, digital data is error free, permits higher maximum transmission rates etc.

Data acquisition is the procedure of measuring an electrical or physical phenomenon such as voltage, temperature, pressure, or sound with a computer [1]. A DAQ system consists of sensors, measurement hardware and a PC with a software. PC based DAQ offers a lot of benefit in terms of processing speed, display resolution and connectivity capabilities. Mainly there are two types of digital data acquisition system in use. The first one consist of a computer, with a dedicated plug-in-board that mainly performs analog to digital and vice versa. With the help of specialized software, the A/D board can be controlled and the computer acts very much like oscilloscope, function generator, multi-meter. The second type consist of a computer with specialized board to communicate with the external digital instruments such as digital storage oscilloscope (DSO), multi-meter, etc. The interface is generally known as General-Purpose Interface Bus. Figure 2.1 shows the main components of a basic data acquisition system.

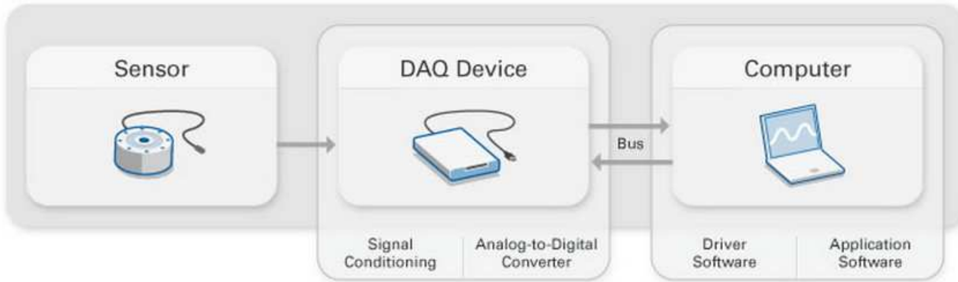

Figure 2.1: Important components of a data acquisition system [1]

There are five main components in a basic DAQ system. They are as follows:

- Transducers and sensors
- Signals
- Signal conditioning
- A/D and D/A hardware
- Computer Software

2.2 Transducer and Sensors

Data acquisition starts with some electrical or physical phenomenon to be measured. This phenomenon could be measurement of acceleration, temperature, pressure, force applied or any other quantity. An efficacious DAQ system should be able to measure all these phenomena.

A transducer is a device that converts a physical phenomenon into a measurable electrical signal, such as voltage or current [1]. The competency of the DAQ system depends on the traducers and sensor to convert the physical quantity into signals. For a particular application we have specific transducer to measure the physical phenomenon in terms of electrical signals. Table.1 lists some common transducers along with the physical phenomenon they measure. Different transducers have distinct prerequisite to convert the physical quantity to a electrical signal.

Table 2.1: List of transducers with the physical phenomena it measures

Physical Quantity	**Transducer**
Temperature	Thermostat
Light Level	Light Dependent Resistor
Sound	Carbon Microphone
Force/Pressure	Load Cells
Position and Displacement	LVDT, Potentiometer
Speed	Tacho-generator
pH	pH Electrode

2.3 Signals

The task of the transducers is to convert the physical quantity into some measurable signals. But, different signals have distinct prerequisites for measurement. Therefore, it's essential to have an idea about different categories of signals and their respective characteristics. Signals can be broadly categorized into two types:

- Analog Signal
- Digital Signal

2.3.1 Analog Signal

An analog signal is continuous signal and can take any value. Few examples of analog signals are temperature, sound, light intensity and volume. Every analog signal has three main characteristics: Level, Shape and Frequency.

1. **Level**

   Since an analog signals can have any value, the level provides a crucial knowledge about the acquired signal. Few examples that demonstrates the importance of level of a signal are: light intensity of a source, temperature of a cabin, sound volume of a speaker. The accuracy with which the DAQ system measures the value is also very important. Generally for analog level measurements, a DAQ that yields high accuracy is chosen.

2. **Shape**

   Some signal have unique shape such as sine, square, saw tooth and triangular. The shape of a analog signal plays an important role because it decides the signal's parameter such as peak value, average value and form factor etc. There are many applications where shape measurements are very important such as analysis of heartbeats, audio and video signals, music, etc.

3. **Frequency**

   All analog signals which are periodic in nature can be characterized by their frequency. It is to be noted that unlike level and shape, frequency of an analog signal can't be measured directly. To determine the frequency information, the signal must be analyzed using a software. This analysis is usually done using Fourier transform algorithms. The signal must be sampled at a suitable rate so that the required information is not lost while signal acquisition. The constraint that decides this speed is known as Nyuist rate. Theoretically the Nyuist rate is atleast two times the highest frequency component of the signal acquired. Few applications where frequency of the signal is of great interest are speech analysis, voice recognition, earthquake analysis, etc.

2.3.2 Digital Signal

Digital signal, unlike analog signal are not continuous in nature. Instead, digital signals have a discrete value at each sampling point. Digital signals are represented with the help of only two states: High logic (1) and Low logic (0). The voltage range for binary logic levels are different for different technologies as shown in Table 2.2.

The important parameters of a digital signals are as follows :-

1. **State**

Table 2.2: Details of Logic family

Logic	Low Voltage	High Voltage	Description
CMOS	0 V to V_D / 2	V_D /2 to V_D	V_D = Supply Voltage
TTL	0 V to 0.8	2 V to V_C	V_C=4.8 V to 5.2 V
ECL	-1.2 V to V_E	0.8 V to 0 V	V_E = -5.2, V_{CC} = Ground

Digital signals doesnt have continuous value with respect to time but consists of different states. States of digital signal are : on or off, high and low. Areas where state of signal are significant are control of switch on and off, threshold level of container etc.

2. **Rate**

   The transition between the states of a digital signal with respect to time is defined by the rate of the signal. An example involving measurement of the rate of a digital signal includes governing how fast data is being transmitted through a communication cable. The rate of a digital signal is also known as baud rate. Baud rate is defined as rate of change of symbols in data transmission.

2.4 Signal Conditioning

Generally transducers and sensor produce signals which are arduous and inappropriate to measure directly with the DAQ device. For example in case of noisy ambiance, low signal strength, high voltages, concurrent signal measurement, signal conditioning becomes an essential thing before any data acquisition. Signal conditioning helps sensors to work satisfactorily and in increasing the overall accuracy of the system.Sometimes transducers produce signals that are too hard to measure directly with a DAQ device. It is crucial to choose the correct device for signal conditioning.

Signal conditioning devices are utilized in number of applications such as:

2.4.1 Amplification

Amplification is the process of boosting the low voltage level to suitable level so as to meet analog to digital converter (ADC) requirements, thus improving the sensitivity and resolution. Also few conditioners situated near to source, boosts the SNR of signal by amplifying the amplitude before it is deteriorated by the noise.

2.4.2 Attenuation

Attenuation is required when voltages level to be sampled are above the ADC specifications. The process reduces the input signal's amplitude so as to be in ADC range. Generally attenuation is done when the signal amplitude is more than 10 Volts.

2.4.3 Isolation

Isolation is the process in which the input signal source is passed to DAQ ports without any physical connection such by using transformer, capacitive and optical coupling. This signal conditioning keeps the measurement device safe from any electrical disturbance from source side. It obstructs high voltage surges, excludes common mode voltage, which can damage the measurement devices.

2.4.4 Filtering

Filters are used to reject unwanted noise corresponding to certain frequency range. There are different types of filters such as low pass filter, high pass filter, band pass filter, etc. Input signal passed through high pass filter would attenuate the low frequency component and allow high frequency components of the input signal. Antialiasing filters attenuate signals above Nyquist frequency.

2.4.5 Excitation

Many transducers require excitation for operation. For example strain gages, thermistors, RTD, all require external voltage or current excitation.

2.4.6 Linearization

Some sensors produce signals which are not linear in nature. In such cases linearization becomes necessary, which can be achieved through software or with signal conditioning. For example thermocouples sensor requires linearization process before it is fed to DAQ hardware.

2.5 A/D and D/A Hardware

Data acquisition hardware functions as the interface between the PC and external sensors. The main task of the hardware is to sample the input signal and convert into digital signal so the computer can analyze it. The rate at which it samples the input signal is known as sampling rate, which is decided according to *Nyquist-Shannon sampling theorem*. The Nyquist-Shannon sampling theorem states that a signal must be sampled at least at a rate twice the highest frequency component of the signal otherwise, aliasing effect will occur [11]. Therefore if the input signal is sampled at a rate less than twice the Nyquist frequency, the output signal will have false lower frequency components. Fig. 2.2 shows a sine wave of F frequency. Due to low sampling rate the sampled signal is falsely appearing as sine wave of F/3 frequency. This phenomenon is known as aliasing effect.

In real world all signal from transducers have frequency components that are more than the Nyquist frequency. The high frequency components after sampling become low frequency component and gets added to signal. This results in error in the final output signal, thereby making data acquisition ineffective. The alias frequency is calculated as absolute value of the difference of the closest integer multiple of the sampling rate and the frequency of the input signal.

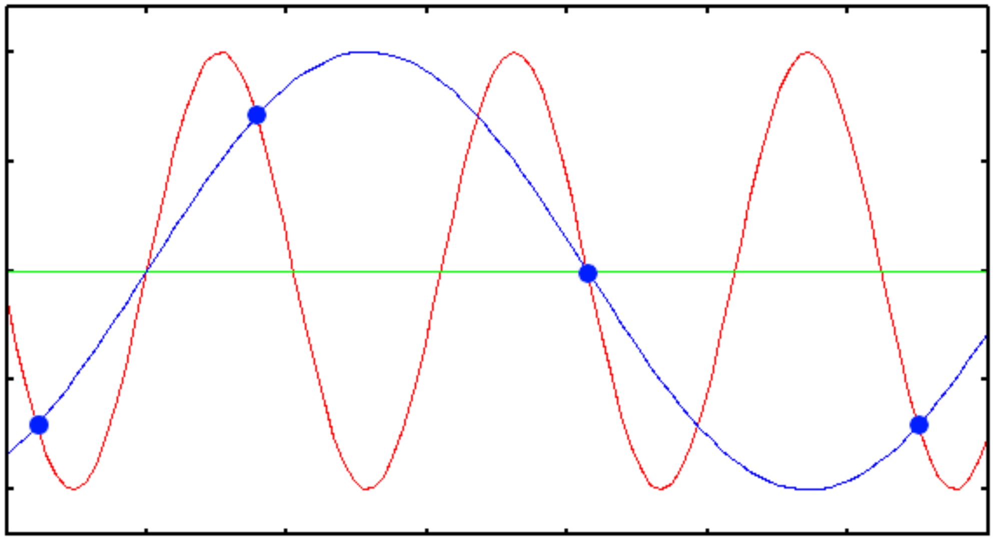

Figure 2.2: Aliasing effect

$$F_{Alias} = |R * k - F_s| \tag{2.1}$$

Where,

F_{Alias} is Alias frequency

k is integer corresponding to close multiple of sampling rate (R)

R is sampling rate

F_s is input signal frequency

The ADC employs a quantizer to round off the continuous set of values to relatively small discrete set. The task of changing analog signal to digital representation is defined as quantization and is performed by the analog-to-digital converter (ADC). The difference between the actual value and quantized digital value is referred as quantization error [11]. The number of binary level is calculated using Equation 2.2.

$$L = 2^{(N_b)} \tag{2.2}$$

Where,

L = Number of levels

N_b = Number of bits used for representation

If device input range is given, the code width may be calculated as:

$$Code\ width = \frac{Device\ Input\ Range}{2^{N_b}} \tag{2.3}$$

2.6 Driver and Application Software

2.6.1 Driver Software

Software application completes the data acquisition by providing it analysis and evaluation tools. Software helps to command or operate the DAQ device. Driver provides a software interface to hardware, which enables operating system and programs to access the hardware. It occupies the central position between the hardware and application software.

2.6.2 Application Software

Application software enables the user to do different analysis on the input signal. It also gives the facility to choose variety of settings for different sensors and transducers. So application software appends calculation and demonstration abilities to driver software.

Chapter 3

BLUETOOTH TECHNOLOGY

3.1 Overview

Bluetooth is a standard radio technology for short range, low power and economical wireless communication. The name *Bluetooth* is named after 10th Centurys Danish king Herald Bluetooth who united Scandinavian tribes into a single kingdom [12]. Bluetooth protocol was developed by Ericsson, a major cell phone manufacturer, as a means to replace serial cables in 1994. But nowadays it finds application in numerous types of gadgets such as mouse, headphones, internet access, cameras, speakers, and embedded devices. Bluetooth Special Interest Group (SIG), a group of major telecommunication companies, work jointly to evolve Bluetooth into an open standard to ensure market compatibility and acceptance [13]. The technology is supported by over 2200 companies around the world. The wireless Personal Area Network based on Bluetooth technology is now an IEEE standard. In fact, Bluetooth is first of its kind in making a single-chip radio that utilize license free 2.45 GHz ISM (Industrial, Scientific, and Medical), RF spectrum.

3.2 Bluetooth Technology Specifications

The Bluetooth devices communicate among themselves according to the Bluetooth specifications as stated by SIG group. Current technology mainly focuses on simple point to point connection between Bluetooth devices within coverage area. However the Bluetooth specification also provides solution for more daedal communication topologies.

Table 3.1: Important Specification of Bluetooth Technology

Connection	Frequency Hopping Spread Spectrum
Frequency Spectrum	2.45 GHz
Modulation Technigue	Gaussian Frequency Shift Keying (GFSK)
MAC Scheduling Scheme	FH-CDMA
Power	> 20dBm
Gross Data Rate	1-2Mbit/s
Distance	1 meter - 100 meter
Devices per Piconets	8 modules
Voice Channels	3

The Bluetooth SIG group has specified Bluetooth profiles to describe how to make use of the specifications to fulfill the required role by the usage models. These models are defined by the SIGs marketing group. The Bluetooth profiles describe the specific message and procedures from the Bluetooth specification. Only those devices which have same profiles are eligible to communicate with each other. For example, a mobile phone can communicate with a Bluetooth headphone only if they both have headset profile. Table 3.2 lists some important Bluetooth profiles along with their description.

3.3 Protocol Stack of Bluetooth

A *protocol stack* is hardware/software realization of the standard protocols which allows the devices to communicate with each other [13]. There are many levels in the protocol which perform different applications. The lowest layer is radio, which explains the attributes of the radio front, permissible power levels, frequency bands, channel arrangements and radio receiver's susceptivity. The following layer

Table 3.2: Profile defined in Bluetooth Technology

Profile	**Details**
Access	Normal procedure for delivery and pairing between Bluetooth devices
Service delivery	Procedures done by the Bluetooth device to discover services listed by the module.
Serial port	Requirement for emulating serial cable connection using RFCOMM among the devices
LAN service	Requirements for Bluetooth module to access LAN access
File transfer	Transfer requirements between two paired devices
Synchronization	Requirement for Bluetooth devices to help in synchronization

is the base band, which takes care of Bluetooths physical and media access control. The paired devices share several control messages for managing and configuring the baseband configurations. Link manger takes care of all processing linked with link manager protocol. Figure 3.1 shows the components of Bluetooth stack and Bluetooth chip.

The Host Controller Interface describes a standard interface, an independent way of communication with the Bluetooth module. Logical link control and adaptation protocol connection are established by the Bluetooth devices as soon as they are in range of each other. Connection is possible only when the service imparted by the server device is discovered by the slave device. The slave device can discover services and its peers by means of service discovery protocol (SDP). The RFCOMM mainly helps in areas where COM port is used for communication purpose. The Bluetooth chip can be easily connected to the PC or other devices using USB, UART protocols.

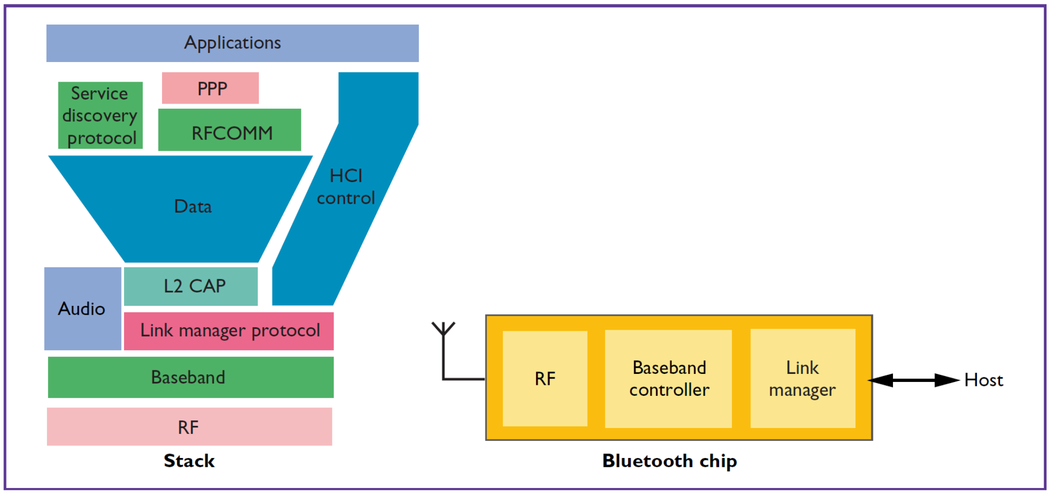

Figure 3.1: The Bluetooth networking stack and chip [13]

3.3.1 Bluetooth Networking

A Bluetooth communication is said to be completed when a master get paired to one or more slave Bluetooth devices. A device can take up any role: Slave or master. This flexibility makes Bluetooth eligible for establishment of ad-hoc networks. One unique property of Bluetooth, unlike WLAN, is that it allows any device to get paired with the other device. Its the task of the master Bluetooth module to decide the frequency hopping pattern on the basis of the slave address. In Bluetooth technology, there are two distinct networking topologies through which devices communicate with each other. They are :

- Piconet
- Scatternet

3.3.2 Piconet

A *piconet* is the Bluetooth network in which devices share collective channel. As indicated in the Figure 3.2 (left side) piconet is a star-shaped arrangement where center position is occupied by the master device surrounded by the slaves devices. Seven slaves can get paired up with the master at a time in the piconet network. For master device to get connected with more than seven devices, it must first direct a slave device to go into low power park mode and then request the other parked slave to become active. This procedure can be reiterated, which enables the master to get paired with more than seven slave devices. Allocation of the entire bandwidth among the slaves and mode of communication between slaves is decided by the master device. The active devices in piconet are denoted by three bits and 248 parked devices with eight bits and many more in standby mode. The active device is functional all the time whereas parked mode device can get activated within 3ms [14]. So for more devices to communicate with each other efficiently, master should cleverly push the device to park and active states. If one of the slave becomes master, the parent piconet gets divided into two piconets which may increase the efficiency of overall system.

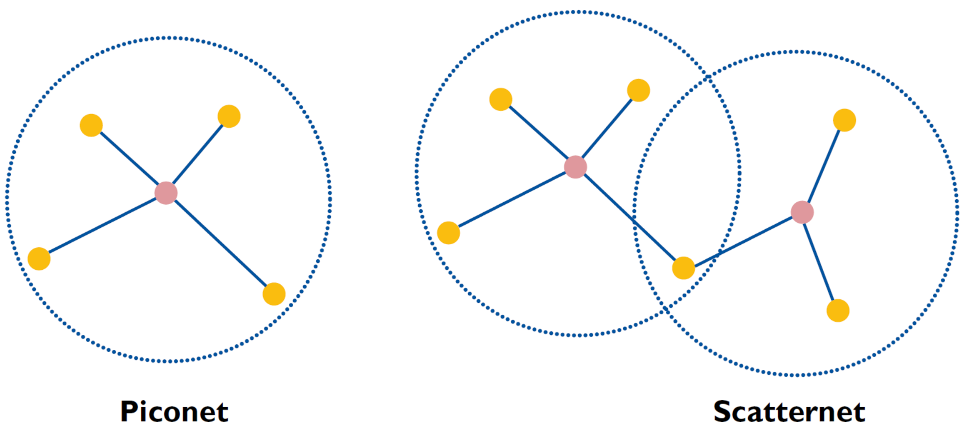

Figure 3.2: Piconet (left) and scatternet (right) topology

3.3.3 Scatternet

Bluetooth technology also specifies a structure called *scatternet* which makes inter-piconet communication very easy and smooth. Number of piconents come together to form a complex structure called scatternet. Multiple piconets overlap coverage region to form scatternet. A master device can abandon its piconet and can connect with another piconet as a slave. A scatternet is utilized to exploit the allotted frequency band. To avoid interference the devices in different piconets use distinct frequency hopping sequence but the entire scatternet share common frequency range. In order to have good transmission data efficiency, the size of the piconet should as small as possible [15]. A scatternet utilizes 79MHz frequency band where as piconet utilizes 1MHz. There is no interference among the piconets since they select different frequency hopping sequence [14].

A bridge node, which occupies the overlapping area in a scatternet, engages with members of different piconets on time sharing basis. It is active in one piconets for a point of time and then changes its frequency sequence in the next point of time. Bridge node can have duplex communication with member of a piconet or can share packets between two piconets. The role of a bridge Bluetooth device can be slave in both the piconets and master in one and slave in another.

3.4 Bluetooth States

Once a Bluetooth connection is established, a Bluetooth device can be any of the eight states, as defined by the Bluetooth specification, as required by the masters commands. The eight states, as shown in figure 3.3 are as follows:

- Standby mode
- Hold mode
- Connected mode
- Transmit mode
- Park mode
- Sniff mode
- Inquiry mode
- Page mode

A device is said to be in *Standby mode* as soon as it is powered on and has not yet connected to piconet. It changes its state to *Inquiry*, when it sends request

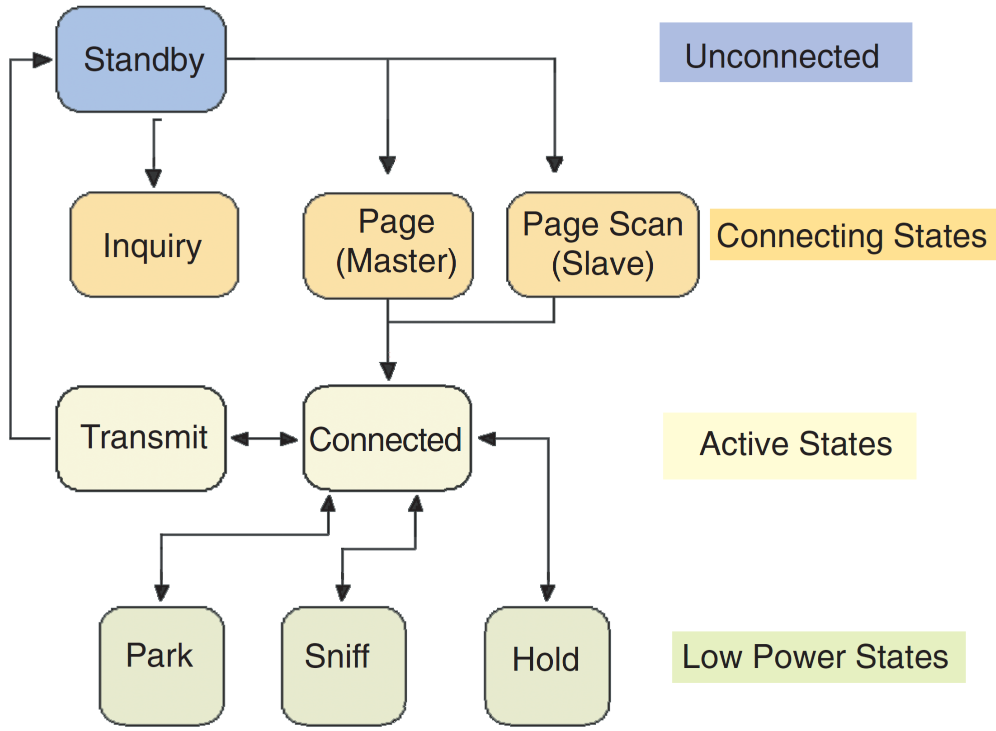

Figure 3.3: Different types of states in Bluetooth technology

to find device around its coverage area to get paired up. The device is said to be in *connected state*, as soon the Bluetooth connection is established between master and slave and it acquires an active address. During connection, master receives the transmitted data from slave and vice-versa. The slave is said to be in *transmit state*, when it is transmitting the data to master device. Once the communication between devices is over, the device abandons the connected state. In more complex networks where there are more than seven slaves, the extra slave devices takes up *Sniff state*. In Sniff state, the slave is virtually connected to piconet but at a reduced duty cycle. In *Park state*, device doesnt take part in data transmission but is linked to piconet. During Park mode the slave surrenders its active address which will be allotted to other slave device. It wakes up back wherever there is need for data transmission. Master device can command a slave device to go into *Hold state*, to form a bigger piconet network. Hold state is also a low power consumption state. These states help the Bluetooth technology to form more complex structure such as piconets and scatternet.

3.5 Bluetooth Coverage

There are different classes of Bluetooth radio based on the coverage range. The Bluetooth SIG specifies three classes of radios:

1. Class 3 Bluetooth Radio: Class 3 radio has a maximum range of 1 meter and maximum power consumption of 100mW.

2. Class 2 Bluetooth Radio: - Class 2 radio has a distance range of 10 meters and power requirement of 2.5mW. These radios are mostly used in mobile phones.

3. Class 3 Bluetooth Radio: - Mostly used for commercial use. Range of 100 meters and Power consumption of 100mW.

Some applications require large area coverage in the range 100-200 meters. In such cases Bluetooths short range could pose an issue as more number of Bluetooth devices would be needed at every 10-100 meters. One solution to this problem is replacement of internal small antenna with a more powerful external antenna [16].

3.5.1 Bluetooth Antennas

The Bluetooth antennas are utilized to enhance the range of the device. The primary task of the enhanced antenna is to transmit and receive the signal. The main attributes of the Blue antenna are its gain, direction and its operation. Antenna performance is very crucial factor as it is responsible for the signal transmission and reception. The main problems that are associated with the Bluetooth antenna are power coupling loss between transmitter and receiver. Placement of antenna is also pivotal in overall performance of the system. The maximum power transmitted from the antenna must accord with the interfaced device [17].

3.6 Bluetooth Vs Other Wireless Technologies

In market there are several wireless technologies available with varied applications. All wireless technologies have different features and specifications. Some of these technologies provide similar properties and attributes as Bluetooth. Table 3.1 compares attributes of Bluetooth with other wireless technologies.

Table 3.3: Comparison of wireless technology

Category	**RF**	**Bluetooth**	**IEEE 802.11**	**IrDA**
Purpose	Home	Cable/WPAN	WLAN	Cable
Technology	FHSS	FHSS	FHSS/DSSS	850nm
Power (dB/m)	20	0-20	20	0-15
Data Rate(Mbps)	0.8	1	11	0.115
Distance (meters)	50	10-100	30-100	5
Topology (Devices)	128	8	128	10
Security	Optional	Authentication	Optional WFP	Application layer

Based on the above information, it can be noted that although there are many technologies offering the similar characteristics as that Bluetooth but they all have few drawback and do not cover all areas as Bluetooth. The following subsection discusses most common technologies properties in contrast with Bluetooth.

3.6.1 Infrared Data Association (IrDA)

Infrared Data Association (IrDA), an optical based transmission, is a simple serial cable replacement technology. IrDA standard were published in 1993. Since it is based optical technology, it is confined short range and only supports line of sight communication. Line to sight communication can only support point to point communication and hence can't support Bluetooth like complex networking facility. Security features of Bluetooth are far better than that of IrDA technology.

3.6.2 Wireless LAN

Wireless Local Area Network (WLAN) appears to beat Bluetooth in all ranges, but since the protocol is based on Ethernet standard, it requires as lot of power. It's mainly used for local area networking and it's use just for serial cable replacement is not justified. Moreover the cost of is very high as compared to that of Bluetooth.

3.6.3 Wireless Fidelity (Wi-Fi)

Wi-Fi is acronym for wireless fidelity. Wi-Fi is a local area wireless computer networking that follows the protocol of IEEE 802.11 family. It has more complex configuration as compared to Bluetooth in terms of both hardware and software. Cost is also high for Wi-Fi configuration. It's generally utilized in organization, apartments, airport terminals, offices and schools to provide wireless internet connection in place of wired LAN connection.These access points are commonly known as hotspots. So application areas of Wi-Fi and Bluetooth are completely different.

Therefore based on above comparison and analysis, it can concluded that Bluetooth provides a better option for wireless data transfer in terms of cost and complexity. The project's maximum distance range requirement is less than 10 meters, so Bluetooth provides that range with less cost, better networking capabilities and security provisions.

Chapter 4

OVERVIEW OF SYSTEM STRUCTURE

The Project aims at designing and implementing an economical, portable, wireless, low power data acquisition system consisting of a hardware circuitry and a software program. The device is provided with a Bluetooth module to provide communication connection between PC and hardware system. There are many different wireless local PAN technologies available in market. Bluetooth is selected over other wireless technology because it provides better overall desired characteristics as required for this project. The hardware device includes microcontroller with ADC to acquire the input voltage signals and HC-05 Bluetooth module for transmitting the sampled data. A Graphical User Interface (GUI) developed in MATLAB environment receives the sampled data sent by microcontroller and plots the signal waveform. This is a primary step for acquiring the signal values, further we can analyze the acquired signal using MATLAB signal processing toolbox.

For constraining the cost and system complexity the following design condition are adopted:

- Economical : The system should be cost effective.
- Speed: It should support required sampling period (Bluetooth can offer a speed up to 1Mbps).

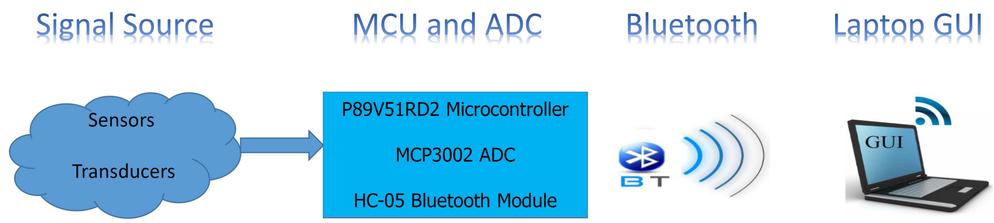

Figure 4.1: Components of the system

- Components availability : The components of system should be easily available in market.
- Power consumption: It should be power efficient.
- Portability: The product should be portable and simple for easy use

The resulting system consists of four different components as shown in Figure 4.1 :

1. Microcontroller (P89V51RD2)
2. Analog to Digital Converter chip (MCP3002)
3. Bluetooth Module HC-05
4. Graphical User Interface (GUI)

4.1 Microcontroller Architecture

The microcontroller acts as brain of the system since it controls all other integrated chips (IC's). The microcontroller is interfaced with ADC which is required for sampling the analog signal. The sampled values are processed in the microcontroller and are transmitted using Bluetooth module. The choice of microcontroller is done based on the following criterion :

1. The first criterion is that it should meet the requirements and should be economical. For this project 8 bit microcontroller is suitable so as to have good accuracy and precision of sampled signals.
   (a) Speed : It should support required sampling period (Bluetooth can offer speed up do 1Mbps).
   (b) Power consumption: voltage - 5V @200 microampere
   (c) A good amount of on-chip RAM for storing the samples.
   (d) A UART port (to communicate with Bluetooth).
   (e) Small physical package (take up less board space).
   (f) Cost per unit: It effects the final cost of project and the microcontroller should be accordingly selected.
2. Second criterion in selecting a microcontroller : how comfortable it is to built products using it. Key factors are availability of assemblers, debugger, C language complier, an emulator etc. In this respect Keil has a good technical support community.
3. Third criterion is availability of microcontroller in market. 80C51 is widely available both online and in local market.

Considering the above criterion, for this project 8 bit microcontroller P89V51RD2 is chosen. The P89V51RD2 is an 8051 microcontroller with 1 kilo bytes of RAM and 64 kB flash memory.

The general specifications of the P89V51RD2 microcontroller:

- 80C51 CPU architecture
- Source voltage : 5 V
- Programmable Watchdog timer (WDT)
- Serial Peripheral Interface and UART pins
- Three 16-bit timers and counters

- Second DPTR register
- Transistor-Transistor Logic and CMOS logic levels compatibility
- Low power states

P89V51RD2 is a forty pin micrcontroller. Figure 3 shows the pin configuration of P89V51RD2 dual inline package (DIP).

4.1.1 Memory Organization

The microcontroller has discrete address spaces for code and data memory.

1. Flash program memory : It contains the user's code. The 64 kB of memory is organized as 512 sectors, each sector consists of 128 bytes.
2. Data RAM memory (Figure 4.3) : The data RAM has 1024 bytes of internal memory. The microcontroller can also address up to 64 kilo bytes for external data memory.
3. Expanded data RAM addressing

   The extended memory from 00H to 2FFH can be assessed by move external instruction (MOVX) and setting EXTRAM bit to '0'.

4.1.2 Micrcontroller Connections

The microcontroller is connected to a replaceable 11.0592MHz crystal oscillator Q1 as shown in figure 4.4. The P89V51RD2 microcontroller does not have an inbuilt Analog-to-Digital converter chip. So for data acquisition, it is interfaced with Microchips MCP3002, a 2-channel SPI based Analog-to-Digital Converter chip. The next section discusses about the configuration and interfacing connection of ADC with microcontroller.

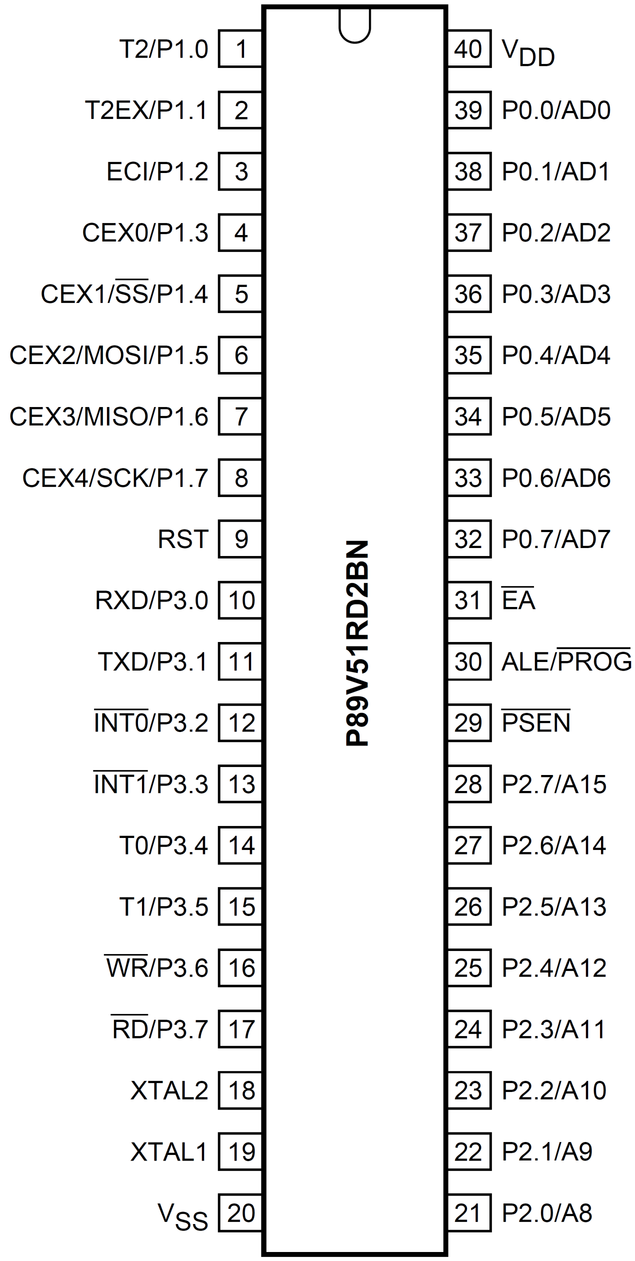

Figure 4.2: Pin configuration of P89V51RD2 DIP

4.2 Microchips MCP3002 ADC

The Microchip MCP3002 is a 10-bit successive approximation based analog to digital converter. The chip acquires a sample on the interior capacitor for 2 clock cycles from the start of second rising edge of clock signal fed to CLK pin. The

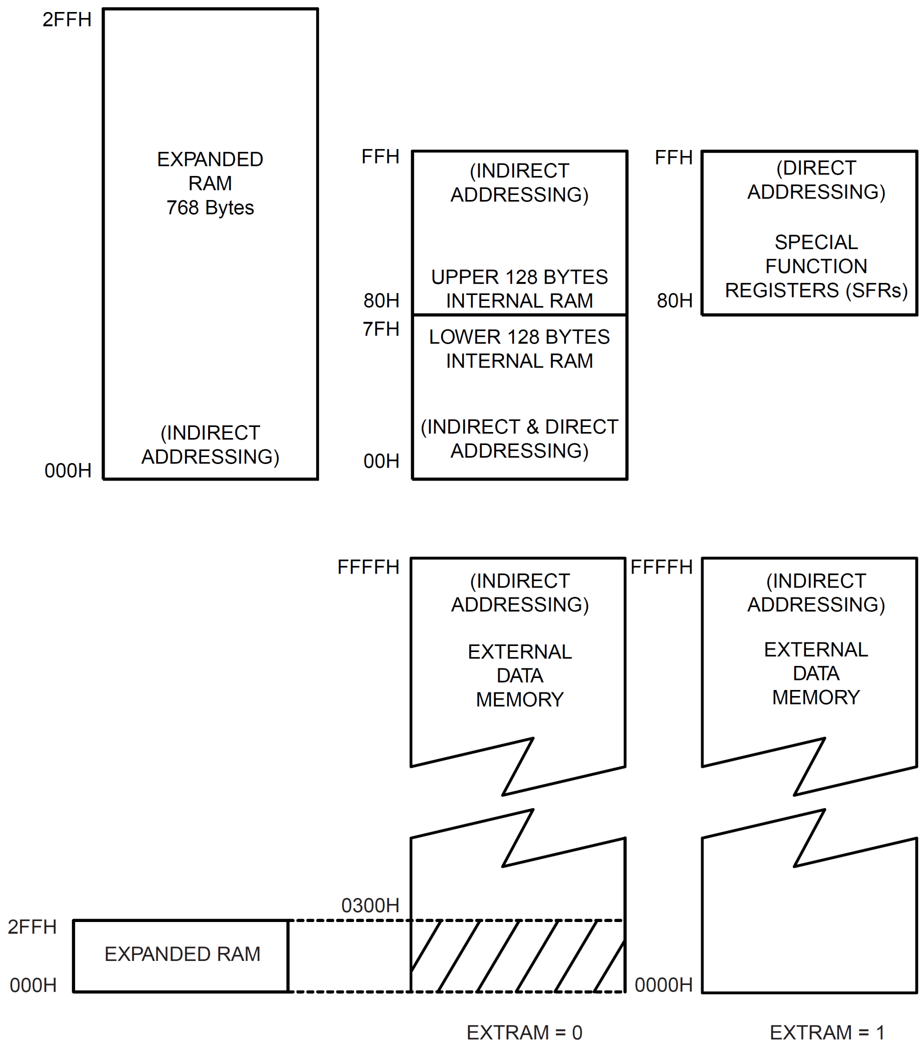

Figure 4.3: Internal and external data memory structure

MCP3002 can be programmed to give a single pseudo-differential input pair or dual single-ended inputs. Microcontroller communicate with the ADC chip based on serial peripheral interface protocol. The chip has capacity of sampling rates of up to 200 kilo samples per second (ksps) at 5V and 75 kilo samples per second (ksps) at 2.7V. The voltage required for the operation of MCP3002 device is in the voltage range of 3V - 5V.

The important features of the MCP3002 are as follows:

- 10-bit resolution

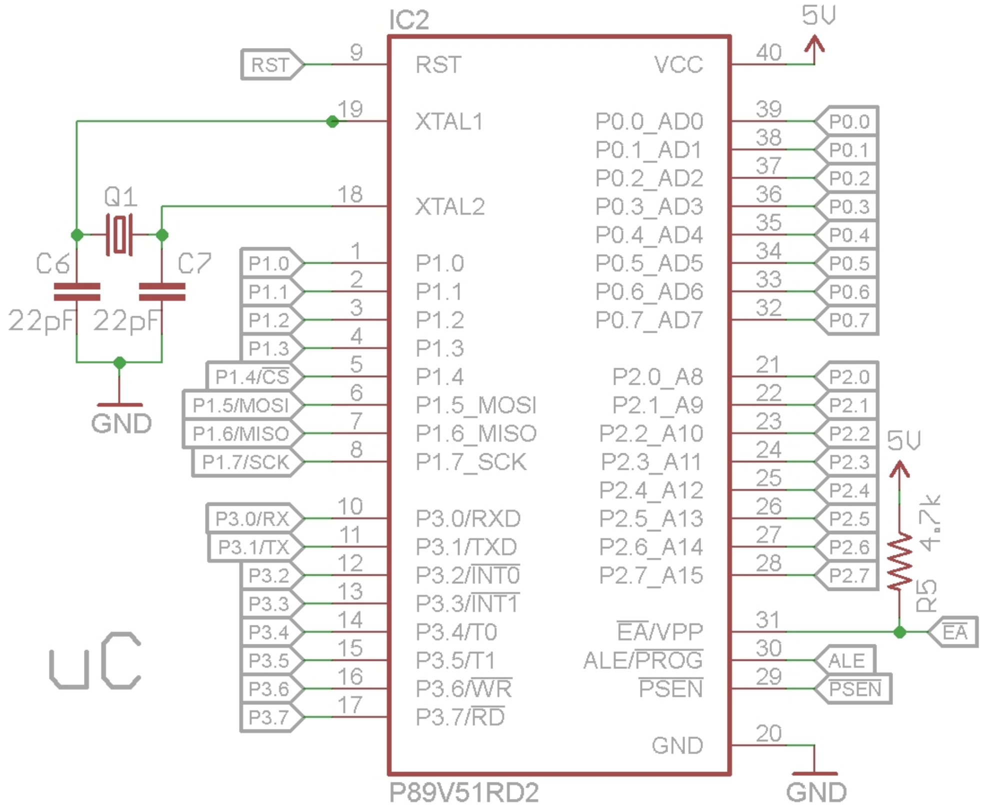

Figure 4.4: Crystal oscillator connection with the microcontroller

- Analog input configuration as single ended or differential mode.
- SPI serial interface
- Inbuilt sample and hold circuitry
- 200 ksps max sampling rate at $V_D = 5V$
- Supply Voltage range : 2.7V - 5.5V
- Low power : 5 nA standby current and 2.1 μA at max

4.2.1 Pin Description

The following Table 4.1 describes the PIN functions of serial ADC MCP3002.

1. CHO/CH1

   The sensor voltage output is fed to either channel 0 or Channel 1. These

Table 4.1: MCP3002 ADC pin functions

PIN Name	**Function**
V_{DD}/V_{REF}	+3V to 6V Voltage Supply
CH0	Channel 0 port
CH1	Channel 1 port
CLK	Input Clock
D_{IN}	Input Data(Serial)
D_{OUT}	Output Data(Serial)
$\overline{CS}$ /SHDN	$\overline{ChipSelect}$ / Shutdown

channels can be programmed to be used as two independent channels or as pseudo differential mode. The modes are selected by configuration bits (SGL, ODD) fed to DIN Port (Table 4.2) . For this project SGL bit is made '1' and ODD bit is made '0'.

2. $\overline{ChipSelect}$ /Shutdown Input($\overline{CS}$/SHDN)

   The $\overline{CS}$/SHDN pin is powered with a low logic to start the conversion process. When the pin is powered with high logic, it will go into low power mode.

Table 4.2: MCP3002 ADC pin functions

	CONFIG BITS		CHANNEL SELECTION		GND
	SGL	ODD	0	1	
SINGLE ENDED MODE	1	0	+		-
	1	1			-
PSEUDO DIFFERENTIAL MODE	0	0	IN+	IN-	
	0	1	IN-	IN+	

3. Serial Clock (CLK)

The pin is used to output the sampled value bit.

4. Serial Data Input (D_{IN}) The D_{IN} pin is used to set the configuration setting of the input channel.

5. Serial Data Output (D_{OUT}) The result of ADC conversion is read at D_{OUT} at every falling edge of serial clock.

4.2.2 ADC Interfacing With Microcontroller

MCP3002 ADC has 8 pins and the connections with the microcontroller is shown in Figure 4.5.

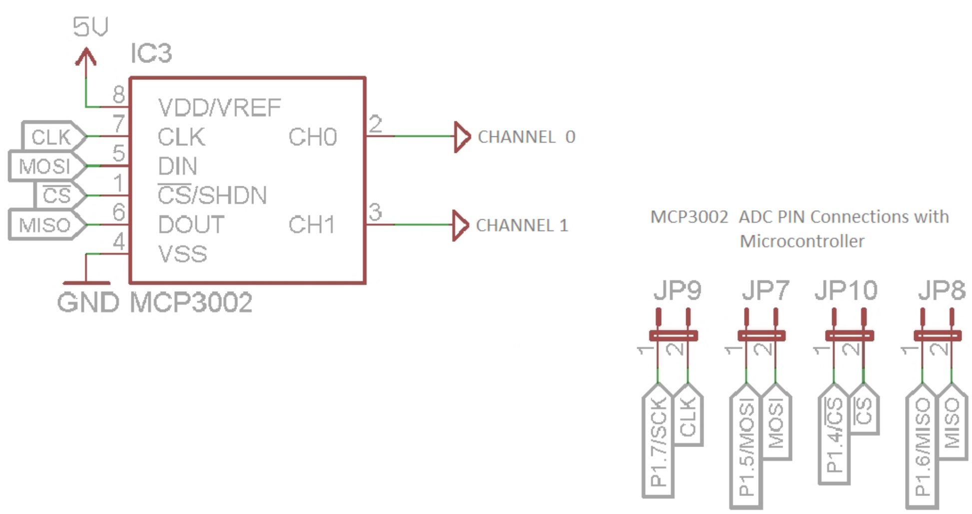

Figure 4.5: ADC interfacing with microcontroller

4.2.3 ADC Operation

To start the communication with the ADC, the $\overline{CS}$ pin is made low (see Figure 4.6). A negative edge is given to $\overline{CS}$ PIN to start the the communication process. The start bit is recorded as the input at DIN pin when the first clock is low. After the start bit, SGL and ODD bit will be recorded and they decide the channel configuration. The configuration details are given in Table 4.2. Next bit is MSBF which is used to select the output mode of the sampled data. If MSBF bit is high, the output data will be provided serially with MSB as first. The ADC will output zero on further clocks with $\overline{CS}$ low. Whereas if MSBF bit is low, ADC will output the result with LSB first and in the next cycle with MSB first.

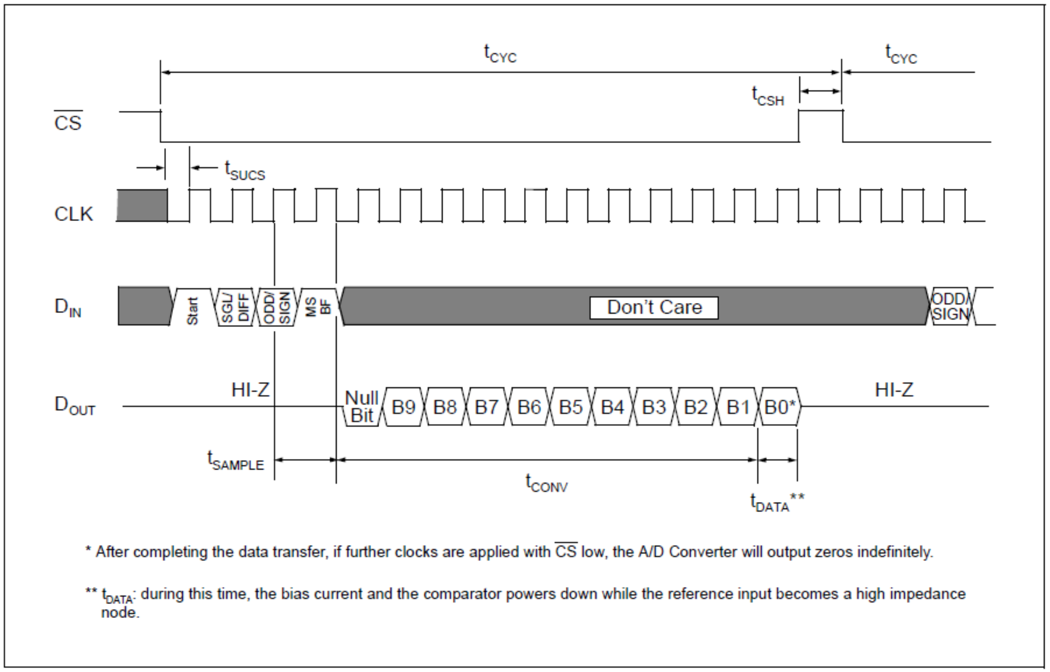

Figure 4.6: ADC MSP3002 timing diagram for MSB first format [19]

The start of the sampling process is marked on the second positive edge of the clock signal. The sampling process conversion will end on the falling edge of the third clock after start bit. Output data is received from DOUT on falling edge of the clock. Figure 5.1 shown the timing diagram of the ADC in operation with MSB first format.

Based on the above explanation, the data to be fed to DIN pin is selected as “1101” to select channel 0 and MSB first format mode. The sampling process function of ADC is called at regular interval using interrupt by microcontroller. Sampling of the signal done by ADC is interrupt driven. The flow chart of the algorithm is discussed in the microcontroller software section of Chapter 5 : Software Development.

4.3 Bluetooth Module HC-05

Bluetooth embedded module is a device used to replace the serial cables with wireless facility. These modules can be configured as two modes: master and slave device. Currently in market Bluetooth serial interface module comes in two level:

1. Commercial level: HC-03, HC-04

2. Civil level: HC-05, HC-06

The device with the even number is configured as master or slave during manufacturing and can't be changed later. But the device with odd number has the facility to change the modes by the user using appropriate AT commands.

In this project HC-05 Bluetooth serial module is used to have both the work mode available for use. The main function of Bluetooth serial module is to substitution of serial port line, such as:

1. Communication between two microcontrollers. One Bluetooth module interfaced with first microcontroller acts as master and other module interfaced with second microcontroller acts as slave. Bluetooth module has follows UART protocol. Have two pin RX, TX for bidirectional communication.

2. If the micrcontroller is interfaced with the slave Bluetooth module, it can communicate with the computer or laptop having Bluetooth facility. This provides a wireless communication between PC and microcontroller.

3. Market is flooded with many Bluetooth enabled devices such as Bluetooth speaker, headphones, GPS. So any master device can pair with these slave devices to extend its application.

Communication between two Bluetooth serial modules must obey these two criteria:

- Pairing is only possible between a master and slave device.

- For better security, password is essential during pairing of modules.

4.3.1 Selection of Bluetooth Module

The Bluetooth module with even model number is congruous each other. It is to be noted that user can't reset the mode of HC-06, HC-04. Also in even model number modules have limited AT commands and functions. Whereas HC-03, HC-05 has more commands and is more versatile than HC-04 and HC-06. Figure 4.7 shows picture of two different Bluetooth modules : HC-06 and HC-05

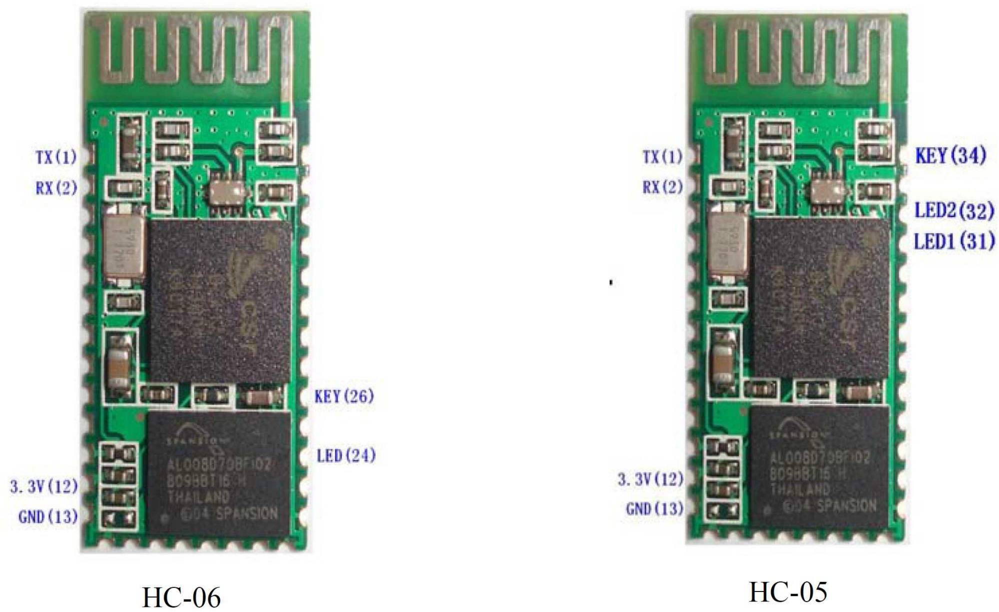

Figure 4.7: HC-06 (Left) and HC-05 (Right) Bluetooth module

Major difference between HC-05 and HC-06 are listed in Table 4.3.

Therefore for better performance of the system, HC-05 Bluetooth Serial Module is used for wireless communication between designed system and computer. User can send AT(Attention) commands to the module to set the control parameters of module. To enter in AT mode a) Input low logic to PIN34. b) Power the module c) Input high logic to the PIN34. Then the module enter into AT mode.

Bluetooth Module HC-05 follows UART serial communication protocol. The main pins of module are as follows:

1. GND: Ground pin, it should be connected to reference voltage.

Table 4.3: Differences between HC-05 and HC-06

HC-05	**HC-06**
Both work mode are possible	Master and slave mode can't be switched
Master doesn't remember the last paired slave device. gets paired with any slave module.	Master module remembers the last slave module and pairs only with that device.
Default communication baud rate: 9600	Default communication baud rate: 9600.
PIN 34 is used to enter the AT mode.	PIN26, for master to flush the memory.

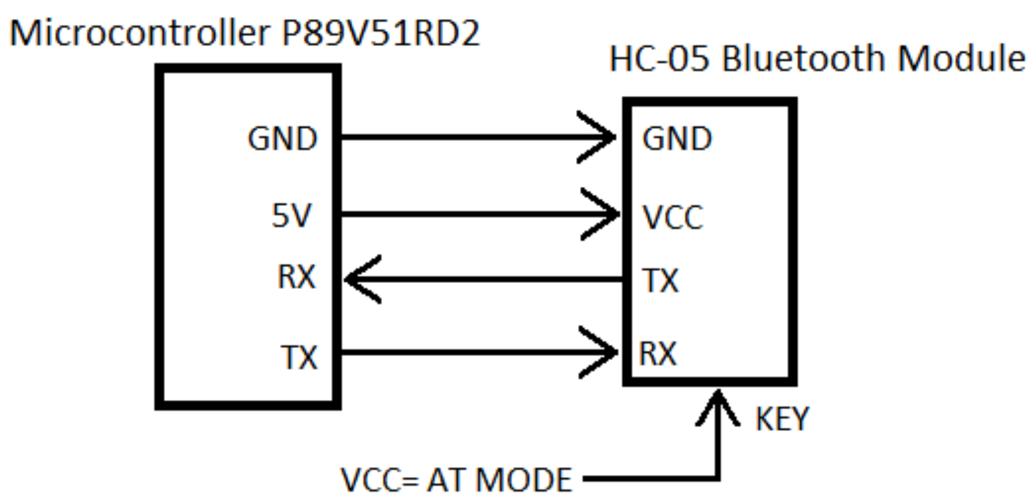

Figure 4.8: HC-06 (Left) and HC-05 (Right) Bluetooth module

2. VCC: Supply voltage, should be powered with 5 Volts.
3. TX : Transmit Pin.
4. RX : Receive Pin.

Typical connection between MCU and Bluetooth module is shown in Figure 4.8.

Chapter 5

SOFTWARE DEVELOPMENT

The microcontroller is interfaced with the serial Microchip MCP3002 ADC and Bluetooth HC-05 serial module. Serial ADC has less pins, thereby saving the area in the main circuit board. The ADC needs to be configured by the control bits as per our requirements. So after powering on the microcontroller, it sends appropriate control bits to ADC. The code is written in assembly language. Assembly language is chosen because of its fast execution and has low space requirements as compared to higher level languages. After sampling process, the sampled values are transmitted wirelessly via Bluetooth serial module. The Bluetooth module uses Universal Asynchronous Receiver/Transmitter (UART) protocol.

On the PC side, a MATLAB based Graphical User Interface (GUI) is developed, which pairs up with the Bluetooth module of the system. After getting paired up, it starts receiving the sampled values continuously and plots it on the screen in real time. This chapter discusses the code details of the microcontroller and GUI.

5.1 Microcontroller Programming

The microcontroller P89V51RD2 can be programmed by loading the hex file in the flash memory. Compilers generate hex files which can be downloaded in the flash memory. The size of hex file is depends on many factors like choice of compiler, language of programming etc. It is very important that the size is kept under limit since microcontroller has limited on chip ROM. The software used for generating hex file is Keil μVision IDE by ARM. The Keil μVision IDE from ARM provides facility for project management, source editing, program debugging, and simulations. The development platform are easy to use. The IDE has both μVision editor and debugger integrated that provides a seamless embedded project development environment [20].

The μVision Debugger supports simulations on PC and debugging using hardware system. μVision also helps the user to avail features like breakpoint, curve trace and logic analyzer. Keil supports both C and assembly programming for P89V51RD2 microcontroller. Choice of language is very crucial since it affects the size of hex file. C programming has following advantages over assembly.

- Its easy to write C code for a complex algorithm as compared to assembly.
- Less time consuming
- Library codes can be used easily.
- A C code written for one microcontroller is also compatible with other devices with little modifications.

But these advantages comes at the cost of large hex file size.

Assembly language is a low level programming language which has a strong accordance with the architecture machine code instruction. Assembler converts the assembly code into a machine code which can be understood by a device. Assembly language uses a mnemonics to denote each instruction or arithmetic calculation. Instructions are encoded as binary instruction codes. Each instruction code contains operation code or opcode, which defines the purpose of the instruction. Many instructions also contain one or more operands along with opcodes. These operands indicate which register or memory data to be used for operation.

Few advantages of using assembly language:

- Assembly language is easy to apprehend. Easier for programmer to access the registers of the microcontroller.

- Assembly language has good execution efficiency because of its correspondence with machine language
- It is easy to debug the errors and correct the instructions .

Considering the small flash memory of P89V51RD2 microcontroller, the whole code is written in assembly language. The code is written for acquiring fifty sampler per 0.06 second i.e. sampling rate is 833 Hz. The sampling process by ADC is interrupt driven.

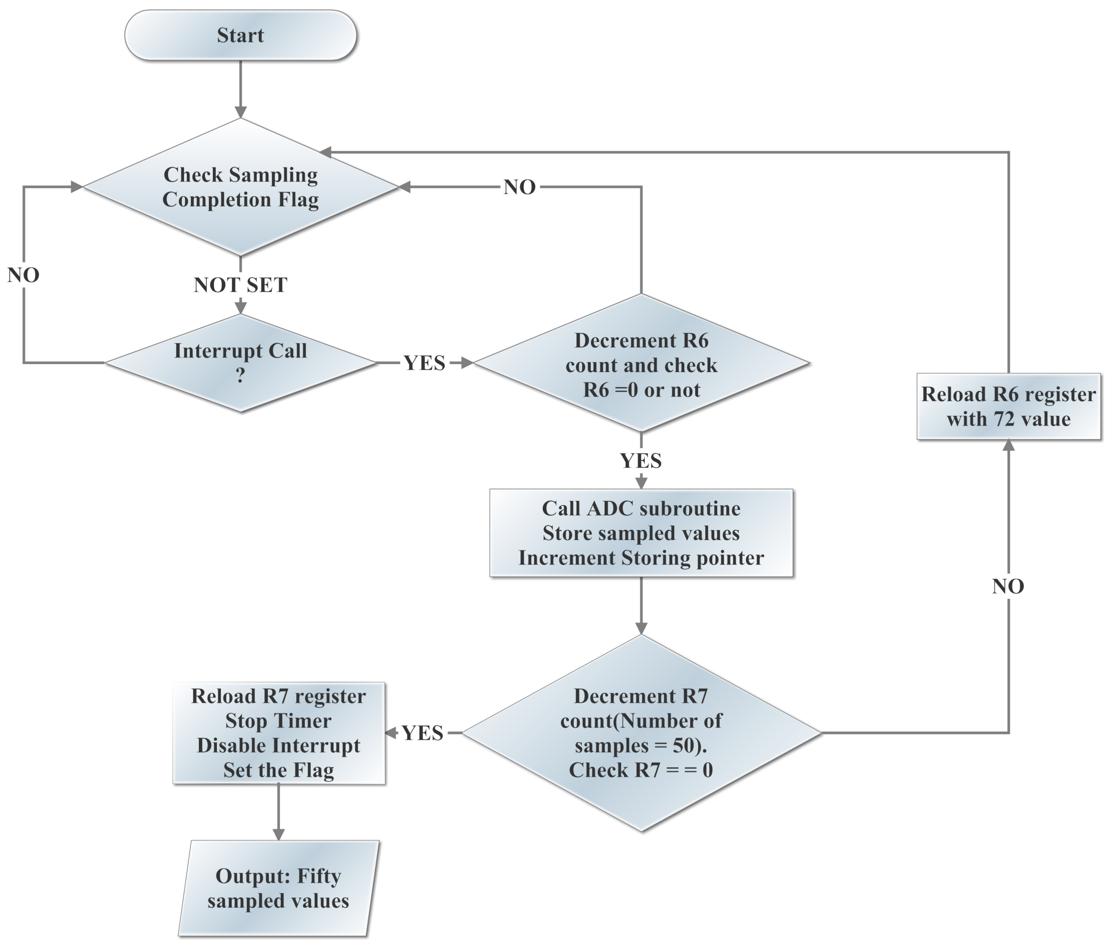

Figure 5.1: Flowchart of algorithm used for storing the sampled values

The ADC subroutine is called at every 1.2 millisecond. The interrupt driven procedure allows the microcontroller to perform other tasks when interrupt is not called. It helps to enhance the overall efficiency of the system. Figure 5.1 shows the flowchart of algorithm used for ADC sampling process. A flag, Sampling completion Flag, is used to check whether fifty values in one cycle are stored or not. If the flag is set, interrupt and timer are disabled to avoid any further interrupt calls. Whereas if it is not set, the interrupt calls the ADC sampling subroutine at an interval of one millisecond. Timers keeps the track of the time interval. Timer 0 of the microcontroller is used in mode 2. Mode 2 of timer 0 is used because of its auto load facility. In mode 0 as soon as the timer counter reaches maximum value its gets reloaded automatically. This mode of timer is highly suitable for repeating time interval. For a delay of 0.06 seconds, two register R6, R7 are used. The following subsection discusses the delay calculation.

5.1.1 Delay Calculation

The microcontroller stores fifty values in an interval of 0.06 seconds. So in 0.06 seconds, the ADC subroutine must be called fifty times by microcontroller. Two registers are used for the delay calculation: R6 and R7. Register R7 contains the value corresponding to the number of samples required i.e. 50. Timer register can contain a maximum value of 256. To have more count, register R6 is used in loop have required time interval. After proper calculation, the register R6 is loaded with a value of 72 and timer register (TL0) is loaded with a value of 241 to have fifteen (15) counts. Microcontroller is clocked with an 11.0592 MHz crystal oscillator. Therefore each timer pulse is of 1.085 microsecond. To have a delay of 0.06sec,

$$\begin{aligned}\text{Total number of counts} &= \tfrac{0.06sec}{1.085\mu s}\\ &= 55300\end{aligned}$$

$$\begin{aligned}\text{Value to be loaded in timer register (TL0)} &= \tfrac{55300}{50*72}\\ &\approx 15\end{aligned}$$

As shown in the flow chart (Figure 5.1) on every interrupt call, R6 count is decremented and check whether R6 = 0 or not. If the condition is satisfied ADC subroutine is called, which samples the data at that point of time and stores in the pre decided memory location. The storing pointer is incremented for new memory location. In next flow of algorithm R7 register is decremented and checked whether it has zero value or not. When R7 becomes zero, it means that fifty values are stored and one cycle of 0.06 seconds is over. If not zero, the R6 register is reloaded with the 72 value. When R7 register becomes zero, the timer and interrupt are disabled and the Sampling completion Flag is set. In the last R7 register is reloaded for next cycle. So in one 0.06 sec cycle, the output is 50 values stored in pre decided location. Which are further transmitted by the Bluetooth module.

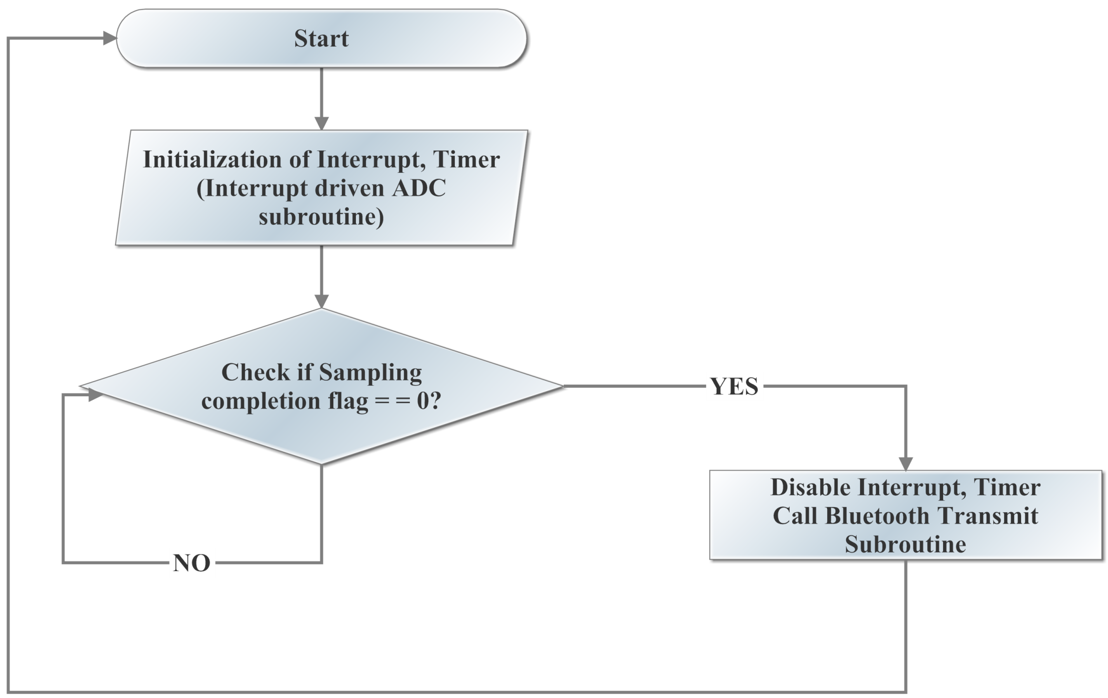

Figure 5.2: Flowchart of complete process

After completion of 0.06 second the whole process repeats continuously. Figure 5.2 shows a flowchart of complete process. As soon as the microcontroller is powered on, the interrupt and timer are initiated. The interrupt gets called and ADC subroutine is executed as discussed in the above. In the background a Sampling completion Flag is monitored, As soon as this flag is set, Bluetooth transmission subroutine is called. Microcontroller is interfaced with Bluetooth using UART protocol. So TX pin of microcontroller is connected to RX pin Bluetooth HC-05 and vice versa as shown in Figure 4.8 . For serial communication the data to send via Bluetooth protocol is loaded into SBUF register by the microcontroller. And transmission completion interrupt bit TI is monitored. After the completion of transmission, the whole process repeats again to get real time data. On the other hand PC enabled with Bluetooth continuously receives the data sent by the DAQ hardware to plot the waveform in real time.

5.2 Graphical User Interface (GUI)

MATLAB ® is universally acknowledged as most powerful data processing platform in academic institution [21]. Wide range of compatibility with high level languages such as C, Java, VB makes it very popular in scientific and research community. A MATLAB based GUI is developed to receive and analyze the data sent by the designed DAQ system in real time basis. This designed GUI helps the user to control the functionality of the complete system.

The designed Graphical User interface (GUI) as shown in figure 5.3 consists of following components :

1. **START button** : The start button is used to begin the communication between the PC and microcontroller.
2. **STOP button** : The stop button is used to terminate the communication link between the PC and microcontroller.
3. **REFRESH button** : The refresh button flushes out the old stored data. Refresh button can be used after start of communication or in between the communication period.
4. **PLOT button** : The plot button is used to start plotting the data received on the axes in real time. To stop the plotting, stop button is used.
5. **STATUS update** : Status update displays the current status of the communication between the PC and microcontroller. If the connection is made successfully after pressing the START button, the status display changes

to *"Connection Established"* from *"Disconnected"*. Plotting is only possible after this status update.

6. **MESSAGE Update** : Message update displays any error encountered during the reception of the data from the microcontroller.

7. **AXES** : An axes plot is used for waveform display and data point analysis.

8. **TOOLBAR** : Toolbar of GUI is equipped with Zoom In, Zoom Out, Hand pan, Data Cursor, Rotate and Save options for waveform analysis.

9. **INSTRUCTIONS** : This instruction section lists the procedure to operate the GUI. The PIN code of the Bluetooth module is 1234.

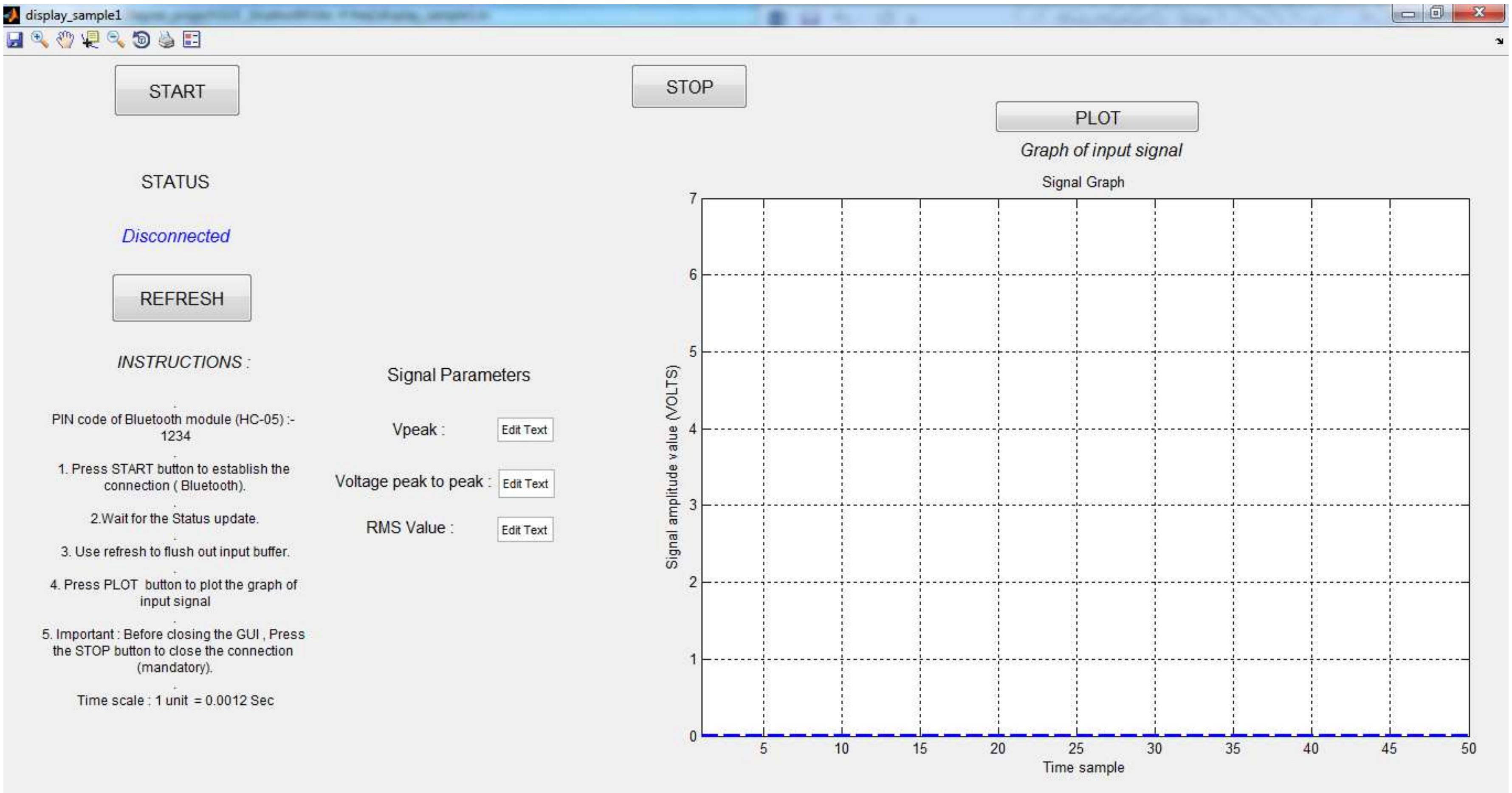

Figure 5.3: Designed MATLAB GUI Layout

The callback function's command that MATLAB executes are shown in Figure 5.4.

The START button callback function performs the following tasks:

- Creates a Bluetooth serial object Bt.
- Open the serial object, Command: *fopen (Bt)*.
- Updates the Status to *"Connection Established"* from *"Disconnected"*.

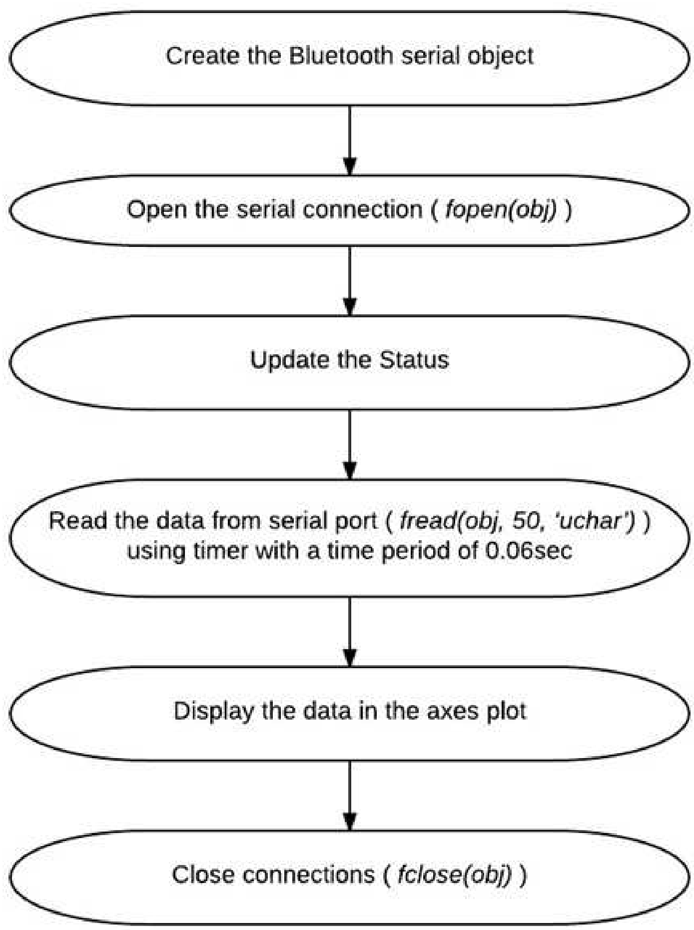

Figure 5.4: Sequence of callback function executed by GUI

The STOP button callback function performs the following tasks:

- Closes the serial object, Command: *fclose (Bt)*.

- Deletes the Serial object from the workspace.
- Updates the Status to *"Disconnected"* to *"Connection Established"*.

The REFRESH button callback function performs the following tasks:

- Flushes the buffer space of the Bt object. Command: *flushinput(Bt)*.

The PLOT button callback function performs the following tasks:

- Reads fifty values from the microcontroller. Command : *fread(handles.Bt,50,uchar)*.
- Updates the Message display in case of any error during reception of data.
- Start of timer object. A timer with a time period of 0.06 is used. After 0.06 seconds, Timer function is called which reads the new sampled values from microcontroller.
- Axes setting and legends are set accordingly.

Chapter 6

EXPERIMENTAL RESULTS

The designed hardware and software are tested and studied by supplying the signal from a function generator to the probes of the system. The designed data acquisition system is tested for both alternating current (AC) and direct current (DC) signals. The important parameters of signals such as Root mean square (RMS), peak value, frequency and peak to peak value are also calculated. The wave variations under attenuation and frequency change are also studied. The AC signals used for the test are: Sine wave, Triangular wave, Square wave.

6.0.1 Testing Setup

The testing setup consist of the following devices:

- Prototype of designed Bluetooth based data acquisition system
- Digital Storage Oscillator (DSO)
- Function Generator
- Laptop with Bluetooth facility

The signal output from function generator is fed to DAQ channel input and DSO to compare the signal waveform and signal parameters. The results analysis for different signal are covered in following subsection.

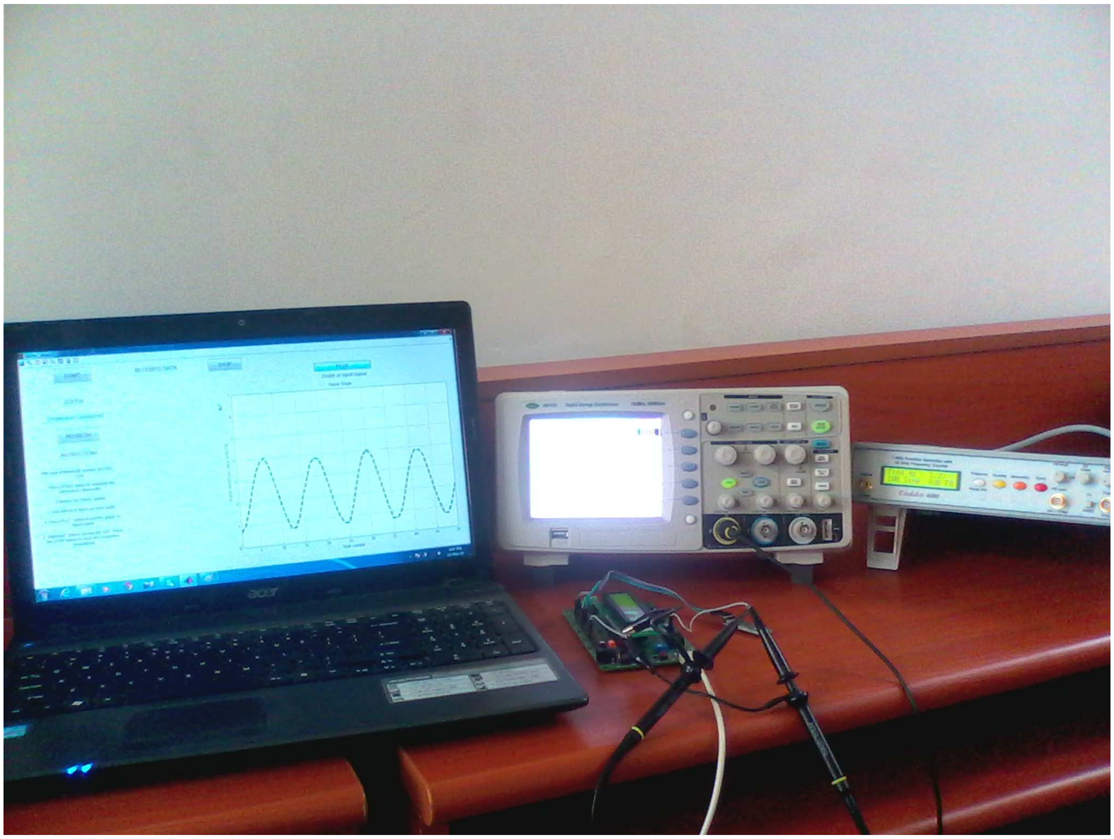

Figure 6.1: Snapshot of testing setup

6.0.2 Input Signal : DC signal

The probes of the DAQ system are connected to the output terminal of function generator. The function generator produces a DC signal with an amplitude of 2 volts. The GUI output for DC signal is shown in figure 6.2.

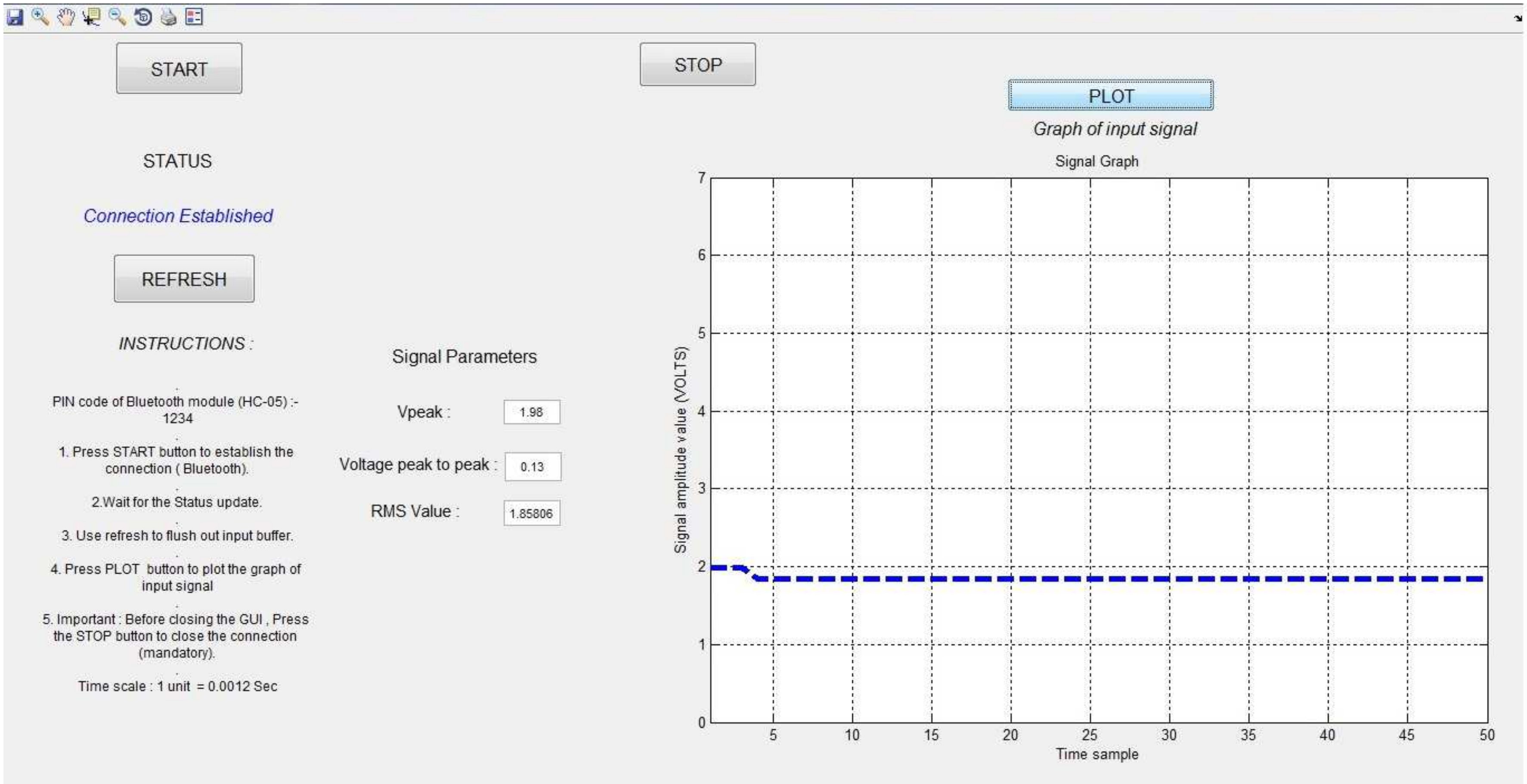

Figure 6.2: DAQ ouput for a DC signal: Amplitude : 2 Volts

6.0.3 Input Signal : Sine Wave

The function generator produces a sine wave with an peak to peak voltage of 3 volts and a frequency of 72 Hz. The GUI output for sine wave signal is shown in figure 6.3.

The signal parameters calculated by GUI are as follows :

- V_{pp} = 3.2 Volts
- V_{RMS} = 2.78
- V_{Peak} = 4.2
- Frequency = 74 Hz

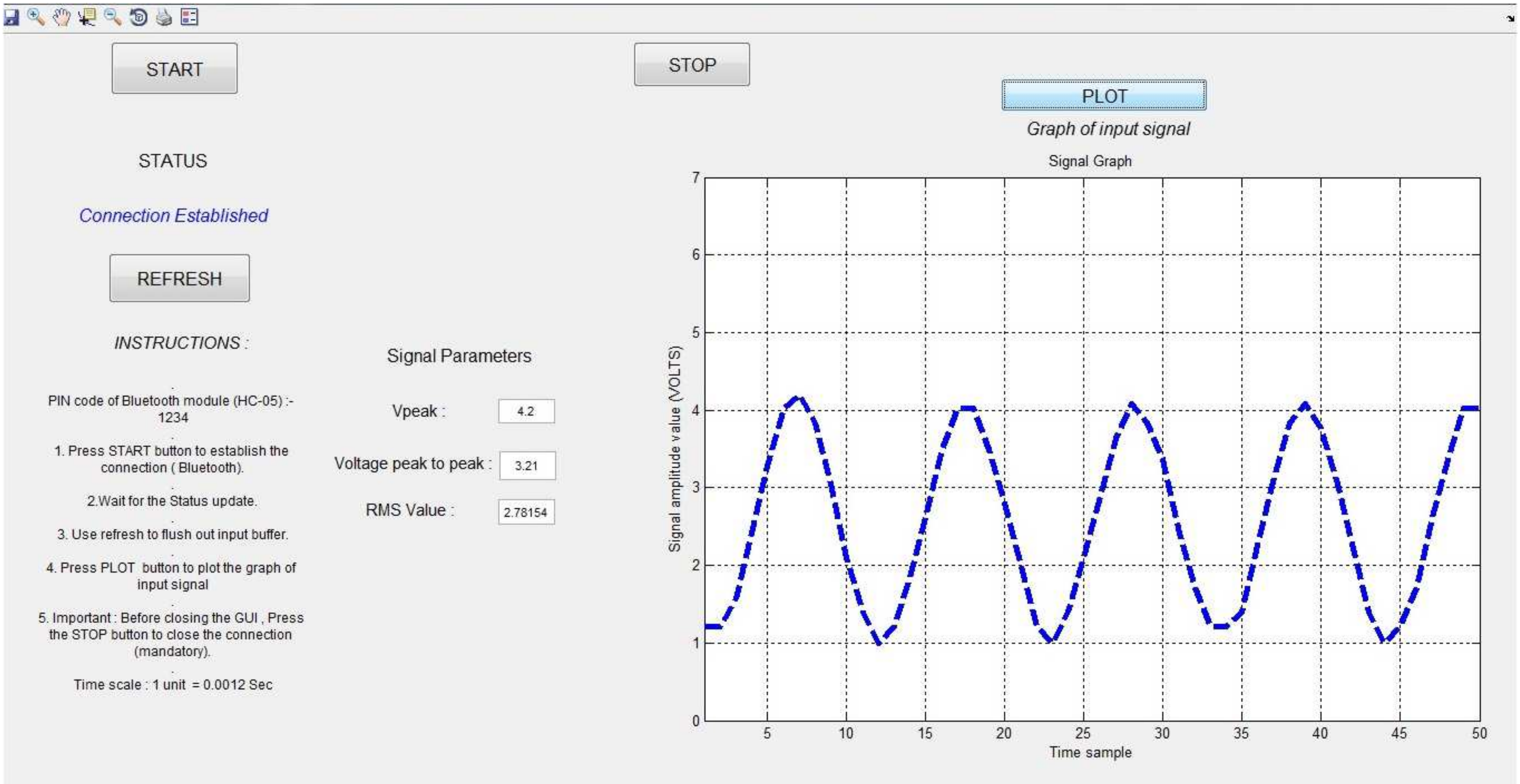

Figure 6.3: DAQ ouput for a sine signal: V_{pp} : 3 Volts, Frequency : 72 Hz

6.0.4 Input Signal : Square Wave

The function generator produces a square wave with an peak to peak voltage of 3.28 volts and a frequency of 72 Hz. The GUI output for square wave signal is shown in figure 6.4.

The signal parameters calculated by GUI are as follows :

- V_{pp} = 3.5 Volts
- V_{RMS} = 3 Volts
- V_{Peak} = 4.26 Volts
- Frequency = 74 Hz

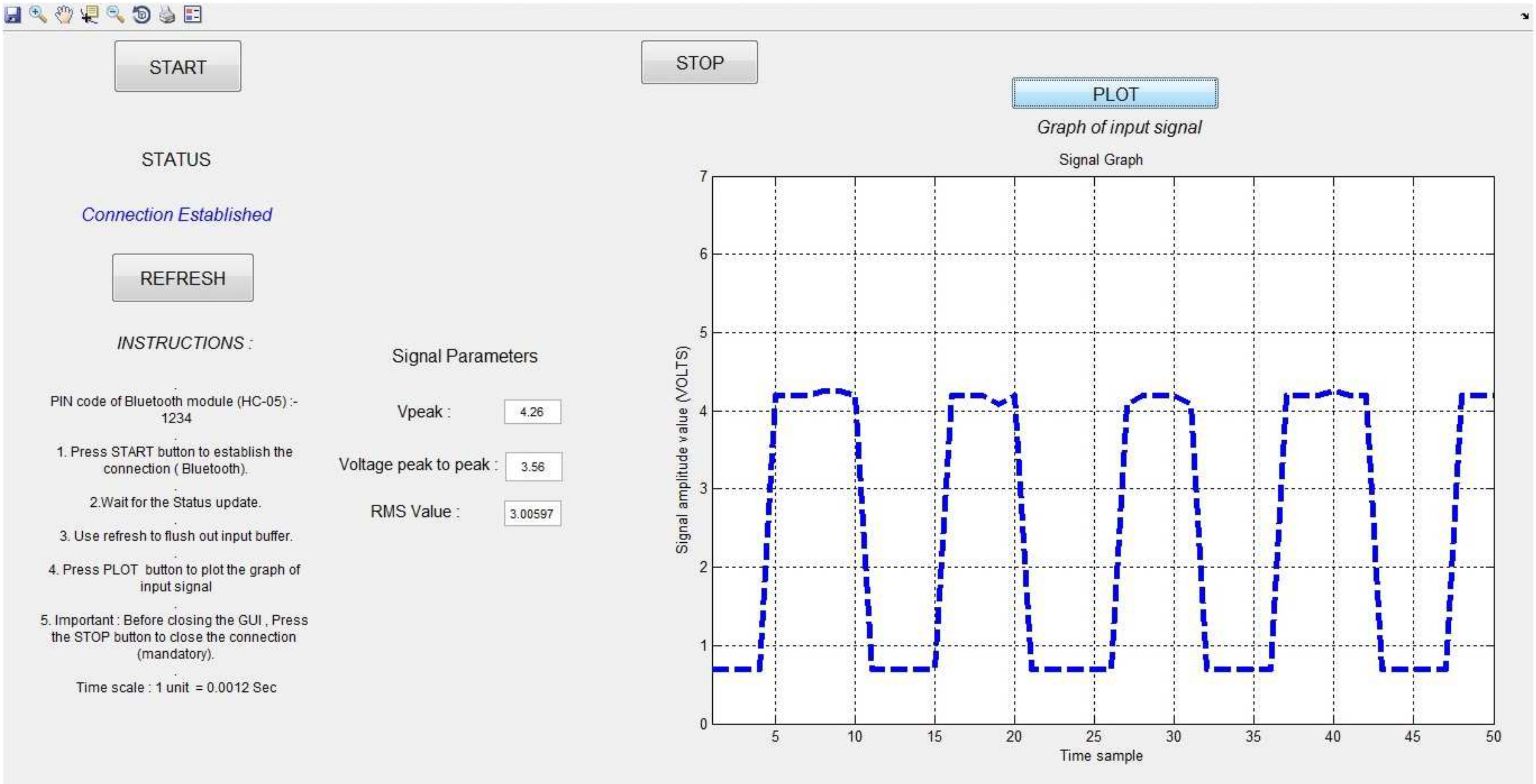

Figure 6.4: DAQ ouput for a square signal: V_{pp}: 3.28 Volts, Frequency : 72 Hz

6.0.5 Input Signal : Triangular Wave

The function generator produces a triangular wave with an peak to peak voltage of 2.8 volts and a frequency of 61 Hz. The GUI output for triangular wave signal is shown in figure 6.5.

The signal parameters calculated by GUI are as follows :

- V_{pp} = 2.92 Volts
- V_{RMS} = 3.1 Volts
- V_{Peak} = 4.32 Volts
- Frequency = 64 Hz

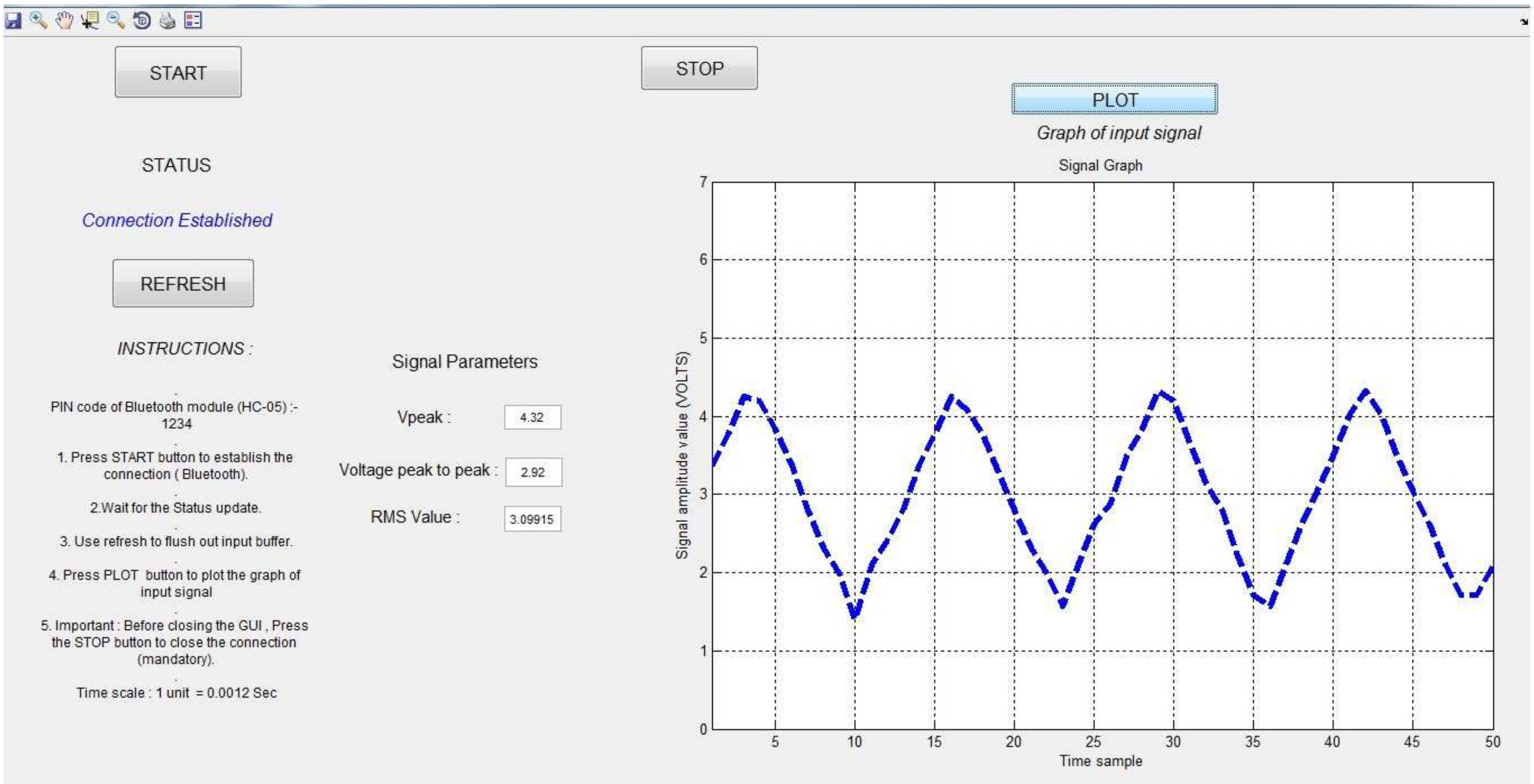

Figure 6.5: DAQ ouput for a triangular signal: V_{pp} : 2.8 Volts, Frequency: 61 Hz

6.0.6 Discussion on Results

The designed wireless data acquisition system was successful in sampling and transmitting the the input signal fed to its probes. The sampling rate has been set to 833 Hz, which can be changed by changing the values in register R6, R7 and timer register. The GUI plots the signal waveform with good quality and efficiency. For better analysis a digital signal oscilloscope (DSO) was also fed with the same input signal. The signal parameters, such peak to peak voltage (V_{PP}) and frequency, obtained from both DAQ system and DSO are analyzed in Table 6.1. It can be observed that there is good match between the measured values and DSO readings. It is also noted that that error percentage for all the measurement is below 5 %. Also there is good match in the signal waveform shape. We can observe a small deviation in GUI generated waveform shape with the standard signal waveform because of the quantization error and approximation of sampled values.

Table 6.1: Analysis of measurements made by DAQ system with DSO readings

Signal	**Parameter**	**DSO Reading**	**DAQ Reading**	**Absolute Error**	**% Error**
DC	Amplitude	2 V	1.98 V	0.02 V	1 %
Sine Wave	Peak to peak voltage	3.84 V	3.98 V	0.14 V	3.6 %
	Frequency	30 Hz	29 Hz	1 Hz	3.3 %
Square Wave	Peak to peak voltage	3.36 V	3.5 V	0.14 V	4.16 %
	Frequency	72 Hz	74 Hz	2 Hz	2.7 %
Triangular Wave	Peak to peak voltage	2.8 V	2.92 V	0.12 V	4.28 %
	Frequency	61 Hz	64 Hz	3 Hz	4.9 %

With an increase in frequency above 250 Hz, the designed hardware system fails to obtain the exact waveform because of fixed sampling frequency. It has also been observed that there is small nonsynchronousness between the microntroller unit and PC timing which results in loss of few cycles between two consecutive reading. MATLAB plotting takes more time which results in delay in receiving the sampled values. The loss of sampled values has been minimized by the use of timer but still need more improvements. Few suggestions and recommendations has been proposed in future work section. Based on the above analysis the proposed prototype proved to be efficient(for lab purposes) in data acquisition of low frequency signal (below 250 Hz). High resolution ADC can be substituted in place of current ADC chip to increase the resolution and productivity.

Chapter 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

The work aims to design and develop a portable, economical and power efficient bluetooth based data acquisition system using MATLAB software. The test signals are generated using function generator and are acquired by the microcontroller using serial MCP3002 ADC. For test purpose the sampling rate is set to 833 Hz. Fifty values are stored in MCU memory in 0.06 second duration. After every 0.06 seconds interval, the stored values are transmitted to PC wirelessly using HC-05 Bluetooth Module. The sampling process to obtain fifty values in 0.06 sec is interrupt driven. On the PC side, the MATLAB GUI reads the fifty value at a regular interval of 0.06 sec using inbuilt timer object. The developed GUI is very interactive and is provided with options for user to control the acquisition process. User can start and stop the acquisition process with ease. The GUI is also provided with the display of signal parameters such as peak voltage, peak to peak voltage and RMS voltage along with waveform display. The GUI developed can be used as standalone application without any need to have MATLAB installed on the PC system. There is good match in the signal's parameter measurements by the proposed system and digital signal oscilloscope (DSO). The absolute error in all voltage measurements is below 0.3 Volts. Whereas percentage error in various measurements is below 5 %. Use of low cost microcontroller and low power Bluetooth module makes the the proposed DAQ application efficient. With a fine tuning in the circuity,the prototype can be used for a number of application such as ECG data acquisition, device controlling, etc. Bluetooth transmission provides a greater power saving and longer battery life. Multiple DAQ systems can be used for wireless distributed data acquisition and controlling of devices. To support high sampling rate, current MSP3002 ADC can be replaced with high speed and high resolution ADC.

7.2 Future Work

There is a lot of scope for further development in functionalities and efficiency of designed prototype. During the testing of the prototype it has been observed that there is a loss in some signal samples between consecutive 0.06 time interval because of timing mismatch between MCU and PC. Also the frequency of input signal is limited because of low sampling rate. One of the solution for this problem is to go beyond the Nyquist sampling rate using the theory of compressive sampling [22] [23]. Few works [23] [24] have shown that it is possible and efficient to acquire the analog signal at sub Nyquist sampling rate. But for this process to work the signal must be sparse signal in some dimension. Random demodulator, a new type of data acquisition system, has been explained in detail in [23].However it is to be noted that these algorithms requires dedicated hardware, which are complex in nature. Also in future, new signal processing functionality will be added to GUI by using MATLAB toolbox libraries. Regarding power consumption, a study can be conducted to evaluate life of a battery under a particular operating situations.

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