Data Acquisition and Linearization of Sensors: Greenhouse Case Study

A thesis submitted in partial fulfillment
of the requirements for the award of the degree of

Master of Technology

in

Electronics and Communication Engineering

(Specialization: Electronics and Instrumentation)

by

Nilimamayee Samal

212EC3160

Department of Electronics & Communication Engineering

National Institute of Technology

Rourkela - 769008, Odisha

INDIA

May 2014

Data Acquisition and Linearization of Sensors: Greenhouse Case Study

A thesis submitted in partial fulfillment

of the requirements for the award of the degree of

Master of Technology

in

Electronics and Communication Engineering

(Specialization: Electronics and Instrumentation)

by

Nilimamayee Samal

212EC3160

Under the Supervision of

Dr. Umesh Chandra Pati

Department of Electronics & Communication Engineering

National Institute of Technology

Rourkela - 769008, Odisha, INDIA

May 2014

Department of Electronics & Communication Engineering

National Institute of Technology

Rourkela – 769008, Odisha, INDIA

CERTIFICATE

This is to certify that the thesis titled **"Data acquisition and linearization of sensors: Greenhouse case study"** submitted by **Nilimamayee Samal** bearing roll no. **212EC3160** in partial fulfilment of the requirements for the award of **Master of Technology** in **Electronics and Communication Engineering** with specialization in **"Electronics and Instrumentation Engineering"** during session **2012-2014** at **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 or Diploma.

Dr. Umesh Chandra Pati

Place: Associate Professor

Date: Dept. of Electronics and Communication Engineering

National Institute of Technology

Rourkela-769008, Odisha, INDIA

ACKNOWLEDGEMENT

I would like to express my respect and gratitude towards my supervisor Dr. Umesh Chandra Pati, who has been the guiding force behind this work. I am greatly indebted to him for his constant encouragement, invaluable advice and for propelling me further in every aspect of my academic life. His presence and optimism have provided an invaluable influence on my career and outlook for the future. I consider it my good fortune to have an opportunity to work with such a wonderful person. I want to express my respects to Prof. U.K. Sahoo, Prof. A.K. Sahoo, Prof. S. K. Patra, Prof. T.K. Dan Prof. K. K. Mahapatra, Prof. S. Meher, Prof. A. Swain, Prof. Poonam Singh, Prof D.P. Acharya and Prof. L. P. Roy for teaching me and helping me to learn. They have been great sources of inspiration to me and I thank them from the bottom of my heart.

I would like to thank my friends Anita Lakra, Prateek Mishra, Sarmistha Sarkar, Siba Prasad Mishra, Jyoti Ranjan Pati, Saurabh Bansod, Ashish Singh, Vikram Javre, Shailesh Singh Badghare, Kuldeep Singh, Dipen Mondal, Abhishek Gupta, Chandan Kumar and all other classmates for all the thoughtful and mind stimulating discussions we had, which prompted us to think beyond the obvious. I have enjoyed their companionship so much during my stay at NIT, Rourkela.

I would also like to thank to the Department of Science and Technology, Ministry of Science and Technology, Government of India for their financial support to setup Virtual and Intelligent Instrumentation Laboratory in Department of Electronics and Communication Engineering, National Institute of Technology, Rourkela under Fund for Improvement of S&T Infrastructure in Universities and Higher Education Institutions (FIST) program in which the experimentation has been carried out.

I am especially indebted to my parents for their love, sacrifice, and support. They are my first teachers after I came to this world and have set great examples for me about how to live, study, and work.

ABSTRACT

This work presents an overview of data acquisition, data logging and supervisory control of different parameters in a greenhouse. Raw measurement data from various parameters (surrounding temperature, pH of liquid, CO_2 gas concentration) are acquired using DAQ and logged in a database for further analysis and supervisory control. For sensing the physical parameters, LM 35, pH probe, CO_2 gas sensors are used. These sensors and DAQ needs uninterrupted power supply. For this purpose renewable energy is used to generate clean energy. Solar radiation can be used to generate electricity using PV (photo voltaic) cell and power conditioning circuit. This thesis is used to study the electrical characteristics of PV cell, which can be used to generate electricity from solar radiation for greenhouse purpose. Simulation studies have been carried out to know the electrical characteristics of PV cell for various irradiation levels. The sensors, which are mentioned above are mostly linear sensors. To use a nonlinear sensor suitably for data acquisition purpose, first of all the sensor linearization is done. In this work a thermistor is considered and its nonlinear characteristics are linearized using two methods (curve fitting method, Steinhart-Hart equation).

Keywords: Greenhouse, Data acquisition & control, Data logging, Linearization

TABLE OF CONTENTS

Page no.

Chapter 1

Introduction 1-3

1.1 Overview 1

1.2 Literature Review 1

1.3 Motivation 2

1.4 Objectives 2

1.5 Organization of Thesis 3

Chapter 2

PC Based Data Acquisition in a Green House 4-19

2.1 PC based Data acquisition Module 5

2.1.1 Authentication Module 6

2.1.2 Data acquisition of temperature using LM-35 7

2.1.3 Data acquisition of pH 10

2.1.4 Data acquisition of CO_2 13

2.1.5 Hardware setup 16

2.2 Solar Powered Green House 17

Chapter 3

Wireless Data Acquisition in a Green House 21-26

3.1 Wireless Standards 22

3.2 Wireless Data Acquisition of Temperature 26

Chapter 4

Nonlinearity Compensation of Thermistor 27-36

4.1 Temperature Measurement using Thermistor 28

4.2 Nonlinearity Compensation in thermistor 31

4.2.1 Series compensation 32

4.2.2 Shunt compensation 33

4.2.3 Logarithmic compensation 34

4.3 Steinhart-Hart Equation 34

Chapter 5

Conclusions 37

5.1 Conclusion 37

5.2 Future Scope 37

Papers Published 38

References 39

LIST OF FIGURES

Figure no.	Title of figure	Page no.
2.1	Schematics of PC based data acquisition and control	5
2.2	Front panel for data acquisition application	6
2.3	Flow chart for authentication module	6
2.4	Front panel for authentication module	7
2.5	LM 35 Sensor and its pin configuration	8
2.6	Flow chart for data acquisition and control of temperature in greenhouse	8
2.7	LabVIEW modules for data acquisition and control of temperature	9
2.8	Vernier Made pH Probe	11
2.9	Flow chart for data acquisition of pH	12
2.10	LabVIEW module for data acquisition of pH	13
2.11	CO_2 sensor provided by Vernier	14
2.12	LabVIEW modules for data acquisition of CO_2	14
2.13	Hardware setup for PC based data acquisition	16
2.14	Operating principle of solar cell	18
2.15	Equivalent circuit of PV cell	18
2.16	V-I characteristics for different insolation	20
2.17	P-V characteristics for different insolation	20
2.18	P-I Characteristics for different insolation	21
3.1	Comparison of different wireless technology	23
3.2	Wireless gateway and sensor nodes	23
3.3	LabVIEW based setup of wireless sensor network-I	24
3.4	LabVIEW based setup of wireless sensor network-II	24
3.5	Mesh network of wireless sensor network	25
3.6	Front panel of wireless data acquisition system	26
3.7	Hardware setup of wireless data acquisition system	27
4.1	Nonlinearity compensation scheme	28
4.2	Resistance-temperature characteristic of thermistor	29
4.3	Temperature measurement using thermistor using micro-ammeter	30
4.4	Temperature measurement using thermistor using micro-ammeter with compensating network	30
4.5	Temperature measurement using thermistor using AC amplifier	31
4.6	Nonlinearity compensation scheme	31
4.7	Series compensation	32
4.8	Shunt compensation	33
4.9	Logarithmic compensation	34
4.10	Nonlinear output voltage v/s temperature of thermistor	35
4.11	Steinhart-Hart linearization of thermistor	35
4.12	Linearized output voltage v/s temperature of thermistor	36

LIST OF TABLES

Table no.	Title of table	Page no.
2.1	Data logged for temperature	10
2.2	Data logged for pH	12
2.3	Data logged for CO_2 gas concentration	15
3.1	Comparison of wireless technology	22

Chapter 1
Introduction

1.1 Overview

The purpose of data acquisition is to measure physical parameters from real world. Data acquisition system measures the physical parameters and displays the current value of the parameter using a computing device. Data acquisition system comprises of different sensors, data acquisition hardware (DAQ unit) and a computing device. The computing device can be anything such as micro-controller, computer or PLC.

In PC based data acquisition, the PC comprises of driver software and application software. The driver software is a medium between real world process and the hardware whereas the application software is the medium between hardware and the user. Some of the well-known application software is MATLAB from Math Works and LabVIEW from National Instruments. The application software stores the measurement data and computes the data as per the requirement of the specific application. MATLAB compiler compiles text based programming whereas LabVIEW is a graphical programming approach. The measurement data from the sensor can be noisy, so before analysing the data, pre-processing of data is necessary. Pre-processing of data includes noise removal, trend and bias removal. The resulting data is stored in a PC for further analysis and this process of storing data is called data logging.

1.2 Literature Review

A remote monitoring system in which the embedded system sends SMS to cell phones of the farmers during any abrupt changes in reading of different environmental variables has been developed by I. D. A. Aziz et al. [1]. Many researchers developed wireless protocol based embedded system which monitors large stretch of greenhouse [2-4]. Various data acquisition systems for greenhouse application have been developed [5-8].

Many researchers have worked on data acquisition and data logging system. Data logging and supervisory control of multiple boiler system is developed by S. Padhee and Y. Singh [9]. Low cost wireless data acquisition system for a weather station is reported M. Benghanem [10]. To give an advanced warning system of Tsunami, a data acquisition system is developed by S. Sreelal et al. [11]. For a large plant like oil refinery supervisory control and data acquisition (SCADA) system is used by I. Morsi, L. M. El-Din [12] for proper monitoring and supervisory control of plant. GPRS based data acquisition and mobile phone based control technique is developed by R. Ionel [13]. A high precision thermocouple based smart thermometer with linearization and advance data logging features has been developed by U. Sharma and P.K. Boruah [14]. A LabVIEW based data acquisition for vibration monitoring and analysis is developed by A .Gani and M.J.E. Salami [15]. A survey on data acquisition system is done by M. Abdullah and O. Elkeelany [16]. An automatic meteorological system based on ARM and CAN Bus has been designed by J. Jin and B. Wang [17]. A portable USB data acquisition system has been designed by Y. Wang and M. Fu [18]. A high Speed Real-Time Data Acquisition System Based on Solid-state Storage technique has been developed by Li Nan et.al [19].

1.3 Motivation

Development of data acquisition system is one of the challenging tasks for an engineer where many design issues have to be considered simultaneously. The choice of data acquisition hardware, sampling rate, design of ADC are some of the core issues which has to be addressed by the designer. When the area is large then wireless system has to be implemented. The wireless system is cost effective in nature and provides reliable reading in hostile environment.

Another major concern of data acquisition system is the nonlinearity of some of the sensors. The nonlinear behaviour of the sensors has to be compensated so that it can be linearized and the sensor can be interfaced with any computing device with ease.

1.4 Objectives

This thesis has following objectives

1. Development of PC based data acquisition system for a greenhouse and show real time trends of various environmental parameters
2. Study of the solar radiation pattern in the greenhouse to develop renewable energy
3. Development of wireless data acquisition system for a greenhouse application and show real time trends of various environmental parameters
4. Study of the nonlinear characteristics of thermistor and perform software linearization

1.5 Organization of Thesis

Chapter 1 provides an introduction of need of PC based or wireless data acquisition system.

Chapter 2 provides a systematic approach of PC based data acquisition of different variables (temperature, CO_2, pH and solar radiation) for a greenhouse application

Chapter 3 provides an overview of different wireless techniques available and implements Wi-Fi data acquisition system for temperature measurement.

Chapter 4 provides an overview of linearization of sensors and performs linearization of thermistor

Chapter 5 concludes the thesis.

Chapter 2

PC based Data Acquisition in a Green House

Greenhouse is a mechanical structure where out season vegetable, fruits and flowers are grown in a controlled environment. There are different kinds of green house and a typical greenhouse covers an area of around 400 m^2 to 10000 m^2. Because the fruits and vegetables are grown in a controlled environment, the greenhouse limits the dependency of the farmer in rain fall and environmental factor. Because of greenhouse many off season vegetables can be brought to the market almost all the year. Controlled Environment Agriculture (CEA) is one of the new research areas where researchers are trying to modernize the age old Green House concept so that different parameters can be monitored and controlled in a more efficient manner.

Greenhouses can be divided into glass greenhouses and plastic greenhouses. Plastics mostly used are PE film and multiwall sheet in PC or PMMA. Commercial glass greenhouses are often high-tech production facilities for vegetables or flowers. The glass greenhouses are filled with equipment such as screening installations, heating, cooling, lighting, and may be automatically controlled by a computer.

Some of the environmental parameters controlled in greenhouse are

1. Soil moisture
2. Soil nutrients
3. Solar flux
4. Air movement
5. Humidity
6. Dry bulb temperature
7. Wet bulb temperature
8. pH of water
9. Different gas concentration
10. Ambient temperature

2.1 PC Based Data Acquisition Module

The block diagram of PC based data acquisition module is shown in Figure 2.1. Different sensors (temperature, pH sensor and gas sensors) are used to measure temperature of environment, pH of liquid and CO_2 gas concentration in air in the greenhouse.

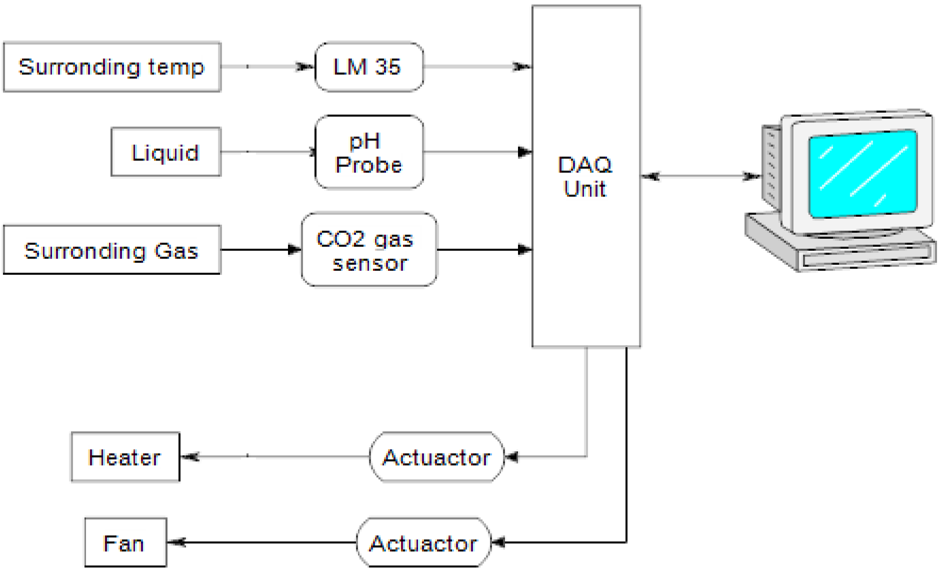


Figure 2.1 Schematics of PC based data acquisition and control

The sensors with the signal conditioning units are connected with data acquisition unit and the DAQ unit is eventually connected with the PC. LabVIEW from National Instruments is used as application software. The driver software is also used for data acquisition. A LabVIEW application is developed which is used to continuously monitor real time trends of the above mentioned physical parameters. The application also stores the sensor data in database for future use and statistical analysis.

Figure 2.2 shows the front panel of data acquisition application. This application is secured because to use the application authenticating username and password is required.

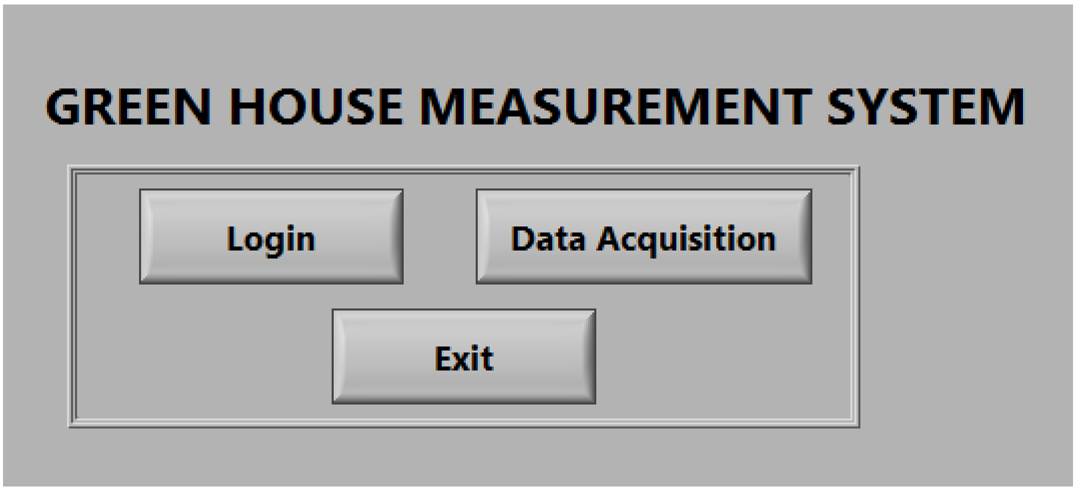


Figure 2.2 Front panel of data acquisition application

2.1.1 Authentication Module

This section discusses the authentication module of greenhouse data acquisition application. The flow chart of authentication module is shown in Figure 2.3.

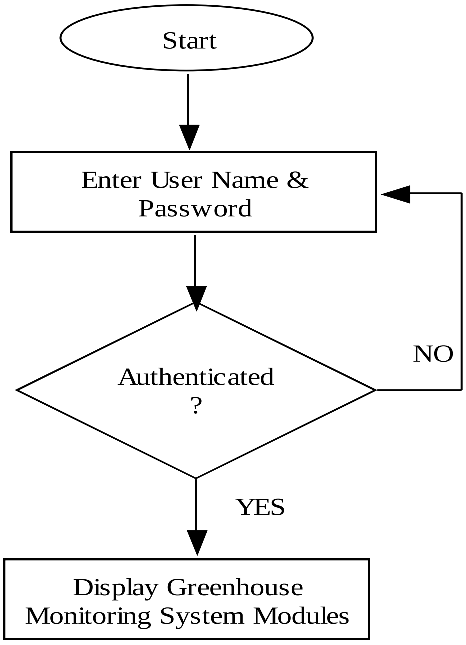
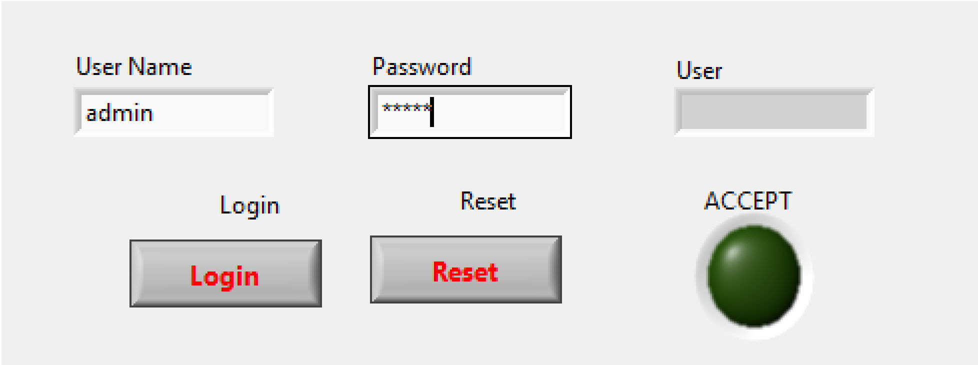
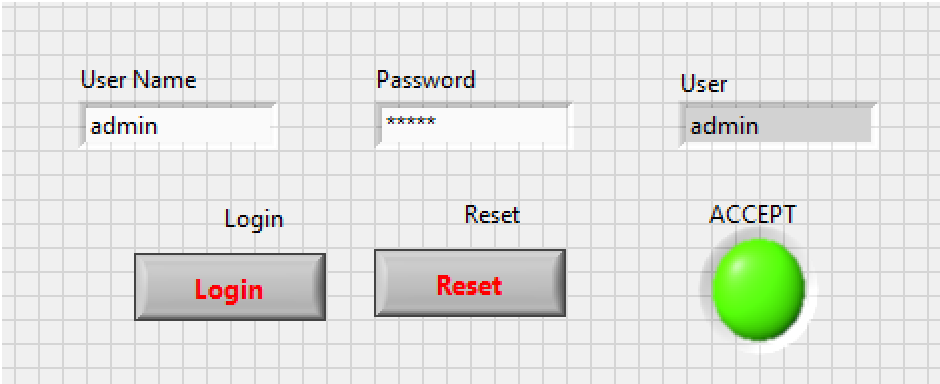


Figure 2.3 Flow chart for authentication module

The front panel of the authentication module is shown in Figure 2.4 (a) and Figure 2.4 (b).



(a)



(b)

Figure 2.4 (a) (b) Front panel for authentication module

2.1.2 Data Acquisition of Temperature Using LM-35

This section discusses the data acquisition and data logging of ambient temperature using semiconductor temperature sensor (LM-35).

LM35 series are precision integrated-circuit temperature sensors, with an output voltage linearly proportional to the Centigrade temperature.

1. Calibrated directly in degree Celsius
2. Linear 10 mV/C scale factor
3. Range of -55°C to 150°C
4. Operates from 4 V to 30 V
5. Low output impedance
6. Low cost
7. Drain current of 60 µA

The pin configuration of LM-35 sensor is shown in Figure 2.5.

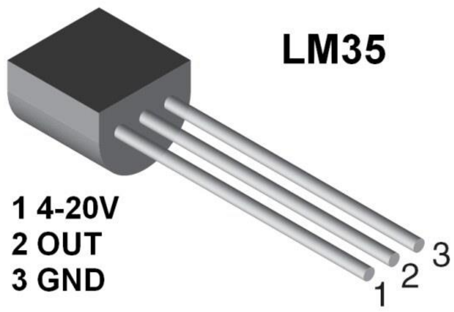


Figure 2.5 LM 35 Sensor and its pin configuration

The temperature of greenhouse should be controlled to a specific temperature which is vital for proper operation of greenhouse. If the temperature exceeds or recedes the desired temperature, then there can be severe damage to the corp. So temperature measurement and temperature control is vital for greenhouse application.

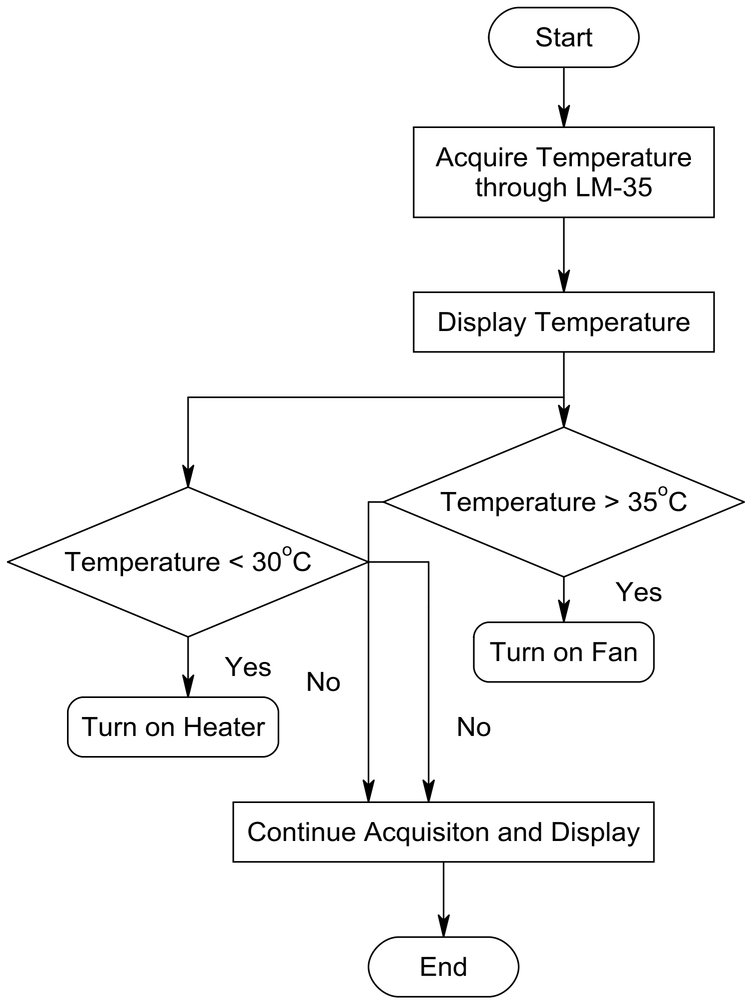


Figure 2.6 Flow chart for data acquisition and control of temperature in greenhouse

Figure 2.6 shows the data logging and control flow chart of temperature in greenhouse. NI-ELVIS II+ is used as a DAQ device for temperature measurement. NI ELVIS II+ is interfaced with the PC with USB protocol. The voltage data sent from LM-35 is converted to temperature and the real time trend of the temperature is displayed in graphical format in LabVIEW. The temperature data is stored in excel sheet for future reference. The logged data is shown in Table 2.1. The front panel for temperature monitoring is shown in Figure 2.7.

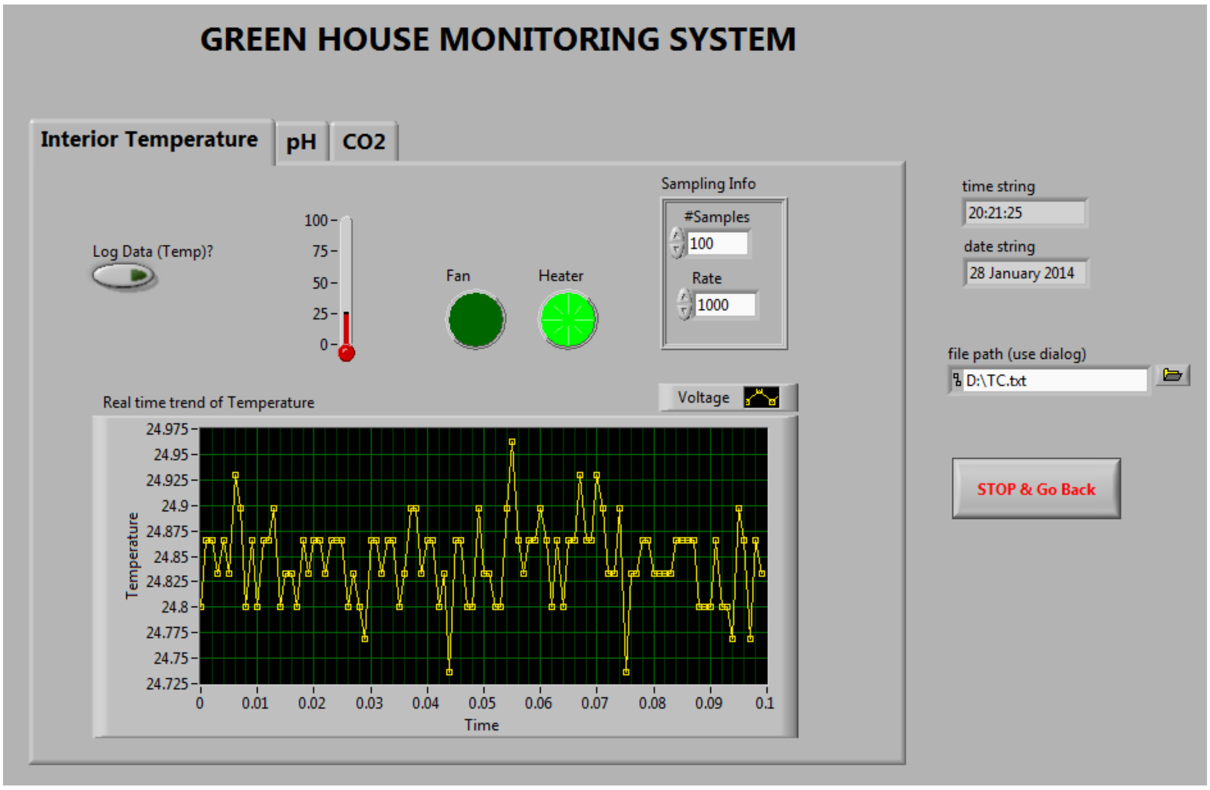


Figure 2.7 LabVIEW modules for data acquisition and control of temperature

If the temperature exceeds 35°C the relay unit activates the cooling fan whereas when the temperature falls below 30°C the relay unit activates the heater. So the temperature is maintained between 35°C.

Table 2.1 Data logged for temperature

Date	Time	Temperature (°C)
29-11-2013	15:46:24	24.028375
29-11-2013	15:46:30	23.355144
29-11-2013	15:46:35	23.262662
29-11-2013	15:46:41	23.860314
29-11-2013	15:46:47	23.781768
29-11-2013	15:46:53	24.425015
29-11-2013	15:46:59	24.260694
29-11-2013	15:47:04	25.627848
29-11-2013	15:47:10	25.163953
29-11-2013	15:47:16	25.625671
29-11-2013	15:47:22	24.991601
29-11-2013	15:47:28	24.745216
29-11-2013	15:47:33	22.301676
29-11-2013	15:47:39	20.820601
29-11-2013	15:47:45	29.884953
29-11-2013	15:47:51	28.859861
29-11-2013	15:47:57	28.754562

2.1.3 Data Acquisition of pH

pH is a measure of acidity or basicity of a solution. pH value ranges from 0 to 14. If the pH is less than 7 then the solution is treated as acidic and if pH is more than 7 then the solution is treated as basic solution.

pH is defined as decimal logarithm of reciprocal of H^+ ion activity in a solution. pH is represented as $pH = -\log_{10}\left[a_{H^+}\right]$ (1)

The other way of representation of pH is by the Nernst equation. pH is represented by Nernst equation by the following formula

$$E = E^o + \frac{RT}{F}\ln\left[a_{H^+}\right] \quad (2)$$

$$E = E^o - \frac{2.303RT}{F}pH \quad (3)$$

Plants need light, carbon dioxide, water and mineral nutrients in order to produce sugars (food) and grow. Water is supplied through the substrate, and it contains dissolved mineral elements. Especially affected are those nutrients that plants require in small quantities, called micronutrients or trace elements. When the pH is too low, the micronutrients become more mobile and are absorbed in excess of what the plant needs, resulting in this potential for toxicities.

Specifications of pH probe

1. Type — Sealed Gel-filled epoxy body, Ag-AgCl
2. Response time — 90% of final reading in 1 sec
3. Temperature Range — 5°C to 80°C
4. Output — 59.2 mV/pH at 25°C

Figure 2.8 Vernier Made pH Probe

The pH probe will give an output voltage of 1.75 V when pH is equal to 7 (buffer). The voltage will increase by about 0.25 V for every decrease in pH number and the voltage will decrease by about 0.25 volts per every increase in pH number.

The flow chart of data acquisition of pH i.e conversion of voltage to pH is shown in Figure 2.9.

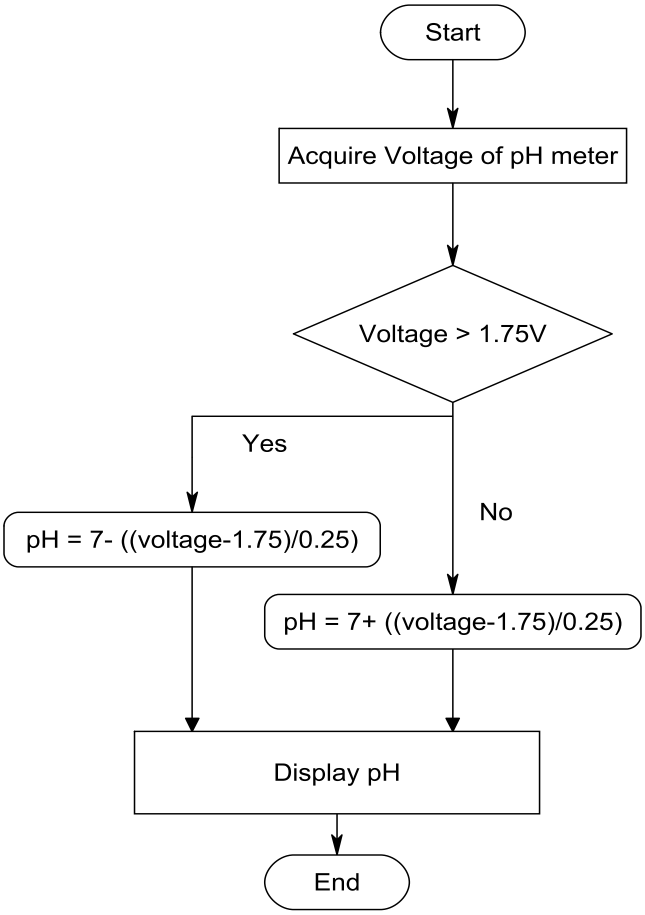


Figure 2.9 Flow chart for data acquisition of pH

Table 2.2 Data logged for pH

Date	Time	pH Value
04-12-2013	17:03:24	4.46271
04-12-2013	17:03:30	4.46271
04-12-2013	17:03:35	4.46258
04-12-2013	17:03:41	4.46271
04-12-2013	17:03:47	4.46852
04-12-2013	17:03:53	4.48526
04-12-2013	17:03:59	4.46852
04-12-2013	17:04:04	4.46271
04-12-2013	17:04:10	4.46271
04-12-2013	17:04:16	4.46258
04-12-2013	17:04:22	4.46271

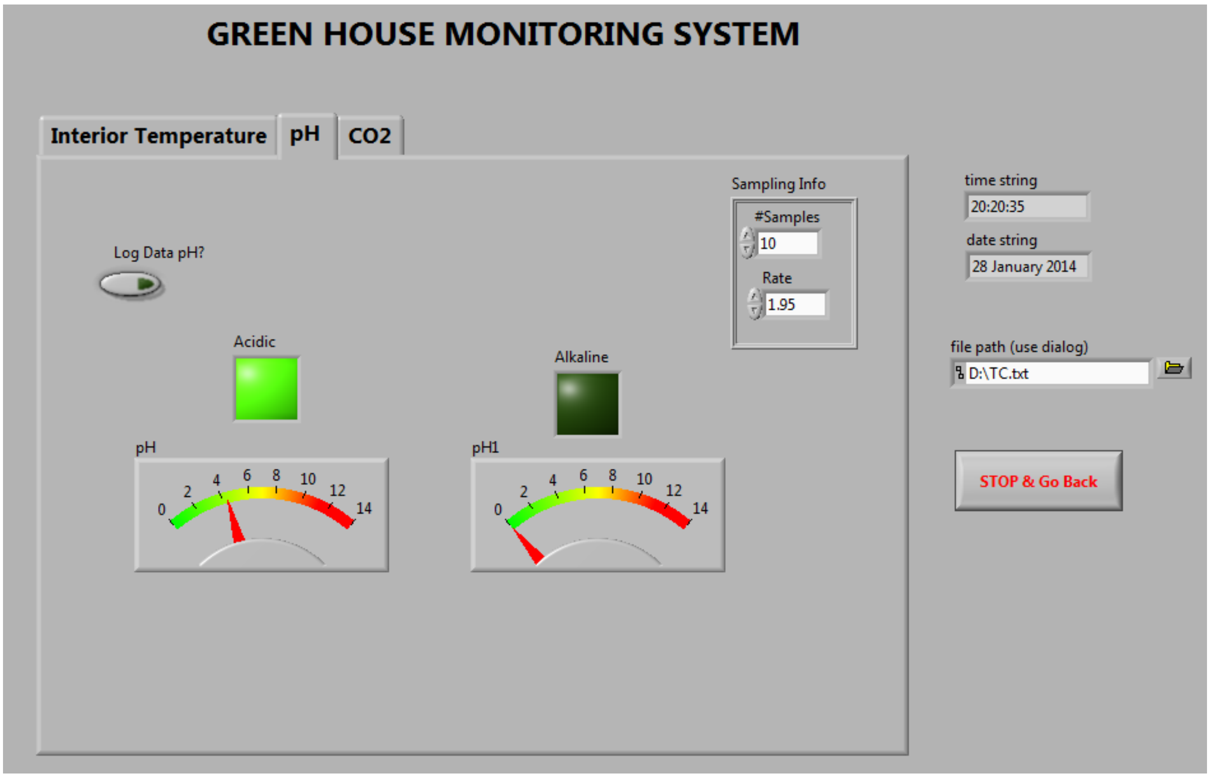


Figure 2.10 LabVIEW module for data acquisition of pH

2.1.4 Data Acquisition of CO_2

CO_2 gas sensor consists of the following components

1. IR source
2. Light tube
3. Interference sensor
4. IR detector

The gas is pumped into the light tube and the sensor measures the absorption of light which is acquired in terms of voltage and appropriate conversion is used to measure CO_2 concentration in ppm.

Figure 2.11 shows the CO_2 sensor provided by Vernier and figure 2.12 shows the front panel of CO_2 data acquisition.

Figure 2.11 CO_2 sensor provided by Vernier

In Figure 2.12, the front panel for LabVIEW module of data acquisition of CO2 gas concentration is shown. Here 10 samples are taken with a sampling rate of 1000/second.

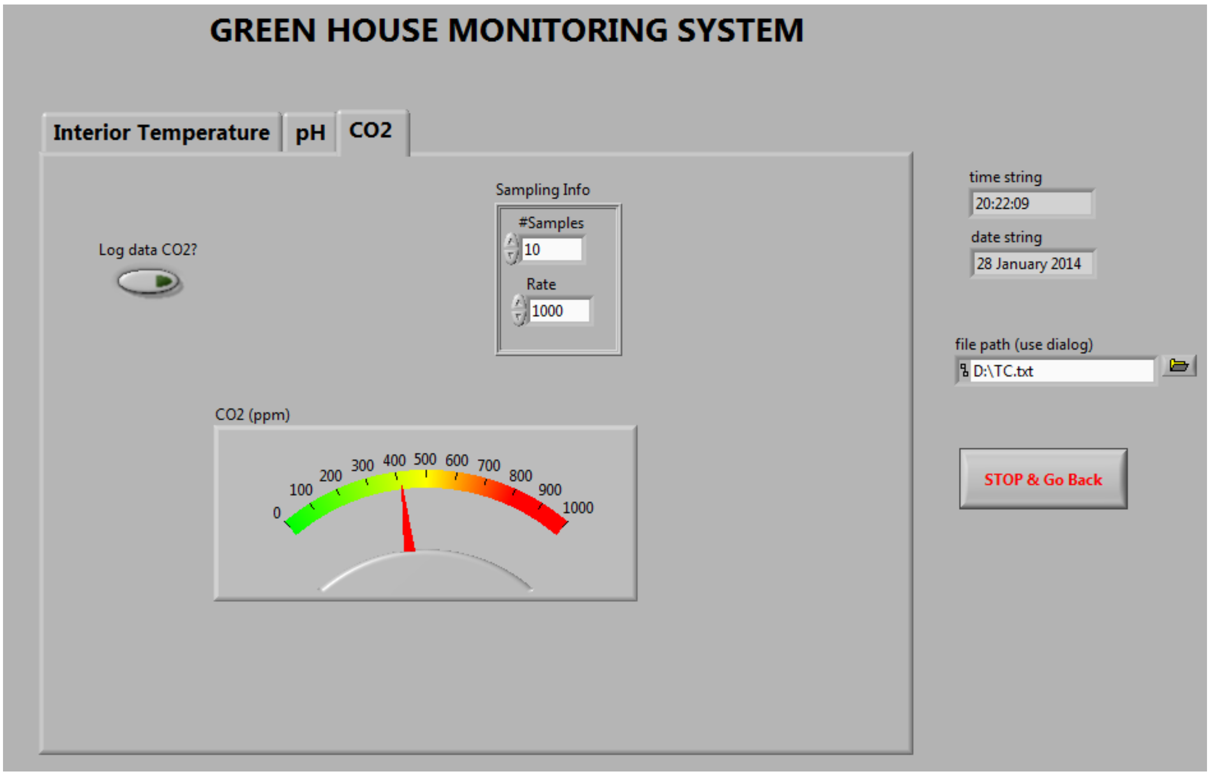


Figure 2.12 LabVIEW modules for data acquisition of CO_2

Table 2.3 Data logged for CO_2 gas concentration

Date	Time	CO_2 Gas Concentration (ppm)
14-12-2013	17:03:24	325
14-12-2013	17:03:30	338
14-12-2013	17:03:35	321
14-12-2013	17:03:41	354
14-12-2013	17:03:47	365
14-12-2013	17:03:53	354
14-12-2013	17:03:59	400
14-12-2013	17:04:04	389
14-12-2013	17:04:10	388
14-12-2013	17:04:16	385
14-12-2013	17:04:22	384
14-12-2013	17:04:28	395
14-12-2013	17:04:33	360
14-12-2013	17:04:39	390

2.1.5 Hardware Setup

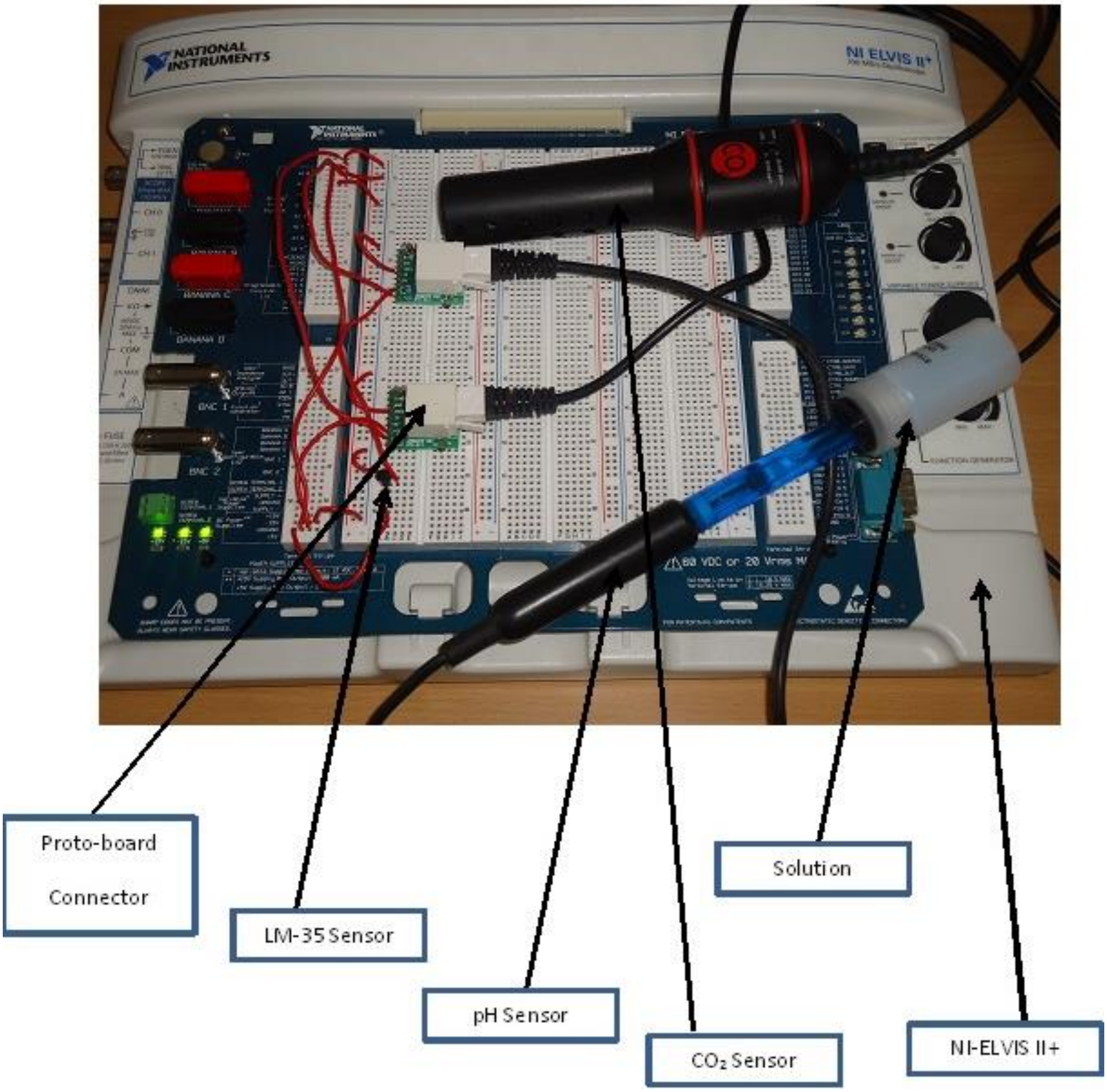


Figure 2.13 Hardware setup for PC based data acquisition

The complete labelled hardware setup for PC based data acquisition system is shown in Figure 2.13. NI-ELVIS II+ is used for data acquisition medium and LabVIEW is used for developing data acquisition application.

For data acquisition purpose, NI ELVIS II+ (National Instruments Educational Laboratory Virtual Instrumentation Suite) is used in this project. This is a multi-purpose device, which is able to substitute 12 electronic devices and perform their task at a time. It simultaneously performs the task done by an oscilloscope, digital multi meter, function generator, bode analyser ,variable power supply, dynamic signal analyser, arbitrary waveform generator, digital reader, digital writer, impedance analyser, 2-wire current to voltage analyser, 3-wire current to voltage analyser .

The DMM is able to measure the voltage (DC & AC) , CURRENT (DC & AC) , resistance, capacitance, inductance and can test the diode and audible continuity. The oscilloscope has two channels, modifiable time base, scaling and adjusting auto knobs, digital and analog hardware triggering. The function generator output is sine, triangular and square wave. It has amplitude selection capability along with frequency setting, offset setting and frequency sweep capability. The variable power supply varies from 0 volt to +12 volt in positive side and -12 volt to 0 volt in negative side. The bode analyser sets the frequency angel of the instrument and it also chooses between the linear and logarithmic scales. The dynamic signal analyser does the continuous and single scan measurement and it apply various windows and filtering options. The arbitrary waveform generator uses the waveform editor and generates two waveform simultaneously or once. The digital reader reads the digital data from eight consecutive lines in a continuous and single reading. The digital writer manually creates a digital pattern or selects a predefined pattern (toggle, ramp etc.). It controls eight consecutive lines and capable of continuous or single write. It is TTL compatible. The impedance analyser is capable of measuring the resistance and reactance for passive two wire elements for a given frequency. The 2-wire current to voltage analyser conduct the diode parametric testing and view the current to voltage characteristics. The 3-wire wave analyser is capable of conducting the transistor parametric testing and view current to voltage curve.

NI ELVIS II+ uses flash type analog to digital converter. It is the fastest ADC which uses the linear voltage adder along with a comparator at each stage of ladder to compare the input voltage with the consecutive reference voltages. These reference ladders re often made up of resistors, but now-a-days modern implementations uses the capacitive voltage division.

2.2 Solar Powered Green House

Due to abundant renewable energy in the form of solar energy, wind energy, biomass, chemical energy available in the environment, scientists are trying to use the renewable energy sources to electricity to cater the human needs.

This thesis studies the most widely used renewable energy source (solar energy) and finds out how it can be implemented in a greenhouse to generate electricity. Solar cells which are semiconductor material convert the solar energy to electrical energy by the following methods

1. Absorption of light energy to create free charge carriers within a material
2. The separation of the negative and positive charge carriers in order to produce electric current that flows in one direction across terminals that have a voltage difference.

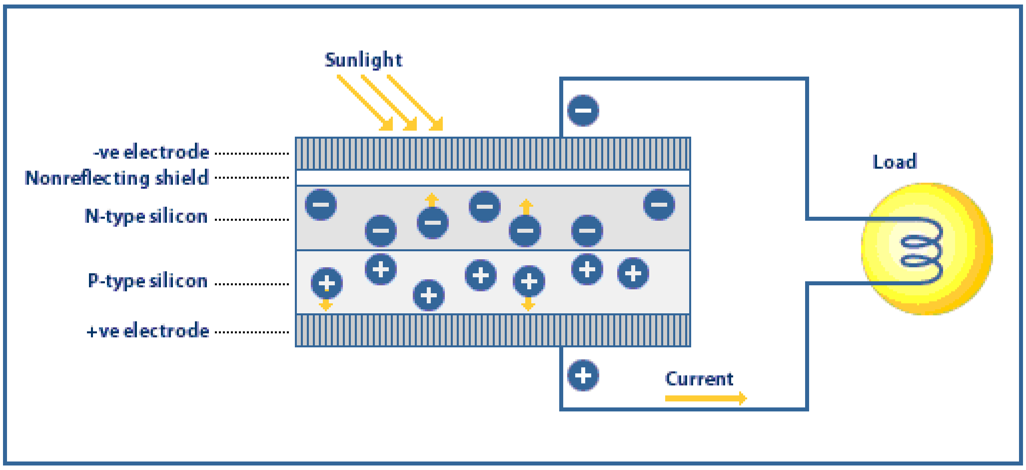


Figure 2.14 Operating principle of solar cell

The circuit diagram of PV cell is shown below.

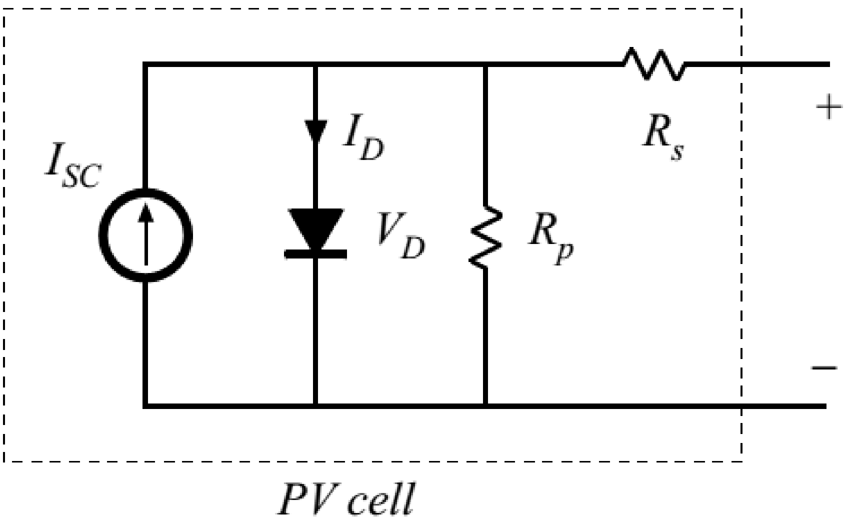


Figure 2.15 Equivalent circuit of PV cell

In Figure 2.15 the series resistance gives the ohmic losses of the front surface of the photovoltaic cell, whereas the parallel (shunt) resistance gives the loss due to the diode leakage current.

$$I_{sc} - I_o\left[e^{\frac{qV_d}{nkT}} - 1\right] = I_L \quad (4)$$

$$V_{oc} = \frac{nkT}{q}\ln\left(\left(\frac{I_{sc}}{I_o}\right) + 1\right) \quad (5)$$

Applying KCL in the above circuit $I_{sc} - I_D - \frac{V_D}{R} - I_{PV} = 0$

The diode characteristics is $I_D = I_o\left(e^{\frac{V_D}{V_T}} - 1\right)$

Applying KVL in the above circuit $V_{PVCell} = V_D - R_s I_{PV}$

$$V_L = \frac{nkT}{q}\ln\left(\left(\frac{I_{sc} - I_L}{I_o} + 1\right) - \frac{V_L + I_L R_s}{R_p}\right) - I_L R_s \quad (6)$$

Efficiency= $\eta = \frac{V_m I_m}{IA}$ (7)

File Factor= $FF = \frac{V_m I_m}{V_{oc} I_{sc}}$ (8)

Here V_m is the cell voltage at maximum power point

I_m is the cell current at maximum power point

I_{sc} is the short circuit current

V_{oc} is the open circuit voltage

V_l is the load voltage

I_l is the load current

q is the elementary charge

T is the absolute temperature in kelvin

K is the Boltz maan’s constant

n is the diode ideality factor (for ideal diode n=1)

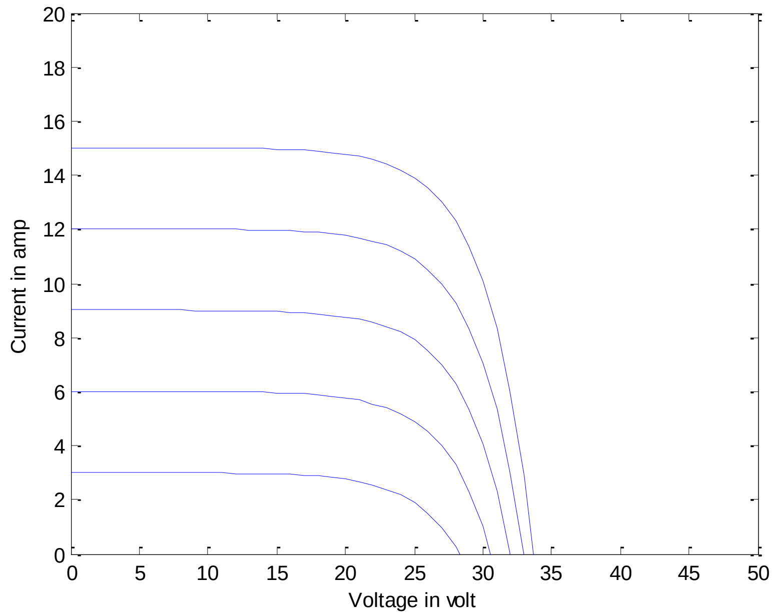


Figure 2.16 V-I characteristics for different insolation

From Figure 2.16, the cell current and cell voltage at maximum power point is noted at a particular irradiance level at a constant temperature. From this curve the short circuit current and the open circuit voltage are also found. Hence putting these values in equation 7 and 8, the performance parameters of the PV cell can be calculated.

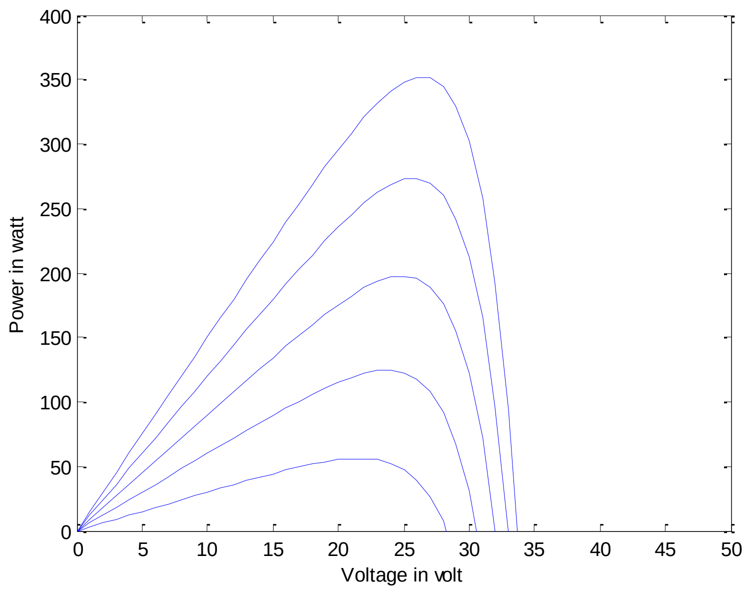


Figure 2.17 P-V characteristics for different insolation

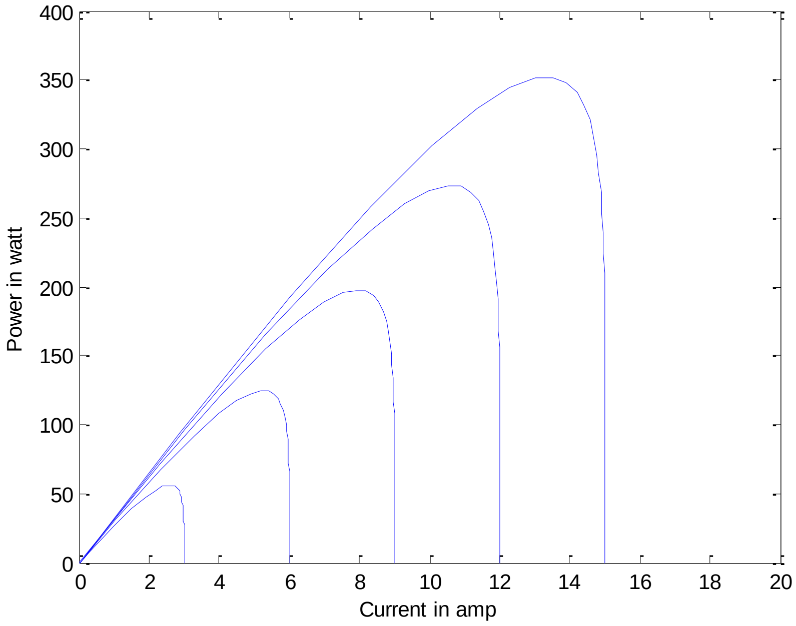


Figure 2.18 P-I Characteristics for different insolation

Obtaining a P-V or P-I curve is a very simple task. The multiplication of voltage and current gives the power. Hence it can be obtained by simply taking the answer from each sample point of the I-V curve and multiplying each point with the incoming voltage value. Then these multiplying values are plotted against voltage or current to obtain the P-V or P-I curve.

Here the Power-voltage, voltage-current and power-current characteristics of a solar cell are studied in different insolation.

Chapter 3

Wireless Data Acquisition in a Green House

NI-WSN 9791 gateway is a programmable Ethernet gateway that connects remote WSN nodes to a computer for data acquisition and control. The NI-WSN 3202 and the NI-WSN 3212 nodes are programmable wireless receivers which has several analog and digital inputs.

3.1 Wireless Standards

The wireless communication between nodes in accomplished with use of IEEE 802.15.4 standard (LR-WPAN)-ZigBee. IEEE 802.15.4 standard defines the characteristics of physical MAC layer for LR-WPAN.

Table 3.1: Comparison of wireless technology

	Zigbee	**WiFi**	**Bluetooth**
Standard	IEEE 802.15.4	IEEE 802.11b	IEEE 802.15.1
Applications	Monitoring and control	Web, email, video	Replacement of cable
System Resources	50 – 60 kB	>1 MB	> 250 kB
Battery life	100 – 1000 days	1 – 5	1- 7
Bandwidth kB/sec	20 – 250	11000	720
Maximum range	300 m	100 m	10 m
Radio	DSSS*	DSSS	FHSS**
Data Rate	250 kbps	11 Mbps	1 Mbps
Nodes/Master	64000	32	7

*DSSS : Direct sequence spread spectrum

**FHSS : Frequency hopping spread spectrum

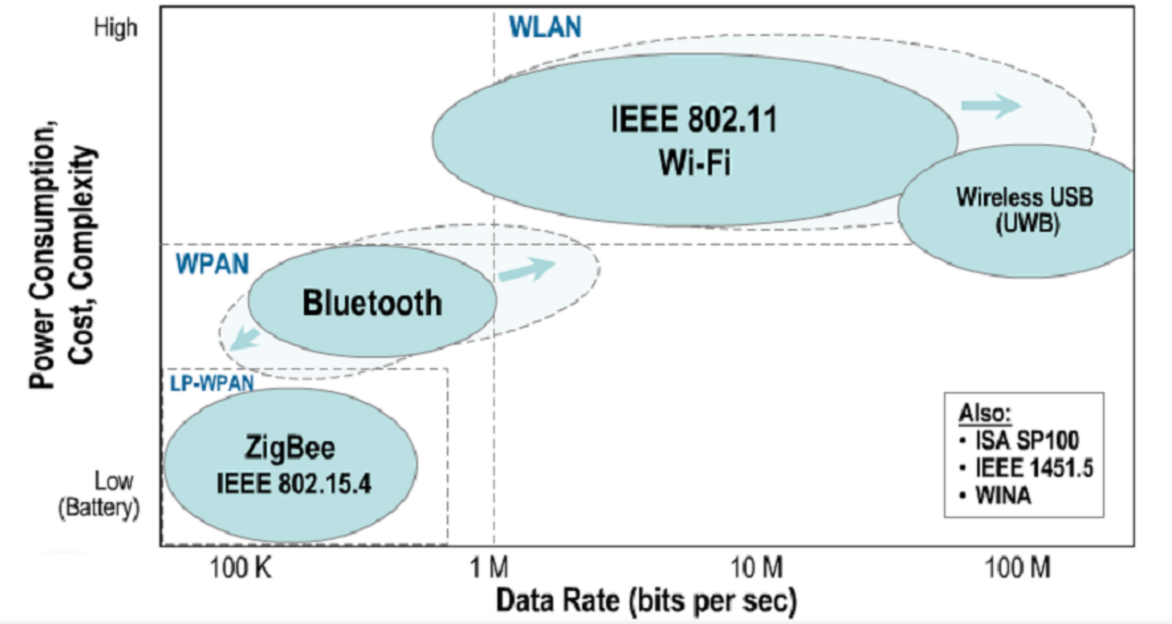


Figure 3.1 Comparison of different wireless technology

Here the protocol used is IEEE 802.11 Wi-Fi. It has a high power consumption, high cost and high complexity, still in most of the cases it is preferred because of its high data rate (10Mbits to 100 Mbits).

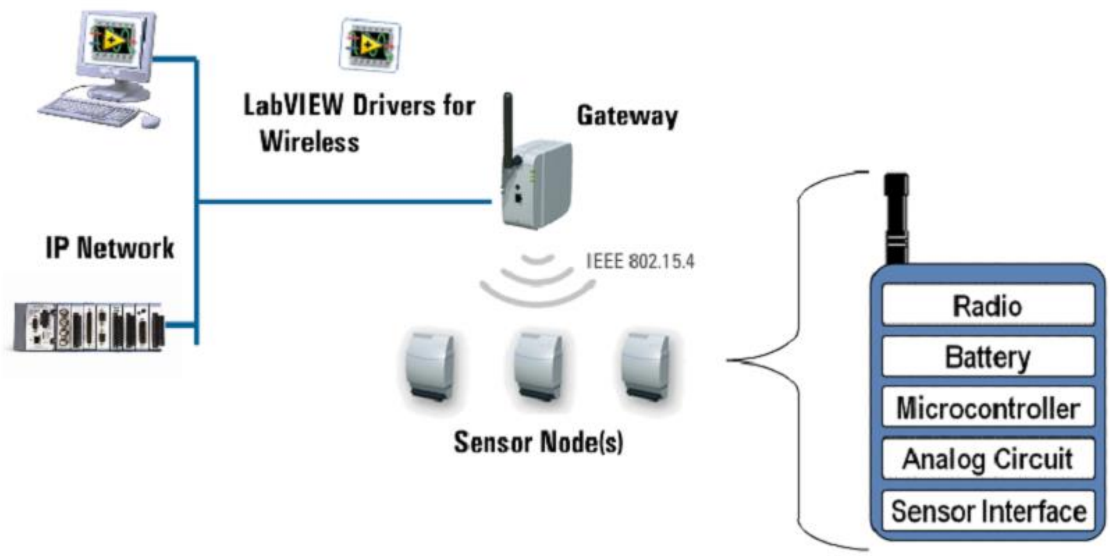


Figure 3.2 Wireless gateway and sensor nodes

The above figure shows that, a number of sensor nodes can be used with a single gateway and a number of sensors can be connected to a single sensor node. Hence using wireless data acquisition method, data from various parameters can be acquired simultaneously.

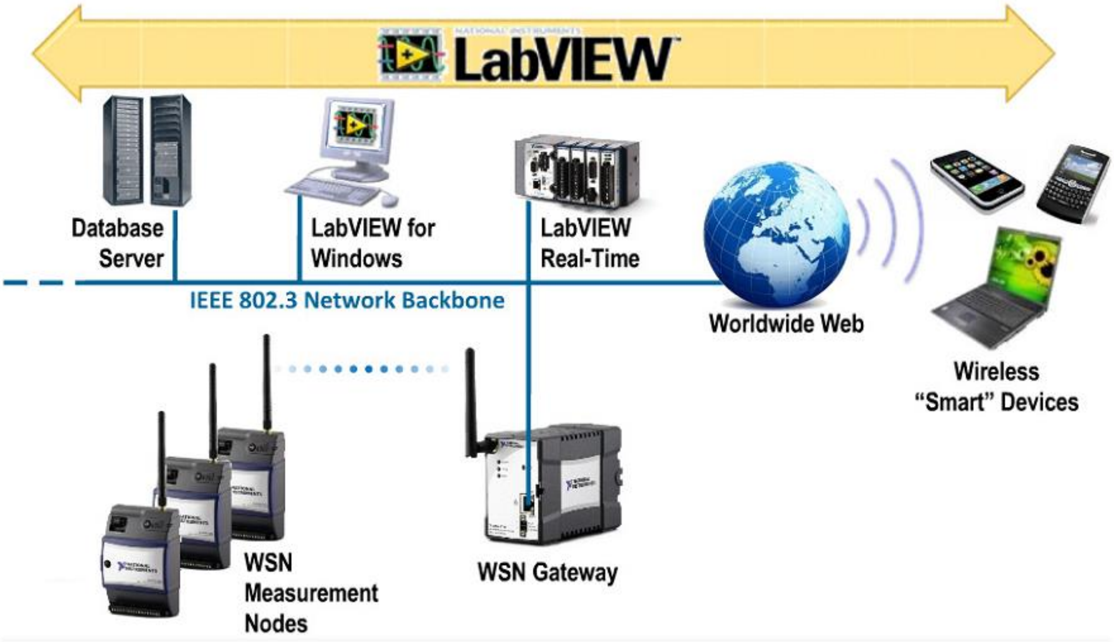


Figure 3.3 LabVIEW based setup of wireless sensor network-I

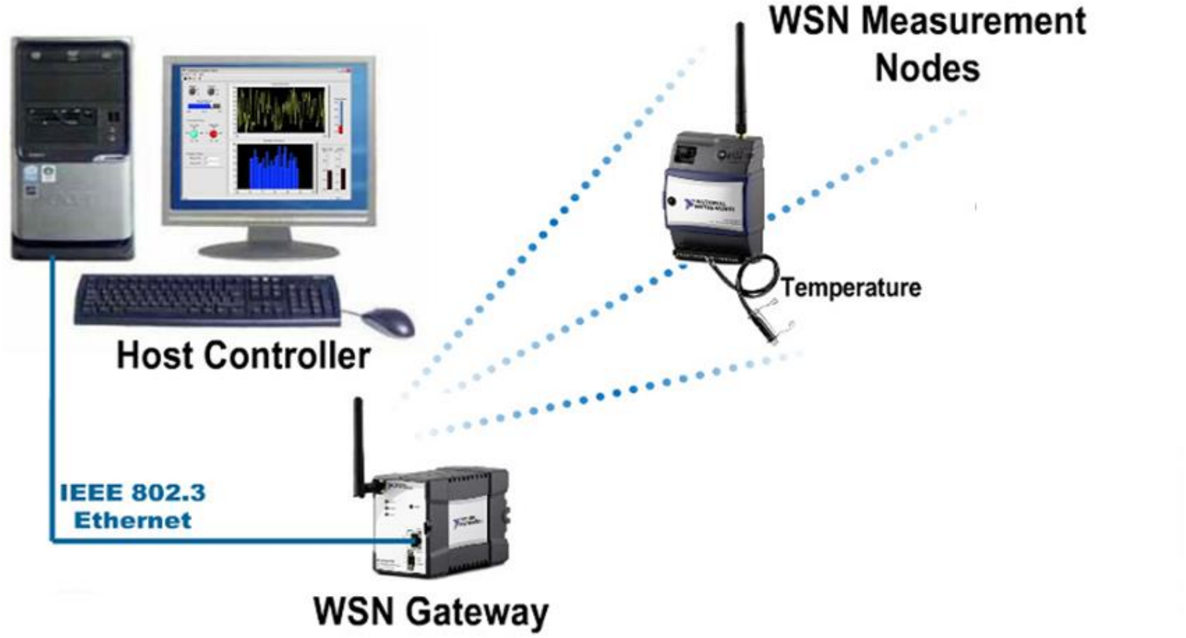


Figure 3.4 LabVIEW based setup of wireless sensor network-II

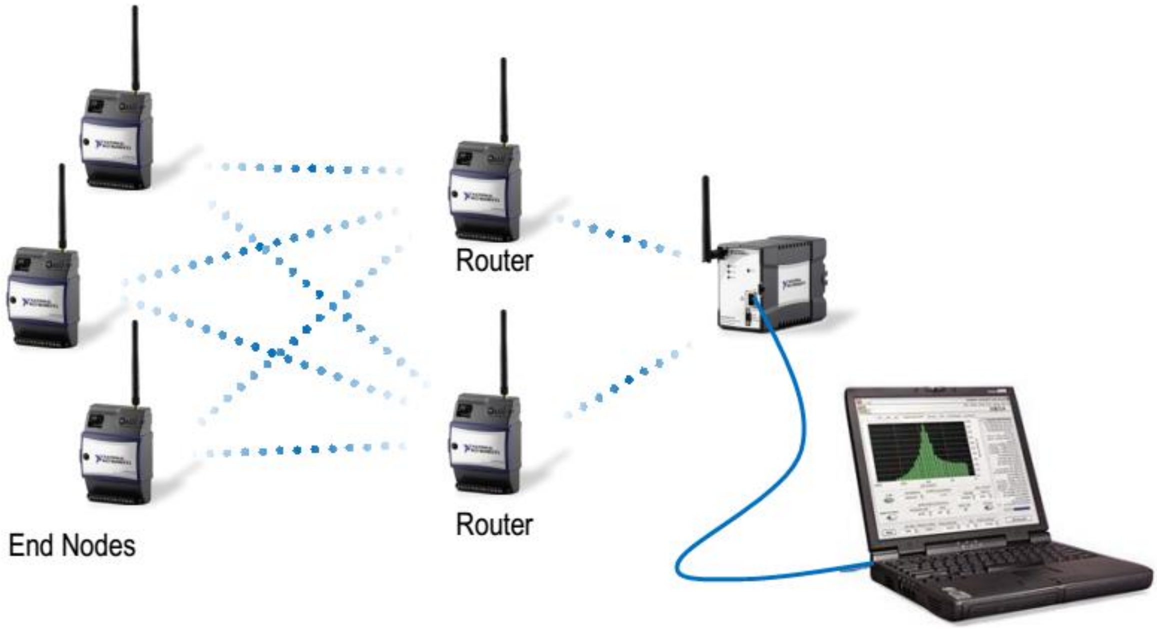


Figure 3.5 Mesh network of wireless sensor network

The National Instruments wireless sensor network (WSN) platform delivers low-power measurement nodes that offer industrial certifications, reliable networking, and optional weather proof outdoor enclosures for long-term, remote monitoring applications. The NI 9792 programmable WSN gateway manages the wireless network of distributed WSN measurement nodes and can communicate with other hardware through a variety of open communication standards such as TCP/IP, Modbus, and serial.

1. 533 MHz freescale MPC8347 real time processor
2. 2 GB onboard storage
3. 256 MB DDR2 RAM
4. Dual Ethernet port
5. HTTP and FTP support
6. 2.4 GHz IEEE 802.15.4 radio for communicating with the nodes
7. Range: 300 m line of sight
8. Supports up to 36 measurement nodes in Mesh topology

3.2 Wireless Data Acquisition of Temperature

A laboratory prototype of wireless temperature measurement using thermocouple is developed. Figure 3.6 shows the front panel of wireless temperature measurement system.

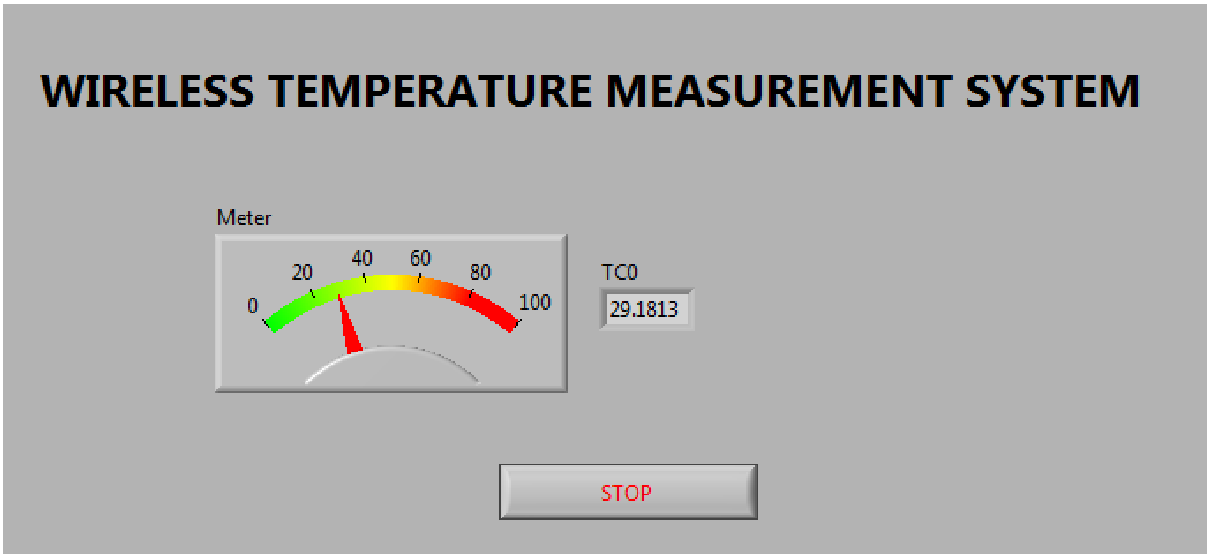


Figure 3.6 Front panel of wireless data acquisition system

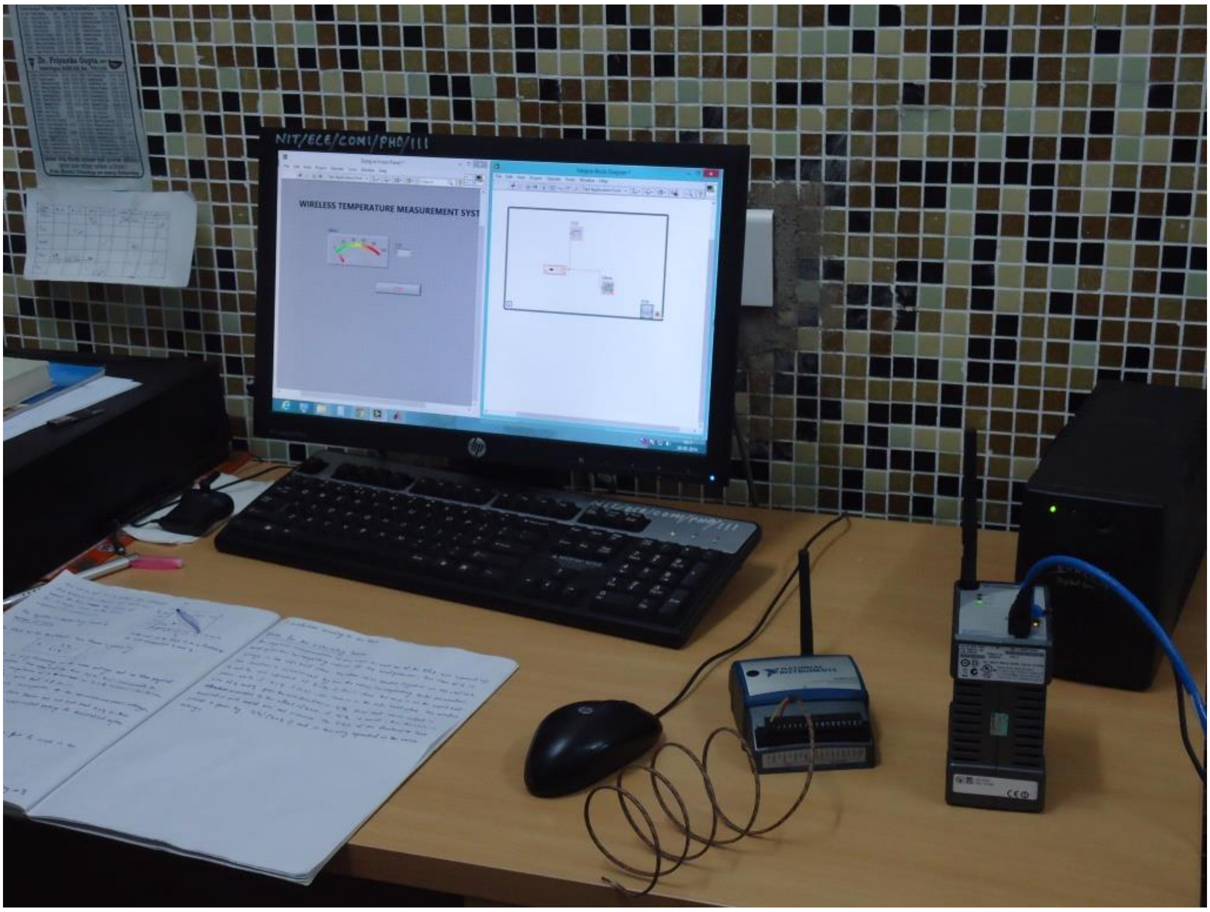


Figure 3.7 Hardware setup of wireless data acquisition system

Chapter 4

Nonlinearity Compensation of Thermistor

Nonlinearity of the sensors creates problems in data acquisition and computer interface. The sensor characteristics should be linear for accurate measurement. To convert the non-linear characteristics to linear, several linearization techniques are used. Some of the widely used methods are

1. ROM based Look up Table (LUT)
2. Nonlinear coding scheme
3. Artificial neural network

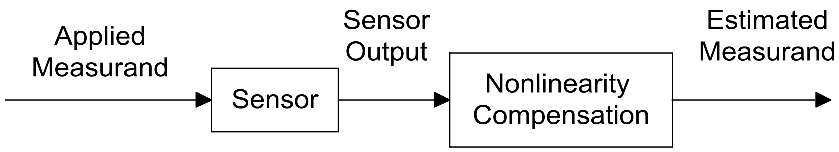


Figure 4.1 Nonlinearity compensation scheme

4.1 Temperature Measurement using Thermistor

Thermistors are manufactured from beads of semiconductor material prepared from oxides of the iron group of metals such as chromium, cobalt, iron, manganese and nickel. Normally, thermistors have a negative temperature coefficient, i.e. the resistance decreases as the temperature increases, according to $R_T = R_o \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)\right]$ (9)

The temperature can be obtained from the above equation by the following expression

$$\frac{R_T}{R_o} = \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)\right]$$

$$\left(\frac{1}{T} - \frac{1}{T_o}\right) = \frac{\ln R_T - \ln R_o}{\beta}$$

$$\frac{1}{T} = \frac{\ln R_T - \ln R_o}{\beta} + \frac{1}{T_o}$$

$$T = \frac{\beta}{\ln\left(\frac{R_T}{R}\right) + \frac{\beta}{T_o}} \qquad (10)$$

R_T	Thermistor resistance at T (K/C)	
T	Thermistor temperature (K)	
R_o	Nominal resistance (Ω) at T_o	10000
T_o	Temperature where R_o is measured	298
β	Thermistor material constant	3548

The nonlinear characteristic of thermistor is shown in figure 4.1.

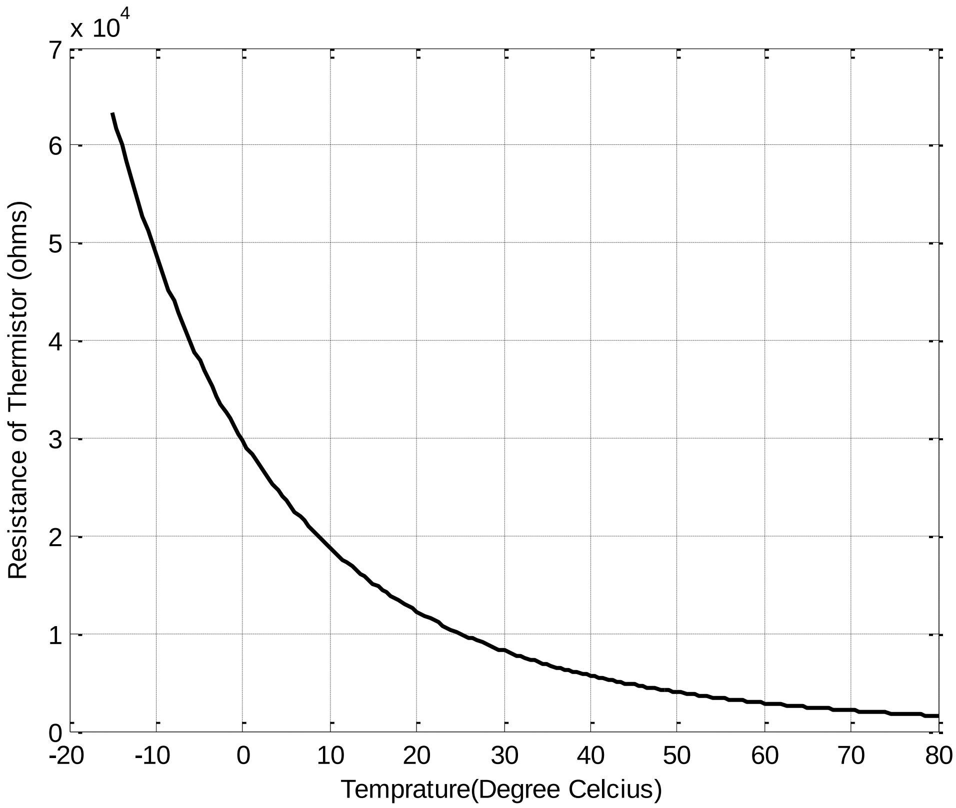


Figure 4.2 Resistance-temperature characteristic of thermistor

Figure 4.2 shows the plot between temperature and resistance of the thermistor. The graph is an exponential curve. This curve shows that the sensitivity of the thermistor is very high, but its range is very low as compared to other temperature sensors.

There are different ways to measure temperature using thermistor. Some of the methods are shown below.

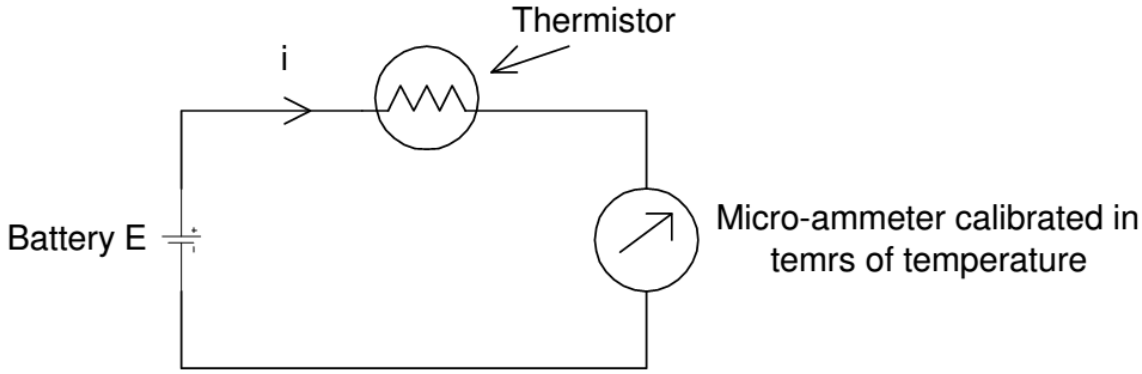


Figure 4.3 Temperature measurement using thermistor using micro-ammeter

In Figure 4.3, the battery voltage is fixed. Hence when the resistance changes due to the change in temperature, the current flowing in the circuit also changes. Hence the current measured using micro ammeter can be easily calibrated in terms of temperature.

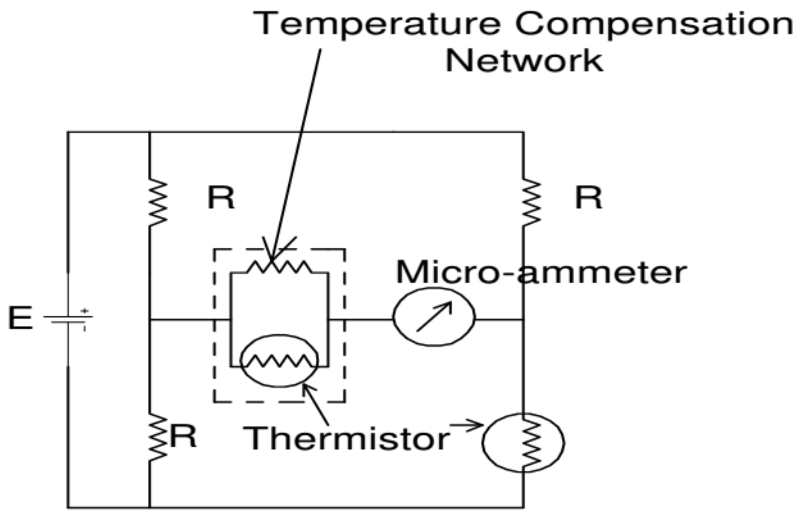


Figure 4.4 Temperature measurement using thermistor using micro-ammeter with compensating network

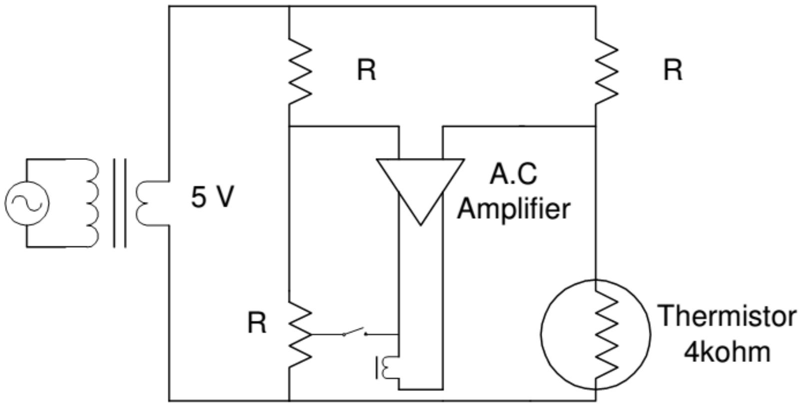


Figure 4.5 Temperature measurement using thermistor using AC amplifier

4.2 Nonlinearity Compensation in Thermistor

There are several methods of compensating non-linearity of thermistor. Some of the methods are discussed below. Figure 4.6 shows the concept of linearization of thermistor where a linearizing network is connected with the thermistor.

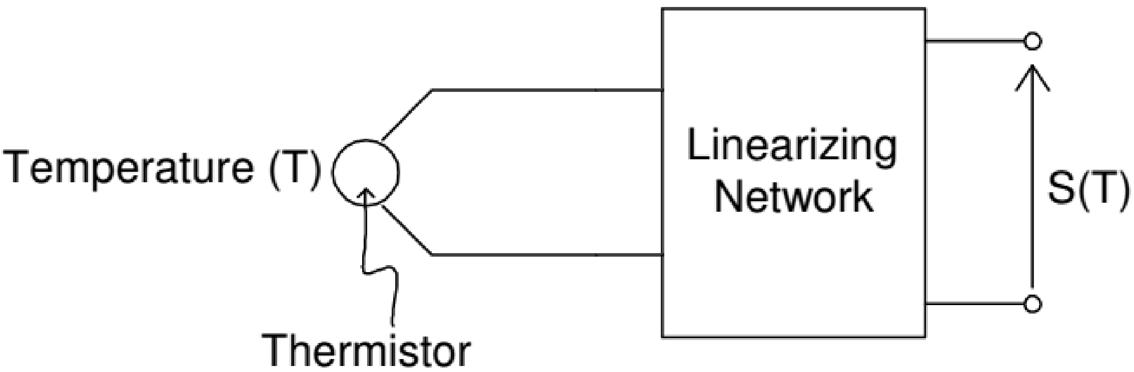


Figure 4.6 Nonlinearity compensation scheme

4.2.1 Series Compensation

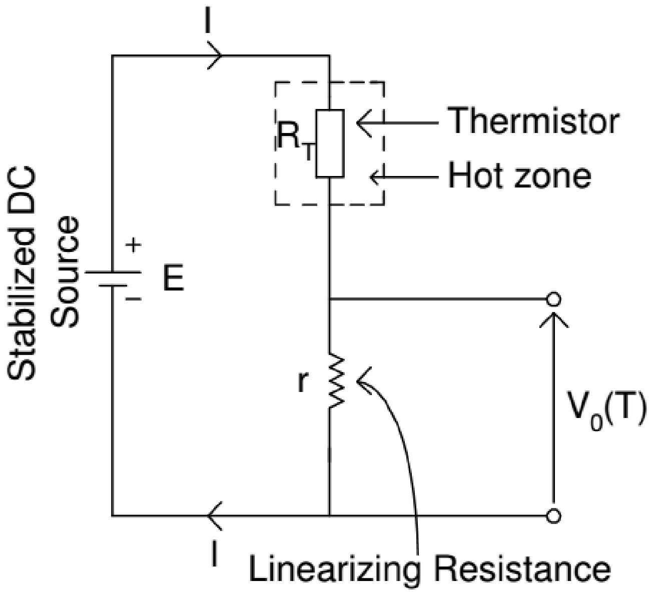


Figure 4.7 Series compensation

Series compensation is one of the simplest hardware sensor linearization methods. In this method a fixed resistance is in series connection with the thermistor. When the temperature rises, the resistance of the thermistor decreases exponentially. Hence the current flowing through the circuit increases and accordingly the output voltage increases. So finally a linear relationship between input temperature and output voltage is established.

4.2.2 Shunt Compensation

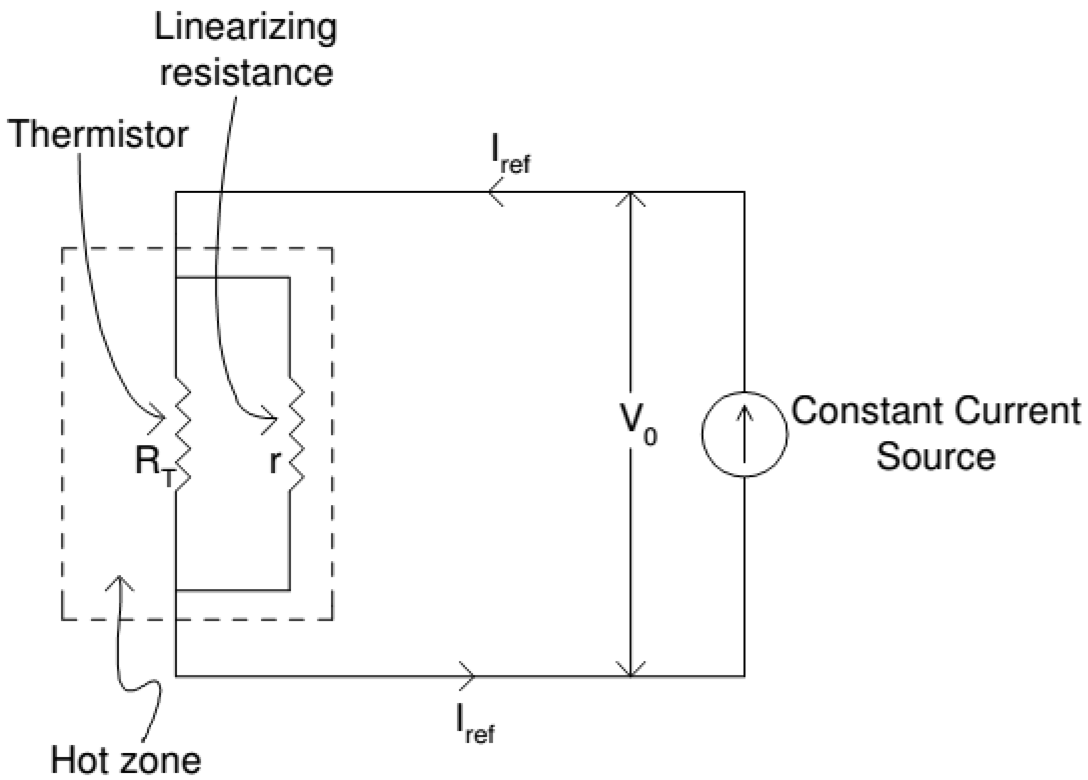


Figure 4.8 Shunt compensation

In the shunt compensation method a constant current source is used and a constant resistance is in shunt with the thermistor. When the temperature rises, the thermistor resistance decreases. The parallel combination of resistances again decreases. When the fixed current flows through it, a linearized output is found with respect to the input temperature.

4.2.3 Logarithmic Compensation

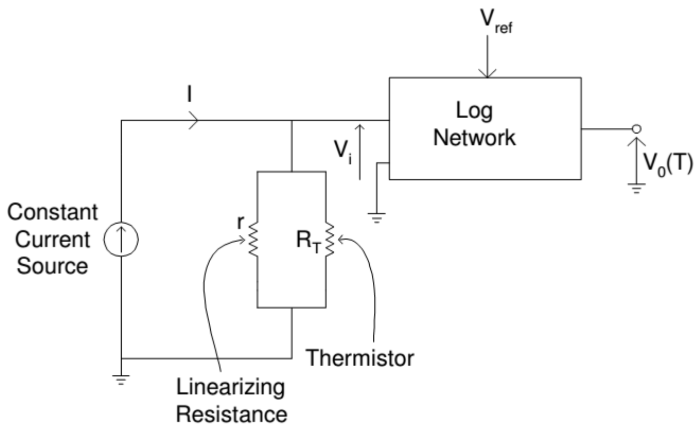


Figure 4.9 Logarithmic compensation

4.3 Steinhart-Hart Equation

In general applications NTC thermistors are used to measure temperature. This is accomplished by measuring the resistance of the thermistor and then using that resistance value to make an estimate of temperature. Because the conduction mechanism in metal oxide semiconductors is a complex one, it is difficult to explain accurately by applying mathematics to a physical model. The method used for accurate mathematical modelling of the resistance versus temperature characteristic of a thermistor is to obtain accurate measurements of resistance and temperature of components and to apply curve fitting techniques to model the relationship between them. An individual thermistor curve can be closely approximated through the Steinhart-Hart equation over a wide range of temperature. The Steinhart-Hart equation is a widely used third order approximation and is given by

$$\frac{1}{T} = a + b\ln(R) + c\left(\ln(R)\right)^3$$

Here a, b and c are Steinhart-hart coefficients which vary according to the type of thermistor and temperature range. T is temperature in Kelvin and R is resistance in ohms

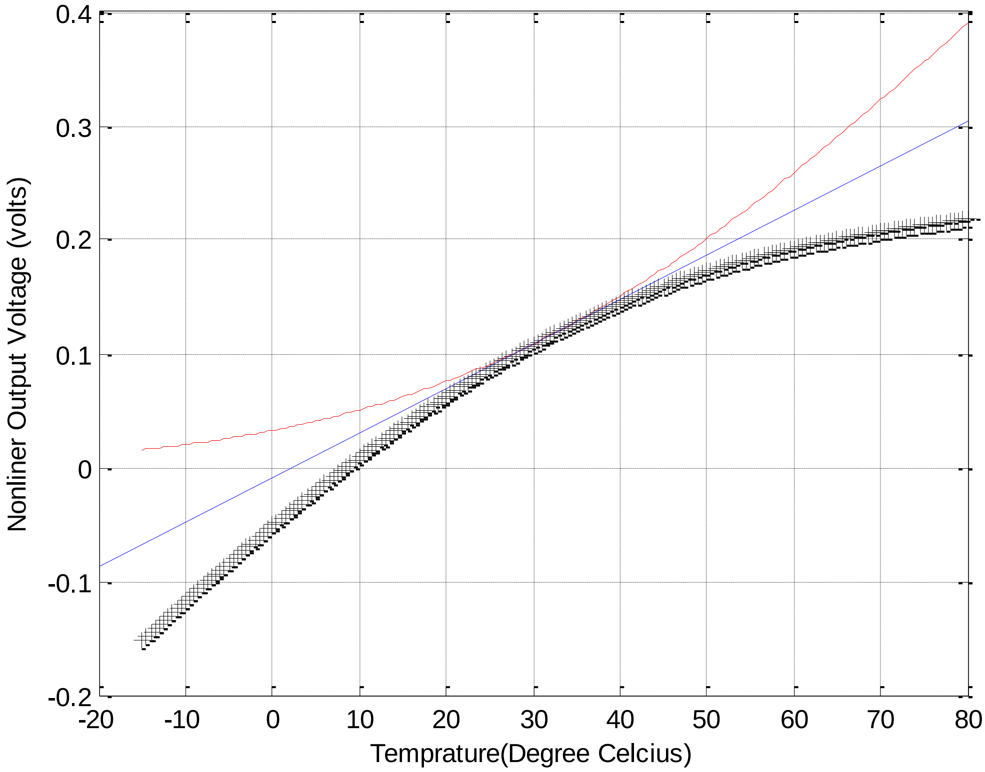


Figure 4.10 Nonlinear output voltage v/s temperature of thermistor

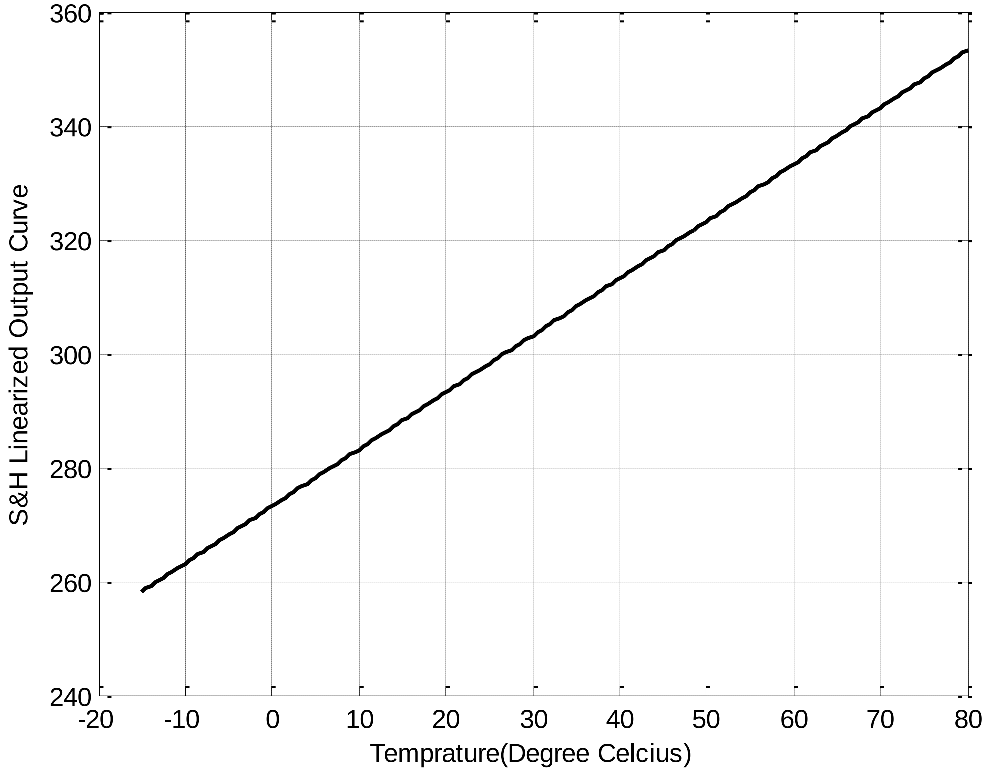


Figure 4.11 Steinhart-Hart linearization of thermistor

The above figure gives the linearized relationship between temperature and the resistance.

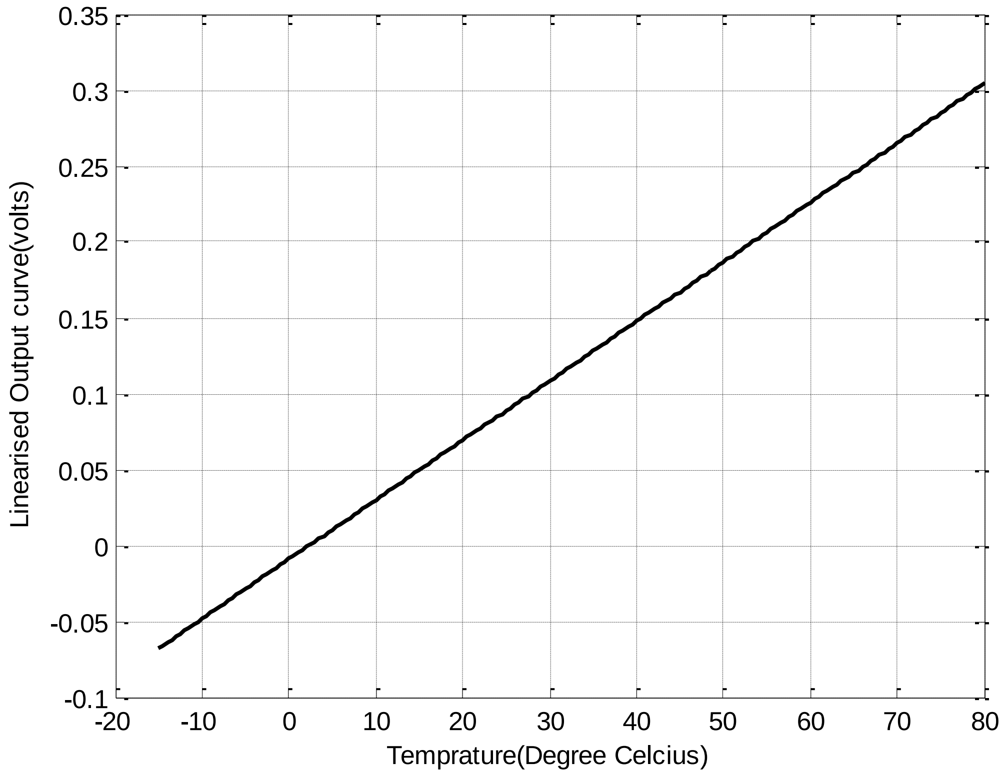


Figure 4.12 Linearized output voltage v/s temperature of thermistor

The above figure shows the linear relationship between temperature and the output voltage.

Chapter 5
Conclusions

5.1 Conclusion

Data acquisition and data logging is the most important aspect of any measurement system. Data acquisition uses data acquisition hardware and a computing device to acquire real time data from the field and display it in monitor. Data acquisition can be PC based or can be wireless. In PC based data acquisition, the PC is used where in wireless data acquisition transmitter and receiver is used to acquire the data. Some sensors are linear and others are non-linear. The linear sensors are easy to interface with a DAQ unit whereas a nonlinear sensor needs a linearizing circuit to linearize the output.

This project develops a hardware prototype of PC based and wireless based data acquisition system for a greenhouse applications. Different physical parameters like temperature, pH, CO_2 are acquired and logged. Wireless data acquisition system is developed to monitor temperature in wireless domain.

Nonlinearity of sensor is a major challenge in data acquisition. Thermistor is a nonlinear temperature measuring device. This thesis implements Steinhart-Hart linearization and artificial neural network based linearization technique to linearize the thermistor characteristics.

5.2 Future Scopes

1. A complete prototype model of PC based and wireless data acquisition system can be developed.
2. Other nonlinear sensors can be linearized using different techniques.

Publications

International Conference

1. **Nilimamayee Samal**, Umesh Chandra Pati, "Multi-channel data acquisition and data logging for green house application," in *Proc. IEEE Student's Conference on Electrical, Electronics and Computer Science (SCEECS)*, Bhopal, 2014, pp. 1-5

National Journal

1. **Nilimamayee Samal**, Umesh Chandra Pati, "PC based data acquisition platform for Green House," *Journal of Instrument Society of India* (in Press)

References

1. Izzat Din Abdul Aziz, Mohd Hilmi Hasan, Mohd Jimmy Ismail, Mazlina Mehat and Nazleeni Samiha Haroon, “Remote monitoring in agricultural green house using wireless sensor and short message service (SMS),” *International Journal of Engineering & Technology,* 9(9), pp. 35- 43, 2009.
2. Akshay C., Nitin Karnewal, Abhfeeth K.A. Rohan Khandelwal, Tapas Govindraju, Ezhilarasi D., Sujan Y, “Wireless sensing and control for precision green house management,” proceedings of *Sixth International Conference on Sensing Technology (ICST),* pp. 52-56, 2012.
3. Nirlipta Ranjan Mohanty, C. Y. Patil, , “Wireless sensor network design for greenhouse automation,” *International Journal of Engineering and Innovative Technology,* 3(2), pp. 257-262, 2012.
4. Mukesh Kumar, Sanjeev Sharma and Mansav Joshi, “Design of real time data acquisition with multi node embedded systems,” *International Journal of Computer Applications,* 42(11), pp. 6-12, 2012.
5. Devendra Samrit, Mayur Parate, Nitin Gawai, “Development of data acquuistion and greenhouse control system,” *International Journal of Engineering Research & Technology,* 2(4),pp. 899-903, 2013.
6. Kratika Sharma, Hemendra Shrimali, Jaideep Sing Hada, Abhishek Chattri, “Data acquisition and supervisory control system for environmental parameters in green house,” *International Journal of Engineering Trends and Technology,* 3(5), pp. 595-600, 2012.
7. R. Jaichandran, A. Anthony Irudhayarj, “Prototype system for monitoring and computing greenhouse gases,” *World of Computer Science and Information Technology Journal,* 1(5),pp. 177-183, 2011.
8. Kiran Sahu and Sushmita Ghosh Mazumdar, “Digitally greeenhouse monitoring and controlling of system based on embedded system,” *International Journal of Scientific and Engineering Research,*3(1), pp. 1-4, 2012.
9. Subhransu Padhee, Yaduvir Singh, “Data logging and supervisory control of process using LabVIEW,” proceedings of IEEE Student’s Technology Symposium, pp. 329 – 334, 2011.

10. M. Benghanem, “A low cost wireless data acquistion system for weather station monitoring,” *Renewable Energy*, 35, pp. 862-872, 2010.
11. S. Sreelal, Smitha Jose, Bibin Varghese, M.N. Suma, R. Sumathi, M. Lakshminarayana, M.M. Nayak, “Data acquisition and processing at ocean bottom for a Tsunami warning system,” *Measurement*, 47, pp. 475-482, 2014.
12. Iman Morsi, Loay Mohy El-Din, “SCADA system for oil refinery control,” *Measurement*, 47, pp. 5-13, 2014.
13. Raul Ionel, Gabriel Vasiu, Septimiu Mischie, “GPRS based data acquisition and analysis system with mobile phone control,” *Measurement,* 45, pp. 1462–1470, 2012.
14. Utpal Sarma, P.K. Boruah, “Design and development of a high precision thermocouple based smart industrial thermometer with online linearization and data logging feature,” *Measurement,* 43, pp. 1589–1594, 2010.
15. A.Gani, M.J.E.Salami, “A LabVIEW based Data Acquisition System for Vibration Monitoring and Analysis,” *Student Conference on Research and Development Proceedings*, Shha Alam, Malaysia,pp.62-65, 2002.
16. Mohammed Abdallah, Omar Elkeelany, “A Survey on Data Acquisition systems DAQ” *International Conference on Computing, Engineering and Information,* pp.240-243, 2009.
17. J.Jin,B.Wang, “Design of Automatic Meteorological Data Acquisition System Based on ARM and CAN Bus,” *International Conference on Measuring Technology and Mechatronics Automation,* pp.989-992, 2010
18. Y.Wang, M.Fu, “ A Portable USB Data Acquisition System” *WASE International Conference on Information Engineering*, pp.170-173, 2010.
19. Li Nan , Nie Hongshan, Wang Yinan, Liu Haijun, Xu Xin, Sun Zhaolin, Xu Hui, “High Speed Real-Time Data Acquisition System Based on Solid-state Storage technique*,” Second International Conference on Digital Manufacturing & Automation*,pp.586-589, 2011.