SENSOR CALIBRATION SYSTEM FOR ENHANCEMENT OF QUALITY OF INFORMATION

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SENSOR CALIBRATION SYSTEM FOR ENHANCEMENT OF QUALITY OF INFORMATION

Thesis submitted in partial fulfillment

of the requirements of the degree of

Master of Technology

in

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by

Gopinath Khakha

(Roll Number: 214EC3175)

based on research carried out

under the supervision of

Prof. Santos Kumar Das

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Certificate of Examination

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We the below signed, after checking the dissertation mentioned above and the official record book (s) of the student, hereby state our approval of the dissertation submitted in partial fulfillment of the requirements of the degree of *Master of Technology* in *Electronics and Communication Engineering* at *National Institute of Technology Rourkela*. We are satisfied with the volume, quality, correctness, and originality of the work.

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Supervisor's Certificate

This is to certify that the work presented in the dissertation entitled *SENSOR CALIBRATION SYSTEM FOR ENHANCEMENT OF QUALITY OF INFORMATION* submitted by *Gopinath Khakha*, Roll Number 214EC3175, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements of the degree of *Master of Technology* in *Electronics and Communication Engineering*. Neither this thesis nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Santos Kumar Das

Dedication

My humble effort, i dedicate my thesis to all hard working and respected **Teachers**

Declaration of Originality

I, *Gopinath Khakha*, Roll Number *214EC3175* hereby declare that this dissertation entitled *SENSOR CALIBRATION SYSTEM FOR ENHANCEMENT OF QUALITY OF INFORMATION* presents my original work carried out as a Postgraduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference" or "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 25, 2016
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Gopinath Khakha

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Abstract

Calibration of different types of industrial instruments is the prerequisite of any of the industrial installations before coming under operation. Modern calibration can be categorized based on the physical quantities they are designed to measure. The categorization may internationally vary but the basic notion of calibration is clear and straight forward whereas the associated standards of calibration vary from parameter to parameter under different physical environment.

Here a data acquisition system has been developed using Arduino Uno R3 and infrared emitter- detector pair. An experimental set up has been build which can collect data from the sensor under calibration, namely ultrasonic sensor HC-SR04. The data acquisition system includes the set up called, the ground truth apparatus which specifically has been designed to carry out repeated experiments to collect data. The process of collection of data involves the infrared based obstacle detection technique.

A number of error compensation technique are being applied. These methods of error compensation technique involves feed-forward neural network with backpropagation, conjugate gradient and regularization training algorithm.

Finally a parameter based analysis of performance for different error compensation techniques is done. Based on the performance analysis some novel approaches for calibrating the information generated by the sensor has been prescribed. A clear distinction in approach between data calibration and instrument calibration is established.

Keywords*: *calibration*; *data acquisition*; *error compensation*; *neural network

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Chapter 1

Introduction

This chapter gives the general overview of the work. This comprises of Calibration and data acquisition system and error optimization followed by literature survey. The objectives and organisation of the thesis are mentioned in this chapter.

1.1 OVERVIEW

We all are surrounded by different equipment. It may be mechanical, electrical, electronic, manually operated or automated. Each equipment is doing some sort of measurements. so all such devices can be brought under the generalisation of measurement systems. Once there is a measuring device, there is a measurability or correctness or accuracy or performance. The concept of calibration as explained in this paper is confined to electronic sensor modules. All the measuring devices go through rigorous calibration before being employed for industrial installations.

Whatever may be the measuring devices it sometimes produces erroneous measurements. The device or the sensor can be used only if the values it is generating meet the actual ground condition indicated by the appropriate concerned parameters of measurement. Even before replacing the faulty instrument or to bring it under physical changes, the degree of faultiness has to be known. And then if possible some techniques has to be applied to make the device measuring correct values.

As per as the calibration of the sensors as prescribed in this paper is concern,rigorous and repeated experiments has been done on the concerned sensors and then depending upon the degree and type of error , appropriate compensation technique has been applied to improve the correctness standards of the sensors. Experimental setups has been designed and measurement has been done inside the laboratory environment. Then based upon the availability of mathematical tools and software based computational packages the data generated by the sensors has been corrected. Finally observations has been made to examine the device characteristics.

The sensors used are ultrasonic proximity sensor and infrared proximity sensor. The collection of data has been done through ATMEGA328 microcontroller and data correction methods are applied making use of artificial neural network techniques inside MATLAB environment.

However the basic practice is, calibration is required whenever there are new installations, exposure of sensor to critical conditions etc. It should be periodical to verify the level of accuracy and correctness of the measuring device. Sensor calibration is a two-step process. First step is data collection and second step is manipulation of error and compensation. For the purpose two sets of data is required, out of which one being considered as standard and another is the one under calibration. Error compensation technique used also plays an important role.

1.2 LITERATURE REVIEW

Saha et.al.[6] It explains the issues related to system design of wireless smart MEMS networks of sensors in applications. He gives an overview of facts that is learnt from previous work done in calibration of sensor, the challenges encountered and the different types of sensor. Few methods have been developed by Proctor et.al.

[7] It depends on the sensors for measuring the various parameters in real time which then changes the position of the robot or the machine tool accordingly. Various factors indicating the improvements in accuracy has been demonstrated.

Magori et.al [8] describes that, According to the influence principle, there are two main types of ultrasonic sensors that can be differentiated. One is propagation path sensor and another is distance sensor. The distance sensor detects the echo reflected by the obstacle using the concept of time of flight and the propagation path sensor provides a faster measurement of concentration gas, changes in temperature, variations in pressure by decoding the propagation information obtained.

Papageorgiou et.al.[9]Here self-calibration techniques based on automated testing is applied. It represents an online monitoring configuration which lead to improvement of performance and life time of the transducer.

Sachenco et.al.[10]Here sensor drift has been predicted using the physical parameters the sensor is measuring. Neural network has been used to enhance the accuracy of measurement. The technique of increasing the data volume increasing predicting neural network training is offered at the expense of various data types in replacement for neural network training and at the expense of the separate approximating neural network .

Vojkto et.al.[11] It describes the use of neural networks to reduce the error. Elastomagnetic sensors are used to measure the huge pressure. The factors deciding the limiting parameters of the Elastomagnetic sensors are hysteresis error and nonlinearity.

1.3 MOTIVATION

Many of the devices in use in our daily life are black box type instruments where only measured values is accessible. Once it start showing deviations in performance level normally these devices has to be replaced with new ones. Even the sensor calibration techniques in industrial applications are complex and costly. So in this paper simple and cost effective calibration technique for enhancing the quality of information produced by the sensors has been prescribed. Not only applying corrective measures but also to decide the degree of correctness also is important. Such techniques can be applied to mass manufacturing units of sensors where it is critical to separate the faulty ones based on the error profile the sensor.

1.4 OBJECTIVES

- To develop a data measuring system and to store it
- Develop error profiles
- Establish degree of accuracy
- Applying error compensation techniques

1.5 ORGANISATION OF THE THESIS

Including the introductory chapter, the thesis is divided into 5 chapters. The organisation of the thesis is presented below.

1.5.1 Chapter 2 Calibration

In this chapter, what is calibration, is introduced. The need for calibration, types of calibration, process of calibration , measurement standards ,uncertainty in measurement and statistics of measurement and associated parameters has been described. The theoretical and practical basis for calibration has been elaborated.

1.5.2 Chapter 3 Data acquisition

In this chapter, a brief idea on data acquisition system is given. Collection of sensor data along with the specifications of the sensors is described in detail.

1.5.3 Chapter 4 Error compensation

In this chapter, the idea of error compensation is described. Then compensation technique involving artificial neural network along with associated results, is given.

1.5.4 Chapter 5 Conclusion

The overall conclusion of the thesis is presented in this chapter. It also contains some future research topics which need attention and further investigation. Also the lacunae and difficulties in the applied methods are being tried to be highlighted.

Chapter 2

Calibration

According to international bureau of weights and measures calibration is, "operation that under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step uses this information to establish a relation for obtaining a measurement result an indication".Calibration is the process involving series of events for checking, by comparing the accuracy and standards of any kind of measuring instrument. A measuring instrument under operation must be properly calibrated. The process might involve adjustments to get the instrument in to standard limits. The standard for various types of instrument or measuring devices depends upon the type of instrument, its construction, parameters of the devices and also the conditions under which the instrument is operating. Even the most precise instruments without accurate reading capabilities. There has to be ways to get the level of errors and types of error it is expected to generate under specified condition.It may also involve adjustment of instrument to get the proper level of accuracy standards.

An instrument under operation has to be checked periodically to test the working standards and the degree of accuracy it is providing. How often an instrument should be rely on how important the measurement made relating to the particular device, the level of wear and tear. In the process the measurement taken previously plays an important role. It provides the previous records which determine whether adjustments are needed in the past successive measurements or not. It ultimately decides the stability of the instrument. Standard recommendations starts with periodicity of 12 months for most instruments with an increase in calibration frequency (to 6 or 9 months) if adjustment is required, and a reduction in periodicity to 2 years after a sequence of annual calibrations has shown that adjustment has not been needed.Calibration results decide the performance levels of an instrument.. With standard certificates, these results should have been compared to the published specification by the calibration laboratory and will normally be categorised to show conformance to specification. The instrument usually is being checked against the known standards as reference to that of themselves. The process includes a series of measurements that obeys the internationally established standards. i.e, the system of SI units – for example meter, liter, voltage, ampere, watt etc.

Practically the instruments today are of various types, i.e, electromechanical, electrical, electronic, IC chips, digital PCs etc. So over ally there are two categories of instruments available as per as calibration of an instrument is concerned. One where each and every component of the instrument is accessible.one malfunctioning part or degraded part can easily removable to correct the overall performance of the system. Another type of instruments is the 'black box' type of instrument. Where only external stimulus can be applied and the output it gives is the actual measurement. Where only the specified output ports or pins are accessible. The internally circuitry or the internal arrangements are not accessible. Here no physical changes can be brought in to correct the output of the instrument. Here calibrator is solely depended upon the measurement values it is providing. The values of the measurement are applicable for adjustment. This is called 'data calibration'. Various analytical and statistical techniques along with supported software packages like MATLAB, LabVIEW, C, are available for data calibration. The methods used can properly be explained by the calibration statistics.In fields of information technology calibration is about correcting the base level of the measuring device. It usually done to match to a dependable and standard known measures. e.g, PLUGE patterns are being used to calibrate the brightness levels of a video display.Various factors like system of measurement, measurement uncertainty, type of calibration error and calibration statistics are involved in calibration.

2.1 Measurement uncertainty

If all the measurements are not completely uncertain, a certain degree of uncertainty exists which has a probabilistic basis and ie describes the incomplete information. By scientific methods the measurement uncertainty can best be described by probabilistic approach. So there exists two type of values. One is measured value and other is possible values or target value. The relative uncertainty between two values can be evaluated using statistical analysis methods. i.e, in terms of mean, median, mode, standard deviations.

2.2 Calibration statistics

There are two main application of calibration statistics related to the calibration problems.

Calibration can be said to be the reverse process of regression. In regression normally a relationship between input and output in a known set of measurement is established. The input and output are taken as two variables, of which one is dependent and another is independent. Here a known observation of the dependent variables is used to predict a corresponding variable which explains the mapping between both the variables. Different mathematical and statistical models are used for it.

Another one is statistical classification to assess the uncertainty of a given new observation related to each of already established classes.

2.3 Calibration is needed for,

- when New systems being installed
- Whenever modification or alternation of instrument is done
- Each and every device or measuring system can work continuously for certain duration without causing significant irreparable damage. If that time duration is elapsed
- Measuring coming under extreme conditions that the device is not used to
- Whenever the instrument is exposed to conditions which may have brought the instrument out of calibration or damage
- All measurement systems are provided with surrogate instrument. These instruments helps in giving important measurement values that can indicate the working condition of the main system. So whenever surrogate instruments give unexpected results, calibration is desirable.
- Whenever requirements are changed.

2.4 Data acquisition system

The block diagram shows the generalised block diagram of a data calibration system. It includes sensors, Data acquisition card or the microcontroller for acquiring data for the sensors, PC, simulation environment like MATLAB, PYTHON etc and storage to store the collected data.

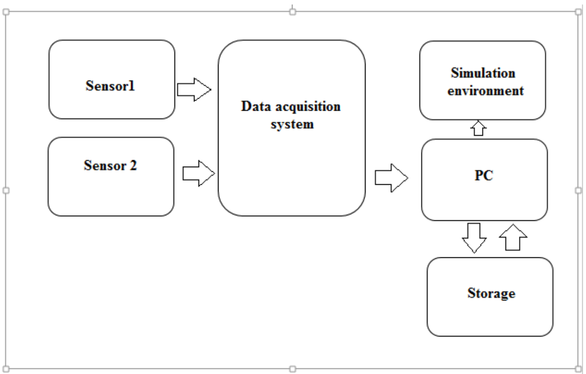

Figure 2.1: Generalized block diagram of a calibration system

Chapter 3

Data Acquisition

In this chapter the concept of data acquisition is being exploited. A data acquisition system(DAQ) has been developed to collect the ground data from the sensors installed in the field of operation. Apart from making use of the theoretical definition, here a system of data and its collection from the generating sources and its processing with the use of different microcontrollers or application specific embedded systems has been developed. Calibration is the most essential part of calibration of any of the instrument.

3.1 Principle of data acquisition:

The Data Acquisition systems in general have the following basic components; digital to analog converter(DAC), analog to digital converter (ADC) digital I/O devices, timer, sample and hold amplifier, and multiplexers. In this paper, an effort has been made to design and develop a smart real time embedded Arduino based data logger for collecting generated data from the various sensors under operation. The data logger is proposed to be developed with the use of Arduino Uno based on ATmega328 microcontroller. The microcontroller board has an inbuilt ADC and other peripheral ICs and circuitries. The physical parameter under measurement is sensed by the sensors and it gives output in the form of analog signal. This analog signal is fed to the ADC pins of the microcontroller. It converts the analog signal to an equivalent digital quantity and then if required it is conditioned by signal conditioning techniques. The digital signal processed out of the microcontroller can be outputted to the serial monitor to display it. Later the data can be saved in the memory and then can be sent to the computer through USB serial port. This data can be saved into the Microsoft excel or work space of the statistical tool used to analyze it which further can be used for computational and graphical representation.

A data logger is nothing but a data recorder. It is an electronic measuring device which collects the data provided by the sensor over a period of time. This device can be a built in instrument or an separate device external to the instrument.But here the experiment includes ultrasonic proximity sensor, and infrared obstacle detector.

The main component of the data logging system is either a computer or a dedicated processor. It processes the data digitally. The device usually have small size, powered by external DC power supplies like battery, are portable and have memory required for storage of data. It has various applications inside satellites, submarines, underwater installations, without man on air surveillance systems like drones. It records data over a longer period of time where data needs to be recorded for months together at a time unattended.

The data logger can be a embedded system. The embedded unit may be a single system which contain required peripheral devices with the required sensors that collects the available physical data. It also is provided with many external sensors called as multiple channel device. Usually the system has dedicated software to run the data recorder. The functions it does are, reviewing and collecting the data. Some other data loggers are interfaced to hand held devices like key-board and to LCD. These are self-contained devices. The direction for data logging is being provided by these self-contained devices.

Currently available data loggers in the market are costlier and it is not affordable for low cost but functionally important systems. The data acquisition systems now a days being used , e.g, DAQs of National Instruments and Honeywell are costly. This project is focused on developing a product that is cheaper with some additional features for data storage, real time data collection and data analysis etc. the idea has been implemented using a general purpose microcontroller and sensors. The microcontroller used i.e, ARDUINO UNO has an ATMEGA328 microcontroller and it has an inbuilt ADC. Here the physical data is being sensed by the externally installed sensors in the field and the microcontroller based data acquisition system collects it. The analog signal generated by the sensors is converted into digital form and then further processing is done on it. It also provides visual interface through the serial monitor window and also through externally interfaced display devices like LCD displays. The ground data collected by the sensors are being collected and stored in the data base. The serial data port of the microcontroller with USB interface provides this facility. The serial data port is externally accessible. The collected data can be put under statistical analysis using tools like MATLAB, C, python, LabVIEW etc.

3.2 Components of DAQ

The data acquisition system includes three main components.

- The experimental setup
- The microcontroller for data collection and processing ARDUINO UNO
- And the sensors used are as follows
  - Ultrasonic proximity sensor HC-SR 04.
  - Infrared emitter-receiver module.

Table 3.1: Arduino Uno Microcontroller Specification

Microcontroller	**ATmega328**
Operating Voltage	5V
Input Voltage(Recommended)	7-12V
Input Voltage(Limits)	6-20V
Digital I/O Pins	14 nos
Analog Input Pins	6 nos
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

3.3 Microcontroller ARDUINO UNO

3.3.1 Hardware Description

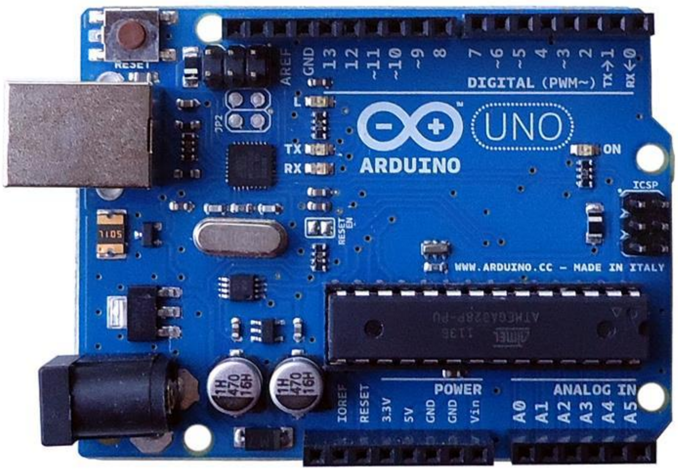

Figure 3.1: ARDUINO UNO Microcontroller

The ARDUINO Uno IS A microcontroller board which includes ATMEGA328 microprocessor. It has three types of pins. i.e, 14 digital I/O pins of which 6 can provide pulse width modulated outputs, and power PINs. A 16 MHz crystal oscillator, a UBS connection, a ICSP header, a power jack and a reset button. It also has the additional support packages it needs to support the microcontroller. A simple USB cable is used to power it with a AC-DC adapter or a battery. It has USB-serial converter instead of FTDI USB to serial converter as used in the preceding ARDUINO boards.

The Arduino board is a complete package where directly a code can be written, then compiled, uploaded and executed.USB connectors are provided for power connection as well as for data communication. The board also can control and regulate the power level provided to it which enables it to communicate to the real world through components connected to the board. The components can be a sensor or an actuator etc. the sensors and the actuators also gets power from the board and accordingly responds to the external world. The sensor can be switches or Ir sensors or Ultrasonic sensors or acclerometer etc. The actuators can be speakers or motors or LED circuitry etc. The figure above shows a basic Arduino.

3.3.2 Software Description

Dedicate software is provided for the ARDUINO board. It uses ARDUINO IDE to generate programs on a computer. The program are written on it and it also allow editing of the program. Then converts the written program code into a series of instructions understandable by the microcontroller. The set of instructions then is uploaded into the microcontroller by clicking the ‘upload’ in the IDE.

3.4 Sensors

3.4.1 HC SR-04

Table 3.2: HC SR-04

Parameters	**Specifications**
Working Voltage	5V
Working Current	15 mA
Working Frequency	40 Hz
Max Range	4 m
Min Range	2 cm
Measuring Angle	15 degrees
Trigger Input Signal	10us TTL pulse
Echo Output Signal	Input TTL level signal

The Ultrasonic sensor module HC SR-04 do non-contact measurement with the range from 2cm-400cm. the ranging accuracy of the module is 3mm. it has three main parts. i.e, transmitter, receiver and control ciruitry. The module uses the time of flight calculation to calculate the distance of the obstacle away from the ultrasonic sensor. The module emits 40 KHz ultrasonic signal in the direction of the obstacle. The reflection by the obstacle makes the trigger signal initiated as high to low. Calculating the time duration of the signal, with speed of the ultrasonic wave known, the distance can be calculate using the given formula.

Distance= (time of trigger signal being high x velocity of sound) / 2

3.4.2 IR Obstacle Detector

The IR obstacle detector circuit consist of one IR emitter diode, one IR detector diode and three resistors of 330 ohm in series with emitter diode, 6.8 kilo ohm and 470 ohm in series

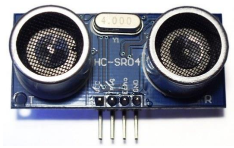

Figure 3.2: HC SR-04

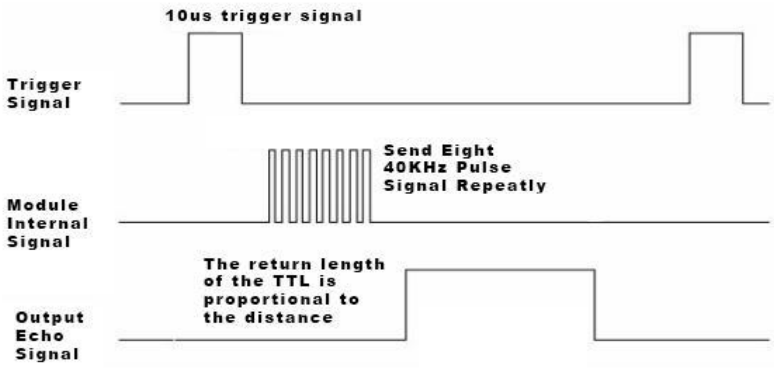

Figure 3.3: Timing Diagram of HC SR-04

with detector diode. both connected to the same power supply of 5 v and both are commonly grounded. The IR emitter diode is forward biased and the IR detector is reverse biased. Under the condition of obstacle is being detected the IR radiation emitted by the IR emitter diode is reflected by the passing by obstacle. it indicates the presence of obstacle in the proximity. The reflected IR radiation increases the reverse saturation current of the detector diode. so voltage drop across the two resistors gets increased. when no obstacle is present less current flows through the detector circuitry. the output is taken across the two resistors in the detector side. the infrared radiation emitted is of wavelength 800 nm and the detection range provided by the detector is about 700- 1100 nm.

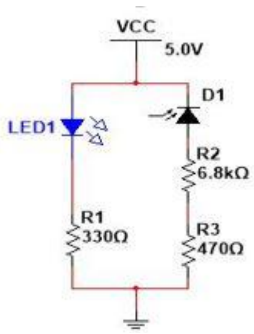

Figure 3.4: IR Obstacle detector

Table 3.3: IR Obstacle detector specification

Components	**Specification**
DC Power Supply	5V
IR emitter diode	650 nm wavelength
IR Receiver	600-1100 nm wavelength
Resistors	330, 470, 6.8 k ohm

Table 3.4: Operating condition of obstacle detector

Obstacle detected	**Voltage across receiver 3.5V**
Obstacle not detected	**Voltage across receiver 0.5V**

3.4.3 Experimental setup

The real figures of the experimental set up has been shown below. two longitudinal views from each side of the setup. The figure shows the experimental setup has been made on a ply board platform. The main constituents of the setup are, the metal railing over which the obstacle made of a simple card board can be manually moved. There are obstacle detector circuits installed side wise along length of the setup at an interval of 10 cm each starting from 10 cm to 80 cm. the ultrasonic proximity sensor is placed at one end of the railing. It can track the movement of the obstacle and continuously gives the distance in the serial monitor window.

The obstacle along the rail is moved from the 0cm to 80cm range manually. whenever the obstacle reaches one IR detector it gets detected which is indicated by the LED circuit glow. Then at that position many readings of distance are taken. Similar experiments are carried away at each of the 10cm distance towards the ultrasonic sensor and several reading were taken from each of the 10 cm mark. The data collected are saved to the workspace of microsoft excell sheet which further can be applied for statistical analysis in MATLAB.

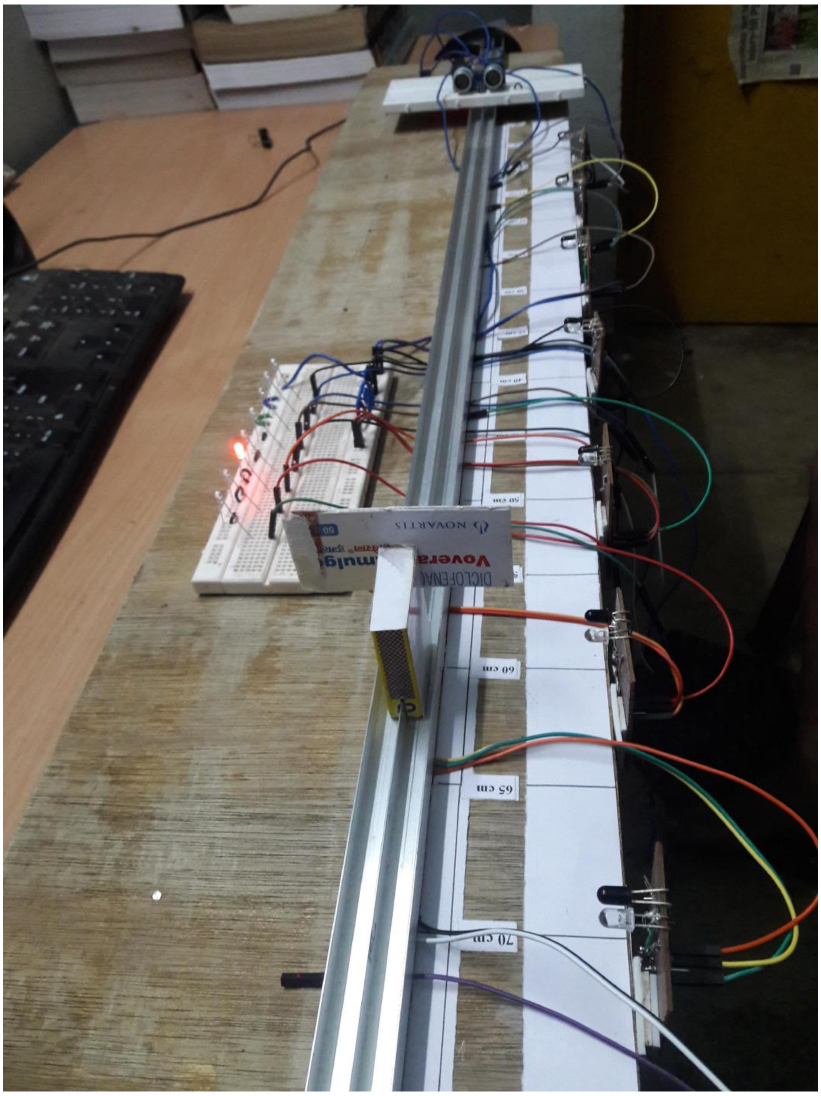

Figure 3.5: Experimental setup figure1

3.5 Data acquisition system

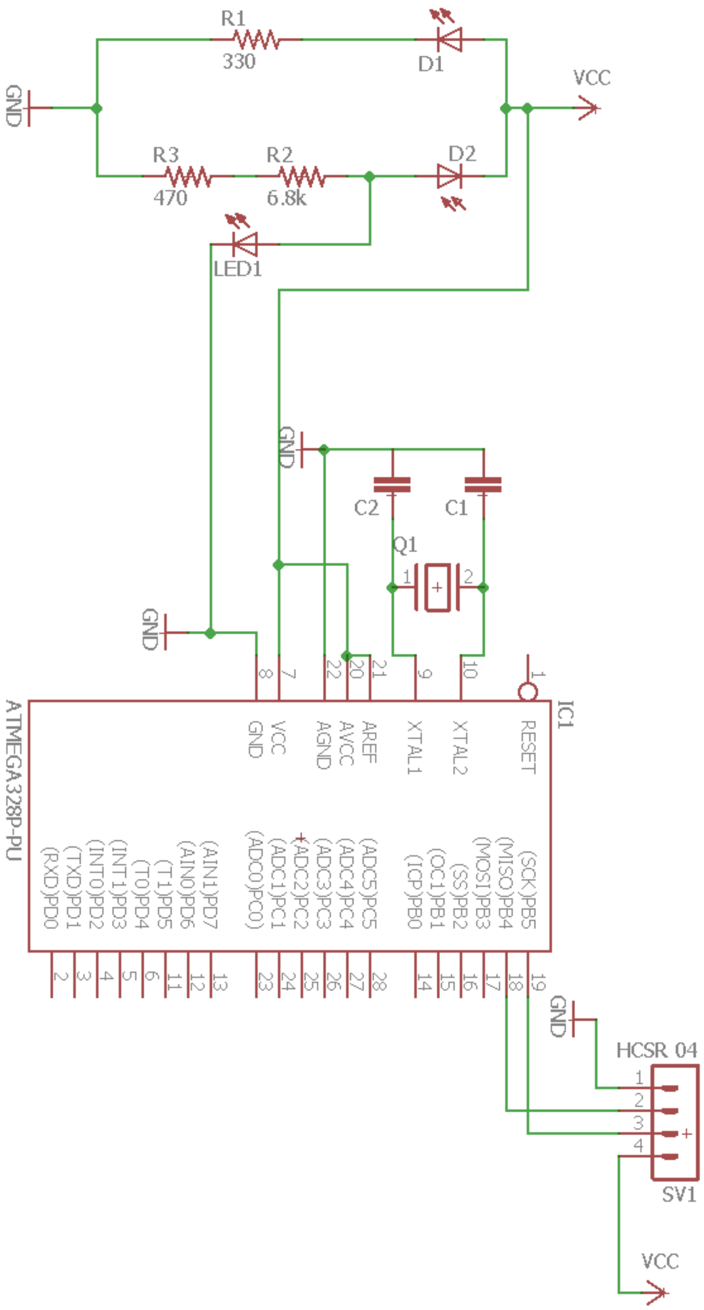

Figure 3.6: Schematics of Data acquisition system

3.6 Data tables

The table shows the data that is being collected from repeated experiments on the experimental setup.

Table 3.5: Data table I

Target Values	5	10	15	20	25	30	35	40
Inputs	4.98	10.79	15	20.11	24.94	30.1	34.61	39.66
	4.87	10.67	15.1	20.11	24.96	30.2	34.75	39.67
	4.86	9.78	15.2	19.98	24.75	30.28	34.75	39.74
	4.65	9.98	15.21	19.95	24.79	30.21	34.81	39.77
	4.9	9.85	15.21	19.95	24.8	30.32	34.84	39.81
	4.65	9.77	15.22	20.11	24.66	30.12	34.89	39.88
	4.86	9.86	15.34	20.21	24.9	30.43	34.91	39.88
	4.99	10.55	15.11	20.11	24.99	30.12	34.95	39.91
	4.54	10.12	15.23	20.12	24.91	30.32	34.99	39.92
	4.86	10.21	15.21	20.44	24.75	30.11	35.03	39.99
	4.6	10.24	15.22	20.12	24.76	29.49	35.07	40.01
	4.75	10.22	15.21	20.11	24.99	29.77	35.12	40.11
	5.12	9.94	15.21	19.34	24.76	29.78	35.17	40.15
	5.11	9.99	15.11	19.21	24.66	29.78	35.18	40.16
	5.2	9.67	15.11	19.23	24.96	29.8	35.27	40.23

Table 3.6: Data table II

Target Values	45	50	55	60	65	70	75	80
Inputs	44.61	49.63	54.65	60.1	65.06	70.1	74.88	80.11
	44.65	49.65	54.97	60.12	65.09	70.11	74.9	79.88
	44.62	49.69	54.67	60.2	65.12	70.01	74.87	79.88
	44.63	49.75	54.98	60.13	65.18	70.11	74.88	79.84
	44.69	49.79	54.79	60.22	65.19	70	74.9	79.97
	44.79	49.81	54.6	59.74	65.2	70.08	74.85	79.91
	44.79	49.81	54.9	60.01	65.17	69.79	74.89	79.89
	44.82	49.85	54.8	60.3	65.24	69.87	74.91	79.9
	44.89	49.89	54.78	60.2	65.4	69.88	74.51	79.99
	44.93	49.89	54.69	60.18	65.17	69.8	74.96	79.9
	44.97	50.05	54.5	60.14	64.88	69.9	75.05	80.1
	45.06	50.11	54.7	60.24	64.89	69.84	75.16	80.05
	45.09	50.17	54.7	59.74	64.85	69.88	75.14	80.19
	45.11	50.21	54.99	59.88	64.71	69.9	75.11	80.21
	45.19	50.27	54.1	59.74	64.64	69.98	75.4	80.2

Chapter 4

Error Compensation

In this chapter error compensation techniques involving neural networks is being discussed. Mathematical models are explained and their MATLAB implementation has been done. The results are closely monitored with various parameters related to the compensation are properly being optimized as per our desired results. The algorithm used is a simple curve fitting problem in neural networks. The neural network works on numeric values. it has one set of numeric data considered as input and other as output. The function used to map the numerical values of input to the output or target values is called as fitting function. It is a process that involves training of the already defind neural network, where the training process tries to generalize the input-output relationship of the sample data and to reduce the mapping into a mathematical model.

The neural network tool box in MATLAB helps to create a network and and in the next stage by training the neural network with sample data, it's performance is evaluated by calculating error, mean square and doing regression analysis.

Here a two layered feed-forward neural network with sigmoid hidden neuron and linear neuron is used. the samples of data taken for training are of three kinds.Training data: the sample data is presented to neural network structure. The neural network calculates the error and in the process of its minimization it tries to update the structure of the neural network in order to optimize the input with respect to the targeted output.Validation data: it works on generalization of data. It evaluate the generalization of the network it provides in the course of training. The criteria to stop training the neural network is set by this generalization factor. When generalization stops improving, the training also stops.Testing data: these have no effect on training and so provide an independent measure of network performance during and after the training.

There are three stages to the error compensation using neural networks.

- Network architecture
- Training
- Performance analysis

In network architecture stage the neural network is been designed. The no of hidden layers and the no of neuron are fixed. Training involving the neural network has been feed with the sample data with different algorithms. Three training algorithms has been used separately and their performance has been observed separately. These are,

- backpropagation method
- regularization method
- conjugate gradient method

Performance analysis has been done based on the performance characteristics of the mean square error, error histogram, and regression analysis.

4.1 Network Architecture

4.1.1 Neuron

The structure of the neural networks shows that it has multiple inputs or input as a vector. The inputs are being fed as scalar vectors. The input matrix is denoted by ‘p’. ‘p’ is multiplied with the weight matrix represented by the structure of the neural network. The output of the multiplication ‘wp’ also is a scalar matrix. Then the weighted sum ‘wp’ is the only argument of the transfer function ‘f’ produce ‘a’ which also is a scalar vector. A bias ‘b’ is added to the network which is shown at the summing junction of the the network structure. The bias ia just an another weight having the value ‘1’. The neuron model is shown below

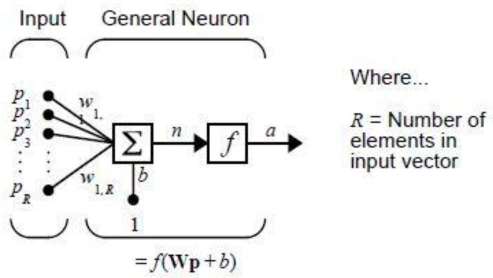

Figure 4.1: Neuron model

The transfer function ‘n’ is f(wp+b). the sum is the argument of the transfer function ‘f’. here the function ’f’ can be a step function or a sigmoid function or log sigmoid function. The transfer function ‘f’ takes the argument as ‘n’ and then produces the output ‘a’.

There are two types of parameters in the neural networks. One is adjustable and another is non-adjustable. The adjustable parameters are the weights of the neurons and the biases. The non-adjustable parameters are the inputs and the targeted outputs. So by adjusting the weight or the bias values in the process of training the network desired optimal solution can be achieved.

The bias value can be anything between 0 to 1. But the typical value chosen is '1'. The bias never is an input but an adjustable parameter. But the fixed bias '1' normally applied appears as an input and the neural network maintains linear dependence of input vector with the bias.

4.1.2 Transfer functions

Hard limit transfer function

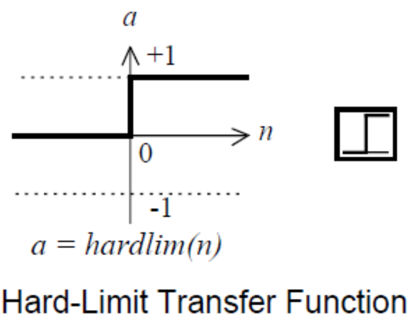

Figure 4.2: Hard Limit Transfer Function

The output of the hard limit function either produces '1' or'0'. Output is '1' for 'n' greater than zero and '0' for 'n' less than '0'.

Log-sigmoid transfer function

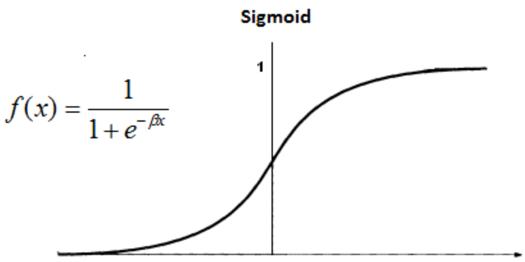

Figure 4.3: Log-sigmoid Transfer Function

The sigmoid function as shown above gives output between 0 to 1. But the input value it take is from minus infinity to plus infinity.This transfer function is commonly used in backpropagation networks, in part because it is differentiable.

The Tan-sigmoid transfer function shown above gives output -1 to +1 for input value ranging from minus infinity to plus infinity.

The linear transfer function shown above gives output minus infinity to plus infinity for input value ranging from minus infinity to plus infinity.

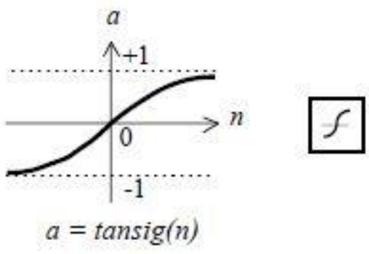

Figure 4.4: Tan-sigmoid Transfer Function

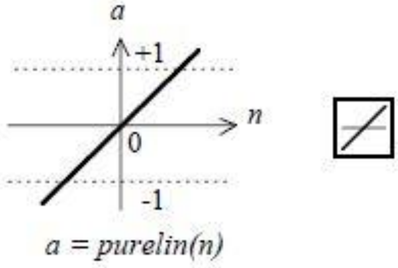

Figure 4.5: Linear Transfer Function

4.1.3 feed-forward neural network

The network here is a static neural network. Because there are no feedback or delays in the network. The input always is treated as concurrent. In case any delay appearing is normally being ignored. The network can be made even simpler by considering the network has only one input vector which is shown below.

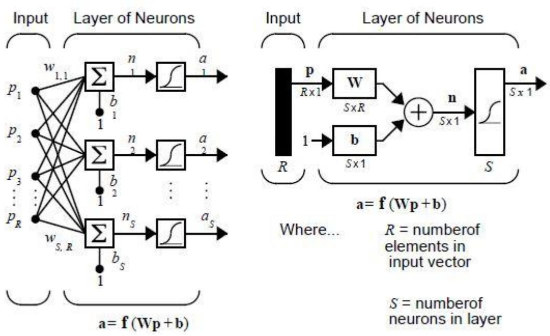

Figure 4.6: Feed-forward neural network

A neuron with a single R-element input vector is shown below where each of the elements of the inputs are multiplied with the weights which has been initialized at the begining. The weighted values then are applied to the summing junction of the network. The sum is 'w.p+b'. where the dot represents the dot product.

A neuron with a single R-element input vector is shown below. Here the individual element inputs are multiplied by weights and the weighted values are fed to the summing junction. Their sum is simply Wp, the dot product of the (single row) matrix W and the vector p.

$$n = w1,1p1 + w1,2p2 + ... + w1,RpR + b \tag{4.1}$$

or

$$n = W * p + b \tag{4.2}$$

The symbol of transfer function is given as f.

$$a = (Wp + b) \tag{4.3}$$

multiple layer multiple input feed-forward neural network:

$$a2 = f2(LW2,1f1(IW1,1p + b1) + b2) \tag{4.4}$$

The network shown above has R1 inputs, S1 neurons in the first layer, S2 neurons in the second layer. The different layers of the neural network have different number of neurons. The bias applied for each neuron is '1'. The output of one layer of the neural network is input to the next layer.Thus layer 2 can be analyzed as a one-layer network with S1 inputs, S2 neurons, and an S2xS1 weight matrix W2.The input to layer 2 is a1; the output is a2.The network layer that produces the network output is called an output layer.The network having delays, the input normally would be sequence of numeral input vector irrespective of the inputs occurring in certain time order.

4.2 Training algorithms

The backpropagation learning algorithm include a multiple layer neural network structure and a transfer function which is nonlinear and differentiable. The main purpose is the input must approximate the output. In the process the network is being trained with the set of input and output. The training stops when the input approximates the output or classify the input vectors. It depends upon the way the neural network is used. i.e for curve fitting or classification. The network includes input vectors representing a set of numerals and target vectors representing an another set of numerals, network biases, the first layer consisting of sigmoid transfer function and the second layer consisting of linear approximating function. In backpropagation algorithm gradient function is computed from evaluated error values. The changes in the weights of the neural network goes with negative of gradient function. This method is called backpropagation neural network with gradient descent algorithm. The gradient function is a function of the error. Based on the standard backpropagation algorithm there are numbers of modified approaches that can also be applied for optimization. These are conjugate gradient method and regularization method . the advantage of neural network is that it gives results for unknown inputs accurately provided the network has been trained properly before.

The process involves the following stages

- Assemble the training data
- Create the network object
- Train the network
- Simulate the network response to new inputs

The process of training starts with proper network structure i.e the feedforward neural network architecture. First the parameters to construct the neural network is being set. The first stage is initialization of weights and biases. After that the network is ready to get trained. There are various approximation functions for which the neural network is being trained. Those are pattern classification function, linear and non-linear regression function, pattern association etc. The training process requires a set of examples of proper network behavior consisting of a set of network inputs and target outputs. The network function always is adjusted iteration by iteration to to get maximum optimization. The parameter most important to get minimized is the mean square error. The gradient descent method minimizes the error function and it also determines the path of minimization. The process of minimization involves performing computation back towards the input of the network. This is called backpropagation computation.

4.2.1 Regularization method

Regularisation method is a modification of the gradient descent method used with backpropagation method. This method improves the generalisation factor.

$$F = mse = \frac{1}{N}\sum_{i=1}^{N}(e_i)^2 = \frac{1}{N}\sum_{i=1}^{N}(t_i - a_i)^2 \tag{4.5}$$

$$msereg = \gamma mse + (1-\gamma)msw \tag{4.6}$$

$$msw = \frac{1}{n}\sum_{j=1}^{n}{w_j}^2 \tag{4.7}$$

It is possible to improve generalization if we modify the performance function by adding a term that consists of the mean of the sum of squares of the network weights and biases. here the gamma represents performance ratio. The 'f' in the equation 4.5 represents the performance function. performance function is the summation ofsquare of all the network errors of the training sample. This function is used to train the feed-forward network.

The advantage of using this performance function is it regulates the magnitude of the weights and biases. Smaller weights and biases gives network response smoother. This reduces the non-linearities which causes the network to fit properly.Because of performance function it is less likely to get overfitting curve. The only parameter has to be properly chosen is the performance ration. The value of performance ratio has to e optimum. Too large performance ratio cause overfitting whereas smaller performance ratio cause inadequate fitting.

4.2.2 Conjugate gradient method

The basic backpropagation method uses gradient descent algorithm. where the performance function is a function of error that gets minimized in a direction opposite to the gradient function by adjusting the weights. The performance function decreases more rapidly in the direction of negative gradient. However it does not gurantee faster convergence. Here in this part in the conjugate gradient method a search parameter is used.The search paremeter operates in conjugate direction unlike only in the direction of negative gradient as in gradient descent method. After each iteration the weight is adjusted to minimize the step size in conjugate direction. The search functions are available in the MATLAB tool box of the neural networks.

The basic backpropagation algorithm adjusts the weights in the steepest descent direction (negative of the gradient). This is the direction in which the performance function is decreasing most rapidly. It turns out that, although the function decreases most rapidly along the negative of the gradient, this does not necessarily produce the fastest convergence.

Always the search operarion starts in the direction of steepest descent as given in the equation below.

$$P_0 = -g_0 \tag{4.8}$$

It is followed by a line search. The line search determines the optimum distance to move along the search direction. Consecutive search directions are determined in a way to conjugate the previous search. In the process actually a new steepest descent is being added to the previous search direction.

$$X_{k+1} = X_k + \alpha_k P_k \tag{4.9}$$

The next search direction is determined by combining new steepest direction with previous search direction.

4.3 Results and discussions

Three methods of neural network has been used to compensate the data being collected. in following sections a comparative analysis between the aforesaid three algorithm has been presented.

4.3.1 Backpropagation algorithm

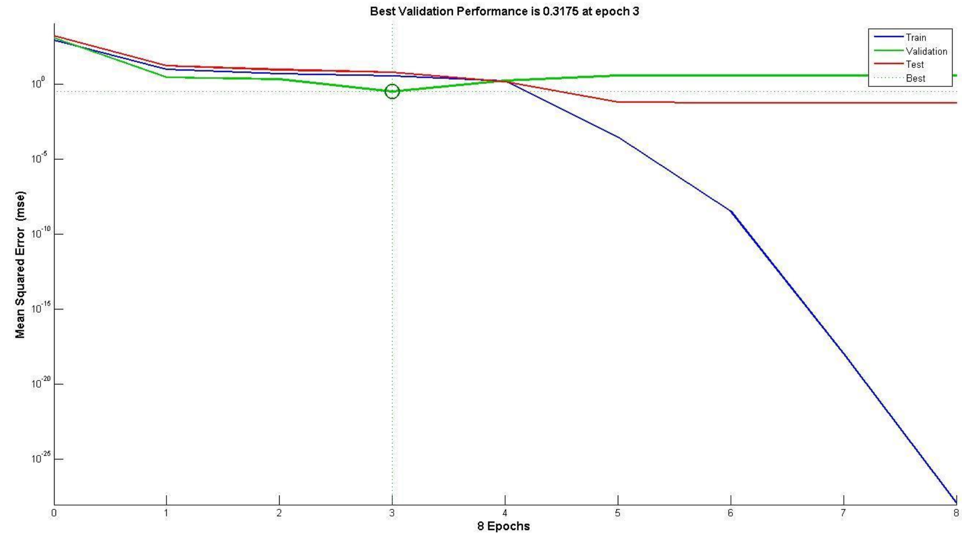

Figure 4.7: Mean square error plot of backpropagation algorithm

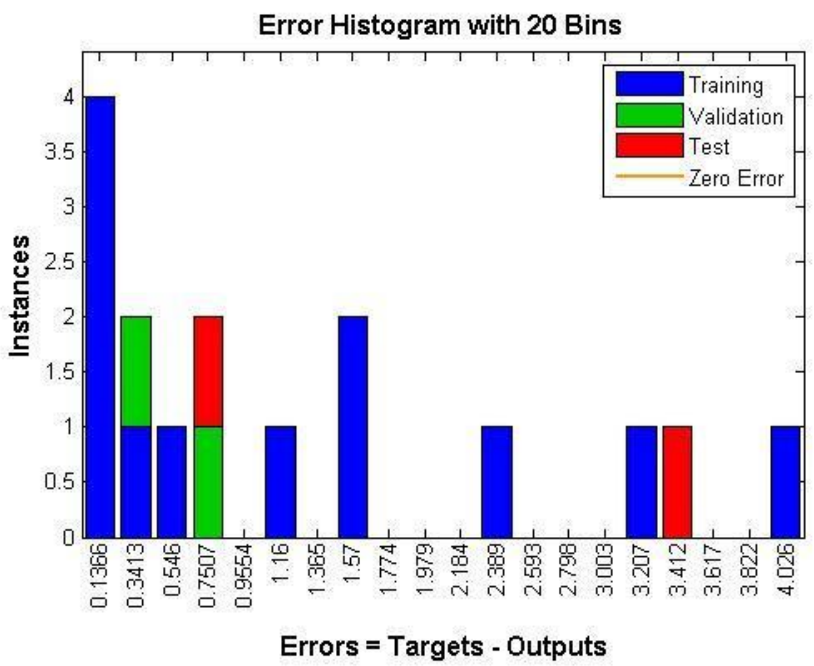

Figure 4.8: Error histogram of backpropagation algorithm

The performance analysis plots the mean square error with respect to number of iterations. the performance analysis shows that the numbers of iterations taken to approximate to its optimum level is low. the graph shows it gives best result at epoch 8. here the mean square error of training error, validation error and test error converge. after

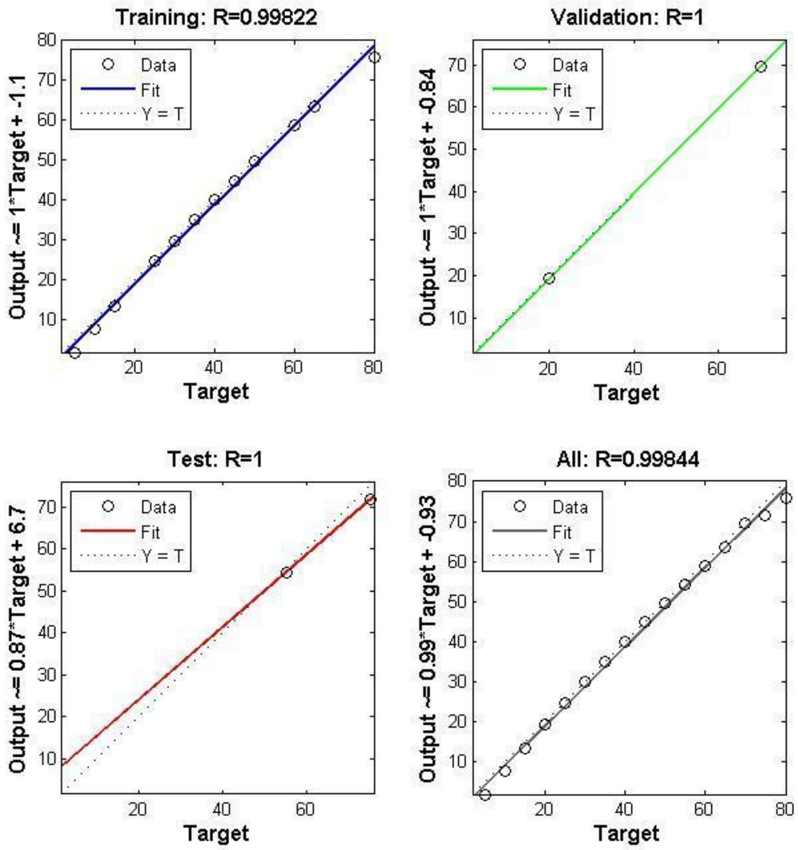

Figure 4.9: Regression analysis of backpropagation algorithm

the point of convergence the generalisation of the network stops improving and the mean square error of the training data stops.

The error histogram shows the errors are widely distributed over the entire spectrum of the error. so it can be said that the non-linearities at almost all levels exist.the

regression analysis shows the correlation factor indicated by ’R’ determines the level of approximation. with increasing in ’R’ factor from 0.99822 to 0.99844 improves the fitting curve. However the one of the test data shows some deviation from fit whereas the validation data shows a proper fit. this indicates there remains some level of non-linearity in the entire range of data.

4.3.2 regularization algorithm

the performance analysis plot. i.e the mean square error plot with respect to the number of iterations shows that the numbers of iteration taken to approximate to its optimum level is high. i.e the time taken also is higher. the generalisation of the neural network keeps on improving till the mean square error gets minimum.

The error histogram shows the distribution of the error over the error spectrum is narrow.

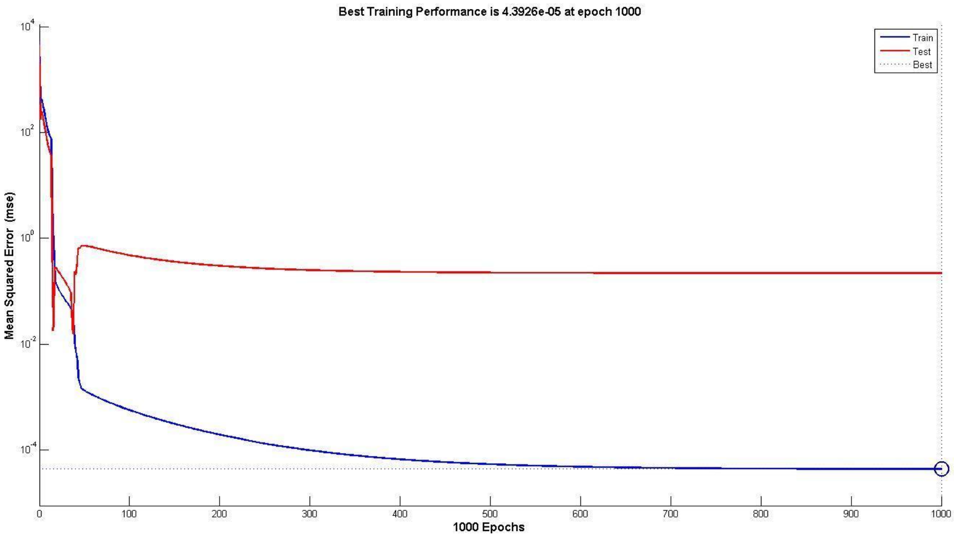

Figure 4.10: Mean square error plot of Regularization algorithm

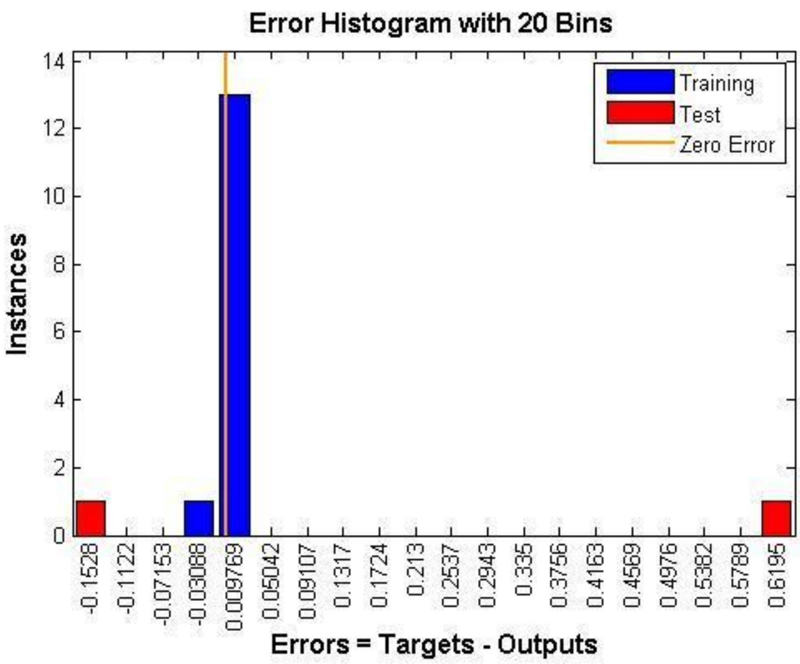

Figure 4.11: Error histogram of Regularization algorithm

i.e, the error of some particular points only are significant. it indicates the non-linearities in approximation is minimum and exists only at some particular points.

The regression analysis shows the correlation factor indicated by R equal to 1 fits all all the inputs to the output.

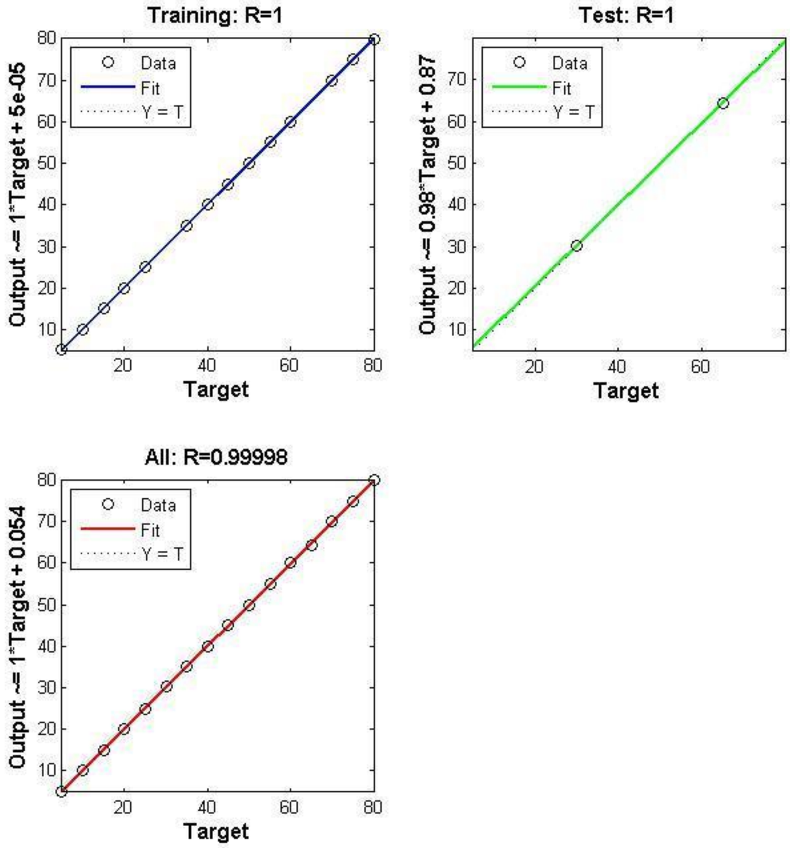

Figure 4.12: Regression analysis of Regularization algorithm

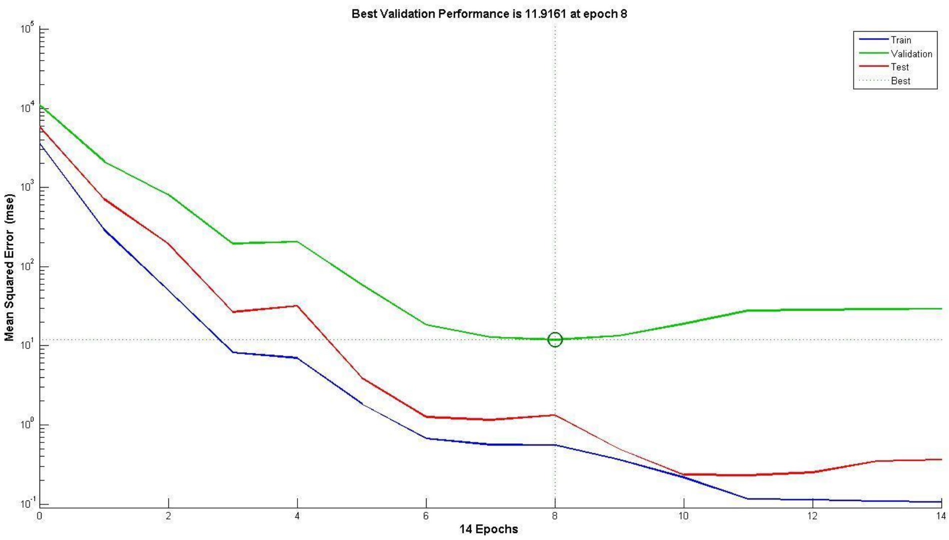

Figure 4.13: Mean square error plot of Conjugate gradient algorithm

4.3.3 conjugate gradient algorithm

The performance analysis plot. i,e the mean square error plot with respect to the number of iterations shows that the number of iterations taken to approximate to its optimum level

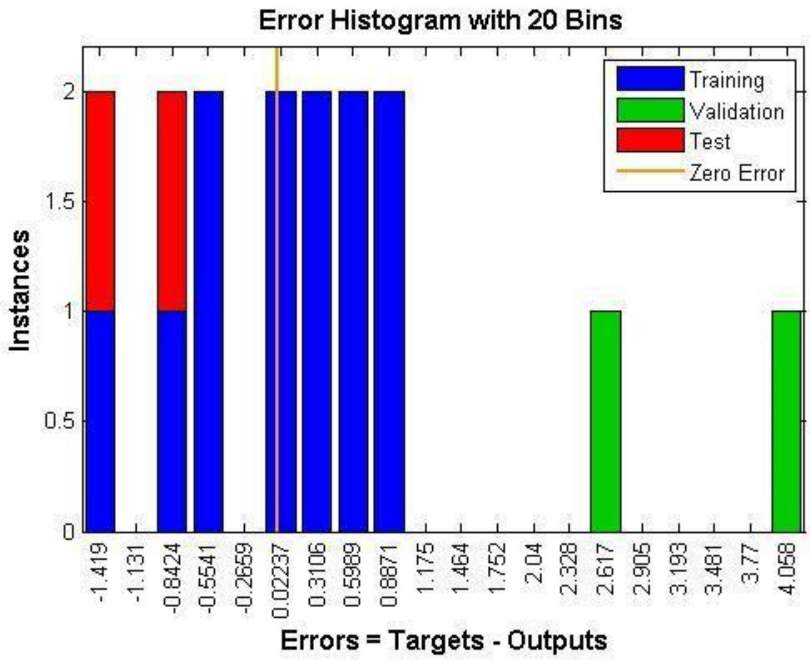

Figure 4.14: Error histogram of Conjugate gradient algorithm

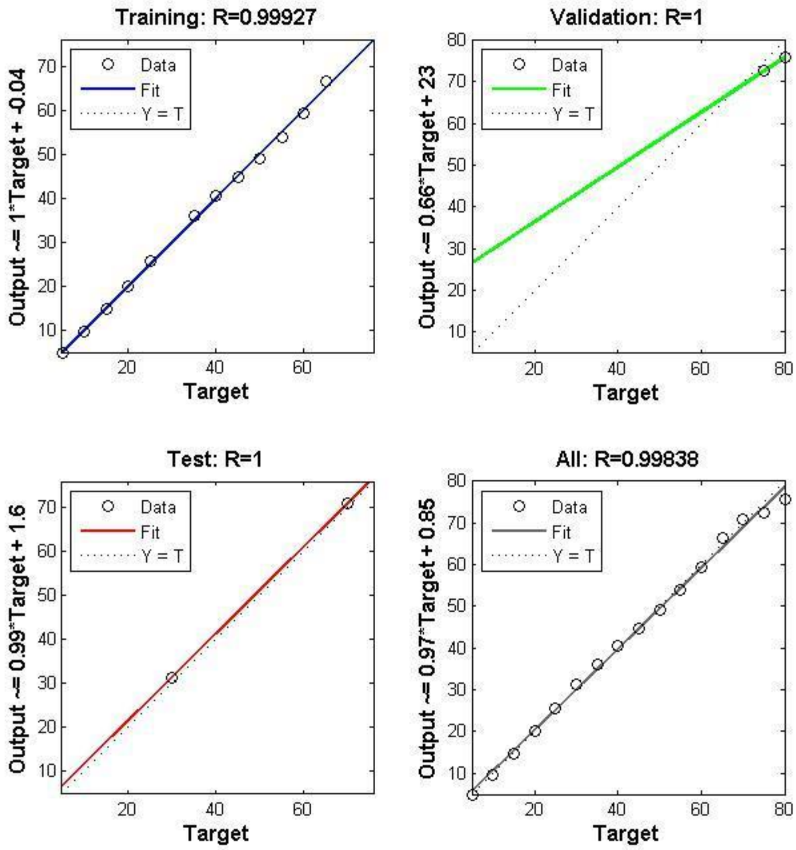

Figure 4.15: Regression analysis of Conjugate gradient algorithm

is higher than backpropagation algorithm. but in terms of numbers it is low. so the time taken to converge is less. the most significant thing is it follows generalisation. the best approximation occures at epoch 8.

The error histogram shows the errors are moderately distributed over the entire range of the error. i., it has moderate non-linearity levels along the data range. the error histogram is better comparison to the backpropagation algorithm.

The regression analysis shows there are non-linearities in the fitting curve. non-linearities are high at the higher values of target.

4.4 summary

Artificial neural network has been employed for data calibration. Data was calibrated using three different techniques in a feed-forward neural network structure. The techniques are backpropagation algorithm using gradient descent method, using regularization method and using conjugate gradient method.Looking into the mean square error plot, error histogram and regression analysis of each of the technique , the regularization technique takes more time or more number of iterations and distribution of error also is minimum. So it produces less linearity for the entire range of the input values and approximate the target better than gradient descent and conjugate gradient method.

Chapter 5

Conclusion

The main motivation behind this work was to make a cost effective data calibration system. The main area of focus was the data generated by the Ultrasonic sensor module HC SR-04. It does not produce any voltage level or current level as output. The module directly produces numerical values which is the distance. So in the process first of all the data has to be properly collected.Then in the second phase the task was to design a system that can provide ground data that can be believed to be true measurement value. In the third phase the task was to apply appropriate compensation techniques for compensating the error in the measurement.

Refeering to the first stage, a data acquisition system was designed with the help of Arduino Uno microcontroller. It was interfaced with the sensor PINs and distance values were collected. The distance values are extracted out of the serial monitor and saved to workspace of the MATLAB tool. This ends the data acquisition part

Refeering to the second stage, a ground truth apparatus was developed. it is nothing but a wooden setup consisting of IR obstacle sensor modules. These modules actually detects the obstacle passing by and provided the distance information of the obstacle

Refeerin to the third stage, compensation of error techniques in artificial neural network is applied. The techniques are backpropagation technique, conjugate gradient technique and regularisation technique.

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