LIQUID LEVEL MEASUREMENT SENSOR FOR FLOW METER AND INDUSTRIAL STORAGE TANK CALIBRATION

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Degree of Master of Science

Department of Electrical Engineering

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Dissertation submitted in partial fulfillment of the requirements for the degree
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DECLARATION

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Abstract

The aim of this research contains two parts, firstly to develop accurate, simple and inexpensive liquid level measurement sensor for underground fuel storage tank and secondly the realization of a new calibration method for liquid flow meters. The level of the liquid can be detected with various methods such as Ultrasonic, Mechanical, Doppler, Capacitive, Optical, and Laser. Even though numbers of level sensors are available in the market the Dipstick is commonly used in industries to measure the liquid height. It is a time consuming manual method. Also standing-start-and-stop method and flying-start-and-finish method are used to calibrate flow meters. But those are expensive and complicated systems.

Proposed capacitive liquid-level sensor measures the electrical capacitance between two electrodes immersed in a liquid and calculate the liquid level from the capacitance. It consists of two electrodes, inner electrode is surrounded by insulation material, and the outer electrode is aluminum pipe. The sensitivity, systematic error, random error and uncertainty of the sensor are better with tap water in the tank rather than petroleum products. The effectiveness of this proposed method is tested by a series of numerical and experimental tests. It reveals that an accuracy of the instrument is ±0.5cm and ±1cm with tap water and petroleum product respectively.

The instrument has been validated against the calibrated dipstick and ultrasonic distance sensometer with liquid as the tap water. And also instrument has been validated by calibrated dipstick and pressure level measurement sensor with petroleum products.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
ANOVA	Analysis of Variance
CDC	Capacitance to Digital Converter
NML	National Measurement Laboratory
PTB	National Measurement Laboratory of German
PTFE	Polytetrafluoroethylene (Teflon)
SCADA	Supervisory Control and DATA Acquisition System

LIST OF APPENDICES

CHAPTER 1
INTRODUCTION

1.1 Liquid Level Measurement Sensor

The measurement of the liquid level is an important parameter in metrological, commercial and technological applications. Many types of industrial processes utilize liquid level sensors to provide the information needed to monitor and control the process. Liquid level sensors measure absolute height along the vertical axis of a storage tank. Liquid level can be measured using different types of methods such as Capacitive [1-5], Doppler sensor [12], Ultrasonic [13], Digital camera [14] or Optical [6-11]. The property of the liquid that is going to be measured should be considered to select the suitable detection method. The type of measurement and the sensor technology will dictate the set of parameters which are important in specifying the appropriate sensor.

The liquid level measurement can be either continuous or discrete. Continuous liquid level measurement sensors detect level within a specified range and indicate the exact amount of liquid height, discrete or point-level sensors only specified whether the liquid is above or below the target point. Also direct method and indirect method are the two categories of the liquid level measurement sensor. Direct methods employ physical properties such as fluid motion and buoyancy, as well as optical, thermal, and electrical properties. Direct level measurement does not require compensation for changes in level caused by changes in temperature. Direct level measurements show the actual level of the interface. Indirect level measurements involve converting measurements of some other quantity, such as pressure to level by determining how much pressure is exerted over a given area at a specific measuring point, the height of the substance above that measuring point can also be determined.

1.2 Originality & Objectives

From the literature review described in chapter 2, it can be understood that there are several kinds of liquid level measurement sensors that have been developed by the scientist. Several kinds of techniques which came up during the literature review are described in section 2.1 and 2.2 in chapter 2. Also in metrological field, flow meter calibration is very important equipment setup which is used in some countries as described in section 2.3 in chapter 2.

Major disadvantage of level sensors is that the readings of the sensors are depending on the properties of the liquid that is going to be measure. In metrological point of view, we can understand the disadvantages of the instrument which is used in specially petroleum industries. So it is necessary to introduce easy, accurate and inexpensive instrument to this industry.

Also on the other hand, as the National Measurement Laboratory (NML) of the country, it is very important to provide flow meter calibration service to the industry. At the moment the NML has not been providing this kind of service to the client. The reason is that the equipment setup which is used to calibrate flow meters is very expensive and complicated. One of the most critical part of this set up is flow diverter mechanism. It is possible to replace the flow diverter system using the even diameter vertical cylindrical tank with proposed liquid level measurement sensor. It will be low accuracy method comparing the flow diverter mechanism. But it is accurate enough to calibrate flow meters in industries which is used in low accuracy flow meters. Even though numbers of level measurement sensors are available in the market, it is not possible to use for this purpose. The reason is that if we use commercially available sensor it is not possible to do modification that are necessary frequently. Actually in the flow meter calibration, we are constructing experimental set up. So it is necessary to do modification repeatedly to get more accurate readings.

Thus, in this research, the objective is to design capacitive base liquid level measurement sensor to fulfill the above two requirements.

The organization of the chapters in this reports as follows. The literature review of the liquid level measurement method is explained in chapter 2 and then chapter 3 explains the development of the sensor, chapter 4 described the validation and analysis of the results. Finally, conclusion and recommendation for the future development are elaborated in chapter 5.

CHAPTER 2
LITERATURE REVIEW

2.1 Liquid Level Detection Method

From the literature review, it is obvious that number of different kinds of techniques have been developed to measure the height of liquid. The level of the liquid can be detected with various method such as dipstick, capacitive, ultra-sonic, laser and optical method. The property of the liquid that is going to be measure the height is the critical parameter in selecting the detection method. Following section described some of those techniques relevant to this study.

2.1.1 Dipstick method

The figure 2.1 showed dipstick that is used to measure the height of the liquid. The simplest and oldest method of level detecting is, of course, the dipstick method. Direct level measurement is simple almost straightforward and cost-effective. It uses a direct measurement of the height from the bottom line.

Figure 2.1: Level Measurement using Dipstick

It is not easily adopted to signal transmission techniques for remote indication or control. It's time consuming manual method and main limitations of this method are low accuracy and result may be depending on the operator.

2.1.2 Capacitive sensor method

In these applications, liquid level is calculated using the fact that capacitance between electrodes change due to the relative permittivity of liquid level (the figure 2.2). That is, the measurements are very sensitive to the type of liquid, particularly the dielectric constant. Another important factor in measurements is the temperature. The dielectric constants are different in different temperatures for any material. The temperature effects the calibration of the sensor considerably, particularly if the temperature of the measurement environment is out of the designated range of the sensor [2].

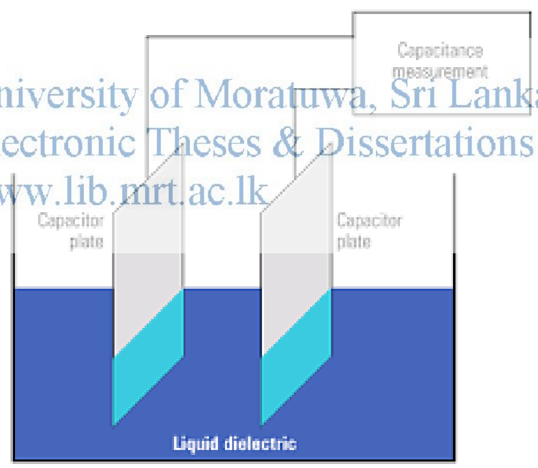


Figure 2.2: Level Measurement using Capacitive Sensor

In case of liquid level in a tank, some vapor comes out, which may change the dielectric constant of air above the liquid surface considerably. Thus, the calibration according to the free air mass dielectric constant may result faulty and unreliable readings. Using only one capacitive sensor cannot eliminate the effect of air mass completely.

Although the error due to air can be made as small as possible thanks to the high dielectric constants of liquids, the moisture in the air can considerably change the readings. Therefore, the neglected effect of air should be validated over a larger range of possible air quality variations [2].

2.1.3. Ultrasonic level transmitters

An ultrasonic liquid level sensor (Figure 2.3) could be used to measure the height between the transducer and the air-liquid surface. The principle is based on the time required for an ultrasound signal to travel from a transducer to the air-liquid surface and back. These sensors use frequencies in the tens of kilohertz range; transit times are ~6 ms/m. The speed of sound (340 m/s in air at 15°C) depends on the mixture of gases in the headspace and their temperature.

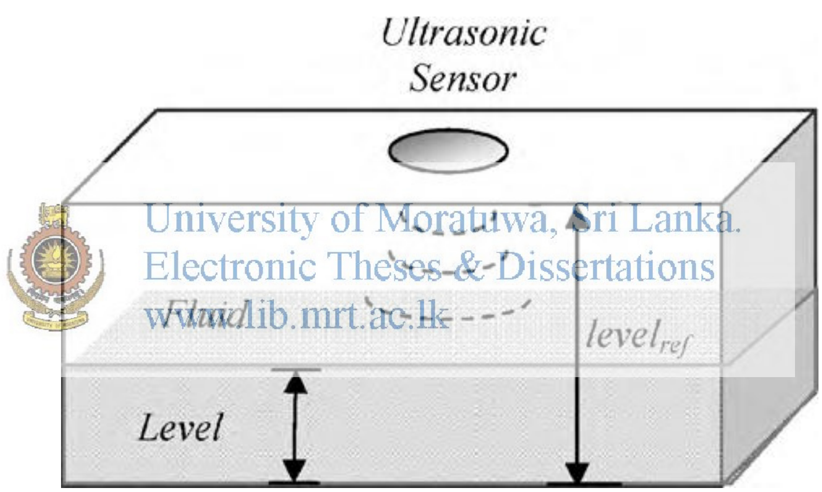


Figure 2.3: Level Measurement using Ultrasonic Sensor

Ultrasonic devices can be used in containers with pressures up to 2MPa, temperatures up to 100^{o}C, and depths up to 30 m, with an accuracy of approximately 2%. The ultrasonic sensor is one example of a compact as well as contact-less proximity sensor [13].

The ultrasonic sensor determines the fluid level by transmitting echo pulses and measuring the return time of the reflected echoes. If the speed of sound in the medium is known then the fluid level can be calculated using the following equation 2.1:

$$level = level_{ref} - \frac{1}{2}vt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2.1)$$

Where $level_{ref}$ is the height of the tank, v is the speed of the sound and t is the time-of-flight of the ultrasonic echo (Fig. 2.3). However, the speed of sound is influenced by the temperature of the medium through which it travels. Therefore, changes in the ambient temperature will create incorrect fluid level readings. The speed of sound in air can be approximated in terms of temperature as in equation 2.2:

$$v(t) = 331.3 + kT\frac{m}{s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

Where, T is the ambient temperature in ^{o}C, k is the rate at which the speed changes with respect to the temperature, which is approximately 0.607 m/s at every change of 1 ◦C in temperature. Ultrasonic sensors are normally pooled with a temperature sensor to compensate for the effects of temperature variations [13].

2.1.4 Laser level transmitters.

It used the speed of the light to find the distance between the air-liquid surface and transducer. Most suitable for bulk solids, slurries, and opaque liquids like dirty sumps, milk, and liquid styrene, lasers operating principle is very similar to the ultrasonic level sensors (Figure 2.4). The key is that lasers have virtually no beam spread (0.2° beam divergence) and no false echoes, and can be directed through spaces as small as 2 in.[2] Lasers are precise, even in vapor and foam. They are ideal for use in vessels with numerous obstructions and can measure distances up to 500 m. For high-temperature or high-pressure applications, such as in reactor vessels, lasers must be used in conjunction with specialized sight windows to isolate the transmitter from the process. These glass windows must pass the laser beam with minimal diffusion and attenuation and must contain the process conditions.

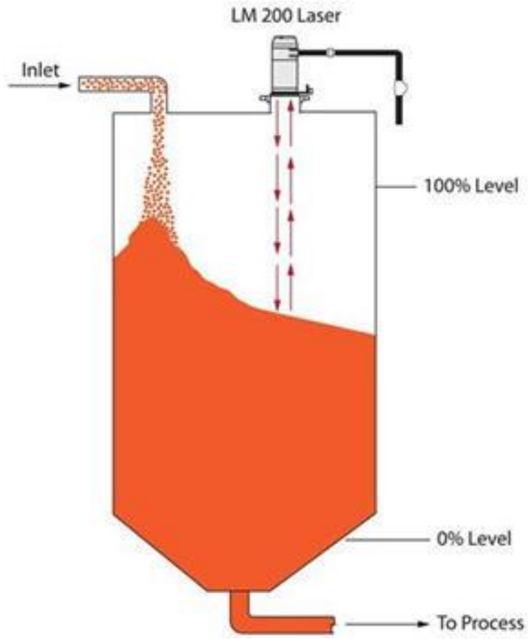


Figure 2.4: A laser transmitter uses a short burst of laser energy to measure level

2.1.5 Optical level measurement

The reflection of light is used to sense the level of liquid. It consists of both a light source and a sensor/receiver. Light (red) is reflected back to the sensor by the conical tip of a quartz light conductor or prism. When material is present, such as when the material level rises, light is refracted into the material. Because of their non-electrical nature, liquid-level sensors utilizing optical fibers are widely required in the chemical industry optical sensors can be used for liquid-level measurement without having to contact the liquid (Fig. 2.5). An optical camera and an image signal processor are used to measure liquid level by detecting the edge of a captured image and calculating the liquid level [6-12].

Optical sensors use visible, infrared, or laser light to detect fluid level. They rely upon the light transmitting, reflecting, or refracting abilities of the material. Optical sensors can be used in contact and non-contact sensing. In non-contacting systems, the light aimed down on the surface of the fluid and the reflected light is detected by a photocell.

Different fluids can be detected at different levels if multiple photocells are used. These sensors have a simple, straightforward design and are reliable sensors which do not be to be recalibrated between batches. They can be integrated in systems where they must be compatible with a variety of process materials and process conditions. Their response time is virtually immediate and highly accurate.

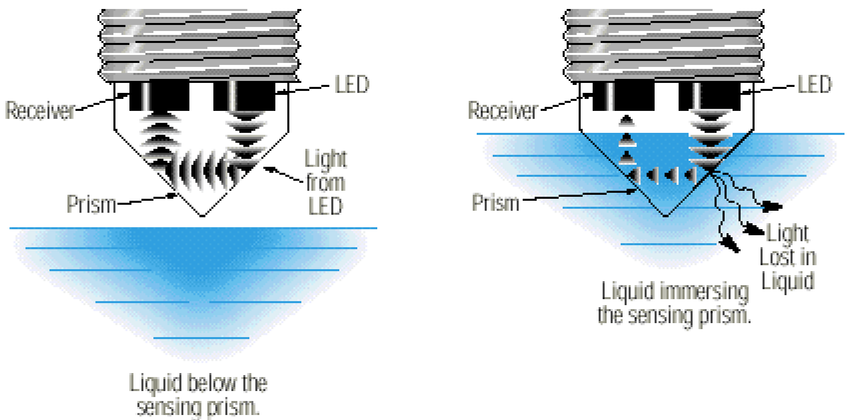


Figure 2.5: Level measurement using Optical sensor

2.1.6 Digital camera

In some applications, it is not possible to install mechanical measurement devices, e.g., pressure sensors. For this reason, contactless and non-invasive methods which do not include electrical connections inside tanks have been developed over the past years. An imaged-based measurement system using a single digital camera and a circular float to measure fill levels in liquid tanks is proposed. Because of the linear relationship between the pixel counts of objects in an image frame and the photographing distance, it can be then use a digital camera to capture images for measuring fill levels in liquid tanks. [14]. By choosing the float in a different color from that of the liquid in the tank, pixel counts of the float in the image captured by the camera can be calculated with the use of chrominance filtering and thresholding techniques.

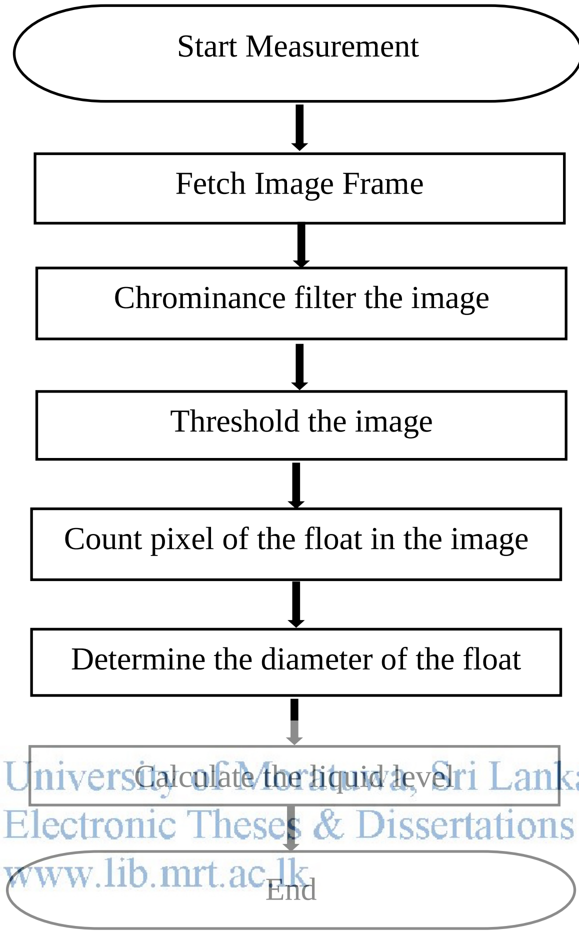


Figure 2.6: Determination of liquid level based on images captured by the digital Camera

Based on an established relationship between the pixel counts of the diameter of the float in the image and the photographing distance, the measuring system can effectively measure the liquid level based on the images captured. Because pixel counts of the float in the image are first determined for calculating the diameter of the float, a sub pixel resolution during the measurement can be achieved. As a result, measuring precision as well as accuracy via the proposed system can be significantly improved. The flow chart of the process is mentioned in figure 2.6.

2.1.7. Selection of liquid level measurement methods

Table 2.1 shows the disadvantages and advantages of the liquid level measurement sensor which have described in above.

Table 2.1: Comparison of liquid level measurement sensor

Sensor type	Advantages	Disadvantages
Dipstick Method	✓ No moving parts ✓ No electronic parts	✓ Time consuming manual method. ✓ Result will be depend on operator
Capacitive sensor	✓ Compatible for vast range of liquid ✓ Compatible for vast range of tank shape	✓ Should be select suitable electrode ✓ Should be maintained constant difference in between two electrode
Ultrasonic Sensor	✓ Result is not depend on color of the air-liquid or reflectivity of the interface ✓ Contactless measurement method ✓ No moving parts	✓ Have a minimum sensing distance ✓ Output will be depend on environmental condition ✓ Relatively expansive
Laser Measurement	✓ High accurate ✓ Can be measure long distance	✓ Very expansive
Optical Method	✓ Non- contact method ✓ Glass window is enough to get reading ✓ Portable device	✓ Not good for opaque liquid ✓ Not good for highly reflective liquid
Camera	✓ Non-contact method ✓ Non-invasive method ✓ Not necessary to open the tank, glass window is enough	✓ Little bit expensive ✓ Little bit complicated method

2.2 Capacitive Sensor Method

Considering described matters, it is understood that capacitive base liquid level measurement sensor is reliable method to measure the height of the liquid level. Also it is suitable to full fill our needs which are described in originality and objectives in chapter 1. So before starting the project, again the detailed literature review has been done under the tropic of liquid level measurement sensor based on capacitive measurement. Numbers of research have been done using different type of capacitive base liquid level measurement sensors as described below.

2.2.1 Parallel plate capacitance to measure the height of the nonconductive liquid

In Fig 2.7, the sensor setup inside a liquid container is shown schematically. Two extra identical capacitive sensors are used as reference sensor. One reference sensor is placed at the bottom of the container for liquid dielectric reference. The air sensor is placed at the top of the container for air dielectric reference. These two sensors are identical, with the same spatial dimensions. The third sensor is the level sensor placed along the height of the silo. The level is measured by this sensor. All three sensors have the same distance *d* between the parallel plates. In addition, the width *W* of the plates is the same for the three of them.

The dielectric values are converted to digital information by a Capacitive-to-digital converter (CDC). A CDC should be used for each sensor. These CDCs should be placed very close to the sensor to reduce the cable loss [2].

Mathematical equation for the system is

$$L_l = L_R L_r \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2.3)$$

Where, L_R is the ratio of the length of the liquid-filled part of the level sensor L_l and the length of the reference sensor L_r. Therefore, once L_R is obtained, simply, it should be multiplied by L_r to get the level of the liquid L_l in the container.

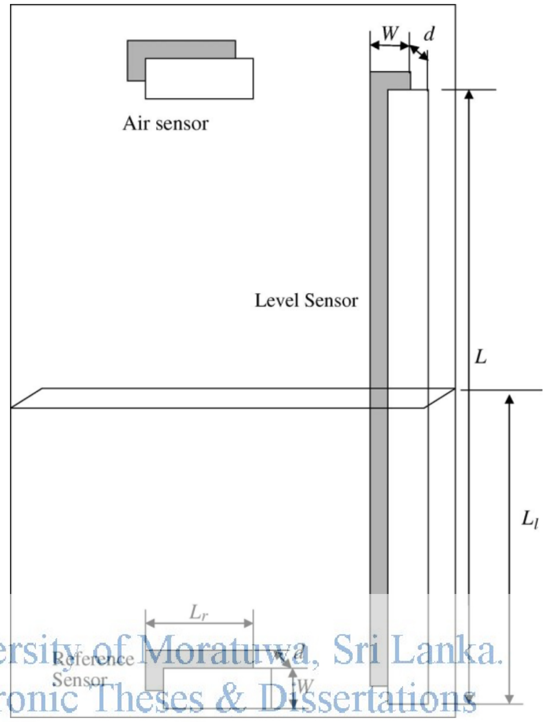


Figure 2.7: Level Measurement using parallel Plat Capacitive Sensor

L -total length of the level sensor;

Ll -length of the liquid-filled part of the level sensor;

Lr -length of the reference and air sensors;

$La = L - Ll$ length of the air-filled part of the level sensor;

W- Width of the sensor plates (the same for all sensors);

d -distance between the sensor plates (the same for all sensors);

ε_l -permittivity of liquid;

ε_a- permittivity of air (typically equal to $\varepsilon_0 = 8.8541878176 \times 10^{-12}$ F/m).

2.2.2 The capacitive sensor which electrodes are built with a rod of stainless steel and a PTFE-insulated wire.

Fig. 2.8 shows a picture of the designed sensor prototype. The sensor is about one meter high and has two electrodes, one of which is insulated to be able to measure conductive liquids. The non-insulated electrode is a rod of stainless steel, which will be connected to the system ground in operating conditions. The insulated electrode is a PTFE-insulated wire whose nominal internal and external diameters are 1mm and 1.5 mm, respectively. Since the sensor capacitance directly depends on the thickness and the dielectric constant of the insulation, it is essential to use a material such as PTFE (commonly known as "Teflon"), which is temperature-stable, non-porous, non-stick and corrosion-resistant. The wire is set in a U-shape so that both ends are out of the water. This configuration avoids the problem of sealing one of the wire ends and, in addition, it doubles the sensor capacitance. According to preliminary experimental tests, it is not advisable to use a twisted wire as an insulated electrode since the linearity and hysteresis clearly worsen; this is because water can more easily stick to the wire in rather unpredictable way. At the top of the sensor, there is a piece of rigid plastic for setting the tension of the wire [1].

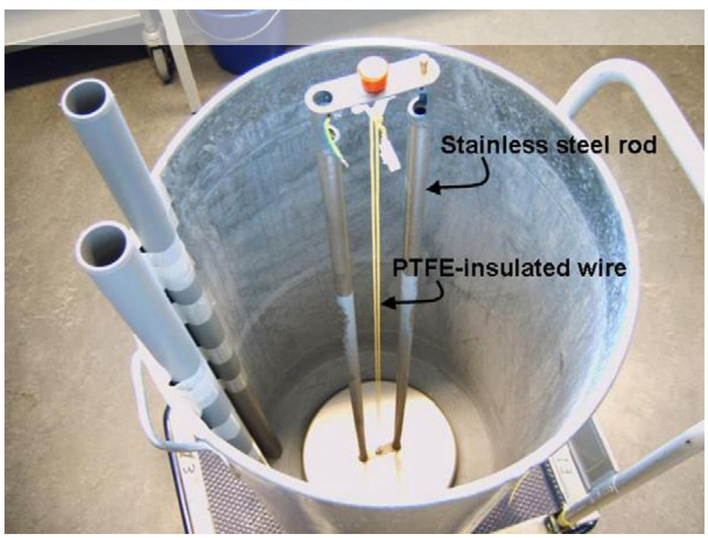


Figure 2.8: Prototype of the capacitive liquid-level measurement sensor inside a metallic container

2.2.3. Multi-Functional parallel-plate capacitor sensor

The structure of this sensor is shown in Fig.2.9, which consists of a pair of parallel-plates (A and B) with some copper electrode (EA, EB1, EB2 and EB3). A and B have a narrow distance between them. Capacitances C_1, C_2 and C_3 are measured as capacitance between EA and (EBl+EBB+EB3), EA and EB1, EA and EB2, respectively, as shown in Figure.2.9. [3].

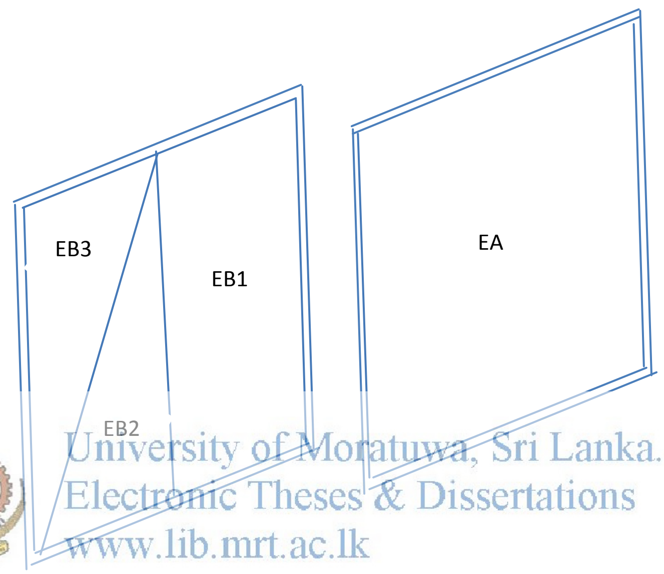


Figure 2.9: Level Measurement using Multi-Functional Capacitive sensor

The measured values, C_1, C_2 and C_3 include the information of the level of liquid (H), permittivity of the liquid (ε_l) and inclination status of the liquid container (θ). The general principle that H, ε_l *and* θ are obtained by the measurement result of C_1, C_2, C_3 is shown equation 2.4. [3]

$$\begin{Bmatrix} C_1 = f_1(H, \varepsilon_1, \theta) \\ C_2 = f_2(H, \varepsilon_2, \theta) \\ C_3 = f_3(H, \varepsilon_3, \theta) \end{Bmatrix} \rightarrow \begin{Bmatrix} H = F_1(C_1, C_2, C_3 \\ \varepsilon_1 = F_2(C_1, C_2, C_3) \\ \theta = F_3(C_1, C_2, C_3) \end{Bmatrix} \dots\dots\dots\dots\dots\dots\dots.. (2.4)$$

2.2.4. Planar capacitive level measurement sensor

The electrode structure spans the whole measuring range and has a maximum length of nearly 4 m. It consists of a long electrode E_0 and one that is divided into insulated segments (E_1 to E_n). The relative position of the electrodes is fixed by the mechanical construction, while the absolute position requires a one-time calibration. All capacitances are connected to either the low-impedance voltage source, the low-impedance measurement-system input or to ground (Fig. 2.10).

The level of non-conducting liquids can be calculated by finding the interface segment i, which has a value between C_{i-1}, the capacitance in the liquid and C_{i+1}, the capacitance in air. Then the capacitance of the interface segment C_i can be interpolated to find the interface position p accurately using equation 2.5.

$$P = l\left(\frac{C_i - C_{i+1}}{C_{i-1} - C_{i+1}} + i\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots (2.5)$$

Where, l is the length of the electrode segments.

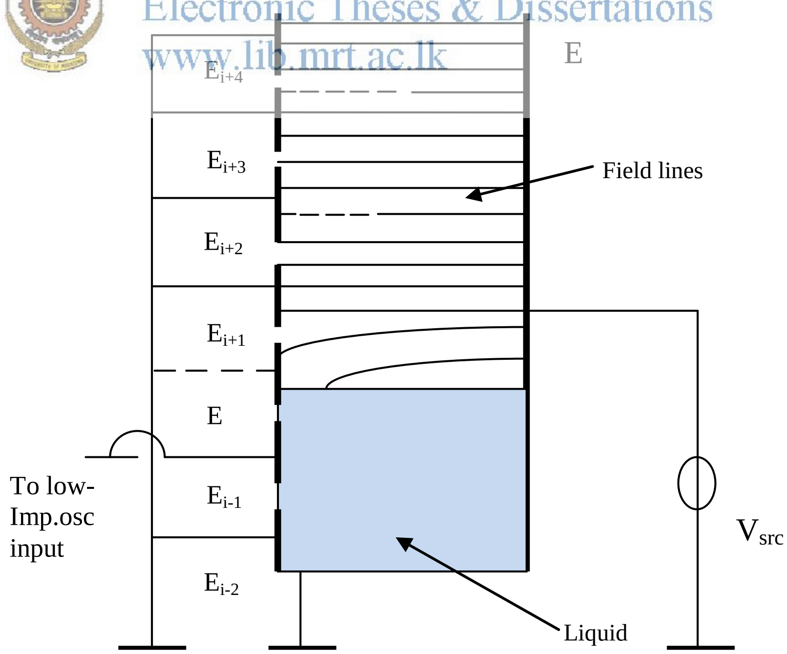


Figure 2.10: Level measurement using Planner capacitive sensor

To measure conducting liquids such as water, a special provision has to be made: To prevent short-circuiting of the input of the measurement system the electrodes need to be covered with an insulating sleeve. This material also protects the electrodes against the possibly aggressive environment. In the proposed setup some electric-field bending around the interface will occur [5].

2.3 Flow Meter Calibration Setup

The international standard, ISO 4064 is the international guideline for the calibration of flow meters. Test to determine Errors of indication, Static pressure Test, Pressure loss Test, Durability Test and Performance Test are the main test which is described in this guideline. In test to determine error of indication, so called "collection method" in which the quantity of water passed through the flow meter is collected in one or more collecting vessel and the quantity determined volumetrically or gravimetrically. This test is completely discussed in section 5 of above mentioned standards. To fulfill requirements which are described in guideline, NMLs of other countries have been used two type of method. It is called standing- start -and -stop method and flying –start –and-finish method for flow meter calibration. These two methods have been described in section 2.3.1 and 2.3.2.

2.3.1 Standing Start and Stop method

The standing start and stop method is generally preferred for meters measuring precise quantities of liquid. 'Standing start and stop' is the easy method available and can be used for both high and low accuracy calibrations. When the vessel is empty, the drain valve is closed, the flow started and the tank filled and when the container is full the flow is stopped using fast active valve (figure 2.11). The volume collected is measured and compared with the flow meter reading, the time to fill gives the flow rate. In this case, the flow has to be started and stopped as quickly as practical to minimize the rise and fall time errors. The stop valve should have a same opening and closing time. The meter being calibrated has to have a fast response time to match the start and stop of the flow.

What is discussed above is a standing start and stop method based on a gravimetric (weighing) method or volumetric method. If we use gravimetric method it is needed to measure mass of the volume that is filled within the known time. If a volume tank is used, we must use standard volume measures. In this case the time that is taken to fill the tank should be measured to find out the flow rate.

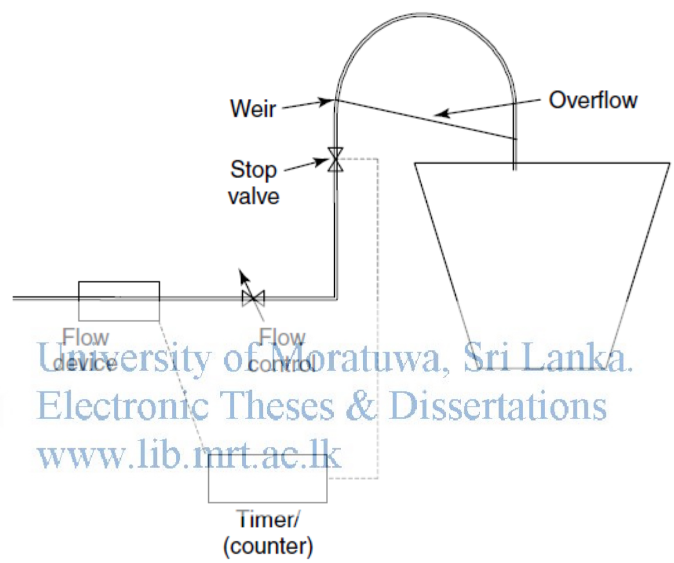


Figure 2.11: Standing Start and Stop method for calibration of liquid flow meters

2.3.2 Flying –Start –and-finish method

This is also called the diverter method where the flow through the meter is not stopped but continues uninterrupted. It means that it is not necessary to open and closed the valve again and again during the test. The flow is physically diverted between a return path to the liquid supply tank and the collection container that will be gravimetric or volumetric. The figure 2.12 shows the schematic diagram the calibration setup. A switch on the diverter mechanism starts and stops a timer and a pulse totalizer. This should be not affected to the flow rate through the device. For this reason the flow into the diverter is normally conditioned by creating a long thin jet impinging on a splitter plate. This will be open to atmosphere ensuring no change of pressure occurs when diverting and hence removing the potential for a change in flow rate during a test.

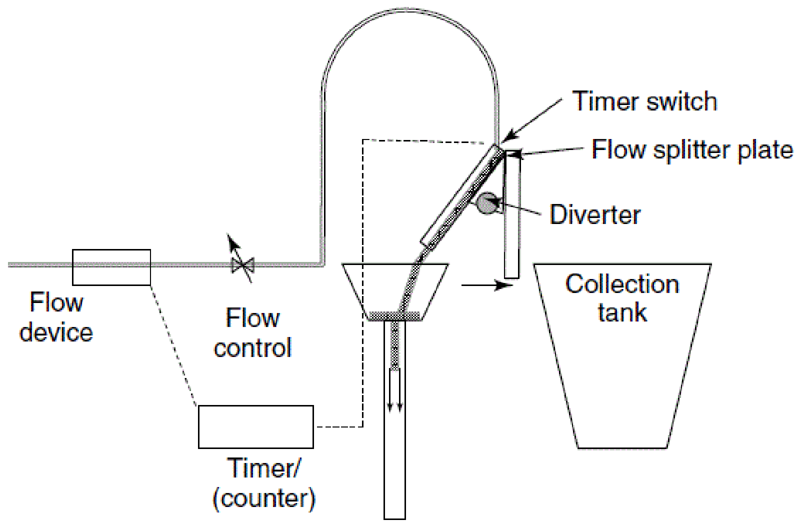


Figure 2.12: Flying –start –and-finish method for flow meter calibration

The diverter is operated as quickly as possible to decrease to ‘timing errors’. The main source of uncertainty lies in the timing error, shown diagrammatically in figure 2.13.

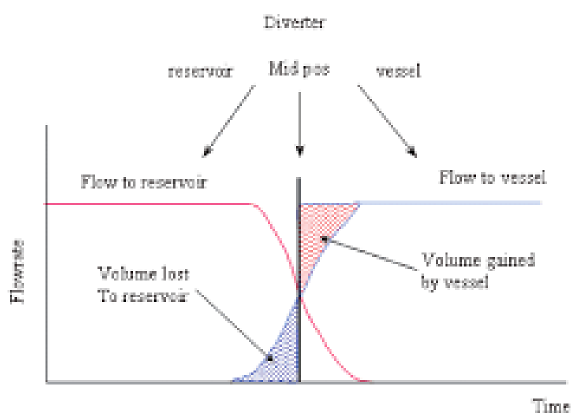


Figure 2.13: Timing error of the flying-start and –finished method for flow meter calibration

2.3.3 Complete flow meter calibration unit

In figure 2.14 illustrated the complicated, expensive and fully automated flow meter calibration system which is used in National Measurement Laboratories (PTB) in German. During the calibration facility's measurement operation the main process quantities (water flow rate, pressure and temperature), are stabilized by a computer-based Supervisory Control and Data Acquisition (SCADA) system, with numerous other relevant process parameters like fluid density, diverter actuation, balance readout and ambient-air conditions, being monitored when the flow meters was calibrated by this setup the expanded uncertainty as low as 0.02% of the total flow rate of the measurement. But unfortunately this type of setup is very expensive and complicated.

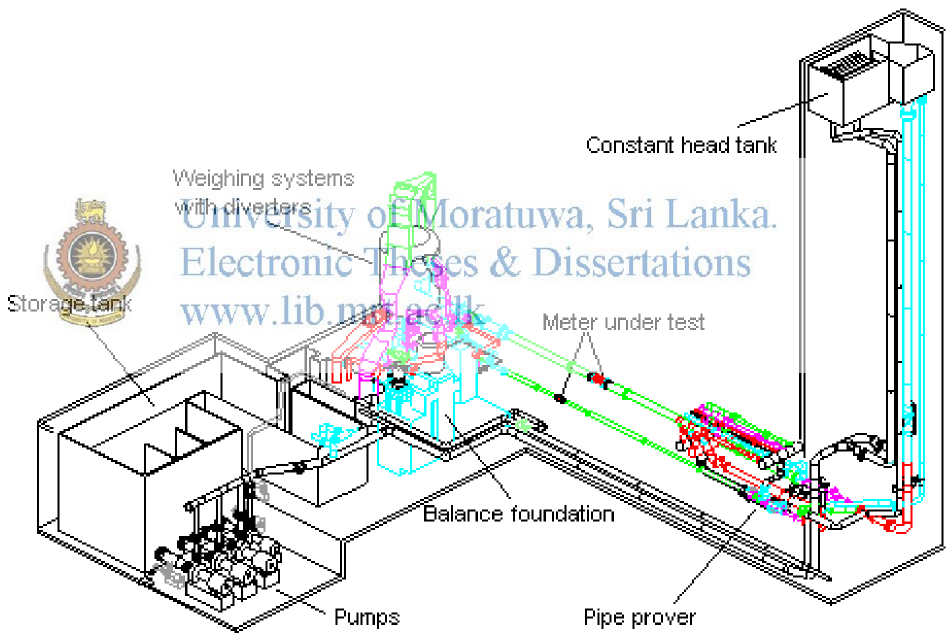


Figure 2.14: Cutaway view of PTB's water flow calibration plant

Flow is generated and stabilised by a system of electronically regulated pumps and a constant-head tank with an overflow weir. The constant head tank has a capacity of 6 m^3, is located 35 m above ground level and serves, in addition, as a high precision flow stabiliser.

The measuring and operating mode in which the highest calibration accuracy is achieved – and which is utilised at PTB's measuring facility is static weighing with flying-start-and-finish operation. In this operation mode, the test liquid is kept in a constant circulating motion through the system's pipe work prior to and during a calibration run. The actual measuring operation is started by switching the diverter's diverting edge from the bypass position into the diverting position in which the liquid flow is directed towards the weighing tank. When passing the centre of the diverter's liquid jet, a gate signal is initiated that launches data acquisition from the test meter's signal output and starts an electronic counter which determines the diversion time. Upon reaching a pre-defined quantity of water in the weighing tank, the diverter is switched back into its initial position. And when passing the jet's centre again, the signal acquisition of the test meter and the time measurement are stopped.

CHAPTER 3

DEVELOPMENT OF SENSOR

3.1 Sensor Prototype

Fig. 3.1 shows a sketch of the implemented sensor prototype. The sensor is about three-meter-high and consists of two electrodes; inner electrode is insulated by polystyrene layer to be able to measure capacitance of liquids. The outer electrode is a pipe of Aluminum that will be connected to the system ground in operating conditions. The internal and external diameters of the insulated electrode are 0.4 mm and 3.5 mm, respectively. The bottom of the inner electrode was sealed by waterproof material to prevent the touch with conductive liquid.

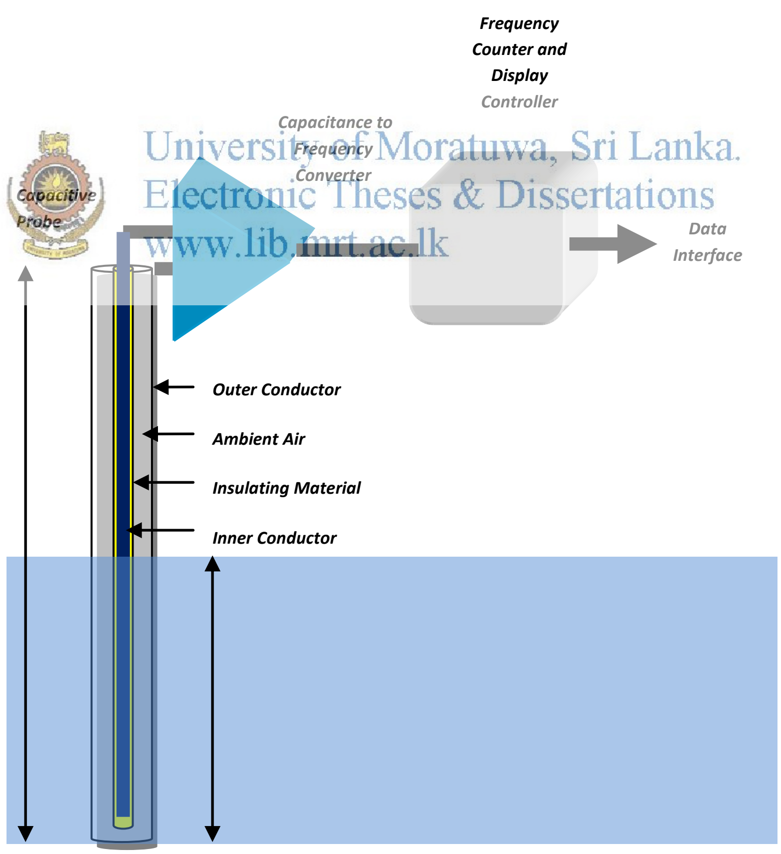


Figure 3.1: Prototype of the proposed capacitive base liquid level measurement sensor

3.2 Ideal Capacitive Sensor

When measuring the height of liquids, the capacitance of the sensor is theoretically equal to the capacitance between electrodes below and above the liquid–air interface. This capacitance shows a cylindrical capacitance configuration.
Therefore, ideally the value of the capacitance can be estimated from [1]:

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{d_2}{d_1}\right)} h \dots\dots\dots\dots\dots\dots\dots.(1)$$

Where ε_0 is the electric permittivity of vacuum (= 8.8542 $\times 10^{-12}$ F/m), ε_r is the relative dielectric constant of the wire insulation, d_1 and d_2 are the internal and external diameters of the wire, respectively, and h is the liquid level. From Eq. (1), for ε_r = 3, d_1 =0.4mm and d_2 = 3.5 mm.

3.3 Equivalent Capacitance of the proposed System

The equivalent capacity of the sensor above the air-liquid interface, equivalent capacity bellow the air-liquid interface and equivalent capacitance of the sensor are explained equation (2), (3) and (4) respectively.

$$C_a = \frac{2\pi\varepsilon_0}{\left\{\frac{ln\left({d_3}/{d_2}\right)}{\varepsilon_a} + \frac{ln\left({d_2}/{d_1}\right)}{\varepsilon_c}\right\}}.(H-h) \dots\dots\dots\dots\dots\dots\dots\dots..(2)$$

$$C_l = \frac{2\pi\varepsilon_0}{\left\{\frac{ln\left({d_3}/{d_2}\right)}{\varepsilon_l} + \frac{ln\left({d_2}/{d_1}\right)}{\varepsilon_c}\right\}}.h \dots\dots\dots\dots..\dots\dots\dots\dots\dots\dots..(3)$$

$$C = \frac{2\pi\varepsilon_0}{\left\{\frac{ln\left(d_3/d_2\right)}{\varepsilon_l} + \frac{ln\left(d_2/d_1\right)}{\varepsilon_c}\right\}}.h + \frac{2\pi\varepsilon_0}{\left\{\frac{ln\left(d_3/d_2\right)}{\varepsilon_a} + \frac{ln\left(d_2/d_1\right)}{\varepsilon_c}\right\}}.(H-h) \ldots\ldots\ldots\ldots..(4)$$

Where ε_0 is the electric permittivity of vacuum (= 8.8542 $\times 10^{-12}$ F/m), ε_a ε_l and ε_c are the relative dielectric constant of the air, liquid and insulation of the wire, d_1 and d_2 and $d_3$are the internal and external diameters of the wire and diameter of the Al pipe, respectively, and h is the liquid level and H is the height of the probe.

3.4 Capacitance to Frequency converter

A relaxation oscillator (Figure 3.2a) converts the capacitance C into a period-modulated signal [1]. Such an oscillator relies on an RC circuit (formed by the resistor R_c and the capacitance C) and a comparator set as a Schmitt trigger. Figure 3.2b shows the waveform of the voltages at the output (v_o) and across C (v_c) [1]:

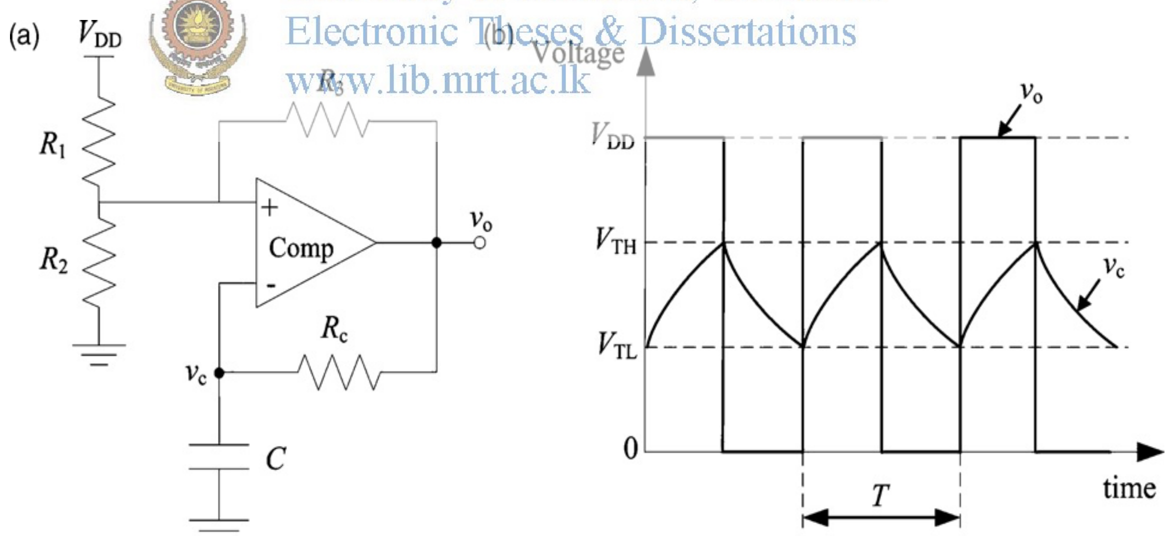


Figure 3.2: (a) Relaxation oscillator used as a capacitance-to-period converter

(b) Waveforms of v_o and v_c when the oscillator is running

The period T of the output signal equals

$$T = R_c C ln\left[\frac{V_{DD} - V_{TL}}{V_{DD} - V_{TH}} . \frac{V_{TH}}{V_{TL}}\right] \dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Which is proportional to C, and the threshold voltages (V_{TL} and V_{TH}) of the Schmitt-trigger comparator equal:

$$V_{TL} = V_{DD}\frac{R_2//R_3}{R_1 + R_2//R_3} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (6)$$

$$V_{TH} = V_{DD}\frac{R_2}{R_2 + R_1//R_3} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (7)$$

Selected values of $R_1 = R_2 = R_3$ (=10 kΩ) so that $V_{TL} = V_{DD}/3$, $V_{TH} = 2V_{DD}/3$, and $T = R_c C ln(4)$. The charging resistor was R_c has been change from 10 kΩ to1MΩ according to the height of the probe.

3.5 Mathematical Equation of the Sensor

To remove the effect of stay capacitance and capacitance change due to the conductivity of the liquid, additional calibration constant has been added to the equation (4). Before getting readings of the sensor, calibration constant C_0 has to be calculated using the initial condition. Using the equation (8), height of the liquid level can be found out.

$$h = \frac{\frac{1}{fR\,ln(4)} - \left\{\frac{2\pi\epsilon_0 H}{\frac{ln\left(d_3/d_2\right)}{\varepsilon_a} + \frac{ln\left(d_2/d_1\right)}{\varepsilon_c}}\right\} - C_0}{\left\{\frac{2\pi\varepsilon_0}{\frac{ln\left(d_3/d_2\right)}{\varepsilon_l} + \frac{ln\left(d_2/d_1\right)}{\varepsilon_c}}\right\} - \left\{\frac{2\pi\varepsilon_0}{\frac{ln\left(d_3/d_2\right)}{\varepsilon_a} + \frac{ln\left(d_2/d_1\right)}{\varepsilon_c}}\right\}} \dots\dots\dots\dots\dots\dots\dots .. (8)$$

3.6 Calculating Procedure of the Relative Permittivity of the Liquid

If we measure the level of the liquid which the relative permittivity is unknown, additional reference cells have been installed to the main sensor to calculate relative permittivity of the liquid. The figure 3.3 illustrated modified system.

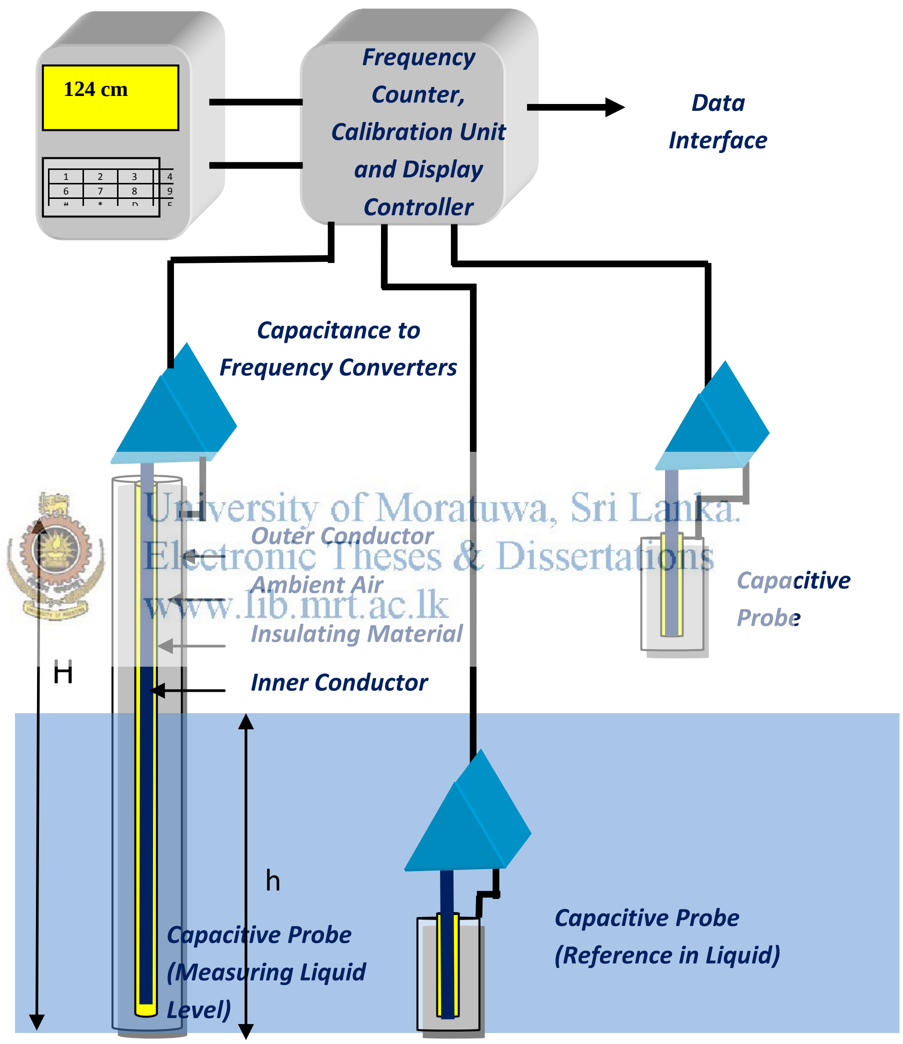


Figure 3.3: Modified Set up to Calculate Liquid Permittivity

Reference sensors constructed by same material of the main sensor have been attached to the system to find the permittivity of the liquid and air. It consists of separate relaxation oscillator to send the frequency output to the main circuit. The values of the relative permittivity of the insulator wire of the inner electrode, thickness of the insulation layer and diameter of the electrode are same. The height of the both sensors has fixed length ($H_b = H_c = 10cm$). The Reference sensor S_b has been attached to the system to find out relative permittivity of the liquid. So it should be immersed totally in the liquid and can be calculated permittivity of the liquid using equation 9. The sensor S_c has been fixed to the setup to find the relative permittivity of the air. So it should set above the liquid-air interface and can be calculated permittivity of the air using equation 10.

$$\frac{1}{f_b R_b ln(4)} = \frac{2\pi\varepsilon_0 H_b}{\left\{\frac{ln\left(d_{b3}/d_{b2}\right)}{\varepsilon_l} + \frac{ln\left(d_{b2}/d_{b1}\right)}{\varepsilon_{bi}}\right\}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(9)$$

$$\frac{1}{f_c R_c ln(4)} = \frac{2\pi\varepsilon_0 H_c}{\left\{\frac{ln\left(d_{c3}/d_{c2}\right)}{\varepsilon_l} + \frac{ln\left(d_{c2}/d_{c1}\right)}{\varepsilon_{ci}}\right\}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(10)$$

3.7 Expected Sensitivity of the Proposed Sensor

The sensitivity of the proposed sensor is derived from equation (11)

$$\frac{\partial C}{\partial h} = \left\{\frac{2\pi\varepsilon_0}{\frac{ln\left(d_3/d_2\right)}{\varepsilon_l} + \frac{ln\left(d_2/d_1\right)}{\varepsilon_c}}\right\} - \left\{\frac{2\pi\varepsilon_0}{\frac{ln\left(d_3/d_2\right)}{\varepsilon_a} + \frac{ln\left(d_2/d_1\right)}{\varepsilon_c}}\right\} \dots\dots\dots\dots\dots\dots\dots..(11)$$

Proposed sensor has been constructed according to the above mentioned parameters. The expected sensitivity for the various liquids is given in table 3.1.

Table 3.1: Sensitivity of the proposed sensor for the selected parameters

	Liquid	pF/cm
1	Tap water	0.54
2	Petrol	0.14
3	Diesel	0.12

3.8 Sensitivity Analysis of the Sensor

Number of factors has been affected to the output sensitivity. So following simulations have been done to find out the affected parameters.

3.8.1 Dimensions and permittivity

Using the figure 3.3, it is possible to understand the parameters which are mainly affected to the sensor output. The one of the most significant parameter of the sensitivity is diameter of the inner electrode. If the diameter of the inner electrode varied from 0 to 5mm the sensitivity will be increased by 4pF/cm. Also other parameter is dielectric constant of the insulation material.

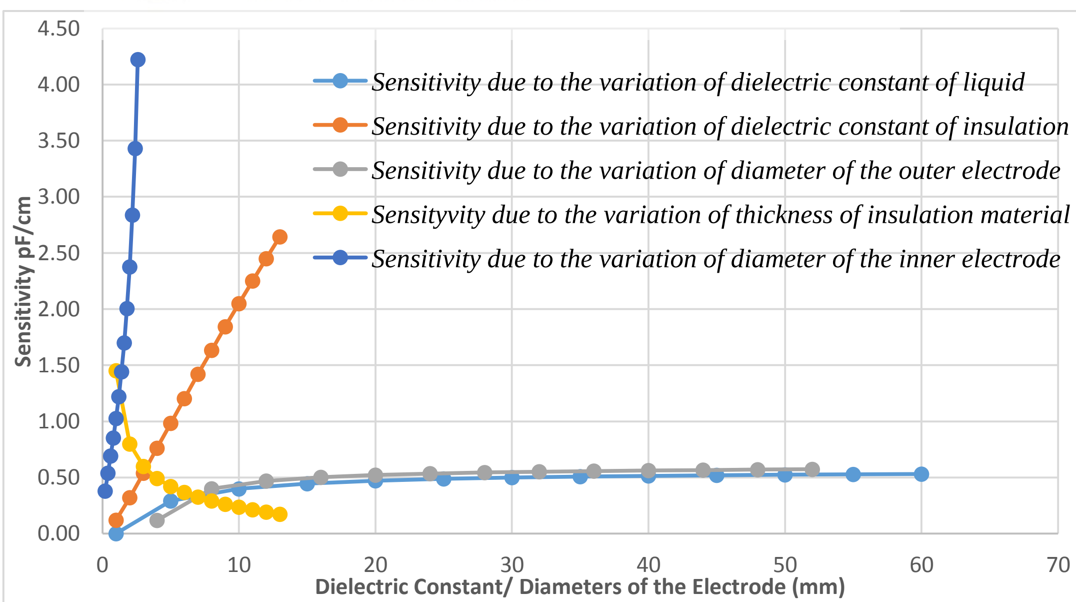


Figure 3.4: Sensitivity analysis

If the thickness of the inner insulation layer is increased the sensitivity is decreased. The behavior of the dielectric constant of the liquid and diameter of the outer electrode are same.

3.8.2 Uniformity in between the inner and outer electrode

Other main sensitive parameter is clearance in between the inner and outer electrode of the cylindrical capacitance. To find out the effect of the gap in between the outer and inner electrode, Ansys Maxwell simulation software has been used. Figure 3.5 and 3.6 shows the capacitance diagram and simulated capacitance value if the center coordination of the both inner and outer electrode is (0,0,0). It means that 7.5 mm uniform gap maintained in between the inner and outer electrode according to the dimensions of the sensor. The voltage difference in between the inner and outer electrode is 2.5v.

The figure 3.7 and 3.8 illustrate the capacitance diagram and output capacitance if the coordinate of the inner and outer electrode is (3,0,0) and (0,0,0) respectively. It means that the inner electrode moves 3mm on the x- axis from the center of outer electrode. Then there is no uniform clearance in between the inner and outer electrode.

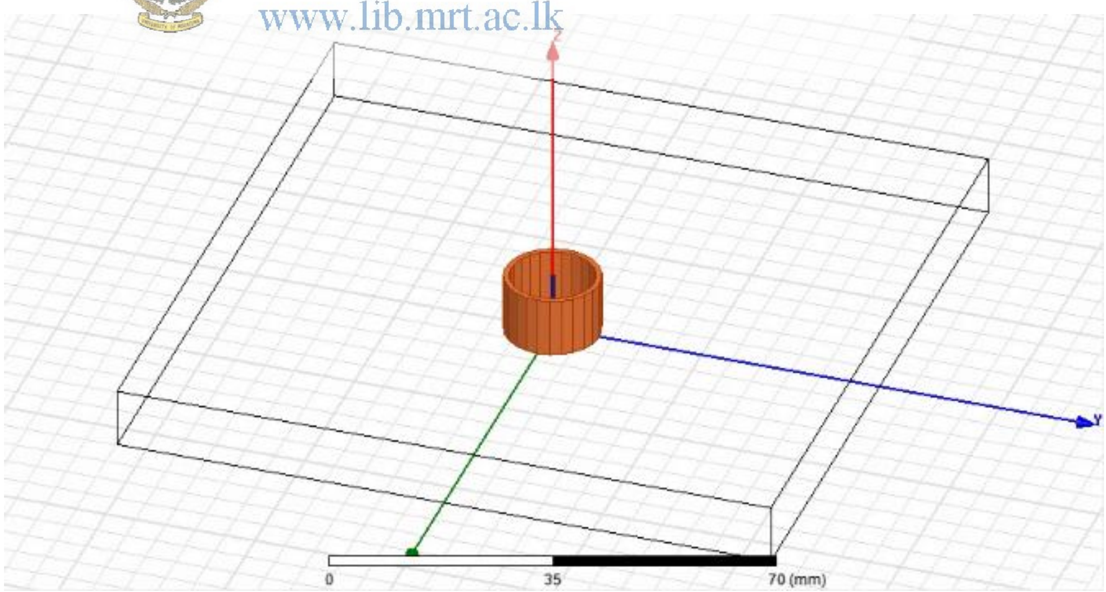


Figure 3.5: Cylindrical capacitance which has same center co-ordinate of inner and outer electrode

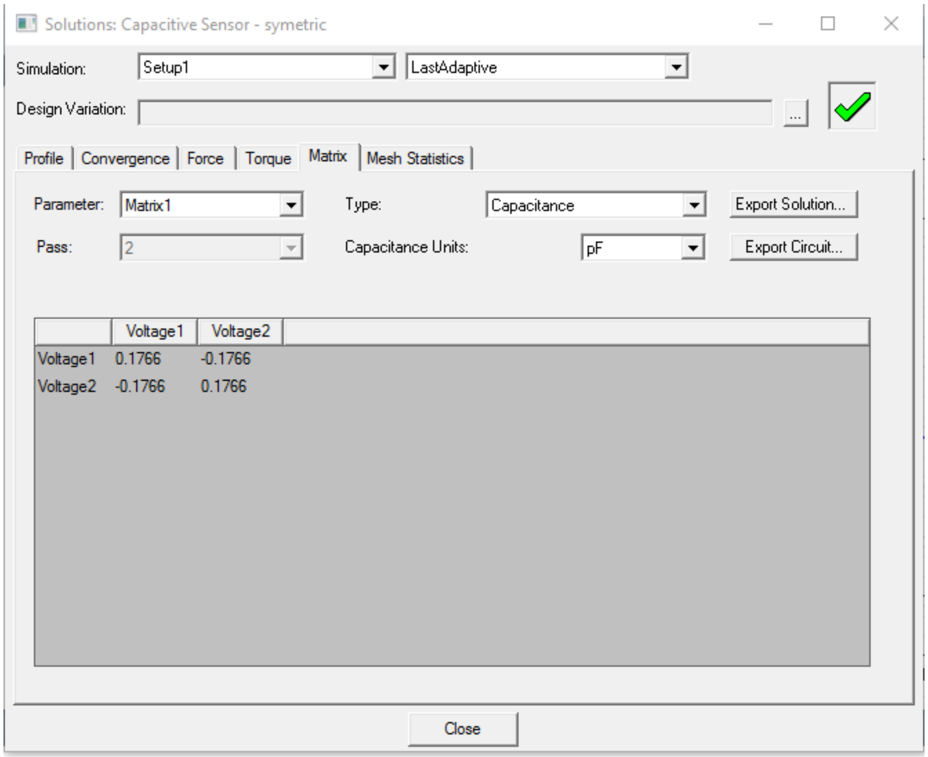


Figure 3.6: capacitance of the capacitor which has same center co-ordinate of the inner and outer electrode

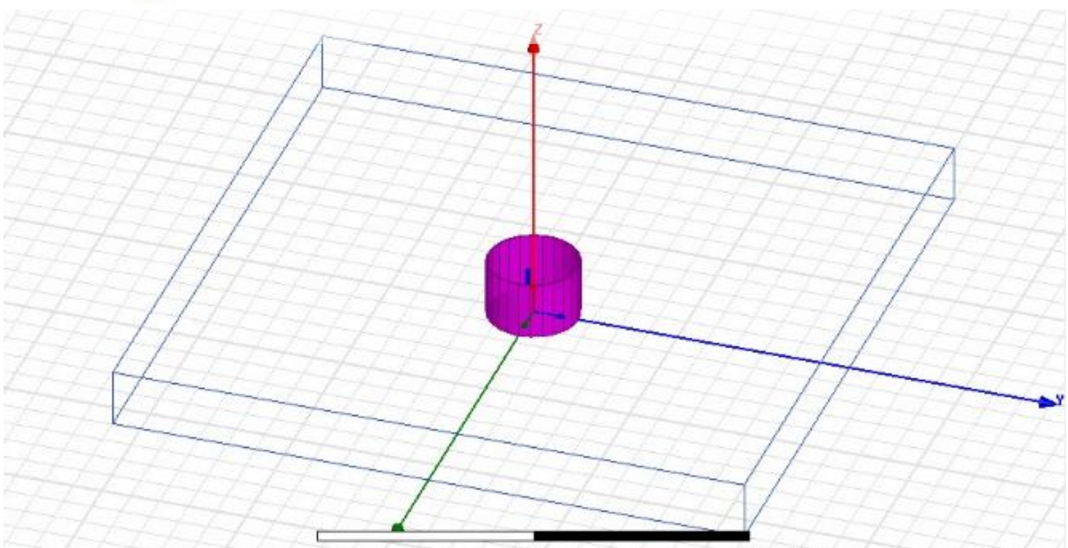


Figure 3.7: Cylindrical capacitance which inner electrode has offset center by 3 mm along the x-axis

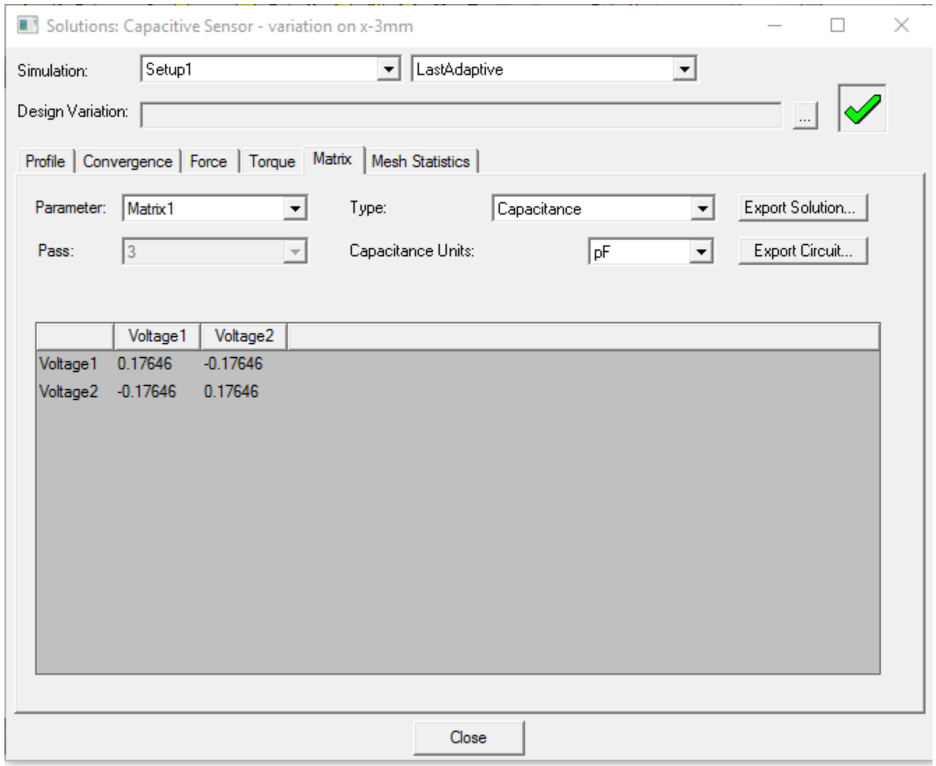


Figure 3.8: Capacitance of the capacitor which inner electrode has offset center by 3mm along the x-axis

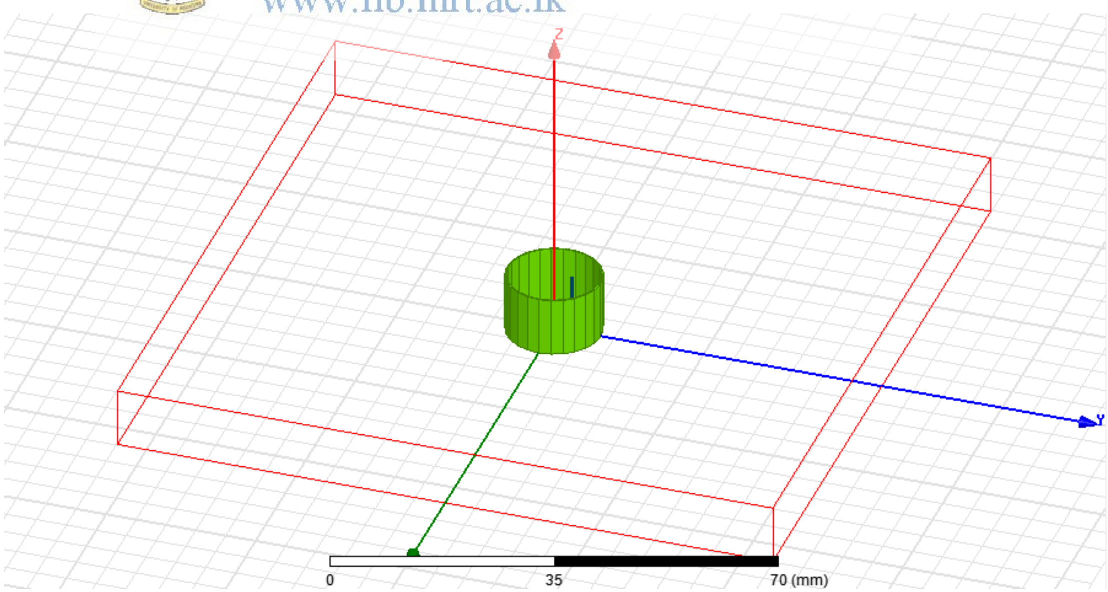


Figure 3.9: Cylindrical capacitance which inner electrode has offset center by 3 mm along the y-axis

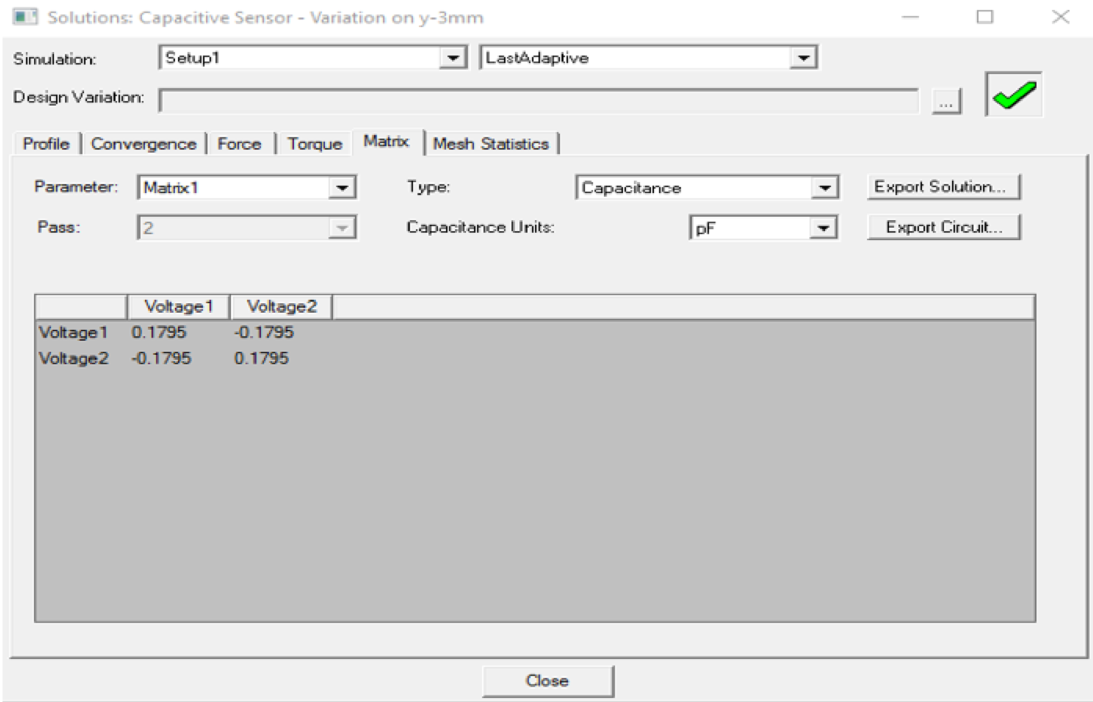


Figure 3.10: Capacitance of the capacitor which inner electrode has offset center by 3 mm along the y- axis

The figure 3.9 and 3.10 illustrate the capacitance diagram and output capacitance if the coordinate of the inner and outer electrode is (0,3,0) and (0,0,0) respectively. It means that the inner electrode moves 3 mm on the y- axis from the center of outer electrode. Then there is no uniform clearance in between the inner and outer electrode.

If the center of inner electrode shifted by 1mm from the center of outer electrode, the sensitivity will be changed by 0.00097 pF.

3.8.3 Conductivity of the liquid

Other vital parameter for the sensitivity is conductivity of the liquid. The relationship among the permittivity, conductivity, dielectric constant and frequency of the water is complex number. The equation 12 illustrates this relationship.

$$\varepsilon = \varepsilon_r \varepsilon_0 - j\frac{\sigma}{2\pi f} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (12)$$

ε - permittivity, σ – conductivity, f - frequency and $\varepsilon_r\varepsilon_0$ – dielectric constant of the water. According to the equation capacitance of water is decreased by increasing the frequency. Liquid with high electrical conductivity have grater capacitance. But in the higher frequencies, the real part of the relative complex permittivity is important. To understand the behavior of the conductivity of the sensor, simulation has been done using Proteus software. Figure 3.11 illustrate the oscillator circuit and Figure 3.12 and 3.13 illustrate the frequency pattern if the resistance changed by 50 % of the initial resistance of the liquid. The initial resistance of the water assumes as 0.01kΩ. The Chanel A line shows the main output. Chanel B denoted the charging discharging pattern of the total capacity. The Chanel C shows the charging and discharging pattern of the capacitor which is filled by liquid. If we vary the resistance of the liquid, two things will happen. One is changing the output frequency and other one is changing the amplitude of the main signal. But the calibration constant has already added to the equation to remove the effect of conductivity of the liquid.

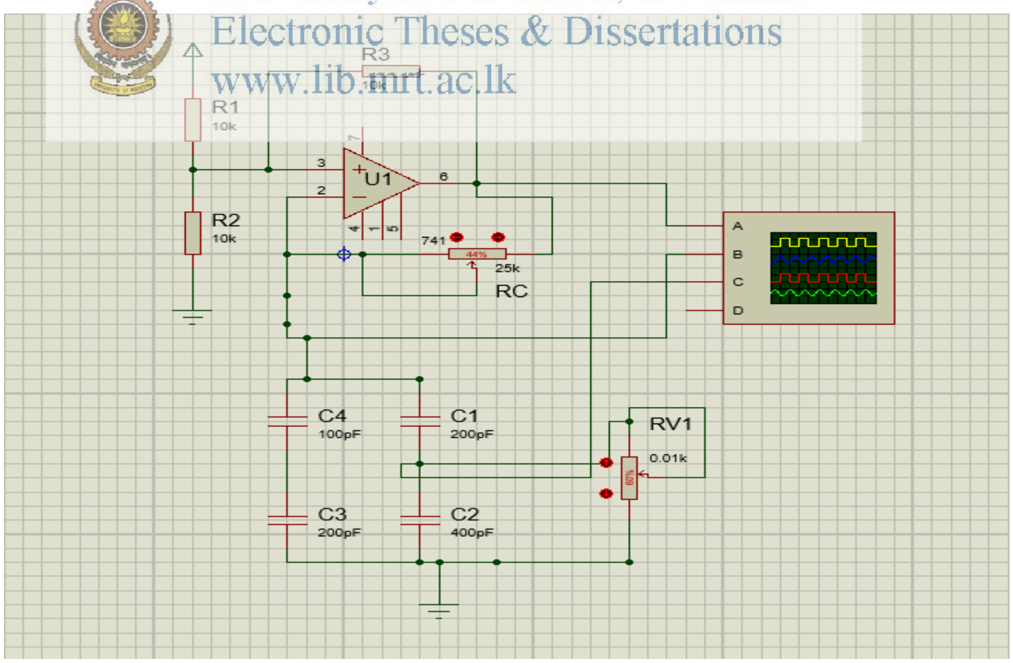


Figure 3.11: Circuit diagram of the oscillator circuit

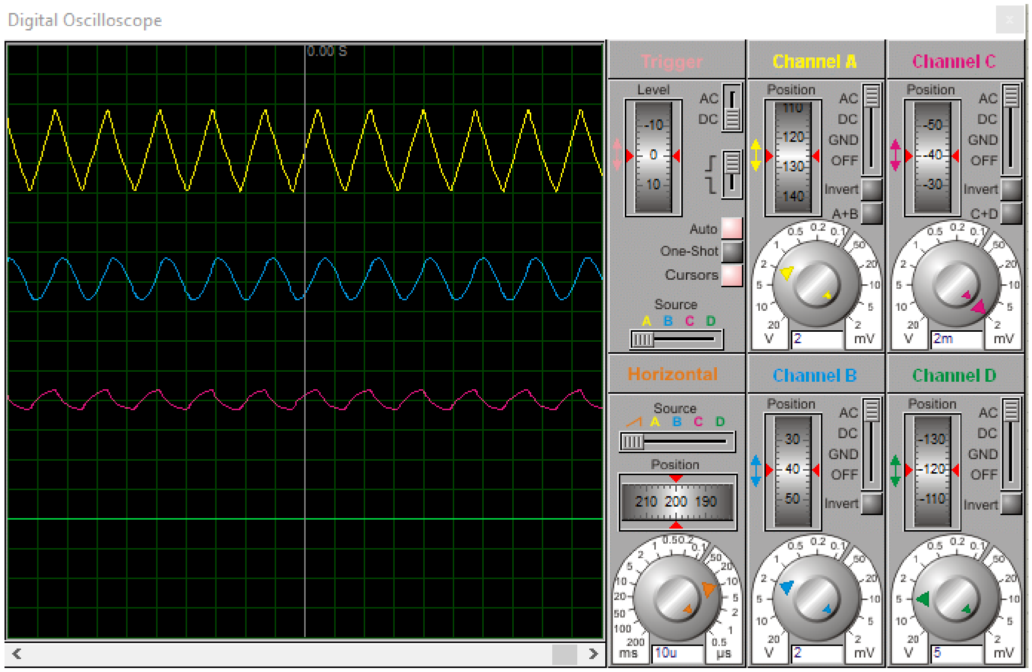


Figure 3.12: Output frequency of the capacitor that has 0.005 kΩ resistance

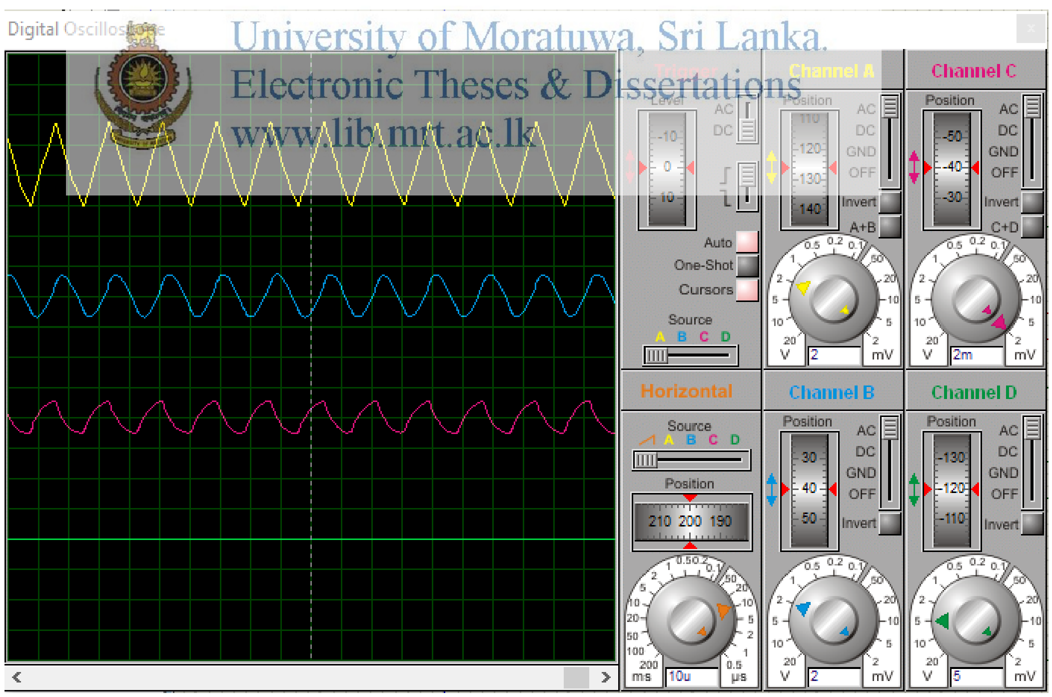


Figure 3.13: Output frequency of the capacitor that has 0.01 kΩ resistance

3.9 Proposed Setup to Calibrate Flow Meters

The main methods of the flow meters calibration are described in section 2.2.1 and 2.2.2 in the chapter 2. Using above method we can reach the higher accuracy level of the calibration but unfortunately this system is very expansive. So national measurement laboratories of varies countries have been developed their own method to provide calibration servicers to their industries. In our country, lots of flow meters are used in industries so it is considered as secondary level instrument. So this proposes method illustrated in figure 3.14 is strong enough to do calibration for low accuracy flow meters.

When the setup is turned on liquid passed through the flow meter under calibration will be collected by the even diameter vertical cylindrical tank. After getting the stable flow rate, the height of the level sensor and should be started the time measurement should be note down. So after reaching the specific time interval, the time and liquid height should be noted down simultaneously. In both stage of the process, flow meter reading should be noted down. Using above reading, the quantity of liquid which passed through the flow meter and flow rate can be calculated.

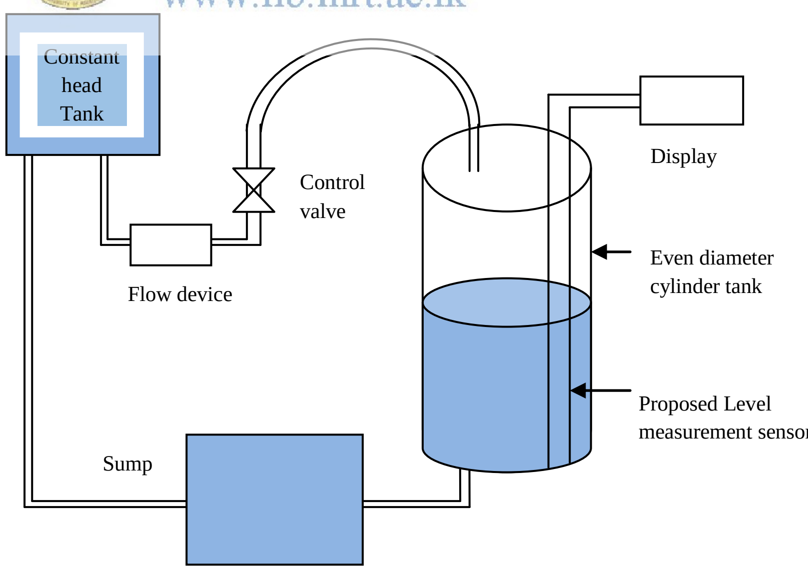


Figure 3.14: Proposed flow meter calibration unit

CHAPTER 4

VALIDATION AND ANALYSIS OF MEASUREMENTS

4.1 Validation of Measurements

As mentioned in Chapter 2, various kind of liquid level measurement sensors have been developed by the scientist. All level sensors have advantages and disadvantages. The various kinds of sensors are commercially available in many countries. But most of the sensors are not available in Sri Lanka. Also some of sensors are very expansive. Considering above reasons, three kind of different sensors have been used to verify the proposed system.

4.1.1 Dipstick

The primary and direct method of the level measurement is dipstick method. The dipstick which is made by stainless steel is used to verify the height which is measured by proposed method. Also the dipstick is calibrated by length laboratory of the National Measurement Laboratory. The accuracy of the dipstick is ±0.5 cm.

4.1.2 Distance sensometer

The sensormeter that has been manufactured by Philip Harris Company of the England is used to validate the proposed sensor with tanks containing water. The sensing method is ultrasonic wave. The sensometer send ultrasonic wave and also detect the wave which is reflected by liquid-air interface. The distance meter is designed to be both a sensor and meter (figure 4.1). It measures distance from the probe in three different ranges:

- 10 beats per second for distance from 0.4m to 10m
- 20 beats per second for distance from 0.4m to 5m
- 50 beats per second for distance from 0.4m to 2m

The major limitation of the Sensometer,

a) Minimum measuring height of the instrument is 40cm.

b) It is not possible to measure tank with small diameter neck.

Due to the above limitation, this sensor meter is used to validate over ground vertical cylindrical water tank. The readings of the instrument are presented in section 4.2.1.1 in chapter 4.

The technical specification of the sensor given in table 4.1

Table 4.1: Technical specification of the sensometer

Resolution, display	±0.5% full scale
Accuracy, display	±1.5% full scale
Accuracy, computer output	±1% full scale
Resolution Computer output	±0.2%full scale

Figure4.1: Ultrasonic distance Sensometer

4.1.3 OCIO- Tank level monitoring system

OCIC instrument that has been manufactured by PIUSI Company of the Italy is used to validate the proposed sensor with tanks containing diesel and petrol. OCIO is an instrument for monitoring the level of liquids containing in thank, Figure 4.2. It indicates tank levels by processing pressure readings made by a probe placed inside the tank.

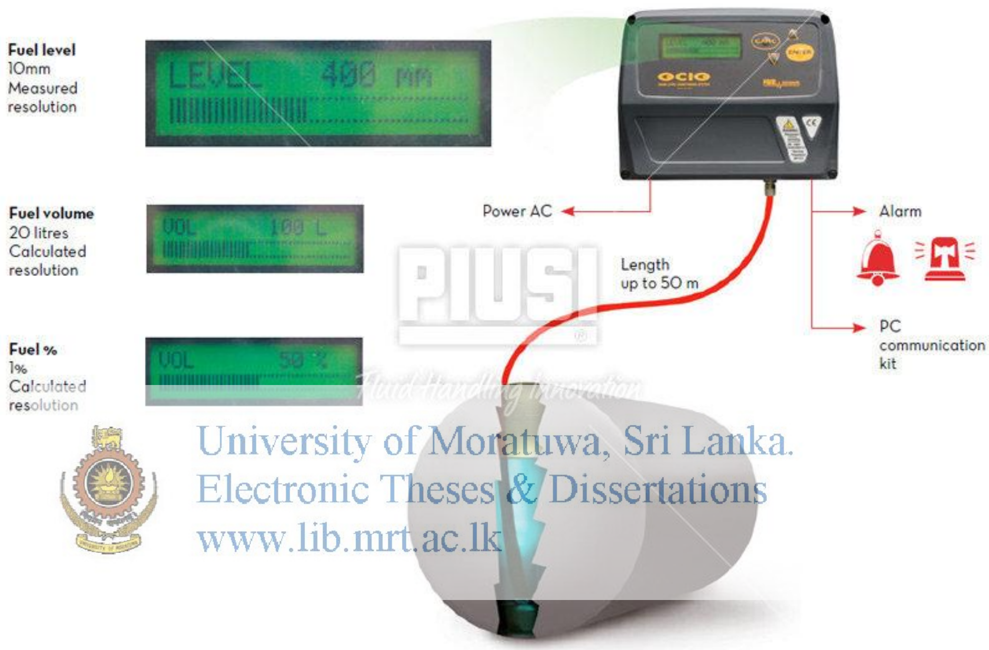


Figure 4.2: OCIO tank level monitoring system

It can be used in the following situation

a) Non-pressurized tanks, where tank pressure is always equal to the atmospheric pressure.
b) Tanks having various shapes and capacities
c) Tanks containing fluid that are not flammable, explosive or corrosive example: admissible fluid, water, diesel, food product.

The fluid contained in a tank applies a pressure at the bottom of the tank that depends on the level of the liquid and the density of the liquid. It measures the pressure applied by the fluid through a probe which is held at the bottom of the tank by a weight. The density of liquid should be entered to the system and then the high of the liquid will be displayed. It is clear that the pressure of the sensor is depending on height of the fluid and density of the fluid. After installation of the sensor, it should be calibrated. Calibration is the operation by which OCIO is assigned a value for the liquid's density. It is factory calibrated for use with tanks containing diesel, with has a density of 0.84 kg/dm3 at a temperature of 20^0C. So if we use liquid other than diesel it should be calibrated again.

The major limitation of the OCIO level measurement system

a) Minimum measuring height of the sensor is 5cm.
b) In the manual, it is not recommended to measure height of the petrol tank.
c) Normally density of the liquid with the temperature, so it is need be calibrated again and to get accurate measurement.
d) The density of the liquid is not known; it can be calibrated by having it read a known level. In this case again we need another accurate level measurement to enter the accurate height of the level to the system.

The technical specification of the sensor is given in table 4.2.

Table 4.2: Technical specification of the OCIO level sensor

Probe Material	Tube: Rilsan and brass weight end
Operating temperature range	-20^{0}C to +50^{0}C
Tank Shape	Vertical Cylindrical (with plat ends), Horizontal cylindrical (with plat end)
Minimum height	50 mm
Maximum Height	4 m
Accuracy	±1% of maximum range
Repeatability	±0.5% of maximum range
Resolution	1 cm

4.2 Analysis of measurements

The performance of the designed instrument was experimentally tested using different kind of liquids. The liquids used were tap water, petrol and diesel. Most important liquid is water which is used in flow meter calibration setup. So using tap water as the liquid, this performance test has been repeated with over ground vertical cylindrical tank and over ground cubical tank in different temperature. Also instrument has been tested using petrol and diesel in fuel distribution center. Most probably diesel and petrol are stored in underground horizontal cylindrical tanks. So using petroleum product as the liquids, instrument has been tested in underground horizontal cylindrical tank with different temperature.

4.2.1 Tap water as the test liquid

The proposed sensor has been tested in over ground cylindrical and cubical tank and performance of the sensor is tested by varying the height of the liquid over the range of 0-80cm, in three different temperature levels. Each sensor reading has been repeated five times to find the repeatability of the proposed sensor. Also sensor has been validated against the ultrasonic level sensor and dipstick.

4.2.1.1 Validation of the results

Figure 4.3 to Figure 4.5 depicts the proposed sensor output and dipstick reading at the different temperature. The proposed sensor has been validated against the ultra -Sonic sensor and dipstick. But resolution of the dipstick is higher than the ultra-sonic sensor. Therefore, graph was plotted with the dipstick reading. There is no major deviation of the readings. But it is not possible to find minor deviation using these figures. Figure 4.6 to Figure 4.8 shows the result of dipstick, ultra-sound and proposed sensor. The midpoint of the readings indicates the average value of the residual (reference value - proposed sensor reading). Using these graphs, it is obvious that there is minor deviation of the residuals. If we get the dipstick reading as the reference value, all the residuals fall down in between 0.5 cm.

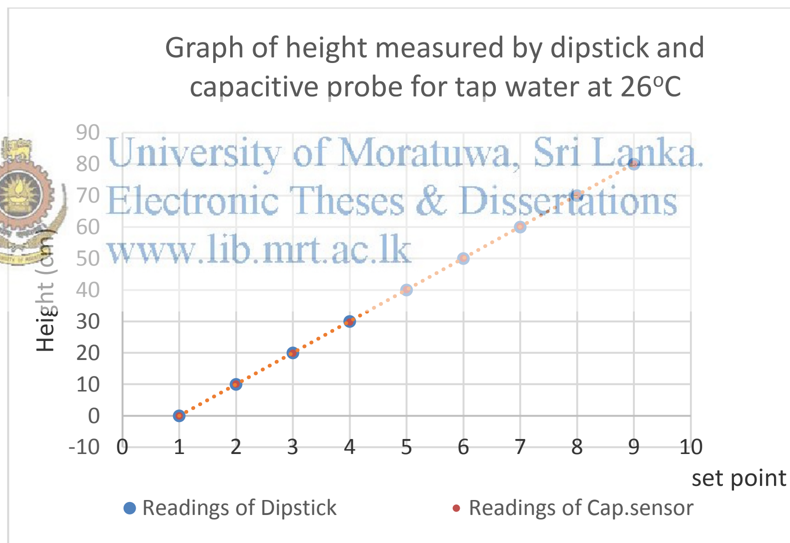


Figure 4.3: Graph of the height measured by dipstick and Proposed sensor for tap water at 26^{o}C

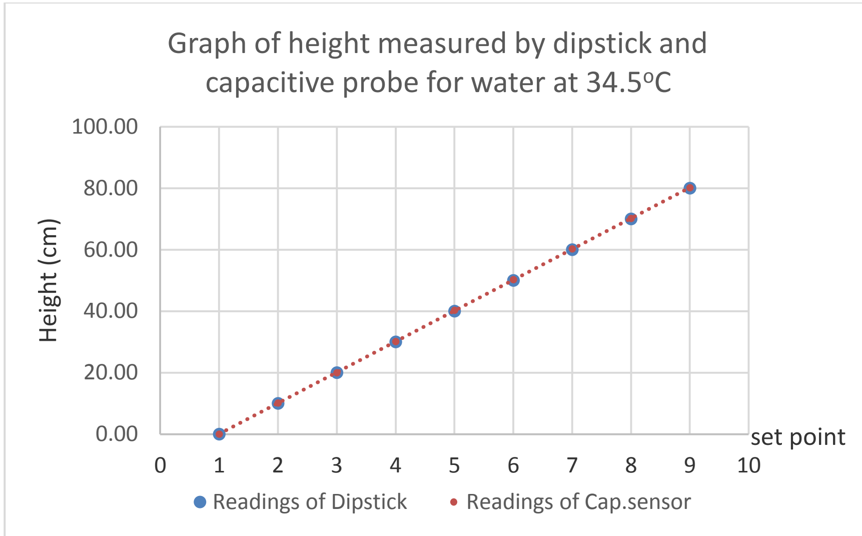


Figure 4.4: Graph of the height measured by dipstick and Proposed sensor for tap water at 34.5^{o}C

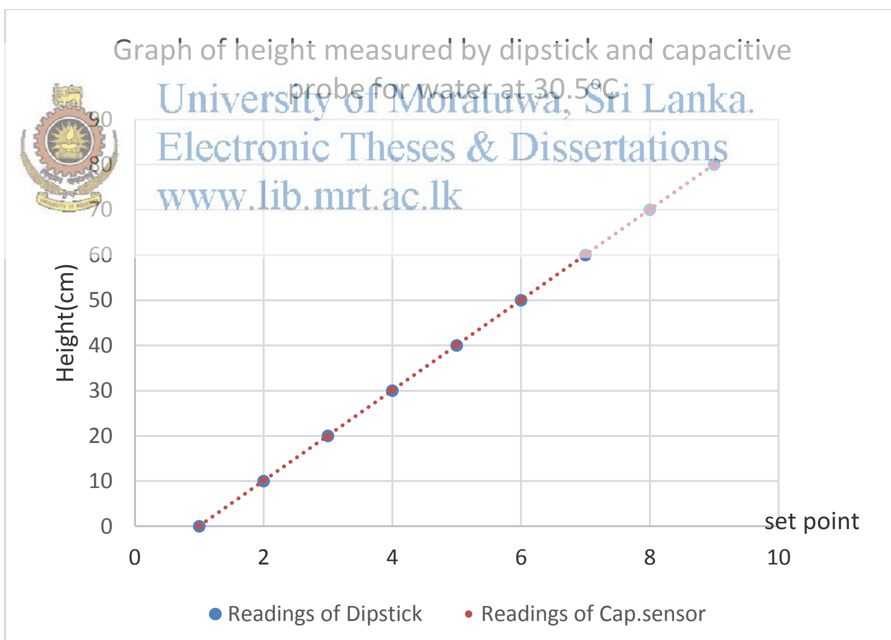


Figure 4.5: Graph of the height measured by dipstick and Proposed sensor for tap water at 30.5^{o}C

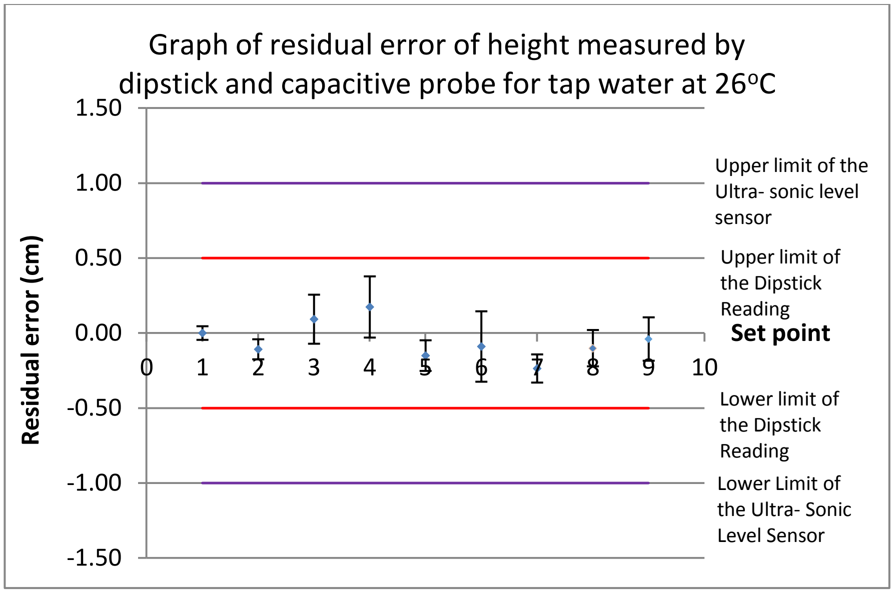


Figure 4.6: Graph of the residual error of height measured by dipstick, ultrasonic sensor and Proposed sensor for tap water at 26°C

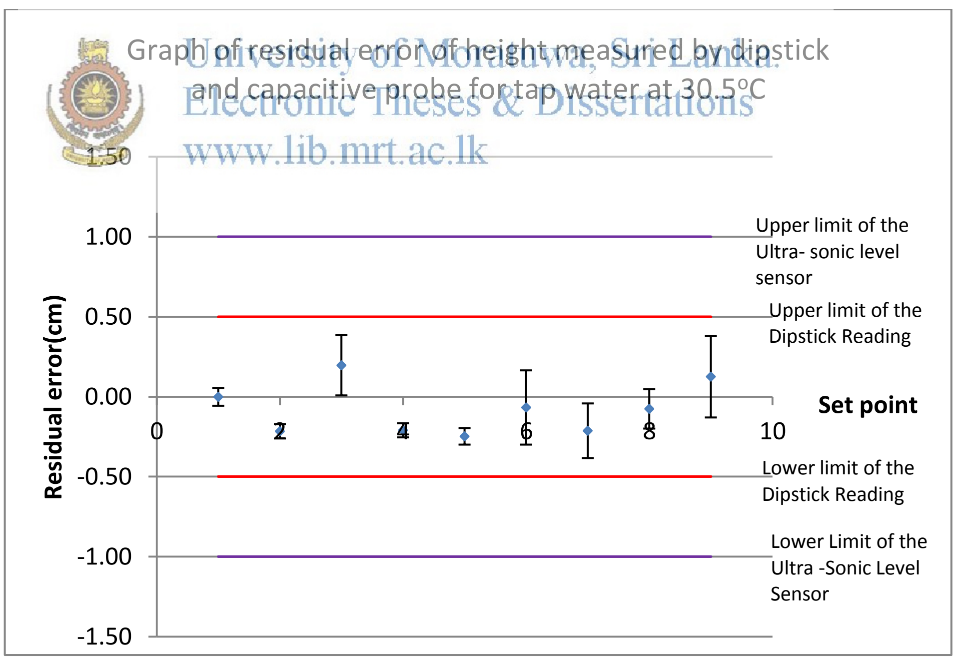


Figure 4.7: Graph of the residual error of height measured by dipstick, ultrasonic sensor and Proposed sensor for tap water at 30.5°C

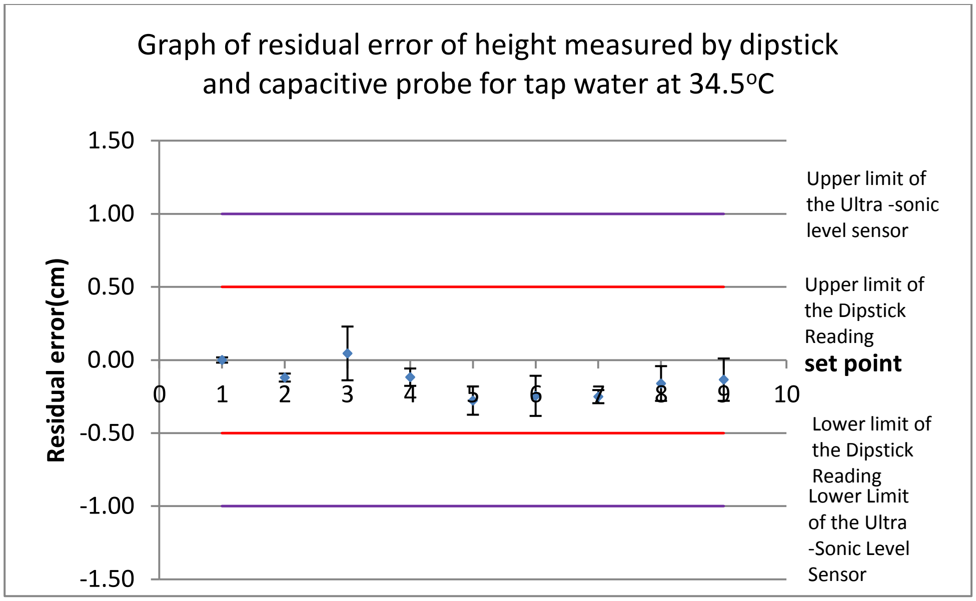


Figure 4.8: Graph of the residual error of height measured by dipstick, ultrasonic sensor and Proposed sensor for tap water at 34.5^{o}C

4.2.1.2 Affected parameters to the results

Figure 4.9, illustrate the parameters that has effected to the measurement error (proposed sensor measurement – Ultra sonic level measurement sensor). It reveals that average errors according to the liquid height are positively shifted. All means of the errors accumulated around 0.08 cm instead of 0.0 cm. It means that all readings have positive systematic error. In the effect of temperature, it reveals that mean error is depend on the temperature of the liquid.

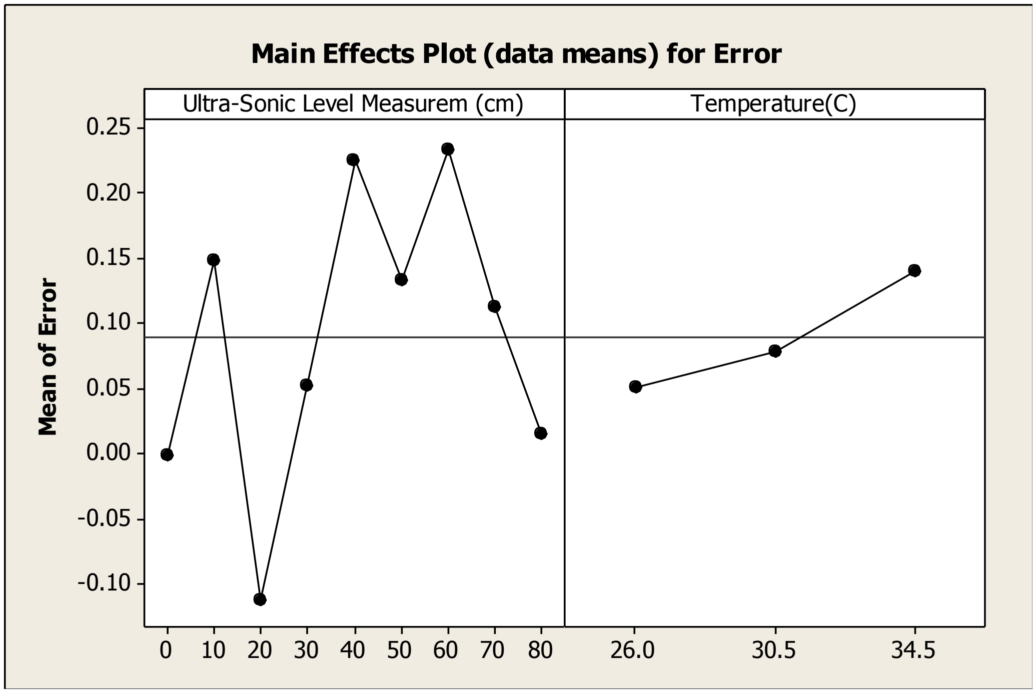


Figure 4.9: Main effect Plot for the Temperature and Liquid Level

To find out significant level of the parameters which is affected to the proposed level sensor measurement ANOVA is performed.

ANOVA: Error versus Ultra-Sonic Level Measurement (cm); Temperature (C)

Factor	Values
Ultra-Sonic Level Measurement (cm)	0; 10; 20; 30; 40; 50; 60; 70; 80
Temperature (C)	26.0; 30.5; 34.5

Analysis of Variance for Error

Source	DF	SS	MS	F	P
Ultra-Sonic Level Measurement (cm)	8	1.50610	0.18826	8.88	0.000
Temperature (C)	2	0.19083	0.09542	4.50	0.013
Error	124	2.62806	0.02119		
Total	134	4.32500			

S = 0.145582 R-Sq = 39.24% R-Sq (adj) = 34.34%

P-values of the both factors are less than the 0.05 ($p<0.05$). So it reveals that the error of the proposed level measurement sensor is significantly affected by the height of the liquid level and the temperature of the liquid. Figure 4.10 shows the interaction plot of the errors. According to the p-value of the ANOVA, identify that the interaction effect is significant.

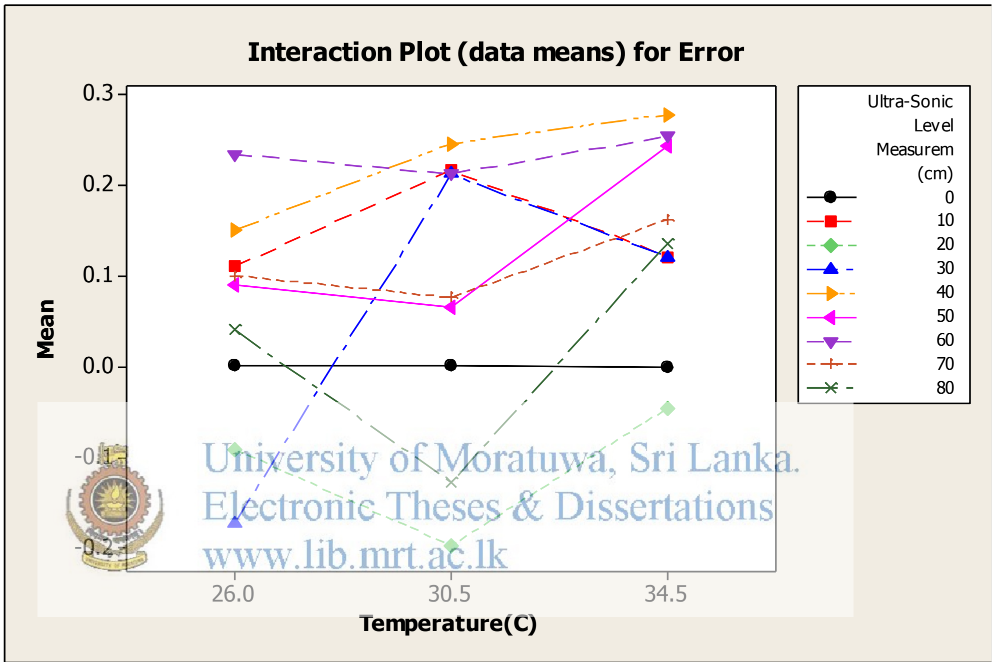


Figure 4.10: Interaction plot of the errors

The performance test is already repeated using the cement cubical tank and pvc tank at the same temperature. Fig 4.11 shows the main effect plot of the various tanks. It depicts that the errors are depend on the type of the tank. The ANOVA has performed to find significant level of the factor and observe that $p=0.695$. So $p>0.05$ and accept the null hypothesis and it is obvious that the error is not affected by the type of the tank.

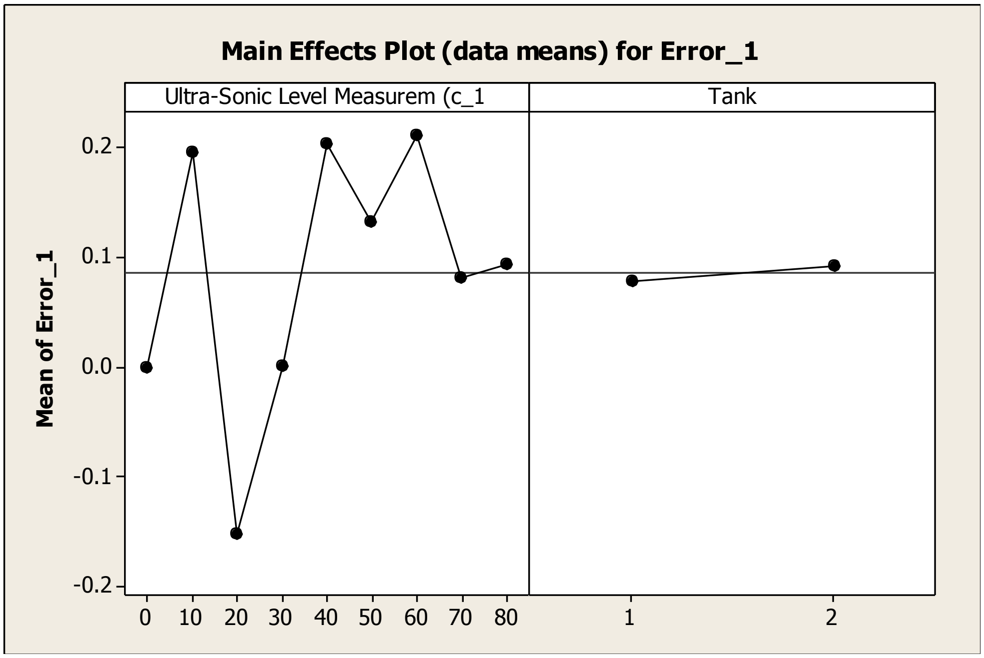


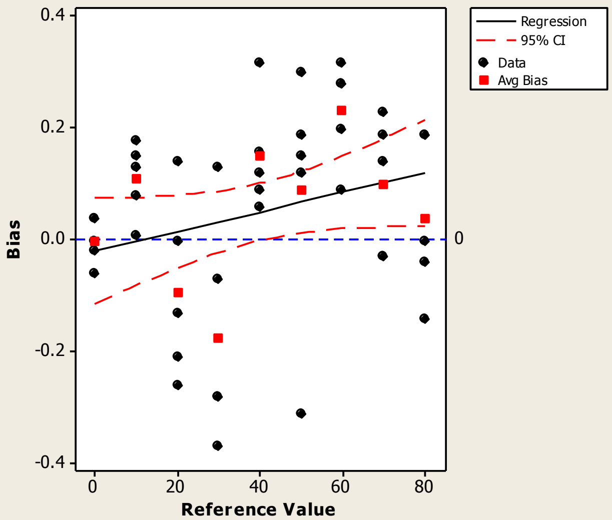
Figure 4.11: Main effect plot for the various tanks and various liquid levels

4.2.1.3 Linearity and bias study

The bias of the results is difference between the observed average measurement and the reference value. The linearity tells au accuracy of the results over the range expected range of the sensor. To find out whether linearity in between the reference value and bias linearity and bias study have been performed. According to the figure 4.11, shows the linearity and bias at 26^{o}C. The p-value of the slop greater than 0.05 (p=0.086). So the is a nonlinear relationship in between the reference value and bias. Also the p value Colum of the bias shows the statistically significant bias appears for the reference value of 10cm, 40 cm and 60 cm. The overall p - value is also small, which means the average bias of all the readings is statistically significant.

Linearity and Bias Of the Sensor at 26C, in Tap Watwer

Reported by :
Tolerance:
Misc:



Gage Linearity

Predictor	Coef	SE Coef	P
Constant	-0.01884	0.04716	0.691
Slope	0.0017433	0.0009906	0.086

S 0.171572 R-Sq 6.7%

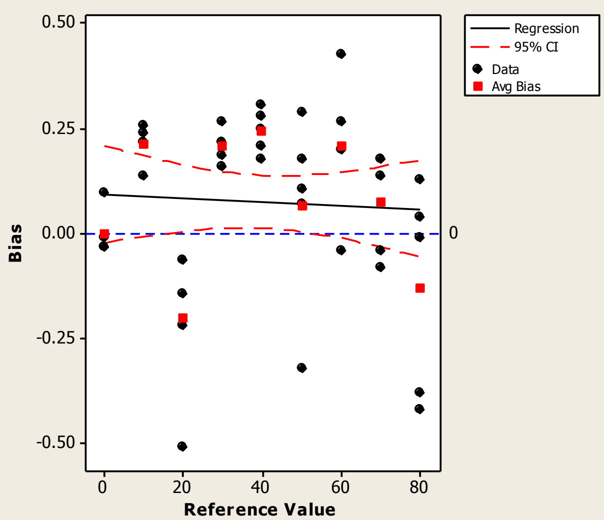
Gage Bias

Reference	Bias	P
Average	0.050889	0.017
0	0.000000	1.000
10	0.110000	0.025
20	-0.092000	0.275
30	-0.174000	0.130
40	0.150000	0.035
50	0.090000	0.461
60	0.234000	0.006
70	0.100000	0.104
80	0.040000	0.540

Figure 4.12: Linearity and the Bias of the Sensor at 26^{o}C

Linearity and Bias Of the Sensor at 30.5 C, in Tap Watwer

Gage name:
Date of study:
Reported by :
Tolerance:
Misc:



Gage Linearity

Predictor	Coef	SE Coef	P
Constant	0.09520	0.05720	0.103
Slope	-0.000430	0.001202	0.722

S 0.208113 R-Sq 0.3%

Gage Bias

Reference	Bias	P
Average	0.078	0.000
0	0.000	1.000
10	0.216	0.001
20	-0.198	0.075
30	0.212	0.001
40	0.246	0.001
50	0.066	0.582
60	0.212	0.070
70	0.076	0.184
80	-0.128	0.270

Figure 4.13: Linearity and the Bias of the Sensor at 30.5^{o}C

The figure 4.13 shows the linearity and bias of the sensor at 30.5^{0}C. According to the p value of the result, it was understood that there is no liner relationship between the bias and reference value of the readings. Also obvious that the measured value 10cm, 30cm and 40 cm paper the significant bias. The overall bias is also significant.

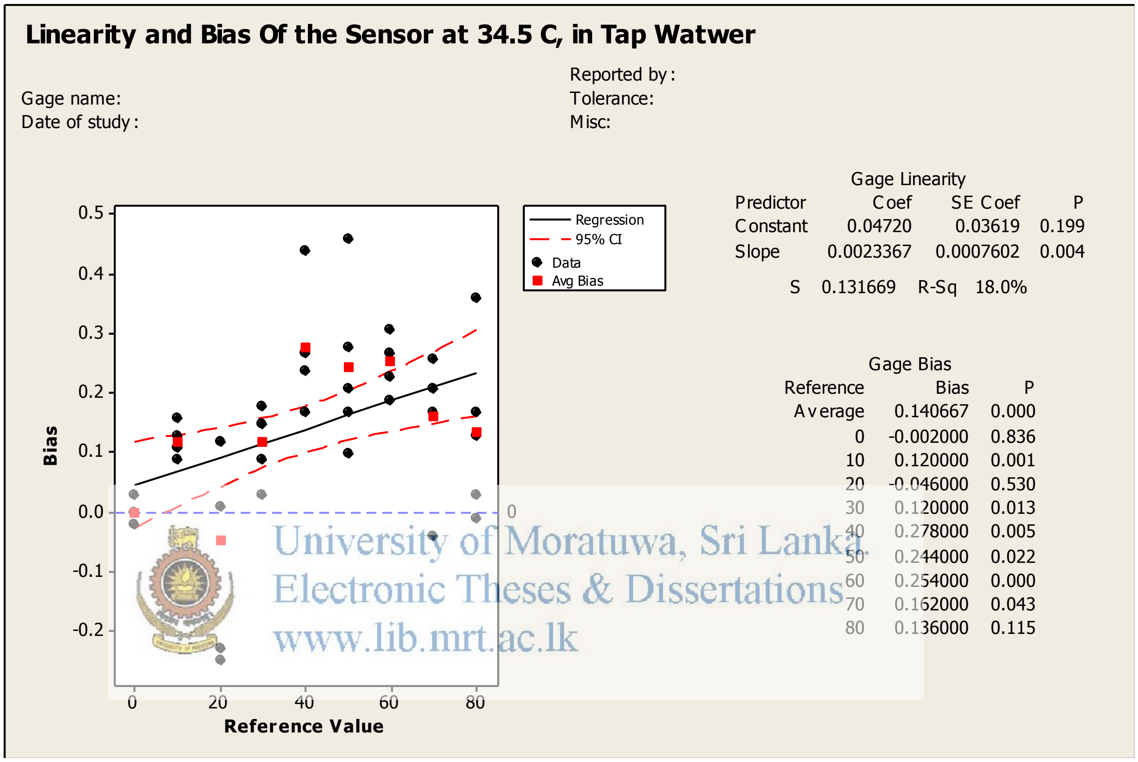


Figure 4.14: Linearity and the Bias of the Sensor at 34.5^{o}C

In figure 4.14 illustrates the relation in between the bias and reference value of the reading at 34.5^{o}C and demonstrate that there is a linear relationship between the reference value and bias. Measured values of the 10cm, 30cm, 40cm, 50cm, 60 and 70 cm paper significant bias. The overall bias is also significant.

4.2.2 Petroleum Product as the Test Liquids

The performance of the sensor has been tested in underground horizontal cylindrical tank filed by petrol and diesel at the three different temperature levels. The readings of the sensor have been validated by dipstick and OCIO- pressure level measurement sensor.

4.2.2.1 Diesel as the test liquid

4.2.2.1.1 Validation of the results

Figure 4.15 to 4.17 shows the result of the sensor. The liquid level of the underground horizontal cylindrical tank is varied from 0 to 120cm at 25.5^{o}C, 31^{o}C and 35^{o}C. The readings have been validated against the dipstick and OCIO- pressure level measurement sensor. Figure 4.18 shows the residual plot of the reading and observe that most of the systematic errors fall in between the dipstick readings and OCIO level sensor.

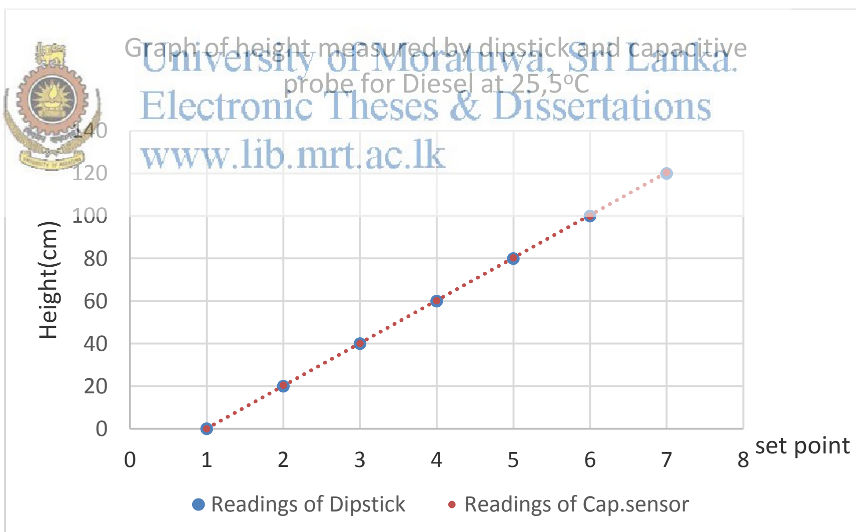


Figure 4.15: Graph of the height measured by dipstick and Proposed sensor for Diesel at 25.5^{o}C

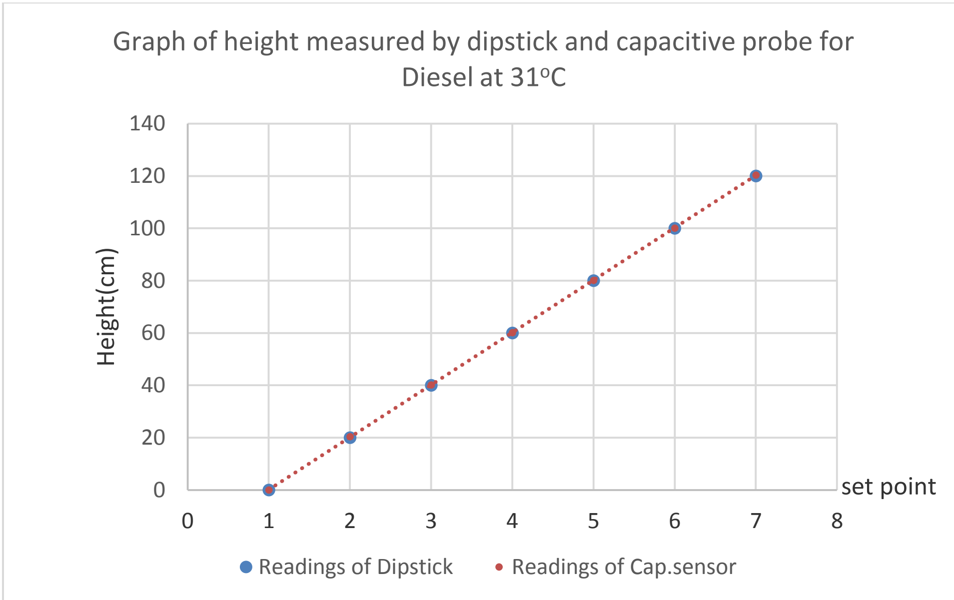


Figure 4.16: Graph of the height measured by dipstick and Proposed sensor for Diesel at 31.0^{o}C

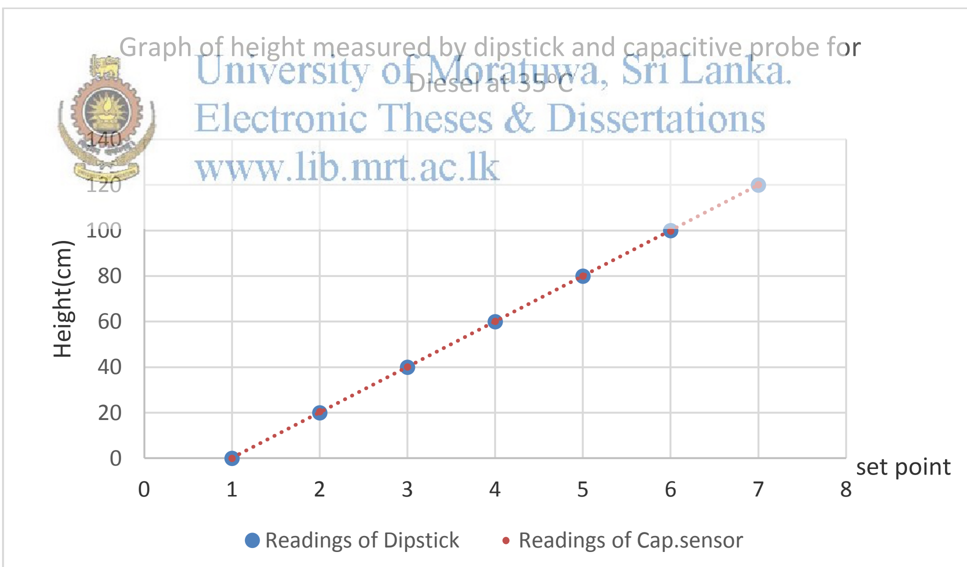


Figure 4.17: Graph of the height measured by dipstick and Proposed sensor for Diesel at 35.0^{o}C

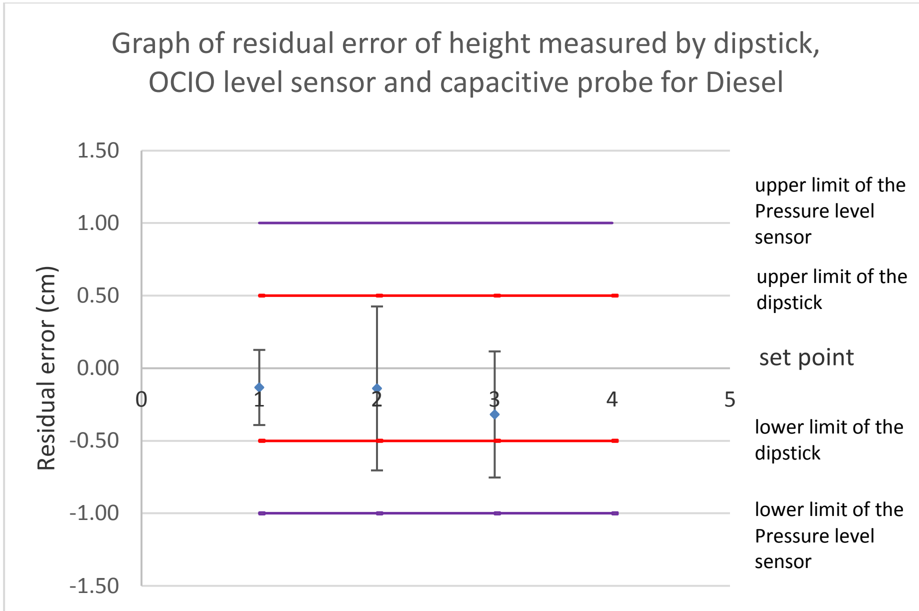


Figure 4.18: Graph of the residual error of height measured by dipstick, OCIO level sensor and Proposed sensor for Diesel

4.2.2.1.2 Affected parameters for the results

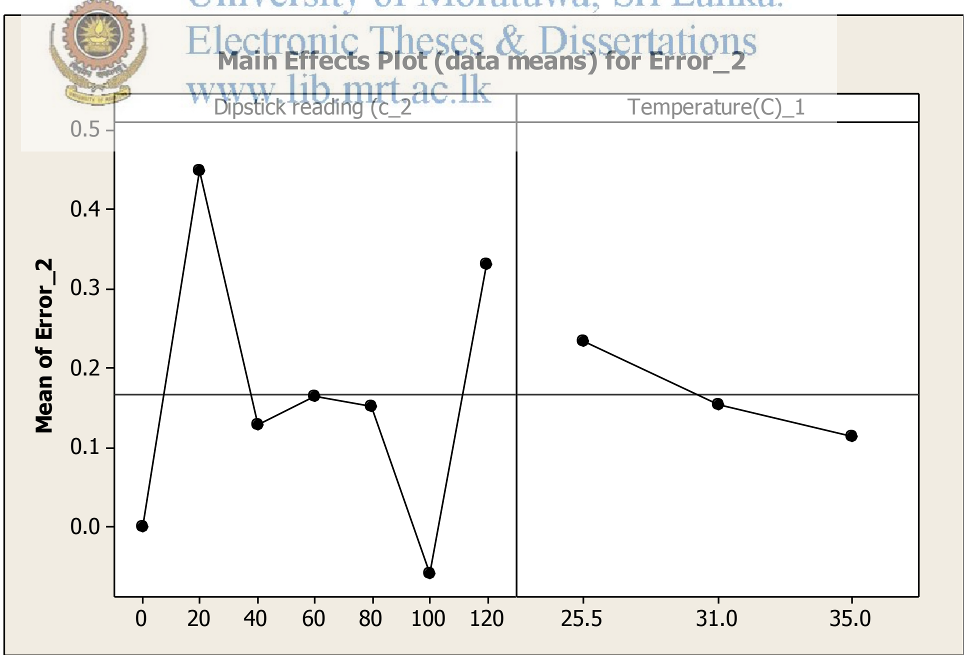


Figure 4.19: Main effect plot for the Temperature and Diesel levels of the underground horizontal cylindrical tank

Figure 4.19, illustrate the parameters that has effected to the error. It reveals that average errors according to the liquid height are positively shifted. All means of the errors accumulated around 0.15 instead of 0.0. It means that all readings have positive systematic error. In the effect of temperature, it reveals that mean error is not depend on the temperature of the liquid. The ANOVA has performed to find out the significance of the factors and implies that liquid level is significantly (p=0.002) affected to the error and temperature is not significantly (p=0.36) affected to the error of the sensor.

4.2.2.1.3 Linearity and Bias Study

The figure 4.20 shows the relation between the bias and reference value of the reading at 25.5^{o}C. Accordingly, it is demonstrated that no linear relationship between the reference value and the bias of the readings. The p value of the gage bias shows that bias is not appeared for all the reference values except for the reference value of 20cm and 120cm. The average p value is small, which means the average bias of all the readings is statistically significant.

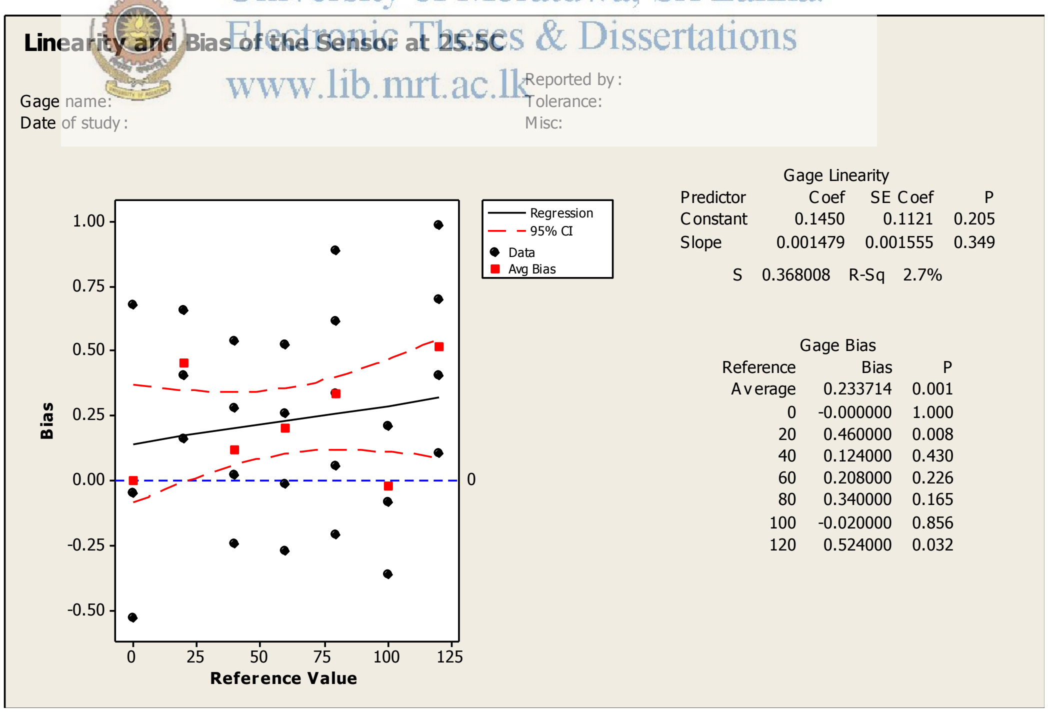
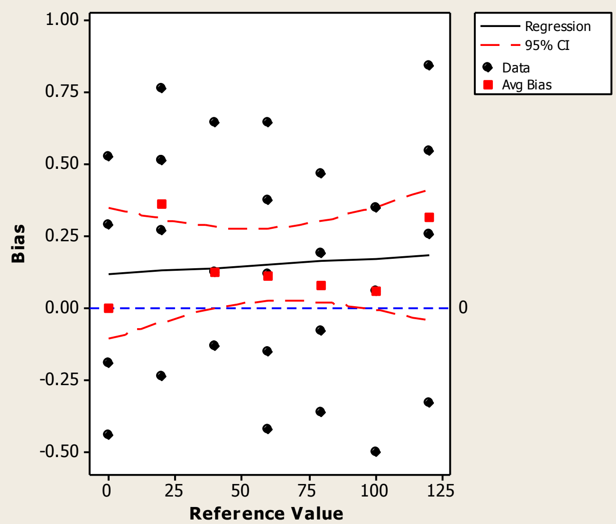


Figure 4.20: Linearity and the Bias of the Sensor at 25.5^{o}C

Linearity and Bias of the Sensor at 31C

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:



Gage Linearity

Predictor	Coef	SE Coef	P
Constant	0.1221	0.1128	0.287
Slope	0.000532	0.001564	0.736

S 0.370085 R-Sq 0.3%

Gage Bias

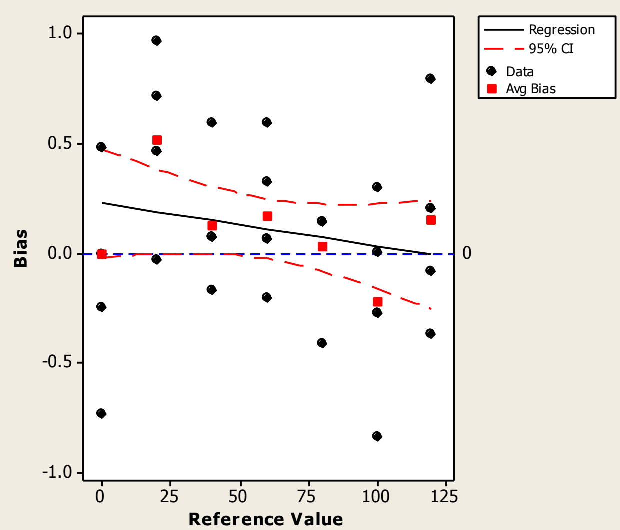
Reference	Bias	P
Average	0.154	0.034
0	0.000	1.000
20	0.368	0.117
40	0.130	0.410
60	0.116	0.582
80	0.082	0.614
100	0.064	0.699
120	0.318	0.213

Figure 4.21: Linearity and the Bias of the Sensor at 31°C

Linearity and Bias of the Sensor at 35C

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:



Gage Linearity

Predictor	Coef	SE Coef	P
Constant	0.2341	0.1219	0.064
Slope	-0.001979	0.001691	0.250

S 0.400191 R-Sq 4.0%

Gage Bias

Reference	Bias	P
Average	0.115429	0.104
0	0.002000	0.993
20	0.520000	0.048
40	0.134000	0.392
60	0.174000	0.297
80	0.038000	0.727
100	-0.214000	0.360
120	0.154000	0.508

Figure 4.22: Linearity and the Bias of the Sensor at 35°C

The figure 4.21 and 4.22 display the linearity of the results at 31^{0}C and 35^{o}C respectively. Also it can be notice that there are no linear relation between the reference value and bias of the results. The overall bias of the results at 31^{0}C is statistically significant but at the 35^{o}C, it is not statistically significant.

4.2.2.2 Petrol as the test liquid

4.2.2.2.1 Validation of the results

Figure 4.23 to 4.25 shows the result of the sensor. The petrol level of the underground horizontal cylindrical tank is varied from 0 to 120 cm at 24.5^{o}C, 30.5^{o}C and 35^{o}C.

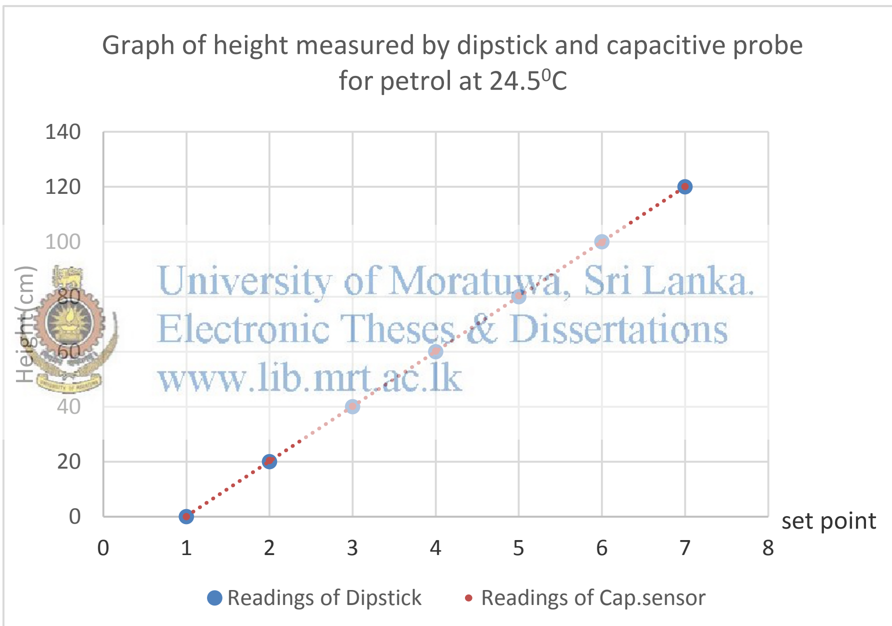


Figure 4.23: Graph of the height measured by dipstick and Proposed sensor for Petrol at 24.5^{o}C

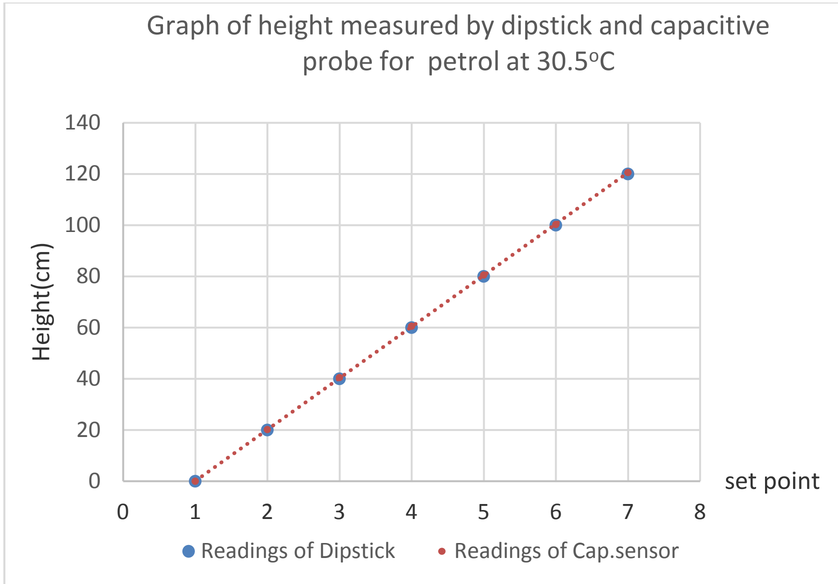


Figure 4.24: Graph of the height measured by dipstick and Proposed sensor for Petrol at 30.5°C

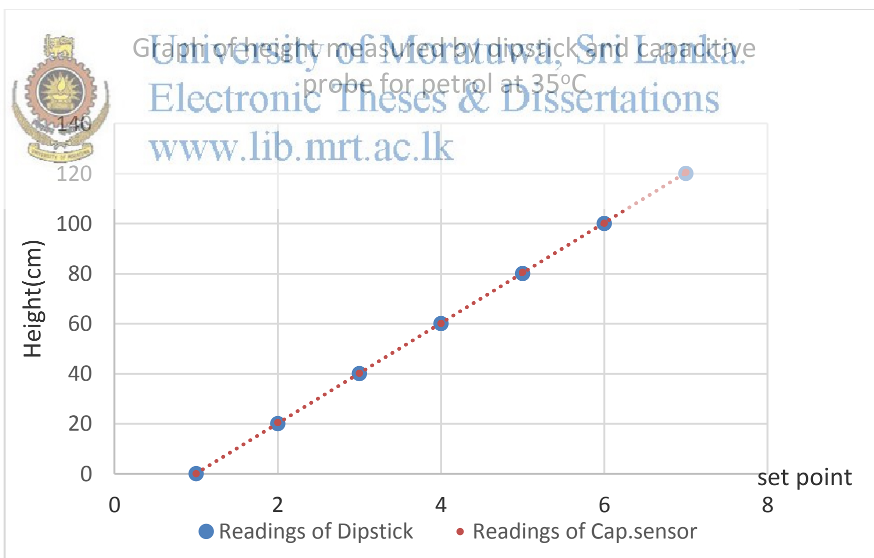


Figure 4.25: Graph of the height measured by dipstick and Proposed sensor for Petrol at 35.0°C

The readings have been validated against the dipstick and OCIO- pressure level measurement sensor. A figure 4.26 shows the residual plot of the reading and observes that most of the systematic errors fall in between the ± 0.5 cm.

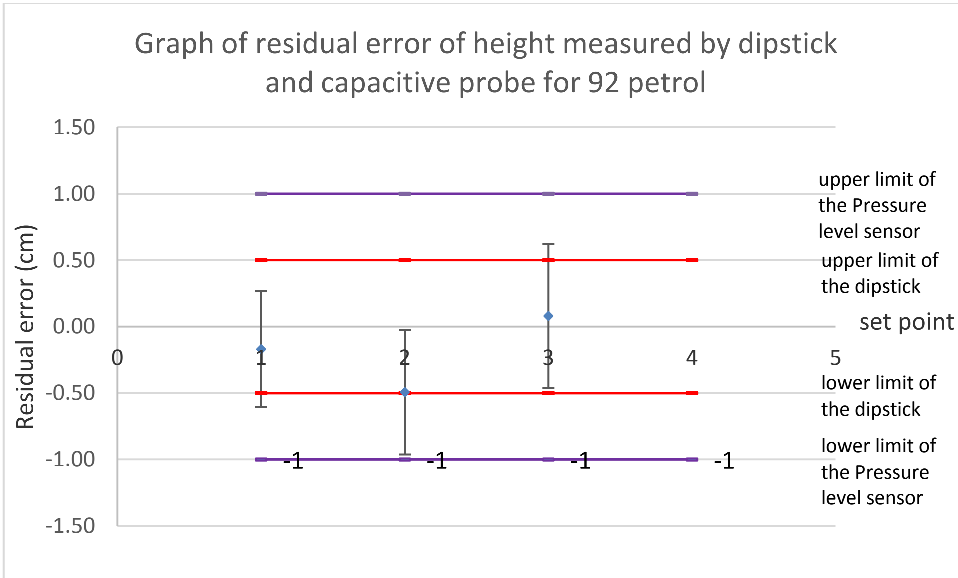


Figure 4.26: Graph of the residual error of height measured by dipstick, OCIO level sensor and Proposed sensor for Petrol

4.2.2.2.2 Affected parameters to the Results

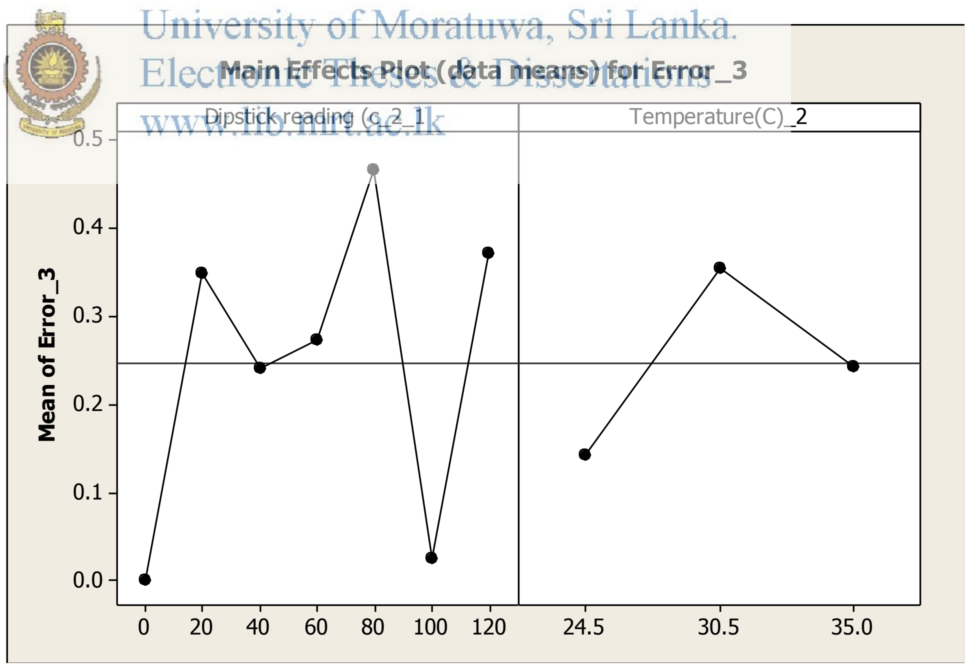


Figure 4.27: Main effect plot for the Temperature and petrol levels of the underground horizontal cylindrical tank

Figure 4.27, illustrated the parameters that has effected to the error. It reveals that average errors according to the liquid height are positively shifted. All means of the errors accumulated around 0.25 cm instead of 0 cm. It means that all readings have positive systematic error. In the effect of temperature, it reveals that mean error is depend on the temperature of the liquid. The ANOVA has performed to find out the significance of the factors and implies that liquid level is significantly ($p=0.002$) affected to the error and temperature is also significantly ($p=0.043$) affected to the error of the sensor.

4.2.2.2.3 Linearity and bias study

The linearity of the bias and reference value demonstrated the figure 4.28 to 4.30 with different temperature. The figure 28 show that there is no a linear relationship between the bias and reference value of the sensor. The bias of the result is not significant for each reading. The average p value of the readings is less than the 0.05, so the overall bias is statistically significant at the 24.5^{o}C.

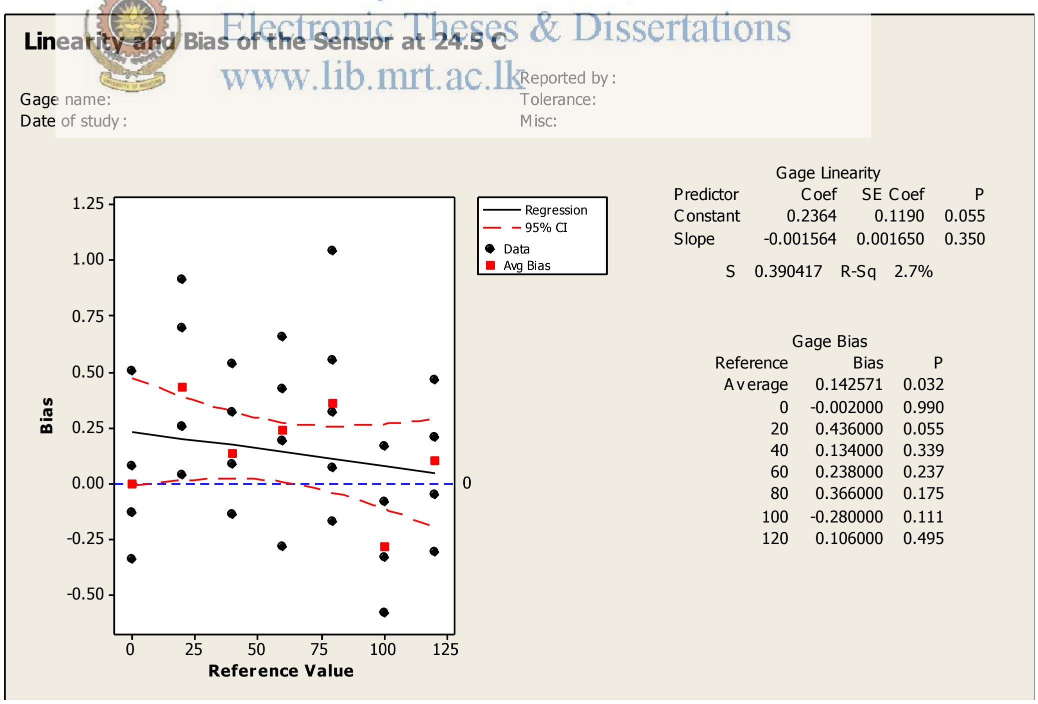
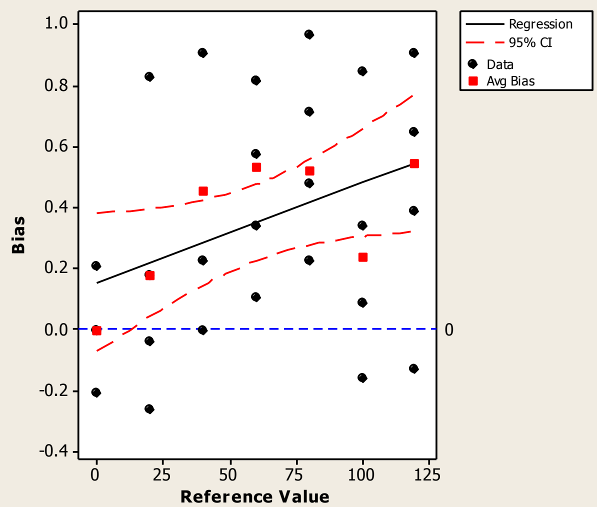


Figure 4.28: Linearity and the Bias of the Sensor at 24.5^{o}C

Linearity and Bias of the Sensor at 30.5 C

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:



Gage Linearity

Predictor	Coef	SE Coef	P
Constant	0.1579	0.1113	0.166
Slope	0.003279	0.001544	0.041

S 0.365270 R-Sq 12.0%

Gage Bias

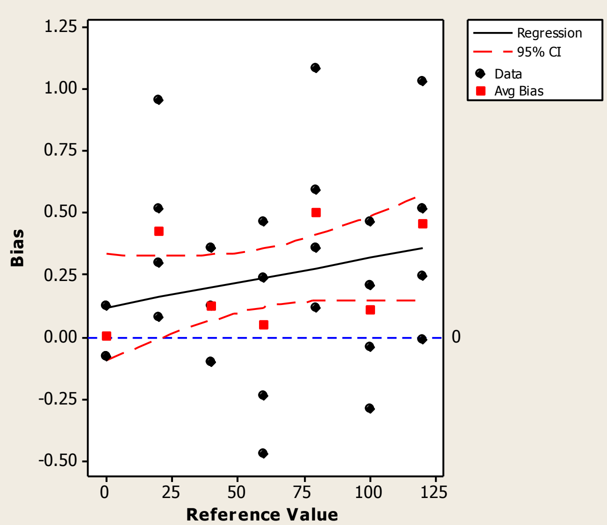
Reference	Bias	P
Average	0.354571	0.000
0	0.000000	1.000
20	0.178000	0.419
40	0.456000	0.053
60	0.534000	0.016
80	0.526000	0.019
100	0.242000	0.258
120	0.546000	0.046

Figure 4.29: Linearity and the Bias of the Sensor at 30.5^{o}C

Linearity and Bias of the Sensor at 35 C

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:



Gage Linearity

Predictor	Coef	SE Coef	P
Constant	0.1227	0.1056	0.254
Slope	0.001993	0.001465	0.183

S 0.346699 R-Sq 5.3%

Gage Bias

Reference	Bias	P
Average	0.242286	0.000
0	0.004000	0.921
20	0.432000	0.056
40	0.130000	0.196
60	0.048000	0.792
80	0.506000	0.047
100	0.112000	0.462
120	0.464000	0.074

Figure 4.30: Linearity and the Bias of the Sensor at 35^{o}C

The figure 4.29 shows the linearity of the sensor at 30.5^{0}C and displays that there is a linear relationship between the bias and reference value. The overall bias is significant. The figure 4.30 demonstrated that linearity is not statistically significant and overall bias of the reading is statistically significant.

4.3 Summary Statistics

Table 4.3 shows the sensitivity, repeatability and uncertainty of the sensor. Figure 4.31 to Figure 4.33 shows the error and uncertainty of the readings. If we use tap water as the liquid of the tank, it is possible to reach ± 0.5 cm accuracy level. But in petroleum liquid ± 1 cm accuracy level can be maintained.

Table 4.3: sensitivity, repeatability and uncertainty of the sensor

	Tap Water			Diesel			Petrol		
Temperature (^{o}C)	26	30.5	34.5	25.5	31	35	24.5	30.5	35
Sensitivity (pF/cm)	0.54	0.54	0.54	0.12	0.12	0.12	0.14	0.14	0.14
Accuracy of full range (%)	±0.29	±0.30	±0.34	±0.38	±0.30	±0.43	±0.36	±0.43	±0.38
Repeatability of full range (%)	0.29	0.31	0.23	0.36	0.35	0.35	0.39	0.36	0.30
Expanded uncertainty (k=2)	±0.52	±0.60	±0.58	±0.77	±0.68	±0.77	±0.72	±0.78	±0.76

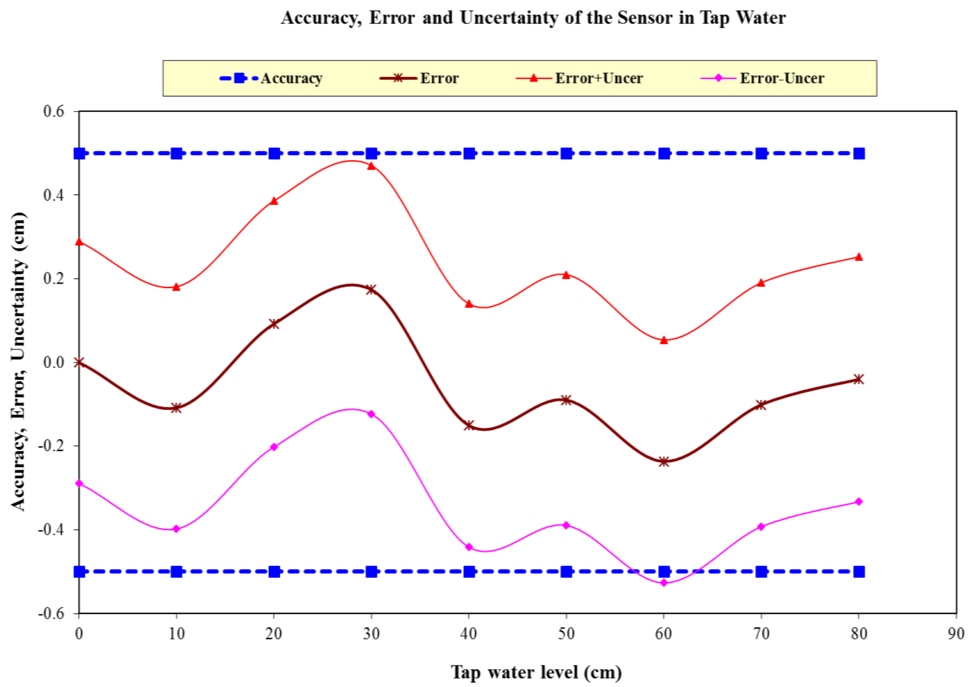


Figure 4.31: Error and uncertainty of tap water as liquid of the tank

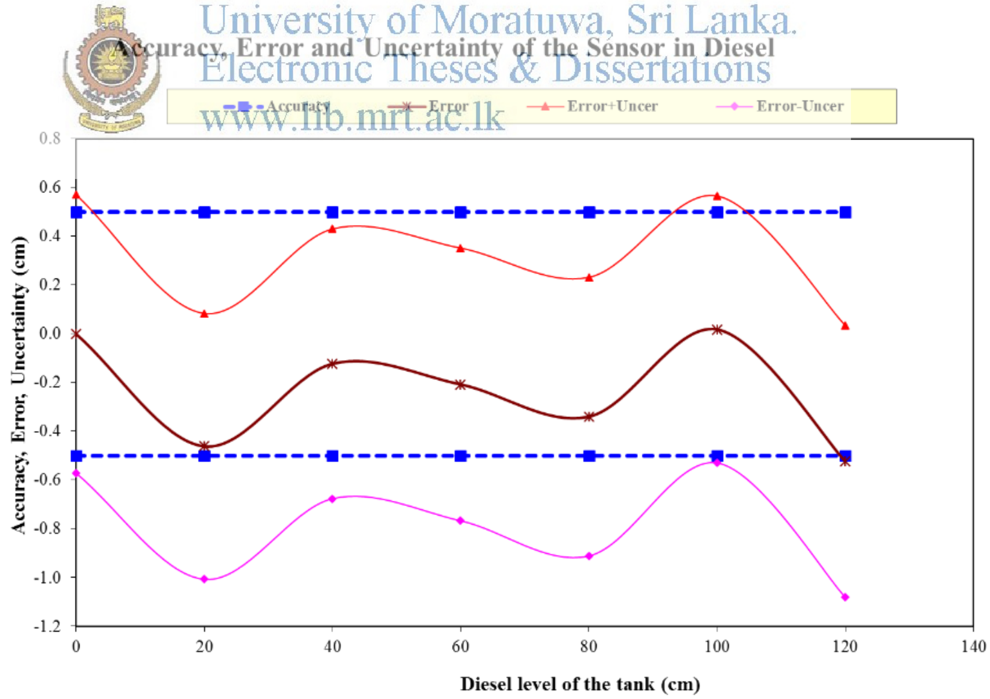


Figure 4.32: Error and uncertainty of Diesel as liquid of the tank

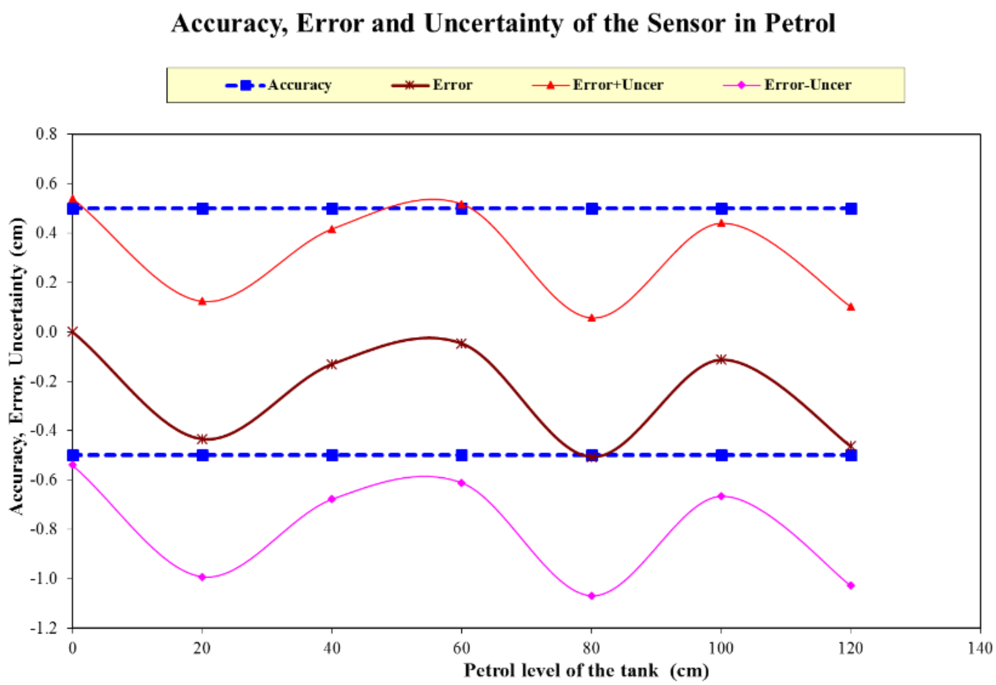


Figure 4.33: Error and uncertainty of Petrol as liquid of the tank

CHAPTER 5

CONCLUSION

5.1 Conclusion

In this research, the technical background behind the capacitance based liquid level measurement sensor is analyzed and a prototype of electronic sensor has been developed to read the liquid level of the underground or over ground tank continuously. The proposed method is cost effective, accurate, simple and straightforward method to read the nonconductive or conductive liquid level of any kind of tank.

After analyzing the data, it can be noticed that the sensitivity, systematic error, random error and uncertainty of the proposed sensor is better in the tap water as the liquid of the tank. The reason is that relative permittivity of the tap water is higher than petroleum product. Also tap water is the conductive liquid but petroleum products are nonconductive. The overall systematic error of the results is gathered around 0.08 cm instead of 0 cm. So the sensor has 0.08 cm positive bias. Also the systematic error of the sensor is affected by the height of the tank and temperature of the liquid. In this case interaction effect of these factors is significant. But temperature effect is less than 0.001 cm/^{0}C. According to the climatic condition of our country, it will not be badly affected to the readings of the sensor. Both of the theoretical and measured sensitivity of the sensor are quite similar. Also there are no significant effects of the material of the tank. So the accuracy of the sensor has been maintained ±0.5cm in full range.

In the field of petroleum product, the sensor parameters which are described in previous paragraph are not better than the tap water as the liquid of the tank. The systematic error of the sensor is estimated around +0.25 cm and +0.18 cm in the horizontal cylindrical tank which is filled with petrol and diesel respectively. In the analysis of the reading, it is depicted that interaction effect of the liquid height of the tank and temperature of the liquid have significantly affected the systematic error of the sensor output. But temperature effect is less than 0.001 cm/^{0}C. In the field of petroleum product an accuracy of ±1cm is generally accepted.

There are number of limitations have been affected to the accuracy of the sensor. If we select the optimize value for the diameter of the outer electrode, inner electrode and thickness of the insulation the accuracy and sensitivity can be developed. But unfortunately, it is not possible to find arbitrary diameters and insulation thickness to construct sensor. The reason is that such type of dimensions is not commercially available. So we use commercially available diameters and insulation thickness to construct sensor. Another matter is stray capacitance of the environment. To eliminate the stray capacitance, the calibration constant has been already added to the equation to remove this effect. But it is not possible to totally remove the stray capacitance.

Another significant parameter is conductivity of conductive liquid. Due to conductivity of the liquid the capacitance will change. The main thing will be happened due to the conductivity of the liquid is change the frequency of the signal. Due to the variation of frequency capacitance will be changed. So it will be directly affected to the measured capacitance. Due to the calibration constant of the equation this effect will be removed for the tap water. But this effect will significant when we use highly conductive liquid.

Thus, in conclusion, the proposed capacitive base liquid level measurement sensor can be used to construct flow meter calibration to full fill technical requirements. In the field of petroleum products, it is possible to use to read the liquid height of the underground storage tank with ±1cm accuracy in full range.

5.2 Further Work

The readings of the proposed system are very sensitive to the value of dielectric constant of the liquid that is going to be measure the height. Also relative permittivity of the liquid can be varying according to the environmental condition. The permittivity of the air will be varying according to the vapor composition of the environment especially in the area that is near to the petrol or diesel tank. To eliminate these errors, two reference sensors can be added to the system and it will be used to calculate permittivity of the liquid and air during the measurement process.

In addition to the above factor, the results are depended on permittivity of the insulator, thickness of the insulator, diameter of the inner and outer electrode, height of the sensor and tension of the inner electrode. To find out the most suitable value for these parameters to get the best results, detail optimization should be done. Then the sensor should be constructed according to the values of optimization. But major difficulty is the parts according to the optimize value will not be commercially available. So it will be needed to construct all parts by us. After that the accuracy will be increased.

Most of the fuel storage tanks which are installed in petrol sheds have water layer in in the bottom of the tank. So it is necessary to find out solution to measure the height of the of the stagnate water in the bottom of the tank in addition to the height of the liquid.

The conductivity of the liquid is most important parameter. The relationship among the permittivity, conductivity and frequency is complex function. So it is possible to develop bode plot to measure the conductivity and permittivity of the liquid.

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Appendix A:

Data

Liquid: Water

Tank: Cement cubical tank

No	Dipstick Reading (cm)	Sensometer Reading (cm)	Capacitive base level measurement sensor (cm)				
			i	ii	iii	iv	v
Temperature			**26°C**				
1	0	0	-0.02	0.00	-0.06	0.04	0.04
2	10	10	10.13	10.08	10.01	10.18	10.15
3	20	20	19.74	20.00	19.87	19.79	20.14
4	30	30	29.72	29.93	30.13	29.63	29.72
5	40	40	40.32	40.12	40.16	40.09	40.06
6	50	50	50.12	49.69	50.19	50.15	50.30
7	60	60	60.28	60.32	60.28	60.20	60.09
8	70	70	70.14	69.97	70.19	69.97	70.23
9	80	80	80.19	80.00	79.86	79.96	80.19
Temperature			**30.5°C**				
1	0	0	-0.03	0.10	-0.03	-0.03	-0.01
2	10	10	10.22	10.22	10.24	10.26	10.14
3	20	20	19.86	19.78	19.94	19.49	19.94
4	30	30	30.22	30.22	30.27	30.19	30.16
5	40	40	40.28	40.25	40.18	40.21	40.31
6	50	50	50.11	49.68	50.18	50.07	50.29
7	60	60	60.20	60.27	60.43	59.96	60.20
8	70	70	69.92	70.14	70.18	69.96	70.18
9	80	80	79.58	79.62	80.13	80.04	79.99
Temperature			**34.5°C**				
1	0	0	0.00	-0.02	-0.02	0.03	0.00
2	10	10	10.11	10.13	10.11	10.16	10.09
3	20	20	20.12	20.01	19.75	19.77	20.12
4	30	30	30.03	30.15	30.18	30.15	30.09
5	40	40	40.24	40.27	40.27	40.17	40.44
6	50	50	50.10	50.46	50.17	50.21	50.28
7	60	60	60.31	60.27	60.23	60.27	60.19
8	70	70	69.96	70.26	70.17	70.21	70.21
9	80	80	80.17	79.99	80.36	80.13	80.03

Liquid: Water

Tank: PVC Tank

No	Dipstick Reading (cm)	SensorMeter Reading (cm)	Capacitive base level measurement sensor (cm)				
			i	ii	iii	iv	v
Temperature			**30.5°C**				
1	0	0	-0.02	-0.04	-0.02	0.04	0.04
2	10	10	10.12	10.12	10.15	10.22	10.27
3	20	20	19.73	19.91	19.91	19.83	20.10
4	30	30	29.67	29.97	29.88	29.67	29.76
5	40	40	40.36	40.17	40.20	40.13	39.94
6	50	50	49.98	50.13	50.23	50.31	50.34
7	60	60	60.25	60.37	60.17	60.25	60.01
8	70	70	70.19	70.02	70.10	70.02	70.10
9	80	80	80.37	80.28	80.51	80.18	80.23

Liquid: Diesel

Tank: Horizontal Cylindrical Tank

No	Dipstick Reading (cm)	Capacitive base level measurement sensor (cm)				
		i	ii	iii	iv	v
	Temperature	**25.5°C**				
1	0	-0.05	-0.53	-0.05	-0.05	0.68
2	20	20.41	20.41	20.66	20.16	20.66
3	40	40.54	40.02	40.02	39.76	40.28
4	60	60.53	60.53	59.99	59.73	60.26
5	80	80.89	80.34	79.79	80.62	80.06
6	100	100.21	99.92	99.92	100.21	99.64
7	120	120.99	120.70	120.41	120.11	120.41
	Temperature	**31°C**				
1	0	-0.19	-0.44	0.29	-0.19	0.53
2	20	20.52	20.27	20.77	19.76	20.52
3	40	40.65	40.13	39.87	39.87	40.13
4	60	60.65	60.38	60.12	59.58	59.85
5	80	80.19	80.19	79.92	79.64	80.47
6	100	100.06	100.35	99.50	100.06	100.35
7	120	120.85	120.26	119.67	120.55	120.26
	Temperature	**35°C**				
1	0	0.49	-0.73	-0.24	0.00	0.49
2	20	20.97	19.97	20.47	20.72	20.47
3	40	39.83	40.60	40.08	40.08	40.08
4	60	60.60	60.33	59.80	60.07	60.07
5	80	80.15	80.15	79.59	80.15	80.15
6	100	99.73	100.30	100.01	99.73	99.16
7	120	120.80	120.21	119.63	119.92	120.21

Liquid: Petrol

Tank: Horizontal Cylindrical Tank

No	Dipstick Reading (cm)	Capacitive base level measurement sensor (cm)				
		i	ii	iii	iv	v
	Temperature	**24.5°C**				
1	0	-0.13	-0.34	0.08	-0.13	0.51
2	20	20.04	20.26	20.26	20.70	20.92
3	40	39.86	40.09	40.32	40.54	39.86
4	60	60.19	60.43	60.66	59.72	60.19
5	80	81.05	80.56	80.07	80.32	79.83
6	100	99.92	99.42	100.17	99.42	99.67
7	120	120.21	119.69	120.47	119.95	120.21
	Temperature	**30.5°C**				
1	0	0.21	0.00	0.00	-0.21	0.00
2	20	19.74	20.18	19.96	20.83	20.18
3	40	40.91	40.23	40.23	40.91	40.00
4	60	60.82	60.34	60.58	60.11	60.82
5	80	80.23	80.48	80.97	80.23	80.72
6	100	99.84	100.34	100.09	100.09	100.85
7	120	119.87	120.39	120.65	120.91	120.91
	Temperature	**35°C**				
1	0	-0.08	-0.08	0.13	-0.08	0.13
2	20	20.52	20.30	20.08	20.96	20.30
3	40	39.90	40.13	40.36	40.36	39.90
4	60	60.47	60.24	59.76	60.24	59.53
5	80	80.12	80.60	80.36	80.36	81.09
6	100	99.71	99.96	100.47	100.21	100.21
7	120	120.52	120.25	119.99	120.52	121.04

Liquid: Petrol

Tank: Horizontal Cylindrical Tank

No	Dipstick Reading (cm)	OCIO level Measurement (cm)	Capacitive Sensor (cm)				
			i	ii	iii	iv	v
1	40	40	39.99	40.22	40.44	40.67	39.54
2	80	80	81.18	80.69	80.20	80.44	79.96
3	120	120	119.29	119.82	120.60	119.55	120.34

Liquid: Diesel

Tank: Horizontal Cylindrical Tank

No	Dipstick Reading (cm)	OCIO level Measurement (cm)	Capacitive Sensor (cm)				
			i	ii	iii	iv	v
1	40	40	40.39	39.87	39.87	40.39	40.13
2	80	80	80.75	79.64	79.92	79.64	80.75
3	120	120	120.85	120.26	119.67	120.55	120.26

Appendix B:

```
#include      <pic.h>
#include      <stdio.h>
#include    <math.h>

#include      "delay.h"
#include      "lcd.h"
#include      "test.h"

/*********************************************************************
MAIN PROGRAM BEGINS HERE
*********************************************************************/
void main()
{
int_port();
init_a2d();
Init_Lcd();
init_portb_change();
Prj_name_Display();
short_beep();
DelayS(1);
lcdclr();

get_parameters();
init_calibration();
DelayS(3);

              FLAG.data_ok=0;       // read temperature
              while(!FLAG.data_ok){
              ADIF=0;
              ADIE=1;
              ADGO=1;
              DelayMs(30);
              }
              ADIE=0;
              sys_temp=actual_temp;
              dis_temperature();

f_count=0;
FLAG.freq_ok=0;
init_usart();

while(1)
{
       if(FLAG.freq_ok){    // 5second average
       fa_total=fa_total+fa_temp;
       f_count++;
              if(f_count==25){
              buzzer();
              T0IE=0;
              fa=fa_total/(float)5000;    //in KHz
```

```
		//fa=56.78;
		//fa_total=fa*5000;

		dis_freq((unsigned int)(fa_total/50));
		send_frequency();
		h=(((eq_F/fa)-(eq_A)-(c0))/eq_B);

			if(h>0){
			b2_bcd(h*(float)10000);
			dis_height();
			}
			else{
			dis_error_height();
			}
		DelayS(3);
		FLAG.data_ok=0;
		while(!FLAG.data_ok){
		ADIF=0;
		ADIE=1;
		ADGO=1;
		DelayMs(30);
		}
		ADIE=0;
		dis_temperature();
			if((actual_temp>(sys_temp+50))||(actual_temp<(sys_temp-50))){
			dis_temp_error();
			DelayS(2);
			}
		fa_total=0;
		f_count=0;
		init_tmr0();
		init_timer1();
		T0IE=1;
		}
	FLAG.freq_ok=0;
	}
}
}

//************************* Interrupt Programme***************

void interrupt isr()
{
	if(T0IF){
	TMR0=7;
	toif_count++;
		if(toif_count==125){
		fa_temp=((float)((TMR1H*256)+TMR1L)*8);
		TMR1L=0;
		TMR1H=0;
		toif_count=0;
		FLAG.freq_ok=1;
		}
	T0IF=0;
```

```
        }

        if(RBIF){
        key_scan();
        RBIF=0;
        }

        if(ADIF){
        ad_value=0;
        ad_value=ad_value+ADRESH;
        ad_value=ad_value<<8;
        ad_value=ad_value+ADRESL;   //10 bit A/D result

        ++a2d_count;
        tot_ad_value+=ad_value;

                if(a2d_count==5)
                {
                a2d_count=0;
                ad_value=tot_ad_value/5;
                tot_ad_value=0;

                temperature=(double)ad_value*0.50968921;
                actual_temp=(unsigned int)temperature;
                FLAG.data_ok=1;
                }
        ADIF=0;
        }
}

//******************************Parameter Request******************
void get_parameters()
{
KEY.press=0;
key_value=0;
menu_l=1;

        while(menu_l==1){
        lcdclr();
        Line_1();
        printf("Do You Know the ");
        Line_2();
        printf("Permittivity..?" );
                if(!KEY.press){
                DelayS(3);
                }
        Line_1();
        printf("If YES-> Press #");
        Line_2();
        printf("If NO -> Press *");
                if(!KEY.press){
                DelayS(3);
                }
                else{
```

```
                    if(key_value=='#'){
                    menu_l=3;
                    }
                    /*else if(key_value=='*'){
                    menu_l=2;
                    }*/
                KEY.press=0;
                }
        }

while(menu_l==3){
lcdclr();
Line_1();
printf("1)Sensor A Para.");
Line_2();
printf("  Da1-> 00.00 mm");
lcd_gotoxy(2,8);
        Write_Lcd_Data(eeprom_read(0)+0x30);
        value[0]=eeprom_read(0);
        Write_Lcd_Data(eeprom_read(1)+0x30);
        value[1]=eeprom_read(1);
        Write_Lcd_Data('.');
        Write_Lcd_Data(eeprom_read(2)+0x30);
        value[2]=eeprom_read(2);
        Write_Lcd_Data(eeprom_read(3)+0x30);
        value[3]=eeprom_read(3);

get_dia_value();
da1=value[0]*10+value[1]+value[2]*0.1+value[3]*0.01;
        for(i=0; i<4; i++){
        eeprom_write(i,value[i]);
        }
DelayMs(250);

Line_2();
printf("  Da2-> 00.00 mm");
lcd_gotoxy(2,8);
        Write_Lcd_Data(eeprom_read(4)+0x30);
        value[0]=eeprom_read(4);
        Write_Lcd_Data(eeprom_read(5)+0x30);
        value[1]=eeprom_read(5);
        Write_Lcd_Data('.');
        Write_Lcd_Data(eeprom_read(6)+0x30);
        value[2]=eeprom_read(6);
        Write_Lcd_Data(eeprom_read(7)+0x30);
        value[3]=eeprom_read(7);

get_dia_value();
da2=value[0]*10+value[1]+value[2]*0.1+value[3]*0.01;
lcd_gotoxy(2,7);
        for(i=4; i<8; i++){
        eeprom_write(i,value[i-4]);
        }
DelayMs(250);
```

```
Line_2();
printf("  Da3-> 00.00 mm");
lcd_gotoxy(2,8);
       Write_Lcd_Data(eeprom_read(8)+0x30);
       value[0]=eeprom_read(8);
       Write_Lcd_Data(eeprom_read(9)+0x30);
       value[1]=eeprom_read(9);
       Write_Lcd_Data('.');
       Write_Lcd_Data(eeprom_read(10)+0x30);
       value[2]=eeprom_read(10);
       Write_Lcd_Data(eeprom_read(11)+0x30);
       value[3]=eeprom_read(11);

get_dia_value();
da3=value[0]*10+value[1]+value[2]*0.1+value[3]*0.01;
       for(i=8; i<12; i++){
       eeprom_write(i,value[i-8]);
       }
DelayMs(250);

Line_2();
printf("  Ha-> 000.00 cm");
lcd_gotoxy(2,7);
       Write_Lcd_Data(eeprom_read(12)+0x30);
       value[0]=eeprom_read(12);
       Write_Lcd_Data(eeprom_read(13)+0x30);
       value[1]=eeprom_read(13);
       Write_Lcd_Data(eeprom_read(14)+0x30);
       value[2]=eeprom_read(14);
       Write_Lcd_Data('.');
       Write_Lcd_Data(eeprom_read(15)+0x30);
       value[3]=eeprom_read(15);
       Write_Lcd_Data(eeprom_read(16)+0x30);
       value[4]=eeprom_read(16);

get_height_value();
ha=(value[0]+value[1]*0.1+value[2]*0.01+value[3]*0.001+value[4]*0.0001);// convert
to meter
       for(i=12; i<17; i++){
       eeprom_write(i,value[i-12]);
       }
DelayMs(250);

Line_2();
Write_Lcd_Data(0x20);
Write_Lcd_Data(0x20);
Write_Lcd_Data(0xE3);
printf("ai-> 00.00      ");
lcd_gotoxy(2,8);
       Write_Lcd_Data(eeprom_read(17)+0x30);
       value[0]=eeprom_read(17);
       Write_Lcd_Data(eeprom_read(18)+0x30);
       value[1]=eeprom_read(18);
```

```
        Write_Lcd_Data('.');
        Write_Lcd_Data(eeprom_read(19)+0x30);
        value[2]=eeprom_read(19);
        Write_Lcd_Data(eeprom_read(20)+0x30);
        value[3]=eeprom_read(20);

get_dia_value();
eai=value[0]*10+value[1]+value[2]*0.1+value[3]*0.01;
        for(i=17; i<21; i++){
        eeprom_write(i,value[i-17]);
        }
DelayMs(250);

Line_2();
Write_Lcd_Data(0x20);
Write_Lcd_Data(0x20);
Write_Lcd_Data(0xE3);
printf("a -> 00.00      ");
lcd_gotoxy(2,8);
        Write_Lcd_Data(eeprom_read(21)+0x30);
        value[0]=eeprom_read(21);
        Write_Lcd_Data(eeprom_read(22)+0x30);
        value[1]=eeprom_read(22);
        Write_Lcd_Data('.');
        Write_Lcd_Data(eeprom_read(23)+0x30);
        value[2]=eeprom_read(23);
        Write_Lcd_Data(eeprom_read(24)+0x30);
        value[3]=eeprom_read(24);

get_dia_value();
ea=value[0]*10+value[1]+value[2]*0.1+value[3]*0.01;
        for(i=21; i<25; i++){
        eeprom_write(i,value[i-21]);
        }
DelayMs(250);

Line_2();
Write_Lcd_Data(0x20);
Write_Lcd_Data(0x20);
Write_Lcd_Data(0xE3);
printf("l -> 00.00      ");
lcd_gotoxy(2,8);
        Write_Lcd_Data(eeprom_read(25)+0x30);
        value[0]=eeprom_read(25);
        Write_Lcd_Data(eeprom_read(26)+0x30);
        value[1]=eeprom_read(26);
        Write_Lcd_Data('.');
        Write_Lcd_Data(eeprom_read(27)+0x30);
        value[2]=eeprom_read(27);
        Write_Lcd_Data(eeprom_read(28)+0x30);
        value[3]=eeprom_read(28);

get_dia_value();
el=value[0]*10+value[1]+value[2]*0.1+value[3]*0.01;
```

```
        for(i=25; i<29; i++){
        eeprom_write(i,value[i-25]);
        }
DelayMs(250);

Line_2();
printf("Ra-> 0       Ohm");
get_resistor_value();
ra=r_temp/1000;
DelayMs(250);

Curser_Normal();
dis_thankyou();
menu_l=0;
}
}

void get_dia_value()
{
lcd_gotoxy(2,8);
Curser_Blink();
        /*for(i=0; i<4; i++){
        value[i]=0;          // clear the variable array
        }      */
key_value=0;
dig_count=0;

        while(dig_count<4 && key_value!='#'){
                if(KEY.press && key_value=='*'){
                dig_count=0;
                lcd_gotoxy(2,8);
                        for(i=0; i<4; i++){
                        value[i]=0;          // clear the variable
                        }
                printf("00.00");
                lcd_gotoxy(2,8);
                KEY.press=0;
                }

                if(KEY.press && key_value>0x2F && key_value<0x3A){
                value[dig_count]=key_value-0x30;
                Write_Lcd_Data(key_value);
                        if(dig_count==1){
                        Cursor_Right();
                        }
                KEY.press=0;
                dig_count++;
                }
        }
KEY.press=0;
}

void get_height_value()
{
```

```
lcd_gotoxy(2,7);
Curser_Blink();
       /*for(i=0; i<5; i++){
       value[i]=0;          // clear the variable array
       }*/
key_value=0;
dig_count=0;

       while(dig_count<5 && key_value!='#'){

              if(KEY.press && key_value=='*'){
              dig_count=0;
              lcd_gotoxy(2,7);
                     for(i=0; i<5; i++){
                     value[i]=0;          // clear the variable
                     }
              printf("000.00");
              lcd_gotoxy(2,7);
              KEY.press=0;
              }

              if(KEY.press && key_value>0x2F && key_value<0x3A){
              value[dig_count]=key_value-0x30;
              Write_Lcd_Data(key_value);
                     if(dig_count==2){
                     Cursor_Right();
                     }
              KEY.press=0;
              dig_count++;
              }
       }
KEY.press=0;
}

void get_resistor_value()
{
lcd_gotoxy(2,5);
Curser_Blink();
       for(i=0; i<7; i++){
       value[i]=0;          // clear the variable array
       }
key_value=0;
dig_count=0;
r_temp=0;

       while(dig_count<7 && key_value!='#'){
              if(KEY.press && key_value=='*'){
              dig_count=0;
              lcd_gotoxy(2,5);
                     for(i=0; i<7; i++){
                     value[i]=0;          // clear the variable
                     }
              printf("0      ");
              lcd_gotoxy(2,5);
```

```
                KEY.press=0;
                }

                if(KEY.press && key_value>0x2F && key_value<0x3A){
                r_temp=(r_temp*10)+(key_value-0x30);
                Write_Lcd_Data(key_value);
                KEY.press=0;
                dig_count++;
                }
        }
KEY.press=0;
}
//***************************Inital Calibration***********************

void init_calibration()
{
lcdclr();
Line_1();
printf("Int. Calibration");
Line_2();
printf("  H -> 000.00 cm");
get_height_value();
h=(value[0]+value[1]*0.1+value[2]*0.01+value[3]*0.001+value[4]*0.0001);// convert
to meter
//h=value[0]*100+value[1]*10+value[2]+value[3]*0.1+value[4]*0.01;
DelayS(3);
Line_1();
printf("Pls. Set Sensor ");
Line_2();
printf("& Press '#' Key ");
menu_l=1;
KEY.press=0;
key_value=0;
        while(menu_l==1){           // check '#' Key
                if(KEY.press){
                        if(key_value=='#'){
                        menu_l=0;
                        }
                KEY.press=0;
                }
        }
Line_1();
printf("Calculating C0..");
Line_2();
printf("Please wait 5sec");

FLAG.freq_ok=0;
fa_total=0;
f_count=0;
init_tmr0();
init_timer1();

//TMR1H=0x07;
//TMR1L=0xB8; //testing
```

```
		while(f_count<25){
			if(FLAG.freq_ok){
			fa_total=fa_total+fa_temp;
			f_count++;
			FLAG.freq_ok=0;
			}
		}

	dis_freq((unsigned int)(fa_total/50));
	fa=fa_total/(float)5000;    // 5sec average in KHz
	DelayS(2);

	//da3=25.5;
	//da2=3.5;
	//da1=0.4;
	//el=80;
	//ea=1;
	//eai=3;
	//h=0;
	//ha=1;
	//ra=100;
	//fa=79.05;

	eq_a=(log(da3/da2)/ea);
	eq_b=(log(da2/da1)/eai);
	eq_c=(log(da3/da2)/el);

	eq_A=(55.65497/(eq_a+eq_b));
	eq_B=(55.65497/(eq_c+eq_b));
	eq_F=(1000000/(ra*log(4)));

	c0=(((eq_F)/fa)-(eq_A*ha));//
	eq_B=(eq_B-eq_A);
	c0=c0-(eq_B)*h;

	b2_bcd((int)(c0*100));
	Line_1();
	printf("Int. Claibration");
	Line_2();
	printf("done. [C0=     ]");
	lcd_gotoxy(2,10);
	Write_Lcd_Data(dig4+0x30);
	Write_Lcd_Data(dig3+0x30);
	Write_Lcd_Data('.');
	Write_Lcd_Data(dig2+0x30);
	Write_Lcd_Data(dig1+0x30);

	f_count=0;
	init_tmr0();
	init_timer1();
	fa_total=0;
	Curser_Normal();
	}
```

```c
//************************General sub functions****************
void int_port()
{
PORTA=0;
PORTC=0;
TRISB=0xF1;
TRISA=0x01;
TRISC=0x81;
//ADCON1=7;
OPTION=0x04;
}

void init_tmr0()
{
OPTION=0x04;  //1:32 pre scaler
T0IF=0;
T0IE=1;
TMR0=6;
toif_count=0;
PEIE=1;
GIE=1;
}

void init_timer1()
{
T1CON=0x33; // P/S=8, Ex clock
TMR1L=0;
TMR1H=0;
}

void init_portb_change()
{
RBIF=0;
RBIE=1;
PEIE=1;
GIE=1;
}

void b2_bcd(unsigned int value)
{
	dig5=value/(int)10000;
	value=value%(int)10000;
	dig4=value/(int)1000;
	value=value%(int)1000;
	dig3=value/100;
	value=value%100;
	dig2=value/10;
	dig1=value%10;
}

void beep(char count)
{
```

```
        while(count!=0){
        RC4=1;
        DelayBigMs(500);
        RC4=0;
        DelayS(1);
        --count;}
}

void short_beep()
{
RC4=1;
DelayS(1);
RC4=0;
}

void key_beep()
{
RC4=1;
DelayBigMs(250);
RC4=0;
}

void buzzer()
{
RC4=1;
DelayMs(250);
RC4=0;
}

void send_frequency()
{
rs232_out('F');
rs232_out(dig5+0x30);
rs232_out(dig4+0x30);
rs232_out(dig3+0x30);
rs232_out('.');
rs232_out(dig2+0x30);
rs232_out(dig1+0x30);
rs232_out('!');
}

void init_usart()
{
SPBRG=129;
TXSTA=0x24;
RCSTA=0x90;
RCIE=1;
PEIE=1;
GIE=1;
}

void rs232_out(unsigned char tx_data)
{
while(TXIF==0){}
```

```
TXREG=tx_data;
}

void init_a2d()
{
ADCON0=0x41;
ADCON1=0x8E;          //Right justify, RA0 input
ADIF=0;
ADIE=0;
}

//****************************LCD sub functions********************

void putch(char c)
{
Write_Lcd_Data(c);
RB7=1;
}

void Prj_name_Display()
{
lcdclr();
Line_1();
printf("----WELCOME-----");
Line_2();
printf(" Modern Sensor  ");
DelayS(2);
lcdclr();
Line_1();
printf("   Liquid Level  ");
Line_2();
printf("   Measurement  ");
DelayS(2);
}

void dis_thankyou()
{
lcdclr();
Line_1();
printf("Setting Complete");
Line_2();
printf("Please wait.....");
DelayS(3);
}

void dis_error_height()
{
lcdclr();
Line_1();
printf("Frequency Error!");
Line_2();
printf("Pls.check sensor");
}
```

```
void dis_temp_error()
{
lcdclr();
Line_1();
printf("Liq.Temp. Error!");
Line_2();
printf("Pls.check sensor");
}

void dis_height()
{
Line_2();
printf("Height: ");
lcd_gotoxy(2,7);
Write_Lcd_Data(dig5+0x30);
Write_Lcd_Data(dig4+0x30);
Write_Lcd_Data(dig3+0x30);
Write_Lcd_Data('.');
Write_Lcd_Data(dig2+0x30);
Write_Lcd_Data(dig1+0x30);
Write_Lcd_Data(' ');
Write_Lcd_Data('c');
Write_Lcd_Data('m');
}

void dis_freq(float freq)
{
Line_1();
b2_bcd((unsigned int)freq);
printf("Freq: ") ;
Write_Lcd_Data(dig5+0x30);
Write_Lcd_Data(dig4+0x30);
Write_Lcd_Data(dig3+0x30);
Write_Lcd_Data('.');
Write_Lcd_Data(dig2+0x30);
Write_Lcd_Data(dig1+0x30);
Write_Lcd_Data('K');
Write_Lcd_Data('H');
Write_Lcd_Data('z');
}

void dis_temperature()
{
b2_bcd(actual_temp);
Line_1();
printf("Liq. Temp :    C");
lcd_gotoxy(1,11);
Write_Lcd_Data(dig3+0x30);
Write_Lcd_Data(dig2+0x30);
Write_Lcd_Data('.');
Write_Lcd_Data(dig1+0x30);
}

//*********************************************************************
```

```
void key_scan()
{
KEY.press=0;
key_value=0;

            if(!RB7)            // Column 1 check
            {
            TRISB=0x7F;         //Row 1 input
            PORTB=0;
            DelayBigMs(10);
                    if(!KEY.press && PORTB==0x77)
                    {
                    KEY.press=1;
                    key_value='1';
                    }
                    if(!KEY.press && PORTB==0x7B)
                    {
                    KEY.press=1;
                    key_value='2';
                    }
                    if(!KEY.press && PORTB==0x7D)
                    {
                    KEY.press=1;
                    key_value='3';
                    }
            }

            if(!RB6)            // Column 2 check
            {
            TRISB=0xBF;         //Row 2 input
            PORTB=0;
            DelayBigMs(10);
                    if(!KEY.press && PORTB==0xB7)
                    {
                    KEY.press=1;
                    key_value='4';
                    }
                    if(!KEY.press && PORTB==0xBB)
                    {
                    KEY.press=1;
                    key_value='5';
                    }

                    if(!KEY.press && PORTB==0xBD)
                    {
                    KEY.press=1;
                    key_value='6';
                    }

            }

            if(!RB5)            // Column 3 check
            {
            TRISB=0xDF;         //Row 3 input
```

```
            PORTB=0;
            DelayBigMs(10);
                    if(!KEY.press && PORTB==0xD7)
                    {
                    KEY.press=1;
                    key_value='7';
                    }
                    if(!KEY.press && PORTB==0xDB)
                    {
                    KEY.press=1;
                    key_value='8';
                    }
                    if(!KEY.press && PORTB==0xDD)
                    {
                    KEY.press=1;
                    key_value='9';
                    }
            }

            if(!RB4)              // Column 4 check
            {
            TRISB=0xEF;           //Row 1 input
            PORTB=0;
            DelayBigMs(10);
                    if(!KEY.press && PORTB==0xE7)
                    {
                    KEY.press=1;
                    key_value='*';
                    }
                    if(!KEY.press && PORTB==0xEB)
                    {
                    KEY.press=1;
                    key_value='0';
                    }
                    if(!KEY.press && PORTB==0xED)
                    {
                    KEY.press=1;
                    key_value='#';
                    }
            }

            if(KEY.press)
            {
            key_beep();
            }

    TRISB=0xF0;
    PORTB=0;
            while(!RB7 || !RB6 || !RB5 || !RB4)              // Wait for KEY
release
            {}
    DelayBigMs(50);
            while(!RB7 || !RB6 || !RB5 || !RB4)              // Wait for KEY
release
```

```
            {}
DelayBigMs(50);
}
```

<u>Test-h</u>

```
void putch(char c);
void MainDisplay(void);
void int_port();
void b2_bcd(unsigned int value);
void init_usart();
void init_a2d();
void init_tmr0();
void dis_value();
void tx_data();
void Prj_name_Display();
void dis_functions();
void init_timer1();
void beep(char count);
void show_temperature();
void short_beep();
void rs232_out(unsigned char tx_data);

bank1 unsigned int ad_value,tot_ad_value,actual_temp;
bank1 double temperature;
bank1 unsigned char key_value,menu_l,dig_count,i,a2d_count,dig1,dig2,dig3;
bank1 unsigned char value[10];

bank1 float ra,r_temp;
bank1 unsigned int pulse_a,pulse_b,pulse_c,fa,fb,fc;

bank1 struct keys
{
unsigned press:1;
}KEY;

bank1 struct flags
{
unsigned data_ok :1;
unsigned freq_ok:1;
}FLAG;

bank2 float da1,da2,da3,ha,eai,ea,el,h;
bank2 float eq_a,eq_b,eq_c,eq_A,eq_B,eq_F;

//bank3 float db1,db2,db3,hb,ebi,c0;
//bank3 float dc1,dc2,dc3,hc,eci;
//bank3 float eq_a;
```


Lcd-c

```
//**************************************************************************/
```

```
#include <pic.h>
#include "lcd.h" // function prototypes, defines..
#include "delay.h"

char lcdtemp;

void CLK_LCD()
{
lcden=1;
DelayUs(250);
lcden=0;
}

void Init_Lcd( void ) // initialize LCD display
{
	TRISA = 0x01;
	lcdport = 0x00;

	DelayMs(20); // ~15mS delay upon powerup
	lcdport = 0x06; // output setup data to LCD
	CLK_LCD();
	DelayMs(6);
	lcdport = 0x06; // output setup data to LCD
	CLK_LCD();
	DelayMs(5);
	lcdport = 0x06; // output setup data to LCD
	CLK_LCD();
	DelayMs(5);
	lcdport = 0x04; // output setup data to LCD
	CLK_LCD();
	DelayMs(5);
	lcdport = 0x04; // output setup data to LCD
	CLK_LCD();
	lcdport = 0x20; // output setup data to LCD
	CLK_LCD();
	DelayMs(5);
	lcdport = 0x00; // output setup data to LCD
	CLK_LCD();
	lcdport = 0x20; // output setup data to LCD
	CLK_LCD();
	DelayMs(5);
	lcdport = 0x00; // output setup data to LCD
	CLK_LCD();
	lcdport = 0x02; // output setup data to LCD
	CLK_LCD();
	DelayMs(5);
	lcdport = 0x00; // output setup data to LCD
	CLK_LCD();
	lcdport = 0x0C; // output setup data to LCD
	CLK_LCD();
	DelayMs(5);
	lcdport = 0x00; // output setup data to LCD
```

```
        CLK_LCD();
        lcdport = 0x28; // output setup data to LCD
        CLK_LCD();
        DelayMs(5);
}

void Write_Lcd_Data(char data)
{
        lcdport = 0x40 + 0x80;

        lcdtemp = lcdport & 0x40;
        lcdtemp |=  (data >> 4)  ;
        lcdport=lcdtemp<<1;

                if((lcdtemp&0x08)==0x08){
                RA5=1;
                }else{
                RA5=0;
                }

        lcdrs = 1;
        CLK_LCD();
        lcdrs = 0;

        lcdtemp = lcdport & 0x40;
        lcdtemp |= (data & 0x0f);

        lcdport=lcdtemp<<1;

                if((lcdtemp&0x08)==0x08){
                RA5=1;
                }else{
                RA5=0;
                }
        lcdrs = 1;
        CLK_LCD();
        lcdrs = 0;
        DelayBigUs(500);
}

void Write_Lcd_Cmd(char cmd)
{
        lcdtemp = lcdport & 0x40; //green led at portd6
        lcdtemp |= (cmd >> 4) ;
        lcdport=lcdtemp<<1;

                if((lcdtemp&0x08)==0x08){
                RA5=1;
                }else{
                RA5=0;
                }
        lcdrs = 0;
```

```
        CLK_LCD();

        lcdtemp = lcdport & 0x40;
        lcdtemp |= (cmd & 0x0f);
        lcdport=lcdtemp<<1;

                if((lcdtemp&0x08)==0x08){
                RA5=1;
                }else{
                RA5=0;
                }

        lcdrs = 0;
        CLK_LCD();
        DelayBigUs(500);
}

void Line_1(void)
{
Write_Lcd_Cmd(0x80);
}

void Line_2(void)
{
Write_Lcd_Cmd(0xC0);
}

void lcdclr(void)
{
Write_Lcd_Cmd(0x01);
}

void Cursor_Right(void)
{
        Write_Lcd_Cmd(0x14);
}

void Cursor_Left(void)
{
        Write_Lcd_Cmd(0x10);
}

void Display_Shift(void)
{
        Write_Lcd_Cmd(0x1C);
}

void Curser_Blink(void)
{
        Write_Lcd_Cmd(0x0D);
}
```

```
void Curser_Normal(void)
{
        Write_Lcd_Cmd(0x0C);
}

void Font_2(void)
{
        Write_Lcd_Cmd(0x12);
}

//#pragma interrupt_level 1
void lcd_gotoxy (char row, char col)
{
int i;
        if (row == 1)
        Line_1();
        if (row == 2)
        Line_2();
        for ( i = 0; i < col; i++)
        Cursor_Right();
}


void Delay200us(void)// approximate 200us delay
{
        char delay;
        for (delay=66; delay>0;delay--);
}
```

Lcd-h

```
// FUNCTION PROTOTYPES
/* Functions defined in file testlcd.c */

void    Init_Lcd( void );
void    Write_Lcd_Data(char data);
void    Write_Lcd_Cmd(char cmd);
void    Line_1(void);
void    Line_2(void);
void    lcdclr(void);
void    Cursor_Right(void);
void    Cursor_Left(void);
void    Display_Shift(void);
void    lcd_gotoxy (char row, char col);
void    Delay200us(void);
void    Lcd_Busy(void);
void    Curser_Blink(void);
void    Curser_Normal(void);

// MACROS ( DEFINED HERE )
#define lcdport PORTA // Port for lcd data
#define lcden RC0
#define lcdrs RC3
```

Delay-c

```
/*

high level delay routines - see delay.h for more info.

Designed by Shane Tolmie of KeyGhost corporation.  Freely distributable.
Questions and comments to shane@keyghost.com
PICuWEB - Program PIC micros with C. Site has FAQ and sample source code.
http://www.workingtex.com/htpic

For Microchip 12C67x, 16C7x, 16F87x and Hi-Tech C

*/

#ifndef __DELAY_C
#define __DELAY_C

#include <pic.h>

unsigned char delayus_variable;

#include "delay.h"

void DelayBigUs(unsigned int cnt)
{
	unsigned char	i;

	i = (unsigned char)(cnt>>8);
	while(i>=1)
	{
		i--;
		DelayUs(253);
		CLRWDT();
	}
	DelayUs((unsigned char)(cnt & 0xFF));
}

void DelayMs(unsigned char cnt)
{
	unsigned char	i;
	do {
		i = 4;
		do {
			DelayUs(250);
			CLRWDT();
		} while(--i);
	} while(--cnt);
}

//this copy is for the interrupt function
void DelayMs_interrupt(unsigned char cnt)
{
```

```
	unsigned char	i;
	do {
		i = 4;
		do {
			DelayUs(250);
		} while(--i);
	} while(--cnt);
}

void DelayBigMs(unsigned int cnt)
{
	unsigned char	i;
	do {
		i = 4;
		do {
			DelayUs(250);
			CLRWDT();
		} while(--i);
	} while(--cnt);
}

void DelayS(unsigned char cnt)
{
	unsigned char i;
	do {
		i = 4;
		do {
			DelayMs(250);
			CLRWDT();
		} while(--i);
	} while(--cnt);
}

#endif
```

Delay-h

```
#define PIC_CLK 4000000 //4Mhz

/*

lowlevel delay routines

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For Microchip 12C67x, 16C7x, 16F87x and Hi-Tech C

Example C:

#define PIC_CLK 4000000

#include "delay.h"

unsigned int timeout_int, timeout_char;

DelayUs(40);  //do NOT do DelayUs(N) of N<5 @ 4Mhz or else it executes DelayUs(255) !!!!
DelayUs(255); //max

dly250n;      //delay 250ns
dly1u;        //delay 1us

timeout_char=timeout_char_us(1147);
while(timeout_char-- && (RA1==0));  //wait up to 1147us for port RA1 to go high
                                    //  - this is the max timeout

timeout_int=timeout_int_us(491512);
while(timeout_int-- && (RA1==0));   //wait up to 491512us for port RA1 to go high
                                    //  - this is the max timeout

*/

#ifndef __DELAY_H
#define __DELAY_H

extern unsigned char delayus_variable;

#if (PIC_CLK == 4000000)
        #define dly125n please remove; for 32Mhz+ only
        #define dly250n please remove; for 16Mhz+ only
        #define dly500n please remove; for 8Mhz+ only
        #define dly1u asm("nop")
        #define dly2u dly1u;dly1u
#elif (PIC_CLK == 8000000)
        #define dly125n please remove; for 32Mhz+ only
        #define dly250n please remove; for 16Mhz+ only
```

```
	#define dly500n asm("nop")
	#define dly1u dly500n;dly500n
	#define dly2u dly1u;dly1u
#elif ( (PIC_CLK == 16000000) || (PIC_CLK == 16257000) )
	#define dly125n please remove; for 32Mhz+ only
	#define dly250n asm("nop")
	#define dly500n dly250n;dly250n
	#define dly1u dly500n;dly500n
	#define dly2u dly1u;dly1u
#elif (PIC_CLK == 20000000)
	#define dly200n asm("nop")
	#define dly400n dly250n;dly250n
	#define dly2u dly400n;dly400n;dly400n;dly400n;dly400n
#elif (PIC_CLK == 32000000)
	#define dly125n asm("nop")
	#define dly250n dly125n;dly125n
	#define dly500n dly250n;dly250n
	#define dly1u dly500n;dly500n
	#define dly2u dly1u;dly1u
#else
	#error delay.h - please define pic_clk correctly
#endif

//*****
//delay routine

#if PIC_CLK == 4000000
	#define DelayDivisor 4
	#define WaitFor1Us asm("nop")
	#define Jumpback asm("goto $ - 2")
#elif PIC_CLK == 8000000
	#define DelayDivisor 2
	#define WaitFor1Us asm("nop")
	#define Jumpback asm("goto $ - 2")
#elif ( (PIC_CLK == 16000000) || (PIC_CLK==16257000) )
	#define DelayDivisor 1
	#define WaitFor1Us asm("nop")
	#define Jumpback asm("goto $ - 2")
#elif PIC_CLK == 20000000
	#define DelayDivisor 1
	#define WaitFor1Us asm("nop"); asm("nop")
	#define Jumpback asm("goto $ - 3")
#elif PIC_CLK == 32000000
	#define DelayDivisor 1
	#define WaitFor1Us asm("nop"); asm("nop"); asm("nop"); asm("nop"); asm("nop")
	#define Jumpback asm("goto $ - 6")
#else
	#error delay.h - please define pic_clk correctly
#endif

#define DelayUs(x) { \
			delayus_variable=(unsigned char)(x/DelayDivisor); \
```

```
        WaitFor1Us; } \
        asm("decfsz _delayus_variable,f"); \
        Jumpback;

/*

timeouts:

C code for testing with ints:

        unsigned int timeout;
        timeout=4000;
        PORT_DIRECTION=OUTPUT;
        while(1)
        {
                PORT=1;
                timeout=8000;
                while(timeout-- >= 1);      //60ms @ 8Mhz, opt on, 72ms @ 8Mhz,
opt off
                PORT=0;
        }

Time taken:     optimisations on:           16cyc/number loop, 8us @ 8Mhz
                optimisations off:          18cyc/number loop, 9us @ 8Mhz
                with extra check ie:        && (RB7==1), +3cyc/number loop, +1.5us @ 8Mhz

C code for testing with chars:
```



```
        similar to above

Time taken:     optimisations on:           9cyc/number loop, 4.5us @ 8Mhz
                with extra check ie:        && (RB7==1), +3cyc/number loop, +1.5us @ 8Mhz

Formula:        rough timeout value = (<us desired>/<cycles per loop>) * (PIC_CLK/4.0)

To use:         //for max  timeout of 1147us @ 8Mhz
                #define LOOP_CYCLES_CHAR    9
        //how many cycles per loop, optimizations on
                #define timeout_char_us(x)          (unsigned
char)((x/LOOP_CYCLES_CHAR)*(PIC_CLK/4.0))
                unsigned char timeout;
                timeout=timeout_char_us(1147);
        //max timeout allowed @ 8Mhz, 573us @ 16Mhz
                while((timeout-- >= 1) && (<extra condition>));      //wait

To use:         //for max 491512us, half sec timeout @ 8Mhz
                #define LOOP_CYCLES_INT             16
            //how many cycles per loop, optimizations on
                #define timeout_int_us(x)  (unsigned
int)((x+/LOOP_CYCLES_INT)*(PIC_CLK/4.0))
                unsigned int timeout;
```

```
                timeout=timeout_int_us(491512);
        //max timeout allowed @ 8Mhz
                while((timeout-- >= 1) && (<extra condition>));        //wait
*/
#define LOOP_CYCLES_CHAR    9                                          //how
many cycles per loop, optimizations on
#define timeout_char_us(x)          (long)(((x)/LOOP_CYCLES_CHAR)*(PIC_CLK/1000000/4))

#define LOOP_CYCLES_INT                 16
        //how many cycles per loop, optimizations on
#define timeout_int_us(x)  (long)(((x)/LOOP_CYCLES_INT)*(PIC_CLK/1000000/4))

//if lo byte is zero, faster initialization by 1 instrucion
#define timeout_int_lobyte_zero_us(x)
        (long)(((x)/LOOP_CYCLES_INT)*(PIC_CLK/4.0)&0xFF00)

//function prototypes
void DelayBigUs(unsigned int cnt);
void DelayMs(unsigned char cnt);
void DelayMs_interrupt(unsigned char cnt);
void DelayBigMs(unsigned int cnt);
void DelayS(unsigned char cnt);

#endif
```