



DEVELOPMENT OF A FUEL LEVEL MEASURING SYSTEM FOR UNDERGROUND LIQUID TANKS

**Adebisi O. I., Adejumbi A. I., Olanipekun A. J. and Bello O. H.*

*Department of Electrical and Electronics Engineering,
Federal University of Agriculture, Abeokuta, Ogun State, Nigeria*

**Corresponding Email: adebisi.oluwaseun@yahoo.com*

Manuscript Received: 20/05/2018 Accepted: 30/06/2018 Published: September, 2018

ABSTRACT

This work presents a simple, robust and low cost fuel level measuring system for underground liquid tanks. The major components of the system include Atmega 328P microcontroller, HC-SR04 ultrasonic sensor, Hitachi HD44780 liquid crystal display. A prototype elliptical tank was modelled and constructed using a modified gas cylinder, having its major and minor diameters and length in cm. The petrol level from the base of the tank was measured by ultrasonic sensor and converted to volumetric equivalent in litres with the aid of tank volume equation programmed into the microcontroller. Performance test was carried out on the developed system. With sensor distance, minor diameter, major diameter and length as 22, 23.39, 23.39 and 26.67 cm respectively, the tank capacity was estimated as 10 litres. The performance test showed that the system was functional and gave a mean absolute percentage error of 4.74%. The developed fuel level measuring system can be deployed for use in petrol stations, depots or other industries where information about the quantity of petrol or other fuels stored in underground tanks is required.

Keywords: *Fuel level measurement, Elliptical tank, Ultrasonic sensor, Microcontroller, Petrol station*

INTRODUCTION

Control engineering has permeated all facets of human life and has contributed immensely to the development of modern and still-to-evolve technologies. It has been applied in diverse areas of human endeavours such as electrical power plants, transportation systems, robotics, weapon systems, computers, medicine and agriculture. Other areas of application include position or velocity control, temperature control, voltage control, pressure control, traffic control, office automation, computer integrated manufacturing and energy management for buildings (Ogata, 2010).

An area where the knowledge and application of control can be further extended is the fluid level measurement, an example of which is integral to petrol station or depot operations. The stakeholders in the petrol sales business – oil marketers, petrol station owners, petrol attendants and others require information about the quantity of petrol or other fuels such as diesel and kerosene in the storage tank for various reasons. This may be for the purpose of taking inventory, verification of fuel deliveries, leakage detection or facilitation of timely refills (Westell, 2016).

In order to overcome the challenge of obtaining the quantity of petrol or other fuels in the storage tanks buried under the ground, the service of a gauge stick otherwise referred to as haulage bar is employed. The haulage bar is a long rod which is used to measure the depth of fuel in an underground tank to a resolution of about 1/8 inch (EPA, 2016). The stick used for this operation must be made of a non-sparkling material, such as wood which is usually varnished to minimize the creeping of fuel above the actual fuel level in the tank. A tank chart is often used along with the haulage bar to convert the number of inches of fuel it measures to its equivalent number of gallons or litres. To improve the accuracy of the bar, a special paste is smeared around an area which is most likely to be the top of the fuel being measured. The fuel affects the paste by changing the colour or by causing a breakage in the continuity of the rubbed area.

According to Osueke *et al.*, (2013), the use of long calibrated rod for fuel level measurement has not always been entirely accurate. In some cases, the tank tends to be bent to one side due to factors such as pressure and gravity acting on it. Montero *et al.*, (2012) stated that the rudimentary method of using measuring rod for fuel level measurement tends to be slow and inefficient. The use of haulage bar exposes the process of fuel level measurement to a lot of errors

such as those due to the operators. The insertion of the gauge bar at an angle other than normal to the surface of the fuel and wrong interpolation of the inches value to gallon value from the tank chart are possible errors associated with the operators during fuel level measurement. Other critical limitations of the primitive method of fuel level measurement involving the use of haulage bar are the creation of unnecessary physical and technical stress for people involved in the measurement and the inability of the bar to detect problems such as tank leakage. Therefore, the need for an efficient, reliable and low cost system or device which can measure fuel level with fast response time, high accuracy and reduced human intervention becomes evident.

In this work, a fuel level measuring system for underground liquid tanks was developed. The developed system has the ability to measure fuel level from the underground tanks and display its volumetric equivalent in litres in very short time of less than a minute and without the operator engaging in any tedious activities other than to hold the device for measurement.

FLUID LEVEL MEASUREMENT

Fluid measurement is the process of measuring or obtaining certain desired parameters of a fluid such as the flow rate of a liquid, the pressure or temperature measurement of a liquid, height or level measurement of various substances such as liquids, solids and fluidized solids. Fluid level measurement is of great importance for diverse applications (Annuar *et al.*, 2015 and Suleiman *et al.*, 2015). Such applications include fuel storage, flood warning and domestic water level control to mention a few.

There are varieties of factors such as state, temperature, pressure, permittivity, density shape, size etc. that determine the choice of a particular fluid level measurement method for different processes. However, the choice of the most appropriate fluid level measurement device for specific application is based on factors such as range of measurement inside the container in which the fluid is stored, fluid characteristics, resolution, accuracy, and environment inside the container of the fluid (Annuar *et al.*, 2015).

There are two types of fluid level measurement which include point level measurement and continuous level measurement (Omega, 2016; Osueke *et al.*, 2013; Suleiman *et al.*, 2015). While point level measurement indicates whether the material whose level is being measured is below or above a pre-determined point, continuous level measurement determines the level within a specified

range. Generally, the information provided by point level measurement is usually employed as a high alarm, signaling an overflow condition or as a marker for a low alarm condition. Continuous measurement is more sophisticated and can provide level monitoring of an entire system, producing an analog output that directly correlates to the level in the vessel (Omega, 2016).

According to literature (Anuar *et al.*, 2015; Suleiman *et al.*, 2015; Tiwari and Jain, 2014; Montero *et al.*, 2012), various fluid level measuring techniques are available. These are but not limited to mechanical, capacitive, inductive, ultrasonic, acoustic and optical techniques. Each of these techniques has been deployed for different applications based on their unique properties. While mechanical and ultrasonic techniques have extensively been used for level measurement of solid materials in the form of dust, capacitive and optical techniques have been adopted largely for level measurement of fluid (Suleiman *et al.*, 2015 and Montero *et al.*, 2012). In this work, an ultrasonic sensor coupled with a microcontroller was used to develop a simple and efficient fuel level measuring system for underground liquid tanks. Ultrasonic sensor was used because of its inherent characteristics which include its ability to be used for continuous and point-level sensing, low cost, high accuracy in addition to its ability to be deployed for remote or wireless operations being a non-contact device. It also consumes small amount of power for its operation and it has a wide range of operation of 0.02 – 4 m. The signal utilized by the device to measure the fluid level travels at 343m/s -which is convenient for the cheap microcontroller to handle. With the microcontroller as the heart of the system, the overall developed system was more robust and compact and the output was digitalized.

MATERIALS AND METHODS

The research work was carried out according to the block diagram of Figure 1.

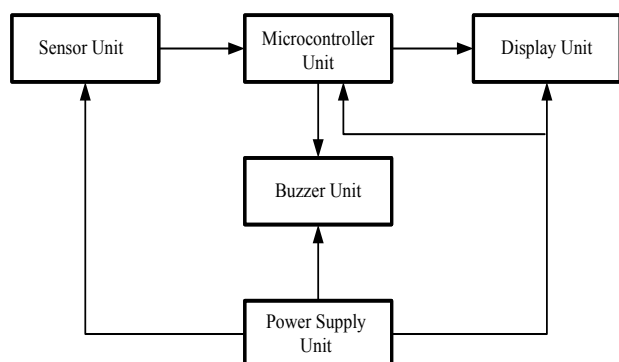


Figure 1: Block diagram of the developed fuel level measuring system for underground liquid tanks

The sensor unit is a data acquisition and transmission unit. It comprises the HC-SR04 ultrasonic sensor which sends and receives signal from the fuel stored in the underground tank to determine its level (height) above the base of the tank. The information obtained by the sensor is then transmitted to the microcontroller unit for further action.

The microcontroller unit is the heart of the system. It comprises the Atmega 328P microcontroller which is an 8-bit microcontroller with about eighteen input and output pins. The information received from the sensor unit (level of fuel in the underground tank) is being processed by the microcontroller to give the volumetric equivalent in litres. This unit also controls the operation of the display and buzzer units.

The display unit is a Hitachi HD44780 Liquid Crystal Display (LCD). It is a 16 by 2 LCD. The processed volumetric information from the microcontroller unit is displayed on this unit in litres. The buzzer unit is an alarm unit integrated into the system for the purpose of alerting the operator in case of fuel leakage from the underground tank.

The power supply unit drives all other units of the system. For the system developed in this work, primary battery was used as the source of power supply since the device will be moved from place to place when in use for fuel measurement for different underground tanks. Therefore, designing a direct current (d.c.) power supply from the alternating current (a.c.) mains was not the best option for the purpose of this work. Coupled with this is the fact that petrol stations, depots or other areas where fuels are dealt with are very sensitive places and any laxity on the part of the operators regarding the a.c. mains supply especially at the regions of the underground tanks where the device is to be used could lead to fire outbreak and severe loss. Hence, the need for primary battery as a source of power in this work was evident.

System Design

The design of the developed fuel level measuring system for the underground liquid tanks in this work was divided into two main stages namely the software design and the hardware design.

Software Design

The software design for this work consists of tank modeling and the algorithm used in programming the microcontroller.

Tank modelling

An elliptical tank of length “L” with semi-major diameter “a” and semi-minor diameter, “b” all

measured in cm was considered on the account that most tanks in petrol stations or depots are of this shape. The tank was assumed to have flat ends and lie along its length such that its major and minor diameters are parallel to the x and y-axis respectively. The cross-section of the tank is shown in Figure 2 with the shaded segment representing the cross-section A_f formed by fuel of level or height, h , from the base of the tank. The height h varies between $-b$ and $+b$ along the minor diameter of the tank.

The standard equation of an ellipse is expressed by equation (1) (Stroud and Booth, 2001):

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{1}$$

Since the level of fuel is along the y-axis, variable x in equation (1) was made the subject of the formula as presented in equation (2):

$$x = \frac{a}{b} \sqrt{b^2 - y^2} \tag{2}$$

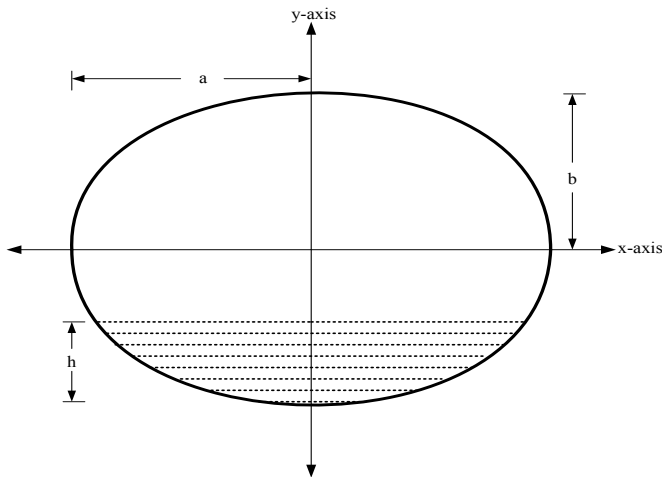


Figure 2: Elliptical tank cross-section showing fuel at a level, h , from its base

The cross-section A_f of fuel formed below the tank was obtained from the integral given by equation (3) which was modified as equation (4) with the substitution of equation (2):

$$A_f = \int_{y_1}^{y_2} x dy \tag{3}$$

$$A_f = \frac{2a}{b} \int_{-b}^b (\sqrt{b^2 - y^2}) dy \tag{4}$$

With the tank height taken as $2b$, if the fuel inside the tank is at level h above the base of the tank where an empty tank is taken as zero level and a full tank as $2b$ level, the level h translates to a y value expressed by equation (5):

$$y = h - b \tag{5}$$

Taking the y value given by equation (5) as the upper limit of the integral in equation (4), equation (4) then

modifies into equation (6) as:

$$A_f = \frac{2a}{b} \int_{-b}^{h-b} (\sqrt{b^2 - y^2}) dy \tag{6}$$

From equation (6), equation (7) is easily evident that:

$$A_f = \left(\frac{a}{b}\right) \left[\frac{\pi b^2}{2} + (h-b)\sqrt{h(2b-h)} + b^2 \sin^{-1}\left(\frac{h}{b} - 1\right) \right] \tag{7}$$

where use has been made of the standard integral given by equation (8) (Stroud and Booth, 2001):

$$\int \sqrt{A^2 - Z^2} dZ = \frac{A^2}{2} \left[\sin^{-1}\left(\frac{Z}{A}\right) + \frac{Z\sqrt{A^2 - Z^2}}{A^2} \right] \tag{8}$$

with A being a constant.

The volume of fuel in litres in the elliptical tank is obtained by multiplying equation (7) with the length of the tank and dividing by 1000, giving equation (9) as:

$$V_p = \left(\frac{La}{1000b}\right) \left[\frac{\pi b^2}{2} + (h-b)\sqrt{h(2b-h)} \right] \text{ (litres)} \tag{9}$$

Equation (9) is the defining equation which was programmed into the Atmega328P microcontroller to convert the level or height h of petrol measured by the ultrasonic sensor HC-SR04 to volumetric equivalent displayed on the Hitachi HD44780 LCD.

Software Algorithm

For the developed system to perform its function, the hardware components were configured in such a way that the microcontroller was programmed in an Arduino Integrated Development Environment (IDE) with C++ programming language to make the ultrasonic sensor measure the fuel level in the model tank and then processes the level obtained to volumetric equivalent in litres. The conversion from level measurement by ultrasonic sensor to volumetric value displayed on the LCD was achieved with the aid of the derived volume equation of the model tank programmed into the microcontroller, detail of which is presented under tank modeling. The algorithm with which equation (9) was implemented in the microcontroller is shown in the flow chart presented in Figure 3. The use of 2 cm in the flow chart of Figure 3 as an acceptable measurement deviation was due to the fact that the model tank considered was relatively small in size and the height from the base of the tank to the sensor level is about 22 cm, so the 2 cm was accepted as enough measurement deviation.

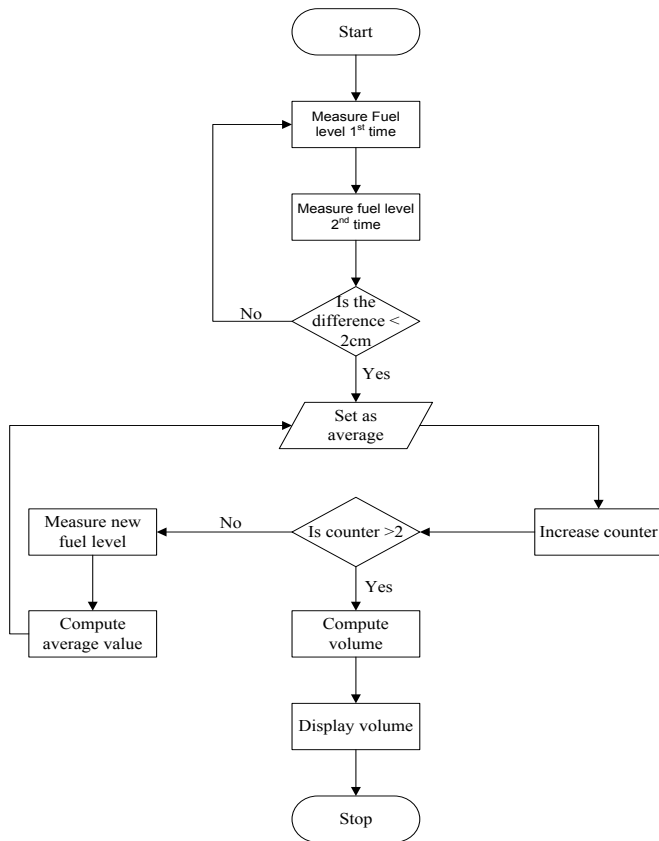


Figure 3: Flow chart software implementation in the microcontroller

Hardware Design

The choice of the hardware components for the developed system was based on some design criteria such as accuracy, fast response, range of operation, power consumption, flexibility, size and cost among others. The components used were majorly modular containing several discrete components such as resistors, capacitors, inductors, transistors, diodes etc. which have been integrated to give desired characteristics and reduce the level of calculations that would have been involved if different discrete components were employed.

Due to the mobility required in operating the developed system during fuel measurement, designing its power source from the a.c. mains was not considered as a choice in this work. This therefore calls for the use of primary battery as power source for the system. Since the hardware components – Atmega328P microcontroller, ultrasonic sensor HC-SR04, Hitachi HD44780 LCD and buzzer employed for the system require 5 V to function, a regulator IC 7805 was used to produce the required 5 V output for the system from a 9 V 6F22 battery. In practice, a certain value of capacitance is usually required at the input and output terminals of regulator IC 7805 to stabilize and improve its output and for the purpose of this work, a 10 μF capacitor was used at both terminals of the IC.

The run time of the 9 V 6F22 battery used to power the developed system was determined using equation (10) expressed as:

$$t_b = \frac{q}{i_{cc}} \dots\dots\dots(10)$$

where t_b = Battery run time in hours
 q = Ampere hour (Ah) capacity of the battery
 i_{cc} = Total current rating of the system hardware component in amperes.

According to the current specification of the components (Arduino, 2016; Avr programmers, 2016; Electroschematics, 2016; Jameco, 2016), the current consumption of the basic hardware components used for this work are presented in Table 1.

Table 1: Hardware components and their current ratings

S/No	Component	Current rating (mA)
1	Atmega 328P	16.0
2	HC-SR04 Ultrasonic sensor	15.0
3	Hitachi HD44780 LCD	2.5
4	Buzzer	20.0

From Table 1, the total current that is required by the system hardware components to function is 53.5 mA. However, allowing for a safety factor due to other components in the system such as the pull-up resistor, the total current required by the system to function is approximated to 60 mA.

Using the total current value of 60 mA required by the system components for their operation with the typical ampere-hour capacity of 9 V 6F22 non-rechargeable battery which is about 400 mAh and from equation (10), the battery run time is appropriately 7 hours. This is considered sufficient for the system since it will not be utilized for more than 2 to 3 minutes a day. Hence, the system can be used for months without changing its source of power supply. The circuit diagram of the power supply unit of the fuel level measuring system developed in this work is presented in Figure 4.

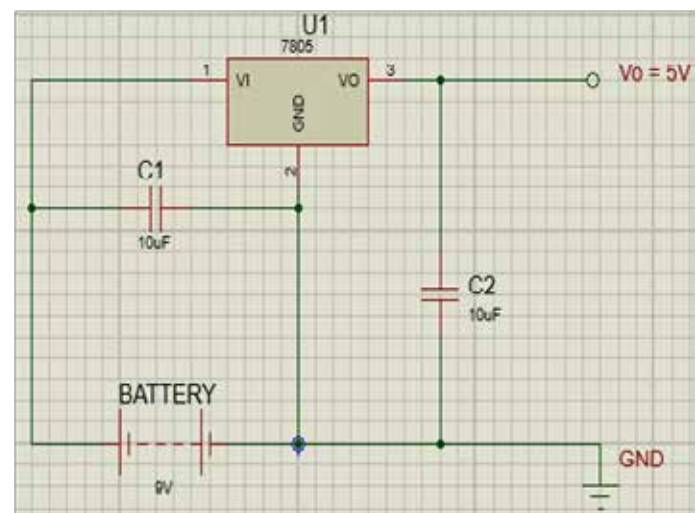


Figure 4: Circuit diagram of the power supply unit

The 5 V d.c. output from the power supply unit from Figure 4 was used to power the main control circuit of the system, presented in Figure 5. The 1 kΩ potentiometer connected to the LCD was used in adjusting its contrast as specified in the datasheet. Also, the two 22 pF capacitors connected to the crystal oscillator whose pins are connected to the crystal pin terminals of the microcontroller were specification from datasheet of the Atmega328P microcontroller used. The value of the current limiting resistor connected to the microcontroller is obtained using Ohm's law expressed by equation (11):

$$V=IR \dots\dots\dots(11)$$

The current entering the microcontroller must be limited to a safe value of far less than 10 mA, which must be sufficient for its operation. Using a current of 0.5 mA which satisfies this stated condition against the 5 V required by the microcontroller for its operation, the value of limiting resistor was obtained as 10 kΩ.

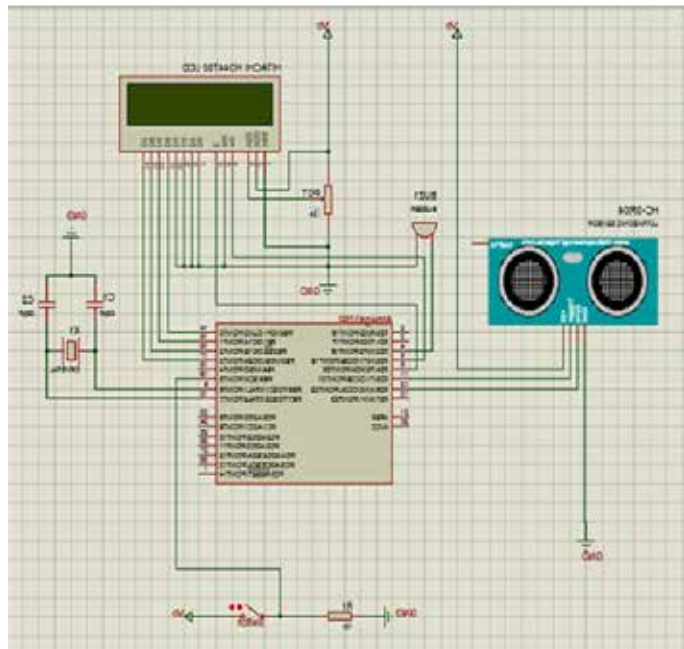


Figure 5: Main control circuit of the developed fuel level measuring system

System Testing

Testing of the developed fuel level measuring system in this work is necessary to validate its usability when the need arises. Hence, performance test was carried out on the system to ascertain its ability to measure volume of fuel from the storage tank.

To test the volume measuring capability of the developed system, a calibrated container was utilized to introduce known volumes of test liquid into the model tank. The fuel level measuring system was then placed on the tank to measure different quantities liquid introduced from the calibrated container. The measured volume of liquid by the system was compared with that of the calibrated container and the error involved in using the developed system for volume measurement with the model tank was estimated using equation (12) expressed as:

$$\% \text{ error} = \frac{V_{lc} - V_{ls}}{V_{lc}} \times \% \dots\dots\dots(12)$$

where V_{lc} = Volume of test liquid introduced into the model tank from the calibrated container in litres
 V_{ls} = Volume of test liquid measured by the developed fuel level measuring system in litres

RESULTS AND DISCUSSION

The constructed tank is shown in Figure 6 while the parameters of the tank are shown in Table 2. The values a, b and L in Table show that the tank is a special case of an elliptical tank where the major and minor diameters are equal. Consequently, the constructed tank for this work has a cylindrical section. A modified gas cylinder was employed to serve this purpose.



Figure 6: The constructed tank

Table 2: Parameters of the constructed tank

Parameter	Value
Length(cm)	26.67
Major diameter(cm)	23.39
Minor Diameter (cm)	23.39
Maximum capacity (Lt)	10.0
Distance of sensor from bottom of tank (cm)	22.0

The internal circuitry of the fuel level measuring system developed in this work shown by the circuit diagrams presented in Figures 4 and 5 was designed using Proteus 8 software and constructed on a Vero board. The fully packaged system is shown in Figure 7 while the internal components are shown in Figure 8.

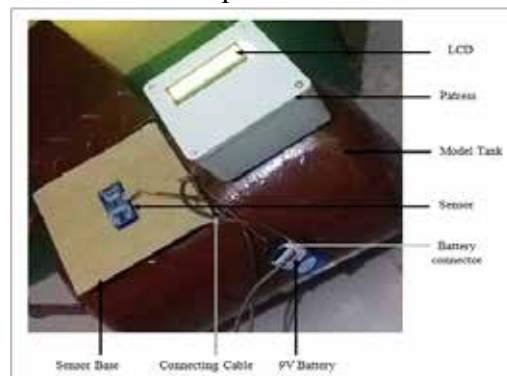


Figure 7: The developed wireless monitoring system for underground petrol tank

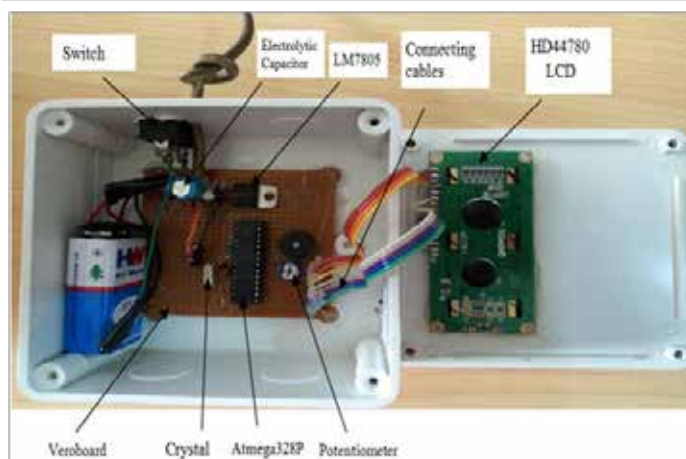


Figure 8: Internal components of the developed wireless monitoring system

Figures 9 and 10 are the results shown by the fuel level measuring system display during testing with known values of 0.0 litre and 7.5 litres quantity of test liquid.



Figure 9: Test result shown when the known value of 0.0 litre of test liquid was measured



Figure 10: Test result shown when the known value of 7.5 litres of test liquid was measured

The obtained results of the volume measurement when the performance of the fuel level measuring system was tested with the constructed tank and the error involved in each measurement according to equation (12) are presented in Table 3. From Table 3, it can be observed that the mean absolute percentage error associated with the developed system for fuel measurement from the model tank is 4.74%, which can be considered acceptable taking into account the

fact that the constructed tank developed in this work was a special case of an elliptical tank.

Table 3: Volume measurement test

S/No	Actual volume of test liquid in model tank V_{lc} in litres	System measured volume of test liquid from the tank V_{ps} in litres	% Error
1	0.00	0.00	0.00
2	0.50	0.45	10.00
3	1.00	0.91	9.00
4	2.00	2.27	13.50
5	2.50	2.73	9.20
6	3.00	3.18	6.00
7	3.50	3.76	7.40
8	4.50	4.66	3.50
9	5.00	5.24	4.80
10	5.50	5.83	6.00
11	6.50	6.41	1.40
12	7.00	7.00	0.00
13	7.50	7.58	1.00
14	8.00	8.16	2.00
15	8.50	8.74	2.90
16	9.00	9.35	3.90
17	10.00	10.0	0.00
Mean Absolute Percentage Error			4.74

CONCLUSION

Fuel level measurement undoubtedly is one of the most essential operations in the petrol sales business. From this operation, information regarding fuel delivery, fuel storage, timely refill, leakages among others can easily be obtained. Due to challenges such as inaccuracy, stress, time constraint etc. associated with the gauge stick or haulage bar commonly employed for this operation, the need for an efficient system which can measure fuel level with fast response time, high accuracy and reduced human intervention becomes unavoidable. In this work, a reliable and low cost fuel level measuring system for underground liquid tanks was developed. The developed fuel level measuring system was able to measure the volume of test liquid from the constructed tank. The performance test carried out with the system showed that it gave an average deviation of 4.74% from the actual liquid volume it measures. Therefore, the fuel level measuring system for underground liquid tank developed in this work is useful for petrol sales business when estimating the quantity of petrol or other fuels such as diesel and kerosene after delivery and after sales for timely reorder. Further work is ongoing to ensure the developed fuel level measuring system incorporates leakage detection in the form of an alarm circuitry (buzzer unit shown in the block diagram of the developed system) which produces sound when there is a fuel leakage problem.

REFERENCES

- Annuar, K.A.M, Hadi, N.A.A, Saadon, I.M. and Harun, M.H. (2015). Design and Construction of Liquid Level Measurement System. *Journal of Advanced Research in Applied Mechanics*, 12(1): 8 – 15.
- Arduino (2016). Specification of LCD Module. Retrieved December 8, 2016 from [http://www.arduino.cc/documents/datasheets/LCD Screens.pdf](http://www.arduino.cc/documents/datasheets/LCD_Screens.pdf)
- Avrprogrammers (2016). Atmega328P Power Consumption. Retrieved December 8, 2016 from <http://www.avrprogrammers.com/howto/atmega328-power>
- Electroschematics (2016). HC-SR04 Datasheet. Retrieved December 8, 2016 from www.electroschematics.com/8902/hc-sr04-datasheet
- EPA (2016). Doing Inventory Control Right for Underground Storage Tanks. Retrieved December 15, 2016 from <https://www.epa.gov/sites/production/files/2014-03/documents/inventory.pdf>
- Jameco (2016). Micro Buzzer 5 V DC/20 mA PCB Type – Sealed. Retrieved December 8, 2016 from www.jameco.com/Jameco/Products/Prods/1956696.pdf
- Montero, D.S., Lallana, P.C. and Vázquez, C. (2012). A Polymer Optical Fiber Fuel Level Sensor: Application to Paramotoring and Powered Paragliding. *Sensors*, 12: 6186 – 6197.
- Ogata, K. (2010). Modern Control Engineering. Prentice Hall, New Jersey, USA.
- Omega (2016). Level Sensor. Retrieved December 2, 2016 from http://www.omega.co.uk/prodinfo/level_measurement.html
- Osueke, G.O., Nnanna, I. and Omonogbo, R.C. (2013). Design and Production of a Fuel Tank Measuring System Using Computer Interface. *International Journal of Advanced Computer Technology*, 2(9): 275 – 284.
- Stroud, K.A. and Booth, D.J. (2001). Engineering Mathematics. 5th Edition. Palgrave, New York, USA.
- Suleiman, M., Saidu, G.I., Ilyasu, M.I., Adeboye, O.A. and Hamza, M. (2015). Ultrasonic Fluid Level Measuring Device. *International Journal of Recent Development in Engineering and Technology*, 4(1): 1 – 5.
- Tiwari, V. and Jain, A. (2014). Implementation of Capacitive Fluid Level Sensor. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 3(1): 7049 – 7057.
- Westell (2016). Fuel Monitoring. Retrieved November 2, 2016 from http://westell.com/fuel_monitoring