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An Automated Capacitance-Based Fuel Level Monitoring System for Networked Tanks

Oke Alice O.
Email: aooke@lautech.edu.ng

Adigun Adebisi A.
Email: aaadigun@lautech.edu.ng

Olaniyi O. M.
Email: olaniyimikail@bellsuniversity.org

***Abstract* – The making of an effective fuel measuring system has been a great challenge in the Nigerian industry, as various oil organization are running into different problems ranging from fire outbreak, oil pilfering, oil spillage and some other negative effects. The use of meter rule or long rod at most petrol filling stations for quantity assessment of fuel in tank is inefficient, stressful, dangerous and almost impossible in a networking environment. This archaic method does not provide good reorder date and does not give a good inventory. As such there is a need to automate the system by providing a real time measurement of fuel storage device to meet the demand of the customers. In this paper, a system was designed to sense the level of fuel in a networked tanks using a capacitive sensor controlled by an ATMEGA 328 Arduino microcontroller. The result was automated both in digital and analogue form through radio frequency Transmission using XBee and interfaced to Computer System for notification of fuel level and refill operations. This enables consumption control, cost analysis and tax accounting for fuel purchases.**

***Keywords* – ATMEGA 328 Arduino Microcontroller, Capacitive Sensor, Fuel Level, Network of Tanks, XBee OEM Radio Frequency.**

I. INTRODUCTION

In a bid to achieve static quantity assessment of liquid products in bulk storage tanks different methods have been employed, which was done purely by human effort using containers of known measurement, and later metallic meter rule dipped into the tanks[16], which proved to be inefficient and very tedious with increasing number of tanks like those found in depots. Whatever method is used, a high degree of reliability and accuracy is of paramount importance when the data is used for inventory control or custody transfer purposes like in refineries where tank gauging is essential. Various technologies to measure fuel have been adopted ranging from the application of the principle of potentiometer [3] to the application of ultrasonic sensors [11]which is the most common and the weighing principle [12] by researchers to effectively measure and manage the use of fuel within the oil and transportation industries.

Liquid level sensing and controlling system has been a dynamic research area as several works had been carried out in the area. Khaled Reza *et al* [8] implemented a microcontroller-based automated water level sensing and controlling system through the use of four homemade water level sensors to detect water level. Inverted sensor data was used as the input to a PIC 16F84A microcontroller by writing into its memory using MPLAB programming software.

Li *et al* [6] designed wireless sensor network that is based on water-level monitoring system and its implementation. Water-level monitoring has been widely used to reduce the danger of disasters and ensure the safety of ship channels as well as monitor and control the aquatic environment. The work defines remote water level monitoring system (RWMS). The RWMS has real-time remote monitoring, it consists of sensor module, data centre module, base station module and web releasing module. It has excellent features in the form of advantages like anti-jamming and expand abilities capabilities. The system gave excellent result in Poyanghu Lake.

Palafox *et al* [14] gave a solution of SMS based water level metering system. The work is helpful as a warning device in flood water level monitoring during typhoons and in heavy downpours. At critical water levels, it can send message to the associated device which will then sound an alarm. The sensors are made up of wires which are connected to make a simple switch. When the sensor is triggered, it follows the instructions and the GSM modem send warning messages at each level.

Afolabi and Oke [1] implemented a computer controlled fuel level monitoring system using ultrasonic sensors at four different levels of the tank. The system was interfaced to a computer using visual basic programming and triggered alarm at a particular threshold. Hemnandan *et al*. [4] applied the implementation of an embedded control-based system to the remote monitoring of fuel level in a diesel generator set. Utilizing ultrasonic sensor to sense the fuel status and the result displayed on both LCD display and LED bar graph. Short message service (SMS) and alarm were incorporated through GSM network to a remote location. Others are the work of Aher and Kokate [2] who combined microprocessor-based fuel monitoring with tracking system for vehicles. A reed switch and GPS device housed inside the vehicle were used for sensing the fuel level and tracking of vehicles respectively. Obikoya [13] included a query module to a fuel level monitoring system built from sensor and a remote Aplicom 12 GSM module in order to interface the connected sensor. The status message from the module was sent back via a Global System for Mobile Communications (GSM) network to the mobile phone that sent the query (or control) message. Almost all the researchers investigated employed the used of ultrasonic sensor, the introduction of capacitive sensor will achieve easier, stress free and more efficient measurement in stations with large number of tanks such as the Nigeria National Petroleum Cooperation (NNPC) depositary stations. This system can also be adopted where the challenge of fuel quantity measurement system is to provide accurate information over a wide range of aircraft attitudes and variations in fuel properties occur [9].

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II. SYSTEM DESIGN OVERVIEW

The design and implementation of the device for measuring the fuel level for a network of tanks involves the use of capacitance sensor, ATMEGA 328 arduino microcontroller, a radio frequency transceiver and graphical user interface. The overall setup is represented by the model of Fig. 1.

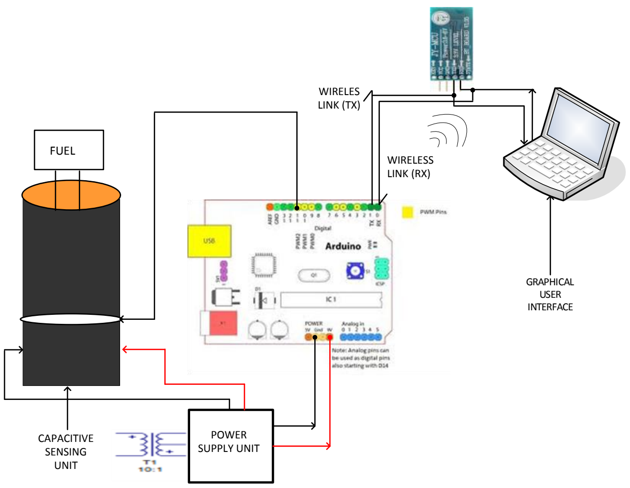

Fig.1. Automated Capacitance-based fuel Level monitoring system

A. Power Supply

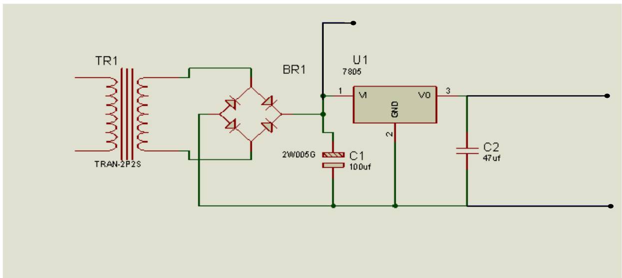

Fig.2. Power source schematics of the System

This unit converts an AC voltage of 200-240V from the main supply to a DC voltage of 5V, 12V,-12V etc. as required by various electromechanical devices. The basic step in a power supply unit is shown in Figure 2. The Transformer stage is used to transform one form of ac signal to another form; in this case a step-down transformer is used to transform the 240V/50HZ AC voltage. In the Rectification stage AC voltage is converted to DC, diodes are used to perform this operation with full wave bridge rectifier method. Filtering stage involves the use of capacitors to smoothen the produced DC voltage from the rectification stage. This is to remove any form of ripples still present in the rectified voltage. Voltage regulation stage utilizes transistors to ensure that a constant voltage is supplied to the components to ensure proper functioning of the components.

B. Capacitive Sensing Unit

Capacitive sensors detect anything that is conductive or has a dielectric different from that of air. Capacitance describes how two conductive objects with a space or dielectric between them respond to a voltage difference applied to them. When a voltage is applied to the conductors, an electric field is created between them causing positive and negative charges to collect on each object [10]. The dielectric constant determines how a non-conductive material affects capacitance between two conductors and Capacitance is typically measured indirectly, by using it to control the frequency of an oscillator. In this paper, the capacitive sensor is represented by plastic tank a dielectric containing the fuel to be monitored and measured. The plastic wall is foiled with aluminum foil and a probe connects the tank of fuel to the microcontroller circuit.

C. The Micro-Controller

An ATMEGA 328 arduino microcontroller was used in the implementation of the micro-controller unit which best suit the transmission process. The microcontroller operates at 5V with 2Kb of RAM, 32Kb of flash memory for storing programs and 1Kb of EEPROM for storing parameters. The clock speed is 16MHz, Which translates to executing about 300,000 lines of C source code per second? The board has 14 digital I/O pins and 6 analog input pins. There is a USB connector for connecting to the host computer and a DC power jack for connecting an external 6-20V power source, for example a 9V battery, when running a program while not connected to the host computer. ATMEGA328 was preferred over other microcontrollers like PIC16F628 because it has a T0CKI (timer zero clock input) which takes a frequency input from the capacitive sensing unit and scales frequency into a range of 0-100, which is used in determining the level of the fuel [7].

D. The Radio Frequency Transceiver

The transmission stage was implemented by using the XBee OEM RF Modules (a wireless transceiver from Digi International) which is engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, more efficient and low-power wireless sensor networks [5, 17]. The modules require minimal power and provide reliable delivery of data between devices through the use of a fully implemented protocol for data communications that provides features needed for robust network communications in a wireless sensor network (WSN). The modules operate within the industrial, scientific and medical (ISM) standard of 2.4GHz frequency band and are pin-for-pin compatible with each other. The choice of XBee is its additional features for monitoring and control of remote devices. It also supports both an AT and an API (Application Programming Interface) mode.

E. Software Development

The development of the software is in two stages: microcontroller and computer system programming. These represent the graphical user interfaces, platforms through which end users interact with the system in term of output to get result that can be interpreted. The first stage which is the hardware interfacing with the software was written with the Arduino Integrated Device Extended (IDE) software program. It is mainly written in C++ with interface as shown in Figure 3. The microcontroller was connected to the required pins on the XBee USB Adapter

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which transmits the values measured to the computer system which is viewed through the graphical user interface. The VDD pin was at 5V when the USB port is providing 5V. The VCC pin was at 3.3V but if it is powered from USB only ~40mA will be drawn from this pin. Connecting voltage to the VDD pin when the USB cable has power

- *LED Status Indicators and Functions*

The XBee USB Adapter has 4 LEDs for status indication. The Yellow LED indicates Power. The Green LED indicates the module is ON (not in Standby mode). The Blue LED is connected to the RSSI pin and the Red LED is connected to the Associate pin. Some of these functions can be reconfigured using the X-CTU software. The USB connector also has two LEDs which indicate TX / RX status. The Red LED indicates data being transmitted to the PC and the Green LED indicates data being received from the PC.

The second stage, which is the computer interface of the program was written using C# in Microsoft visual studios 2010. It was chosen because it has the serial port needed to communicate with this hardware and is easier to implement as compared to other languages. The interface is as shown in Fig. 4.

Fig. 3: showing Arduino interface

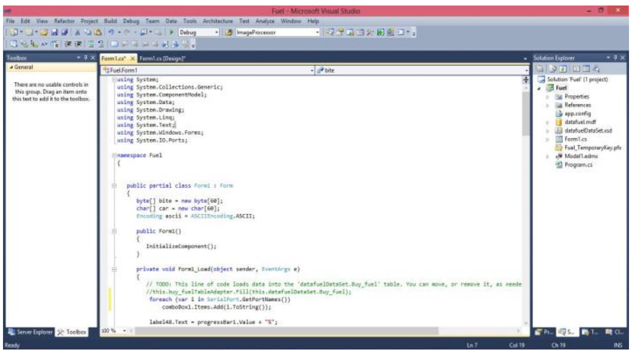

Fig.4. Showing visual studio interface

III. System Operation

The system is made up of two sensors connected as a network which is represented by the capacitive tanks; the tanks act as capacitors (dielectric) in which the probe determines the level of fuel in the tanks by measuring their capacitance. As the fuel level rises in the tanks, the total capacitance value increases. Capacitance is calculated using equation (1), in the formula, since dielectric constant is a constant, it does not change. The distance between the plates also does not change. Therefore, the only variable in the above formula is the area of the plates in the fuel.

$$\text{Capacitance} = \text{Dielectric constant} \times \frac{\text{Area of the plates}}{\text{Distance between plates}} \qquad (1)$$

This area changes as the fuel rises or falls in the tanks. Therefore, the total capacitance changes approximately proportional to the fuel rise or fall in the tank. The fuel level is then determined electronically by the change in capacitance and calibrating it into frequency [15]. The higher the level of the fuel in the tank, the higher the capacitance but the higher the capacitance the lower the frequency output from the circuit. As soon as fuel touches the bottom part of the probe, the capacitance changed abruptly to a lower frequency, which begins the measurement range. As the level rises, more capacitance lowers the frequency linearly. At the highest fill level, the lowest frequency was measured. The output of the circuit is supplied as input to pin- 4 of the ATMEGA328 Micro-controller which then scales the frequency from 0 to 100 to represent the level of the fuel at each frequency. The level is transmitted by the radio frequency transceiver which is received by another transceiver connected to a Computer through a USB. This supplies the readings viewed on the graphical user interface which has the model of the two networked tanks and shows the level of the fuel in each tank. The rise and fall of the fuel in the tanks can then be seen on the computer screen. This gives room for easy monitoring in fuel depositories or filling stations. The complete setup of the system is as shown in Fig. 5 while Fig. 6 shows the schematic of the level of fuel in the tank with respect to frequency.

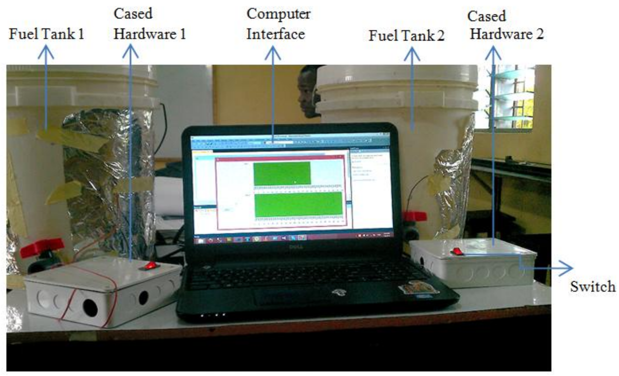

Fig.5. Complete Setup of the fuel level measuring system.

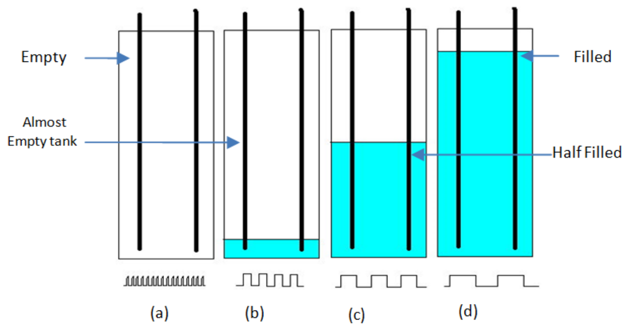

Fig.6. The capacitive sensor (a), Empty tank, (b) Almost empty, (c) Half-filled tank, (d) Filled tank.

IV. Results and Discussion

The system was implemented and stage by stage testing was carried out according to the block representation on the breadboard, before soldering of circuit commenced on Printed circuit board. The process of testing and implementation involved the use of Bench Power Supply; this was used to supply voltage to the various stages of the circuit during the breadboard test before the power supply was soldered and the stages tested after which they were finally soldered. Digital multi-meter was also used basically to measure voltage, resistance, continuity, current, frequency, temperature and transistor. The system was thereafter coupled to a plastic casing designed with special perforation and vents as depicted in Fig. 5. The calibration of frequency was achieved with special consideration to a controlled environment that is void of weather conditions like humidity and breeze blowing on the aluminum foil. Percentage fuel level calculation for the output on the graphical user interface was achieved by the parameters below and results presented on Figs. 8 to 10 showing when the tanks are empty, tank 1 and 2 at 78% and 45% respectively and also tank 1 and 2 at 100% and 50% respectively.

Frequency f when tank is empty = 55300.

Maximum liters = 36l

Bit range (streamed frequency) = (10bit = 2^{10} =1024)

Calibrating value = bit range + 1* maximum liters. = 36900

Tank reading = $((f_{current} - f_{empty} / \text{Calibrating value} * 100))$.

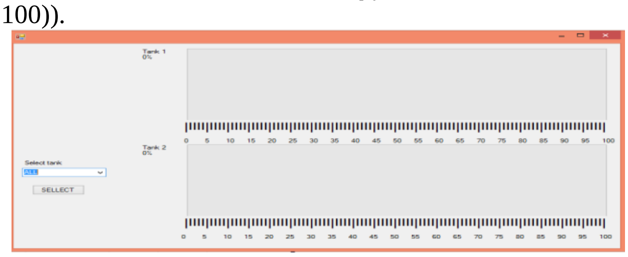

Fig.8. Empty tanks.

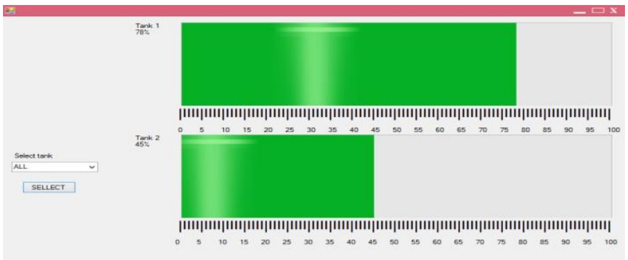

Fig.9. Tank 1 – 78% and tank 2 - 45%

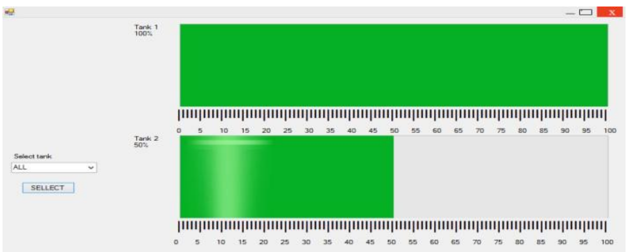

Fig.10. Tank 1 – 100% and tank 2 - 50%

V. Conclusion

This work has successfully implemented an automated fuel level monitoring system in a networking environment with the use of capacitive sensors rather than the common ultrasonic sensor being used by several researchers. Though, two networked fuel tanks were monitored in this paper, there is provision to accommodate more tanks in the network. This makes the maintenance, control and monitoring of fuel consumption and stock in depository stations easier and more efficient with the choice of arduino microcontroller, programming language and the Xbee radio frequency. No doubt this work proffers lasting solution to the use of meter rule or rod in determining the volume of fuel in tanks.

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AUTHOR'S PROFILE

Oke Alice O.
obtained B.Tech (Hons) Computer Engineering (1998), She obtained M.Tech Computer Science (2005) and batch her PhD Computer Science (2012) in Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo State, Nigeria.

She is currently a SENIOR LECTURER in the Department of Computer Science and Engineering of the same institution. A position she steadily rose to from Graduate Assistance. She has over 25 publications in reputable Journals and learned Conferences both locally and internationally. Her research interests are on signal and image engineering, and hardware system design and implementation using wireless network of communication.

Engr. Dr. Oke is a Registered Engineer with The Council for the Regulation of Engineering in Nigeria (COREN) and belongs to the following Professional bodies: full member of Computer Professional (Registration) Council of Nigeria, (MCPN) and the National Computer Society (NCS).
Email: aooke@lautech.edu.ng.

Adigun A. Adebisi
obtained B.Tech (Hons), M.Tech and PhD in Computer Science from Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo State, Nigeria in 1996, 2001 and 2011 respectively.

She is presently a SENIOR LECTURER in the Department of Computer Science and Engineering of the same institution where she has been an academic staff since 1998. She has over 20 published papers in both local and international journals. Her research interests are data mining and knowledge discovery.

Dr. Adigun is a member of Computer Professionals of Nigeria (CPN) and the National Computer Society (NCS).
Email: aaadigun@lautech.edu.ng.

Olaniyi O. Mikail
obtained B. Tech. Degree in Computer Engineering (LAUTECH) in 2005; M.Sc. Degree in Electronic and Computer Engineering (University of Ibadan, Nigeria) in 2011 and Doctor of Philosophy Degree in Computer Security (LAUTECH) in 2015 respectively.

He is a Lecturer in the Department of Computer Engineering, Federal University of Technology, Minna, Niger State, Nigeria. He has published a number of articles in reputable Journals and International Conferences. His research areas among others include: Computer and Information Security, Intelligent Systems, Embedded Systems and Medical Informatics.

Engr. Dr. Olaniyi is a Registered Engineer with the Council for the Regulation of Engineering in Nigeria (COREN). He is a member of The Institute of Electrical and Electronics Engineers' (IEEE), Association of Computer Machinery (ACM), The Institute of Research Doctors and Engineers (IRED), International Association of Engineers and Computer Scientists (IAENG), Nigeria Computer Society (NCS) and Cyber Security Experts Association of Nigeria (CSEAN).
Email: olaniyimikail@bellsuniversity.org.