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Design and Construction of a Refractometer for Measuring Dielectric Constant of Fuels

Folorunsho M. Odeyemi, Sunny Orike, and Benjamin U. Igbinomwanhia

Department of Electrical Engineering, Rivers State University
Nkpolu-Oroworukwo, Port-Harcourt
orike.sunny@ust.edu.ng.

ABSTRACT

The increased air pollution, explosions that will lead to injury/fatality as well as reduced fuel performance caused by adulterated/impure petroleum products are detectable and preventable. In this paper, a portable microcontroller-based refractometer petroleum purity tester for detecting adulterated/impure petroleum products by measuring the dielectric constant value of the liquids was designed and implemented, focusing on households. The design was based on the principle of lasers and photoconductivity (light dependent resistor). The device was calibrated for the following fuel products: Premium Motor Spirit (PMS), Automotive Gas oil (AGO) or diesel, House-Hold Kerosene (HHK) with a tolerance of ±0.02 from standard dielectric constant value of the liquids. The device was used to test unknown fuel samples. The refractive index of the measured fuel product was converted to dielectric value and compared with its standard dielectric constant (PMS = 2.0, AGO = 2.1, HHK = 1.8). The device was able to detect adulterated and non-adulterated fuel products. The device is suitable for households to make real time decision and avoid home accident.

KEYWORDS: Adulteration, Dielectric constant, Household user, Lasers, Photoconductivity

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1. INTRODUCTION

Petroleum products are hydrocarbon fractions obtained from the processing of crude oil. These products include Aviation Turbine Kerosene (ATK), Gasoline or Petrol, industrially referred to as Premium Motor Spirit (PMS), Automotive Gas Oil (AGO) or diesel, Household Kerosene (HHK) simply called kerosene. These products have found increasing use largely as fuel (both domestically and industrially) following the demands of modernization and high technology (Umoren, 2004). Petroleum products have been taking advantage in the area of transportation and power generation as fuel, generally in regular daily existence (Bharath & Himanth, 2017). In recent times, adulteration of petroleum products has become very rampant. A vast number of consumers of these products are facing petroleum products adulteration or impurity threat. This exposes them to a number of problems ranging from poor vehicle engine performance, increased air pollution, incredible hazard to human well-being, home accidents, huge loss of tax revenue, etc. (Garg *et al*., 2015).

Many researchers have used different techniques in detecting adulteration in fuel. The methods are either laboratory-based or equipment are too bulky and costly which are not easily accessible to households who uses the products hence high rate of accidents in the homes. Kude and Patil (2017) presented a real-time sensor framework capable of detecting the level of debasement in fuel and diesel by kerosene in the vehicle itself. The sensor utilizes optical fiber evanescent wave method and has the capacity of detecting 5% adulterants in gasoline/petrol and diesel utilizing evanescent wave absorption method. Daingade *et al.* (2018) presented a research study on “the quality and quantity testing of gasoline fuel using sensing method” to tackle the issue of fuel adulteration. Anpat *et al*. (2018) introduced a PIC16F628 microcontroller-based portable spectroscopy sensor that measures the dielectric constant of liquids. The developed sensor system is based on the principle of frequency variation by dielectric medium. Ghuge and Kolhare (2017) developed a prototype for measuring the dielectric constant of liquid, the protocol was designed using PIC16F877A microcontroller. The system measures dielectric constant of liquid using Wheatstone bridge network and is mainly a process of understanding the dielectric constant of liquid to meet in one hand goal of miniaturization, low cost and portability and which measure dielectric constant of liquid and temperature in air.

A modified operational amplifier-based Wheatstone bridge network was used to compute resistance and hence calculate dielectric constant of liquids. Felix *et al.* (2015) introduced several techniques of contamination detection strategies that are economical and can be adjusted in any car with little changes. Rawat *et al.* (2016) presented a device that is capable of detecting kerosene adulteration in petrol and it operates based on the concept of electric meta-material namely complementary split-ring resonator (CSSR), operating at 2.47GHz (The industrial, scientific, and medical radio band – ISM band). Mishra *et al.* (2008) did a study on adulteration detection by employing long-period fiber grating sensor technology. The group utilizing LPFG method presented the ability of long-period fiber grinding (LPFG) sensor innovation to sense the presence of 10 percent pollutant in automotive fuels whereas the conventional technologies can identify the presence of over 20 percentage pollutant in automotive fuels. Umoren (2004) designed and fabricated a high-sensitive float capable of showing significant depth variations in the range of petroleum products to detect minor adulteration in petrol, diesel and kerosene.

Laboratory test for adulteration on the pure sample petroleum products of petrol, diesel and kerosene obtained in various corporations were carried out using their relative densities. Kanyathare and Peiponen (2018) presented a basic estimation and investigation strategy to screen diesel oils that were adulterated as a result of kerosene. They developed a generally simple estimation strategy to detect contamination and estimate the rising sequence of the quantity of kerosene existing in contaminated samples in field conditions that is dependent on an economical, handheld Abbe refractometer.

1.1 Adulteration

The term "adulteration" is usually used for the inclusion of undesirable substances (Dharurkar & Wadhekar, 2016). Though fuel debasement is primarily a spontaneous outcome of decreasing the dissimilarity at current market price of various vehicle fuels and an endeavor to regulate fuel costs for the sake of equity, the final outcome is air contamination.

1.2 Standard dielectric constant of Fuels

Table 1 shows the standard dielectric constant of diesel, gasoline and kerosene.

Table 1: Standard Dielectric Constant of Petrol, Gasoline, Kerosene (Engineeringtoolbox, 2008)

Liquid	Temperature ^{0}C	Dielectric
Diesel (AGO)		2.1
Gasoline (PMS)	21	2.0
Kerosene (HHK)	21	1.8

1.3 Refractive Index

Refractive index n of a material is a dimensionless number that is associated with the speed of light when going through a dielectric medium Ortega *et al.* (2019). The formula is given below:

$$n = \frac{c}{v} \quad (1)$$

Where n is the refractive index, c is the velocity of light in a vacuum (3 × 10 m/s), v is the velocity of light in a substance

In this paper, we designed and constructed a real-time portable microcontroller-based refractometer petroleum purity tester that can detect adulterated petroleum products namely petrol, diesel and kerosene using one of their properties - dielectric constant. The adulteration is determined from a sample mixture of the petroleum product to be tested. The system measures dielectric constant of fuel using the principles of refraction and diffraction of light rays. The developed device was based on the principle of lasers and photoconductivity (light dependent resistor).

2.0 MATERIALS AND METHODS

2.1 Materials

The portable microcontroller-based refractometer petroleum purity tester in this work comprises of the following:

i. Laser Diode
ii. Arduino Nano ATmega328 based Microcontroller
iii. Liquid Crystal Display (LCD)
iv. Stepper Motor
v. ULN2003A Relay Driver
vi. Light Dependent Resistor (LDR)
vii. Power supply unit (Battery)
viii. Voltage regulator

2.1.1 Laser Diode

Semiconductor Laser Diode- 620 nm wavelength was used to generate light. The laser diode is widely used in Fibre-optic communication, optical disk drives, barcode scanners, cutting and welding materials, military, in laser lighting displays for entertainment, laser surgery, laser pointers, laser printers, CD/DVD players and so on (Hecht, 2020).

Figure 1 Laser Diode- 620 nm Wavelength

2.1.2 Arduino Nano ATmega328 based Microcontroller

Arduino Nano 3.0 was used in the design and implementation. Arduino Nano is a small, complete, compatible, pliable and easy-to-use microcontroller board Aqeel (2018). It is programmed using the Arduino Software Integrated Development Environment (IDE), common to all boards and running both online and offline.

Table 2: Arduino Nano Technical Specifications (Components101, 2018)

Microcontroller	ATmega328P – 8 bit AVR family microcontroller
Operating Voltage	5V
Recommended Input Voltage for Vin pin	7-12V
Analog Input Pins	6 (A0 – A5)
Digital I/O Pins	14 (Out of which 6 provide PWM output)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 mA
Flash Memory	32 KB (2 KB is used for Bootloader)
SRAM	2 KB
EEPROM	1 KB
Frequency(Clock Speed)	16 MHz
Communication	IIC, SPI, USART

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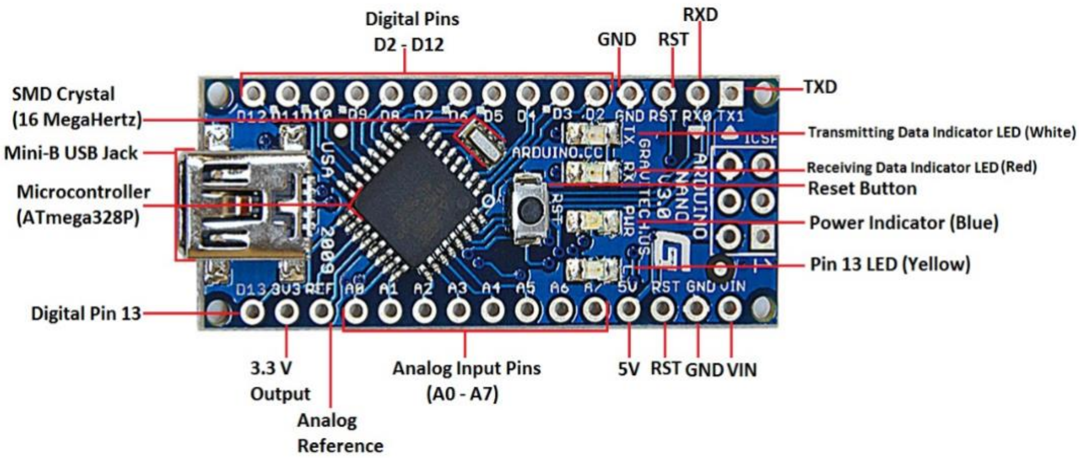

Figure 2 Arduino Nano PIN Diagram (Circuitstoday, 2018)

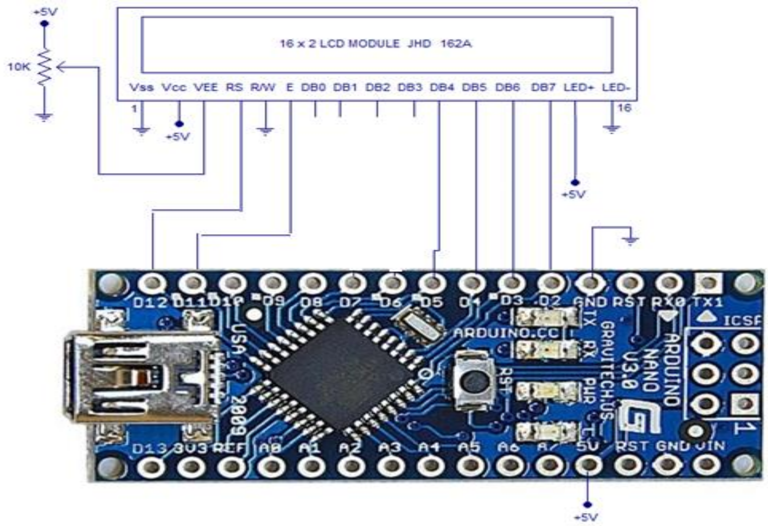

Figure 3 Arduino Nano to 16 X 2 LCD (Circuitstoday, 2018)

2.1.3 Liquid Crystal Display (LCD)

The JHD162A 16 X 2 alphanumeric LCD module was used in this design as display unit to show results. Figure 3 shows the interface connection between Arduino Nano and JHD162A 16X2 LCD

2.1.4 Stepper Motor

A stepper motor is an electromechanical device that converts electrical power into mechanical power. The stepper motor utilizes the theory of operation for magnets to make the motor shaft turn exact distance when a pulse of electricity is applied. CD-ROM Stepper Motor was utilized to control the to and fro movement of the LDR. It requires +5v to operate.

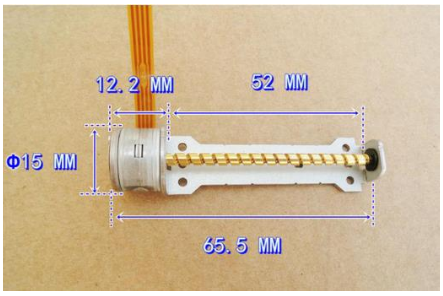

Figure 4 CD-ROM Stepper Motor

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2.1.5 ULN2003A Relay Driver

ULN2003 is a relay driver IC comprising of a Darlington array. They are generally utilized as relay drivers to drive various kinds of loads. It works on 5V and TTL (Transistor Transistor Logic) and CMOS (Complementary Metal Oxide Semi-Conductor). In this work, ULN2003A was used as relay driver. It was used to interface stepper motor to the microcontroller.

2.1.6 Light Dependent Resistor (LDR)

Light Dependent Resistor (LDR) is a component that has a (variable) resistance that changes with the light intensity that falls upon it. These resistors work on the principle of photoconductivity. In this work, LDR is connected to Arduino Nano pin A0 via a 1K resistor. It measures the refractive index. See Figure 5.

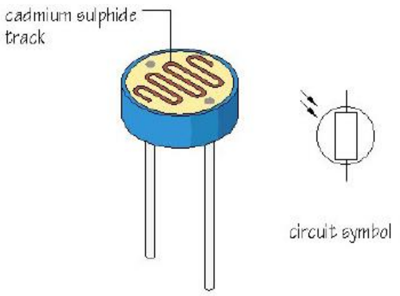

Figure 5 Typical Light Dependent Resistor

2.1.7 Power supply unit (Battery)

Single power supply module was designed to fulfill the requirement of all the different devices/electronic components. 12V battery is given for power supply. This 12V battery voltage is converted to 5V via a low-cost voltage regulator to supply power to the entire system, independent of current drawn from the supply. The voltage regulator circuit comprises of a regulator integrated circuit and filter capacitors ceramic type. The two capacitors (C1 and C2) filter any noise that is combined with the Input voltage. Figure 6 shows Power Supply Unit.

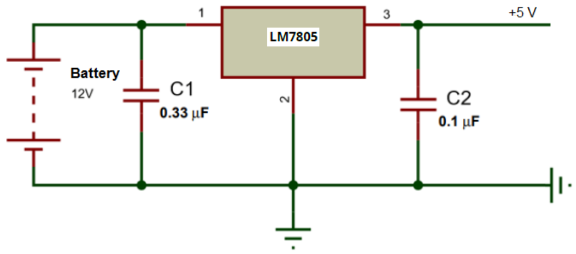

Figure 6 Power Supply Unit

2.1.8 Voltage regulator

Voltage regulators are very common in electronic circuits. They provide a constant output voltage for a varied input voltage Components101 (2017). LM7805 Voltage Regulator IC was utilized in the power supply unit.

2.2 Methods

Hardware and Software approach were adopted in the design and construction of the portable refractometer tester.

2.2.1 Hardware Design

The system consists of 620 nm Laser Diode, LDR, +5v Stepper Motor, +5v ULN2003A Relay, an LCD to show the output. The system is controlled by utilizing Arduino Nano. Figures 7 and 8 show the system block diagram and system circuit diagram respectively.

2.2.2 Software Design

Arduino Integrated Development Environment IDE, and Proteus were installed in the programming PC. The software that manages the operations and functions of the portable petroleum purity tester was developed using the IDE and uploaded and to the board. The code was written using C/C++. Proteus software was used to design the device circuit. Figure 10 shows the logic flowchart.

2.2.3 Sampling/Testing

Fuel Samples were collected in test tube container. Using a portable microcontroller-based refractometer petroleum purity tester, adulteration test was conducted on Petrol, Diesel and kerosene respectively. Also, we carried out test on different mixtures of the fuel products. Each test result was tabulated

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and displayed on the LCD. Sample tests were carried out under room temperature of between 24-26 degree Celsius. Test was done to determine if any of the three fuels under study were adulterated or not.

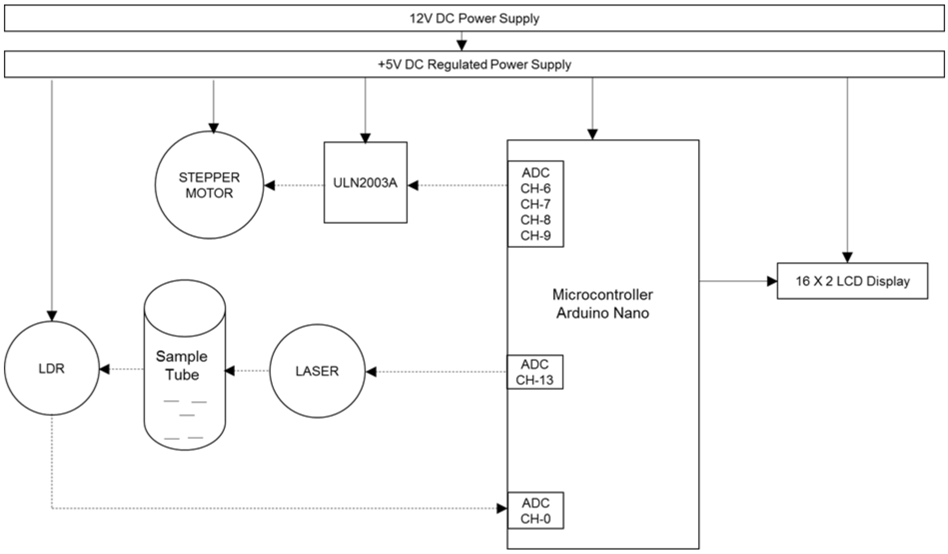

Figure 7 System Block Diagram

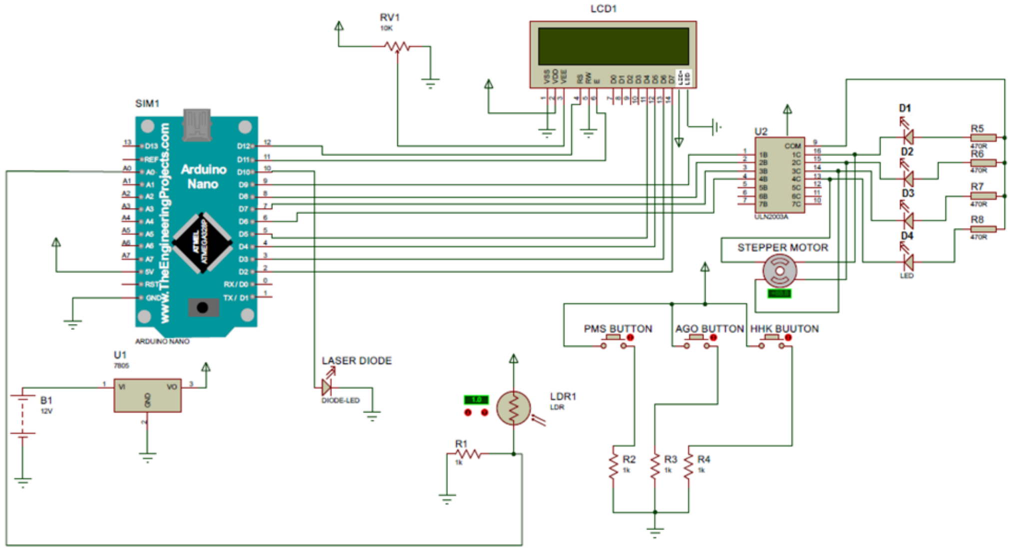

Figure 8 System Circuit Diagram

2.2.4 Working Principle

The system circuit diagram shown in Figure 8, consists of an Arduino Nano controller, a 16X2 LCD screen, a 620nm laser diode, an LDR, 1K resistor, PMS button, AGO button, HHK button, a 5V stepper motor and a ULN2003 stepper motor driver. Here, we explain the

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theory and step-by-step of operation of the working principle.

(a) Theory of Operation

Operation of the purity tester device is based on Snell's law. The law states that the ratio of the sines of the angles of incidence and refraction is equivalent to the ratio of phase velocities in the two media, or equivalent to the reciprocal of the ratio of the indices of refraction. In this case, the media are the air and the petroleum product (AGO, HHK and PMS) to be investigated. The laser diode producing the incident light ray which is refracted by the test sample and again refracted in air before striking the LDR. Theoretically, this can be expressed as:

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1} = \frac{n_1}{n_2}$$
(2)

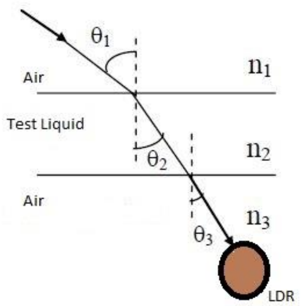

Figure 9 Measurement of the Refractive Index in the Test Liquid

Applying Snell's law to Figure 9, we have equation (3).

$$n_2 = n_3 \sin\theta_3 \quad (3)$$

(b) Device Operation

The Petroleum sample to be verified is first poured into a test tube. The test tube containing the test sample is then inserted into the device. The system operates on the principle of refraction and diffraction of light rays. This light ray is generated by the 620nm laser diode. The laser diode is positioned such that its beam is directly incident on the LDR which is placed 1 inch away from it. This separation is provided for the test sample contained in the test tube to be inserted into. The Laser diode is connected to digital pin 13 of the Arduino Nano controller and only emits beams when a mode is selected. The Light Dependent Resistor (LDR) is connected to Arduino Nano pin A0 via a 1K resistor. The LDR is mounted on a screw attached to a stepper motor. As the LDR moves To and Fro, the LDR measures the refractive index of the light ray penetrating through the test tube. The measured refractive index by the LDR is fed to the controller via analog pin A0. Mode selection is done by pressing any on the buttons. Buttons 1, 2, and 3 are used in setting the device to PMS, AGO and HHK modes respectively. The measured refractive index n (or index μ) is converted to Dielectric constant using formula in (4).

$$\varepsilon_r = n^2 \quad (4)$$

The calculated dielectric constant is compared with literature dielectric constant of fuel. Device will display if the tested fuel is adulterated or not. There is a tolerance of ±0.02 in the calculated values.

3.0 RESULTS AND DISCUSSION

3.1 Results

Figures 11 and 12 show the complete device and the control circuitry of the portable microcontroller-based refractometer petroleum purity tester.

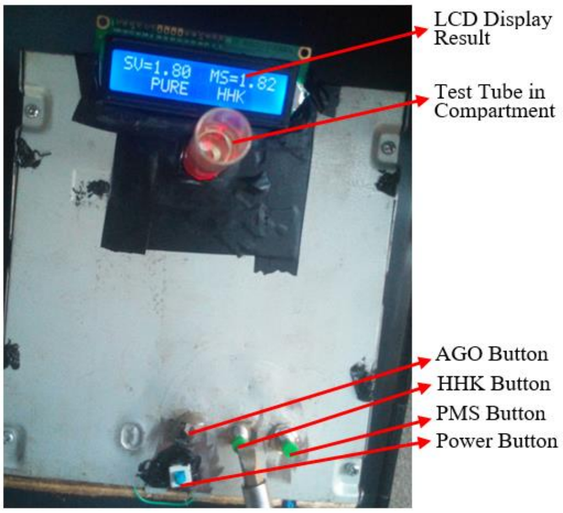

Figure 10 Portable Fuel Refractive Index Tester.

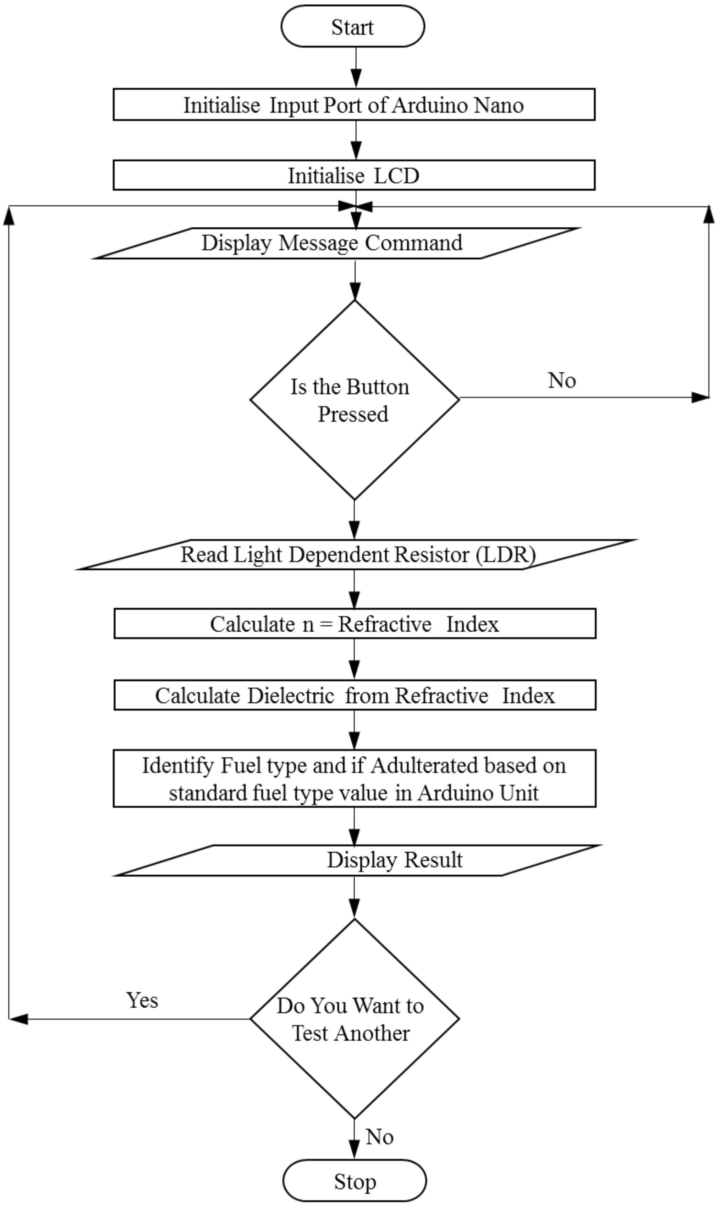

Figure 11 Design Flowchart

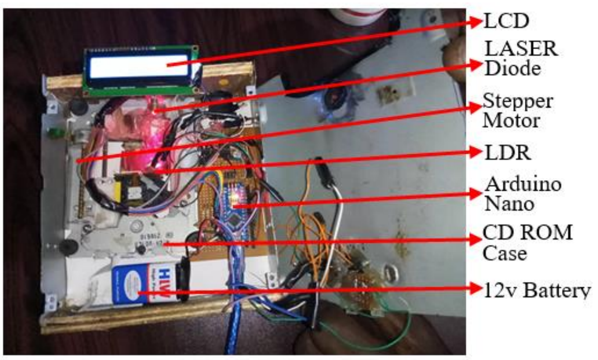

Figure 12 Control Circuit

Arduino Software IDE web editor that was used to
program the logic. Figure 8 shows the designed circuit using Proteus.

3.1.2 Pure Fuel Sample Test

Pure samples of Petrol, Diesel and Kerosene were prepared and tested with the portable refractometer petroleum purity tester. The results were obtained with a tolerance of ±0.02 for each sample test as shown in Table 3.

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Table 3: Test for Pure Fuel Samples with a Tolerance of ±0.02

Pure Sample A	Adulterant Sample B	% Mixture A:B	Literature Dielectric Value	Measured Dielectric Value	Displayed Result on LCD
Diesel (AGO)	-	-	2.1	2.10	Pure
Gasoline (PMS)	-	-	2.0	2.01	Pure
Kerosene (HHK)	-	-	1.8	1.82	Pure

3.1.3 Adulterated Fuel Sample Test

Different samples of the mixture were prepared. Purity test was carried out for specific fuel product in the mixture. The results are shown in Tables 4 to Table 6 respectively.

Table 3: Test for Diesel Purity with Tolerance of ±0.02: Pure Diesel (sample A) mixed with adulterant Gasoline (Sample B).

Pure Sample A	Adulterant Sample B	% Mixture A:B	Literature Dielectric Value	Measured Dielectric Value	Displayed Result on LCD
Diesel (AGO)	Gasoline (PMS)	90:10	2.1	2.07	Impure
		70:30	2.1	2.05	Impure
		60:40	2.1	2.04	Impure

Table 4: Test for Gasoline Purity with Tolerance of ±0.02: Gasoline (sample A) mixed with adulterant Kerosene (sample B).

Pure Sample A	Adulterant Sample B	% Mixture A:B	Literature Dielectric Value	Measured Dielectric Value	Displayed Result on LCD
Gasoline (PMS)	Kerosene (HHK)	90:10	2.0	1.97	Impure
		70:30	2.0	1.94	Impure
		60:40	2.0	1.90	Impure

Table 5: Test for Kerosene Purity with Tolerance of ±0.02: Kerosene (sample A) mixed adulterant Diesel (sample B).

Pure Sample A	Adulterant Sample B	% Mixture A:B	Literature Dielectric Value	Measured Dielectric Value	Displayed Result on LCD
Kerosene (HHK)	Diesel (AGO)	90:10	1.8	1.85	Impure
		70:30	1.8	1.88	Impure
		60:40	1.8	1.92	Impure

3.2 Discussions

The designed system was simulated by testing for purity with sample fuel products. It was able to detect pure and impure fuel products based on it measured dielectric constant value. The displayed results help to identify pure and adulterated fuel products. The output result in Table 3 is a summary when the fuel products are not adulterated. Pure sample of each fuel product was poured into the test tube container and content tested for purity with the device. For each test, a corresponding push button was pressed to activate the logic code. As the push button is pressed, the laser diode beam light through the tube containing the product and the Light Dependent Resistor measures the refractive index and send to the microcontroller. The refractive index value is used to calculate the dielectric constant. The obtained dielectric constant value is compared to their respective literature value. "PURE" was displayed on the LCD since it is not adulterated.

Similar tests described for Table 3 above were carried out when the fuel products were mixed or adulterated with each other. From the output results obtained in Tables 4 to 6, it is observed that the device was able to detect adulterated/contaminated fuel product hence displayed "IMPURE" on the LCD. Also, Tables 3 to 6 show that the device can detect adulterated and none adulterated fuel product hence, help to guide potential buyer/user.

Overall, the developed microcontroller-based sensor system is sufficiently robust and flexible enough to detect adulterated fuel. With this household user of the product is assured of good quality.

4.0 CONCLUSION

This paper presents a portable microcontroller-based refractometer petroleum purity tester system that is capable of detecting adulterated fuel products. The fuel products include petrol, diesel and kerosene. The portable device was able to detect adulterated and none adulterated fuel. It is cheap, simple to operate, portable, robust, and apt at this period. This reduces the number of fire incidents in household that uses these fuel products.

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