Design and Construction of an Ultrasonic Sensor Based System for Determination of Fuel Adulteration Content by Refractive Index Analysis

O.J Dada[1], E.O Oloyede[2], A.O Ayannusi[3], A.I Oyedeji[4]

Abstract— The design and construction of a non time-consuming sensory device that can measure the refractive index of a fuel sample in order to check whether the fuel is adulterated or not is presented. In this research, three fuel samples were experimentally examined using an ATMega328 microcontroller based ultrasonic sensor with the help of combined lenses to determine their respective refractive indices, and thus, the percentage differences when compared to the theoretical value of the index of refraction of unadulterated fuel. The results of this research work shows that the non adulterated sample (A) has refractive index of 1.4384 with relative percentage error 1.29%, adulterated sample (B) has refractive index to be 1.3902 and the percentage error of 0.02%, and adulterated sample (C) has a high refractive index of 1.5534 with relative error 9.38%. The sensory device is useful for determination of adulteration in fuel samples with an accuracy of up 0.02% deviation from the refractive index of genuine fuel.

Keywords— fuel, Adulteration, Refractive index, ATMega328 microcontroller, Ultrasonic sensor, Relative error.

1 INTRODUCTION

Petroleum products are being exploited as fuel in power generation and transportation, universally in everyday life. The consumption of these fuels escalates every single year to the tune of nearly 4%. The business person and pirates, who vend and transport fuels, do make use of fraudulent practices for their profit by combining low-priced hydrocarbon additives with the genuine fuel [1].

Fuel adulteration is an imminent harm that occurs in many local refineries due to unstable fuel prices compared to other cheap refined petroleum products. Adulterated fuel has harmful effects both on automobile engines and human health. The emission gas from the affected automobile engine produces harmful pollution to the environment.

Regulatory bodies such as the Department of Petroleum Resources (DPR) and the American Society for Testing and Materials (ASTM) have various test methods for gasoline (petrol) and diesel which were limited to the determination of the physical and chemical properties of the fuel. There are different time-consuming tests in the laboratory namely; Evaporation test, Density test, Gas chromatography, Distillation test, etc. These tests help to determine if the fuel being tested is adulterated or not. In order to check and control the adulterants both in gasoline (petrol) and diesel there should be an impeccable mechanism for tests both at the statutory as well as the laboratory level. On-point fuel adulterant detection sensors give easy and fast detection of adulterants in the fuel quicker than the expensive and wearisome laboratory methods. Different fuel adulteration detection sensors have been designed and fabricated to determine fuel adulteration. In addition, computational techniques also have been embraced to detect fuel adulteration. Recently, different research is on-going with the use of sensors to develop less time-consuming means of detecting fuel adulteration using optical fibers. Optical fibers are suitable due to their inherent immunity to electromagnetic interference, their safety in hazardous and explosive environments, their high sensitivity and their ease of use for long distance remote measurements [2]. Specific sensors can be developed to sense different properties of the fuel.

A sensor is a basic device that functions majorly in detecting and responding to some type of input from the physical environment. The input could be of environmental parameters such as; heat, pressure, moisture etc. The output signifies to human-readable display or through sound buzzer electronically.

Sensors are widely used in this digital modern world unlike analog sensors such as force-sensing resistors and potentiometers. Major applications include airplanes, cars, robotics, medicine, manufacturing and machinery, and many other aspects of our daily life.

The purpose of this research is as follow:

i. Construct a sensory device that can determine, at a statutory level, whether a particular fuel is genuine or adulterated.
ii. Develop a non time-consuming sensor that can check for fuel adulteration.
iii. To calibrate a microcontroller based sensor that can determine the refractive index of fuel using the principle of combined lenses.

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2. MATERIALS AND METHODS

The material used for this research is as follow:

a. Point LED
b. Biconvex Lens
c. Plain mirror
d. ATMega 328 Microcontroller
e. Ultrasonic Sensor
f. Plastic transparent screen

The ATMega328 microcontroller based on an ultrasonic sensor was used to determine the refractive index by measuring the positive lens focal distance (F_1), the combined lens distance between the positive lens and the liquid (F_C) through the reflection of the shadow and radius positive lens (R). The ultrasonic sensors were used as a digital distance measuring device.
The refractive index of the fuel was obtained by placing a sample of the fuel in-between the flat mirror and the biconvex lens. The clearest shadow distance captured by the viewing screen is the combined focal distance between the positive lens and the liquid lens (Fc). The focusing distance of the fuel lens (F_2) was easily determined and mathematically calculated to give the refractive index. In this design, a calibrated microcontroller-based sensor that can determine the refractive index of fuel using the principle of combined lens was used with the ultrasonic sensor which was able to provide a precise measurement of distances ranging from 2-centimeters to approximately 4 meters (0.79 inch to 9.84 feet). It works by emitting a short ultrasonic burst and then measures the time it takes the burst to bounce back when it hits an object. By timing this process, it is able to calculate the exact distance between the sensor and the object.

Figure 1: Practical picture of the lens / mirror setup.

The sensor has a three-pin connector: GND, 5V DC, and a signal line. The signal line will return the distance measured in *pulses.* The sensor runs at a voltage value of 5V and uses pulse-trigger and pulse-width to trigger. A microcontroller, ATMEGA328P, is connected to the sensor to generate the pulse and also to measure the pulse.
To activate the sensor, a *low-high-low* pulse is sent to trigger it. After it is triggered, it will wait for almost 200 microseconds before sending out an ultrasonic burst. In the meantime, one will wait for the burst to be bounced back; this entire pulse duration (which starts when the burst is sent) represents the round-trip distance from the sensor to the object one is detecting .In the microcontroller, each *pulse* has a duration of 2µs (two microseconds). Hence, in order to convert the pulse to time, the number of pulses is multiplied by a number of 2. This will give the time in µs. Because the measured pulse is for the trip to and fro, it is divided by 2 to get the time from the sensor to the detected object. Sound travels through air at a value of 1,125-1,130 feet per second at sea level; this was achieved to be 1 inch in 73.746 µs (or 1 cm in 29.034 µs). To convert the time measured in µs to a distance in centimeters, one needs to multiply the time by 29.034 (or 30 for simplicity). This will give the distance in centimeters.

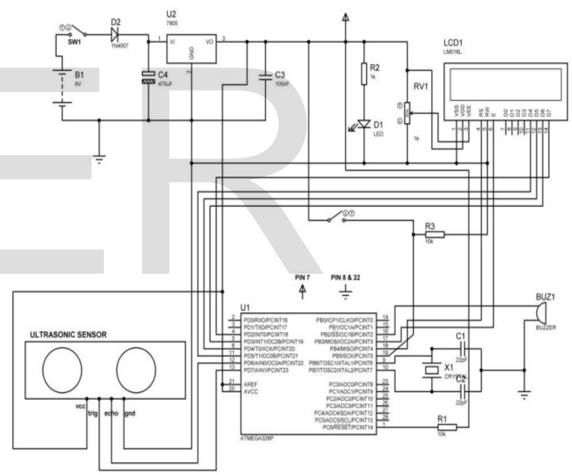

Figure 2: Circuit diagram of ATMega328 with Ultrasonic sensor to measure the focal distance

3. RESULT AND DISCUSSION

After the program software was developed using Arduino Uno for coding on the ATMega328 microcontroller, the circuit diagram in Figure 4 above was finally built. In this design, a pointing LED bulb, two biconvex lenses, and a flat mirror with a less reflective plastic container were used. At first, the focal length of the positive lens biconvex lens (F_1) was determined by observing the clearest shadow captured on the adjustable screen or the distance between the adjustable screen and the double lenses without placing the liquid on the container, observed values is shown in Table 3 below.
The fuel to be checked for it refractive index was poured into a container whose bottom / base was a flat mirror. The fuel samples were poured on the surface of the flat mirror,

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and then the second biconvex lens was placed on top without touching the fuel, see figure 8.
The clearest shadow was seen through the adjustable screen, the distance captured by the ultrasonic sensor was displayed on the LCD screen and recorded in Table 2 below.
Finally the fuel focus distance (F_2) can be easily calculated using the combined lens equation between F_1 and the combined lens (F_C) using equation 1 below:

$$\frac{1}{F_C} = \frac{1}{F_1} + \frac{1}{F_2} - - - - - - - - - - - - (i)$$

After knowing the fuel focus distance (F_C), the refractive index n of the fuel can be calculated using lens forming equation (ii) below:

$$\frac{1}{F} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] - - - - - (ii)$$

Where R_1 and R_2 are the radii of the positive lens and the fuel lens, respectively. The fuel lens was assumed to be in the form of a concave lens since the two lenses were touching each other. The flat side, which is the bottom end of the fuel cannot be set to infinity (∞) since R_1=R_2 for both biconvex lenses.

$$\frac{1}{F_2} = (n-1)\left[\frac{1}{R_1} - \frac{1}{\infty}\right] - - - - - - (iii)$$

Conclusively, the radius R of the biconvex lens was determined using fingered biconvex lens with Spherometer to be 28.12cm [3].

The equation (iii) above can be reduced to equation (iv) below: with R as the radius of the biconvex lens. The refractive index can be easily obtained with a reduced equation (iv) below:

$$n = 1 + \frac{R}{F_2} - - - - - - (iv)$$

Where $R = 28.12\text{cm}$, and *n* denotes refractive index.
Fuel Sample A is a non-adulterated fuel, fuel sample B is a mixture of kerosene and gasoline fuel, while fuel sample C is fuel mixed with diesel.
Equations (i) and (iv) were carefully used to calculate the focusing distances (F_2^a, F_2^b, F_2^c) of the fuel samples and their refractive indices n_a ,n_b and n_c respectively in other to deduce table 4.
Equation (v) was used to compute the percentage relative error in Table 4.

$$R.E = \frac{Experimental\ value - Theoretical\ value}{Theoretical\ value} \times 100 - - - - - (v)$$

The image formed by the first biconvex lens lies parallel as if there were no second lens obstructing the image, and the ray on the second biconvex lens with the shadow formed by the first biconvex lens acts a real object for the second biconvex lens. The second image F_2 formed is the final image of the system, the earlier image formed by the first biconvex F_1 and F_c may produce virtual image and treated to be negatives, if the image is directly formed at the backside of the second biconvex lens as it appears in the Figure 7 below [4].

The average refractive index and standard deviation for each fuel sample (i.e. fuel A, fuel B, and fuel C) were deduced as follows (see Table 4 below); 1.438403±0.051229, 1.42047±0.044159, and 1.553434±0.070336 respectively.

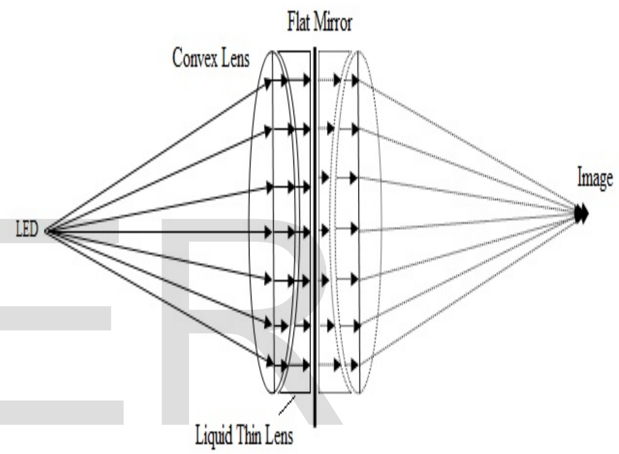

Figure 3: Rays on Focus Determination of Combined Lenses (F_C), taken from [3].

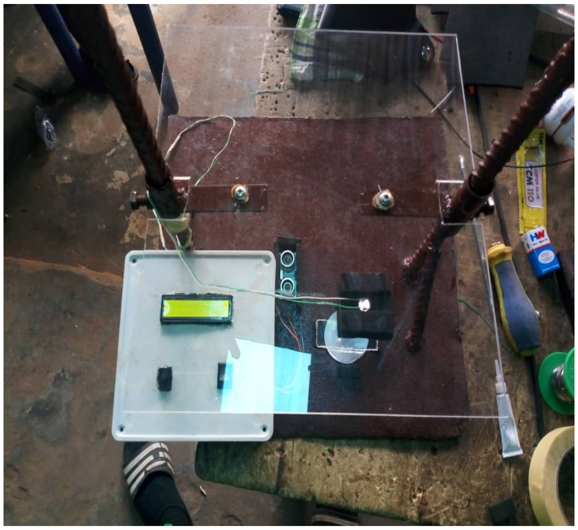

Figure 4: Constructed experimental work that determines fuel refractive index.

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Figure 5: Side view of constructed experimental work that determines fuel refractive index

Table 2: Observed data of negative focus distances of combined lenses with ordinary fuel (A), fuel mixed 5% with kerosene (B) and fuel mixed 5% with diesel (C).

Combined focus distances ($-F_C$) in cm			
S/N	**Fuel (A)**	**Fuel (B)**	**Fuel (C)**
1	21.4	20.6	23.2
2	21.1	21.1	22.5
3	20.7	20.7	22.2
4	20.9	20.6	24.0
5	21.2	20.9	23.4

Table 3: Data of negatives focus of biconvex lenses (F_1)

S/N	$-F_1$ (cm)
1	15.7
2	15.6
3	16.4
4	15.5
5	16.1

Table 4: Observed results of refractive index of non adulterated fuel sample A and adulterated fuel samples B and C.

S/N	FUEL SAMPLE	REFRACTIVE INDEX	THEORY	RELATIVE ERROR
1	A	(1.4384 ±0.0512)	1.4201	1.29%
2	B	(1.4205 ± 0.0442)	1.4201	0.02%
3	C	(1.5534 ± 0.0703)	1.4201	9.38%

4. RESULTS AND DISCUSSION

The observed results obtained in this research work for the refractive index of three fuel samples (A, B, and C) are not too different from the theoretical value of fuel index of refraction as seen in Table 5. The non-adulterated fuel (Sample A) was observed to have refractive index 1.4384 with relative percentage error 1.29%, almost equal to the theoretical value 1.420, unlike the other adulterated samples which were mixed with kerosene and diesel respectively.
Adulterated sample C (i.e fuel mixed with diesel) has a high refractive index of 1.5534 with relative error 9.38% which is very different from the theoretical value as a result of high viscous and density value of the adulterant. Several factors may affect the high deviation such as temperature, molecular / atomic composition of the adulterant.
The observed index of refraction for sample B with kerosene adulterant is almost equal to the theoretical value due to the less viscous value of the kerosene adulterant and its refractive index of 1.3902. The percentage error of 0.02% is less compared to other crude oil products.

5. CONLUSIONS

The main goal behind this research was to determine the refractive index of fuels in order to know if the fuel is genuine or adulterated. This goal was achieved by using combined lenses with focus distances determined by the ATMega328 microcontroller based ultrasonic sensor. The clearest shadow distance seen through the adjustable screen without the addition of fuel sample (F_1), and the combined lens with the fuel sample (F_C) is the positive focal distance and combined fuel focus distance while F_2 and R are the fuel image focus distance and fuel lens radius determined by spherometer respectively. In conclusion, the greater the viscosity of any liquid sample, the greater its index of refraction, however, this method is 90% accurate to differentiate between genuine and adulterated fuel of about 5%.

5.1 RECOMMENDATION

Uncontrolled emissions of polluted gases from the tailpipe of affected automobile engines which inadvertently use adulterated fuel affects human health and also shorten the lifespan of most automobile engines. In order to control

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and rectify these practices, a proper measure must be put in place to check at statutory whether the fuel is genuine or adulterated. The result of experimental research work should be widely considered as a useful gadget that can measure mathematically the refractive index of fuel and later relates its measured value with the theoretical value. This comparison helps to determine whether the fuel was adulterated or not.

i. In recommendation, the government should put attention in this area by making this adulteration detector available to all fuel stations for consumers to see how genuine the fuel is before consuming.

ii. More research should be done on this work by producing a well compatible device that can be used by end-users in order to check how genuine the fuel is before consumption.

6. Acknowledgment

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