Optical Sensing System for Detecting Water Adulteration in Milk

Aditya Dave Dishant Banwari
Birla Institute of Technology and Science (BITS)
Goa Campus
Sancoale, Goa 403726, India
{f2013133[1a] & f2013186[1b]@goa.bits-pilani.ac.in}

Satyam Srivastava Shashikant Sadistap
Academy of Scientific and Innovative Research(AcSIR)
CEERI, Pilani
Pilani, Rajasthan 333031, India
satyamsrivastava2442@gmail.com, ssadistap@yahoo.co.in

***Abstract* - There has become an ever increasing need for detecting good quality of milk against the bad one because of the vast number of methods now known and used for milk adulteration. Especially since India has a vast and thriving dairy industry committing an adulteration fraud can reap rich profits and exploit poor people if undetected. Traditional methods involve measuring the specific gravity (e.g. Lactometer). But if the weight after introducing the adulteration is kept constant, such methods fail. The ones that have overcome this flaw and are presently prevalent are contact based methods that involve contact with the milk samples and hence the samples cannot be used again. Such methods lead to large amount of wastage of milk since the reliability seen thus far does not guarantee accurate adulteration detection within short number of tests. This paper proposes a completely non-contact type method for detection of milk adulteration, preserving the consistency and quality of milk sample and making it reusable for testing again. About 500 raw milk samples were considered for the study and categorized into 3 categories namely Cow milk, Buffalo milk, skimmed milk. Fresh samples obtained were from different dairies and commercial local brands like Saras, Anand, Amul etc. An embedded system consisting of AVR micro-controller integrated with the optical sensor, LCD and keypad was built. Refractive index was the principle parameter involved in detecting the adulteration. As the amount of water adulteration changed, the refractive index changed and these relations were used to configure the system for detecting adulteration of a random milk sample. The results obtained detected the adulteration with an accuracy of about 95 ± 1% which show an increase in misclarification accuracy of about 200% over traditional methods such as spectroscopy.**

Index Terms* - *Raw milk samples, Adulteration, Embedded System, Optical.

I. Introduction

Growing commerciality of a product is directly proportional to chances of the product being misused for monetary gains. Especially when the consumer is lacking awareness the manufacturers tend to pry on this and exploit the consumer. India being a largely vegetarian society depends on milk rather than meat for its nutritional needs. Thus dairy is a major industry and adulteration of milk is a very common business that suppliers/manufacturers engage in. Most of the people who are a part of this industry are villagers who sometimes have very little awareness that they are being exploited. Hence in an initiative to support the humanitarian cause aimed at stopping the practice of adulteration of milk and the ill-effects associated with it the authors have come up with the idea of building a portable embedded system which can detect the adulterants present in milk.

Diluting the milk with water reduces its nutritive value and also exposes a number of health risks when contaminated water is used. Diseases like cholera, jaundice and typhoid are very common [1]. Other adulterants include urea, caustic soda, formalin etc. While short term effects of ingesting these include diseases like gastroenteritis long term effects can be even more severe like hypertension and heart ailments [2]. Taking all this into consideration it has become extremely necessary to address this issue right away.

In the past contact based methods have been used in order to detect the adulteration present in milk. These methods involve preforming chemical reactions on the milk to detect adulteration [3]. The process involves mixing the MALDI sample in a large quantity of milk and the amount of absorption of the ultraviolet light which is then converted to heat determines adulteration. While these methods yield results, the samples cannot be used again and this leads to wastage of milk. Also the amount of sample required is large and hence this method is not always viable. Other than chemical methods, various researchers contributed different destructive type of technologies [4-6]. E-tongue [7,8] is one of the most recognized method of adulteration detection and it reached a commercial level. It used 36 cross – sensibility sensors allowing successful recognition of 5 basic taste standards. Although it detects many types of adulterants, the process is time consuming and not very accurate. Later non-contact methods like spectroscopy were proposed which can retain the sample for further use [9, 10]. However such methods suffer from lack of accuracy and hence are not always reliable. The method in [10] reported an accuracy of 92% which is certainly improved by the proposed system.

The proposed system though limited to water adulteration detection as of now, is extremely cost effective since it involves the use of a microcontroller ATMega32 which is cheaply available, an LCD display and keypad. The sensor used has been made out of using a LED array as light source and OPT101 photo-detectors which are one of the cheapest available in the category of photo-detectors.

The components used in building the system have been briefly explained in this section.

A. Optical Sensor

The optical sensor was specifically constructed for obtaining a high accuracy since the commercially available

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ones did not meet the desired levels of detection required. The optical sensor constructed involved placing 9 photo-detectors at distinct angles 20 degrees apart so as to measure the intensity of the refracted light from the sample and determine the angle of refraction. This in turn helped calculate the density of the medium and determine the amount of adulterant present. The light incident to the sample was from a raw led source consisting of an array of 7 LEDs arranged in a cyclic pattern to get uniform illumination.

B. Embedded System

The whole setup was integrated to build a portable embedded system consisting of a 20X4 LCD to display the percentage adulteration and a keypad for selecting different modes of operation. ATmega 32, an 8-bit AVR based microcontroller was used for the system.

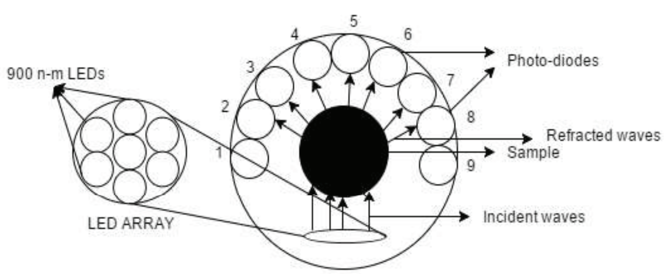
C. Peripheral Circuitry

Peripheral circuitry consisting of basic op-amp amplifiers and comparators was needed to get amplify the signal and eliminate noise from the sensors' output. After a good enough SNR was achieved interpreting and analyzing the data became simpler.

Section II deals with the Optical Sensor design, section III deals with the measurement procedure. Section IV describes the building of the embedded system. Section V contains conclusion, limitations and future work followed by references.

II. Optical Sensor design

900 nm wavelength LEDs forming a circular array were used as the source of light to obtain uniform illumination. On the receiver side 9 photo-diodes (OPT101P) each at an angle 20 degree apart were placed to form a semi-circular arc. The setup becomes clear by the depiction in figure (1) below.



TOP VIEW OF OPTICAL SENSOR

Fig. (1)

Figure (1) shows the top view of the optical sensor assemble consisting of 9 photo-diodes arranged in semicircular fashion and an array of LEDs as source.

The refracted angle was computed using Snell's law of refraction given in equation (1).

$$\frac{v_i}{v_r} = \frac{\sin \Theta_r}{\sin \Theta_i} \qquad (1)$$

Here (Θ_i) is the angle of incidence, (Θ_r) is the angle of refraction, 'v_i' is refractive index of the incident medium, 'v_r' refractive index of the other medium.

The rays were incident at different angles since each LED has been assumed to be a point source emitting light with equal intensity in all directions. The angle of refraction was known by the data obtained from the photo-diodes. The obtained output was in the form of the voltage generated due to varying amount of light incident on the photo-diodes. The data was segregated to identify the photo-diode at which the refracted light was maximum received and this led to the determination of the angle of refraction. This was put in the equation (1) governed by Snell's law and the refractive index of the medium found out. The refractive index is proportional to the density of the sample which in turn depends on the amount of adulteration. To understand what exactly happens in the sensor, incident waves at three different angles have been taken and the process is illustrated in figure (2) below.

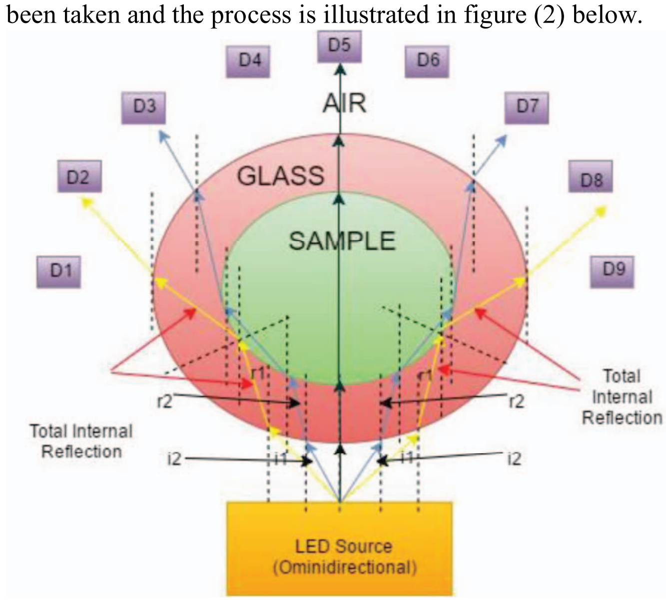


Fig. (2)

Figure (2) represents the actual path that the waves traverse depending on the Snell's law. D1 - D9 are photo-diodes. The whole setup is confined in a dark container a shown in figure (3) so that external light does not enter.

The incident wave represented by yellow color suffers total internal reflection at the glass surface and hence does not pass through the sample. The wave represented by black line is incident normal and thus does not suffer any deviation at any of the surfaces. Apart from these cases, most of the waves show a behavior represented by the purple incident wave. The refractive index of pure milk is generally considered to be 1.33 in for most purposes. The refractive index of milk after adulteration would be in most cases lesser than 1.33, since the density always decreases on adding the adulterant. So in every case the surrounding coating of glass, whose refractive index is taken to be 1.5, will always be denser than the sample. Hence the wave will always bend away from the normal at the surface of glass and sample when travelling from glass to the sample. Similarly at the air-glass interface the wave will always bend toward the normal when travelling from air to glass, since glass is denser than air whose refractive index is considered to be 1. Thus after all the refractions, the wave will finally emerge on the other side and it is detected at one of the detectors. Placing 9 detectors in a semicircular pattern ensures that the wave is precisely detected. Each detector is placed at an angle 20˚ apart. For example an equal output at detectors 2

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and 3 will mean that the light is equally falling upon them. Hence the angle at which it arrives should be

(3 * 20 + 2 * 20) / 2 = 50°.

In figure (2), applying the Snell's law for the air to glass interface at incident angles i1 and i2, and refraction angles r1 and r2, we would get the following set of equations.

$$\frac{v_i}{v_r} = \frac{\sin r_1}{\sin i_1} \quad 2(a)$$

$$\frac{v_i}{v_r} = \frac{\sin r_2}{\sin i_2} \quad 2(b)$$

Similar equations can be applied at each interface to calculate the refractive index. The figure below shows the assembly of the optical sensor that was used in the system for detecting the amount of adulterant present by analyzing the milk samples.

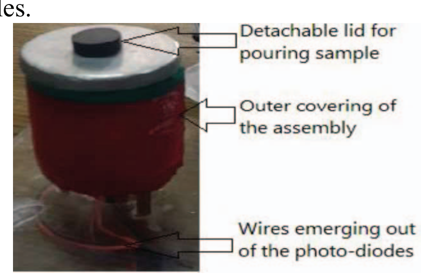

Fig. (3)

Figure (3) explains the parts of the optical sensor. The rubber lid fixes tightly over the top to ensure that no external light enters the assembly.

III. Measurement Procedure

The photo-diodes were classified into 2 groups. The three right in from of the source i.e. the ones labeled 4, 5 and 6 had the highest value of output voltage when maximum amount of light falling onto the sample was transmitted. Hence they gave an output when the adulteration was very high, almost close to 100%. The ones at 3 and 7 gave high values as the amount of adulteration kept on decreasing since that led to the sample being thicker. The diodes at position 2 and 8 gave maximum output at very low values of adulteration (typically lesser than 15%). Hence the diodes at positions 1, 2, 3, 7, 8, 9 constituted the second group which gave a higher output only when there was some amount of adulteration present. The data obtained from the diodes was fed to the ADC pin. Again similar algorithm of using a subtractor was put in place in case the voltage exceeded 5 Volts. The system then determined the refractive index of the sample by using the equations fed in the codes which related the Refracted Index the angle of refraction and the ADC readings. The flowchart given below in Figure (4) puts all this information into a pictorial form. The milk samples were prepared from skimmed milk with varying concentration of adulterant increasing 10 % with each sample until 60 and then 80%. The data was obtained according to the algorithm as described in the flowchart and the ADC readings for different amount of adulterant concentrations is reported below. For greater accuracy, the ADC was sampled at a high rate and 100 values taken over 5 iterations were averaged and then printed on the LCD. The reason for this was that the sampling was started immediately after the lid was closed. Since the settling of the milk takes some time sometimes this created a difference in the ADC readings taken immediately after closing the lid and the ones taken after allowing the milk to settle for some time.

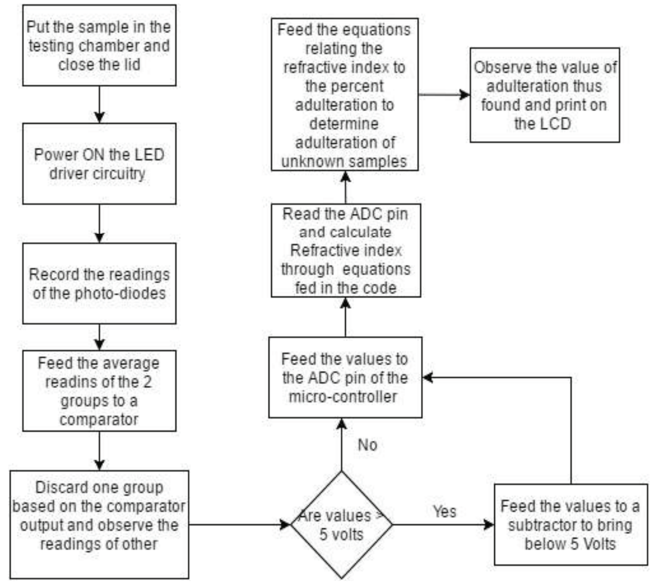

Fig. (4)

Figure (4) provides the pictorial flowchart of obtaining and analyzing data from the optical sensor.

Taking an average ensured that there was consistency among the readings. The change in adulteration affected the refractive index of the sample which in turn affected the ADC reading of the photo-diodes. Hence a direct relation between the ADC reading and percentage adulteration was mapped out through the data reported below. The change in the refractive index is the cause for the change in the ADC values but the stage of actually calculating the refractive index may be bypassed because we can have a direct mapping between the change in ADC values and percentage adulteration.

TABLE I
COMPARISON OF AVERAGE ADC READINGS

Percent Adulteration	Average ADC values (skimmed milk)	Average ADC values (buffalo's milk)	Average ADC values (cow's milk)
0	126	103	135
10	131	107	144
20	135	112	149
30	144	115	156
40	151	124	166
50	161	129	179
60	171	138	189
80	202	160	215

When curve-fitting with 2nd order polynomial was used, the following graph and correlation values shown in figure (5) were obtained. The samples were classified into three different categories since from the data it can be seen that a pure sample of cow's milk gives almost similar readings as that of 20 % adulterated skimmed milk and 50 % adulterated buffalo's milk. Hence it is necessary that there be this classification in order for the system to work correctly. The system detects adulteration of an unknown sample belonging

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to one of the three categories with an accuracy of about 98% as would be seen in the testing part.

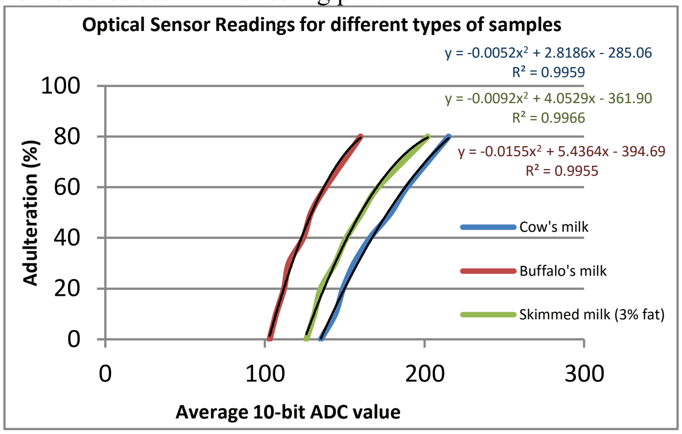

Fig. (5)

Figure (5): The second order trend-lines for each of the three types of milks aptly correlate the given data with a correlation of almost 1. These equations are fed in the code to detect the adulteration of unknown sample based reading.

The three equations obtained from the graph are used in the code to help the system predict the adulteration of the unknown samples.

$$Adul(Cow) = -0.0052 * (ADC)^2 + 2.8186 * ADC - 285.06 \quad 3(a)$$
$$Adul(Ski) = -0.0092 * (ADC)^2 + 4.0529 * ADC - 361.9 \quad 3(b)$$
$$Adul(Buf) = -0.0155 * (ADC)^2 + 5.4364 * ADC - 394.69 \quad 3(c)$$

These equations are used in the code as per the choice entered by the user.

IV. EMBEDDED SYSTEM CONSTRUCTION

In order to make the system usable by common man, it is essential to have a good user interface. Hence an embedded system was built with a thought of providing compactness and facilitating multi-purpose use of the system. The system was built using an ATmega 32 micro-controller on an AVR development board manufactured by Robosapiens. The IC belonged to DIP package hence efforts can be made to make the system even more compact by using SMD ICs. A brief layout of the system in terms of listing all its components is described in figure (6) below.

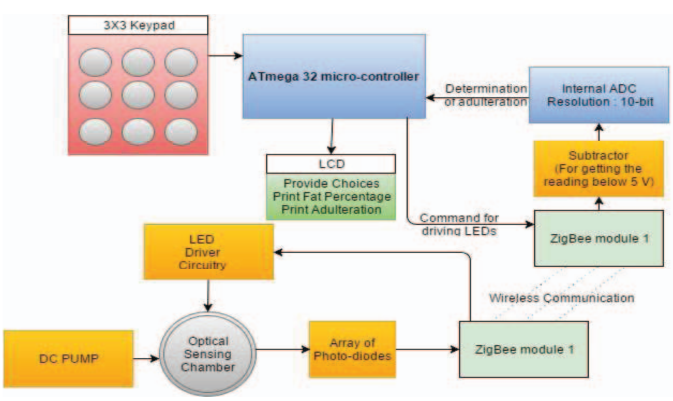

Fig. (6)

Figure (6) The embedded system consisting of Sensor, pre-processing and post-processing circuitry and a keypad and LCD to provide user interface all integrated with an 8-bit microcontroller ATmega32.

Two zigbee modules have also been added to wireless transmit the data obtained by the optical sensor to the system. Both the zigbees are capable of a two way communication. System's zigbee communicates with the sensor's zigbee for turning on the LED driver circuitry and then sensor's zigbee sends the output of the sensor to the system's zigbee. The keypad acts as an input device allowing the user to enter one of three choices displayed on the LCD. The three choices presented are

1) Cow's milk
2) Buffalo's milk
3) Skimmed milk
4) RESET

The user enters one of the three choices and the code applies the relations accordingly. The LCD is an output device and it has three functions

1) Displaying Choices
2) Displaying 'PROCESSING'
3) Displaying the value of fat
4) Displaying the value of adulteration

The keys 1-4 were used on the keypad. A D.C. pump also has been interfaced with controller unit to suck milk sample out from the sensing chamber and also in cleaning process. In order to maintain the voltage lesser than 5 volts the difference amplifier with a gain less than 1 is used. It is shown in figure (7). The difference amplifier is constructed using an op-amp.

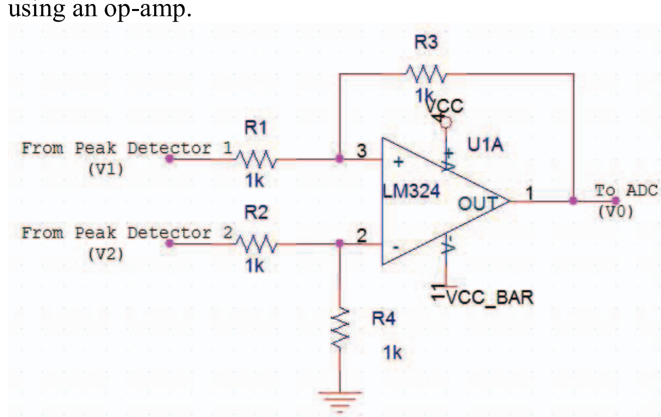

Fig. (7)

Figure (7) shows the op-amp used as a difference amplifier. The equations governing its operation have been explained below.

The output voltage 'Vo' can be written in terms of the difference between the input voltages V1 and V2 and the gain of the amplifier according to equation (4).

$$Vo = \frac{R2}{R1}(V2 - V1) \quad (4)$$

This equation is valid provided that $\frac{R2}{R1} = \frac{R3}{R4}$.

It was seen that the maximum voltage that was recorded from the optical sensor was close to 11 Volts and the minimum was close to 4 Volt. The negative input to the op-amp (V2) was made 1 Volt and the gain of the op-amp ($\frac{R2}{R1}$)

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was made 0.5 so that the output (Vo) now ranged from 1.5 to 5 Volts.

In order to read photodiode sensing array, a trans-impedance amplifier with a scaling circuit have been deigned to scale photodiode analog signal from 0 to 5 volt. An inverter circuit followed by a low pass filter circuit is also implemented to invert acquired signal phase and remove high frequency noise respectively. These both are shown in figure (8).

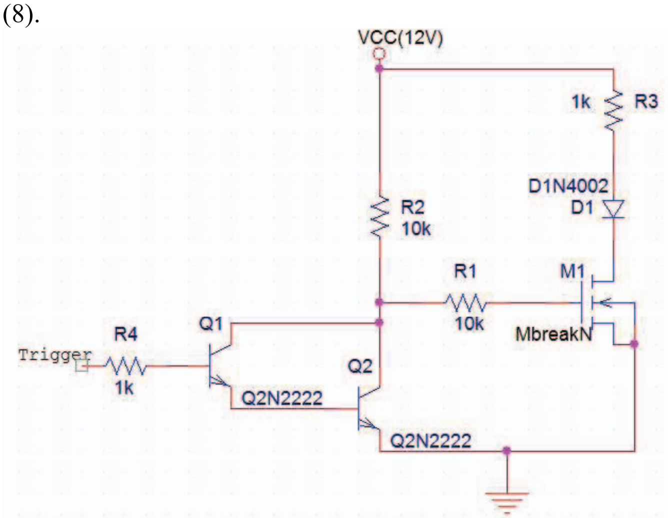

Fig. 8(a)

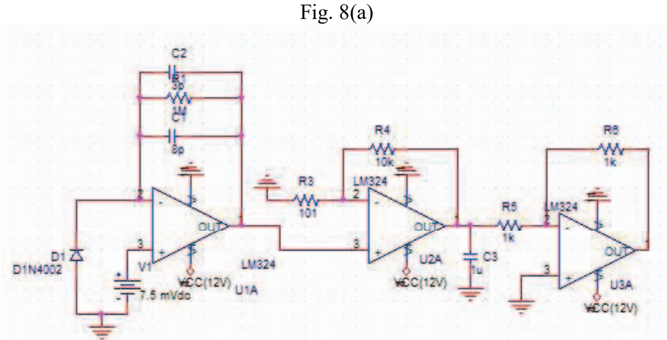

Fig. 8(b)

Figure (8) shows optical transmitter and receiver interface and amplifier pre-processing circuitry.

The internal ADC of the micro-controller is used and the PORT A pins PA0, PA1, PA2 of the micro-controller are used to convert the temperature value and the values obtained from the voltage obtained at the difference amplifier output in case of Ultrasonic and Optical Sensors. Using a resolution of 10-bit in the ADC meant that there were 2^{10} i.e. 1024 digital values possible. The values were converted from digital to analog in the code itself by using the relation in equation (5)

$$V_{analog} = \left(\frac{V_{digital}}{1024}\right) * 5 \qquad (5)$$

Here V_{analog} represents the analog value and $V_{digital}$ represents the digital value. Now the all components of the system have been explained, the testing and validation of the system is explained in the next section.

V. Testing and Validation

The system was tested on close to 150 unknown samples over a period of 2 days. For testing, the samples prepared were prepared with 10% to 70% adulteration increasing by 20. The accuracy of optical sensor was reported close to 95±1%. The depiction of the system user interface can be seen in figure (9) below.

Fig. (9)

Figure (9) shows UI of the embedded system.

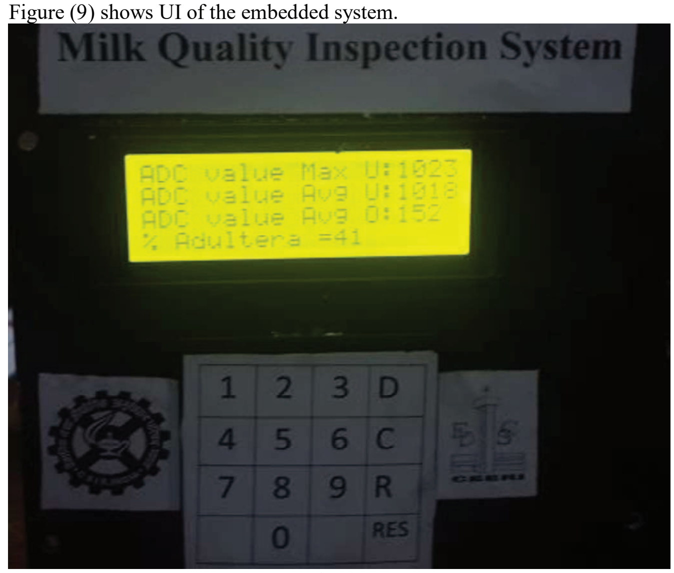

Fig. (10)

Figure (10) shows the Adulteration output to be 41 % when 40% adulterated samples was put in the container. The LCD also displays the ADC value for validation purposes. 'U' indicates the upper limit of ADC which is 1023 since it's a 10 bit ADC. 'O' indicates the ADC value of the optical sensor output.

After the samples were tested the following results were observed.

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TABLE II
TESTING THE SYSTEM

Actual Adulteration Value (%)	Observed Adulteration value (%)
10	12
30	30
50	49
70	72

Below in figure (11) is the setup of the whole system.

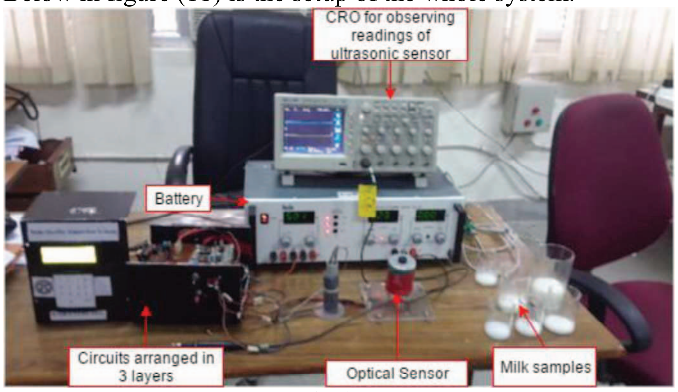

Fig. (11)

Figure (11) shows the arrangement of the whole system used in detecting milk adulteration.

V. Conclusion, Limitations and Future work

The system for detecting adulteration of water was successfully constructed and verified on random milk samples.

However this technique also does suffer from some limitations. The fat content of the milk has not been considered. Since the amount of fat also changes the density of the milk, this directly affects the refractive index and hence the reading of the optical sensor. As it can be seen in figure (5), an almost 70% adulterated sample of buffalo's milk will give readings similar to a pure sample of cow's milk. For this reason the type of milk sample must be known beforehand and the system will fail if a false type is specified.

For the cases pertaining to the above limitations, the system worked with an accuracy of almost 95% indicating that it has a great potential for commercialization if adequate features are added. These include finding the fat content of the milk and training the system appropriately to take into consideration the fat content which affects the density while calculating the adulteration, making the system multi-beverage, i.e. making it capable to distinguish between local beverage brands from the authentic ones for example Jumpin from Frooti etc. This includes most of the future work related to the system. Apart from this the system should also be capable of detecting synthetic milk from the real one. Synthetic milk is prepared by adding urea or detergent into the milk and this can have some very serious health effects. A work to detect adulterants other than water is already in process.

Also, the use of Zigbee module for wireless transfer of data, makes using the system a lot more convenient in places like big dairy farms.

However, as earlier pointed out the system is comparatively bulkier because of the use of DIP ICs. The future work involves replacing them with their SMD counterparts for reducing the area. It was also proposed that all tests be made by bringing the sample to the same temperature to the one that the system was trained on. By interfacing a heater we look to perform all the tests for the Optical sensor by bringing the cold samples to room temperature thereby getting a greater accuracy in the readings.

The system implemented thus has the potential of really improving the life of people who are subject to such inhumane practices of adulteration of milk making this effort a truly humanitarian cause.

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