Design of embedded system to determine liquid refractive index based on ultrasonic sensor using an ATMega328

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Abstract. The occurrence of the broken pencil shadow into a glass of water becomes an interesting matter to be learned. The students of senior high school still find difficulty in determining liquid refractive index. To overcome this problem, it needs to develop an experimental tool to determine liquid refractive index by utilizing the newest technology. It is expected to be useful for students. This study is aimed to (1) make the design of physics learning experimental tool determinant of a liquid refractive index assisted by microcontroller based on ultrasonic sensors ATMega328 (2) explain the working principle and experimental result of liquid refractive indexing instrument assisted with ATMega328 microcontroller based ultrasonic sensor. This research used the experimental method. The result of the research shows design of physics learning experimental tool determinant of a liquid refractive index assisted by microcontroller based on ultrasonic sensors ATMega328 that has relative counting mistake of 0.36% on the measurement of aquades liquid refractive index, relative mistake of 0.18% on the 5% NaCl measurement, 0.24% on 5% glucose, and relative mistake of 0.50% on the measurement of 5 % fructose liquid refractive index. It has been created a proper device to be used in determining liquid refractive index.

1. Introduction

Light refraction is one of Physics phenomena that is often found in everyday life. Light refraction is one of the most observable optical phenomena [1]. A refraction is an event of a change of direction from light when it comes to a boundary surface that separates two different mediums. The transmitted light is the result of interference from the incoming light waves and the light waves generated by the absorption and re-radiation of light energy by the atoms in the medium [2]. In the event of refraction of light known term refractive index of the material. The refractive index of the material is one of the most important optical parameters in the design of glass optics or bulk crystals [3], waveguide design [4], and nonlinear effect analysis for high power pulsed laser systems [5]. The refractive index of a substance is a dimensionless parameter that is an essential property of importance that describes how the speed of light decreases in the material with respect to its vacuum value. This is the electronic charge distribution response to the disturbance caused by the electromagnetic field components of event radiation.

Determination of refractive index of light has been done by using a simple tool. The tool uses the principle of a biconvex lens to determine the refractive index value of a liquid. Focal distance determination is obtained by observing the shadow that is most clearly captured on the screen. This experiment is done in a dark place so that in determining the distance of the shadow will have difficulty.
Many traditional measurement methods of refractive indexes, such as based on the minimum deviation method (MD) and Snell's law for the determination of refractive index of various materials up to the second to fifth decimal and has some limitations [6-10]. Another method of measuring the refractive index is to use the Liquid refractive index sensor based on slow light in slotted photonic crystal waveguide (S-PhCW) to determine the refractive index of different concentration of the measuring liquid [11]. S-PhCW requires equipment that is a bit complicated and at a fairly high cost. Therefore it is necessary alternative refractive index determinator that more affordable, one of them through the liquid refractive index determinants assisted with ultrasonic sensors based on ATmega328 microcontroller. The tool aims to produce experimental devices that can determine the refractive index of a liquid. The experimental tool to be made is expected to improve the accuracy of the data to be obtained in the experiment, thereby improving the weakness of the pre-existing liquid refractive index determinants.

Ultrasonic sensors work by generating sound waves at high frequencies emitted by transmitter sections. The reflection of the wave that hit the object in front of it will be captured by the receiver. The length of time between the sound waves emitted until recaptured can be calculated the distance of objects in front of the module. The sound speed is 340 m/sec. The length of time the sound waves multiplied by the speed of sound, then divided by 2 will produce the distance between the ultrasonic modules with the object in front of it [12]. Arduino is a microcontroller board based on ATmega328. Arduino UNO contains everything needed to support a microcontroller, easily connect it to a computer with a USB cable or supply it with an AC adapter to DC or use a battery to start it. ATmega328 on Arduino Uno comes with a bootloader that allows us to upload new code to ATmega328 without using external hardware programmers [13].

2. Methods
In the experimental determinants of the refractive index of the liquid assisted by ultrasonic sensors based on ATmega328 microcontroller required point light source, flat lens, biconvex lens and liquid to be searched its refractive index. Determine the refractive index by measuring the positive lens focal distance (f1), the combined lens distance between the positive lens and the liquid (fcom) through the reflection of the reflection and the radius of the positive lens (R).

The light coming from the point light source (LED) at the focus will be refracted parallel to the main axis by the positive lens then the shadow parallels to the main axis reflected by the flat mirror, thus forming the central shadow of the centralized system at the focus. The distance between the focusing the shadows (the most obvious shadow) on the surface of the positive lens is called the focal distance of the lens (f1), this distance measurement using the ultrasonic sensor as a digital distance measuring device.

2.1. Hardware Design
Determining the refractive index of the liquid (n) by placing the liquid between the flat mirror and the biconvex (positive) lens. The clearest shadow distance captured by the screen is the combined focal distance between the positive lens and the liquid lens (fcom). After the focal distance of positive lens (f1), and the combined lens (fcom) can be determined the focal point of the lens (f2). The fluid focus distance (f2) and the radius of the liquid lens (equal to the radius of the positive lens) can be used to find the refractive index of the liquid. Design of experimental tool determinants of liquid refractive index assisted by an ultrasonic sensor based on microcontroller ATmega328 can be seen in Figure 2.

2.1.1. Microcontroller Arduino ATmega328. The Arduino integrated development environment (IDE) is a cross-platform application written in Java. Arduino programs are written in C or C++ [14]. The Arduino Uno Boards are launched with specific programs that enable them to present their required operation [15]. Arduino is flexible and inexpensive (it offers varied inputs, interface, and output). Arduino can also be communicated with software working on your computer [16]. This component is
functioned as the main part of the developed device. This part receives a signal of the ultrasonic sensor and changes it into an information in the form of number showed in LCD 16x2.

2.1.2. Ultrasonic Sensor HC-SR04. The ultrasonic sensor works based on the reflective principle of the sound wave. It is used to detect the existence of a certain object in the front and its working frequency in an area of the sound wave from 40 kHz to 400 kHz [17]. The ultrasonic sensor is a kind of electronic device that transforms the electrical energy into mechanical energy in the form of ultrasonic sound waves. The ultrasonic sensor is mostly used because of its simplicity and low cost. The sensor consists of a series of ultrasonic transmitter and receiver. The accuracy of the measured distance depends on the separation between the ultrasonic transmitter and receiver [18].

![Figure 1. Working principle of ultrasonic sensor](image)

The use of ultrasonic sensor is to measure the distance of an object in the path of a person, equipment, or a vehicle, stationary or moving is used in a large number of applications such as robotic movement control, vehicle control, blind man’s walking stick, medical devices, binary gas mixture fraction, etc [19-21].

The usage of the device is to measure the ultrasonic waves. Ultrasonic waves are mechanical waves which have longitudinal characteristic and commonly have a frequency more than 20 kHz. Ultrasonic waves can transmit through the solid, liquid or gas. Ultrasonic waves consist of energy distribution and mechanical momentum that spread through the third element as the interaction with the molecule and the nature of the medium inertia path [22].

2.1.3. LCD 16x2. The distance between the ultrasonic modules with the object in front of it showed on this device.

![Figure 2. Design of experimental tool](image)

![Figure 3. The making of distance measurement program on Arduino IDE](image)
2.2. **Software Design**

The embedded program was developed using Arduino IDE. Preparation of coding adapted to the ultrasonic sensor used, then first download the "library" Ultrasonic Sensor HC-SR04. Then put it in the Arduino IDE program and just call it to be included in the coding. The coding arrangement is adjusted with an ultrasonic sensor. Firstly, download "library" of UltrasonicSensor HC-SR04. Then, put in the program of Arduino IDE and call it to be inserted into coding.

3. **Results and Discussion**

After the design is completed and the materials have been prepared, then assembled to become an experimental tool to determine the complete refractive index as shown in Figure 4 below.

![Figure 4](image-url)

**Figure 4.** Experimental tool determinants of liquid refractive index assisted by an ultrasonic sensor based on microcontroller ATMega328.

In the study of the determination of refractive index of the liquid, used four different types of fluids. The first step by determining the focal length of the biconvex lens ($f_1$). Focal distance determination is obtained by observing the clearest shadow captured by the screen. The distance between the lens and the screen is displayed on the 16 x 2 LCD automatically. The distance data of the biconvex lens ($f_1$) can be seen in Table 1.

| No. | $f_1$ (cm) |
|-----|------------|
| 1.  | 17.7       |
| 2.  | 17.8       |
| 3.  | 18.0       |
| 4.  | 17.7       |
| 5.  | 17.9       |
| 6.  | 17.8       |
| 7.  | 18.1       |
| 8.  | 17.9       |
| 9.  | 17.8       |
| 10. | 18.0       |

The next step is to determine the fluid focus distance ($f_2$). The determination of the fluid focus distance can be done by first finding the combined focal distance between the biconvex lenses with the liquid measured by its refractive index, by observing the clearest shadow captured by the screen. The distance between the lens and the display as (fcom) is displayed on the 16 x 2 LCD automatically. Liquids used in this experiment include aquades, spiritus and premium gasoline. The experimental results of each liquid are presented in Table 2 and Table 3.
Table 2. Data of focus distance of combined lenses between biconvex lenses with aquades, NaCl 5%, Glucose 5%, Fructose 5%

| No. | \( f_{\text{com}} \) (cm) |
|-----|-------------------------|
| 1.  | 22.7                    |
| 2.  | 22.7                    |
| 3.  | 22.6                    |
| 4.  | 22.2                    |
| 5.  | 22.4                    |
| 6.  | 22.8                    |
| 7.  | 22.7                    |
| 8.  | 22.8                    |
| 9.  | 22.9                    |
| 10. | 22.6                    |

Determining the radius of a biconvex lens with a spherometer, the following data are obtained:

\[
R = \frac{a^2 + b^2}{2b}
\]

Given the length \( a = 2.2 \) cm and \( b = 0.086 \) cm so obtained the length of radius of lens \( R \) by using Phytagoras theorem as follows:

\[
R = \frac{2.2^2 + 0.86^2}{2(0.86)}
\]

\[
R = 28.12 \text{ cm}
\]

Figure 5. Determine Fingered Biconvex Lens with Spherometer

Based on the data obtained from the results of the research conducted a quantitative analysis to determine the refractive index of each liquid. Using biconvex radius reference \( R = 28.12 \) cm and biconvex lens focus distance \( f_1 \). While \( f_{\text{com}} \) as the combined focus of biconvex lens and focus of fluid and \( f_2 \) as the focus of the liquid lens.

This study aims to determine the refractive index of liquids using the principle of combined lens. In this experiment used a biconvex lens, a light source, a flat mirror, a screen, a liquid to be searched for its refractive index, ultrasonic sensors, Arduino Uno and LCD 16 x 2. The working principle of this experiment, the light source of the biconvex lens focus is biased parallel to the major axis so that forming an infinite shadow.

The imperceptible shadow parallel to the major axis of the system is regarded as object 2. The object 2 is reflected by a flat mirror and refracted by a biconvex lens to form a final shadow of the system at the focus captured by the screen.
The distance between the final shadow of the system and the surface of the biconvex lens is called the biconvex lens’s focus distance \((f_1)\). Then determine the focal distance of the combined lens between the positive lens and the liquid \((f_{\text{com}})\). Once known the focal distance of the combined lens can be known the focus of the fluid \((f_2)\). The lens used is double biconvex and the liquid bottom is a flat mirror then the liquid forms a concave lens plan with a liquid lens radius for the same side as the biconvex radius of the lens.

Two thin lenses are used to form the shadow, then the system has the following provisions. First, the first shadow formed by the first lens lies in the same place as if the second lens does not exist. The ray for the second lens with the shadow formed by the first lens acts as an object for the second lens. The second shadow formed is the final shadow of the system. If the image formed by the first lens is located on the back side of the second lens, then the image is treated as a virtual object by a second lens which means the distance of the negative object \([14]\).

Assuming two thin lenses touching each other are equivalent to a single thin lens, the focal radius of the lens \((f_2)\) lens can be determined by using a combined lens equation between a positive lens and a liquid lens. A positive lens as \((f_1)\) and liquid lens as \((f_2)\).

\[
\frac{1}{f_{\text{com}}} = \frac{1}{f_1} + \frac{1}{f_2} \tag{1}
\]

After the focusing distance of liquid \((f_2)\) is known then in determining the refractive index value of the liquid can use the lens forming equation as follows:

\[
\frac{1}{f} = (n - 1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \tag{2}
\]

So that the liquid lens is in the form of a concave lens plan, the radius of the liquid includes \(R\) for the concave side and not to \((\infty)\) for the flat side of the lens \([14]\).

\[
\frac{1}{f} = (n - 1) \left( \frac{1}{R_1} - \frac{1}{\infty} \right) \tag{3}
\]
The radius of the liquid lens for the lens of concave has the same value as the positive lens radius because the two lenses are touching each other. The liquid formed by the concave lens means the focal distance of the liquid lens \((f_1)\) and the fingers are both negative. Based on equation (3) the liquid refractive index value can be obtained by the equation:

\[
n = 1 + \frac{R}{f_2}
\]  

(4)

Using the refractive index equation then obtained the results of research refractive index of each liquid listed in Table 3.

Table 3. The Observation result of refractive index of liquid

| No. | Liquid    | Refractive index  | Theory | KR  |
|-----|-----------|-------------------|--------|-----|
| 1   | Aquades   | (1,331±0,004)     | 1,333  | 0,36% |
| 2   | NaCl 5%   | (1,338±0,002)     | 1,3418 | 0,18% |
| 3   | Glucose 5%| (1,336±0,003)     | 1,3402 | 0,24% |
| 4   | Fructose 5%| (1,337±0,006)    | 1,3402 | 0,50% |

The result of the research shows that the refractive index of the measurement results shows that the value is not far deviate from the index of refractive literature. There are several factors that may affect the deviations of these measurements, including the temperature and viscosity of the liquids. The refractive index of the liquid is also affected by the density of the medium through which it is also a function of the concentration of the liquid.

The molecules and atoms contained therein will absorb and re-irradiate the light at the same frequency but the wave rate is different. The lights are irradiated by the molecules and the atoms are phased out of phase with the incoming waves so that at the same time the waves passed do not travel in the medium as long as the original wave comes in so that the wave velocity passed is less than the speed of the incident wave. The greater the concentration of the solution, the greater the number of molecules and atoms that interact with the waves of light, so that the lag phase experienced by the coming waves is greater. This means that the light rate is getting smaller as the concentration of the solution increases.

Based on the analysis of experimental results obtained the conclusion that the greater the viscosity of liquids the liquid refractive index is also greater. Another factor that is very influential in determining the refractive index in this experiment is the accuracy factor determining the brightest focus so as to affect the shadow distance measured. This can be seen from the percentage of error on the measurement, the smaller the percentage of measurement error the more accurate the data generated.

4. Conclusion
The working principle of the liquid refractive index determiner assisted by the microcontroller based ultrasonic sensor of ATMega328 is 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 \((f_{com})\) through the reflection of the shadow and radius Positive lens \((R)\). This distance measurement uses ultrasonic sensors as a digital distance measuring device. Determining the refractive index of the liquid \((n)\) by placing the liquid between the flat mirror and the biconvex lens. The clearest shadow distance captured by the screen is the combined focal distance between the positive lens and the liquid lens \((f_{com})\). After the positive lens focal distance \((f_1)\), and the combined lens \((f_{com})\), the focusing distance of the liquid lens \((f_2)\) can be determined. The focusing distance of the liquid \((f_2)\) and the fluid lens radius.

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