Determining the Time of Flight and Speed of Sound on Different types of Edible Oil

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Abstract. Edible oil is mostly plant-based oils that have been extracted from various seeds. There are cases where the fully virgin edible oil was found to be a fraud. The adulterated edible oil indicates the intentional, fraudulent addition of extraneous, improper or cheaper ingredients puts into the oil or the dilution or removal of some valuable ingredient of the oil in order to increase profits. Hence, decrease the reliability of the Malaysian food product quality. This research was done by using the method of time of flight obtained using the Texas Instrument board, TDC1000-TDC7200 EVM connected to an ultrasonic transducer with 1 MHz frequency. The authors measured the time of flight and temperatures controlled from 20°C to 40°C of five vegetable oils (olive oil, sunflower oil, corn oil, coconut oil, and mustard oil). The value is observed and compared with other research from the literature review. From the study, time of flight values decreases exponentially while speed of sound value increases. This relationship will be useful in spectrum unfolding method to investigate the adulteration in different type of edible oil. This research outcome is to investigate the quality value of the different type of edible oil while eliminates the issues where the quality of Malaysian food product is not reliable.

1. Introduction
Malaysian product has been exported worldwide centuries ago and have received much admiration and respect from importing countries due to its high quality and reliability. However, the economy is growing faster and there must be many ways to increase the value and trust of Malaysian Product. One of the ways is by reducing the fraud from the processed food. While, processed food means foods that require little processing or production and packaged to stay fresh and save time for consumers. A few examples of processed foods include canned and frozen fruits and vegetables, packaged foods labelled “natural” or “organic,” such as cereals, fresh meat and poultry, and jarred baby foods. Also, the foods with health and nutrition claims on the label, such as “may reduce risk of heart disease,” “low in fat” or “high in calcium” and foods fortified with nutrients such as fiber, vitamin D and omega-3 fatty acids [1].

Hence, one way to reduce the fraud in pure liquid material is by being able to determine the type of liquid before been sent to consumers. When compared to chromatographic techniques, infra-red spectroscopy is an attractive option for detection of adulterations in oils and fats due to the speed of analysis, and minimal sample preparation [2]-[3]-[8]. Instrumental techniques based on chromatography and spectroscopy have received particular attention from researchers worldwide since they are efficient and able to control adulteration practices in food lipids [3].
Ultrasonic Spectroscopy is the characterization of the ultrasonic response of a material to the propagation of a low energy ultrasonic wave which can measure the absolute frequency dependent and attenuation of liquids. The ultrasonic spectroscopy characteristics which is Non-destructive, Non-Intrusive and in-situ is one major contribution [4]. The method of ultrasound spectroscopy is suitable for determining the properties of liquids.

A standard development organization that serves as an open forum for the development of international standard control value called ASTM International (American Society for Testing and Materials) is useful for the characterization of materials depends on the materials speed of sound, density, velocity, melting points and boiling points. Differential scanning calorimetry technique for detecting lard adulteration in butter required sample preparations kept in glass vials under refrigerated condition with temperature control and tends to be laborious since the sample need to undergo the blend process according to percentage of lard in buffer [4].

The frequency dependence of liquids is proved where the frequency used in the related research controlled from 1MHz, 2MHz, 3MHz, and 5MHz to study the different acoustic impedance value in different liquid. The result showed for the acoustic impedance is dependent on the frequency of the ultrasound [5]. Attenuation occurs with any type of signal, whether digital or analog. Attenuation is a natural consequence of signal transmission over long distances [6].

Determination of the real time density to monitor the ultrasound velocity are further classified techniques into Multiple Reflection Method (MRM), Reference-Reflection Method (RRM), Transmission Reflection Method (TRM), and Angular Reflection Method (ARM). ARM and RRM are proven suitable for highly sound absorbing liquids, however requires calibration measurements [7]. Sound absorption refers to the process by which a material, structure, or object takes in sound energy when sound waves are encountered, as opposed to reflecting the energy [6].

The changes in the quality of liquid are premeditated from the changes in the parameters such as viscosity, density, ultrasonic velocity, acoustic impedance, and intermolecular free length [9]-[10]. Each oil type have their own physical properties divided in density, viscosity, and saturated acid. Pressure-viscosity coefficient increases exponentially with the adiabatic bulk modulus [11]. The relationship demonstrates that the pressure-viscosity coefficient can be predicted from the adiabatic bulk modulus [11]. Based on the relationship on the adiabatic bulk modulus, the value for the speed of sound for different type of oil can be calculated.

2. Experimental

2.1 Experimental Set Up
The TDC1000-TDC7200EVM evaluation module is an ultrasonic for Time-of-Flight (TOF) applications operating with ultrasound frequencies up to 4MHz. The TDC1000-TDC7200EVM is then connected to the computer through USB. For the research, the 1MHz transducer is used.

2.2 Preparation of sample
Olive oil, Mustard oil, coconut oil, Sunflower oil and Corn oil were tested. All samples were obtained from commercial sources and used as supplied without further purification. The list of tested oils and their physical properties are given in Table 1.

| Oil name     | Density ρ[g/cm³]  | Viscosity ν[mm²/s] |
|--------------|------------------|-------------------|
|              | 15 °C            | 40 °C             |
| Olive Oil    | 0.917            | 38.7              |
| Mustard Oil  | 0.920            | 44.1              |
| Coconut Oil  | 0.926            | 26                |
| Sunflower Oil| 0.919            | 35                |
| Corn Oil     | 0.942            | 31                |
2.3 Time of flight measurement
Time of flight was measured by the TDC1000-TDC7200EVM board. The board is connected to an ultrasonic transducer. The 1MHz transducer is attached to a beaker. The board combines with the ultrasonic transducer and measures the ultrasound wave spread in a sample liquid. The basic principle of this device is the ultrasonic wave pulse echo launched from the transmission transducer propagates in the sample and its echo is received to the same transducer. It is converted as start and stop pulse by the TDC1000-TDC7200EVM board, while the distance from the start to the stop pulse is known as time of flight. Time of flight is the duration it takes for the ultrasound to travel through the media and return back to the receiver.

![Figure 1. The block diagram.](image)

3. Results and Discussion
Time of flight (TOF) describes a variety of methods that measure the time that it takes for an object, particle or acoustic, electromagnetic or other wave to travel a distance through a medium. This measurement can be used for a time standard, as a way to measure velocity or path length through a given medium, or as a way to learn about the particle or medium such as composition or flow rate. The advantages of using the techniques is the traveling object may be detected directly. The changes in the composition of the liquid can be detected directly when there is absolute changes in the time of flight. For the research, the value for time of flight proves the changes in speed of sound values which change proportionally with the temperatures since the molecular bonding is loosened due to the increase in temperature. Refer to table 2 showed below, the value of time of flight is increasing when the temperature is increasing. Based on the formulae calculating the speed of sound, where $C = \text{Speed of sound}$ of a medium, $D = \text{distance}$.

$$C = \frac{2D}{\text{Time of flight}}$$ (1)

The speed of sound is inversely proportional to the value of time of flight on a different medium. Based on the molecular structure of an oil, they are composed of molecules known as triglycerides, which are esters composed of three fatty acid units linked to glycerol. An increase in the percentage of shorter-chain fatty acids and/or unsaturated fatty acids lowers the melting point of an oil.

The different type of edible oil, which are olive oil, mustard oil, corn oil, sunflower oil, and coconut oil was chosen based on their popular availability on the market. It proves that the consumer choses to buy these type of edible oil on their daily cooking basis rather than any other vegetables oil which is hard to come by. Oils recognised as essential nutrients for consumers. They provide the most concentrated source of energy of any foodstuff, supply essential fatty acids and contribute greatly to the cooking satisfaction. The results from this research showed the different types of edible oil is investigated in three different controlled temperature to observed the effect of temperature on the values of speed of sound.
To achieve the different in temperature, the oil is kept in refrigerated condition to obtain 20 °C, while the oil is heated to obtain the 30 °C and 40 °C. Then, the oil is put inside a closed beaker to avoid any disturbance from outside air or any unwanted noise. The time of flight measurement is obtain and the changes in speed of sound is observed. From the result, the time of flight values is increasing and compared to the speed of sound value is decreasing. Obviously, the changes in temperature also affect the value in both the time of flight and speed of sound on different type of edible oil.

Table 2. Comparison the experimental and calculated results for different type of edible oil.

| Type of Edible Oil | T (°C) | U (ns) | S (m/s) | K (m/s) | Error (%) |
|--------------------|--------|--------|---------|---------|-----------|
| Olive Oil          | 20     | 120077 | 1432    | 1431    | -0.07     |
|                    | 30     | 121969 | 1410    | 1430    | 1.39      |
|                    | 40     | 124500 | 1381    | 1397    | 1.14      |
| Mustard Oil        | 20     | 118642 | 1449    | 1490    | 2.75      |
|                    | 30     | 121356 | 1417    | 1426    | 0.63      |
|                    | 40     | 124205 | 1384    | 1362    | -1.61     |
| Corn Oil           | 20     | 119404 | 1440    | 1460    | 1.37      |
|                    | 30     | 121636 | 1414    | -       | -         |
|                    | 40     | 123912 | 1388    | -       | -         |
| Sunflower Oil      | 20     | 121826 | 1418    | 1423    | 0.35      |
|                    | 30     | 121783 | 1418    | -       | -         |
|                    | 40     | 123784 | 1389    | -       | -         |
| Coconut Oil        | 20     | -      | -       | -       | -         |
|                    | 30     | 125488 | 1370    | 1378    | 0.58      |
|                    | 40     | 127948 | 1344    | 1361    | 1.25      |

The transducer was mounted on acrylic beaker to maximize the sensor sensibility and flexibility. The sensor accuracy were determined based on the percentage error. The speed of sound from the literature is compared with the speed of sound obtained from the experiment. The percentage error is in the range of -5% up to +5%. The accuracy of the transducer is reliable and the value obtained can be used for further examining the quality of the different types of edible oils. The transducer is compatible with the TDC1000-TDC7200EVM in determining the fraud in the pure quality edible oil. The difference value in speed of sound and time of flight can be used to determine the type of liquid tested and using the technique spectrum unfolding approach, supposed the quality either the edible oil is pure or fraud can be investigated.
Figure 2. Relationship between the temperature and speed of sound for different type of edible oils.

4. Conclusion
The ultrasonic studies in liquids are of great use in understanding the nature and strength of molecular interactions in oil. This research works on demonstrating the usefulness of the ultrasonic technique for on-line process monitoring the composition of different type of edible oil. The simplicity, portability and low cost of ultrasound devices make them essential elements in research laboratories, pilot plants and processed food industries.

The relationship between the time of flight and the speed of sound is investigated in this study, being compared with corn oil, olive oil, sunflower oil, coconut oil, and mustard oil. The following conclusion can be drawn from the study: From the study, it is found that time of flight values decreases exponentially with the increase of speed of sound. This relationship will be useful in spectrum unfolding method to investigate the adulteration in different type of edible oil. The spectrum unfolding is a new method to unfold the time of flight and the speed of sound to actually gain the critical values of the oil so that the system is able to demonstrate the type of oil and what is inside the combination of few oils mixed together. This will actually help increase the Malaysian Food Qualities.

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Acknowledgments
This research is supported by the Fundamental Research Grant Scheme (FRGS) by Ministry of Higher Education Malaysia (MOHE) to the Department of Mechatronics Engineering at the International Islamic University Malaysia (FRGS16-065-0564)