Simulation Study of Ultrasonic Tomography Approach in Detecting Foreign Object in Milk Packaging

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ABSTRACT

Contaminant issues are one of the major concerns in food and beverages (F&B) industries because it compromises the product and brand. In general, there are three types of food and beverages contaminant, which are biological, chemical, and physical hazards. The physical hazard is the most common occurred in the F&B manufacturing industries. The current application of solid contamination detector such as X-Ray machine and metal detector involves hazardous radiation. Therefore, tomography approach is proposed due to its ability to detect contamination with less or little hazardous radiation. This research focuses on non-invasive and non-intrusive tomography techniques to detect foreign objects without affecting the ingredient and the original form of food. Moreover, a simulation will be performed to detect the existence of foreign objects in small milk carton using ultrasonic tomography approach via COMSOL Multiphysics software. This paper discusses the conceptual modelling design of ultrasonic tomography approach and the analysis of its voltage output. 1 mm size of foreign object is deliberately put inside the milk packaging. The results show that the proposed conceptual modelling can identify the existence of foreign object in the homogenous milk medium.

Keywords: Ultrasonic Tomography, COMSOL Multiphysics, food and beverages (F&B), foreign object

1. Introduction

The food and beverage (F&B) industries are expanding rapidly all over the world. The dairy industry is one of the high-demand industries due to the nutrition provided by milk offering a lot of benefits to the human body. Milk contains a lot of protein, calcium, and other nutrients that are helpful for keeping your body healthy. Additionally, dairy products such as cheese, butter, and yoghurt are frequently used in cooking and baking. To ensure that milk products are free from contamination, the manufacturing process should be carried out carefully and effectively. Some contamination issues have been reported where melamine was discovered in milk, which is considered as a risk [1]. Also, insects, hair, metal and glass have been found in milk productions [2].

In F&B industries, a real-time monitoring system is critical to ensure their products are free from contaminants issues. Contamination issues arise will result in major issues, costly recalls, and loss of consumer confidence. Nowadays, various techniques have been implemented to detect foreign objects in the food industry such as metal detectors and X-Ray machines. However, X-ray machine had been reported as unsaved due to the exposure of hazardous radiation to the people in the inspection zone. Even though it does not compromise the quality of food, this X-ray machine may give bad impacts to the workers who are being exposed for longer time. Moreover, X-ray has limitations in detecting tiny foreign object such as 1 mm long. Therefore, this research aims to study a technique that apply a non-invasive and non-intrusive ultrasonic system which detects the existence of foreign objects which is 1 mm in beverages. A simulation will be conducted to verify the proposed conceptual model.

2. Tomography Process

The word 'tomography' comes from the two Greek words which are 'tomo' means slice or section and 'graphy' which is an image. In general, tomography can be defined as a method of imaging the internal structures of a solid object in 3-Dimension (3D) by observing the variations of the energy waves reflected on the structures [3]. A tomographic imaging system developed to examine objects with waves or radiation, and to analyze their compositions. This tomography system can visualize the internal characteristics such as concentration, particle sizes distribution and mass flow rate [4].

A basic block diagram for tomography system is shown in Figure 1, which consists of hardware and software parts. The tomography process requires a medium that will be investigated such as concrete, pipeline and F&B packaging. Multiple sensors are located around the medium to measure the data or signals from the target object. Then, the data acquisition will convert the data collection from analog signals into digital format. Lastly, a computer is used to display the image of materials via image reconstruction algorithms. This algorithm uses mathematical or computational methods to estimate the internal structure of the medium [5].

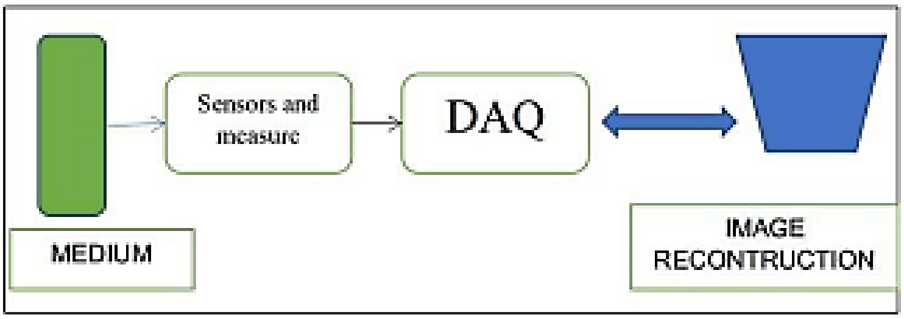

Figure. 1. Basic block diagram for tomography system [4].

In tomography measurement systems, image reconstruction comprises forward and inverse problems. The forward problem uses to stimulate the measurement process that is obtained by the sensors. While the inverse problem involves recovering the object's characteristics based on the measured data collected from sensors using the image reconstruction algorithm, where the algorithms that are commonly used are the linear back-projection (LBP) and convolution back-projection (CBP) algorithms with the help of Hamming, Hanning, and Ram-Lak filters [6].

Ultrasonic tomography is a technique that uses ultrasonic sensors to transmit ultrasonic soundwaves to the beverage packaging with specific frequency. These sensors are used to send and receive ultrasonic pulses that give the information of an object's proximity in distinct echo patterns based on the frequency [7]. Figure 2 shows the block diagram of an ultrasonic tomography system. In this system, the ultrasonic sensor transmitter is connected to an amplifier circuit to convert electrical signals to ultrasonic waves. The receiver then took in the sound waves and converted them into electrical signals.

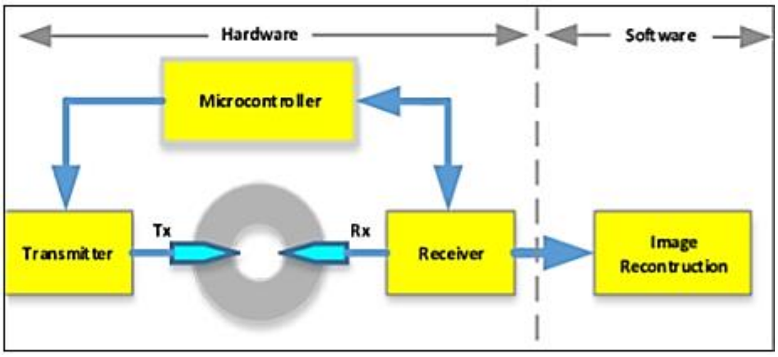

Figure. 2. Block diagram of an ultrasonic tomography system [7].

There are three types of sensing mode for the ultrasonic sensor which are transmission, reflection and diffraction modes as displayed in Figure 3. These modes are activated depending on the position of ultrasonic transmitter and receiver. The receiver is placed in front of the transmitter for the transmission mode. For the reflection mode, the ultrasonic transmitter and receiver are located at the same side. Meanwhile, the receiver is placed at the top of the transmitter for diffraction mode. Commonly, most ultrasonic technology uses transmission mode. This is classified as a direct method because the ultrasonic wave transmits direct from transmitter to receiver [5].

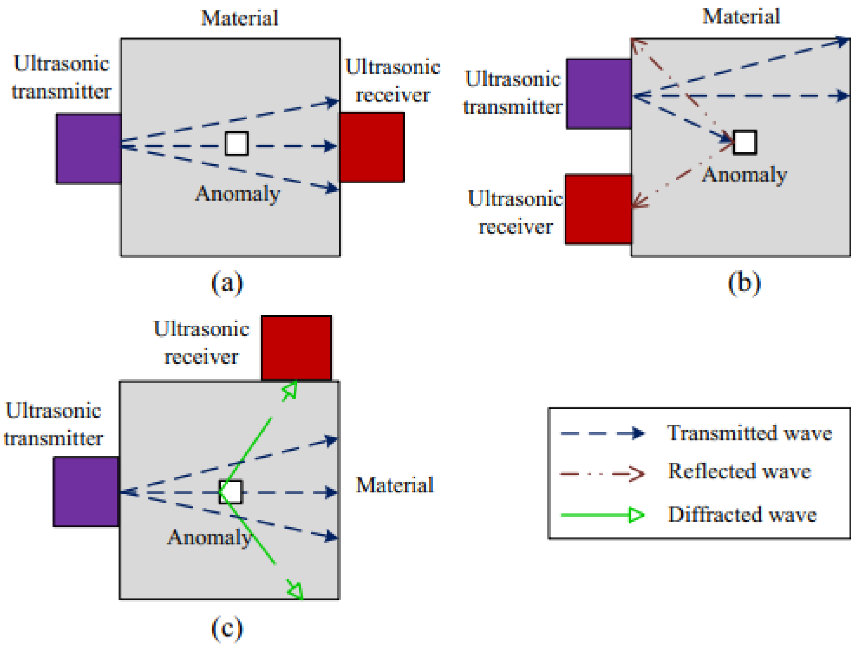

Figure 3. Type of ultrasonic sensing modes (a) transmission (b) reflection (c) diffraction [5].

3. Methodology

This research will use software named COMSOL Multiphysics for simulation and Minitab for data analysis. In general, the flowchart of the research is shown in Figure 4. The research starts with identifying the parameters involved in constructing the ultrasonic tomography simulation system. In the simulation part, there are two main conditions involved in the simulations: normal condition of milk packaging and milk packaging with the existence of foreign object. There is a single type of foreign object involved in the investigation: metal piece with size less than 1 mm. The statistical analysis is then performed using Minitab software and the performance of the model is validated.

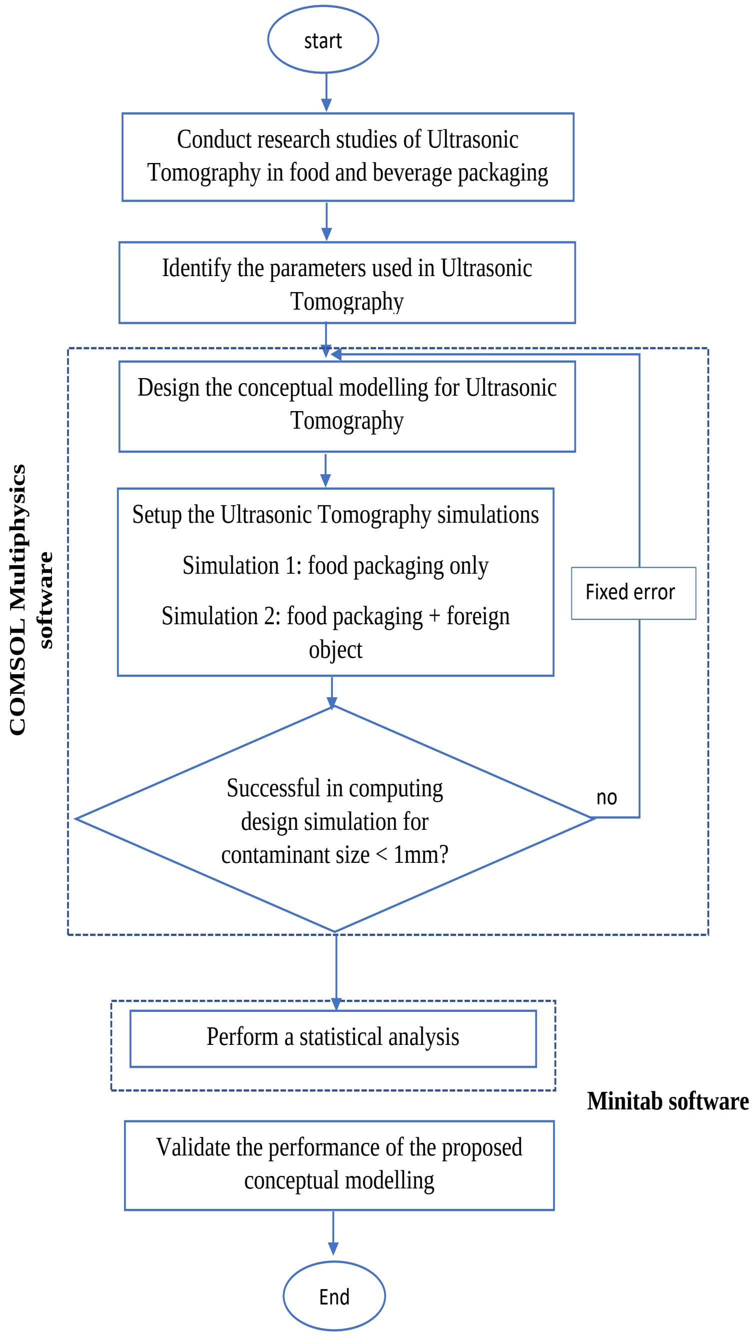

Figure. 4. The flowchart of the research.

4. Ultrasonic Tomography Measurement Design

The ultrasonic tomography measurement system for detecting foreign objects in milk packaging is designed as shown in Figure 5. The design has been constructed based on the parameters from previous research findings [8] [6] [9]. The design is modelled based on the real measurement of small carton Dutch Lady 70 mm x 50 mm. The conceptual modelling which is designed using COMSOL Multiphysics software. The capacity to cover the entire region of the material being investigated and provide a high-quality tomographic image typically determines how many transducers should be used. In this study, there are nine transmitters and nine receivers located around the rectangular shape. The transmitters and receivers have a centre frequency of 333 kHz with diameter 9.3 mm.

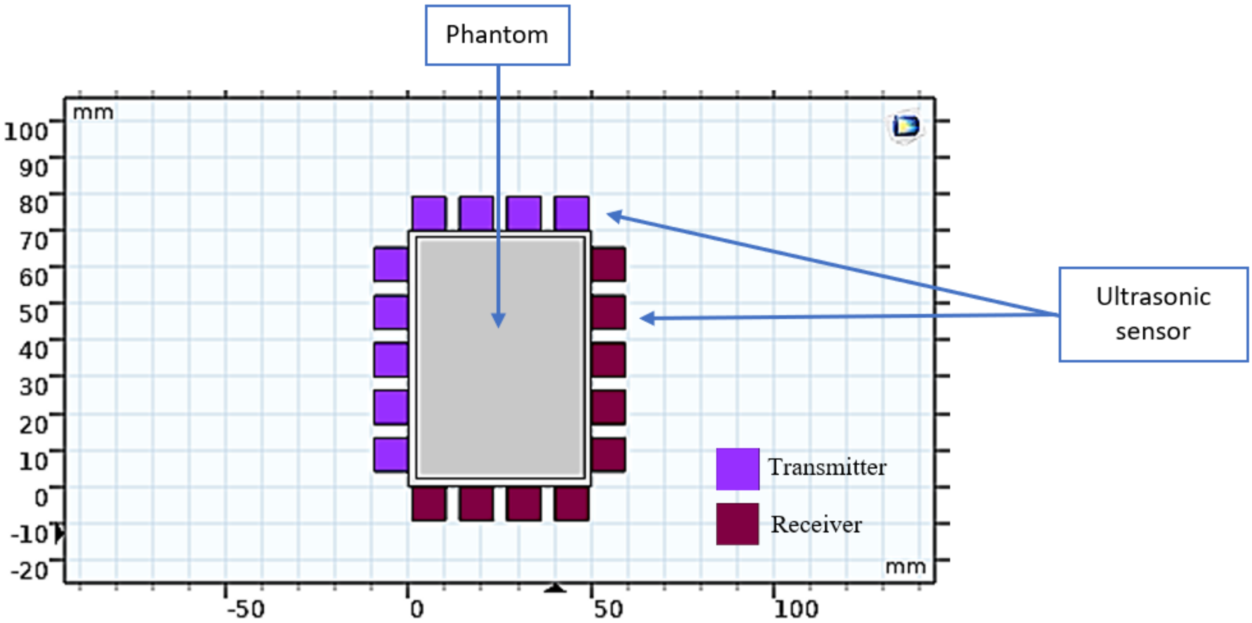

Figure. 5. Rectangular paper carton of ultrasonic conceptual modelling design.

After the design phase is completed, several simulations are performed by computing the suitable frequency according to the foreign object and beverage packaging as tabulated in Table 1 and Table 2. Table 1 shows the values of density and speed of sound for several types of material that are commonly used in food detection. The selection of material depends on the desired target to investigate the performance of the tomography system. In this paper, the material used is 1 mm metal piece.

Table 1. The values of density and speed of sound [8].

Type of Material	Density, (kg/cm^3)	Speed of sound, (m/s)
Paper	800	3000
Milk	1037	1548
Metal	8060	5800
Plastic	1537	2395
Glass	1199	2750
Wood	722	3850

Meanwhile, Table 2 shows the list of frequency ranges of ultrasonic sensor in various types of beverage packaging. The selection of the ultrasonic sensor's frequency is done depends on the type of beverage packaging. In this research, 333 kHz of ultrasonic sensor is selected to compute in the design. Meanwhile, the type of beverage packaging being chosen in this simulation is paper.

Table 2. The frequency range of ultrasonic sensor in different type of beverage packaging [6], [9].

Type of beverage packaging	Frequency range of ultrasonic sensor
Metal	1 to 4 MHz
Paper	333 kHz
Can tin	4 MHz
Bottle	15 MHz

After the selection of material and ultrasonic sensor, all the parameters are computed in the conceptual design. Figure 6 shows the conceptual modelling design when the existence of the foreign object located at the upper left of milk packaging. The location of foreign object can be anywhere in the milk packaging. the position of foreign object is located at the upper left of milk packaging. Several simulations can be done by changing the size and position of the foreign object in the milk packaging for observing and make a comparison when in different conditions.

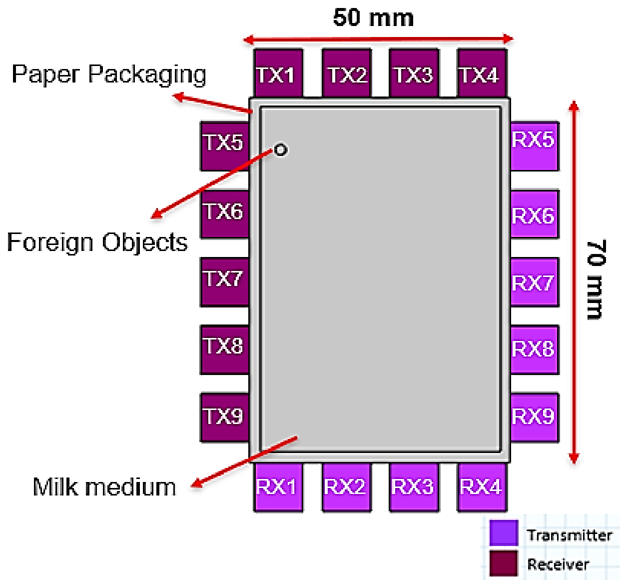

Figure. 6. Final conceptual design of ultrasonic tomography with foreign objects.

5. Result and Discussion

The ultrasonic wave from the transmitter is propagated through the homogenous milk medium and sensed by the receiver as illustrated in Figure 7. There is an initial condition where the diffraction does not occur due to the absence of a foreign object. Meanwhile, Figure 8 shows the graph of voltage versus time in homogenous milk medium.

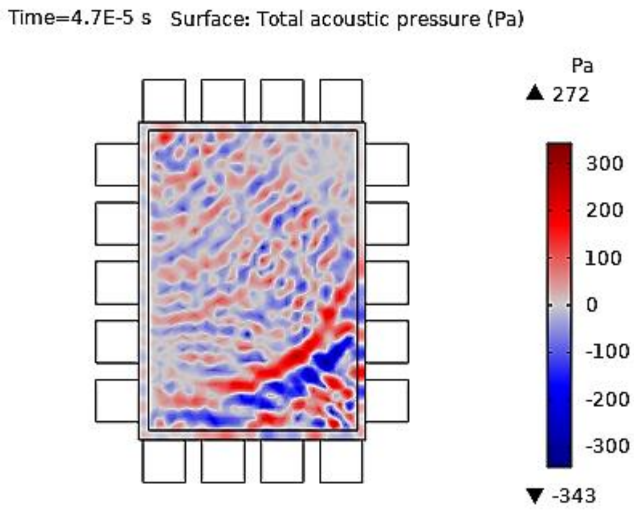

Figure. 7. Propagation of waves in homogenous milk packaging.

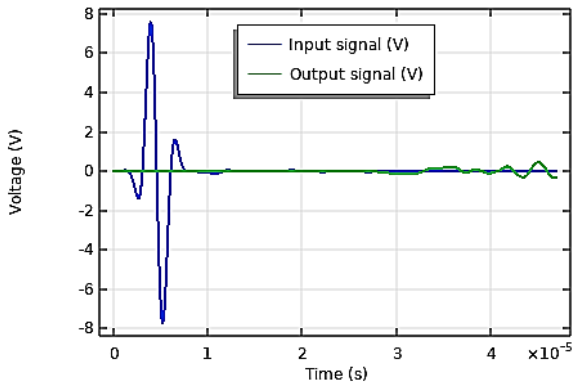

Figure. 8. Graph of voltage vs time in homogenous milk medium.

Figure 9 shows that propagation of wave in non-homogenous milk medium due to the existence of 1 mm metal. Compared to Figure 7, there is a diffraction occurred because the signal wave is blocked by the 1 mm metal. Besides, the peak amplitude shown in Figure 8 is higher than peak amplitude shown in Figure 10.

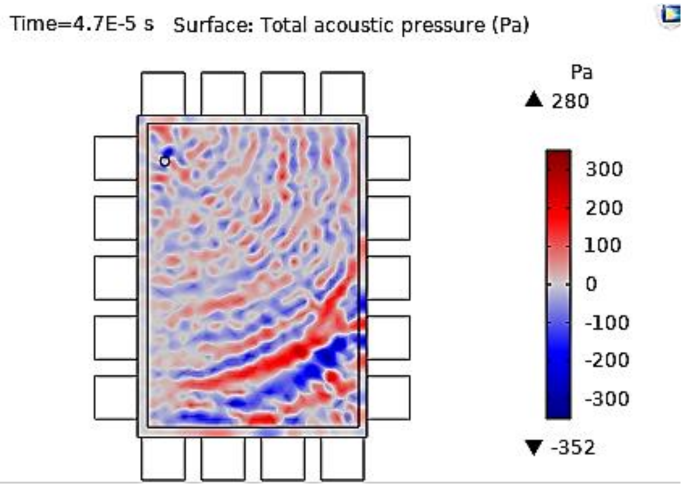

Figure. 9. Result obtained in non-homogenous milk packaging with 1 mm size of metal piece.

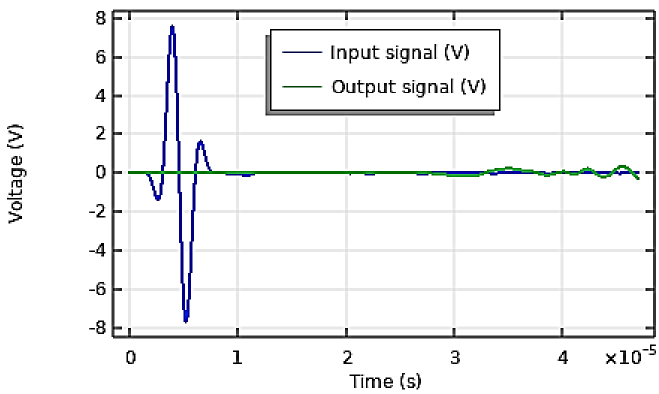

Figure. 10. Graph of voltage vs time in non-homogenous milk medium.

Table 3 shows the data for the maximum peak of wave amplitude when the condition of milk packaging is homogenous and non-homogenous. This maximum peak value is taken from the data collection of the output signal and analysed using Minitab software. From the table, the value of the non-homogenous condition is lower than the homogenous due to the presence of the 1 mm metal piece. The existence of 1 mm metal piece will make the energy amplitude level decreases when it reaches the receiver because the wave energy attenuates when it travels through the milk [6]. From the analysis, this conceptual modelling can distinguish the presence of the 1 mm metal piece in the milk medium.

Table 3. The wave amplitude.

Condition	Wave amplitude (V)
Milk medium only (Homogenous)	0.44341
Milk medium with metal piece (Non-Homogenous)	0.41656

6. Conclusion

This research gave an overview of the basic ultrasonic tomography modelling design for detection foreign material in milk packaging. The initial concept of the ultrasonic tomography technique is also explained. Besides, the types of material and density, speed of sounds for each contained material are identified. Further research can be carried out through several simulations by applying different types of foreign objects in milk packaging. The results showed the effectiveness of the proposed technique in detecting food contaminants by monitoring the inner section of food packaging. In future, a variety of analyses can be done, including acoustic impedance, arrival time, and voltage to determine whether the milk contains any foreign objects or not.

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7. References

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