Monitoring of defrosting in food by ultrasound measurement techniques

Ruchi Jha, Walter Lang, Reiner Jedermann,
Institute for Microsensors, Actuators, and Systems (IMSAS), University of Bremen, Bremen, Germany

Abstract

Ultrasonic measurements are widely recommended for food processing systems. Multiple processes in the food industry starting from storing, freezing, thawing, and packaging involve time and human labor. To be able to automate the processes, it is required to monitor and control the food processing steps, e.g. the defrosting process. This paper discusses an ultrasonic sensor system and its various performance parameters based on contact material, frequency, and food type. For chicken soup, one of the sample food products, we could demonstrate a change of 60.7 % in the signal delay due to defrosting. The research aims to discuss various influential factors for ultrasonic measurement systems and comment on the suitability of a test setup designed for monitoring the defrosting of food.

1. Introduction

Freezing is one of the traditional and efficient techniques of food preservation. It not only stops the growth of micro-bacterial but also slows down the enzyme activity, which can spoil the food [1]. Alongside the growth of the food industry, a well-equipped freezing system is always in demand. Single or multiple sensor-based systems are often used to monitor and control freezing systems. The sensor systems aim to observe the content of ice in the food and the condition of food in general to evaluate the quality of food. The information on ice content is crucial for quality control and monitoring of frozen food and storage [2]. A wide range of sensor technologies, such as x-ray, near Infra-Red, electromagnetic measurements, ultrasound, magnetic resonance imaging, and image processing. are being used in the food industry [3]. Some Industrial infrared sensors are designed in such a way that they can quickly read the temperature of frozen food from the conveyer belt directly. Later, a controlled freezing system is developed using the well-known proportional relationship between temperature and freezing. However, it can still be challenging to monitor the start of the decay of food at a molecular level. Another widely used method is by determining the change in dielectric properties of food using microwave systems. It was used to predict the time and temperature of storage for frozen hake fish. The changes in the microwave dielectric properties were monitored and using the linear predictive method a success rate of 92 % was obtained [4]. Radiofrequency systems are also used for a similar purpose and the obtained results were used for monitoring and controlling heating and thawing frozen tuna fishes [5]. A few food storage companies have a smart wireless camera installed with a sophisticated image processing algorithm. Digital images of food items can be differentiated based on elements like size, color, and pixels. With the help of a large number of training samples, the algorithms are trained to detect the changes in food items (decaying). Most times detection of foreign objects during packaging is also a crucial application of the system [6]. However, it is not practical to use image processing techniques to detect the slight initiation of decay processes. Some food items might take a longer time to reflect a physically noticeable change. It is more accurate to use a secondary method that could detect the changes in the internal structure of food together with image processing systems. Food health monitoring using methods based on heat or high frequencies is likely to damage the food item. Considering such parameters, it’s needed to have low power, non-destructive method measurement method.

Ultrasound technology, being a low-cost, sustainable, and eco-friendly technology is very popularly used in the food industry. The various other applications associated with food processing, where the ultrasonic systems are already being used are extraction, thawing, sterilization, etc. [7]. These methods are widely used on various food products; however, the processing of meat, fish, and seafood depends on a good preservation technique. Most food comes with a challenge of suitable packaging and processing and it is not advisable to have them exposed to the environment for long, during experimental hours as well. Since ultrasonic measurements can be performed in non-destructive modes, it is also an important reason for its being widely recommended for food processing systems.

In this paper, a monitoring system based on the concept of varying speeds of ultrasonic sound is discussed. The temperature change has an impact on the phase (liquid / solid) of the free water content in the product and thus, the acoustic impedances change over time with temperature. This research studies the change in speed of sound through the food items as a function of temperature. To establish a test case, an experiment was first conducted on an ice block of known length to study the change of speed of sound through the various phases of meltdown (starting from completely frozen to completely liquid). To achieve so, a suitable transmitter-receiver electronics system and microcontroller board were used to generate pulses for transducers. The goal of the setup was to be able to transmit and receive ultrasonic sound waves through selected food items and observe the delay in the signal recorded at the receiving end, thus establishing a relationship between the type/parameter concerning the food items and the speed of sound. Later, the experiment was repeated for multiple trials for frozen / non-frozen food material with varying factors

ISBN 978-3-8007-5835-7

based on the type of transducers used, the frequency of operation, contact material, pulse length, type of spring and setup, etc. The research aims to discuss various influential factors for a contact-based ultrasonic measurement system and to comment on the suitability of a test setup designed for monitoring the defrosting of food.

2. Material and Methods

The ultrasonic system works on the principle of sound transmission and reflection. The basic idea is to be able to monitor the delay in the received signal once it undergoes food material or a test object. Based on the properties of food materials and their acoustic impedance, the received signal has a delay compared to the transmitted signal. These differences are further analyzed and studied to comment on the quality of food, ice content, the contact material, and the various other parameters used in the setup.
The ultrasonic experimental setup contained ultrasonic transducers working on frequencies ranging from 40 Hz to 20 MHz. Four commercially available transducers, operating at 40 kHz, 200 kHz, 1 MHz, and Omron ultrasonic transducers (with an optional wide range of frequencies between 1 k to 20 MHz) were used to send and detect ultrasonic pulses. To generate pulses and channel them through the test food item, a suitable pulse generating circuit was designed. The entire electronic circuit can be divided into three parts:

Pulse Generation: Arduino Nano was used to generate pulses by switching off and on its internal registers with a selectively time delay and duration. The pulse generated is later fed to the transmitter. It was observed that based on the sensor in use, the pulse length needs to alter. For example, using 20 µs of alternate varying polarity pulse defined the best performance of 40 kHz and 200 kHz sensors. whereas, for 1 MHz, the changing polarity with 4 µs of pulse length was found more suitable.

Transmitter: It consists of industrial transistors and suitable power adapters. For the current research a high voltage, the TC6320 low threshold package of MOSFETs was used [8]. This combination produces a device with the power handling capabilities of bipolar transistors and with a high input impedance.

Receiver: Good amplification and filtering were required to receive ultrasonic frequencies and provide an equivalent electrical voltage. AD8429, 8091 are the two choices on industrial amplifiers, used to amplify and provide the readable output. while using a 1 MHz sensor set, we also used damping resistors to suppress the oscillations coming from the wired connections. To keep the system suitable for an unpredictable signal response, two stages of the amplifier were designed.

Table 1: Electronic System - Design and specifications

Resonance frequency	200 kHz	40 kHz	40 kHz	1 MHz	Wide range (1 k to 20 MHz)
Holder Material	Flexible	Rigid	Flexible	Flexible	Rigid
Amplifier	AD8429	AD 8429, 8091	AD 8429, 8091	AD 8429	AD 8429
Gain of first stage amplifier	91.90	391.87 (for cucumber) 91.90 (in general)	391.87 (for cucumber) 91.90 (in general)	91.90	91.90
Damping Resistor	None	None	None	Variable from 1to 20 k	1 k Ohms
Pulse Voltage	15V	15V	15V	15V	10V
Pulse Length	20 ms	20 ms	20 ms	4µs	20 ms/4µs
Polarity	Alternate positive and negative pulses	Alternate positive and negative pulses	Alternate positive and negative pulses	5 Pulses with alternate polarity	Negative pulses
Tested Food Item(s)	Radish Sweet potato Beetroot Chicken soup Ham	Radish Cucumber Sweet potato Beetroot Chicken soup	Radish Cucumber Sweet potato Beetroot Chicken soup	Radish Sweet potato Chicken soup	Radish Sweet potato Chicken soup

Table 1 contains the various electronic elements that were needed to design the measurement system. Apart from the major three parts of the electronics assembly, a few extra resistors were also needed to provide damping or improve gain. Electronic circuits based on industrial FET switches, MOSFETS and instrumentation amplifiers were designed for pulse generation and transmission.
Our mechanical setup consisted of metal plates (120 mm* 60 mm) to dampen vibrations and springs to press the transducers with constant force on the probe. A few self-designed laboratories-based 3-D printed and support structures holders (Figure1, in red and yellow) were also used with the mechanical setup. Figure 1 is an example picture for the measurement setup designed for recording the change in signals through chicken soup (Upper rack) and Ham (lower rack). The food item to be tested was kept in the fridge overnight, along with a stable mechanical setup aimed to keep the food steady and thus not affect the signal change. The measurements were conducted overnight when the temperature was maintained at -10 °C. In some cases, we also monitored the change in delay signal while the temperature was made to change from + 10 to -10 °C, to see how quickly food responds to freezing.

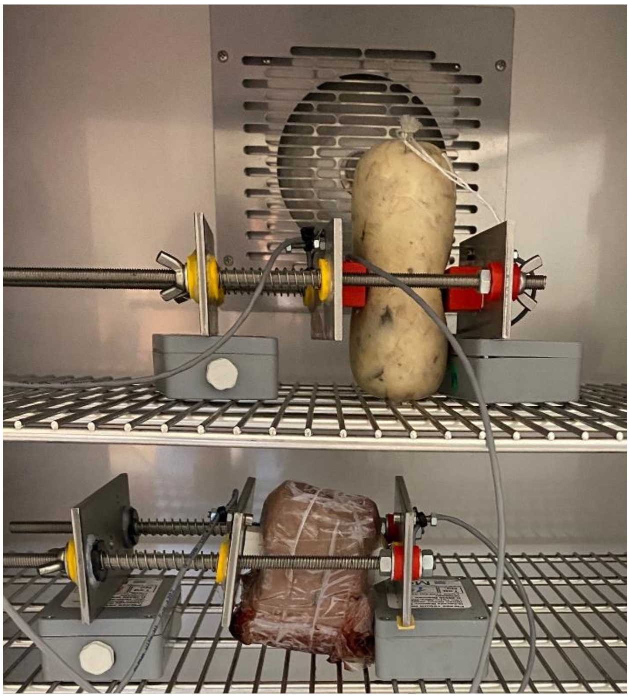

Figure 1 Measurement setup with chicken soup and Ham in the fridge.

Figure 2 is a screenshot obtained from the oscilloscope. Here the pink line shows the active trigger, which could be understood as the switch which starts sending the transmitted signal, marked in green. Which when passes through the food experiences a delay and is later recorded. The first stage amplified output is marked in yellow and the second stage is in blue. The time taken from the first peak of the transmitted signal to the first peak of the reflected yellow signal is the delay value, which is specific and a dependent entity of the physical changes happening in the food item during freezing.

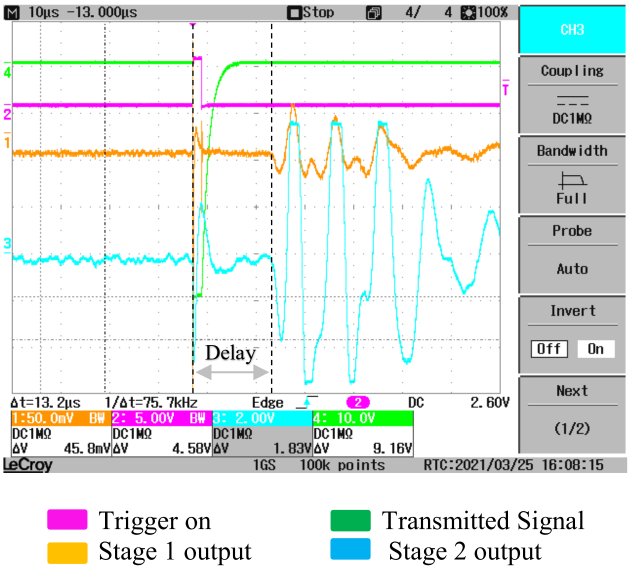

Figure 2 Oscilloscope screenshot for chicken soup as an example.

In the initial tests, slices of ice with increasing thickness were placed in a box with water. As the speed of sound is faster in ice, the percentile ice content had an almost linear effect on the average sound speed changing from 1.35 km/s (0% ice + 100 % water) to 2.71 km/s (100 % ice + 0% water). The effect of freezing on the speed of sound was tested for various food products; the chicken soup was maintained at +10 °C and later the temperature was reduced to - 10 °C. The delay values were noted at regular intervals.

3. Results

Several experiments were conducted on different types of food (beetroot, radish, cucumber, sweet potato) and commercially available packed meat, chicken soup, and fresh meatloaf as well. To be able to design a good setup, various other factors like frequency, pulse length, spring type, nature of contact were studied for the measurements. It was taken care that to study the influence of one parameter on the entire setup, the other parameters were kept constant.
As shown in figure 3, a change in delay values concerning the change in the physical state of chicken soup could be noticed. At the beginning of the experiment, the soup was maintained at + 10 °C and the measured delay value was 55.6 µs. In the further course of the experiment, the temperature of the fridge was reduced to -10 °C and the delay values were measured for regular time intervals. As the soup was completely frozen at -10 °C, the delay was found to be 33.8 µs. 200 kHz sensor set up along with a coupling agent as a contact material between sensor and soup, provided the most precise measurement values.

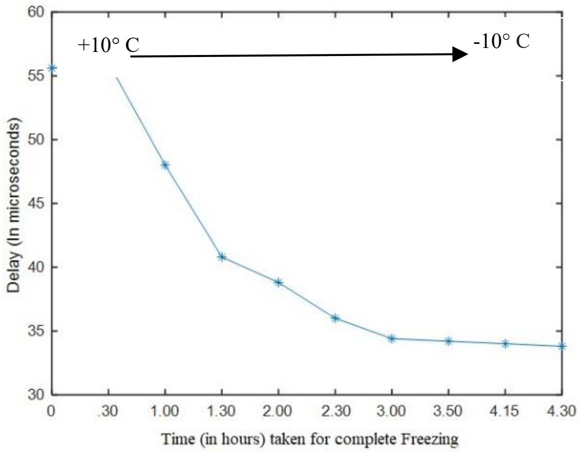

Figure 3 Record of change in time taken by ultrasound to pass through chicken soup.

During ultrasonic measurements, the contact nature or material between the sensor probe and the food item is of critical importance for accuracy. To study the impact of the same, a silicon strip, coupling gel, and direct contact was established. It was taken care that the test food item and the temperature are maintained at the same value while switching from one method to another. The delay obtained in the test food item was already known and the resultant delay values from the three cases were compared. As shown in figure 4, a comparison was made using three different sensor types and it was observed that using a coupling gel the accuracy obtained was the best compared to the other two cases. (for the silicon strip and direct contact the measured delay values were higher than the expected value. During the measurements using the direct contact, we also noticed that signal strength had weakened and in some cases, an additional noise signal was also observed.

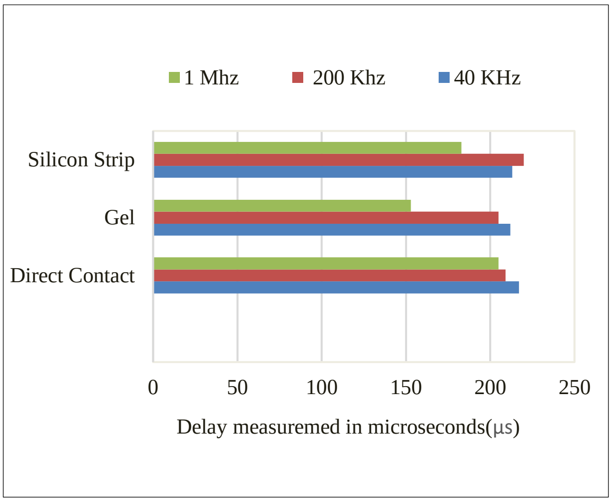

Figure 4 Effect of contact Material on delay measurements on frozen food products.

4. Conclusion

A low-cost electronic setup capable of recording ultrasonic measurements was achieved. It could monitor the start of defrosting by an increase of the signal delay by 60.7 % for chicken soup as a sample product. It is also recommended to use a coupling gel for maximum accuracy and avoid having direct contact between the sensor and food item. However, no significant change in signal was obtained while testing for frozen Ham. During the measurements with soft food items (for example, fresh meat), the shape of the test food changed during defreezing and it created missing or loose contacts with the sensor setup. This further brought inaccuracy in the measurements. Hence it is recommended to use a stable mechanical setup that could adapt itself to changing shapes in food and thus ensure a stable contact throughout the measurement. It was also noticed that ultrasonic transducers working at different frequencies worked best based on the food type used. Thus, it is recommended to use multiple sensors for continuous monitoring in an industrial setting.

5. Literature

[1] Douglas L. Archer: Freezing: an underutilized food safety technology, International Journal of Food Microbiology, Volume 90, Issue 2, 2004, Pages 127-138.

[2] C. Aparicio, L. Otero, B. Guignon, A.D. Molina-Garcıa, and P.D. Sanz.: Ice content and temperature de-termination from ultrasonic measurements in partially frozen foods, DOI: 10.1016/j.jfoodeng 9 February 2008.

[3] Mohd Taufiq Mohd Khairi, Sallehuddin Ibrahim, Mohd Amri Md Yunus and Mahdi Faramarzi: Contact and non-contact ultrasonic measurement in the food industry: A review, : Measurement Science and Technology, Volume 27, Number 1.

[4] Michael Ken, Reinhard Knochel, Frank Daschner, Ove Schimmer, Margarita Tejada, Almudena Huidobro, Leonor Nunes, Irineu Batista & Andreia Martins, Determination of the quality of frozen hake using its microwave dielectric properties, International Journal of Food Science and Technology 2005, 26 August 2004.

[5] Yvan Llave, Yuina Terada, Mika Fukuoka, Noboru Sakai: Dielectric properties of frozen tuna and analysis of defrosting using a radio-frequency system at low frequencies, Journal of Food Engineering 139 (2014) 1–9, 2014 Elsevier Ltd.

[6] Xinfeng Cheng, Min Zhang, Baoguo Xu, Benu Adhikari, Jincai Sun: The principles of ultrasound and its application in freezing related processes of food materials: A review, Ultra sonics Sonochemistry, Volume 27, November 2015, Pages 576-585.

[7] Lili ZhuPetros SpachosErica PensiniKonstantinos N. Plataniotis: Current Research in Food Science, https://doi.org/10.1016/j.crfs.2021.03.009. 25 March 2021.

[8] Datasheet of MOSFET TC6320