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REAL-TIME SEAFOOD QUALITY MONITORING SYSTEM USING INTERDIGITAL SENSOR

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Abstract. *Many studies showed that seafood consumption contains many health benefits. However, the spoilage of such products causes the vast economic loss each year. An effective monitoring and inspection system for quality is required during the storage of these products. Most existing methods for such inspection require laboratory tests. In this study, the interdigital sensor was developed and applied to inspect the spoilage of seafood. The sensor was designed to monitor the change of impedance during spoilage progression of seafood. The result revealed that impedance of liquid decreased overtime. This coincides with the fact that spoilage of seafood generates ammonium ion which causes decrease in the impedance of the liquid. The designed sensor was then merged with the proposed system which consists of a sine wave circuit, a voltage control current source circuit, an interdigital sensor, an amplifier circuit, a rectifier circuit, a low-pass filter circuit, a comparator circuit and a display circuit. These circuits adjusted the signals received from the sensor to be proper to the application. The experiment was designed to have conditions similar to the real-world situation of how seafood is stored. The experimental results showed that the proposed system effectively indicated the change of seafood quality.*

Keywords: Interdigital sensor, Impedance measurement, Seafood inspection

1. **Introduction.** Seafood is an important source of energy and protein for humans. It contains significant nutrients such as Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA). Popular seafood includes fish, squid, crab, shrimp, oyster, etc. Seafood demand has been increasing steadily due to its health benefits. The major problem in seafood product is the contamination of bacteria such as Listeria monocytogenes, Salmonella, and Escherichia coli. The sickness caused by bacteria includes Gastroenteritis, Septicemia, Typhoid fever, etc. The virulence depends on the type and the amount of bacteria intake [1,2]. The techniques often used in seafood quality inspection are culturing method, polymerase chain reaction (PCR) test, and quantitative PCR (QPCR) test. Such methods are not practical for application in seafood stalls or food markets since they require laboratory test, technical skills, high cost, and long period of time [3,4]. This paper developed a system for the seafood quality monitoring and inspection. The proposed system is based on the measurement of the impedance change of the liquid soaking the seafood.

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The paper is organized as follows. First, the fabrication, experimental design and results of the interdigital sensors are explained in Section 2. Section 3 presents the proposed system used to connect with the selected interdigital sensor. System evaluation and conclusion are in Section 4 and Section 5, respectively.

2. **Interdigital Sensors.** Seafood is a perishable product of which the quality declines after trawled from the sea. The spoilage is caused by bacterial contamination. Seafood contains organic compounds including lipid, protein (enzyme), and carbohydrate. The degradation of these compounds by heterotrophic bacteria, spoilage-causing microorganisms, results in the release of inorganic components including carbon dioxide, water and ammonia. The ammonia from the decomposition of the protein can be dissolved in water and becomes ammonium ions (NH4+). The presence of such compound in water results in reduction of water impedance. Thus, the investigation of water impedance values may be a promising approach for the seafood-spoilage monitoring and inspection. In this s-tudy, a sensor measuring impedance in liquid soaking in seafood was developed and its application for measuring in quality of seafood was evaluated.

2.1. **Sensor fabrication.** From the proposed concept, the variation in the impedance of the liquid used to soak the seafood is related to the change of the seafood quality. In this section, the interdigital sensors were designed to measure the impedance of the liquid soaking the seafood samples [5-9]. The proposed interdigital sensor was made of a printed circuit board (PCB) FR-4 with dielectric constant (εr) of 4.7. Four types of sensors with different sizes and electrode configurations were designed and evaluated. The sizes were selected to be suitable to be used in food stall. Figure 1 shows the electrode configurations and dimensions of the interdigital sensors. Figure 2 shows the corresponding fabricated interdigital sensors.

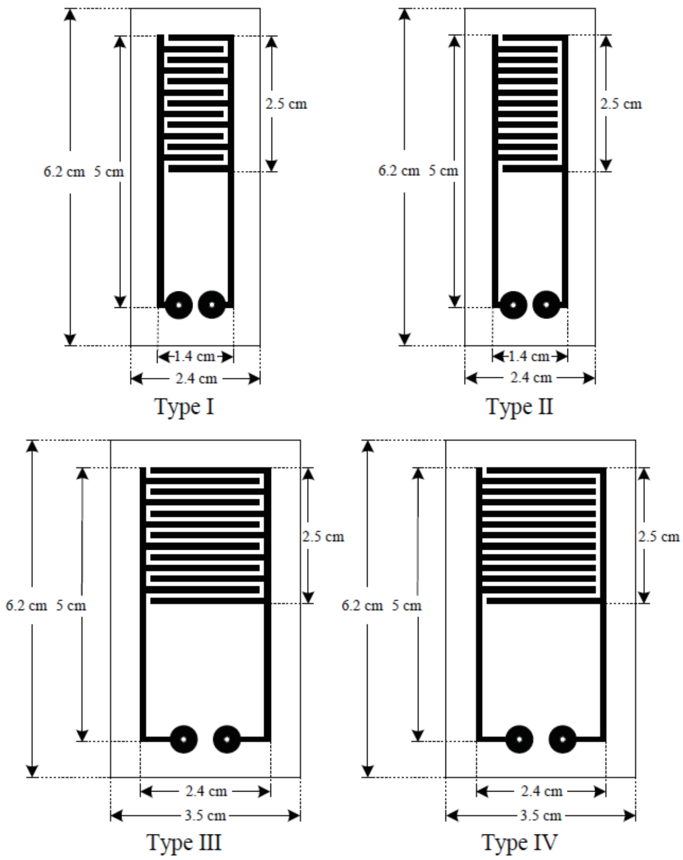


FIGURE 1. The dimensions and electrode configurations of the interdigital sensors

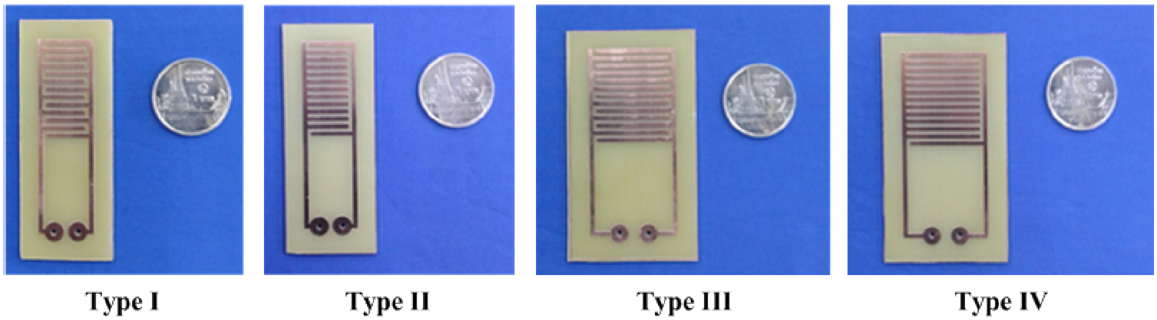


FIGURE 2. Four types of the fabricated interdigital sensors

2.2. **Experimental design.** To study the performance of the designed sensors, the impedance values of two types of the seafood samples, cuttlefish and oyster, were measured in the experiment. Each type of seafood was evaluated at 2 selected frequencies, 10 kHz and 100 kHz. In the first part, the reference impedance values of the sensors were measured to observe the characteristics of the sensor when no subject was connected to the sensors. The impedance measurements were performed using Hioki 3532-50 LCR HiTester in LCR measurement mode. The amplitude of test voltage was set to 1 Vp-p. In the second part, the performances of the proposed interdigital sensors were evaluated through the experiment using real seafood samples. In the experiment, 20 grams of the seafood samples, cuttlefish or oyster, were placed in a container with 100 ml water. The impedance value of interdigital sensor was recorded every 30 minutes for 8 hours.

2.3. **Experimental results.** The measured reference impedance values for each type of sensor are shown in Table 1. The values of impedance as a function of time for cuttlefish using interdigital sensor types I, II, III, and IV are shown in Figure 3. Similarly, the values of impedance measured as a function of time for oyster using interdigital sensor types I, II, III, and IV are plotted in Figure 4. From the experimental results, the sensor type IV was selected for the application since it provides the smoothest responses and largest amount of decrement of impedance among the four types. The sensor was selected to be used in the proposed system discussed in the following section.

TABLE 1. The results of impedance measurement of each sensor

Interdigital sensor	Test frequency	
	10 kHz	100 kHz
Type I	1.3419 MΩ	128.91 KΩ
Type II	2.2543 MΩ	201.86 KΩ
Type III	1.8918 MΩ	171.84 KΩ
Type IV	6.3527 MΩ	606.93 KΩ

3. **The Proposed System.** To observe the value of impedance using the designed interdigital sensor, other circuits are required to amplify, compare and display the signal received from the sensor. The proposed system consists of a sine wave circuit, a voltage control current source circuit, an interdigital sensor, an amplifier circuit, a rectifier circuit, a low-pass filter circuit, a comparator circuit and a display circuit.

Figure 5 shows a block diagram of the proposed system for the seafood quality monitoring and inspection using the interdigital sensor. A sine wave oscillator was used to generate a sine wave signal with amplitude 10 Vp-p and at frequency of 100 kHz. A voltage control current source circuit (VCCS) was used to control the output current sent to the interdigital sensor to have the amplitude 1 mAp-p. The signal received from the

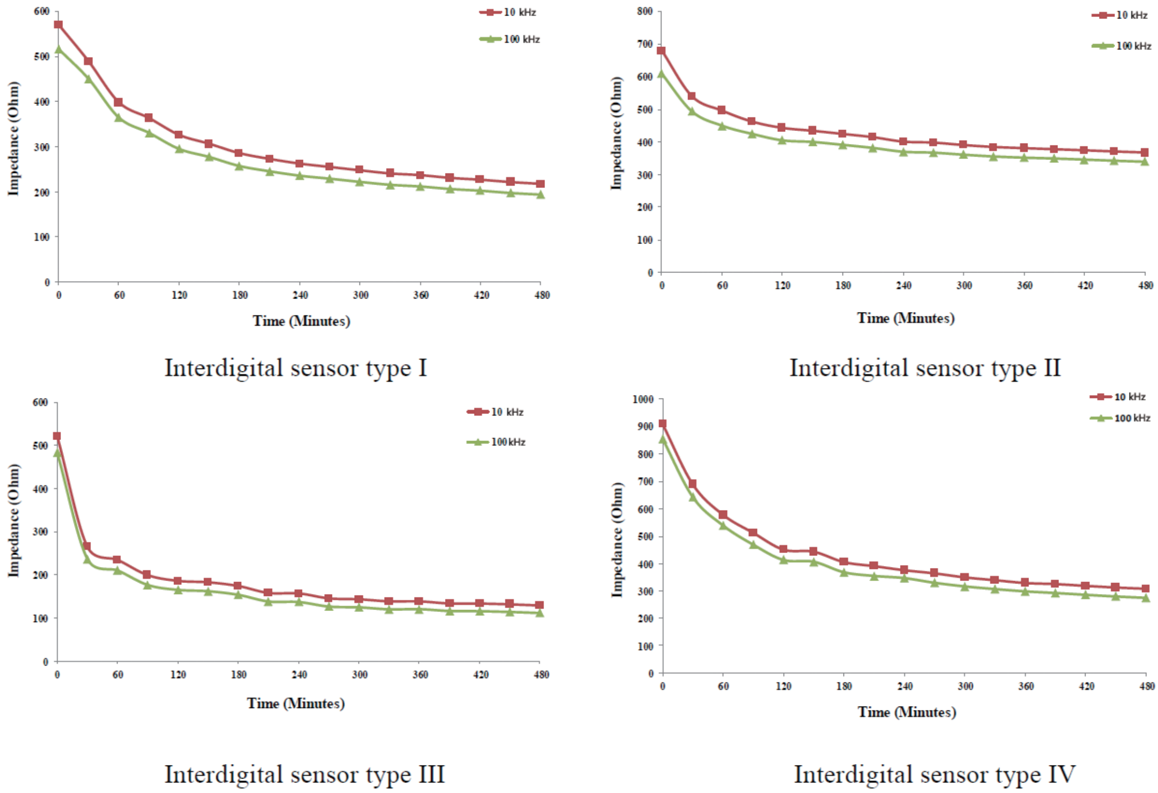


FIGURE 3. The recorded impedance values as a function of time using interdigital sensor types I, II, III, and IV for the cuttlefish samples

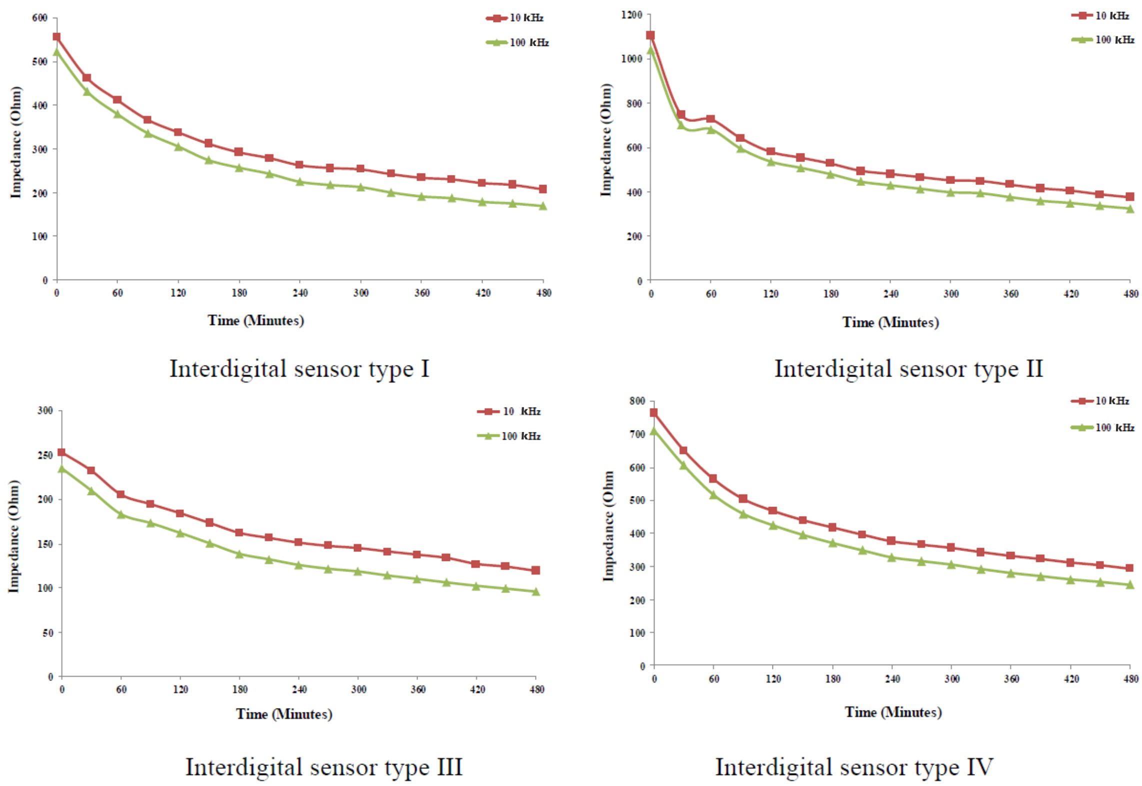


FIGURE 4. The measured impedance values as a function of time using interdigital sensor types I, II, III, and IV for the oyster samples

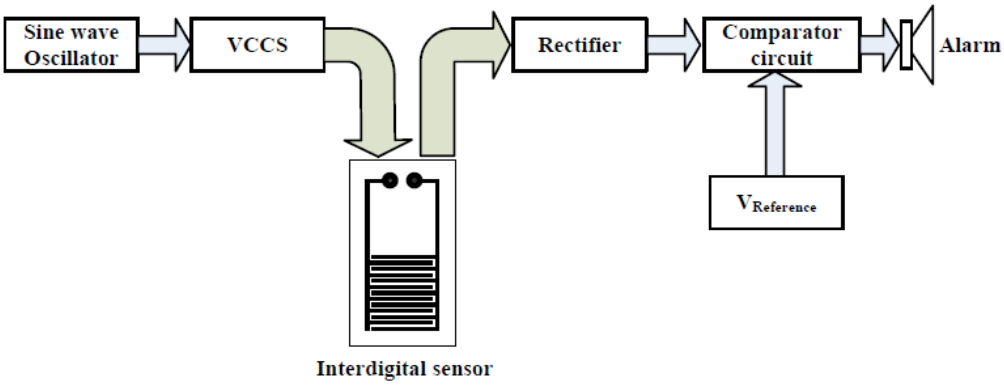


FIGURE 5. The block diagram of the proposed system for the seafood quality monitoring using the interdigital sensor

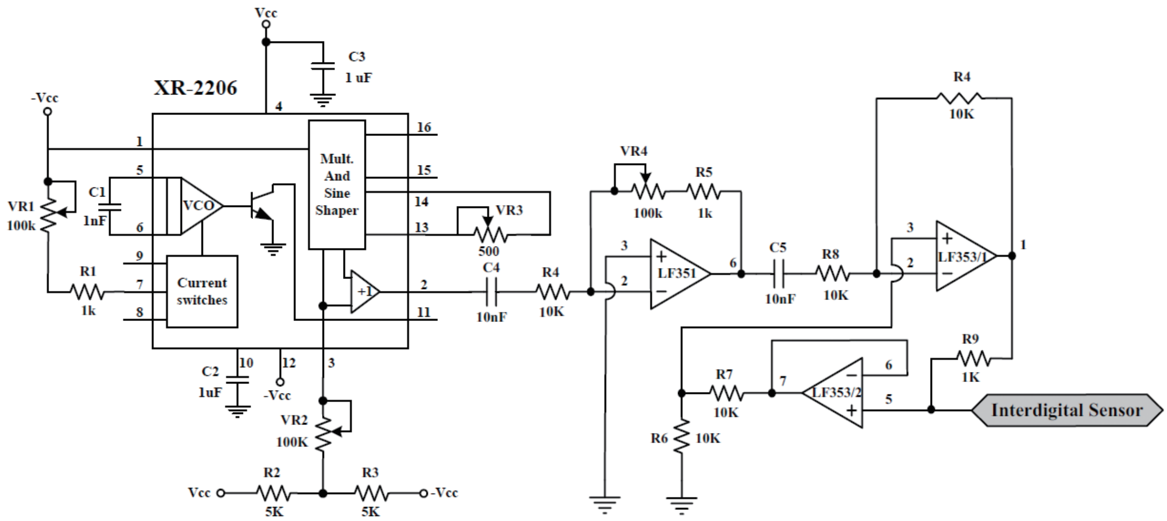


FIGURE 6. The proposed circuit for current injection to the interdigital sensor with amplitude 1 mAp-p

interdigital sensor could be used to calculate the impedance values of the liquid contacting to the sensor. Then, the rectifier circuit converted the signal to direct current (DC) signal. The low-pass filter circuit rejected the ripple voltage of the rectifier circuit before the output signal was sent to the comparator circuit. The comparator circuit compared the signal received with the referenced voltage, and generated the output signal to drive the buzzer and the LED when the output signal from the low-pass filter circuit is less than the referenced voltage. The implementation of the proposed system for the seafood quality monitoring and inspection using interdigital sensor can be divided into two parts as shown in Figure 6 and Figure 7. For the first part, the circuit was used for current injection into the interdigital sensor with control amplitude at 1 mAp-p. For the second part, the circuit was used to detect signals from the interdigital sensor, compare the output signal with referenced voltage, and turn on the alarm circuit when the impedance is lower than the set value.

4. **System Evaluation.** The proposed circuits in Figure 6 and Figure 7 were built using commercially available devices and applied to the sensor type IV. The power supply voltage was set to ±12 V. The performance of the proposed system was evaluated through the experiment by using two types of the seafood samples, cuttlefish and oyster. Each type of the seafood was tested in two conditions, water without ice and water soaking ice which imitates the real conditions of how seafood is usually kept in the food stall.

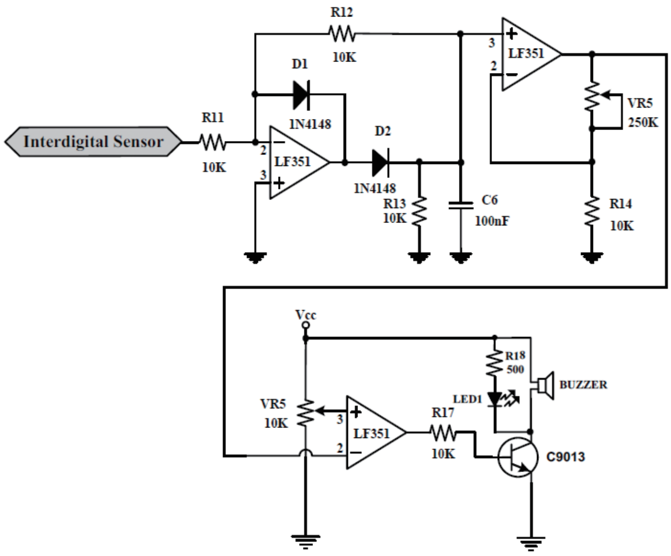
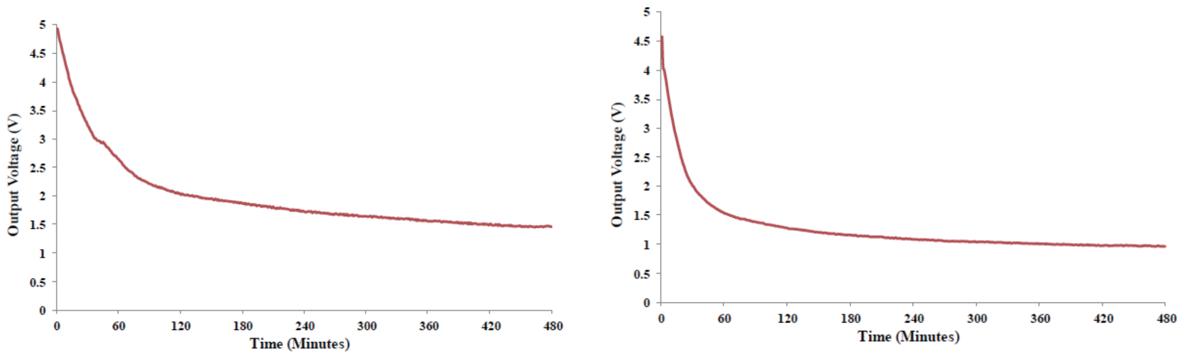


FIGURE 7. The proposed circuit used to detect the output signal from the interdigital sensor



(a) Cuttlefish sample

(b) Oyster sample

FIGURE 8. The output voltage of water (without ice) soaking the seafood samples, (left) cuttlefish and (right) oyster, as a function of time

The procedure of the experiment can be explained as follows.

Case 1: Seafood soaked in water without ice.

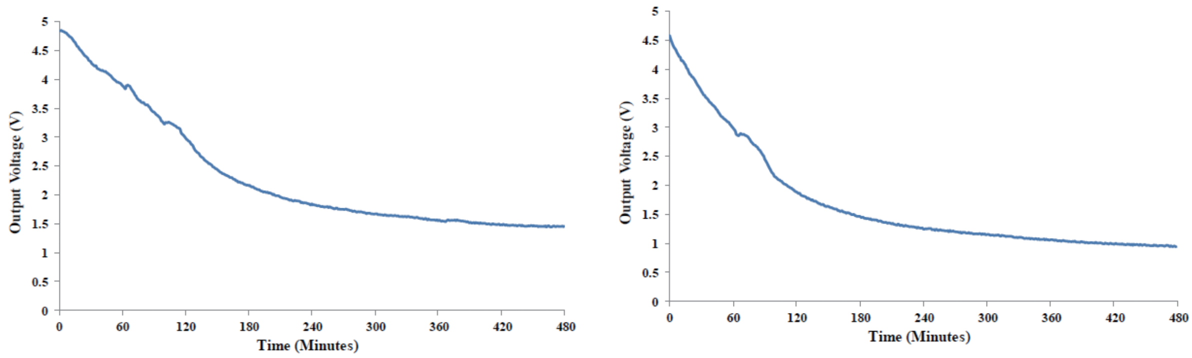
1) Prepare the seafood sample, 20 grams of cuttlefish or oyster.
2) Place the seafood sample in a container.
3) Fill 100 ml of water into the vessel.
4) Measure the output voltage every 30 minutes for 8 hours.

The measured output voltage as a function of time for the seafood samples in water without ice is shown in Figure 8.

Similarly, to imitate the real condition in the market, the procedure for the second case can be listed as follows.

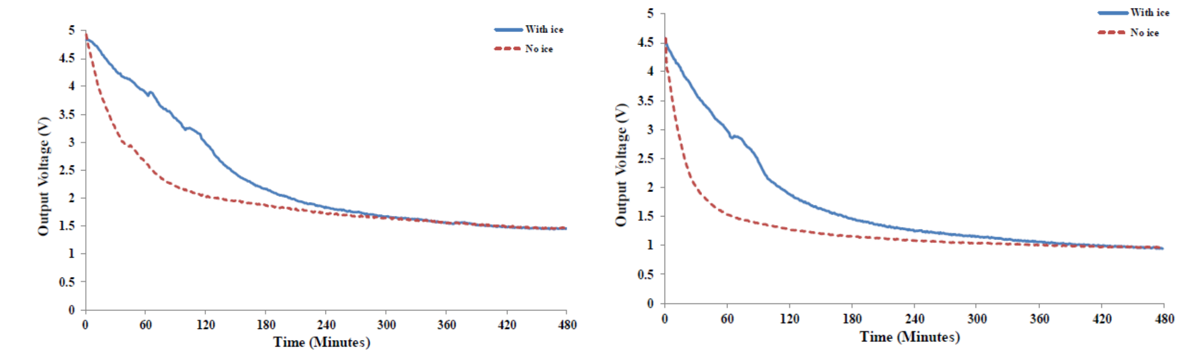
Case 2: Seafood immersed in water with ice.

1) Prepare the seafood sample, 20 grams of cuttlefish or oyster.
2) Place the seafood sample in a container.
3) Put 20 grams of ice and fill 80 ml of water into the container.
4) Measure the output voltage every 30 minutes for 8 hours.



(a) Cuttlefish sample (b) Oyster sample

Figure 9. The relationship between the time and the output voltage of the proposed system of seafood sample, (left) cuttlefish and (right) oyster, soaked in ice water



(a) Cuttlefish sample (b) Oyster sample

Figure 10. The comparison of output voltage in case 1 (no ice) and case 2 (with ice) of cuttlefish and oyster samples

The relationships between the output voltage and time of the proposed system of the seafood samples in case 2 are shown in Figure 9. Figure 10 shows the comparison of the output voltage between the two cases for cuttlefish and oyster samples.

5. **Conclusion.** This paper presents the system development for seafood quality inspection using interdigital sensor. First, four types of sensors for impedance measurement of liquid soaking in seafood were designed and evaluated. Sensor type IV was selected to be applied in the system since it provided the smoothest response among the four types. Then, the proposed system using the interdigital sensor with additional circuits was verified in the experiment. The experiment imitated the condition of how seafood is usually stored in the real world market where seafood is either soaked in water or soaked in water with ice. The experimental results showed that the proposed system can detect the change of seafood quality effectively. The sensor is practical to be used in the real world market since it provides fast result with a warning when the quality of seafood is below the selected threshold.

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