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# Development of Interdigitated Electrodes for Cooking Oil Detection using AD5933 Impedance Analyzer

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**Abstract**: This study consists of designing Interdigitated Electrodes (IDE) using AutoCAD for chemical solution detection. Three types of IDE sensors were designed based on different types of parameters such as length, width, space between electrodes and sensing area and the effect of electrode spacing and electrode length were then analysed for chemical solution characterization. The IDEs were fabricated on FR4 using photolithography techniques. The sensing approach was based on distinguishing a shift in impedance value of the sensor when material under test is introduced at the sensing area. The IDEs were then experimentally presented as sensing elements for characterization of liquid substances such as tap water, distilled water, ethanol, methanol, vegetable oils with animals fat. The impedance measurements were collected and analysed using LCR Meter and AD5933 Impedance Analyzer. Data that has been obtained from Impedance analyzer were then tabulated using Microsoft Excel. From the experiment conducted, an observable shift of impedance values was identified upon the introduction of material under test. It is identified all the parameters affect the impedance value of the chemical solvents. Therefore, the impedance measurement given by the proposed sensors is very potential to provide information for liquid detection.

**Keywords**: *Interdigitated Electrode, Impedance Analyzer, Sensor*

## 1. Introduction

The use of science and technology in advanced food preparation leads to food adulteration, which provides an attractive and lucrative (method) in preparing raw materials for every food and beverages manufacturer (N. A. Fadzlillah et al., 2017). Adulteration can be defined as the act of intentionally taking the form of substitution of one species for another whereby the food products from one species have been mixed intentionally with either similar substitute ingredients or cheaper species. Food adulteration is a serious problem worldwide not just because it is fraud to consumer, but it can also cause harm to human health (B. Stephen Inbaraj & B. H. Chen, 2016).

Among the food products, edible oil has been identified as one of the top ingredients involved in food fraud. Adulteration in cooking oil can be considered as one example of an activity that deals with food authenticity. As we know, cooking oil is an important product in the Malaysia food industry. Most of the cooking oil products are based on palm oil (B. Kuswandi et al., 2017).

As been reported by several researchers, some of the unethical food business operators were using recycled frying oil to save costs. The practice is a considerable concern as recycled frying oil taken from non-halal food premises should not be used by halal food premises. This is a matter of concern to Muslim consumers, who have to be sure that their foods are halal and free from haram ingredients (B. Kuswandi et al., 2017). In addition, the repeated use of cooking oil at high temperature results in generation of undesirable substances, which may cause harm to human body. Generally, the fats and oils in recycled frying oils would undergo thermal and oxidative decomposition which will increase the viscosity of the oils, darken the colour, increase foaming and decrease the smoking point.

Degradation of frying oils may affect the texture, taste and overall flavour perception of the food (Khamil et al., 2017).

Rapid and reliable on-site analysis for preliminary and meaningful information extraction are urgently needed solving food adulteration issue. To date, there are many instruments have been developed to measure the different chemical and physical parameters of frying oil. For example, the chemosensory system for controlling the quality of oil in food industries, Fourier transforms infrared (FTIR) to differentiate between good and inadmissible oils chromatography to measure dielectric constant, smoke point and viscosity and image analysis to determine the TPC rate in frying oil. However, these detection techniques as mentioned in the literature are huge, not portable, expensive and time consuming. (M.A Sairin et al., 2019)

In addition, sample preparation is still a bottleneck for the field of food mobile diagnostics, which aim is to bypass the use of expensive and bulky instrumentation-based tests, operated by trained personnel. Sampling performed by non-expert user may lead to unwanted contamination, resulting in defiled measurements. (G. Rateni et al., 2017).

Currently, a lot of researchers have employed Interdigitated Electrode (IDE) for chemical and biomolecule detection. Interdigitated electrode sensor has lots of advantages especially its simple structure design (Khamil et al., 2017). In addition, one of the potential benefits of this type of IDE is the ability to integrate with other electronics instruments due to their flexibility in design (S.Partel et al., 2017). They have been widely used for the detection of capacitance, dielectric constant and bulk conductivity in biological mediums (Mazlan N. et al., 2017).

The detection mechanism for these IDEs was based on measuring the changes in capacitance or impedance when biomolecular binding occurs. Further, the IDE based sensor is currently being used in gas sensor application (G. P. Alcantara & C. G. M. Andrade, 2015) and electrochemical sensor (Farehanim et al., 2017). IDE sensor is also used for signal acquisition as a part of sensor application (Kostal E. et al., 2018).

Generally, IDE is a type of sensor that works based on the capacitive sensing method. By applying the concept of capacitive sensing, the Interdigitated Electrode (IDE) is composed of two parallel plates with two positive and negative connections tracks (Md, Nurul et al., 2016). These two plates can generate a capacitive sensing field and are able to measure the changes of dielectric material. Since each material has its own relative permittivity, $\varepsilon_r$, this method is basically based on a general equation of capacitance plate by the difference value of permittivity of material under test.

$$C = \frac{\varepsilon_r \varepsilon_o A}{d} \tag{1}$$

where $\varepsilon_o$ permittivity of vacuum, $A$ is the area of the plate and $d$ is the distance between the plates (A. R. Mohd Syaifudin et al., 2009)

Therefore, the determination of food authenticity and detection of adulteration between halal (permissible) and haram (non-permissible) ingredients are major concerns not only to consumers, but also to industries and policy makers at all levels of the production process. In addition, to support the agenda in identifying the authenticity of the halal food itself, the marriage of novel sensing technologies with portable devices enables the development of powerful lab-on-chip platforms for many important applications including medical diagnosis, environmental monitoring, and food safety analysis allowing rapid and on-site analysis for preliminary and meaningful information extraction (G. Bülbül et al., 2016).

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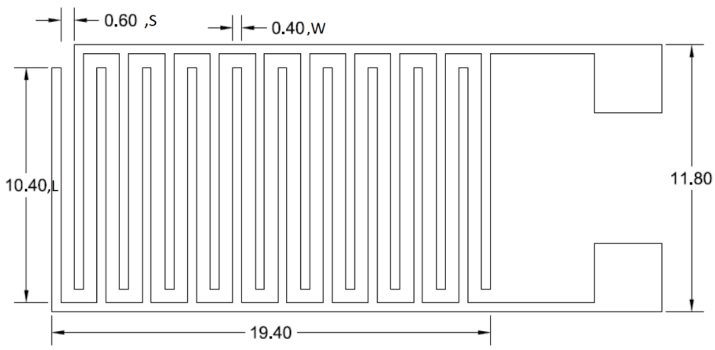
## 2. Methodology

This project introduced the sensing method for oil detection based on impedance spectroscopy AD5933 using an interdigitated electrode. Since one of the most popular practices in the unattitude adulteration activities is by mixing lard with another oil, due to cheaper production cost, it raised concerns within Muslims, Judaism and vegetarian consumers.

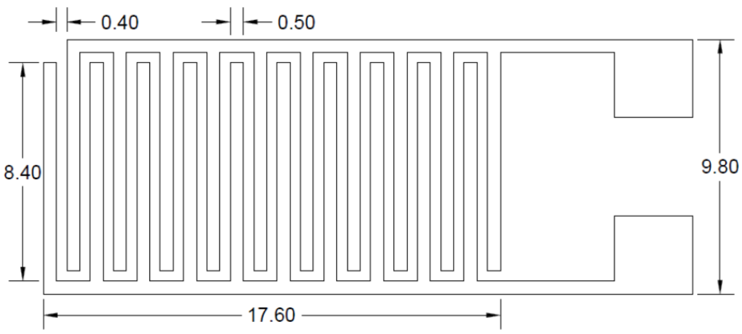
An experimental investigation was conducted to explore the combination of two different types of oils based on the spectroscopy method by using interdigitated electrode. Impedance Spectroscopy method uses the interaction of molecules with electromagnetic radiation to study the physical and chemical properties of materials. Interdigitated electrode is a simple, cheap and small transducer that can be easily employed together with the impedance measurement device, AD5933. The development of the project is divided into three parts.

### 2.1 The development of Interdigitated (IDE) Sensor

The working mechanism of planar interdigital sensor basically follows the rule of two parallel plate capacitors, where electrodes open up to provide one-sided access to the material under test (MUT). The electric field lines generated by the sensor penetrate into the MUT and will change the impedance of the sensor. The sensor behaves as a capacitor in which the capacitive reactance becomes a function of system properties. Therefore, by measuring the capacitive reactance of the sensor the system properties can be evaluated. The Interdigitated Electrode (IDE) was designed by varying the width, length and spacing of electrode. These parameters are a few factors that affect the influence of sensor sensitivity. Fig. 1 illustrates the structural designs of IDE for this study and Table 1 shows the specification for some proposed sensors. The proposed interdigitated electrodes were designed using AutoCAD and fabricated using photolithography techniques. The designs were then transferred to FR-4 printed circuit board as a substrate for fabrication processed. Fig. 3 depicts the photographs of the fabricated sensor.




(a)




(b)
**Fig. 1** Structure and dimension of proposed IDE -2

**Table 1.** Specification of Sensors

| Name of IDE | Number of electrodes | Width of electrodes (mm) | Length of Electrodes (mm) | Space between electrodes (mm) | Sensing Area of IDE (mm) |
|---|---|---|---|---|---|
| 20.1 | 20 | 0.4 | 8.4 | 0.4 | 15.6 × 10.0 |
| 20.2 | 20 | | 10.4 | 0.6 | 19.4 × 11.8 |
| 20.3 | 20 | | 12.4 | 0.8 | 23.2 × 14.0 |
| 20.4 | 20 | 0.5 | 8.4 | 0.4 | 17.6 × 9.8 |
| 20.5 | 20 | | 10.4 | 0.6 | 21.4 × 12.0 |
| 20.6 | 20 | | 12.4 | 0.8 | 25.2 × 14.2 |
| 20.7 | 20 | 0.6 | 8.4 | 0.4 | 19.6 × 10.0 |
| 20.8 | 20 | | 10.4 | 0.6 | 23.4 × 12.2 |
| 20.9 | 20 | | 12.4 | 0.8 | 27.2 × 14.4 |

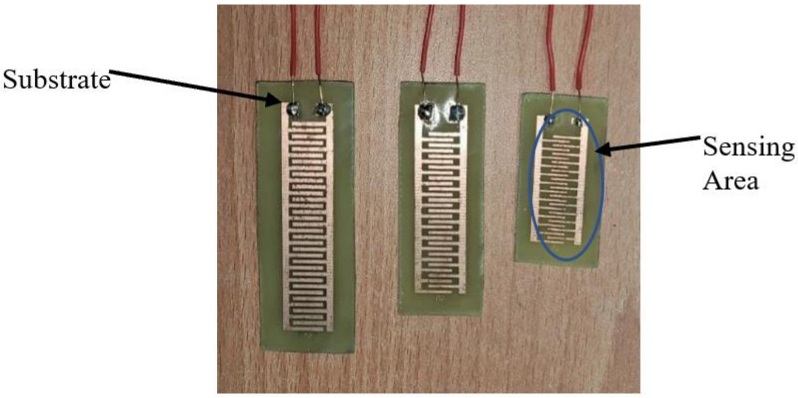



**Fig. 2** Photograph of the fabricated sensor

## 2.2 Preparation of material under test

A few material undertest were used for validation of the proposed sensor. All sensors were first being tested using chemical solvents (ethanol and methanol) as these substances have a standard dielectric value. In addition, the calibration process is conducted by using distilled water due to the dielectric constant of distilled water is more constant as compared to other types of material. Then, the palm oil, chicken and fish were purchased from a local store. Chicken and fish were cut into small pieces. 200 ml of palm oil was heated at 180$^{O}$C for 5 min. using an electric stove that has a temperature indicator. Chicken and fish samples were deep-fried separately using different palm oil at 180$^{O}$C for 5 min. Then, the used frying oils were filtered and transferred into a clean container. Another sample of non-heated palm oil is used as a control sample. Fig 3 shows oil samples that have been used in the whole experiment.

**Fig 3** Oil sample which include from left, the non heated sample of palm oil, palm oil with fish and palm oil with chicken.

## 2.3 Impedance Measurement

Impedance measurement for chemical substances and frying oil were measured using LCR meter. Fig. 4 shows the outline of the experimental setup. To validate the results, the material under test was also being measured using impedance converter evaluation kit AD5933 as in Fig. 5. The measurements process was conducted at room temperature. A 10 ml beaker was used to pour the sample. The proposed IDEs were then fully immersed in the sample. The result of the measurement was recorded at frequencies 1 kHz, 10 Khz and 100 Khz.


**Fig. 4** Experiment Set-Up

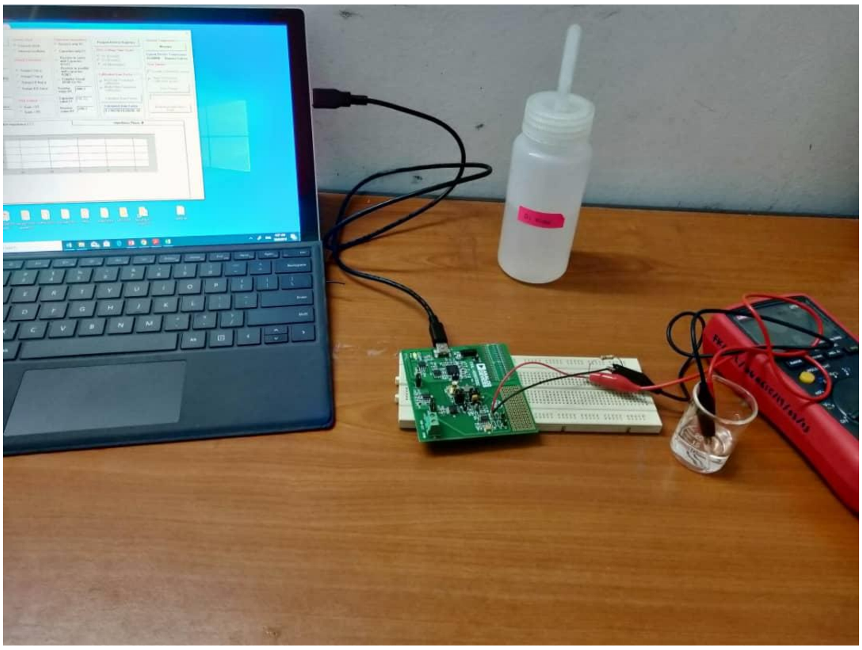


**Fig. 5** Impedance measurement test using AD5933 evaluation board with software used to display the data

## 3. Results and Discussion

In general, every material has its own dielectric value. Therefore, this project is carried out to analyse the presence of different types of oil that have been mixed together. Since every type of oil, example, animal-based oil and vegetable-based oil have different composition of fatty acids, it is expected the different concentration of two different types of oil would cause different interaction of molecules and electromagnetic radiation. Hence, a unique pattern of impedance behaviour can be used to sense the difference of oil material. The sensors were tested with oil sample. Fig 6 and Fig 7, show the result of impedance value measurement that has been carried out with two different IDE. All the results are recorded in .csv file on a laptop based on data collected through AD5933 impedance analyzer.

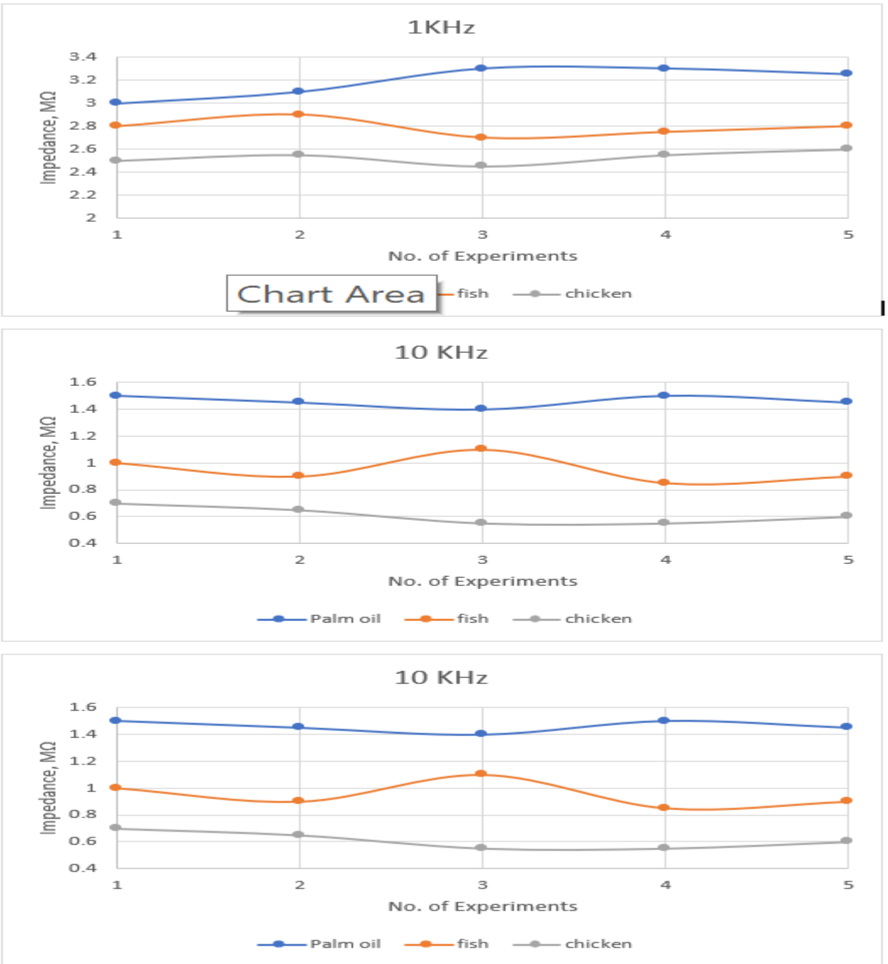



**Fig. 6(a)** Impedance measurement at different frequencies for IDE 1

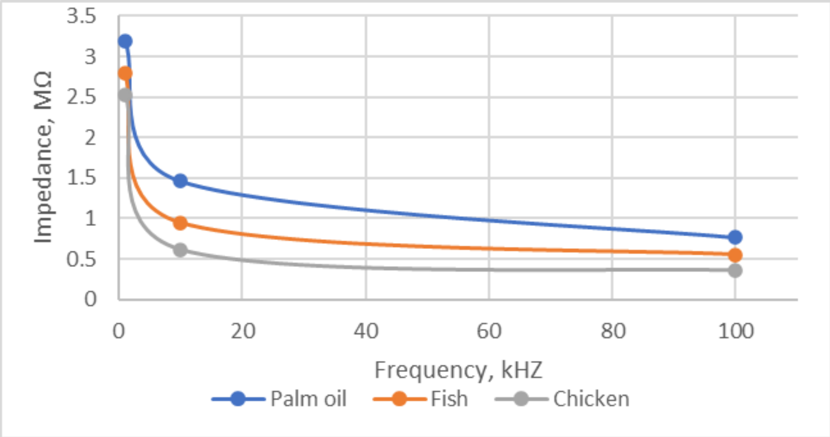



**Fig. 6(b)** Compilation of Impedance measurement at different frequencies for IDE 1

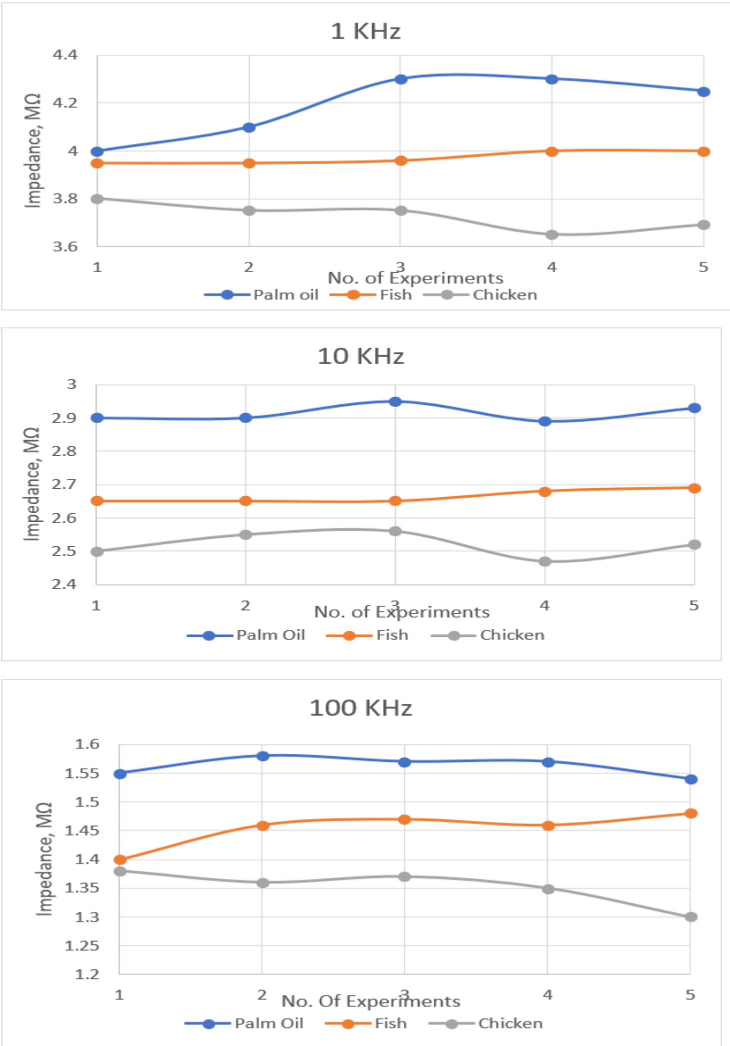



Fig. 7 (a) Impedance measurement at different frequencies for IDE 2

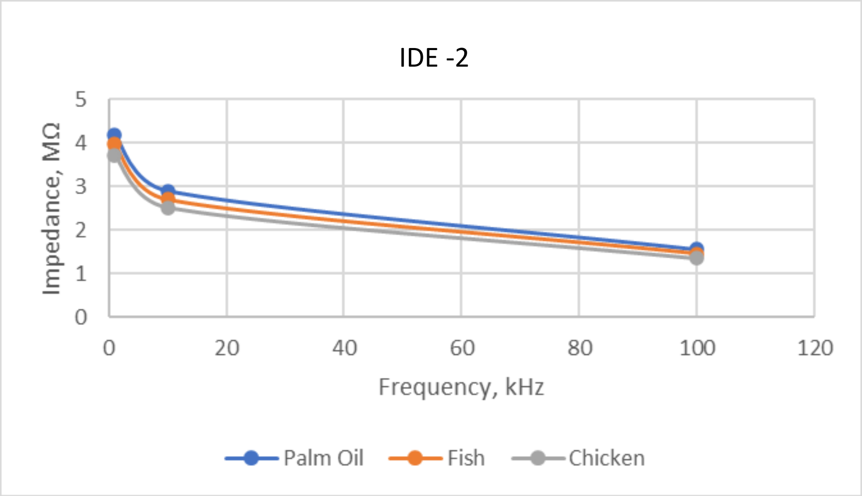



**Fig. 7 (b)** Compilation of Impedance measurement at different frequencies for IDE 2

From the results it shows that the impedance spectra decrease with increasing applied frequency. It indicates that the impedance value is being affected by frequency. From the results, it shows that IDE with a bigger sensing area has a higher impedance value. Other than that, it is identified increasing the number of electrode fingers as well as the width yielded a proportional increase in signal detection due to the increment of the contact surface between the electrode and material under test.

## 4. Conclusion

A simple and portable impedance spectroscopy was introduced to sense the presence of different types of liquid. The system was developed by using an interdigitated electrode as the sensors and AD5933 evaluation board as an impedence analyzer.

During this study, the focus has been on the interdigitated electrode (IDE) sensor. The structure of IDE definitely trumps over other structures of electrodes for designing the sensor device due to their low cost, ease of fabrication process and excellent sensitivity. The operation of Interdigitated Electrode is based on the dielectric sensing method, where these sensors is used to measure the changes of impedance due to changes in the dielectric value of the material. Therefore, by exploiting the special relationship of capacitance and impedance value, an Interdigitated Electrode is able to act as a sensor to detect the presence of liquid material under test. The frequency range from 1 KHz to 100 Khz is considered suitable to measure the presence of oil.

As a result, the proposed sensor showed an observable value of impedance when the highest permittivity value of the liquid material was being tested. It is identified that different oil products have different Impedance values. In addition, each of the parameters involved in designing the sensors gives a significant impact on the sensitivity of the proposed sensor. In terms of material, copper is not suitable for sensing a liquid that has a low relative permittivity value. On top of that, an issue of a copper trace on IDE is discovered where it tends to scratch off whenever we try to clean up the sensor. For future recommendation, a commercial IDE from Dropsens can be purchased since it may enhance the sensitivity and the detection limit.

## 5. Acknowledgements

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