Real-Time Microwave Based Sensing Method for Vegetable Oil Type Verification

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Abstract

A novel monitoring approach that allows real-time identification of the vegetable oil types is reported. Unlike other available detection methods, which are only lab based, this developed technique exploits a low-power microwave sensing principle and provides for cost-effective, portable, on-the-spot verification of the cooking oil type, which is vital not only for compliance with Food Information Regulation, but for consumer safety, food quality monitoring and customs control.

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Keywords: microwave sensors; vegetable oil types verification, real-time monitoring, reusable sensor, IDE antenna, food labelling.

1. Introduction

The new Food Information Regulation (FIR) 1169/2011, designed to make food labelling easier to understand for consumers, was adopted by the European Union at the end of 2011. One of the main points in the FIR is that the types of vegetable oil used in food, such as palm, rapeseed, sunflower or corn oil blends, must be stated within a generic ‘vegetable oil’ declaration.

This paper reports on a novel monitoring approach that allows real-time identification of the vegetable oil types. Unlike other available detection methods, which are only lab based, this developed technique exploits a low-power microwave sensing principle and provides for cost-effective, portable, on-the-spot verification of the cooking oil type, which is vital not only for compliance with FIR, but for consumer safety, food quality monitoring and customs control.

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Foods can contain a complex mixture of saturated, monounsaturated, and polyunsaturated fatty acids, each with a variety of carbon chain lengths. Various identification and quality control methods of vegetable oils are based on conventional methods for the determination of acid index, ratios of unsaturated to total fatty acid content, saponification, iodine and refraction indices, as well as triacylglycerol determination [1]. Available standard methodology for analysis of vegetable oil is Fatty Acid Methyl Esters (FAME). Alternative techniques that may be employed for the determination of oil type of unknown samples include: gas chromatography, gas chromatography-mass spectrometry, high-performance liquid chromatography (HPLC); size-exclusion HPLC; differential scanning calorimetry, infrared spectroscopy, supercritical fluid chromatography, thin layer chromatography, ultraviolet spectroscopy, fluorescence spectroscopy, isotope ratio mass spectrometry, gravimetry and the emulsion stability of nitromethane/vegetable oil method [2]. These methods are bulky, expensive, time-consuming and more importantly, they do not provide adequate information on the composition of the oil being tested if a number of unknown components in unknown proportions is present.

2. Novel approach: microwave technology based sensors

Microwave sensing is a developing technology which has been successfully used as a sensing method for various industrial applications including water solution concentrations [3-5] and water level measurements [6], material moisture content [7, 8], for continuous process monitoring for biogas plants [9] and in the healthcare industry, for example for non-invasive real-time monitoring of glucose in diabetic patients [8, 10, 11]. Microwave sensors in the form of cavity resonators or in a wide shape of antennas operate based upon the interaction of the electromagnetic waves and the material, i.e. oil sample, being tested. This interaction manifests itself as a frequency change, attenuation or reflection of the electromagnetic signal. By considering how transmitted (S\text{21}) and reflected (S\text{11}) microwave powers vary at discrete frequency intervals, the change in the signal can be linked to the composition/type of the vegetable oil under test.

3. Experimental Procedure

In this work, an antenna in the form of traditional interdigitated electrodes (IDE) was used to provide maximum interaction with the tested oil samples. Fig. 1 details the layout used along with IDE dimensions, which are in mm. Standard 1.57 mm thick FR4 substrate (supplied by Mega-UK) covered with 35 μm Cu layers from both sides was used, on one side of which IDE antenna was patterned with Bungarde CNC router. Standard MOLEX 5-pin SMA connector was soldered to both antennas to feed the microwave signal, as shown in Fig. 2. Various vegetable oil samples were bought from local supermarkets (see Fig. 3) and tested (20 ml volume) to verify the applicability of the proposed novel microwave sensor. The experimental setup used to test the IDE antenna response is shown in Fig. 4. It comprises a Hewlett Packard Vector Network Analyser (VNA), microwave sensor and N-type cable to connect the VNA and sensor. The connection arrangement allowed reflected power S\text{11} analysis.
4. Results and Discussion

Fig. 5 illustrates the microwave response of IDE antenna in a frequency range up to 15 GHz for air and for four different oil types. To trace the effect of each oil sample on the sensor response, the focus can be made on the biggest resonant peak (5-8 GHz frequency range) which experienced frequency shift depending on the oil type in contact with the sensor, as shown in Fig. 6. Importantly, after each oil sample measurement the sensor response has returned to its original position, namely the air spectrum was mostly identical, thus making the sensor reusable for numerous measurements. Small hysteresis could have been caused by a residue oil layer and could be avoided by using an appropriate oil cleaning process between each oil type measurement. Alternatively, new sensor head can be used each time, as the proposed IDE antenna is a cost-effective solution.

![Experimental setup: VNA displays the response of IDE microwave sensor.](image1)

![Microwave response of IDE antenna in 1-15 GHz range for air and four different types of vegetable oils.](image2)

![Frequency shift in the microwave spectra resonance peak of the antenna pattern indicates the type of a vegetable oil in contact with it.](image3)

Notably, the sensor dimensions were dictated by a compromise between, on one side, customer requirements for potability and convenience when using the developed oil type verification system, and...
achieving clearly measurable sensor response with high signal-to-noise ratio to eliminate the need in further signal conditioning and modification.

The observed sensitivity of the developed sensor to various types of vegetable oils suggest that this novel approach can serve as a platform for a cost-effective real-time food quality monitoring system, as required by the FIR legislation.

5. Conclusion

Novel real-time method of vegetable oil verification is reported. It is based on a microwave sensor system with IDE antenna made from Cu to which a GHz signal is fed via SMA connector and reflected power $S_{11}$ is analysed. Microwave spectra experienced a shift in a resonant frequency peak depending on a type of oil brought in contact with the sensor, thus providing clear identification method for customs control and food labelling purposes. From the database of previously measured oil samples, one can determine in real-time what type of the cooking oil is present and whether it corresponds to the declared type. Other antenna patterns and material are being explored to achieve the highest sensitivity and selectivity of the sensor response. Moreover, a combination of different antennas into a single system could be an option if a complex mixture of different vegetable oils needs to be precisely determined.

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