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Real-Time Detection of Plastic Shards in Cheese Using Microwave-Sensing Technique †

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† Presented at the 6th International Electronic Conference on Sensors and Applications, 15–30 November 2019; Available online: https://ecsa-6.sciforum.net/.

Published: 14 November 2019

Abstract: Recently, Lidl had to set a recall action due to dangerous pieces of plastic found in the cheese products. The plastic shards, if swallowed, can cut the oral cavity or obstruct breathing. Current inspection techniques in the cheese industry are for the detection of metals using X-ray that does not offer a complete solution, as many foreign bodies can go undetected. This paper demonstrates the use of a portable real-time microwave sensing technique for the nondestructive detection of plastic in cheese. The electromagnetic (EM) patch antenna was designed and tested on five Cheddar cheese samples. Different sizes of plastic shards, 1 × 10 mm, 2 × 15 mm and 5 × 20 mm, were inserted into the samples, and measurements were taken with and without foreign objects. The initial results demonstrated that the patch antenna at 4GHz was able to detect and classify Polyvinyl Chloride (PVC) shards with an R^2 = 0.95. The initial results are promising, and further investigation will be undertaken to detect different shapes and types of foreign objects in food products.

Keywords: cheese industry; electromagnetic spectroscopy; nondestructive testing; plastic shards; sensors

1. Introduction

The detection of foreign objects during the food inspection process is critical to ensuring the quality of food products [1]. Recently, Lidl had a recall action on Gouda Cheese products because of the risk of injury due to plastic shards in the cheese [2]. At present, foreign substances in food are detected mainly by using mechanical and optical methods as well as ultrasonic techniques. These techniques detect a large portion of foreign substances based on their mass (mechanical sieving), their color (optical method) and their surface density (ultrasonic detection) [3]. Moreover, X-ray systems can reveal items made of hard nonmetallic materials, namely, stone, glass, bone, rubber and plastic, when embedded in food products. However, for soft materials (often organic materials) inside food products, accurate identification by X-ray systems is known to be difficult [4]. The X-ray method is an expensive and complex method, which is followed by complicated postimage processing procedures [5]. Cho and Irudayaraj [5] proposed noncontact air instability compensation ultrasound transducers, which improved the velocity and thickness measurements of the calibration standard in varying temperatures. However, the recognition of differences between fragments and internal disorders in foods is still difficult.

Electromagnetic sensors are widely used and investigated in various applications and industries. The authors of [6] used microwave spectroscopy for online nondestructive monitoring of meat drying and water holding capacity [7]. Electromagnetic sensors are also used for monitoring of excess moisture content in building fabrics [8,9] as well as in public health for monitoring of insecticide levels in developing countries [10]. The aim of this study is to use a portable real-time microwave sensing technique for the nondestructive detection of plastic in cheese.

2. Experimental Setup and Methodology

The purpose of this investigation is to detect plastic shards in cheese using microwave technology, namely, via utilizing a microstrip antenna. Five packages of 400 g Mature Cheddar cheese (see Figure 1a) were purchased from a local Tesco shop for the investigation. Here is a list of equipment/items used for this experimental work:

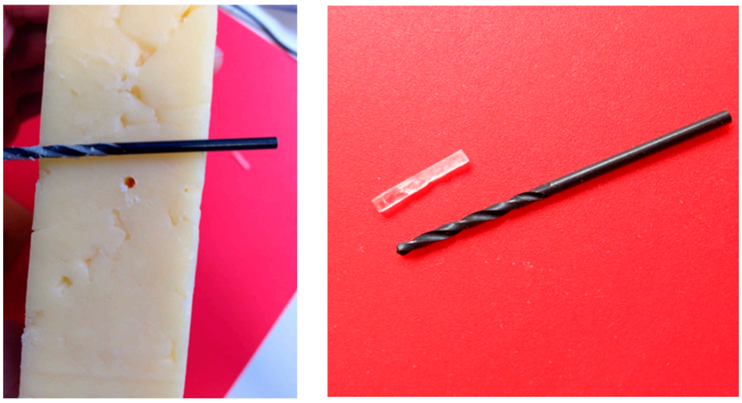
(1) Vector Network Analyser (VNA)
(2) Plastic shards
(3) 2.45 GHz patch antenna
(4) Drill (to make holes for the plastic shards), Figure 2.

2.1. Samples and Plastic Shards Preparation

Polyvinyl Chloride (PVC) plastic was used as shards for this study. The plastic was cut into three different sizes, namely, 2 × 15 mm, 1 × 10 mm and 5 × 20 mm, shown in Figure 1b. The microwave measurements with the cheese samples were taken prior to inserting the plastic shards into them. Once the measurements were completed, the plastics shards were inserted into the cheese samples starting with the smallest size. A detailed measurement procedure is provided in Section 2.3.

(**a**) (**b**)

Figure 1. (**a**) Five packages of cheese and (**b**) plastic shards in three dimensions.

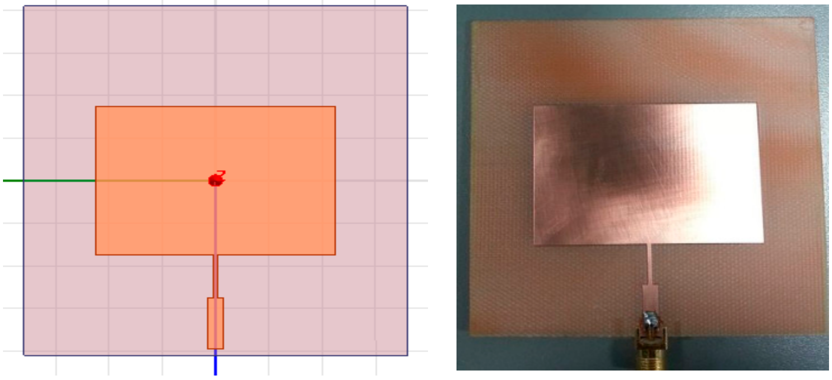


(**a**) (**b**)

Figure 2. (**a**) Cheese sample with a hole for the insertion of a plastic shard and (**b**) drill bit with a plastic shard.

2.2. Microwave Patch Antenna

A rectangular patch antenna was modelled and fabricated for this investigation. The antenna is presented in figure that was designed to resonate at 2.45 GHz frequency [11], which is an Industrial, Scientific and Medical (ISM) band. The ISM bands are frequencies reserved internationally for the use of radio frequency energy for industrial, scientific and medical applications. The antenna was modelled and simulated via High-Frequency Structural Simulation (HFSS) software (see Figure 3a) and fabricated (see Figure 3b) on Bungard CCD2 Computer Numerical Control routing machine at Liverpool John Moores University.



(**a**) (**b**)

Figure 3. Microwave Patch Antenna: (**a**) High-Frequency Structural Simulation (HFSS) model and (**b**) fabricated antenna on a printed circuit board (PCB).

2.3. Experimental Setup and Data Acquisition

The patch antenna is connected to the VNA (see Figure 4a) to record a reflection coefficient. The calibration setting for this investigation is as follows: range 1GHz-6GHz, sweep points—4000, measurements—S_{11}. The five cheese samples are unpacked and measured one by one by placing the sample on the patch area of the antenna (see Figure 4b). Sample monitoring was implemented using Vector Network Analyzer (VNA) for attenuation of the electromagnetic wave propagation in the cheese. All the experimental results were recorded using Graphical User Interface designed in LabVIEW—the measurement time of one sample was less than 5 s. Five repeatability test for each sample was performed.

(**a**) (**b**)

Figure 4. (**a**) Experimental setup and (**b**) cheese sample placed on the patch antenna.

3. Results and Discussions

The microwave measurements were repeated five times for each cheese sample, and the response then was averaged and analyzed in order to determine the plastic shards in the cheese samples. The full captured frequency spectrum (1–6 GHz, 4000 sweep points) from the sensor was scanned across using a bespoke LabVIEW program, namely, to identify a linear relationship between the sensor response (S_{11}) and the plastic shards (mm^3). The raw data presented in Figure 5 shows that the resonant frequency is shifted closer 1 GHz owing to the direct contact with the cheese sample. The noticeable change of the sensor response (S_{11}) was between 3.5–4.5 GHz, and the signal above 5 GHz was noisy, which was caused by a coaxial cable.

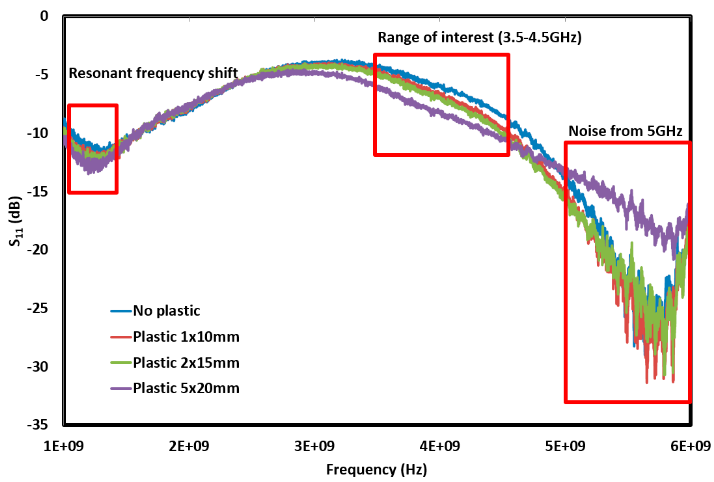


Figure 5. Raw data (S_{11}) from the sensor.

The linear fit between S_{11} change at the frequency range of 3–4 GHz and plastic shards was more consistent and stronger than the rest of the spectrum (see Figure 6). The largest span (dB) can be seen in the frequency range of 3.7–4.3 GHz (the span above 5 GHz is not considered owing to the noise level); therefore, the linear correlation at 4 GHz is presented in Figure 7, with $R^2 = 0.95$. The amplitude of the sensor response prior to inserting the plastic shards was −5.9 dB. Once the plastic shards were inserted, namely, 1 × 10 mm, 2 × 15 mm and 5 × 20 mm, the amplitude decreased to −6.6 dB, −6.9 dB and −8.2 dB, respectively. The changes in the amplitude of the signal is thought to be caused by the change of the dielectric properties of the measured area of the cheese samples, i.e., the properties were altered by inserting various sizes of plastic shards, which have different chemical and dielectric properties compared to cheese samples.

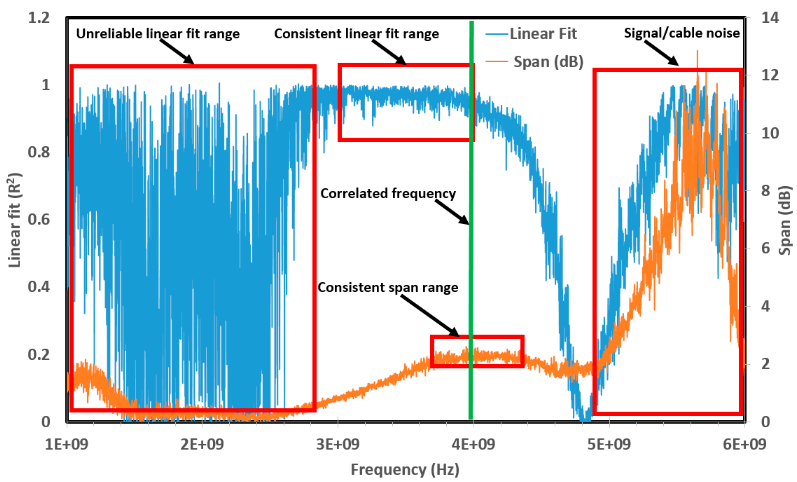


Figure 6. Linear correlation and span between S_{11} change and the full captured frequency range (1–6 GHz).

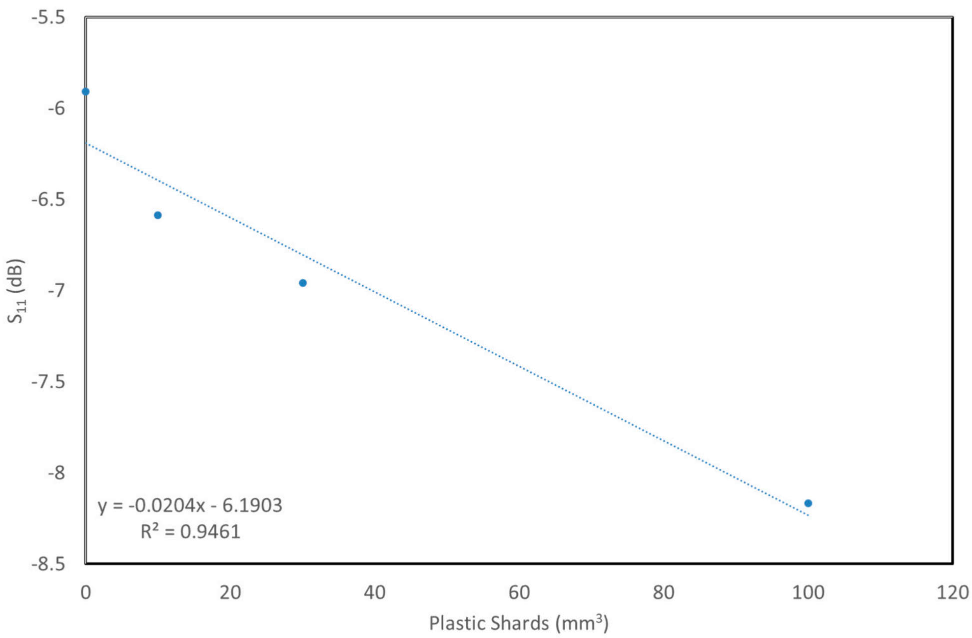


Figure 7. Linear correlation between sensor response at 4 GHz and plastic shards.

4. Conclusions

To conclude, a microwave patch antenna resonating at 2.45 GHz was designed, constructed and utilized as a sensor to determine plastic shards in cheese samples. The microwave measurements were provided by S-parameters (S_{11}, reflection coefficient) and repeated five times for each cheese sample prior to inserting plastics shards and with three different sizes of the shards inserted. The linear relationship between various plastic shards and an amplitude change of the reflected signal form the microwave sensor across the full captured frequency spectrum (1-6 GHz) was investigated. The data analysis demonstrated a strong linear correlation at 4 GHz, with $R^2 = 0.95$. This study presented a potential use of microwave sensing as a new technique to determine plastic shards in cheese products for health and safety purposes in the food industry.

Author Contributions: M.M. and P.K. organized the conceptualization of the idea and the methodology employed in this paper. Following that, M.M., P.K. and K.H. worked on the software, data validation and formal analysis for the investigation. B.A. and A.M. worked on the samples preparation. M.M. undertook data accusation. The original writing and draft preparation was carried out by M.M., P.K. and K.H., and B.A., A.M., A.S. and A.A.-S. carried out the review and editing. The project is supervised under M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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