Preliminary In-Line Microwave Imaging Experimental Assessment for Food Contamination Monitoring

Preliminary In-Line Microwave Imaging Experimental Assessment for Food Contamination Monitoring

Marco Ricci*, Jorge A. Tobon Vasquez*, Rosa Scapaticci †, Giovanna Turvani *, Mario R. Casu *, Lorenzo Crocco†, Francesca Vipiana*

*Dept. of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy, email: francesca.vipiana@polito.it

†CNR-IREA, Consiglio Nazionale delle Ricerche, Napoli, Italy, email: crocco.l@irea.cnr.it

***Abstract*—Food producers must deal with contaminants (wood, plastic, glass) inside packaged products that could lead to customer dissatisfaction. The assessed technologies fail to detect some of these contaminants, leading to the need for new technologies with different signal qualities, such as microwave sensing. This paper presents a preliminary result of a microwave imaging system designed for industrial applications. The measurement system was designed for and works on an industrial conveyor belt where packaged products are scanned. The scanned signals are processed to obtain an accurate 3D image of the size and position of the contaminant inside the food package. In addition to the results, we describe the implemented system and some considerations on data acquisition.**

***Index Terms*—microwave imaging, food safety, food security, measurements**

I. Introduction

Food safety is an issue in the industrial world that needs to be addressed. Manufacturing industries often have to deal with contamination which results not visible from the currently employed inspection devices. This lack is due to some intrinsic limitations in the detection principle of the standard techniques available in the market. FDA (Food and Drug Administration) [1] in the US, and RASFF (Rapid Alert System for Food and Feed) [2] in the EU collect the notified recalls of contaminated items, demonstrating the existence of the problem. These official data are usually a small subset of the actual number of contaminated items going to the market (customers do not want to report or are not aware), suggesting that the problem is more extensive than reported.

The consequences the system wants to avoid consist primarily of potentially severe health hazards for consumers: damage to the whole digestive system and the risk of choking, higher for sensible categories such as seniors or children. Moreover, industries affected by recalls due to contaminated products may have substantial impacts on their reputation or even legal consequences, which can be expensive to face.

Currently employed devices in industries have limitations: checkweighers have a small degree of sensitivity, metal detectors can notify the presence of conductive materials only, while the most effective mean, X-rays-based devices [3], has an intrinsic limitation due to its detection principle; indeed, it is based on the density of the materials, so if the foreign body has a low density, or too close to the product to inspect, those devices may fail in the detection.

The scientific community is trying to propose alternative solutions to the problem: hyperspectral imaging [4], near-infrared (NIR) [5], and terahertz spectroscopy [6] are currently under investigation to cope with the issue, but for different reasons, as high costs, slow acquisitions or limited penetration depth, they result not suitable for an in-line implementation (i.e., monitoring all the samples during the production process).

Microwave imaging (MWI) [7] is a novel approach, extensively applied to the medical field in the last decade [8], [9], and recently extended to the problem of food contamination monitoring [10].

A first assessment from the authors' research group is presented in [11], but the limited number of acquired information led to improvable imaging performance. An improved system with an increased number of transceivers was numerically assessed in [12], and a preliminary experimental validation is described in this paper.

II. MWI system

A. Prototype description

The implemented prototype consists of both hardware and software parts. The hardware side comprehends the sensors (antennas), the shielding box, and the transmitter-receiver (Keysight VNA M980xA [13] in this implementation). The system characteristics are detailed in [14], where the collected information was used for classification, while here, we propose a 3D imaging approach. To reach this 3D imaging goal, we base the software part on a linearized inversion algorithm (Truncated Singular Value Decomposition - TSVD) with the support of the Illumination Balance Algorithm (IBA) (both used in [12]). TSVD permits reconstructing an image of a localized, "weak" scatterer (a characteristic of our contaminants) inside our domain of interest (DoI) through the Born

approximation. IBA equalizes the radiation inside the DoI as the actual antennas do not illuminate the jar homogeneously, due to the physical constraints of the specific application (the presence of the conveyor, the in-line procedure, measuring an object moving along a linear path).
It is essential to highlight that the system must acquire and process the data fast due to the high speed of conveyor belts. For the hardware, it means fast response in the transceiver, avoiding switching or multiplexing. The speed requirement is another reason for a linear inversion algorithm, as the times are negligible compared to non-linear iterative solutions. This short time means a limited quantity of measured data, which usually is a challenge for imaging algorithms, where a complete multiview is the ideal scenario. The following section discusses the data acquisition of the system in motion.

B. Data acquisition considerations

The system briefly described in the previous section has six monopole antennas in an arch on top of the conveyor belt, surrounding the item to inspect, and allowing its flow without interruptions or delays. Each antenna works as a transmitter-receiver: when an antenna transmits, the other five receive. The movement of the conveyor belt permits a broader view of the packaged object (jar) passing below the arch, adding information to that given by the "instantaneous picture" obtained for an unmoving scenario. We can think of an immobile jar with moving antennas along the belt axis in a simple change of reference system. When the transmitter antenna changes, the scenario changes too, but knowing the velocity and relative position, we can know the antennas' radiation in each situation. This detailed knowledge of antenna-object position is necessary for the 3D imaging algorithm, as the field illumination is used in its kernel.

From a practical point of view, we also considered the VNA acquisition speed in relation to the belt speed and the desired number of measurements. This number depends on the information required for a reliable 3D image reconstruction. We want more measurements from different points of view while the jar is still in the arch radiation region.

III. Experimental results

Most food products can be classified as oil-based or water-based. In this paper, we approach the first class, but the second one can be easily addressed by adjusting the operating frequencies. The system testing is performed by measuring an oil jar (Fig. 1) representing a complete family of possible products, such as hazelnut cocoa spreads, oils, almond butter, Etc. One advantage of the oil in a laboratory test is that we can easily position and see the contaminant inside.
An optimized sequence of antenna pairs is selected to cover the region of interest, following the considerations of the previous section. The antennas' radiation is obtained numerically, considering the oil dielectric properties and the positions as input for the imaging algorithm. This is done to compute the kernel, useful to reconstruct the tomography by using the current measured data.

Fig. 1. Plastic jar filled with commercial oil with wooden foreign body used in experimental testing.

In this experience, we consider two different cases, each with the wood fragment as a contaminant in a different position (Fig.1).

The jar is put on the belt, and measurements are acquired while it passes under the shielding box. These data consider the uncertainties due to system vibration and acquisition times, demonstrating the system's robustness to these effects.

The data processing is done in real-time through the above-mentioned linear algorithm and improved with the balancing technique IBA.

The results of this procedure are depicted in Fig. 2, where the two contaminants are located in the right positions and with the correct size.

IV. Conclusion

Here we presented a first image result for the challenging case of small and immersed contaminants in packaged food while measurements were performed in real-time on conveyor belts. We faced this challenge by ensuring fast and synchronized data acquisition and using a linearized imaging algorithm. The antennas' characteristics and position with respect to the jar lead to a non-homogenous electromagnetic field inside the DoI. We compensate for this through the illumination balancing algorithm (IBA), improving the quality of the obtained 3D image. The presented results show that our system can give accurate information on the position and size of the contaminant.

Acknowledgment

This research was supported in part by the project PON Research and Innovation, "Microwave Imaging and Detection powered by Artificial Intelligence for Medical and Industrial Applications (DM 1062/21),"; and the PRIN project "BEST-Food, Broadband Electromagnetic Sensing Technologies for Food Quality and Security Assessment." Both projects are funded by the Italian Ministry of University and Research (MUR).

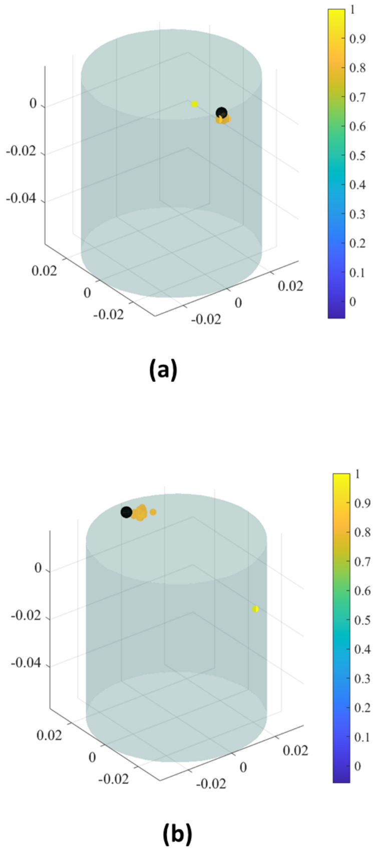

Fig. 2. Microwave imaging reconstruction of the target in two different cases ((a) and (b)): the expected position is represented as a black sphere, while the thresholded reconstruction values are sketched as yellow spheres.

References

[1] U.S. Department of Agriculture. Recalls and public health alerts, *https://www.fsis.usda.gov/recalls*

[2] European Commission - Rapid Alert System for Food and Feed, *https://food.ec.europa.eu/safety/rasff-food-and-feed-safety-alerts_en*

[3] R.P. Haff and Natsuko Toyofuku. X-ray detection of defects and contaminants in the food industry. Sensing and Instrumentation for Food Quality and Safety, 2, Dec. 2008.

[4] A.A. Gowen, C.P. O'Donnell, P.J. Cullen, G. Downey, and J.M. Frias. Hyperspectral imaging – an emerging process analytical tool for food quality and safety control. Trends in Food Science & Technology, 18(12):590–598, 2007.

[5] Jan U. Porep, Dietmar R. Kammerer, and Reinhold Carle. On-line application of near infrared (nir) spectroscopy in food production. Trends in Food Science & Technology, 46(2, Part A):211–230, 2015.

[6] Leili Afsah-Hejri, Parvaneh Hajeb, Parsa Ara, and Reza J. Ehsani. A comprehensive review on food applications of terahertz spectroscopy and imaging. Comprehensive Reviews in Food Science and Food Safety, 18(5):1563–1621, 2019.

[7] M. Pastorino. Microwave Imaging. Wiley Series in Microwave and Optical Engineering. Wiley, 2010.

[8] J. A. T. Vasquez, R. Scapaticci, G. Turvani, G. Bellizzi, D. O. Rodriguez-Duarte, N. Joachimowicz, B. Duchêne, E. Tedeschi, M. R. Casu, L. Crocco, and F. Vipiana. A prototype microwave system for 3d brain stroke imaging. Sensors, 20(9), 2020.

[9] M. R. Casu, M. Vacca, J. A. Tobon, A. Pulimeno, I. Sarwar, R. Solimene, and F. Vipiana. A cots-based microwave imaging system for breast-cancer detection. IEEE Transactions on Biomedical Circuits and Systems, 11(4):804–814, 2017.

[10] Joe LoVetri, Mohammad Asefi, Colin Gilmore, and Ian Jeffrey. Innovations in electromagnetic imaging technology: The stored-grain-monitoring case. IEEE Antennas and Propagation Magazine, 62(5):33–42, 2020.

[11] J. A. Tobon Vasquez, R. Scapaticci, G. Turvani, M. Ricci, L. Farina, A. Litman, M. R. Casu, L. Crocco, and F. Vipiana. Noninvasive inline food inspection via microwave imaging technology: An application example in the food industry. IEEE Antennas and Propagation Magazine, 62(5):18–32, 2020

[12] Marco Ricci, Jorge A. Tobon Vasquez, Rosa Scapaticci, Lorenzo Crocco, and Francesca Vipiana. Multi-antenna system for in-line food imaging at microwave frequencies. IEEE Transactions on Antennas and Propagation. DOI: 10.1109/TAP.2022.3177436

[13] Keysight Technologies. M980xA Series PXIe Vector Network Analyzer. Data Sheet, 2020.

[14] M. Ricci, B. Stitic, L. Urbinati, G. D. Guglielmo, J. A. T. Vasquez, L. P. Carloni, F. Vipiana, and M. R. Casu. Machine-learning-based microwave sensing: A case study for the food industry. IEEE Journal on Emerging and Selected Topics in Circuits and Systems, 11(3):503–514