A Simple Imaging Strategy for In-Line food Inspection via Microwave Imaging

A Simple Imaging Strategy for In-Line food Inspection via Microwave Imaging

G. Bellizzi[1], L. Crocco[2], M. Cavagnaro[3], M. Ricci[4], J. A. Tobon Vasquez[4], and F. Vipiana[4]

[1] DIETI Università degli Studi di Napoli Federico, City, Napoli, Italy, email: gbellizz@unina.it
[2] CNR-IREA, Consiglio Nazionale delle Ricerche, Napoli, Italy, email: crocco.l@irea.cnr.it
[3] DIET, Università La Sapienza, Roma, Italy, email: marta.cavagnaro@uniroma1.it
[4] DET, Politecnico di Torino, Torino, Italy, emails:{jorge.tobon, marco.ricci, francesca.vipiana}@polito.it

***Abstract*— Microwave imaging can represent an alternative for in-line inspection of food products, to reveal the presence of possible foreign bodies that may have contaminated the product during the transformation and/or packaging stages. To this end, a microwave system specifically meant for such purpose has been recently proposed. With respect to this device, a novel imaging strategy is presented, which allows one to build the image of the target without the need of a contaminant-free item used as reference sample. The idea is still to perform a differential imaging taking advantage of possible symmetries of the object under test with respect to the imaging system. These symmetries only occurred in a contaminant-free item, while are broken by the presence of an inclusion, thus revealing their presence. A quite common case is that of food packaged in circular plastic/glass jars. A simple numerical example is provided showing the capabilities of the approach.**

***Index Terms*—microwave imaging, non-invasive diagnostics, food inspection, food security, food safety.**

I. Introduction

In food industry, the detection of the presence of small foreign inclusions, that may have contaminated food during the transformation and/or the packaging stages, represents a key step for manufacturers to guarantee prescribed quality and safety standards. Accordingly, a careful check of the products, before their commercialization, is mandatory. Such an inspection can be made off-line, on selected samples, or in-line, (i.e., directly on the production line, without stopping or delaying it). The former is surely a less effective and more expensive solution, as the presence of even a single contaminated product brings to discarding the entire batch. The second solution is, therefore, preferable. Typically, such an in-line monitoring task is implemented by employing metal detectors, x-ray scanners, near infrared sensor and/or optical cameras specifically designed to fit and be compliant wherein the production chain. However, the occurrence of missed detections (i.e., false negatives) remains significant. As a matter of fact, metal detectors can only detect metallic objects; x-ray can fail in recognizing low-density foreign bodies such as several types of plastics, thin pieces of glass or wood (the most common type of contaminants) and can be potentially harmful for operators working on the production chain; infrared are limited by the short penetration in the sample; optical camera are viable only for transparent food and packaging.

A valuable alternative to the above technologies is represented by microwave imaging (MWI) [1]–[3]. This has motivated the recent development of a microwave imaging whose hardware design and processing tools are specifically meant for such purpose [4], i.e., the detection of plastic or glass fragments into homogeneous food packaged in plastic or glass boxes or jars, representing a quite common case in food industry.

From a hardware point of view, the device is simple and cheap, being made by just a pair of antennas, and it is easily integrable within an industrial production chain. Concerning the adopted imaging strategy, it essentially relies on the assumption that on a production line all the items are almost identical to each other (except for the possible presence of foreign inclusions). This enables adopting a differential processing approach, wherein the data measured for an "uncontaminated" object, initially acquired and stored, are used as "reference" and subtracted to those measured for the object under test during the process. In this way, the presence of contaminants can be easily and quickly established whenever a non-null differential signal (namely, above a threshold related to the measurement noise) is detected. In addition, as shown in [4], an image of the contaminant can be rapidly formed by processing these differential data by means of a linear inversion algorithm, which is a key requirement for the in-line application.

A shortcoming of this approach is that the basic assumption of items all perfectly identical, could not be always verified in practice, thus leading to the occurrence of false positives, namely to the wrong detection of inclusions in contaminant-free products. Although this does not increase the risk of placing contaminated products on the market, it represents, in any case, a detriment for the manufacturer which will be forced to discard an amount of product larger than the necessary. To overcome this inconvenience, in this paper a different imaging strategy is proposed, which allows one to perform the imaging without the need of a reference

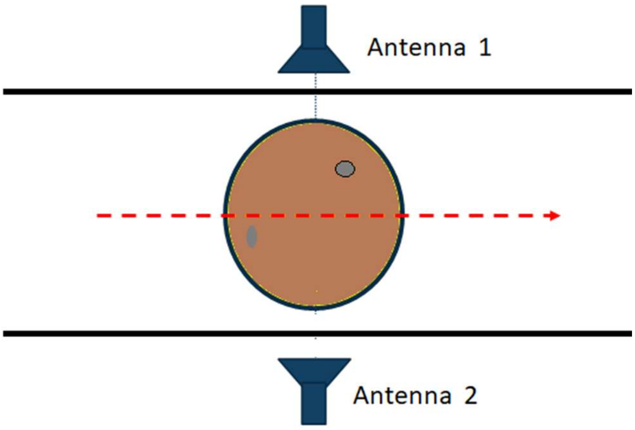

Fig. 1. Scheme of the microwave imaging system scheme: food product (brown circle) moving along the conveyor belt with the two antennas at the two sides of the line;.

sample. The idea is to exploit the possible symmetries of the item itself with respect to the imaging system since such symmetries can only be broken by the presence of contaminants. As such, the differential signal arising from the enforcement of the symmetries can be processed to reveal the possible presence of an inclusion.

In the following Sections, the features of the device are recalled, and the proposed strategy is presented and numerically assessed in a simple, yet meaningful, case. Other, and more realistic, examples will be presented to the conference.

II. Overview of the Designed MWI Device and Imaging Algorithm

The basic architecture of the system is sketched in Fig. 1. As it can be seen, it consists of two identical antennas placed in front to each other at the two sides of conveyor belt on which the products move [4]. The antennas operate in both transmission/reflection mode so that, for each measurement, one can acquire the entire 2x2 scattering matrix by means of a two-ports vector network analyzer (VNA). To increase the number of independent data available for the imaging, each scattering matrix is measured at M=9 working frequencies, from 9 to 11 GHz with a step of 0.25 GHz. Moreover, by exploiting the movement, each scattering matrix is measured at N=13 different relative positions of the object under test with respect to the antenna location on the belt (here assumed as reference position), from -6 to +6 cm with a step of 1 cm (it is the same concept underlying the synthetic aperture radar). This configuration is fully equivalent to a synthetic array in which N "virtual" antennas are placed on both sides of the line while the object stands still in the middle. Of course, in this equivalent configuration, not all the possible pairs of scattering parameters are measured, but only those relative to the pair of (virtual) antennas facing each other.

Under the above-described conditions, the total number of independent scattering parameters acquired for each object is 3*N*M=351 (by considering the reciprocity of the transmission scattering parameters). These data are, then, subtracted to those initially measured (and stored) for an identical, but contaminant-free, object, assumed as reference, and the difference is processed to image possible presence of undesired inclusions.

Specifically, denoted with $S_d(i, j, f_m, x_n)$ such a difference and with $\chi(\underline{r})$ the (unknown) variation of electric contrast due to the presence of the contaminant, it results (apart from an unessential multiplicative constant):

$$S_d(i,j,f_m,x_n) = \int_{D(x_n)} E_i(\underline{r},f_m)\chi(\underline{r})\, E_j(\underline{r},f_m)d\underline{r} \qquad (1)$$

where $D(x_n)$ is the domain occupied by the object when at position x_n (n=1,…, N) and $E_{i[j]}(\underline{r}, f_m)$ is the electric field radiated in $D(x_n)$ by the i [j]-th antenna (i, j=1,2), at frequency f_m (m=1,…, M).

Note that, since the inclusion has usually a small size (compared to the wavelength) $E_{i[j]}$ in (1) is practically the field radiated in the contaminant-free object, namely in the reference object (distorted Born approximation) As a result, (1) describes a linear integral operator between the data and the unknown, where the kernel is given by the product of the electric fields. This allows one to turn the imaging task at hand in the solution of a linear inverse problem, thus enabling real time monitoring.

To this end, the truncated singular value decomposition (TSVD) scheme is adopted [4]:

$$\chi = \sum_{h=1}^{T} \frac{1}{\sigma_h} \langle S_d, u_h \rangle v_h \qquad (2)$$

where (σ_h, u_h, v_h) is the singular value decomposition of the integral operator in (1), while T is the truncation index representing the regularization parameter of the linear and ill-posed inverse problem in (1) and it is chosen as a trade-off between accuracy and stability of the reconstruction.

Further details about the device and the imaging algorithm can be found in [4].

III. A Simple Imaging Strategy Exploiting Symmetries

The idea of the proposed strategy is summarized in Fig. 2. The considered case is that (quite common in food industry) of homogeneous food (like yogurt, honey, milk, hazelnut–cocoa cream, peanut butter and so on) packaged in a plastic or glass box/jar of rectangular/circular shape, moving just at the center on the conveyer belt. As it can be observed, when the object under test moves along the belt, its relative position is always at an even distance from each of the two antennas. Accordingly, the two-ports device, made by the two antennas and the object under test, is perfectly symmetric with respect to the central plane, so that the scattering parameters measured at each port of the VNA have to be identical (apart from the measurement noise).

However, when a foreign body, not located on the symmetry plane, is presented in the object, this symmetry is destroyed and a diversity in the measured scattering

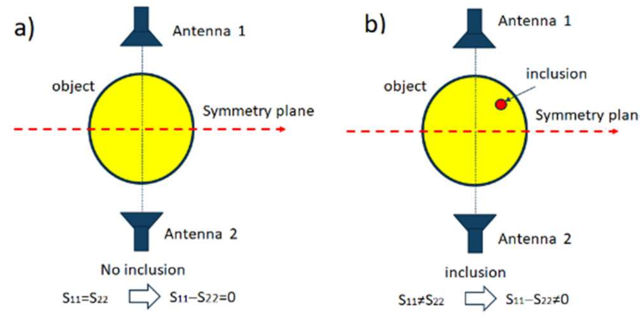

Fig. 2. Microwave imaging measurement set up in the case of a circular and homogeneus object; (a): the object is contaminat-free, hence the two-ports device, made of the cascade of the two antennas and the object, is perfectly symmetric, so that the reflection parameters measured at each port are identical; (b): the the presence of an inclusion breaks the symmetry introducing a difference in the reflection parameters.

parameters, in particular the reflection ones, is observed. Therefore, by performing the difference of these parameters one can immediately establish the presence of inclusions by simply comparing the differential data with a prescribed threshold dictated by the measurement noise. In addition, such a differential data can be exploited to form an image of the inclusion still by exploiting (2), in that, in this case, the relationship between the unknown $\chi(\underline{r})$ and the differential data is still given by (1), with $i=j$ (=1, 2).

Accordingly, by exploiting the symmetry of the object, it is no longer necessary employing a different "reference" object to perform the differential imaging as the reference becomes the object under test itself. This solution is surely more robust than that of subtracting to the measured data the ones relative to a different object.

Figure 3 shows a numerical example concerned with a 2D scenario in which a small inclusion is embedded in a circular cross-section glass jar filled with cream. The set up and the object under test are the same as in [4]. The antennas are two ideal current wires (TM polarization) distant 14 cm to each other. The working frequencies and the relative positions at which the scattering parameters are acquired are those indicated in Section II. Shape, size and electric properties of the object and of the contaminant are shown in Fig. 3(a)-(b).

Figure 4(a) shows the simulated $|S_{11}\text{-}S_{22}|/|S_{11}|_{max}$ vs frequency for all the considered positions, x_n, of the object under test with respect to the antenna system ($|S_{11}|_{max}$=max $|S_{11}|$ over all the considered frequencies and positions of the object).

The reconstruction of the inclusion, by processing the data in Fig. 4(a) (both amplitude and phase, here not shown) and (1)-(2), is shown in Fig. 4(b). The data were corrupted by additive Gaussian noise characterized by a max signal-to-noise ratio of 40 dB. The adopted TSVD threshold was set at -30 dB as in [4]. As it can be seen, the position of the inclusion (marked by the black circle) is well reconstructed. One can also observe a second spot located at the specular position, with respect to the symmetry plane. This ambiguity is related to the fact that one would measure the same differential data (apart from the sign) if the inclusion is located at the specular

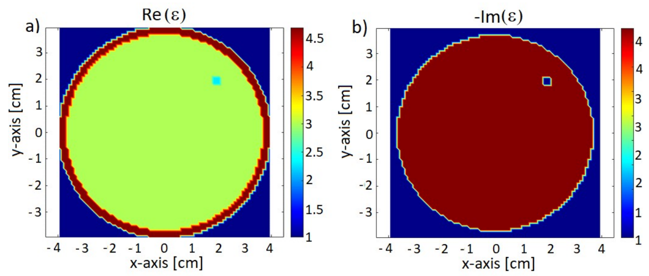

Fig. 3. Shape, size and electric properties of the object under test; (a): real part of the relative permittivity at f=10 GHz; (b): opposite of the immaginart part of the relative permittivity at f=10 GHz.

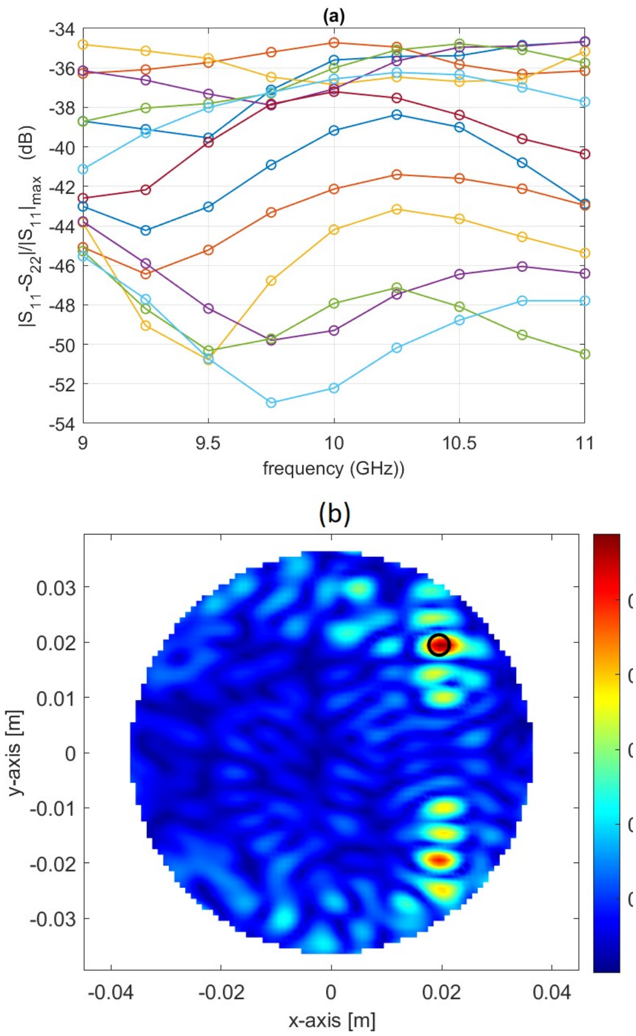

Fig. 4. Numerical results; (a) $|S_{11}\text{-}S_{22}|/|S_{11}|_{max}$ vs frequency for all the considered relative positions of the object with respect to the antenna system; (b): reconstruced image of the inclusion (black circle provides the actual position of the inclusion in the object).

position with respect to the symmetry plane. This ambiguity can be solved in time domain, by looking at the propagation time or by exploiting other symmetries along other directions (for instance, that orthogonal to the object movement).

Other results will be presented at the conference.

ACKNOWLEDGMENT

This work was supported by the Italian Ministry of University and Research under the PRIN project "BEST-Food, Broadband Electromagnetic Sensing Technologies for Food Quality and Security Assessment."

REFERENCES

[1] Z. Wu and H. Wang, "Microwave tomography for industrial process imaging: Example applications and experimental results," *IEEE Antennas Propag. Mag*., vol. 59, no. 5, pp. 61–71, 2017.

[2] M. Asefi, I. Jeffrey, J. LoVetri, C. Gilmore, P. Card, and J. Paliwal, "Grain bin monitoring via electromagnetic imaging," *Comput. Electron. Agric.*, vol. 119, pp. 133–141, Nov. 2015.

[3] Foodradar. [Online]. Available: http://www.foodradar.com/.

[4] J.A. Tobon Vasquez et al., "Noninvasive Inline Food Inspection via Microwave Imaging Technology: An Application Example in the Food Industry", *IEEE Antennas Propag. Mag.*, vol. 62, n. 5, pp. 18-32, Oct. 2020.