Microwave Imaging System for In-Line Security Assessment

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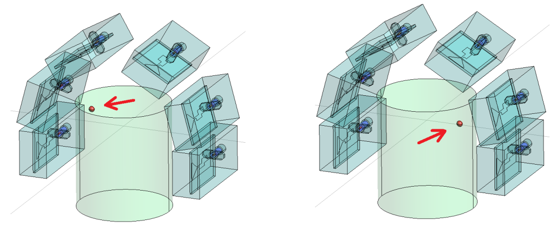
***Abstract*—The accidental foreign bodies contamination is still a major issue for food manufacturing industries. The continuous growth of automation along production lines together with the increasing attention of the customers towards food products quality, improved the industries care aiming to avoid complaints and ensure the best possible quality. As a matter of fact, several technologies are employed, but they lack in detecting certain class of contaminants, such as low-density plastics or small glass fragments that could turn into a severe threat, in particular for children. This work proposes a microwave imaging system in order to overcome these limitation in employed technologies. The design and characterization are reported in this paper; the simulations are addressed to the realization of a system prototype.**



(a) Position 1 (b) Position 2

Fig. 1. System architecture and two configuration examples varying contaminant position in the jar.

I. Introduction

Foreign bodies contamination is attracting increasing attentions for food manufacturing industries in the last few years. Companies aim to avoid potential issues, such as health hazards for consumers, large expenses for recalling the bad batch or loss of trust in the brand; the improvements in automation of packaging processes, and the growing customer awareness in food quality led to an increase of complaints. Employed technologies aimed to ensure food safety, such as metal detectors (MD), X-ray (XRI) or near-infrared (NIR) have still limitations, since they may fail in detecting certain classes of contaminants, e.g. low-density plastics or small fragments of glass; furthermore, the potential risk for operators for the presence of ionizing radiations (XRI), or the limited penetration depth (NIR) are matters at hand to consider. As a consequence, it arises the need of a new device able to address such requirements and overcome the existing limitations.

Recently, investigations on the potential of microwave imaging (MWI) arose [1]; the applications on monitoring food quality are still limited in literature [2], and basically deals with devices based on microwave but unable to reconstruct an image of the test sample [3], or without experiments nor simulations to assess the technology [4]. An industrial implementation has been developed too [5]: a device able to inspect fluids or liquids flowing along pipes. It consists in comparing the measured signal to a reference one, and if beyond an empirical threshold, the contaminant is detected. It is intrinsically different from the approach here proposed, which is able to reconstruct a 3D image as a map of the dielectric properties of the object under test. Further, it inspects the end-product after packaging, which is one of the primary causes of accidental foreign bodies contamination.

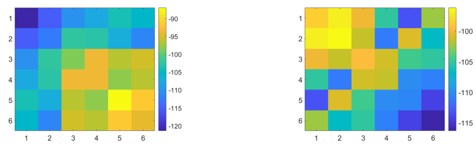
This work proposes the configuration of a microwave imaging (MWI) prototype, studied to fit along an industrial line; it is cost efficient, consisting of off-the-shelf components, as the antennas surrounding the object under test which are printed monopoles; the dimensions of the contaminant, and the dielectric contrast which have been considered, are actually challenging: a 2 mm radius sphere, whose dielectric constant is different from the food content by means of decimals. The MWI system is therefore assessed with a suitable geometry for an industrial implementation through an appropriate configuration satisfying the mentioned requirements.

II. MWI system configuration

The adopted configuration consists in a gallery-shaped set of six antennas; it is thought as a device to be installed around an industrial line without interfering with the production. It is shown in two considered scenarios (Fig. 1); the singular value decomposition (SVD) of the discretized scattering operator has been studied to select the number of antennas and their relative positions with respect to the target [6].

The position of the contaminant, a 2 mm radius PET sphere, is displaced inside the volume, which is a cylindrical jar whose radius and height are respectively 3.3 cm and 7.5 cm; it contains hazelnut-cocoa cream, and the ratio of its dielectric contrast with respect to the intrusion is $\epsilon_{r,c} \div \epsilon_{r,i} = 1.117$.

An analysis on the conductivity of such class of food, consisting mainly of oil, influenced the choice of the working frequency: $\sigma_c = 0.21\ S/m$, measured with a probe, led the



(a) Position 1 (b) Position 2

Fig. 2. Differential scattering matrices for the two considered cases [dB].

operational frequency at 10 GHz; it allows a sufficient penetration depth in the considered jar, keeping the resolution accurate enough to detect contaminants with millimetrical dimensions. The reported values are valid at the stated frequency.

The employed configuration aims at getting a complete view from the gallery surrounding the jar; a switching matrix has been set up to control the interaction between couples of antennas, and eventually resulting in a 6×6 scattering matrix. It is then compared with a reference one, a non-contaminated case: the resulting differential matrix is consequently the effect of the intrusion only. The distorted-Born approximation, assuming a low contrast between the contaminant and the surrounding matter, provides the background to represent the tomographic image of the dielectric contrast, on the condition that the obtained difference is higher than the noise level.

Therefore, the imaging problem can be modeled as the solution of the following integral equation [7]:

$$\Delta S(r_p, r_q) = \frac{-j\omega\epsilon_b}{4} \int_D E_b(r_p, r) E_b(r, r_q) \Delta\chi(r)\, dr = L(\Delta\chi) \quad (1)$$

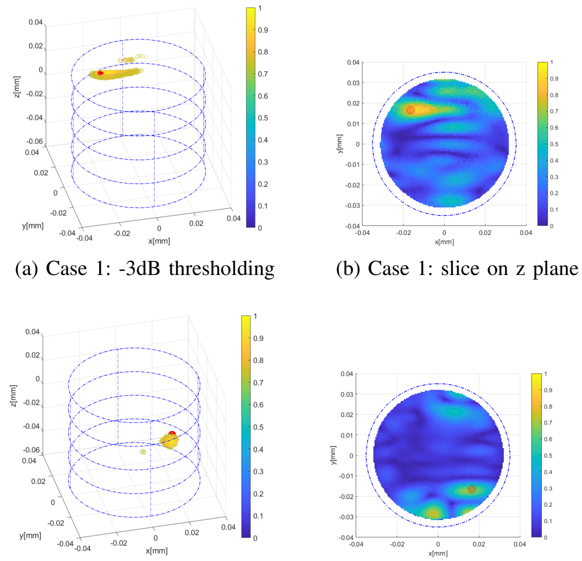
where p and q are the transmitting and receiving sources, $\Delta\chi$ is the contrast caused by the intrusion, E_b is the total field in the reference case, so in absence of contaminants, L is the linear operator associating the differential matrix with the unknown contrast, and D is the volume of interest.

Finally the image can be computed by the projection of the differential result onto the Truncated Singular Value Decomposition of the reference case [8] .

III. Numerical Results

The two configurations shown in Fig. 1 are a part of the whole simulation set used to validate the procedure; the PET contaminant is represented as a red sphere. Fig. 2 displays the differential scattering matrices respectively. The TSVD algorithm is applied and each matrix is projected onto it. Fig. 3 resumes the reconstruction results: fig. 3a and 3c show a $-3dB$ thresholding upon the obtained values within the volume of interest, and filtered points can be noticed around the expected position of contaminant in both cases. Fig. 3b and 3d display a xy cut corresponding to the z coordinate of the intrusion, whose values are normalized in the whole volume; again peak values correspond to the intrusion position, depicted as a red circumference.

The values of reconstructions are slightly stretched along the x axis; that is expected and due to the deficiency of antennas along that direction.



(a) Case 1: -3dB thresholding (b) Case 1: slice on z plane

(c) Case 2: -3dB thresholding (d) Case 2: slice on z plane

Fig. 3. Image reconstructions for the two examples.

IV. Conclusion and On-going Work

This paper demonstrates the possibility to employ MWI technology to detect millimetrical sized contaminants in cocoa-cream. Its validation through effective measurements will be presented at the conference, in a realistic scenario.

Next steps involve intrusions detection with the food products in motion along the line. The measure will be synchronized by means of a standard photocell to trigger the operation and to control the effective positions of the object to analyze. An appropriate selection of the transmitting and receiving antennas is necessary to maximize the target illumination; it would ideally enhance the reconstruction by compensating the distortion along the x axis, exploiting the object movement.

Acknowledgement

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