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Microwave Imaging Technology
for In-line Food Contamination Monitoring

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Abstract—**Foreign body contamination in food is one of the major sources of complaints against food manufacturers, and it can lead to injury, loss of brand loyalty and large recall expenses. Different technologies, such as X-ray or infrared techniques, are currently applied to detection systems used for food inspection, but physical contamination, with e.g. wood, plastic, metal and glass fragments, is still present in food. For this reason, there is the interest to develop new technologies able to address the still unmet needs of food industry. In this paper, we report about preliminary investigations of the use of the microwave imaging technology for food contamination monitoring. Numerical results show the feasibility of the proposed approach. The realization of prototype measurement system is under development.**

Keywords—microwave imaging; non-invasive diagnostics; food inspection; food security; food safety.

I. INTRODUCTION

Microwave imaging technology [1] is able, through low-power electromagnetic (EM) waves at microwave frequencies, to non-invasively penetrate an object and provide a spatial map of its EM properties. Such a capability is herein relevant due to intrinsic difference in such properties between food and beverage products and possible contaminants, such as wood, plastic, metal or glass fragments.

The main objective of this work is to realize a prototypal device able to identify foreign objects in food and beverage products using microwave imaging, in order to verify if it is possible to apply this technology in an industrial configuration, with a certain number of constraints. The designed device will be non-destructive and contactless, as well as safe for operators, thanks to the use of low-power, non-ionizing radiations. Moreover, we expect to be able to provide in-line monitoring in food manufacturing, thanks to tailored processing algorithms and their hardware implementation, and to be cost-efficient, thanks to the involved low-cost technologies. In the present paper, we describe the designed system and some preliminary investigations of its capabilities.

II. MICROWAVE IMAGING SYSTEM DESIGN

To enable real-time monitoring, a "model-based" differential imaging approach based on the distorted Born

approximation [1][3] is developed. In particular, the tomographic images are obtained by processing the data obtained from the difference of the signals measured for the object under test and those measured for a "standard" uncontaminated object. This approach is reasonable in this application, because all the objects, along the food supply-chain, are expected to be identical. Moreover, due to the small size of possible contaminations, e.g. fragments of glass or plastic, it is reasonable to assume a linearized model of the electromagnetic scattering, as the one underlying the adopted approximation. In the designed system, the tomographic image is formed by using the Truncated Singular Value Decomposition (TSVD) scheme [2][3], that can be also hardware accelerated in order to enhance real time monitoring capabilities [4].

Taking advantage of the movement of the object along the supply-chain, the microwave imaging system is simply constituted of an antenna pair, at the two opposite sides of the chain. The two antennas are connected to a vector network analyzer that measures the 2X2 scattering matrix at different time instants, while the object is moving along the chain. This allows different views of the same object. Finally, the measured S matrices are differentiated with respect to the S matrices of the standard (uncontaminated) object in the corresponding positions, and given in input to the TSVD imaging algorithm.

III. 2-D NUMERICAL RESULTS

As first test case, we consider a 3 mm thick glass jar filled with hazelnut-cocoa cream and with diameter equal to about 8 cm. The dielectric properties of glass are considered constant with respect to frequency and equal to $\varepsilon_{glass} = 4.7$ and $\sigma_{glass} = 0$ S/m, whereas the hazelnut-cocoa cream properties are updated accordingly to the frequency, as shown in Fig. 1(a) and (b). The contaminants are modelled as plastic inclusions of 2 mm in size, whose dielectric properties are $\varepsilon_{plastic} = 2.3$ and $\sigma_{plastic} = 0$ S/m, constant with respect to frequency.

In the performed numerical simulations, the whole system is represented by a canonical 2-D geometry, modelling the glass jar filled with hazelnut-cocoa cream as well as the inclusions as infinite cylinders, and the antennas as line currents aligned with the cylinder axis. Thirteen line-current antennas are placed on two opposite sides with respect to the jar along a length of 12

cm, centered with respect to the jar. The chosen numerical configuration is fully equivalent to the movement of the jar along the food supply-chain with just two antennas placed on the two opposite sides of the chain. Considering a line velocity of three jar per second, the expected antenna measurement sweep time should be equal to around 13 ms.

The system working frequency is a trade-off between the achievable resolution, increasing with frequency, and the penetration depth, decreasing with frequency. Fig. 1(c) and (d) show, for the considered test case of the hazelnut-cocoa cream, the quarter wavelength, that is a rough estimation of the imaging algorithm resolution, and the penetration depth within the cream, respectively. Moreover, we underline that, at lower frequencies, the system control electronics costs and complexity are lower.
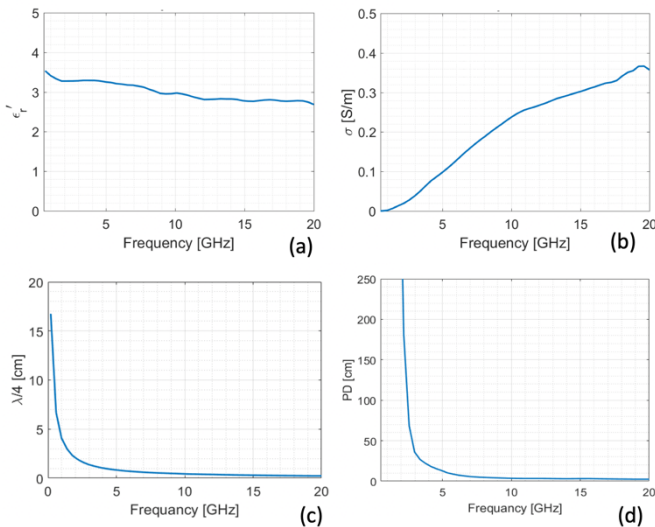

Fig. 1.   Characterization of hazelnut cocoa cream in the frequency range 1-20 GHz; (a): measured relative dielectric constant; (b) measured conductivity, S/m; (b) quarter wavalength, cm; (d): penetration depth, cm.

In order to determine the most appropriate working frequency, 36 antennas are placed around the jar under test at 3 cm from the jar edge. The sensitivity in frequency of the antennas configuration is then investigated looking at the differential field induced from the variation of the contrast with respect to the reference scenario due to the food contamination, in the range 1-20 GHz and considering 2-mm plastic contaminants placed in different locations. It has been numerically verified that, in the lower frequency range, the plastic sample is too small (with respect to the probing wavelength) to be detected, while, instead, in the higher frequency range losses start become significant. Thus, 10 GHz was found to be a good trade-off.

Finally, Fig. 2 shows the obtained reconstruction at 10 GHz with the described system applying the TSVD algorithm. The line-current antennas are placed along the x axis on the two opposite sides of the jar. The correct location and size of the contaminants is highlighted with black dots. It is evident that the two contaminants are detected correctly, but some replicas are

present along the y axis, orthogonal to the antennas' axis. This is due to the limited multi-view of the system along the y-axis, in order to be able to apply the present concept to an in-line monitoring. Moreover, we underline that the main aim of the system is just to detect the presence or not of contaminants, hence a precise reconstruction of their position and size is not a priority.
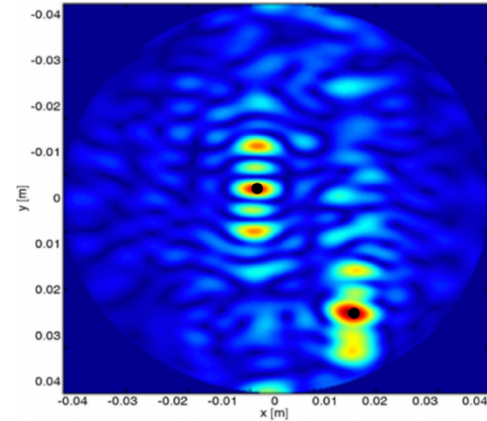

Fig. 2.   TSVD reconstruction at 10 GHz; black dots: position and size of the plastic contaminants.

IV. CONCLUSION AND PERSPECTIVES

In this contribution, we have described the design of a simple microwave imaging system for in-line food contamination monitoring. The reported initial numerical results have shown promising capabilities. The main next step of our research activity is the realization of a prototype measurement system in order to experimentally verify the obtained numerical results. Moreover, we are investigating the use of other imaging algorithms, such as time-reversal (TR) based techniques via the decomposition of TR operator (DORT) algorithm [5] and the multiple signal classification (MUSIC) algorithm [6], together with the possibility to apply a multi-frequency analysis.

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