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Recent Developments in Microwave Sensing and Imaging for Food Quality Control

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Non-destructive inspection of food to reveal the presence of foreign bodies in packaged products is of crucial importance for food industry. To this end, X-ray imaging is the mostly employed tool. However, it can fail in detecting contaminants made of low-density materials, like plastic, glass, wood, widely employed in the packaging. Such a limitation can be overcome by Microwave Imaging (MWI) techniques, thanks to the remarkable difference existing between the electric properties of these contaminants and those of food products [1].

In this framework, an effective MWI approach is the one presented in [1], wherein the detection/imaging of the presence of possible contaminants is carried out exploiting differential approach, i.e., by subtracting to the data acquired for the object under test (OUT) the ones acquired for an identical, but contaminant-free, object used as reference object (RO). The differential aspect of the approach is important, since it allows to address the imaging of small inclusions as a linear inversion problem, thus enabling real-time (hence, inline) inspection of the product. However, the need of an RO represents a limitation of this approach, since an inaccurate knowledge of the RO may introduce a modeling error overwhelming the useful signal.

To avoid the above-mentioned limitation, two different solutions have been recently developed. The first approach exploits the machine learning (ML) paradigm to perform an accurate and real-time detection/classification of possible inclusions [2], without the need of an RO. A neural network has been trained to recognize the presence and the type of inclusion directly from the acquired raw data. The development of the ML model and its testing have been carried out in a realistic industrial scenario. The design constraints are related to the acquisition and processing times, in turn, related to the speed of the production line, which reduces the available data. Nevertheless, exploiting the fast decision-making of ML algorithms, the implemented classifier, once trained, can perform in real-time. Preliminary experimental trials have shown a detection accuracy of the classifier greater than 99% in the case of mm-sized inclusions, made of wood, plastic, and glass, hosted in water and oil jars.

As the ML based approach provides excellent detection/classification performances, but it cannot provide an image of the inclusion, a second approach has been developed. This is still a differential imaging approach, but leveraging the symmetries (both geometrical and electrical) usually occurring in food items, instead of the data from an RO. The idea is that if the OUT exhibits particular geometrical symmetries, these will reflect in the measured data (if properly acquired), so that their combination can return a null signal. On the other hand, if an inclusion is present, the symmetry is broken and consequently a non-null signal will be observed, revealing the presence of the inclusion. Therefore, this signal can be used to image the inclusion. Preliminary experimental trials, with a simplified measurement scheme, have shown the effectiveness of the approach [3].

The ongoing experimental activities concerning the validation of the proposed RO-free MW approaches for food inspection will be presented at the conference, together with an assessment of the robustness of MW approach to possible disturbances arising in the industrial setting wherein they will be ultimately deployed.

1. J. A. Tobon Vasquez, et al. “Noninvasive inline food inspection via microwave imaging technology: An application example in the food industry,” *IEEE Antennas and Propag. Magazine*, **62**, 2, pp. 18–32, 2020, doi: 10.1109/MAP.2020.3012898.

2. A. Darwish et al., “Physical contamination detection in food industry using microwave and machine learning,” *Electronics*, **11**, 19, pp. 3115-, 2022, https://doi.org/10.3390/electronics11193115.

3. G. Bellizzi et al., “A Simple Microwave Imaging System for Food Product Inspection through a Symmetry-Based Microwave Imaging Approach” *Sensors*, **24**, 24, pp. 99, 2023, https://doi.org/10.3390/s24010099.