Design and Validation of a Microwave Device for Food Contamination Real-time Sensing and Imaging

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The goal of this work is the investigation for a solution to improve the degree of quality in food products: physical contamination can have severe consequences for consumers health primarily, but also can affect industries reputation and lead to potential legal consequences.

Existing devices currently employed have some drawbacks, intrinsic in their detection principle: X-ray imagers, the most effective in industries, may fail in detecting some classes of intrusions, given their sensing principle based on materials density. Plastic, wood, and glass are largely present in production facilities, and might be hard to be correctly detected.

This thesis presents the development of a microwave sensing device, exploiting a novel detection principle, to overcome these drawbacks and to offer to industries an attractive solution. It consists of a cost-efficient implementation, employing non-ionizing low-power microwave radiations , so totally safe for operators and not altering the inspected items. Further, it requires minimal adaptation to existing facilities, and it is able to provide an in-line real-time inspection for all processed products, without the need of stopping or even delaying production processes.

The exploited principle is based on the dielectric contrast between the potential intrusion and the food item. The alteration of the EM waves sensed by the antennas surrounding the target can be elaborated to properly identify presence of a foreign body. The positioning and the number of the sensing elements around the target to inspect is dictated by two considerations: enough data must be acquired to properly inspect the volume under test, and physical constraints, due to the adaptation of the system onto existing production facilities, must be considered as well. Further, another constraint is posed by the need of a fast acquisition, to be compatible with motion speed of items along a line. The choice of the operating frequency is then set as a trade-off between sufficient penetration depth in the food medium at the maximum possible resolution.

A microwave imaging (MWI) approach is numerically assessed, then experimentally validated for two classes of food mediums, oil-based and water-based, which

can be seen as models mimicking the behavior of a huge set of commercial products. It consists of reconstructing a 3-D map of the products' dielectric properties, based on a differential approach: items along a given production line can be considered equal; it is then possible to fix a reference case, from which any deviation can be checked. The numerical study shows excellent performance, enhanced by an algorithm, developed during the progression of this work, to compensate for the effect of physical constraints, not allowing to have a uniform illumination of the target under test. Its application allows to correctly map millimetric-sized foreign bodies positioned in the whole volume of interest.

The experimental validation is carried out by the development of a prototype: printed-circuit board antennas are used as sensing elements, held by a 3-D printed support surrounding the target as numerically assessed. A photocell on the available test line triggers the measurements, and the signals are acquired through a commercial Vector Network Analyzed (VNA), properly programmed to perform the acquisition subject to the required time constraints. The quality of the reconstructed 3-D images is excellent, correctly detecting the tested intrusions, which are millimetric-sized low-density bodies.

The possibility to validate the developed system in an industrial facility, with a dedicated loop allowing to acquire a consistent number of measurements with no particular efforts, pushed the development of a further approach to discern the presence of an unwanted intrusion. As industries are mainly interested in avoiding unsafe products to go to market, machine-learning based techniques have been implemented for the scope, to binarily classify items as contaminated or not. Remarkable performances are obtained through neural networks, correctly classifying all the tested intrusions, consisting in different kind of plastics, glass, and wood, for an amount of acquisitions in the order of thousands. The really promising obtained results call for further validation and development of the system, as an attractive device for food manufacturing industries.