Design of a Microwave Sensing System for the Detection of Food Contaminants in Near-Field

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***Abstract*—In this paper, a novel microwave sensing (MWS) system for the detection of food contaminants in the near-field region is designed. The MWS system is composed of a pair of radiating and receiving horns and a pair of transmissive metasurface arrays with electrically reconfigurable unit cells. By manipulating the phases of the unit cells, the radiating electromagnetic beam can be focused at different target parts of the food package to be inspected. Experiment results show that, the electric field at the detection position in near-field is enhanced by almost 20% and the detection area is larger for the proposed MWS system compared with that for the traditional system without the arrays.**

I. Introduction

There is a large demand for the evaluation and monitoring of food quality and safety due to the increasingly complex food production scenarios with diverse types of food [1]-[3]. Traditionally, the X-ray detection techniques and metal detectors are commonly used for identifying food contaminants [4]. However, X-ray is not effective for detecting low-density contaminants and potentially bring safety risks to users. Metal detectors are limited to the identification of metallic objects, while most of the food contaminants are non-metallic materials.

To address the limitations of the traditional food inspection methods, microwave sensing (MWS)-based techniques have been used [5]-[8]. The conventional MWS systems are composed of a pair of radiating and receiving horns. However, since the radiating electromagnetic beam of the horn lacks the focus property and the detection area of the systems is limited, the food package to be inspected should be put close the horns, which limit the wider application of the conventional systems.

In this work, we design a novel MWS system for the detection of the food contaminants in near-field with the use of a pair of transmissive metasurface arrays located between the food and the horns. By manipulating the phase distributions of the electrically reconfigurable unit cells of the arrays, the radiating electromagnetic beam can be focused at desired parts of the food packages. Experiment results are presented to show that the proposed MWS system has the enhanced electric field at the detection position in near-field and larger detection domain than the conventional system without the arrays.

II. Design of the MWS System

Figure 1(a) briefly describes our designed MWS system for the detection of the contaminants in food jars filled with edible oil. A pair of horns and metasurface arrays are placed on the two sides of the food production line. The distance between two arrays is 1m. The height and diameter of the food jars are 18cm and 8cm, respectively. The details of the design of the 20 × 20 unit cells of the arrays can be referred to [9] [10]. Figures 1(b) and (c) present the layout of the array with the FPGA control board and the fabricated prototype, respectively. The center frequency of the feed source is 10GHz.

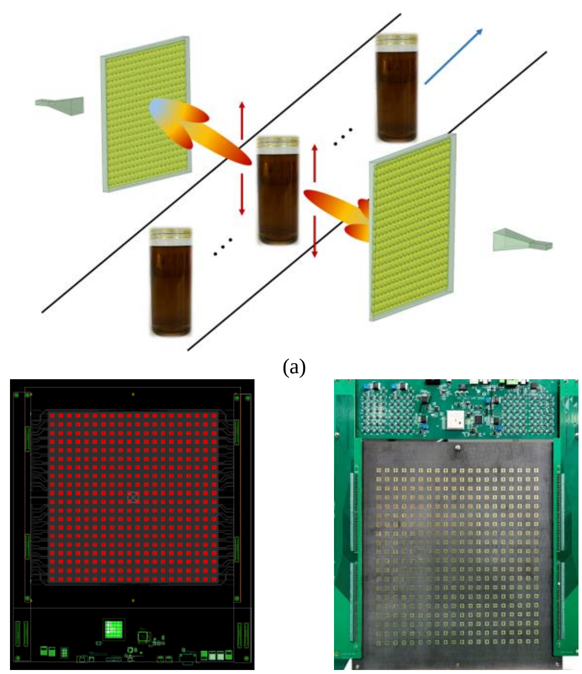
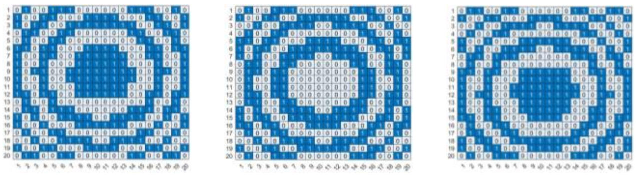


Fig. 1. (a) The designed MWS system; (b) The layout and (c) the fabricated prototype of the array and the FPGA control board.

By manipulating the phase of the unit cells of the array using the FPGA, we could control the beam scanning and focus of the radiating electromagnetic wave at different target detection positions along the horizontal and vertical directions. For example, Figs. 2(a)-(c) presents the phase compensation distributions of the unit cells for the beam focus at the upper, middle, and lower parts of the food jar located at the center between the two arrays with the height of 6cm, 0cm, and -6cm compared with the middle position, respectively.



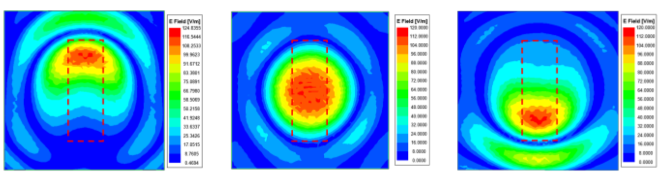
(a) (b) (c)

Fig. 2. The phase compensation of the unit cells for the beam focus at the (a) upper, (b) middle, and (c) lower parts of the food jar located at the center.

III. Simulation and Experiment Results

In this section, simulation and experiment results are presented to investigate the beam scanning and focus performance of the proposed MWS system and demonstrate its advantages over the conventional system.

First, Figs. 3(a)-(c) present the simulation results of the electric field at the positions located 50cm away from the array at the middle position within the domain in size of 30cm × 30cm (termed as the "simulation domain") for the beam scanning at the upper, middle, and lower parts of the hypothetical food jar located at the center between the two arrays (its cross section is described using the red dashed lines in Fig. 3), respectively. The figures clearly show that the beams focus at the desired detection positions along the vertical direction.



(a) (b) (c)

Fig. 3. The electric field within the simulation domain for the beam scanning at the (a) upper, (b) middle, and (c) lower parts of the hypothetical food jar indicated with a red dashed line.

Next, we investigate the near-field performance of the proposed MWS system using experiments in an anechoic chamber as shown in Fig. 4. The measurement probe is located 50cm away from the array within the domain in size of 20cm ×10cm (termed as the "measurement domain").

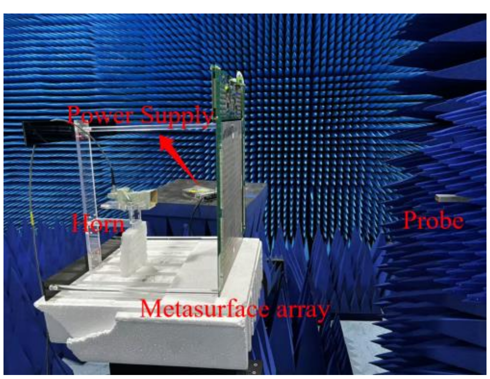
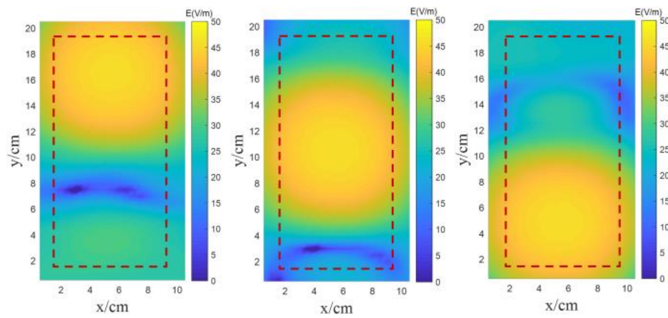


Fig. 4. The experimental scenario for investigating the near-field performance of the proposed MWS system.

Figures. 5(a)-(c) present the measured electric field within the measurement domain for the beam scanning at the upper, middle, and lower parts of the hypothetical food jar located at the center between the two arrays (its cross section is described using the blue dashed lines in Fig. 5), respectively. As seen from the figures, the beams focus at the expected positions. Additionally, the measurement results in Fig. 5 match with the simulation results in Fig. 3 in terms of the focusing effect at different positions. It is worth noting that the source power of the measurement is different from that of the simulation.



(a) (b) (c)

Fig. 5. The electric field within the measurement domain for beam scanning at the (a) upper, (b) middle, and (c) lower parts of the hypothetical food jar. The jar at the expected position is indicated with a red dashed line.

Finally, we measure the electric field within the measurement domain of size 30cm × 30cm using the conventional system by removing the array in Fig. 4. The corresponding measured electric field generated only by the horn antenna without the array is given in Fig. 6.

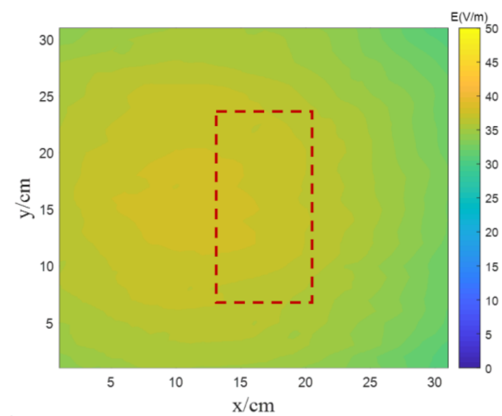


Fig. 6. The electric field within the measurement domain with the horn antenna only. The jar at the expected position is indicated with a red dashed line.

The beam of the conventional system is almost fixed at the middle part of the hypothetical food jar. Therefore, the proposed system with the array has a larger detection area (upper, middle, and lower parts), especially for large food packages, due to the flexibility of its beam scanning. Moreover, the maximum amplitude of the electric field measured using the system without the array in Fig. 6 is 37.95 V/m while those using the proposed system with the array in Figs. 5(a)-(c) are 45.80, 45.94, and 45.89 V/m, which are increased by 20.7%, 21.1%, and 20.9%, respectively. Clearly, the proposed MWS system with the metasurface array has the enhanced electric field at the detection positions than the conventional system without the array.

IV. Conclusion And Perspectives

In this paper, we propose an MWS for food contaminations detection. Instead of the traditional method with only horn antennas, the system is designed with a pair of transmitting and receiving arrays. Each array is composed of 20×20 unit cells with different phases to focus the electromagnetic wave to desired positions. An experiment has been conducted and it is found that the strategy of using the array expands the detection range for food jars significantly as well as enhances the electric filed intensity in the detection domain.

Deep learning can be employed in the following steps of identifying the existence of contaminants. The present system is expected to exhibit higher accuracy compared with the traditional method, as the stronger electric field and wider detection range may bring greater changes of scattered electric field from potential contaminants. This investigation will be presented in our future work.

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