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An experimental microwave imaging prototype for food quality assessment

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Abstract

Research on microwave imaging techniques for various applications has received growing attention over the past two decades. One of the potential applications of microwave imaging is food quality testing. Rapid worldwide increase in food demand and consumption requires development of novel non-destructive methods to both reduce the product wastage and increase consumer safety. This paper presents our first imaging results using a limited view microwave radar imaging prototype. Potato samples were used as material under test and image processing has been performed through a Huygens based algorithm. We show that our experimental prototype can detect potato defects, thus paving the way for several food quality assessment applications.

1 Introduction

The food testing market is forecasted to reach 24.6 million dollars by 2023, with an annual increase of 7.7% over a 5-year period [1]. Non-destructive food testing methods are receiving high demands largely due to the rapid increase in the world's demand and consumption. Current quality assessment methods largely rely on manual exam, which is time-consuming, expensive and subjective, and existing destructive technologies result in food wastage. Current non-destructive imaging techniques include X-rays, ultrasound, magnetic resonance imaging (MRI) and near-infrared (NIR). However, each of these has limitations (e.g. high cost, operation dependence [2], and safety issues [3]) which prevent their widespread use, and the need to propose alternative non-destructive techniques is growing.

Microwave imaging (MWI) is an emerging non-ionizing and non-invasive technology being investigated for a variety of applications. Our recent work has demonstrated that radar-based MWI algorithm can potentially detect and locate seeds inside selected fruits and can distinguish between seeded and seedless products [4], taking advantage of significant variation in the dielectric properties of the fruit seeds and its surrounding flesh.

Developing a practical MWI-based food assessment system requires optimization both in terms of scan time and the field of view. For example, tomographic imaging of individual products is neither economical nor practical for scanning products continuously on conveyor belts or below ground. To this end, this paper presents for the first time a MWI prototype that performs radar-based measurements using a reduced field of view. Images are obtained with the Huygens-based algorithm, which had been used previously only for 360 degrees field of view. In particular, previous applications of the algorithm assumed an experimental setup which had receiving positions spread radially across the object to ensure successful back-propagation. Our investigation in [5], however, showed that it is possible to reduce the views, prompting us to design and test a custom-made limited view imaging prototype. The experimental results in this paper confirm the detection potential of using this prototype with limited antenna views for practical food testing applications.

The remainder of paper is structured as follows. Section 2 summarizes the employed radar-based algorithm. The measurement setup and the prototype are described in Section 3. Measurement results are presented in Section 4, while Section 5 provides some concluding remarks.

2 Imaging Method

The proposed prototype employs the Huygens-based radar algorithm [6], which we have tested previously for medical and food imaging applications. This work reports our first attempt, however, to use the algorithm with experimental data from a measurement configuration limited to 180° view angles. Huygens algorithm virtually back-propagates the measured external field into the imaging domain to reconstruct the internal field within the object as follows:

$$E_{\mathrm{HP}}(\rho, m, f) = \sum_{n=1}^{N} \left(E_{nm}(f) G(k|\vec{\rho}_n - \vec{\rho}|)\right) \qquad (1)$$

In Eq. (1), E_{nm} is the received field from transmitter m at receiver n, $G(k|\vec{\rho}_n - \vec{\rho}|)$ indicates the Green's function as defined in [6] at location $\vec{\rho}$, and k is the wave number of the medium in free-space at the frequency f. To achieve the resulting intensity image the algorithm incoherently sums all the signals from all frequency points and all transmitter positions.

3 Measurement Setup

The measurements in this paper were performed with our automated prototype shown in Figure 1. The setup consists of one transmitter and one receiver antenna connected to a two-port Anritsu Shockline vector network analyzer (VNA). The custom-designed spear-shaped antennas are designed on a 28.42 mm by 18.25 mm FR-4 [7] with a spear shape patch fed by a transmission line. The step motion of the antenna positioners is generated by steeper motors and controlled through Arduino hardware.

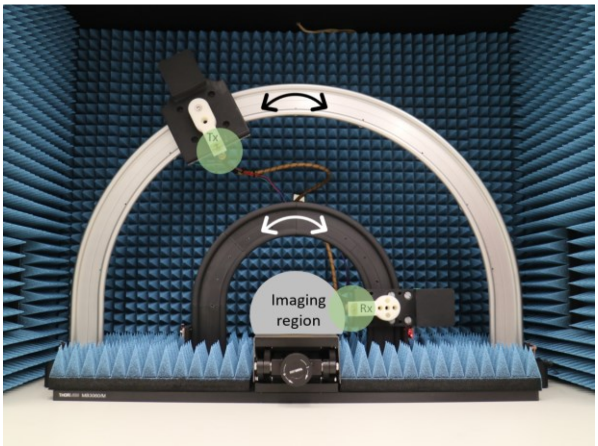


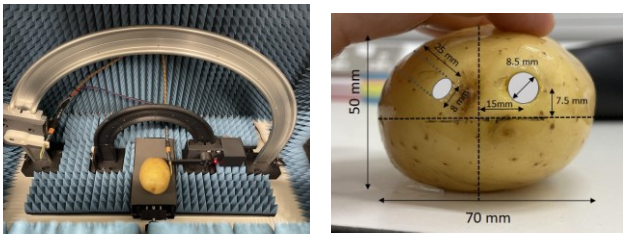
Figure 1. Measurement setup. The receiving antenna rotates along the smaller black ring while the tranmitter rotates along the larger silver ring. The antennas are connected to a 2-port VNA.

To confine the radar measurements within the area occupied by the food material under test (MUT), we designed and fabricated an automated positioning system that can perform measurements at a maximum span of 180 degrees (see Figure 1). The setup includes a robust base to place the MUT, a number of ABS 3D printed supporting structures, two curved double rails and the mounting carriages for both the transmitting and receiving antenna. The transmitter and receiver are mounted and revolving on a half-circle slider at an adjustable rotation diameter of 600 mm and 150 mm, respectively. The imaging region can contain items of up to 120 mm in diameter and its height can be adjusted using a vertical positioner, so as to align the center of the object to the desired section. The setup is surrounded by microwave absorbing material to reduce unwanted reflections from the surrounding environment.

The measurement sequence begins with the transmitter and receiver at 0°. The receiver then rotates with a step of 15° to measure at 13 receiving positions from 0 to 180°. Subsequently, the transmitter moves to 90° and 180° positions, where in each case the receiver again scans at the same positions as those of the first transmitting position.

4 Results

A potato with a diameter of 70 mm and height of 50 mm was used as MUT (Figure 2(b)). The potato was placed on the imaging region so that the receiver was distanced 5 mm from its surface (Figure 2(a)). The automated scan was performed through running a script on MATLAB which controls the Arduino software and records 801 frequency samples in the range of 1-8 GHz via the VNA. Next, a circular diagonal hole was created on the left side of the potato (upper left quadrant of Figure 2(b)), by cutting a 25 mm circular hole through the potato, leaving an air gap of ~8 mm diameter and then placing the remaining outer part of the potato section back in. Figure 3 shows the normalized reconstruction image of the potato obtained through Eq. (1) after subtracting the received field of the potato with and without the first hole.



(a) (b)

Figure 2. (a) Image of the setup with potato as an MUT. (b) Dimensions of the potato and the created holes.

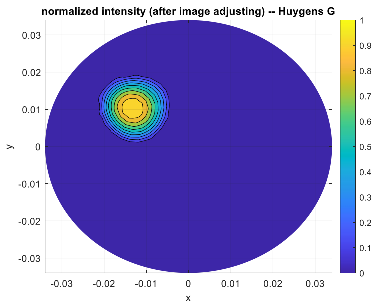


Figure 3. Image of the potato with a single hole. The location of the hole mimicking an airgap is detected and localized; x and y axes are in meters.

Then, a second hole was added to the potato, this time cutting a hole (8.5 mm diameter) horizontally all the way through the potato without refilling (upper right quadrant of Figure 2(b)). Figure 4 shows the normalized reconstruction image of the potato obtained after subtracting the received fields of the potato with two holes and the potato without holes. An artefact can be spotted between the two holes, which has a lower intensity than the holes and can be removed through thresholding.

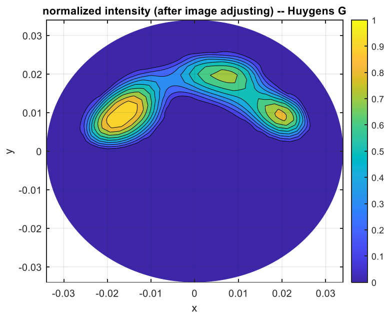


Figure 4. Image of the potato with two holes. The two holes are detected and localized in their approximate locations; x and y axes are in meters.

5 Conclusion and Future Work

This paper presented our first imaging results using a purpose-built limited view microwave imaging prototype. The results indicate that our Huygens based algorithm is capable of detecting and localizing air gaps inside the potatoes using a limited data from only 3 transmitting and 13 receiving positions. The 50% decrease in our recorded data does not have a noticeable effect on the detection capabilities compared to the full view 360 degrees system, while it greatly enhances the scanning speed, testing efficiency and the versatility of the imaging process. Improving target localization when having multiple inclusions in a limited-view scenario remains a challenge to overcome in our future work.

Our research in this area is still in its preliminary stages and we will continue to access various food science applications to tackle the challenges of more effectively using limited view data in more complex and realistic problems. An important technical issue that requires further investigation is how we can move from subtracting the exact signals from the object without the defect to a more realistic scenario where we can only have approximate knowledge of the "background scenario". Additional results to address this issue will be presented in the conference.

6 Acknowledgements

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7 References

[1] Markets and Markets, "Food Safety Testing Market Size, Share, and Growth - Forecast to 2023 | COVID-19 Impact on Food Safety and testing market |", Marketsandmarkets.com, 2021. [Online]. Available: https://www.marketsandmarkets.com/Market-reports/food-safety-365.html. [Accessed: 27- Jan-2021].

[2] N. Galili, A. Mizrach, and G. Rosenhouse, "Ultrasonic testing of whole fruit for nondestructive quality evaluation," in American Society of Agricultural Engineers, paper no. 93-6026, Spokane, Washington, 1993.

[3] N. Kotwaliwale, K. Singh, A. Kalne, S. N. Jha, N. Seth, and A. Kar, "X-ray imaging methods for internal quality evaluation of agricultural produce," *Journal of Food Science and Technology*, **51**, 1, Jan. 2014, pp. 1-15.

[4] N. Ghavami, I. Sotiriou and P. Kosmas, "Experimental investigation of microwave imaging as means to assess fruit quality," 2019 13th European Conference on Antennas and Propagation (EuCAP), Krakow, Poland, 2019, pp. 1-5.

[5] N. Ghavami, I. Sotiriou and P. Kosmas, "Limited-view Prototype Design for Radar-based Fruit Imaging," *2020* 14th European Conference on Antennas and Propagation (EuCAP), Copenhagen, Denmark, 2020, pp. 1-5, doi: 10.23919/EuCAP48036.2020.9135213.

[6] N. Ghavami, G. Tiberi, D. J. Edwards and A. Monorchio, "UWB Microwave Imaging of Objects With Canonical Shape," *IEEE Transactions on Antennas and Propagation*, **60**, 1, Jan. 2012, pp. 231–239.

[7] S. Ahsan, W. Guo, O. Karadima and P. Kosmas, "Experimental Comparison of Two Printed Monopole Antenna Designs for Microwave Tomography," 2019 IEEE Asia-Pacific Microwave Conference (APMC), Singapore, 2019, pp. 500-502, doi: 10.1109/APMC46564.2019.9038734.