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Feasibility Study of Terahertz Imaging for Non-Visible Defect Detection in Hazelnuts

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***Abstract*— The successful application of millimeter-wave (mmW) imaging to the quality assessment of soft fruits [1], such as apples and peaches, has motivated the exploration of higher-frequency techniques in the terahertz (THz) range. This study aims to evaluate the effectiveness of THz imaging in more challenging scenarios, particularly for certain types of seeds like hazelnuts. We investigate whether a THz imaging system can be used to assess the quality of hazelnuts affected by spoilage or fungal infections that are not visible to the naked eye, even after shell removal and prior to their use in food manufacturing processes, such as hazelnut cocoa cream production. Using reflection coefficient in the frequency range 105–175 GHz and rotational scanning, we evaluate the system's ability to detect spoilage or fungal infections. Tests include hazelnuts with and without defects, as well as samples with inserted metal intrusions. The initial results show the system can distinguish between different conditions, highlighting its potential for non-destructive food quality inspection.**

Keywords—THz imaging, radar, food safety, FFT, Signal processing

I. INTRODUCTION

As food safety becomes an increasingly important global concern, the need for advanced and reliable inspection technologies has grown substantially. Among nondestructive testing methods, X-ray imaging, near-infrared (NIR) spectroscopy, and ultrasonic techniques are widely used. X-ray imaging [2] offers strong penetration capabilities, making it highly effective for internal structural inspection. However, its use on foods containing active biological elements, such as lactobacilli or fungi, raises concerns due to the potential for radiation-induced damage or residual exposure affecting sensitive components. NIR spectroscopy [3] has emerged as a rapid and non-destructive alternative to conventional food safety techniques. It provides valuable information, including the quantitative analysis of chemical components, moisture content, and overall sample quality. Nevertheless, NIR spectroscopy has certain limitations: it depends on chemical reference methods for calibration and, due to its low penetration depth, requires the spectrometer to be positioned very close to or in direct contact with the sample. Ultrasonic techniques [4], although free from radiation-related concerns, are constrained by their low spatial resolution and poor signal transmission across interfaces between materials with contrasting acoustic properties. In contrast, terahertz (THz) technology has recently gained attention as a promising nondestructive inspection approach. Its advantages include effective penetration through various non-metallic materials, low energy, and submillimeter spatial resolution. These characteristics make THz imaging especially well-suited for evaluating food products that may contain delicate internal structures or biologically active components, without risking thermal or radiation-induced damage.

II. PRELIMARY EXPERIMENTAL RESULTS

The reflectivity images obtained by processing the reflection coefficients (S_{11}) from the THz imaging system reveal distinct spatial variations in the internal structure of the hazelnuts. By acquiring frequency-domain measurements while rotating each sample relative to the fixed horn antenna, we reconstructed angularly resolved reflectivity profiles that enhance the detection of anomalies across different orientations. Applying the inverse Fourier transform (IFFT) to the wideband S_{11} data (105–175 GHz) allow for depth-resolved reflectivity mapping. We successfully observe distinct differences in the reflectivity patterns among the various test cases, including healthy hazelnuts, spoiled ones, samples with inserted metal spines, and hazelnuts glued with an intentional air gap. These differences are clearly reflected in the amplitude and spatial distribution of the reflected signals. The results demonstrate that the THz imaging system, combined with frequency-domain measurements and rotational scanning, is sensitive enough to detect structural differences. This confirms its potential as a non-destructive tool for distinguishing between healthy and defective hazelnuts in food quality inspection scenarios. The next work step is the automated classification of the measured data.

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