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Abstract

Sub-terahertz wave detection of foreign matter in filling containers †

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Abstract: In recent years, electromagnetic waves (terahertz waves) with frequencies between 0.1 and 10 THz, which exist between radio waves and light waves, have attracted much attention. These electromagnetic waves have both the linearity of light waves and the transparency of radio waves and are expected to be applied to the field of human non-destructive testing. While it is known that terahertz waves can be used to detect foreign matter inside an object, we thought that by irradiating terahertz waves to the object to be measured from various directions, it would be possible to analyze the location and direction of contamination by comparing the scattering of the terahertz waves irradiated to the foreign matter. The samples were biomass resources in a jar with an opening of 53 mm and a diameter of 66.8 mm, and an aluminum plate with 76 × 50 mm. When terahertz waves were irradiated from the side of the jar with the biomass resources in it and the aluminum plate inserted, the transmission was higher when the metal plate was parallel to the light source and detector. This indicates that the transmission tendency of terahertz waves changes depending on the position and angle of the metal strip inside with respect to the direction of terahertz wave irradiation. This transmission tendency enables us to locate the position of a foreign object by irradiating terahertz waves from multiple directions, which is expected to be applied not only to the removal of foreign objects but also to various non-destructive inspection.

Keywords: Terahertz wave; Foreign material inspection; Recycling; Biomass

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1. Introduction

In recent years, because of the development of high-frequency devices, we are focusing on terahertz waves, which can now be generated in a stable manner. These terahertz waves are electromagnetic waves with frequencies ranging from 0.1 to 10 THz that lie between radio waves and light waves. These electromagnetic waves have the characteristics of both the linearity of light waves and the transparency of radio waves. They are also non-invasive to the human body, and unlike X-rays, they do not accumulate damage to cells. Therefore, we can use it for a long time even in environments where we are working. In fact, it is beginning to be used for inspecting foreign objects in products and exterior walls, such as the characterization of building materials (Yutaka et al., 2009), nondestructive testing of concrete interiors (Chihiro et al., 2024), and detection of foreign bodies in grain (Yuying et al., 2019).

Such use of terahertz waves has shown that foreign matter inside objects can be detected, but under certain conditions, the possibility arises that foreign matter cannot be detected. For example, when focusing on a foreign object inside, the intensity of the transmitted terahertz waves may differ depending on the position of the buried foreign object, the size of the foreign object, and the direction and angle of the buried foreign object in relation to the irradiated terahertz waves.

Thus, even just with respect to the positional relationship between the foreign body and terahertz waves, multiple factors can be cited that inhibit the identification of foreign bodies. In this study, we focused on the direction and angle of foreign matter burial and thought that by irradiating terahertz waves from various directions the position and direction of foreign matter burial could be analyzed by comparing the scattering state of the irradiated terahertz waves. We verified what extent the position and angle of foreign matter inside the object to be measured affect the transmission measurement of terahertz waves.

2 Materials and Methods

To make samples for the measurements, we used a glass jar with an opening of 53 mm, a diameter of 66.8 mm, and a height of 65 mm, an aluminum plate measuring 76 mm long x 50 mm wide, and two biomass resources: coffee powder and purified rice. First, the biomass resources were poured into the empty jars until they were full. Next, three sample jars were prepared: one containing only the biomass resource, one with the aluminum plate placed vertically, and one with the aluminum plate placed at an angle of approximately 60° from the bottom. In addition, a sample with coffee bean powder and a sample with refined rice were also prepared as biomass resources.

The apparatus was prepared in advance by combining a signal generator, a light source, and a detector. We used a CW signal generator with an average output of 1 mW as the signal generator, and a horn antenna with a beam diameter of 30 mm as the light source and detector. The signal generator was set to emit electromagnetic waves at 12.1 GHz, which has a high detection voltage in air.

For the experimental method, first, as shown in Figure 1, I prepared a light source to generate electromagnetic waves and a detector to receive electromagnetic waves and placed the sample between them. Second, the sample was irradiated with longitudinal electromagnetic waves set at 12.1 GHz, and the electromagnetic waves transmitted through the sample were received by the detector. Finally, the sample was manually rotated by each 30° with the center of the sample as the rotation axis, and the detected voltage at each angle was read with an oscilloscope and the detected voltage values were compared.

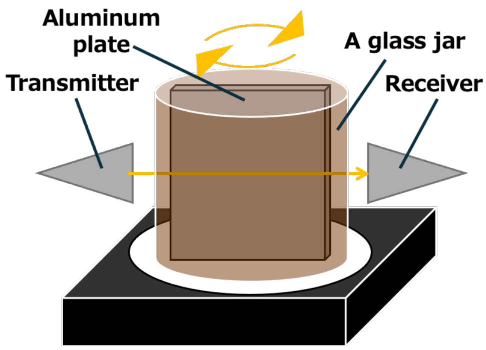

Figure 1. Experimental Methods (Equipment and sample positioning)

3. Results

Figure 2 shows the change in detection voltage when three different samples containing coffee powder were irradiated with 12.1 GHz electromagnetic waves and the samples were rotated each 30°.

First, the transmittance of the sample in an aluminum plate was mixed was lower than that of the sample in which it was not mixed. This confirms that terahertz wave detection of foreign matter is possible. In addition, compared to the samples with a metal plate inside, the detection voltage was higher, especially at 90 and 270°. In this case, the aluminum plate was fixed parallel to the direction of the electromagnetic wave. This suggests that it is difficult to recognize foreign objects when it is parallel to the direction of the electromagnetic wave.

Furthermore, a comparison of the average of the transmittance at all angles from 0° to 360° for each sample shows that the transmittance is higher when the aluminum plate is inserted at an angle of 60° diagonally than when the aluminum plate is inserted perpendicularly to the coffee powder. This indicates that electromagnetic waves are scattered by the position and angle of the aluminum plate in the sample, and that the transmittance varies depending on the measurement point.

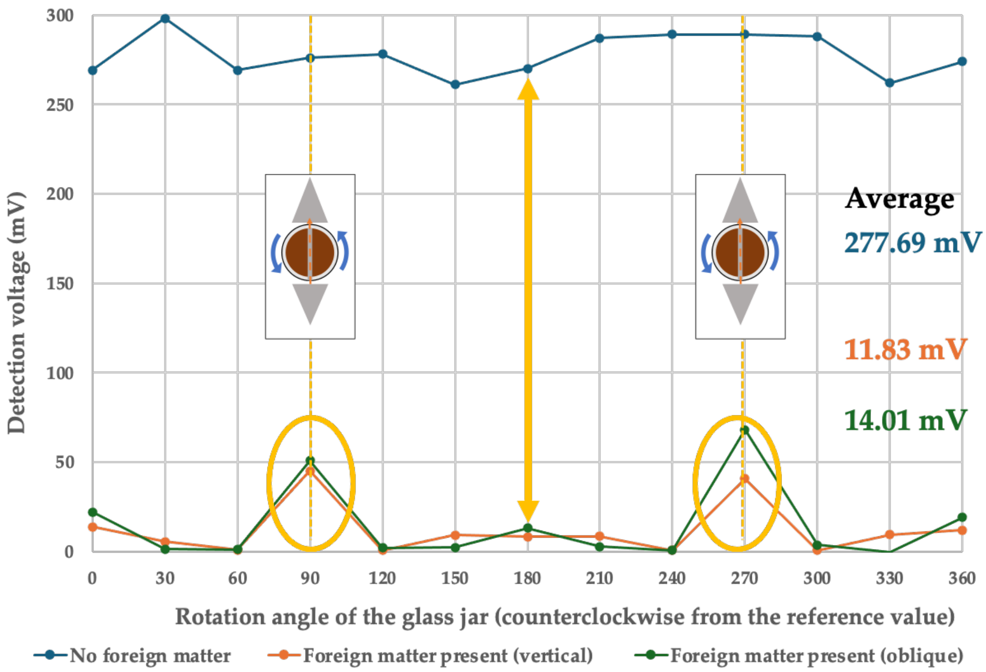

Figure 2. Detection voltage of the sample at each angle at 12.1 GHz

4. Conclusions

In this experiment, terahertz waves were irradiated from various directions to the object to be measured. The purpose of this experiment was to see if the position and direction of foreign matter contamination could be analyzed by comparing the scattering of the irradiated terahertz waves. The following points are discussed from the measurement results. One is that the transmittance of the irradiated terahertz wave changes depending on the foreign matter inside the sample. The other is that the position and angle of the metallic fragments inside the sample change the scattering tendency of the irradiated terahertz wave, which in turn changes the transmittance of the irradiated terahertz wave.

By analyzing the scattering tendency of the terahertz wave, it is possible to locate the position of the foreign object in the measured object, which may be applied to inspections in various fields.

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References

1. Oyama, Y.; Zhen, L.; Tanabe, T.; Kagaya, M.; Sub-terahertz imaging of defects in building blocks. *NDT&E International* **2009**, *42*, pp. 28-33. [https://doi.org/10.1016/j.ndteint.2008.08.002]
2. Kobayashi, C.; Nishiwaki, T.; Tanabe, T.; Oohashi, T.; Hamasaki, H.; Hikishima, S.; Tanaka, A.; Arita, K.; Fujii, S;. Saro, D.; Kidokoro, T.; Non-destructive testing of reinforced concrete structures using sub-terahertz reflected waves. *Developments in the Build Environment*, **2024,** *18*, 100423. [https://doi.org/10.1016/j.dibe.2024.100423]
3. Jiang, Y.; Ge, H.; Zhang, Y.; Detection of foreign bodies in grain with terahertz reflection imaging. *Optik* **2019**, *181*, pp.1130-1138. [https://doi.org/10.1016/j.ijleo.2018.12.066]

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