Open Journal of Antennas and Propagation, 2023, 11, 26-35
https://www.scirp.org/journal/ojapr
ISSN Online: 2329-8413
ISSN Print: 2329-8421

Investigation of Tablet Defects by AI Based Terahertz Technology

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How to cite this paper: Yadav, N.P., Hu, G.Z. and Singh, R.K. (2023) Investigation of Tablet Defects by AI Based Terahertz Technology. *Open Journal of Antennas and Propagation*, **11**, 26-35.
https://doi.org/10.4236/ojapr.2023.112003

Received: October 16, 2022
Accepted: May 5, 2023
Published: May 8, 2023

Abstract

Recently a lot of medical tablets with special packets in the global market are available. For the safety and purity of the tablet, we need to scan it by developed scanner technology, which should be not more expensive and easily available in the market. The THz technology is one of them. In the proposed work, we have tasted tablet images with the help of the THz super-resolution scanner, which is already available in our lab. The AI machine learning data concept has been investigated. Good resolution of images has been obtained. Furthermore, the challenging research problems are discussed. Finally, it summarizes the recent updates in terahertz technology for drug inspection and medical applications with potential research challenges.

Keywords

THz Radiation, Nano Drugs, Tablets Sample, Covid-19, Medical Application, 3D Imaging, Layer in Tablet, AI

1. Introduction

A THz CCD camera is a novel instrument used to visualize images of medical tablets and Covid-19 drugs in an enlarged form. The term “terahertz radiation”, which is also recognized as THz waves or THz light (1 THz corresponds to 10^{12} Hz, 33.3 cm^{-1}, 4.14 meV, with a wavelength of 300 μm), is located between microwave and far-infrared region. Recently, the scanning techniques for the medicine and investigation of Covid-19 drugs by using Terahertz Parametric Imaging (TPI), has great potential for medical applications since it is a non-destructive imaging method. It does not cause any ionization hazard on biological samples due to the low energy of THz radiation. Recent investigations suggest that the

TPI method can be used in the early identification of medical tablets using techniques that rely on X-rays [1] [2]. The terahertz imaging (TI) system is developed for dental diagnosis, due to essential advantages in medical studies. TI dental diagnosis has considerable demands in hospitals, mainly in China and other Asian countries due to the large population. However, X-ray is a commonly used method for determination in dentistry [3] in addition to other biological applications. However, the frequent application of ionizing radiation causes a harmful effect on human health [4] [5]. APAC countries are estimated to have huge opportunities for the terahertz scanner devices market due to the wide existence of built-up firms in countries, such as China, and India. Currently, a few TI techniques are available, which can be an alternative to X-rays. However, to detect the damage in any Covid-19 medicine with high probability, there is no current technique possible [6]. Some reports have come out to evaluate the efficiency of different diagnostic modalities for the early detection of dental caries in children [7] [8] [9] [10]. The above reasons create a need for a new method of inspection in which we can detect maximum internal and outer defects in the human tooth, different parts of the human body and medical drugs. The non-ionizing properties of TI can be helpful when interacting with biological samples [11]. Recently, using THz-TDS (THz time-domain spectroscopy) methods based on analysis of absorption and refractive index variation, significant differences were found between permanent and primary teeth and between healthy and primary teeth [12]. The size of the sample is 10 mm. The three-dimensional terahertz imaging has been implemented in [13], and further work has been performed *in vivo* [14]. This technique has also shown the promise of measuring the effect of mineralization and demineralization [15]. A lot of pharmaceutical residues research has been done [16]. It has been done the research review on related topic Covid-19 issues and tablet and drugs scan by different methods [17]-[24]. Very few methods are available in the globe for scanning the new productive medicine. In proposed work, we are presenting one novel technique Terahertz Scanning Device for future application in medical and industries. The super-resolution through polarization microscopy (THz PIMI) by using the novel metamaterials-based THz antenna will be the next plan for the coming new report. We have already reported the image resolution by developing our parametric indirect microscopy imaging system (PIMI) [25]-[32]. After that, the results have been reported based on THz technology in medical application [33] [34]. Many researchers were worked on the metamaterials. Very few researchers have reported the image resolution through metamaterials, THz antenna. Another important thing is the form of the issue represented by the relatively high cost of THz systems that blocks the routine and continuous use in real-life applications. Our recent report is based on THz camera in medical application. Further, the calculated histogram value and plotted intensity curve by using python have been discussed. Details discussion about experimental setup and its optical function results in studies, and finally, the conclusions are given in Sections 2, 3 and 4 respectively.

2. Experimental and Principal of Terahertz Technology

2.1. Theory

Reported in [35], THz wave concentration received at the detector can be written as

$$I(\alpha,\varphi) = I_P + \frac{\omega n^3 E_{THz} r_{Jd} L}{2c}(\sin\alpha\sin 2\varphi + 2\sin\alpha\cos 2\varphi) \quad (1)$$

Here I_P and ω are the initial intensity and angular frequency of THz wave η is the reflective index of the detecting object (stone, teeth, tablet, Covid-19 drugs) to the THz wave, r_{Jd} and L is the non-zero coefficient of tensor and the depth of the antenna, E_{THz} is the electric field and c is the light speed. The φ is defined as the angle between a polarizer and the axis of the detecting camera. In the experiment polarizer were set in front detector axis, mainly, $\alpha = 90^\circ$; Intensity a were concluded by observing Equation (1) are,

$$I(\alpha = 90^\circ, \varphi = 0^\circ) = 2S \quad (2)$$

$$I(\alpha = 0^\circ, \varphi = 0^\circ) = 0 \quad (3)$$

$$I(\alpha = 90^\circ, \varphi = 45^\circ) = 0 \quad (4)$$

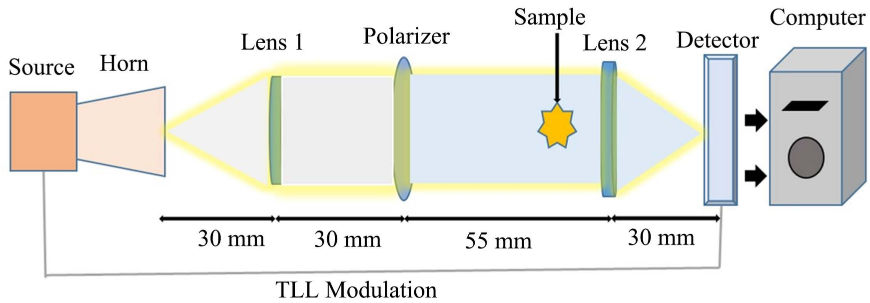
$$I(\alpha = 0^\circ, \varphi = 45^\circ) = 2S \quad (5)$$

$$H = I_p \frac{\omega\eta^3 E_{THz} r_{jd} L}{2c} \quad (6)$$

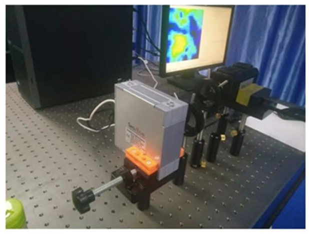
Equation (2)-(6), can explain that intensity changes with straight component (S) the change in polarization and can be measured through the detector of the direct field and their proportional coefficient is 45˚. Based on the above investigation polarization intensity deviation is obtained. It helps in the extent and effect of polarization for the sample. Directions need to be the same for more accurate testing.

2.2. Terasense Setup and Basic Principle

The THz experimental setup and its demonstration are shown in **Figure 1**. Lens-free made by the semiconductor THz sensor is a modern imaging technique whereby the sample is placed directly into or very close to the THz sensor, and illuminated by a partially THz source located far above it. The THz camera has a frequency range from 0.05 to 0.7 THz, and the pixel model is 1024. The detailed optical THz setup with step-by-step separation between instruments can be seen in **Figure 1**. The THz scanner machine consists of IMPATT (IMPact ionization Avalanche Transit Time diode) generator with a frequency of 100 GHz and production power of 80/180/400 mw supported by THz imaging cameras with a wide spectral range of 50 GHz to 0.7 THz in addition to HRFZ-SI-H lens of a diameter of 50.8 mm, (focal length 40 mm), polarizer POL-HDPE-OD of a diameter of 50, range of (0.01 - 30 THz).



(a)



(b)

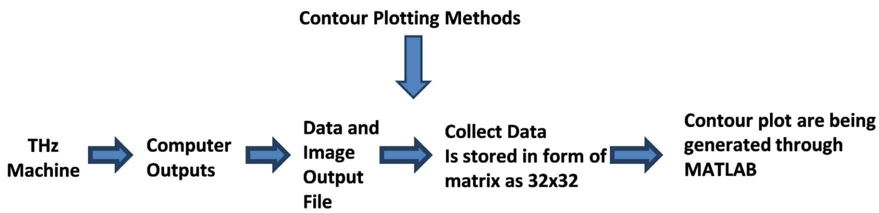


Figure 1. Details THz optical setup with a working function. (a) Optical THz setup with complete working processes; (b) THz hardware setup with complete working processes.

2.3. Basic of Image Resolution by Using Optical Source

The working function and implementations of the optical imaging especially for depth of focus can be seen [28]. The above **Figure 1(a)** shows the Optical THz setup for super-resolution imaging. The details of Optical THz imaging and data calculations are shown in **Figure 1(b)** and the contour plot table. Depth of field or depth of focus is a distance range where the image optical resolution is as high as possible for that lens, *i.e.* an image appears to be in focus. In an optical microscopy, the diffraction limit is the challenging factor for getting higher resolutions. Therefore, we need to be infringement the diffraction limit by using different methods like depth imaging by using machine learning or scattering, infringement the diffraction limit, collecting an evanescent wave, and so on. Here are some basic formulas, which help to calculate the resolution, and Rayleigh unit by using numerical aperture, wavelength, and refractive index.

$$\text{Rayleigh Unit} = RU = \frac{1}{4}\frac{\lambda}{n - n\cos\theta} \approx \frac{n\lambda}{2NA^2} \tag{7}$$

$$\text{Resolution} = \delta d = \frac{1}{v_{x\max}} = \frac{\lambda}{NA(1+\sigma)} \tag{8}$$

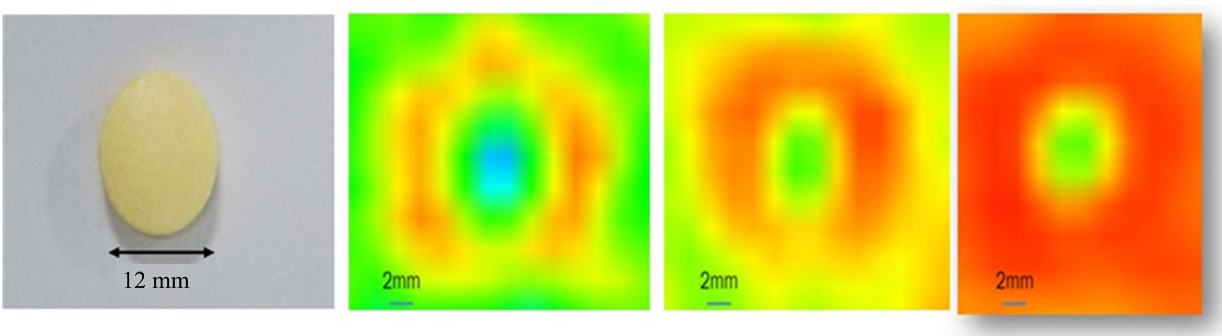
With help of the above concept and the above two Equations (7) and (8), we have developed one standard optical imaging system, Parametric Indirect Microscopic Imaging (PIMI). Our research group has already published a lot of research articles on the related optical system [26] [27] [28]. In this PIMI setup, the light path is including the conventional optical microscopy, incident light from the resource with the module's rotation polarizer control, analyzer of polarization composed of a quarter and a polarizer, optical image field detection matrix(CCD). We have calculated the high resolution of an above-developed optical system is 150 nm, which has been mentioned in above references.

3. Results and Discussion

Figure 1 shows the experimental setup of THz instruments with complete optical and hardware working system. The THz scanner has gained more effectiveness in the medical society since it is non-ionizing and used in applications where one has to get the image below the plane of the sample. Such attributes make it a novel system to investigate its inspection of medical tablets especially for Covid-19 drugs and for dental applications. The tablet samples were prepared. It is observed that the wet samples have higher absorption and lower refractive index as compared to dry samples. Therefore, these results (mentioned in **Figure 2**) show that there is a clear difference between different brightness. The contour plot methods are given in below by using THz image data.

THz technology may indeed develop independently of science and run fast successfully well ahead of scientific reason. An increasing demand of the new version of terahertz scanner due to its better responses in terms of barrier penetration and high resolution without any damage and usage of terahertz technology in R&D also boosts the market growth. One of the most encouraging medical applications of the THz scanner is cancer imaging in early stage due to high resolution capability. Most cancers cells are found in mm scale and start on the surface of soft tissues, which is the first most important target for superficial imaging using THz waves.

THz Images of Pharmaceutical Tablet



Real image of Tablet (a) | Brightness-1 (b) | Brightness-2 (c) | Brightness-3 (d)

Figure 2. The image of sample Tablet (a); brightness-1; (b) brightness-2; (c) brightness-3 (d).

We have tested the tablet sample of size length 12 mm by using polarizer based THz scanner; which can be depicted in Figure 2. (a) is the real image of tablet image whose diameter is 12 mm, (b)-(d) images are THz images with different brightness. X and Y scales are in mm. On the right transmitted light intensity scale in arbitrary units. After receiving the images, we have used the contour plot methods and python for the specification of intensity and resolution by using pixel values. This result indicated that the potential of a novel terahertz scanner for the analysis of tablet different layers' thickness by illustrating the technique on tablets. It is hence of great interest for these coating properties to be monitored and fixed before the final production of tablets.

The images taken by the THz camera were apparent. One can easily clear the difference between TPI images. We have noticed that the resolution of the instrument is about 1 mm. Breaking the diffraction limit and improvement of the resolution of terahertz imaging is always playing a vital role for researchers. The THz imaging or diagnosis procedure can be seen from the above contour plotting methods. Further, we have calculated and plotted the curve, relation between intensity, pixel value, and histogram value of different tablet images by using python can be seen in Figure 3. Further, we have compared each tablet image, shown in Figure 4. Image segmentation is also one of key point for improving the image resolution and detecting the object through any THz scanner.

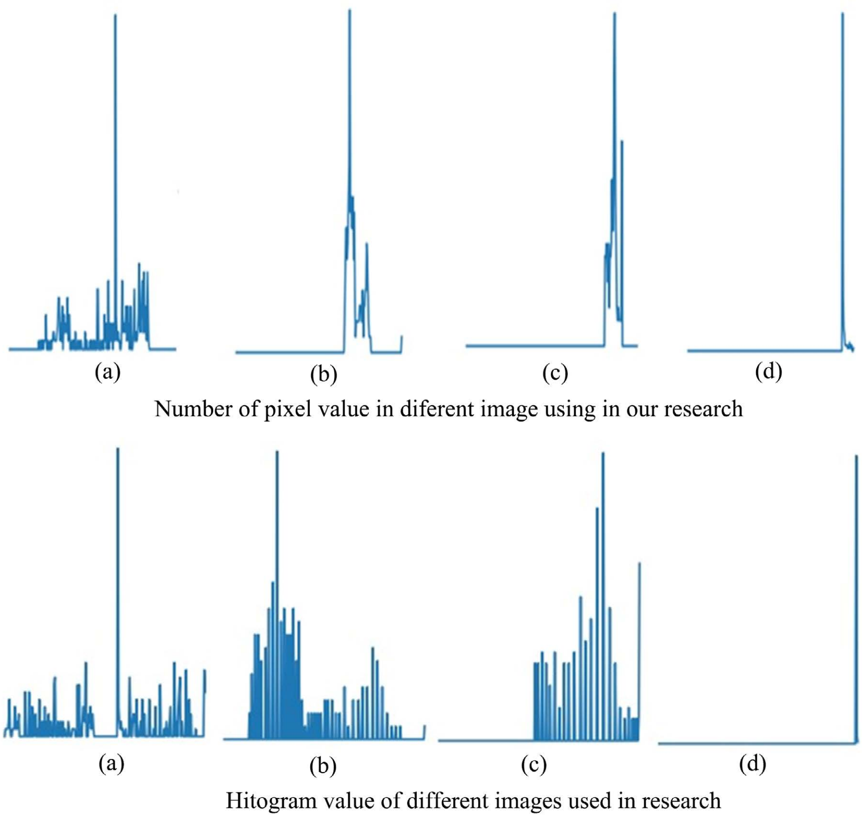


Figure 3. (a) Number of pixels and (b) Histogram value of different tablet images by using A. I.

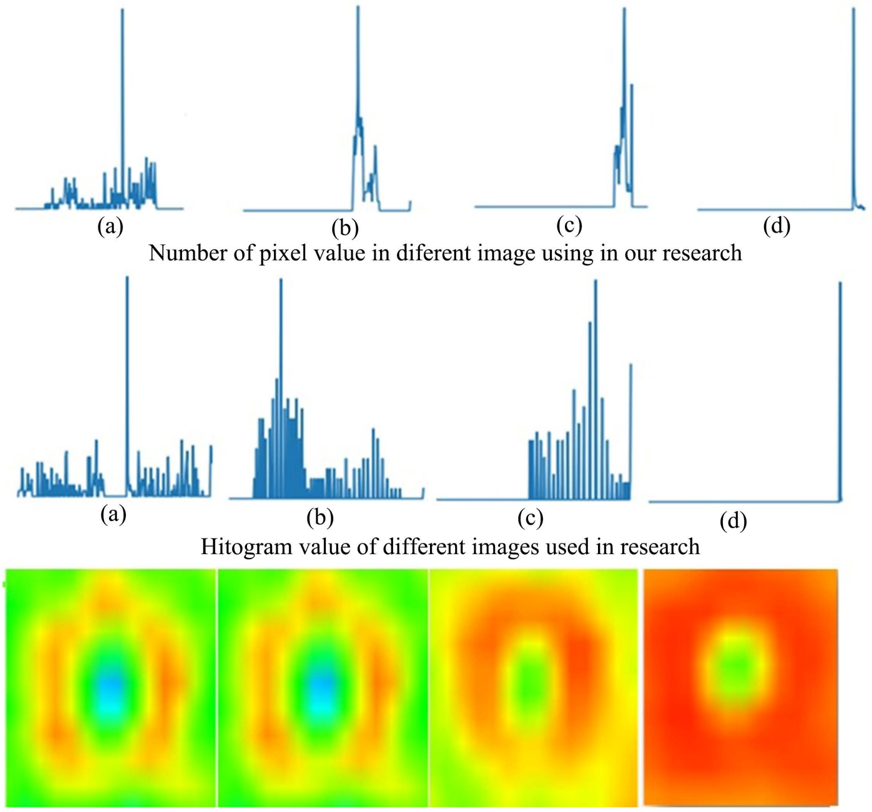


Figure 4. (a) Number of pixels and (b) Histograms values of different tablet images by using A. I.

It is generally used in special applications like central processing unit vision, digital prototype recognition, automaton vision, robotic mission, A. I, machine learning, etc. Histogram was the earliest feature that has been used for separating objects from their surroundings, it is generally relevant in different applications in which one needs to partition the image into different regions like background and object.

Currently, terahertz imaging cannot compare head-to-head with these mature technologies because it is at an early stage of development. One of the industry application, for example, we have tested one special stone by our THz CCD camera.

From the above discussion, we can say that the THz system can be applied in different applications around the globe. In human life, health issues are the most common point for every scientist for the early stage diagnosis of different deceases and Covid-19 variants are coming from time to time. From the above results and discussion, we can summarize that the development of our THz scanning machine will be useful in different areas.

4. Conclusion

THz-based technology is a promising and innovative new tool for medical application. Present report has been investigated the tablet images by using the

THz system. The THz camera captured the image, which is perfect, and the resolution is about 1 mm. These are the first results in terahertz imaging that shows THz technology is a significant demand for medical industries, especially in Asian counties. 2D THz images were obtained by measuring the reflect THz peak amplitude across the sample. The intensity curve and histogram value of the tablet images are calculated by using python. One can use the THz technology in medical research but also implemented in security purposes, food inspection, and nanotechnology.

Acknowledgements

The authors wish to acknowledge the financial support by a special project for guiding local science and technology development (2018ZYYD006) and the Hubei Polytechnic University Laboratory fund (19XJK24R). Special thanks to Ratnesh Shukla SIET, for help to improve the report.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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