Terahertz detection of substances for security related purposes

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ABSTRACT

Terahertz (THz) radiation has many far reaching applications—of specific interest is that many non-metallic and non-polar substances are transparent in the THz frequency range. This provides many practical uses for security purposes, where it is possible to detect and determine various substances that may be hidden or undetectable via conventional methods such as X-rays. In addition to this property, terahertz radiation can either be used in reflection or transmission modes.

This paper will look into the use of transmission techniques to detect various substances using a terahertz system. Common materials used in bags and suitcases such as nylon, polycarbonate (PC), and polyethylene (PE) are tested for transparency. These materials then sandwich various illicit substances, and are scanned by the terahertz system to obtain spectral data, simulating the probing of a suitcase. The sample materials are then subtracted from the obtained data, which is then compared with previously obtained data of known substances, and an examination of features in the sample is carried out to determine if a particular substance is present in the sample.

Keywords: THz, terahertz, detection, security

1. INTRODUCTION

With the current global security standards being constantly upgraded, a method in which to rapidly and non-invasively scan bag and package contents is an ever growing concern. As current imaging techniques have difficulty in scanning and identifying non-metal and biological substances that could be hidden within a bag or a packages, the need for detection of these potential hazards becomes increasingly important. Terahertz-Time Domain Spectroscopy (THz-TDS) can provide an efficient method of detecting the substances under test. Biological substances, explosives and narcotics have already been proven to show a distinctive spectral signature under THz-TDS,[1–4] however work is still required to ensure these signatures can be detected within a concealed bag or package, which is explored in this paper.

2. AIM

The work that this paper aims to express is a proof-of-concept in the use of THz-TDS in secure areas, such as airports, postal agencies and shipping ports to accurately and efficiently identify substances that are hidden inside bags and packages brought into these areas. This is achieved by a number of steps. Firstly, THz spectra of materials found in bags, (for example, plastics and cotton) must be recorded. Then, after the bag or package is scanned, an algorithm along with the previously recorded reference data interrogates the spectral content of the bag or package to determine the contents. For illicit substances the algorithm then flags the bag or package, displays the type of illicit substance detected, and notifies the operator immediately to take action.

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Smart Structures, Devices, and Systems III, edited by Said F. Al-Sarawi, Proc. of SPIE
Vol. 6414, 64141U, (2007) · 0277-786X/07/$15 · doi: 10.1117/12.695716

3. METHODOLOGY

Initially, spectral data from common packing materials are examined for transparency under THz, following which the THz spectrum of the materials are then collected. Plastics that are used in common backpacks or suitcases are investigated, tested for transparency and their respective THz spectrum is recorded. Cotton is also tested for transparency to simulate clothing and its THz spectrum is also recorded. The THz spectrum of a given substance can then be recorded for use in an algorithm for detection.

From a cross-sectional angle, bags and suitcases can be viewed as two plastic sheets forming the outer layers, while the contents (for this work, simple clothing) can be simulated by a cotton sheet. This then forms the basis for the simulation of a suitcase and contents (Figure 1). A substance can then be laced onto the cotton, and its signature can be recovered if the data from a clean simulation sample is subtracted from the laced sample data.

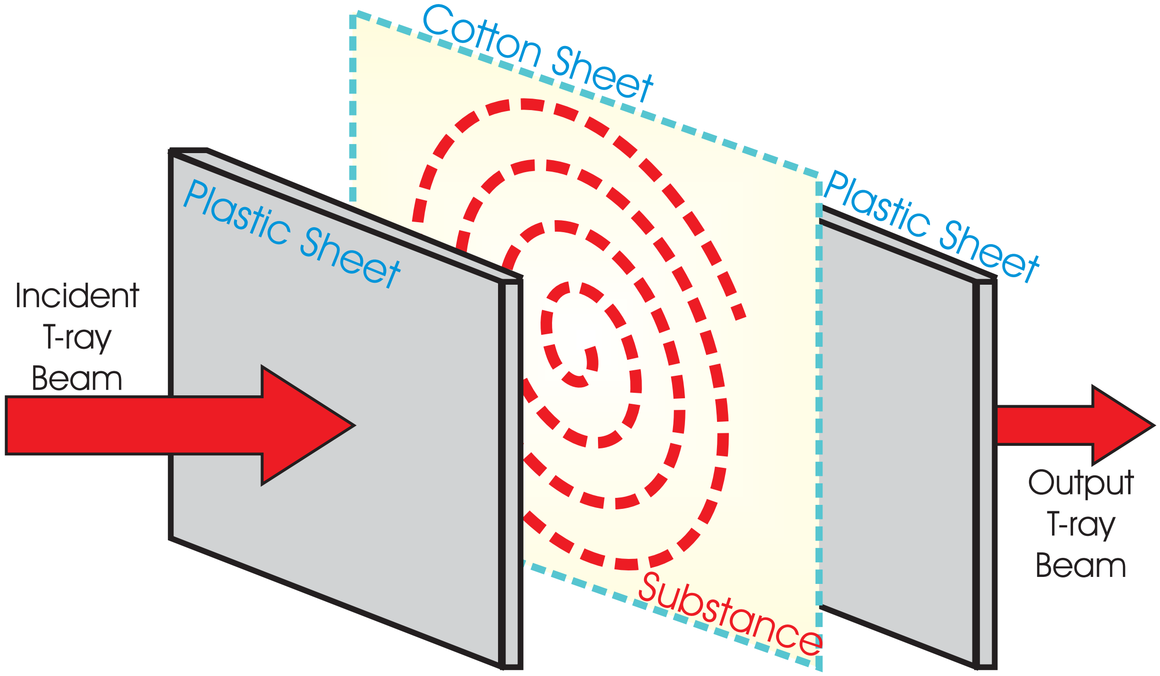


Figure 1. The faux suitcase showing two plastic outer layers, with cotton sandwiched between, and laced with a substance. Note that the spiral indicates the laced substance.

A specialised stand is designed and implemented to carefully hold the sample in place and ensure the air gap between the various materials is kept to a minimum. This involves clamping the materials together as tightly as possible (Figure 2). The thickness of the samples is variable, while the width and length of each sample remains as a 50 mm square.

A Picometrix T-ray 2000 system is used for data collection, while MATLAB$^{\mathrm{TM}}$ is used to analyse the data obtained.

4. EXPERIMENTAL SETUP

The Picometrix T-ray 2000 pulsed system used is pumped by a MaiTai titanium sapphire laser with a center wavelength of 800 nm, a repetition rate of 80 MHz, a pulse rate of 120 fs and average laser intensity of 1.26 mW. Both the emitter and detector utilize photoconductive antennas. The sample, along with the transmit and receive heads, is placed within a semi-airtight box. The box is then purged with pure nitrogen to remove water vapor—this is carried out at a slow rate to minimise vibrations in the setup. The purging minimises water lines from appearing in the measured spectrum. The ambient room is 295 K (22°C).

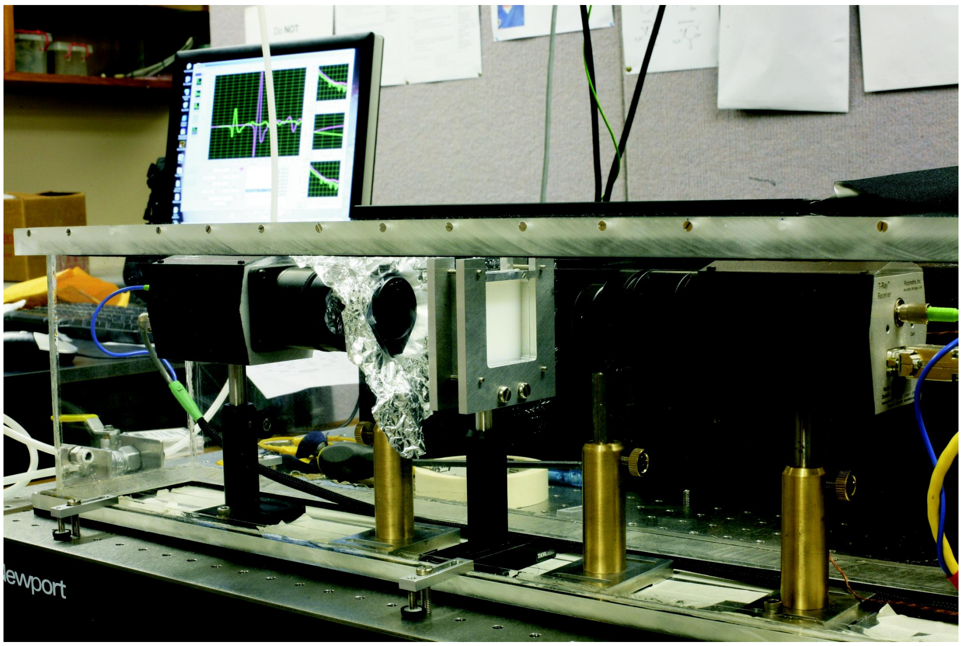


Figure 2. The T-ray setup, showing the sample holder in the center, and the Picometrix T-Ray 2000 system.

To ensure the plastics and cotton fit onto the metal sample holder and be pressed together to minimise air gaps, the sheets are cut into 50 mm square pieces with 2 holes drilled into each corner. Two plastic sheets were needed for each sample. The lacing of the cotton is carried out with 2 mg of α-lactose monohydrate (Sigma-Aldrich Co.), which is mixed into a solution with 10 ml of water and poured over the cotton sheet to create an even layer of lactose across the cotton. The cotton is then left to dry and then placed inbetween the plastic sheets.

5. RESULTS

Various plastic samples are used, which include: HIPS (high impact polystyrene), lexan (a form of polycarbonate), nylon, PETG (glycol-modified polyethylene teraphthalene), polycarbonate and polyethylene. These are of varying thicknesses ranging from 2 mm to 5 mm in width. The cotton sheet used is 0.44 mm in thickness, while the substance used for lacing the sample and for substance detection is lactose (as described in Section 4).

All the plastics prove to be transparent to T-rays, and only attenuate the signal with no distinct spectral signatures within the THz range from of 0.1 to 1.5 THz. Nylon proves to be the least absorbing, while PETG shows the strongest absorption of the plastics tested (Table 1). Cotton is also readily transparent, and also does not display any noticeable spectral signatures over the useable bandwidth (Figure 3). This is in stark

Table 1. Measured absorption coefficients at 0.8 THz for test materials.

Material	Thickness	Absorption Coefficient @ 0.8 THz (per cm)
Nylon	3.205	0.400
Polyethylene	4.562	0.515
HIPS	2.910	1.500
Cotton	0.442	3.755
Lexan	1.539	6.400
Polycarbonate	2.057	6.955
PETG	1.955	12.200

contrast to the lactose used as a trace substance. Lactose presents strong absorption peaks at approximately 0.52 THz and 1.18 THz, providing a distinct THz signature.

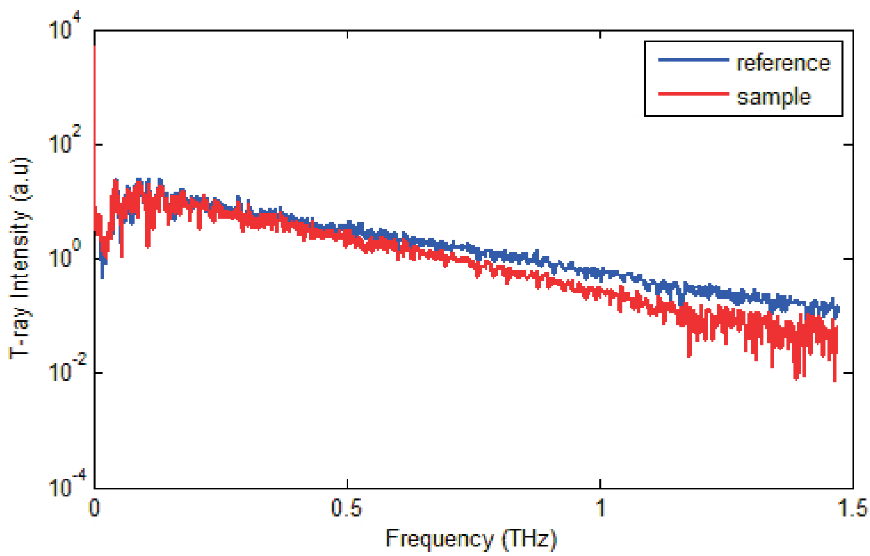
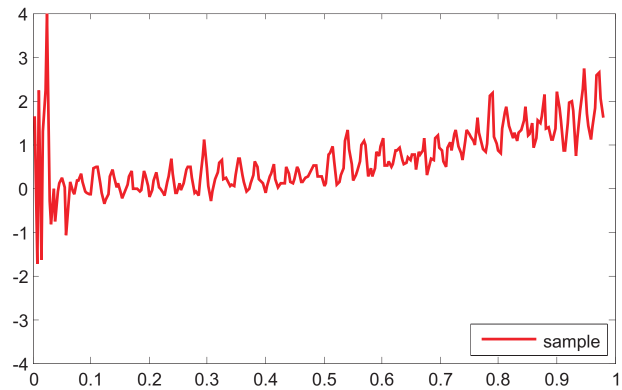


Figure 3. Spectrum of a clean sample, containing two sheets of nylon and one sheet of cotton. There are no absorption peaks present, while the signal is merely attenuated slightly from the reference signal (no sample).

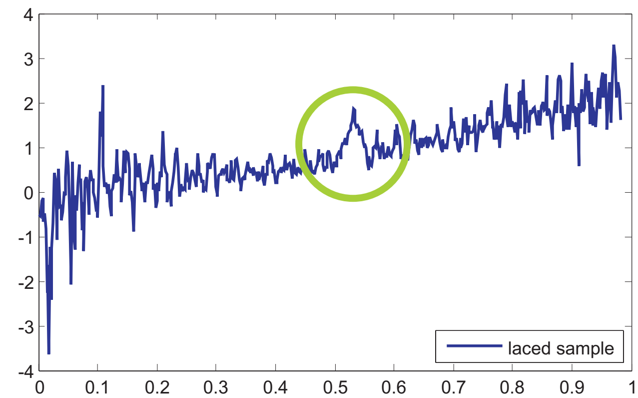
After lacing one of the samples with 2 mg of lactose, this sample is then scanned, and the data recorded. This is then compared with a clean sample, to determine if lactose is present, due to noticeable absorption peaks at approximately 0.55 THz and 1.2 THz. These peaks correlated with those measured from pure lactose, and do not appear for the clean sample. Simple identification that a substance is indeed present within the sample is evident. This can be seen in Figure 4, where the absorption peaks can be clearly discerned from each other.

6. OUTLOOK

From these experiments, a proof-of-concept of the use of THz-TDS in secure areas, for the screening and detection of illicit substances in bags and packages, is achievable provided that a library containing spectral signatures of many substances is available and a suitable and accurate algorithm to determine the substances is present. For future work, higher bandwidth T-ray signals would also aid is the detection and identification of illicit substances, as this would provide a larger set of unique features due to the wider frequency range. Deeper penetration of bags and packages would also be required, thus greater signal power is needed. If this can be achieved, the possibility of bringing such a machine into reality and use in secure areas is entirely possible.



(a)



(b)

Figure 4. Absorption curves of clean and laced samples of the faux suitcase. Clean sample on the left (a), with no absorption peak. Laced sample on the right (b), showing a clear absorption peak at approximately 0.55 THz (circled). A discernable difference is readily apparent and easily identified. For clarity, only 0 to 1 THz is shown.

7. FUTURE WORK

More work remains to be carried out to bring an accurate classification algorithm[5] into fruition. There are also a myriad of implementation problems, such as the thickness of suitcases requiring deeper penetrating signals, and also the collection of data to form a complete library for classification.

Hybrid scanning machines implementing both X-rays and T-rays could also be a subject of further work. Such a machine would provide for imaging and scanning of not only metals, but of other substances not readily scannable using X-rays alone (e.g. ceramic knives).

ACKNOWLEDGMENTS

The authors would like to acknowledge both Acrilix Plastics Pty. Ltd and Mulford Plastics Pty. Ltd. of South Australia for generously supplying the plastics used in these experiments. Further acknowledgements must be made to the Australian Research Council (ARC), the Sir Ross and Sir Keith Smith Funds for providing funding for this research.

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