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To cite this version:

Patrick Mounaix. Advanced Data Processing For Tomography and 3D Rendering With Terahertz Waves. 2022 47th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), Aug 2022, Delft, Netherlands. pp.1-2, 10.1109/IRMMW-THz50927.2022.9895653 . hal-03845666

HAL Id: hal-03845666

https://hal.science/hal-03845666

Submitted on 18 Nov 2022

Advanced Data Processing For Tomography and 3D Rendering With Terahertz Waves

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Abstract— **Terahertz technology (between 0.1 and 4 THz) is now a well-established tool to achieve contact- free and non-destructive testing (NDT). Among the technologies, THz CT and phase retrieval are emerging techniques which have been investigated during the last decade. Thus, in this presentation, we focus on the analyze capabilities from 3D reconstructed volumes of a complex object obtained by a real time-THz imaging system. We demonstrate that images obtained are compatible with an automated processing composed of: i) an ad-hoc segmentation, extracting the sample from the background and reconstruction noise ii) a component labelling, iii) a skeletonization, providing additional meta-data about the sample morphology. We also present how we can assess to phase information of the object by phase retrieval from intensity measured in a volumetric grid.**

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I. INTRODUCTION

Terahertz Computed Tomography (THz CT) is an emerging technique providing 3D visualization of an object from its set of radiographs acquired at different viewing angles. The low absorption and large penetration depth of transmitted THz wave led to a sufficient contrast allowing the reconstruction of volumes, imaging the internal structure of transparent objects [1]. These materials (such as plastics, wood or paper) are troublesome to inspect with other tomographic techniques such as X-Rays. But to access to the object properties, deep data processing of images is necessary to get rid of some artefact induced by physical effect but also numerical calculation [2]. Nevertheless, THz-CT remains extremely time-consuming to obtain a relevant graphical depiction requiring several hours of measurements for a 3D tomographic reconstruction. This tedious process is far from matching with the required frame-rate targeted for quality control or non-destructive testing applications. To face this limitation, research groups and cutting-edge technology centers have developed a variety of compact and uncooled terahertz matrix sensors based on several technological advances, from micro-bolometer integration to semi-conductors hetero-structures. In this presentation, we will describe two experimental achievements : THz tomography and advanced data processing implementation for 3D rendering and terahertz phase retrieval from a set of axially separated diffractive intensity distributions which is a promising single-beam computational imaging technique that ensures the obtention of high spatial resolutions and phase wave fronts. These two results were obtained using real time THz apparatus.

II. EXPERIMENT

We used a bolometric camera for full-field imaging to assess a diffraction field or radiographies. In a straightforward transmission configuration, such a recording setup of the subsequent intensity profiles, should simply be completed by the illumination source, and eventual beam-shaping elements. In this work, we employed a Lytid's teracascade 1000 QCL source. In order to overcome the limiting artifacts induced by the high coherence of such THz QCL sources, and ensure the versatility of the imaging system, the homogeneous illumination in the object plane is performed via a combination of fast beam steering centering purposes, as well [3]. For tomography experiment, the sample is positioned onto a rotation stage and acquisitions were performed in real time.

III. DATA PROCESSING

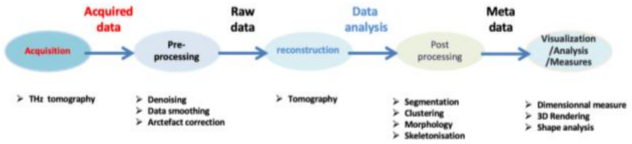

Fig. 1 Data and image processing sequences implemented

We performed reflection and transmission imaging of two samples: three dried leaves and a PE plate. We automated various visualization techniques based on time-domain data and frequency domain as illustrated in Fig1. Moreover, we improved skeletonization module for complex 3D structure. The projection set is processed by a tomographic algorithm to reconstruct a 3D volume of the scanned object. In the tomogram, the 3D structure of the sample is revealed thanks to proportionality between the intensity of each reconstructed voxel with the overall attenuation encountered by the THz radiation at the corresponding position in the sample. In the THz range, this attenuation is mainly proportional to the extinction coefficient (neglecting optical effects). We used a regularized 3D implementation of the THz Ordered Subsets Convex (THz-OSC) algorithm. For diffractive imaging process, a multiple-plane phase retrieval is an efficient approach. It relies on the measurements of a set of axially separated transverse intensity distributions. Similar to the competing holographic techniques, it also makes use of processing algorithms adapted from methodologies developed in the visible frequency range. The most popular algorithms are single-beam multiple intensity reconstruction (SBMIR) and the transport of intensity equation. This multiple plane approach is characterized by the extreme simplicity of the object illumination setup and guarantees better convergence compared to single-plane phase retrieval algorithms, but the recording of the diffraction patterns often remains time-consuming. We will present two new algorithms that were investigated namely the algorithm of unordered propagation and the algorithm of data self-extrapolation, abbreviated as SBMIR-U and SBMIR-S correspondingly[4].

The distinctive feature of SBMIR-U is the use of intensity distributions in a stochastic order. It was previously shown in a visible range phase retrieval that this algorithm may accelerate the convergence and allows to reduce the required number of intensity patterns to use as an input data. The second algorithm, SBMIR-S, implements the extrapolation of the wavefield outside the spatially limited registration area, which allows to improve the resolution in the object plane.

IV. RESULT

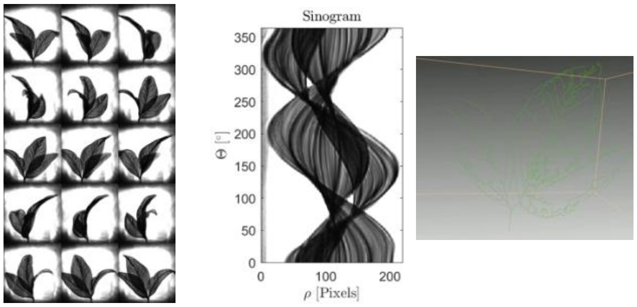

Fig. 2 Selection of 2D projections, recorded in real-time, (b) recorded sinogram relative to the central recording plane, (c)Skeleton of the leave reconstructed by terahertz tomography

Indeed, an image, that would take several hours to be recorded using a raster scan approach, is instantaneously available through full-field imaging. More specifically, considering the 25 FPS frame rate and 240x320 array size, a recording rate of 1.9210^{6}pixel .s-1 is achieved. Through this real-time recording improvement, a full sinogram recording is easily obtained under 1 minute. An example of this fast-recording process where a triple leaf has been investigated at 2.5 THz. A single-frame illumination, scaled to the leaf size was used as to take advantage of the full frame rate of the TZCAM sensor while allowing for a proper power density. A rotation speed of 25°.s-1 allowed for a total 360° sinogram recording in under 15 second with a projection every degree. The OSC [5], specifically designed for a convergence over few projections, necessary in the case of focused point tomography, is applied. Thanks to the skeletonization and the set of orthonormal planes extracted along the graph, we can compute several dimension statistics and report on fig 3c the 3D structure of the sample .

For diffractive imaging , one can aim to simply illuminate the sample with a collimated beam of suitable diameter, then retrieving the transmitted diffracted field in a selection of planes along . An optimal proximity of the first recording plane with respect to the sample can then be expected as to ensure the collection of diffracted high spatial frequency components. Large numerical aperture focusing is then possible. First, from such intensity data sets, the unsorted SBMIR algorithm has been considered for the retrieval of the phase information and the focused reconstruction on the object plane..

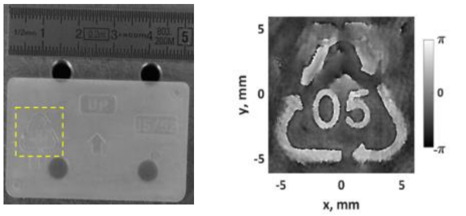

Fig 3 : Sample used in the experiment and reconstructed image

This technique allows to minimize required measurement time and simplify the process of data acquisition. Single-scan detection ensures the collection of an exhaustive dataset that provides substantial flexibility in the post-processing extraction steps of the wavefront. SBMIR-S is especially relevant in case of spatially limited diffraction patterns utilization. Self-extrapolation allows to recreate the data beyond the registration area, in places where the scattered field was located but not measured, which, in turn, leads to resolution enhancement of the focused in the object plane distribution.

For SBMIR-S investigation, intensity patterns were employed, cropped to area 4 times smaller than the original size. The corresponding Fresnel numbers have been also reduced by the same factor [4]. In this case unmodified SBMIR have not ensured the convergence. By the SBMIR-S algorithm the cropped distributions were extrapolated to the initial size, thereby providing the same resolution as conventional SBMIR did with the use of uncropped intensity patterns. SBMIR-S algorithm is relevant for measurements in the raster scanning mode. With its implementation it is possible to reduce the registration area, and, respectively, the measurement time.

V. CONCLUSION

Real time THz CT has been demonstrated . An advance 3D data processing renders the 3D reconstructed sample with an automated component labelling, a skeletonization step which provides additional meta-data about the sample morphology. Concerning lens less imaging, optimized SBMIR algorithms of unordered propagation and self-extrapolation have been investigated in THz phase retrieval for the first time. SBMIR-U allowed to reduce the number of used intensity patterns and to obtain the same resolution. It provided faster convergence in retrieval from data of near-field Fresnel diffraction zone. SBMIR-S allowed to improve the resolution in retrieval from intensity distributions characterized by low Fresnel numbers. It is especially relevant to use in a raster scanning mode.

VI. REFERENCE

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