A fast and homogeneous illumination applied to full-field terahertz imaging

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***Abstract*—In order to overcome the coherence-induced artifacts, the illumination heterogeneity as well as a limited dynamic range when using full-field technique, a solution employing a galvanometric beam-steering is proposed, demonstrating the possibility for real-time imaging in terahertz domain. Working toward industrial applications, different imaging illumination process, including Lissajous pattern for fast beam steering, are evaluated thanks to the versatility of the lighting method.**

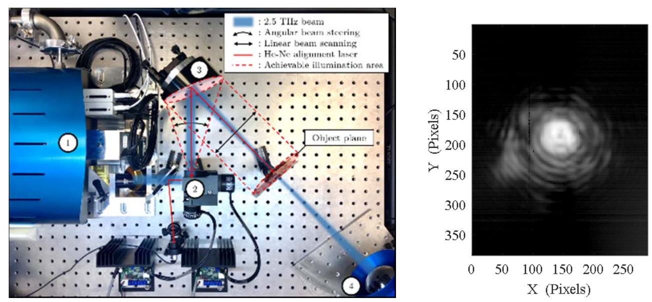
I. Introduction

For now more than two decades, active terahertz imaging has been investigated and demonstrated capabilities to reveal hidden parts or defects through optically opaque materials [1] and has been applied for non-destructive testing (NDT) [2], art history [3] and medical purposes. Further processing, enables 3D terahertz reconstruction either via computed tomography [4] or, more recently, using shape from focus measurement [5]. However, most of such terahertz images are performed using a slow punctual raster-scanning scheme in a fully controlled environment, and without acquisition time constraint. While this method is applicable to art history inspection for example, it is not conceivable for an industrial application or NDT. In an effort toward real time imaging capabilities, research groups and technological centers developed compact sensor matrix [6], such as uncooled microbolometer arrays THz cameras tailored to the 0.6 – 4 THz range, sold by INO or I2S. Yet, despite their high sensitivity and low minimum detectable power (below 100 pW), the reduced power density remains an issue when using the major portion of the array, in order to keep suitable SNR level. Moreover, for such far-field imaging systems, implementing optimized THz lens, the use of highly coherent light sources induces strong interferences artefacts in the imaging plane, emerging from the coherent contribution of multiple optical path through the lens, resulting in non-exploitable images [7]. A way to overcome this drawback consists in quickly changing the optical path, either using a scrambler to reach a quickly varying instantaneous random power distribution, or thanks to galvanometric mirrors [8]. While the first solution results in a fixed non optimizable beam shape, the second one gives a full control on the object area to illuminate, ensuring optimum versatility of the system. We propose to investigate this solution by implementing a double mirror galvanometer together with a commercially available source and detector array with aspherical terahertz lens.

II. Results

This section includes the experimental setup description, different simulations of the illumination pattern using galvanometric beam steering, and finally, the experimental illumination as well as transmission mode images of an optically opaque object using two different configurations.

The experimental imaging setup (see Fig. 1a) is based on a 2.5 THz quantum cascade laser as lighting source, and a camera, IRXCAM (288 x 384 microbolometer pixels with 35µm pitch), associated with f/0.8 lens as detector. The angular beam steering is ensured by a double mirror galvanometer controlled by two voltage functions corresponding to the two rotation axis x and y. This angular beam steering is converted to a rectangular scanning through a 45° off-axis parabolic mirror ensuring to cover the entire object plane area. In order to localize the beam center position and visualize the illumination pattern in the camera object plane, the setup features an alignment red laser following the terahertz beam thanks to a 2µm thick membrane.



(a) (b)

Fig. 1 (a) Experimental imaging setup implementing (1) a 2.5 THz Lytid mW commercial TeraCascade 1000 QCL source, (2) a double mirror galvanometer, (3) a 45° off-axis parabolic mirror and (4) a 288*384 pixels' camera (INO) coupled to Lytid terahertz lens **(b)** Still mode image beam revealing the interference fringe in a non-homogeneous illumination pattern.

The terahertz beam image recorded without any galvanometric fast scanning (see Fig. 1b) highlights strong circular interference pattern induced by the optical path differences from the source to the camera image plane that hampers any imaging possibilities. Considering the long time response of the camera microbolometer sensors (~10 ms), a quick variation of the detected intensity on every pixel would result in a more homogeneous illumination.

Based on optimized surface scanning, several imaging systems are using 2D Lissajous curve for application in microscopy [9] or for lidars [10], allowing to adjust a trade-off between pixel density, SNR and frame rate. Lissajous curves are defined, in 2D, by two sinusoidal functions considering their respective angular amplitude A and B, frequency F_x and F_y, and the relative phase φ. While A and B give the height and width of the illuminated area, allowing an illuminated surface optimisation, the frequencies F_x and F_y, and the relative phase determine the Lissajous pattern. These parameters are set by the limits of the mechanical frequency of the galvanometer (130 Hz) and by the ratio F_y/F_x which is required to be rational in order to obtain a repeatable pattern. Figure 2a displays the simulation of the Lissajous illumination pattern, calculated from the sum of 5000

2D Gaussian fit of the still mode image in fig 1b displaced along the red plot with $F_y = 125\ Hz$, $F_x = 6.25\ Hz$, $A = B = 4°$, and for the two extremal relative phase shifts $\varphi = 0\ rad$ and $\varphi = \pi/40\ rad$, mimicking a fast raster scanning. More details concerning the optimization of the terahertz illumination homogenization with Lissajous pattern can be found here [11]. As observed, the simulated illumination can be considered homogeneous in the area delimited by the maximum and minimum reachable beam position center regardless the phase shift φ.

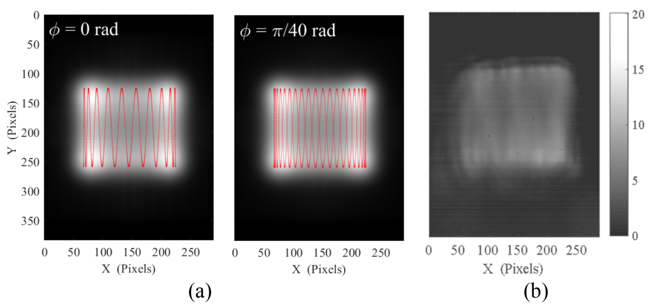


Fig. 2. Lissajous illumination pattern with $A = B = 4°$, $F_y = 125\ Hz$ and $F_x = 6.25\ Hz$. (a) Simulation from the sum of 5000 Gaussian fit of the still mode image for two relative phase shifts **(b)** Experimental lighting at image plane using the μ-bolometer array (INO 384*288 pixels)

The experimental illumination (see fig. 2b) reveals reminiscences of the interference pattern, especially at the boundaries of the square where the variation of the optical intensity on the sensors is the slowest. Nevertheless, this procedure results in a more homogeneous lighting and can be used for imaging in reflection or transmission mode. Moreover, thanks to the versatility of the system, different imaging configurations are possible. First, we can limit the area of the sample (see fig 3a) to be illuminated in order to optimize the imaging dynamic range of the system. Then, considering different offset angles on the galvanometer, a multi-exposure imaging can be performed (see fig 3b). Finally, by recording the illumination background, the reconstruction of the object absorbance image (see fig 3c) is retrieved and no reminiscence of the inhomogeneity is noticeable.

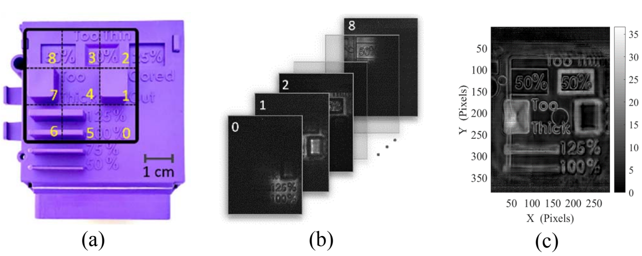


Fig. 3. (a) Picture of the high density polyethylene object with visualization of the sub-illuminated areas (b) stack of the unprocessed recorded transmission sub-images at 2.5 THz (c) reconstructed multi-exposure image in absorbance.

Another possible imaging configuration, especially suitable for in-line scanning consists of a linear illumination (see fig 4a) with $F_y = 125\ Hz$, $F_x = 0\ Hz$, $A = 0°$ and $B = 8°$. The sample is moved with a controlled speed along the horizontal axis (see fig 4b) and provide a stack of images where different parts of the object are illuminated. Considering the object displacement speed and camera frame rate, an absorbance image of the entire object is performed.

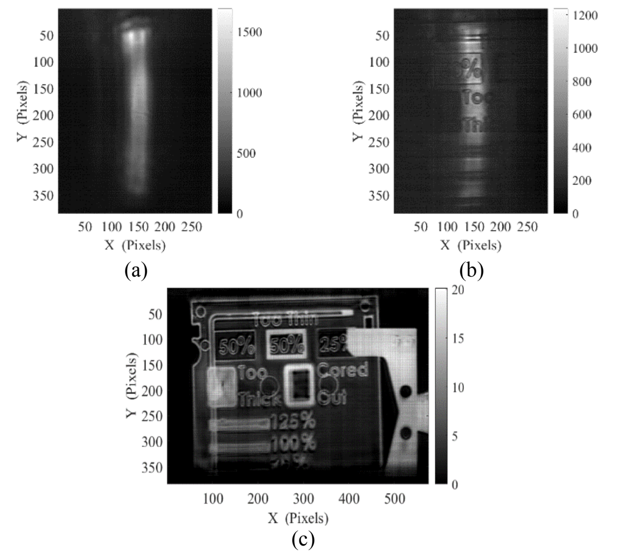


Fig. 4. (a) Background linear illumination pattern (b) single frame image corresponding to a narrow part of the sample reconstructed (c) absorbance image of the scanned object.

Taking advantage of the lighting pattern versatility and adaptability, a large variety of object geometries can be considered with optimized lighting parameters. Further specific imaging capabilities have been explored and optimized ensuring image quality and suitable FPS rate for fast industrial application implementations.

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