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Single pixel sensing for THz laser beam profiler based on Hadamard Transform

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ABSTRACT

We present our experimental set-up and results for a THz beam profiling system based on a mechanical spatial light modulator (SLM) for one pixel sensing. By placing a synthetic aperture into the path of a propagating THz beam we achieved the optical ON/OFF keying of its various intensity components. Further, by successively expose a series of predesigned binary masks we manage to encode within their features the beam spatial distribution. The masks used are of a predefined size and can be designed for different resolutions. Our approach eliminates the need of using an array of pixels for detection while still maintaining the high sensitivity and dynamic range of one detector.

1. Introduction

Ranging from 30 μm to 3000 μm, THz radiation manifests unique properties among which we can mention: the penetration of opaque materials, chemical selectivity; properties exploited in numerous image and spectroscopy applications from various fields of research [1–8]. In addition the non-ionizing nature of this radiation and safe interaction with human tissue has opened the path for new biological applications [4].

Although THz domain presents all the markers that makes it suitable to be scientifically harvested, a technical limitation still exist, and the modest progress recorded in the last two decade support this fact. Nonetheless recent advancements push this technological limit towards developing more efficient and cost-effective THz sources and detectors [1–3].

In line with the development of higher emission power THz sources, lies the technology for performance assessment in terms of spectral purity, power, beam shape and quality etc. Nowadays the common method used to provide the information mentioned above require the use of pixel array detectors such as CCD or CMOS both ineffective in THz domain. Designing a sensor array detector, tailored for THz radiation sensing, impose certain challenges related to proper pixel scaling and sensitivity. Although the trend is towards developing sensors with smaller pixels, the minimum size may still be too big, compared to achievable sizes using state of the art nanofabrication approaches.

Alternatively several methods were reported in the past years for THz beam profiling, namely knife edge beam sampling and raster scanning, all with well-known advantages and disadvantages [5–7].

A promising solution to this matter might stand in the use of single pixel camera design [6]. Exploiting this concept we have managed to successfully develop a single pixel device for 2D THz beam reconstruction. To demonstrate its functionality we used a CW THz gas laser (Edinburg FIRL100) tuned at 118.5 μm with a nominal power of 150 mW. The beam waist was determined and the intensity map was obtained. For the implementation of the algorithm a sequence of mechanical masks was used with both reflecting and absorbing features, designed specifically to behave like a group of small ON/OFF radiation switches. Doing so, the radiation, deflected toward a single sensing detector, could be controlled in such way that only certain combinations of rays are passed forward. The working resolution for the mask sequence is 15×17 pixels with a total number of 255 encoding masks. The complexity of the masks can be easily increased for higher resolutions.

2. Single pixel camera and Hadamard Transform

2.1. Single pixel camera architecture

Single pixel sensing is a fairly new concept developed to offer support or even substitute conventional imaging systems in certain applications where detectors matrix are too complex or do not exist. For THz domain, where detectors are bulky and difficult to assemble into arrays, this approach might be the key for creating a versatile imaging system.

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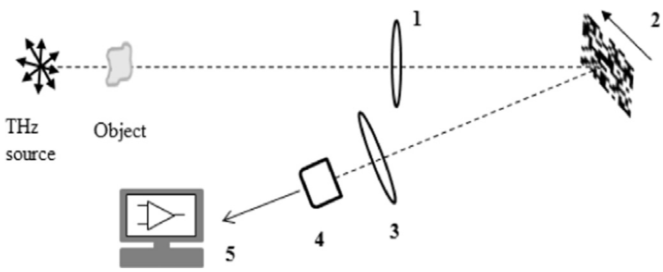

Fig. 1. Basic design of a single pixel camera: imaging lens (1, 3), SLM (2) (mechanical or electro-optic), detector (4), computational algorithm for image retrieval (5).

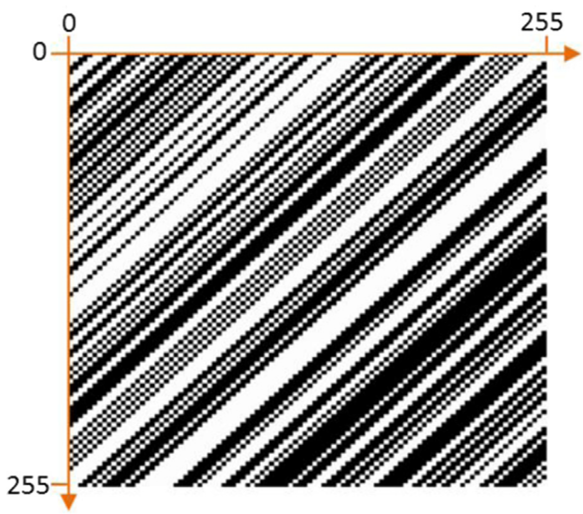

Fig. 2. Example of S_{255} cyclic matrix.

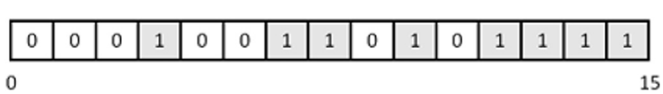

Fig. 3. First row of an S_{15} cyclic matrix.

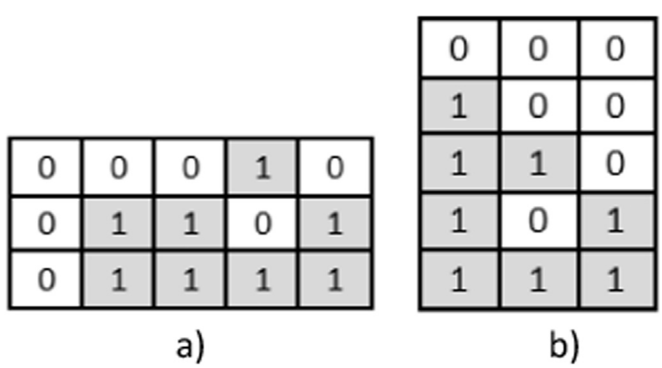

Fig. 4. Two dimensional folding of the first row of a S_{15} cyclic matrix: (a) $N=3\times5$, (b) $N=5\times3$.

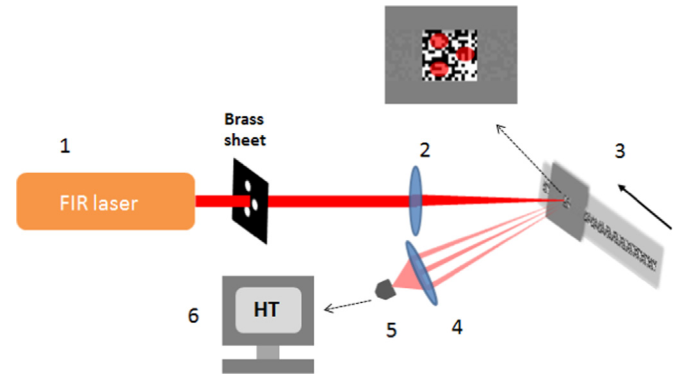

Fig. 6. Single pixel sensing beam profiler set-up: 1-Thz laser, 2- lens, 3- mask, 4-collecting lens, 5- pyroelectric detector, 6- HT processing unit.

In practice there are several designs for single pixel camera, depending on what kind of mask projection we intend to use: mechanical mask projection, electro optical projection (using a LCD or a DMD) [2,3,8]. The electro-optical approach offers great flexibility when it comes to exploring different mask complexities, but the major drawback is the incapacity of these devices to operate at THz domain wavelengths. Mechanical approach on the other hand does not suffer from adaptability and mask features can be sized, in relation to wavelength, for different resolutions.

It can be observed that single pixel camera stands out through the simplicity of the optical design, comprised of a few key components: two imaging lens (1, 3), SLM (2) (mechanical or electro-optic), detector (4) and processing interface (5) for image retrieval (Fig. 1). The object image is formed on the surface of the encoding device by using a lens (1). The encoding process begins as soon as the masks starts pending, in the image plane, either by physically translating a series of mechanical masks or in a static manner by ON/OFF keying the DMD or SLM (2) pixels, in relation with a digitally predesigned binary masks. At this stage the radiation is passed forward, from the masks reflecting features, through a second lens (3), onto the surface of a single pixel photo detector. The string of values, collected by measuring the intensity for each N masks, represents the image encoded within the masks features. For the final stage of the process, a computational algorithm (5) is needed to extract the image from the encoded data.

2.2. Hadamard Transform

Since its early stages, single pixel camera served as a tool for the development and implementation of many types of multiplexing methodologies from which we can mention: Hadamard Transform – HT, Compressive Sensing – CS, Walsh or Noiselet transform etc. [9–12]. Depending on the application, either one of the methodologies mentioned above manifest some advantages over the others, and can be successfully used for image encoding/decoding. The reasons we chose to use HT is for its fast mathematics and reconstruction quality, compared to other multiplexing methods that might suffer from “lossy” compression and time consuming reconstruction process.

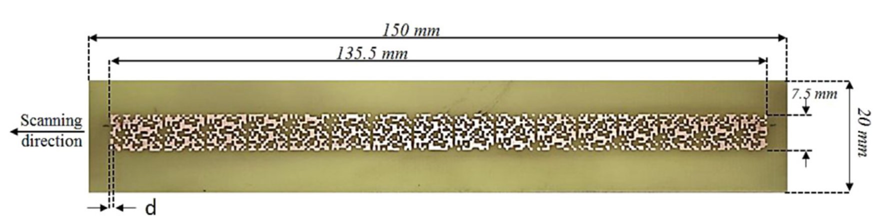

Fig. 5. Physical mask printed on a sheet of PCB.