Blackbody source-based terahertz nondestructive testing with augmented reality

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ABSTRACT

We present original work on non-destructive testing with an imaging solution combining a sensor that can measure the millimeter-wave radiation of a black body at temperatures between 290-400°K and a portable solution based on augmented reality with a smartphone. This handy portable solution makes it possible to do away with mechanical scanning systems which are heavy and slow, and therefore may be suitable for civil engineering detection or imaging applications, or in the field of aeronautics.

Keywords: Terahertz imaging, THz characterization, passive imaging, zero power, blackbody source, Augmented reality, smartphone, non destructive testing

1. INTRODUCTION

Non-destructive testing and imaging [1] at terahertz frequencies has demonstrated applications for the inspection of composite materials for aeronautics [2], the diagnosis of art paintings [3], the detection of fractures and lithological changes [4] in rocks or for the analysis of polymers [5]. Most of these systems use THz sources and detectors, associated with a mechanical scanner, which is not practical for making measurements outside the laboratory. In order to provide a portable solution adapted to environments difficult to access, we had proposed in previous works a solution using augmented reality (AR) and a frequency modulated continuous wave radar [6]. However, this solution requires signal processing calibrated upstream as a function of the application, and is not suitable for certain applications, such as in places that prohibit the emission of millimeter waves. In addition, certain applications such as the detection of hot spots, overheated wires or short circuits behind insulating panels are not possible with thermal cameras. Consequently, the detection of THz signals emitted by a black body, already used for radioastronomy, can also be used for non-destructive testing. We propose to present the system and the technology used, its calibration, then to show different study cases of augmented reality terahertz imaging with blackbody sources.

2. EXPERIMENTAL SETUP

In order to obtain an easy-to-use portable system, we have chosen to combine room-temperature electronics-based sensor able to detect blackbody radiation and a smartphone with an augmented reality interface based on the camera. We can see on Figure 1a photography of the setup including a OnePlus 7T Pro and the sensor.

We use the smartphone for focus guidance, using the camera which provide the distance to the sample and localize in 3D the position of the measured signal. Then the smartphone performs the acquisition and rendering, by superimposing the processed terahertz data and the visible image from the camera. We have then the possibility to do post processing and see later the scene when terahertz signal in augmented reality. This approach was initially developed by *Luxondes* for the near-field analysis of radiation in the GHz range for electric field mapping applications, useful in particular for electromagnetic compatibility studies [7-8].

The marker less tracking is implemented using Google ARCore library, and can be applied to a flat or spherical surface. First, a global overview of the environment allows the detection of distinctive characteristics using the phone's camera.

Then, a cartesian space is created and the phone can detect its position with a millimeter scale resolution, using both camera and data fusion from several phone sensors like the accelerometer and the gyroscope.

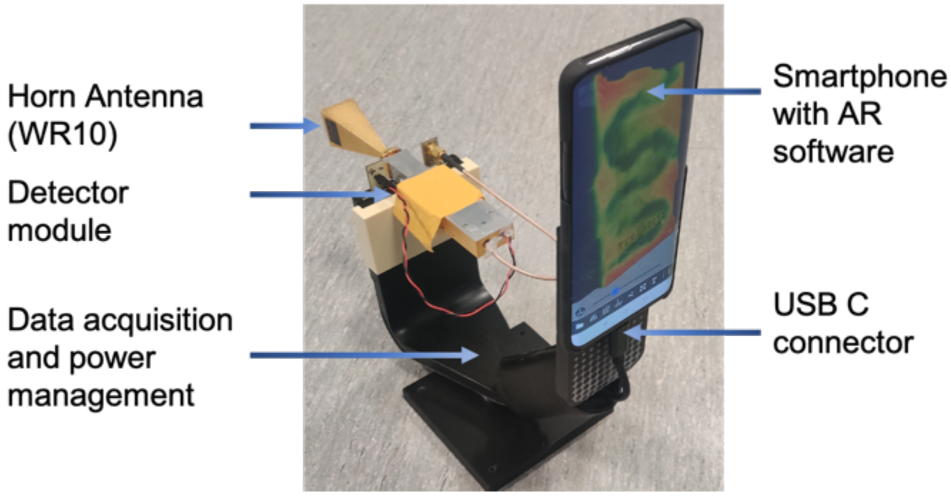


Figure 1 : Photography of the system, including smartphone, detector, hors antenna and data acquisition electronics.

Then, the radiometric W-band passive detector, made by *MC2 technologies*, associated with a WR10 hors antenna is based on a zero-bias detector and low noise amplifiers. This type of detector is for example used for passive imaging systems for people screening and security at video rate [9]. This signal is then provided to a data acquisition and power management electronics systems located inside the mechanical structure between the smartphone and the detector.

3. SAMPLE UNDER INVESTIGATION

The object investigated in this study is a heating wire, simulating a short circuit problem or too high a current in an electrical circuit. This type of situation is critical in the fields of building or aeronautics, especially since insulators are often placed in front of the electrical wires, which prevents direct detection using a thermal camera. A heating wire with a diameter of 4 mm at 60° C. is placed on a 120cm by 60cm wooden panel as illustrated by a sectional diagram in Figure 2 and in a photograph in Figure 3 (b). We can observe on Figure 3 (a) that it is possible to detect the heat of the wire with a thermal camera FLIR T165 when there is no insulating panel on the experiment.

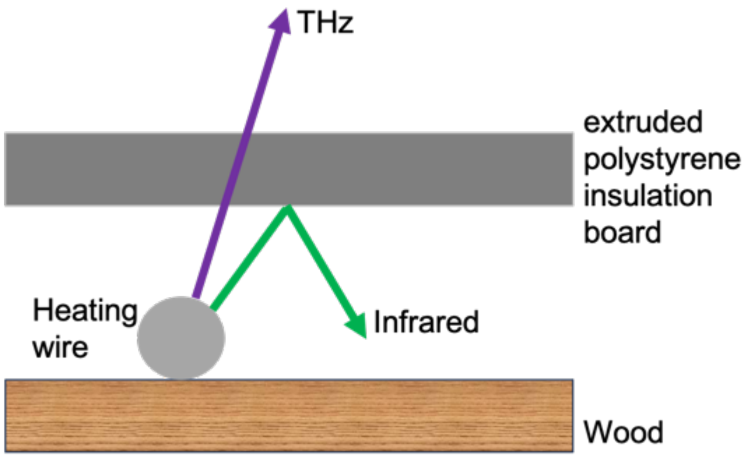
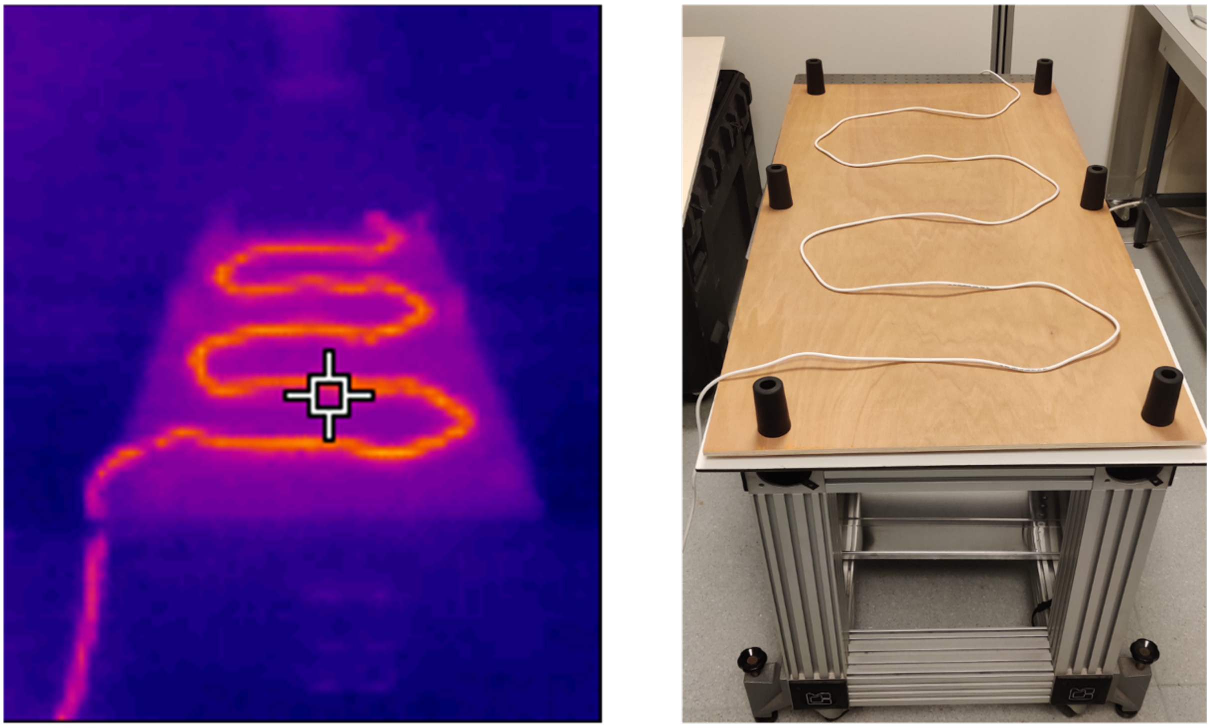


Figure 2 : Schematic sectional view of the experiment showing the interest of THz waves which can pass through a dielectric insulator while the IR radiation is filtered.



(a) (b)

Figure 3 : Setup without the extruded polystyrene board
(a) Far Infrared image showing the heating wire
(b) Photography of the setup the insulation panel

In order to represent typical hot wire cases of the sectors of the building or aeronautics, we add to this configuration a 8 cm insulating panel above the heated wire Figure 4. This panel consists of extruded polystyrene with a thickness of 2 cm covering the whole setup, as illustrated in the photography in Figure 4(b). We can observe in Figure 4(a) that the thermal camera is no longer able to detect the heating wire through the insulation. In order to ensure that phenomena of heat transmission with convection could not print an image on the insulation, this measurement with the thermal camera was made 20 minutes after the installation and it was still not possible to see the heating thread even after a wait. In addition, we identified during the first tests that the homogeneity of the insulation sometimes made it difficult to locate 3D of augmented reality. Indeed, the ARcore Library needs to identify patterns that help location, so we added felt-tip illustrations on the insulation panel to facilitate 3D location of the AR algorithm as illustrated on photography in Figure 4(c).

The measurement itself took five minutes. First, a rapid scan is performed in order to create a 3D spatial reference. Then the system represents a view of the sample from the camera with a superimposed representation of a grid, with gray squares at the beginning. Then, the user must then scan manually the object in order to get the THz radiation amplitude value for each location, revealing immediately the color of the pixel that appears in superimposition.

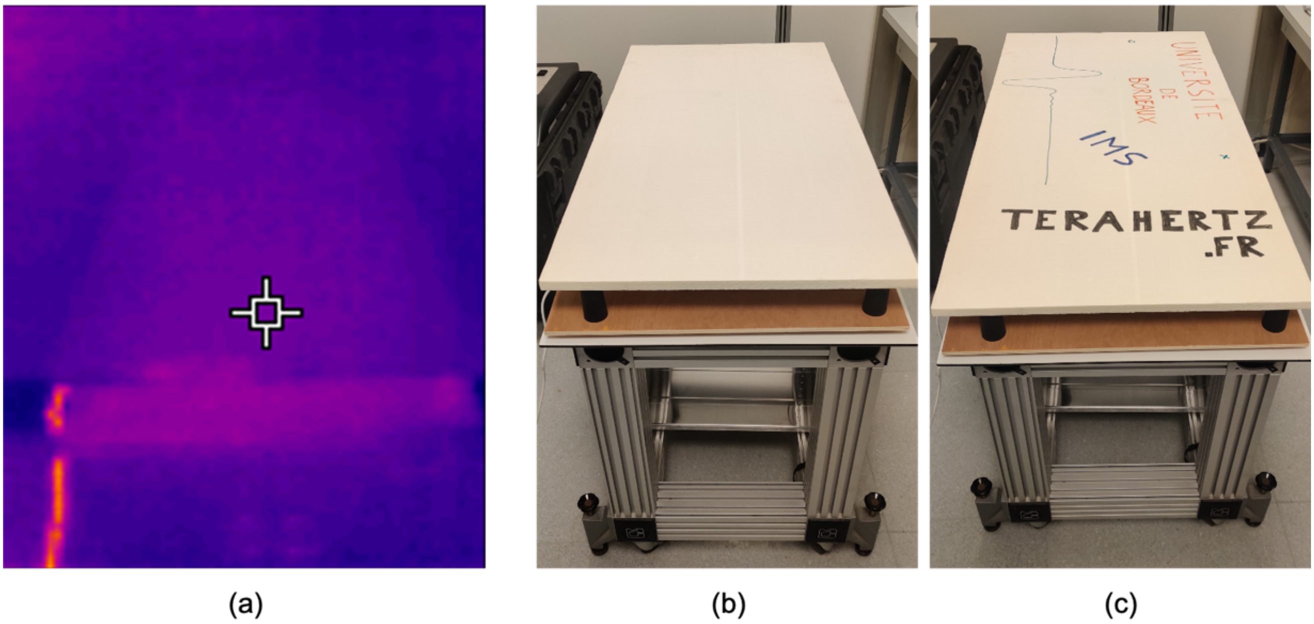


Figure 4 : Setup with the extruded polystyrene board
(a) Far Infrared image. We can observe that the thermal camera is not able to see the hot wire under the insulation panel
(b) Photography of the setup
(c) Photograph of the setup with felt-tip illustrations on the insulation panel to facilitate 3D location of the AR algorithm.

4. RESULTS AND DISCUSSION

The result of this measurement, presented in the Figure 5 makes it possible to reveal very clearly the coil-shaped heating wire. The system is therefore able to detect a heating wire through insulation, in an experiment where the thermal camera was unable to measure a signal. It is important to note that the size of the pixel chosen in this experiment was 2cm, so as to be able to make a manual quick scan of a large object. By using lenses and smaller pixels, it would have been possible to obtain a better resolution, but the acquisition time of several tens of minutes would not have been consistent with the objective of simplicity and portability of the system. Moreover, the use of a portable system implies a position instability of about 1cm, and the resolution is therefore in line with the context of the experiment. This experiment is therefore located halfway between a manual point detection and millimetric imaging with a precise raster scan with motorized stages.

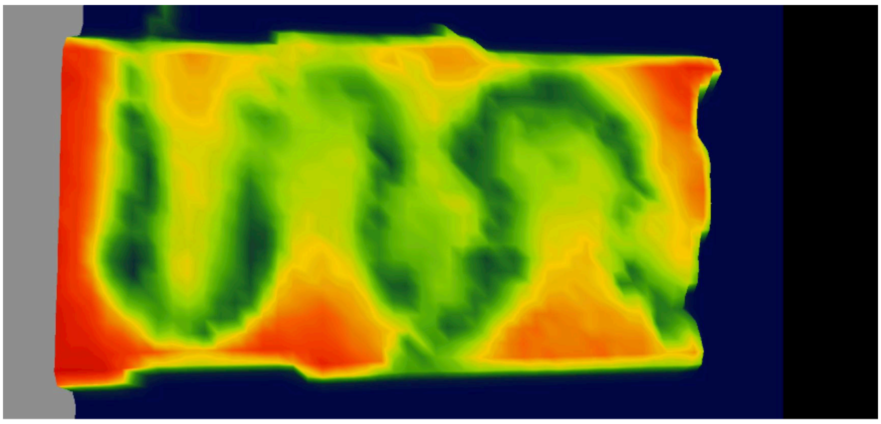


Figure 5 : Passive mmW image (120cm by 60cm) made using the augmented reality system, revealing the hot wire under and insulator.

5. CONCLUSION

In this study, we have integrated a passive room temperature millimeter wave sensor with an augmented reality system. It shows that a portable solution with a smartphone is an efficient tool for both detection and imaging of heat source below an insulator, that are not detectable using NIR or LWIR cameras. This approach makes it possible to detect mm-sized heat sources through an insulation distance of more than 10 cm and also offers the possibility of a manual scan and an augmented reality representation, which brings to the user an ease of use and allows a penetration of terahertz technologies on practical situations.

Moreover, this work has the enormous advantage of not needing a terahertz source, which eliminates all the problems related to the regulation of electromagnetic sources, in particular between 100 GHz and 300 GHz, which are today more and more a subject of concern for manufacturers of millimetric systems for non-destructive testing uses. This opens up applications in the field of civil engineering both for the analysis of the presence and quality of insulators, and in the field of aeronautics to detect any wires that heat up or short circuits through insulating panels or composite materials.

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