Active terahertz imaging with high acquisition rates and its application for moisture sensing

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In this paper we give a short introduction on THz imaging and exemplarily present possible applications in the paper fabrication and in the security sector. Then we describe a method for depth imaging with a frequency-swept continuous-wave (FMCW) electronic THz source.

1 Introduction

In the electromagnetic spectrum, the frequency range between microwaves and the infrared is often called the THz gap, because it has been rarely used in technology, because of a lack suitable sources and detectors. One can approach this gap from both sides, as from high-frequency electronics or long-wavelength optics.

Some properties make THz waves interesting for applications. First, due to the low photon energy, the risk of harm through ionization seems negligible. Many materials like paper, plastics and fabrics are transparent to THz radiation, while water absorbs and metals reflect the radiation. Due to its long wavelengths, the radiation is insensitve to surface roghness. Finally, many organic substances have characteristic spectroscopic signatures in the THz range.

Several possible applications of THz radiation in imaging have been demonstrated, taking advantage of one or more of the properties mentioned in the paragraph above. Sections 2 and 3 give two examples, while Section 4 demonstrates a way for depth imaging.

2 Moisture Sensing with THz radiation

One example for a possible industrial application is the measurement of moisture content in paper during its fabrication. This measurand plays an important role, because of its influence on paper quality and on energy consumption of the fabrication process. The common method is based on transmission measurements at several wavelenghts in the infrared, which differ in their extinction by water. In the regime of low moisture content, this method suffers from strong scattering due to the fibrous structure of paper.

Due to its long wavelength, THz radiation is barely scattered by the paper structure, and since the transmittivity of paper is much higher than that of water in this spectral region, moisture imaging allows for a high contrast. The transmission coefficient as well as the phase delay of the THz wave provide useful information even in the case of low moisture contents. Details on measurements with an electrooptical 0.6-THz system are given in [1].

3 Security Applications

In the security sector, the transmittivity of THz waves through fabrics can be used to detect concealed weapons. Here, the non-ionizing character of THz photons is the main benefit compared to alternative methods like X-ray imaging, especially if people are to be examined. The practical usage requires – like most other applications– high image acquisition speeds.

Figure 1 shows the 2D single-pixel scanner we utilized to take THz images of a concealed weapons at 620 GHz as well as at around 300 GHz. It typically requires 9 s to take a single image.

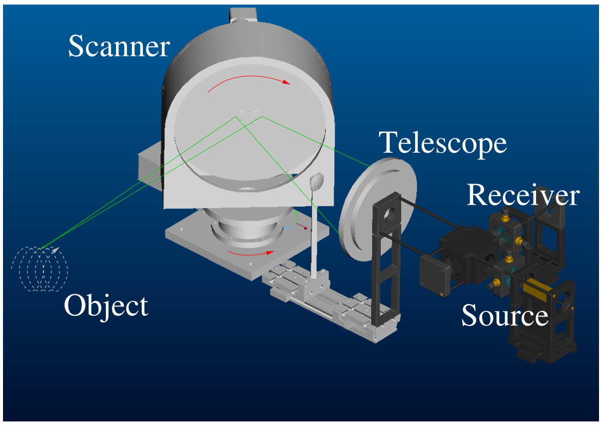

Fig. 1 3D CAD drawing of the single-pixel scanner setup

Figure 2 shows a 620 GHz image pair of scissors, hidden in a cloth bag, the inset shows a photograph of the non-covered object.

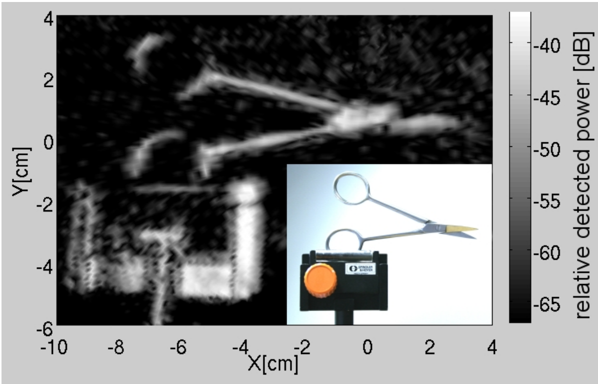

Fig. 2 *620 GHz image of the scissors shown in the inset*

With the next camera system, we are currently working on, the image acquisition time will be reduced further. The camera will operate at 812 GHz and utilize 32 detectors arranged in a line. A full image can then be taken per each revolution of the scanning mirror. We expect to reach at least 600 rpm corresponding to 10 fps.

4 Ranging

We employ two methods of obtaining information on the optical path length and hence the object's topography. First, the phase information on the THz wave provides –similar to an interferometer– high resolution, but suffers from ambiguity, if the path length varies by more than a wavelength.

The second approach was adopted from frequency-modulated continous-wave (FMCW) radar. Figure 3 illustrates the basic principle:

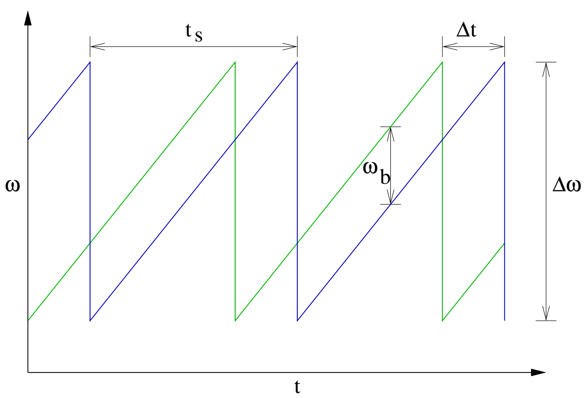

Fig. 3 *Illustration of FMCW ranging by sawtooth sweeping*

The frequency of the source is swept with a sawtooth time dependance. One part of the radation is directly fed into the detector, while the other one takes the longer path to the object and back before it also reaches the detector. Here, the two waves are mixed. Since the signal wave is delayed by Δt with respect to the reference wave, the frequencies differ by ω_b, which is also the modulation frequency of the resulting beat signal. ω_b is directly proportional to the time delay and the path difference. The unambiguous range is given by the sweep rate $1/t_s$ and typically large compared to the wavelength, while the resolution is determined by the frequency swing $\Delta\omega$. If signals from different depth layers are received, they can be seperated by means of fourier analysis. A detailed description on FMCW ranging in the 600 GHz range is given in [2].

Figure 4 shows a FMCW-ranging image of a hand with a fingers resting on a metal block (a photograph is shown in the inset). The data was recorded with the commercial SynViewScan system operating with frequency swings from 230 GHz to 320 GHz. The acquisition time for this raster-scanned image was about 15 minutes, other ranging images taken with the rotational single-pixel scanner introduced in Section 3 had a measurement time of 9 s.

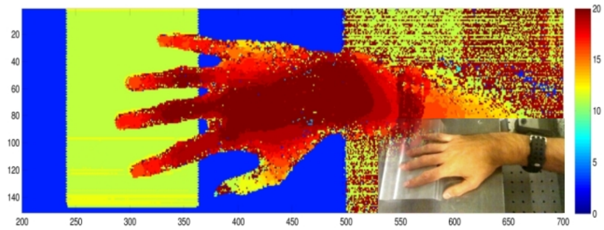

Fig. 4 *300 GHz FMCW-ranging image of a hand*

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