The influence of smoke on THz imaging

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Abstract—The influence of smoke on THz imaging was examined. We tested experimentally a passive THz camera - TS4 from ThruVision Systems Ltd. The camera detects natural human radiation at a frequency of 0.25THz. The distance camera-target could be 3-15 meters. Moreover, Time Domain Spectroscopy was used to investigate the influence of the amount of smoke on transmission in the (0.1÷2.5)THz range.

Electromagnetic radiation from different ranges is widely applied in military and civilian security to prevent and detect threats. Optoelectronic systems are commonly used not only by the army but also by the police or the fire service. Optical detectors of smoke and fire [1] utilize radiation from ultraviolet (UV), visible (VIS) and infrared (IR) ranges. The above mentioned detectors are usually connected into one fast automatic system for fire detection and extinguishing. These systems are commonly used in server rooms. Detectors based on optical scattering and absorption are applied to identify unknown gases and materials. For example, multiwavelength lidars are used to identify air pollution. X-rays, UV radiation and IR cameras are applied to find the cause of ignition during investigations. A specialized search and rescue group successfully applies cameras with speculum (VIS), IR cameras or seismic and acoustic devices (like geophones) to find people in a fire environment and after building disasters.

Currently, scientists and institutions from around the world are working on terahertz (THz) radiation in order to apply it in the security area. The development of terahertz technology is connected with unique properties of terahertz radiation. The terahertz region of electromagnetic spectrum is defined as (0.1÷10)THz or (3000÷30)μm [2] and is located between the domains of infrared and microwaves. These waves are long enough not to be absorbed by nonpolar, nonmetallic materials but still short enough to form an image using optical components [3]. The second advantage of the THz radiation is that it poses a minimal risk for human beings because of the fact that photon energy is very low (1THz radiation coresponds to 4.4meV). **A**nother advantage is that the radiation could be used to detect dangerous materials. Because of the fact that the emissivity of many explosive materials such as Hexogen (RDX), Penthryte (PETN), Octogen (HMX) has some characteristic transmission features in the THz region [4, 5].

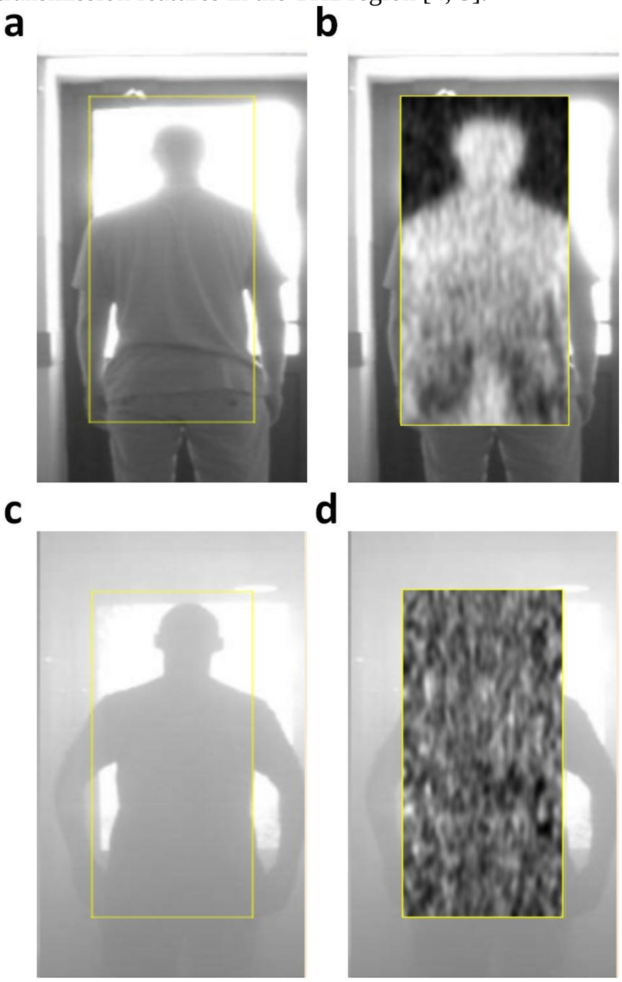

Fig. 1. Pictures in visible range (CCD camera) a) before c) after smokiness and in THz range (TS4) b) before d) after smokiness.

In our work, a screening camera TS4 from ThruVision Systems Ltd. [6] operating in the THz range was tested in a smoky environment. The number of pixels in the THz image is 80x50. The working distance of the camera is 3-15 meters. The camera operating frequency is 0.25THz,

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thanks to the fact that the camera could be used to detect natural human radiation. Clothing transmits well in this range and it is also possible to observe dangerous objects hidden under clothing, such as guns or knives.

In our investigations, a TS4 camera connected with a small visible camera (CCD) was used to observe the scene. They were connected to a computer and software. The images can be recorded independently or a THz image can be superimposed on a visible image (Fig.1). Smoke aerosol particles were produced from paraffin in a smoke generator. It is a popular method during exercises of the fire service. The aerosol has similar properties like real smoke: the visibility in visible light deteriorates, particle sizes are similar and it is safe for human beings. The distance between the camera and the target (a man) was about 6 meters.

The results of the experiment are seen in Fig. 1 (Figs.1a, b before and Figs. 1c, d after smokiness). The man in the experiment was in a marked position in both cases. Figure 1a presents a visible image of the man. A THz image superimposed on a visible image is shown in Fig. 1b in the yellow frame. The image in the THz range has a lower quality than from the one from the visible camera, but the contour of the man is still seen. The reason of this is that performance of the passive THz camera is still limited due to insufficient resolution and sensitivity in comparison to the visible camera. In Figs. 1c and d one can observe the influence of a certain amount of smoke on images in both considered wavelength ranges. In the visible range (Fig. 1c), the image has a lower contrast, but still the man is visible. The man is not seen in the THz camera.

In simulated fire conditions, the emission of large amounts of smoke could deteriorate the THz image due to scattering or absorption. The efficiency of scattering depends on the diameter of particles and used radiation. The diameters of smoke particles are from 0.01 to about 10µm, depending on a burnt material. Since the particles are smaller than the operation wavelength of the THz camera (0.25THz~1.2mm), we can conclude that scattering does not influence the transmission. Its influence is only in the visible and near IR range. We think that the lack of visibility in the THz range is connected with absorption. In fire (smoke) conditions,THz radiation is absorbed mostly by water vapour and carbon dioxide $(CO_2)$and less by other gases like hydrogen cyanide (HCN), carbon monoxide (CO), hydrochloric (HCl), nitric oxide (NO), and sulphur dioxide (SO_2). In the examined case it was not only the pure paraffin but also water vapour.

In order to check the influence of smoke on transmission in the THz range, we exploited Time Domain Spectroscopy (TDS) [2, 4, 5] . The TDS gives us opportunity to measure transmission in the (0.1 ÷2.5)THz range. In the experiment setup we applied a spectrometer TPS Spectra 3000 from TeraView [7].

Time Domain Spectrometry setup with pulses generated by an 800nm femtosecond Ti:Sapphire laser (a pulse duration less than 100fs, repetition rate of 80MHz, and average power of 300mW) is presented in Fig. 2. The laser beam is split into a pump and a probe and directed through a system of mirrors to an emitter and a detector which is based on low temperature grown GaAs dipole antennas. The pump beam is focused on the biased emitter antenna to generate THz pulses through a photoconductive phenomenon. Such pulses last about 1ps (Fig. 3) and have a broadband spectrum, usually in the 0.1-3.0THz range or more.

The transmitted THz beam can be detected by means of a detector antenna gated using a laser probe beam and a mechanical delay line. A lock-in amplifier and some software are used to collect and process data. The system is purged with dry air to eliminate water vapor.

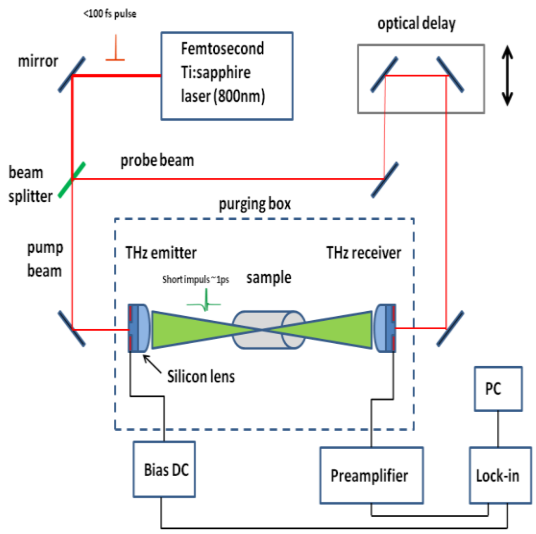

Fig. 2. Setup of Time Domain Spectroscopy.

The analyzed sample had the shape like a cylinder. It was filled with particles of aerosol produced on the basis of paraffin, the same as in the previous experiment. The sample was sealed on both sides with polypropylene foil, transparent to THz radiation. In all cases, the humidity inside the sample was measured. The sample was placed in the middle between the emitter and the detector, perpendicularly to the THz beam (Fig. 2).

Figure 3 presents impulses measured for the sample as well as the reference impulse acquired for the empty chamber. It is clearly seen from the inset that smoke inside the sample changes the main peak only in a limited way. The main influence of smoke is observed for the position of the delay line longer than 39.7mm. The reference impulse is flat in this region while the smoke inside the sample causes characteristic disturbances.

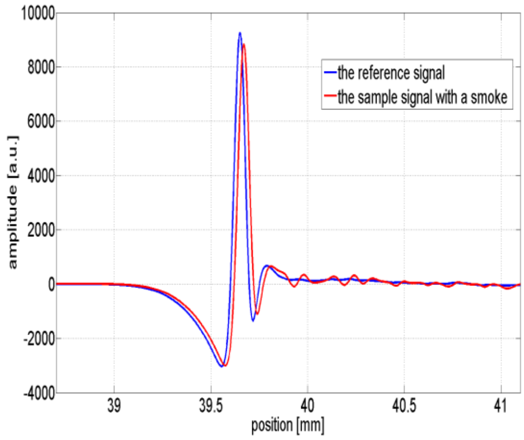

Fig. 3. THz pulses used in TDS: the reference and the sample (parameters of the sample: the volume 196cm^3 and the humidity 52%).

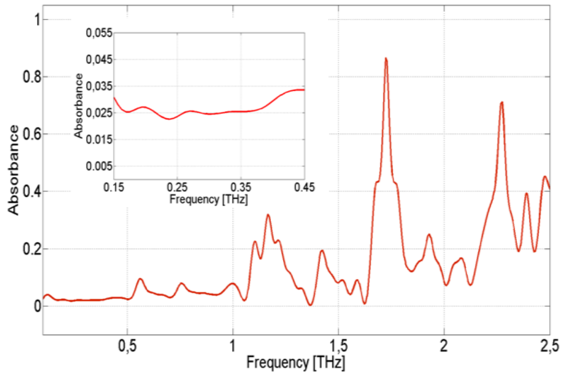

Fig. 4. Measured spectra of absorbance for the sample like above.

The transmission spectra of a sample can be presented as absorbance A:

$$A = -\log_{10}\left(\frac{T_M}{T_R}\right) \quad (1)$$

where T_M is the sample spectrum and T_R is the reference spectrum.

The absorbance of the considered sample is presented in Fig. 4. Since the sample consisted of water vapour and smoke, the lines connected with water vapour (e.g. at 1.1, 1.7, 2.2THz) are clearly seen. Obviously, not only the presence of smoke particles but also water vapour has effect on the absorption. The (0.1÷0.5) and (0.5÷1)THz ranges compared to higher frequencies with few exceptions have the lowest absorbance. The absorbance for the frequency 0.25THz for the 10cm sample is about 0.025. While a distance of 6 meters will give the absorbance 60 times higher and it will be 1.5. It means that the atmosphere with smoke attenuates $10^{-1.5}$ and the level of transmission is about 3%. It explains the reason of visibility loss in the previous experiment with a THz passive camera.

Summarizing, in this work the influence of smoke on THz imaging was examined. Unfortunately, the performance of commercially available passive cameras is still limited due to insufficient resolution and contrast in comparison to other wavelengths, as seen in Fig.1 a. It has also influence on vision in the case of a cloud of smoke. The 0.25THz frequency emitted by human beings has for the range of (0.1÷2.5)THz one of the highest transmission (Fig. 4), but absorption is high enough to lose visibility in this range (Fig. 1a). Attenuation of the radiation is related to absorption by aerosol of paraffin and water vapour. The scattering has a small influence on attenuation, because the size of the molecules of the aerosol is smaller than the wavelength of the radiation utilized.

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