Active MMW multi-parametric imaging technique for security applications

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***Abstract*—Active millimeter wave (MMW) imaging is currently being considered as a technology that can essentially contribute to security applications in both outdoor and indoor scenarios. Proposed novel active quasi-optical imaging technique being based on multi-parametric encoded illumination of observed scenes adds principally new possibilities for imaging of the scenes. The technique allows to reveal multiple distinctive features of threat objects hidden beneath person clothes that essentially increases probability of object true recognition. The technique is potentially capable to be applied for terahertz imaging as well. In the present work, an experimental set up for MMW multi-parametric quasi-optical imaging in reflective mode was developed. Informative MMW images of different concealed objects including threat ones were obtained.**

I. Introduction And Background

MMW/terahertz radiation is penetrative through the clothes and other non-conducted materials that allows to use the radiation in security applications. By the moment a lot of person-screening imagers exploiting different operation principles have already been developed [1-4]. Majority of ones are quasi-optical imagers wherein a focusing lens or a mirror (or its modification) focuses radiation incoming from observed scene onto focal plane array (FPA) for spatial sampling and digital conversion. Affordable quasi-optical imagers additionally include different mechanical scanners [2,4]. Scene illumination is a key factor determining the information volume that can be extracted by the imagers from the scene. The information becomes accessible due to differences in radiation reflectivity of spatially different parts of scene objects and its surroundings [2]. Generally, native emission radiation illumination is used for outdoors MMW/terahertz (passive) imaging. Illumination contrast needed to acquire scene reflectivity signature takes place due to low level of thermal emission from the clear sky against the higher levels of thermal emission from ambient bodies. In indoor scenarios, which are typical for security applications, the native illumination contrast is not enough for optimal imager operation. To provide the required contrast, different artificial illumination approaches, which mimic the sky illumination conditions, are currently used. It is considered that the illumination radiation has to exhibit low level of temporal and spatial coherence [2]. In [3], a spatially extended panel cooled by nitrogen is used for contrast illumination indoors. In [2], it is a spatially-extended chamber consisting of 5 "untuned cavity" panels each of which is illuminated by a particular broadband noise source. Combination of the noise sources and hot/cold load panels is applied in [4].

Aforesaid MMW illumination approaches are well-known in optics where demonstrate good results due to diffuse reflections of objects. In security applications, majority of objects of interest reflect MMW radiation specularly, so primarily low spatial coherence of the object-illuminating radiation recover own high level in the PPA plane providing coherent noises in acquired MMW images The effective radiation temporal incoherence is limited with bandwidth of the imager FPA receivers (typically it is about 10-15 GHz) which is not enough for required enhancement of image quality [5-6]. The approaches do not allow to separate informative reflections of hidden objects from noisy reflections of person skin and clothes. Moreover because reflections of different object parts are essentially varied in intensity it is impossible to reveal a lot of distinctive object spatial features which produce weak reflections.

The novel active multi-parametric imaging technique is capable to overcome aforesaid difficulties and provide new imaging possibilities [5-8]. The aim of the present work is to demonstrate technique potential for informative edge detection low-noisy imaging of concealed objects.

II. Results

Basically, the proposed active multi-parametric imaging technique is based on preliminary decomposition of radiation into multiple distinctly-encoded partial radiation components exhibiting different physical parameters (angles of propagation, polarization states and frequencies), illumination of observed scene with the encoded radiation, real-time formation of the component-related multiple partial images by means of a quasi-optical imager and following synthesis of resultant informative images [5-8]. The technique multi-angle (multi-static) illumination of scene objects is similar to target-probing approach applied in bi-static/multi-static radars which are effective for detection of specular "stealth" targets. The proposed technique allows to acquire particular two-dimension reflective signature in every spatially-resolved scene point within imager field-of-view (FOV) in real time [6-8]. In contrast with the "sky-imitating" illumination, it permits to reveal and acquire weak reflections of a character spatially-small object part distinctly even when other object parts producing strong reflections fall within the same imager-resolved point (related to a particular image pixel). It gives possibilities to sense any bulk concealed objects in detail and separate its reflection signature from disturbing strong reflections produced by surroundings (including specular person skin reflections). Additional encoded frequency-different and polarization-different components of object-illuminating radiation are capable to increase object information acquired in real time.

Apparatus realizations of the technique are based on usage of specially designed safe illumination subsystem and related quasi-optical FPA imager. Spatially extended diffuser being digitally controlled is a key unit of the subsystem. The diffuser

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consists of array of independently controlled switching cells with radiation transmitting/reflecting small-size apertures. The cells may have different performance but preferentially ones are an antennas or a quasi-optical conducting arrays ports of which are loaded by non-linear elements (p-i-n, Schottky diodes, etc). MMIC technology is potentially applicable for the fabrication of such diffuser cells. Change of impedance(s) of the cell element(s) due to applying appropriate bias voltage causes change of radiation transmitting/reflecting status of the related cell. Single or limited number of mutually-coherent MMW radiation sources illuminate the diffuser to scatter the radiation towards imager FOV. Distinct high-speed biased switching of different cells causes generation of multiple angle-different modulated/encoded radiation components. The diffuser and the sources may have both single and multi-frequency performance. All units of the illuminating subsystems and the related quasi-optical imagers are described in details in [7]. The active imaging systems using mutually-coherent MMW sources with and without ordinary diffusers are considered in [8].

The technique gives unique possibilities for effectively processing the acquired multi-parametric image data and for extracting object-related information [6-8]. Edge detection imaging technique for object shape recognition may also be realized due to aforesaid possibilities of sensing of bulk nature of concealed objects.

In the present work, an experimental set up for MMW multi-parametric quasi-optical imaging was developed The set up included a Cassegrian mirror scanning quasi-optical imager with a heterodyning receiver and scanning illumination subsystem with a MMW narrow-band fixed frequency source (operation frequency is 94 GHz) which was used for step-by-step multi-static illumination of imager FOV within wide solid angle (2 sr). The imager provided low (5 degree of the FOV per second) precise (0,03 degree) scanning of the FOV with spatial resolution about 7 mm. The distance between objects and the imager was 1,2 m. High-resolution video camera being linked to a capture board used for feedback between video and MMW images on PC screen. The objects were disposed on a high-reflecting wood panel and covered by shirt cloth attached to the panel. The panel could rotate to provide additional possibilities for angle-different object illumination. Illuminating power was less 10 μW per cm^2 on the objects. Set up units were under PC control. The multiple partial object images were acquired sequentially in time for distinct radiation illumination angles. Edge detection software algorithm used for processing object partial images was implemented for automatically synthesizing resultant images containing shape information of concealed objects. In the work, enhanced low-noise MMW images of different concealed objects were obtained. The MMW images of a PM pistol (Fig.1), a mobile phone (Fig.2) and an explosive simulating soap (Fig.3) every of which was hidden beneath the cloth are presented. To scale object sizes, the visual object images additionally contain a coin (diameter 25 mm) being not used in the MMW imaging. Presented MMW images exhibit extremely low level of reflections of object flat parts and noises produced by the strongly reflecting panel. Ones contain shape information of the concealed objects being enough for its identification. The images demonstrate possibilities of the proposed imaging technique for informative edge detection imaging of concealed objects.

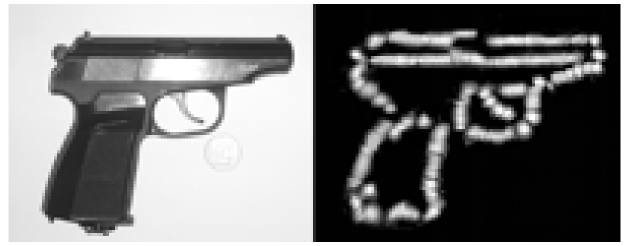

Fig.1. Visual image of a PM pistol, left, and MMW image of the pistol hidden beneath cloth, right.

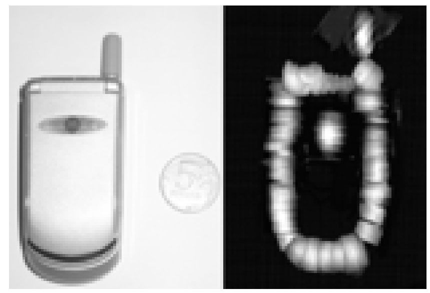

Fig.2. Visual image of a V150 Motorola mobile phone, left, and MMW image of the phone covered by cloth, right.

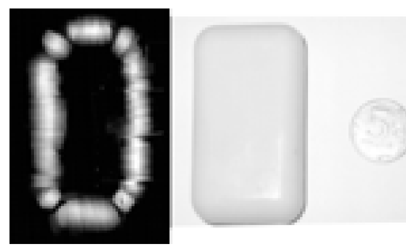

Fig.3. MMW image of a cloth-covered soap, left, and visual image of the soap, right.

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