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Concealed Objects Detection in Visible, Infrared and Terahertz Ranges

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Abstract**—**Multispectral screening systems are becoming more popular because of their very interesting properties and applications. One of the most significant applications of multispectral screening systems is prevention of terrorist attacks. There are many kinds of threats and many methods of detection. Visual detection of objects hidden under clothing of a person is one of the most challenging problems of threats detection. There are various solutions of the problem; however, the most effective utilize multispectral surveillance imagers. The development of imaging devices and exploration of new spectral bands is a chance to introduce new equipment for assuring public safety. We investigate the possibility of long lasting detection of potentially dangerous objects covered with various types of clothing. In the article we present the results of comparative studies of passive imaging in three spectrums – visible, infrared and terahertz.

Keywords**—**Infrared, image processing, object detection, screening camera, terahertz.

I. Introduction

PREVENTION of terrorist attacks is very serious issue of public safety. There are many solutions for preventing terrorists [1]. However, one of the most popular is vision systems. One of the most challenging problems of threats detection is visual detection of objects covered with fabrics. It is very important to detect a threat as early as possible in order to neutralize it. One of the very challenging problems is detection of dangerous objects hidden under human's clothing [1], [2]. There are several solutions of the problem and the most effective utilize multispectral systems of imagers. Due to the rapid development of imaging devices and exploration of new spectral bands new equipment for security systems can be introduced. It has been proven that the terahertz imaging is of great interest for the screening of people, particularly the detection of dangerous objects at standoff range. The terahertz radiation offers great application possibilities in the field of imaging and spectroscopy [3]. The terahertz radiation can penetrate fabrics as well as other materials [4]-[6] and because the radiation does not ionize the matter it is not harmful to humans. However, practical real-time imaging in the terahertz band is difficult because the THz imagers offer low spatial resolutions and low image quality [7], [8].

Another possible solution is a high resolution infrared camera. The infrared imagers also seem to be very useful in the search for concealed objects. Because of the fact that infrared cameras can detect the temperature differences on the surface of the object, it is justified to investigate the possibilities of applying these type of imagers for detection of hidden items [9]. Both infrared and terahertz imagers are not harmful to humans.

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II. Measurement Methodology

In order to investigate the possibilities of detection of objects covered with various types of fabrics, the measurement methodology was developed. The measurement methodology consists of methods and algorithms used during the measurements as well as the hardware setup. The measurement setup consists of several devices – four cameras, [10], [11], two thermoelements and a thermo-higro-barometer. The cameras were selected to cover very wide range of spectra. The four cameras employed during the measurements – visible light (VIS) camera, passive terahertz (THz) camera and two infrared cameras are commercially available. In order to provide a controllable and uniform background of measurement scene, a photographic fabric was used. The measurement setup is presented in Fig. 1.

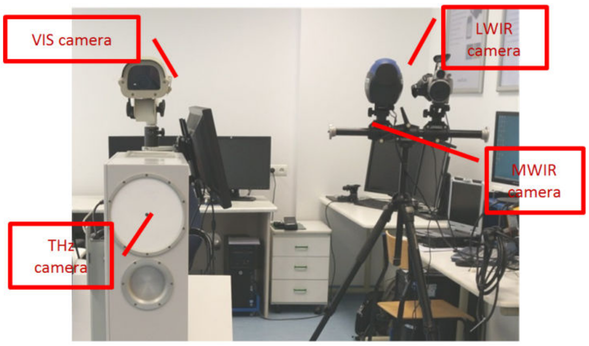
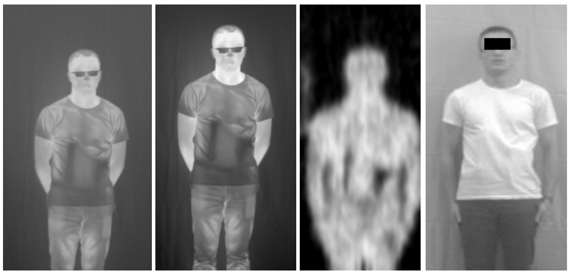


Fig. 1 Measurement setup

In order to investigate the possibilities of detection of hidden object in the terahertz range, an imager operating at 250 GHz is used (Digital Barriers, ThruVision, London, United Kingdom). The possibilities of detection of hidden objects in infrared range were investigated using two cameras. The first infrared camera used during the measurements is a long-wavelength infrared (LWIR) camera supplied with uncooled microbolometer detector working in the range of 7,5-13 μm and with resolution of 640x480 pixels (FLIR Systems Inc., Wilsonville, Oregon, United States) [10]-[12].

The second infrared camera is a mid-wavelength infrared

(MWIR) camera supplied with cooled InSbfocal plane array detector (3-5 μm) with resolution of 640x480 pixels (FLIR Systems Inc., Wilsonville, Oregon, United States). Complementary images acquired with the four cameras are presented in Fig. 2.



(a) (b) (c) (d)

Fig. 2 Complementary images; (a) LWIR image, (b) MWIR image, (c) THz image, (d) VIS image with hidden gun and a metallic tube

The parameters of measurement equipment used during laboratory measurements are presented in Table I.

TABLE I
MEASUREMENT EQUIPMENT

Types of Systems	Parameters
IR Camera SC 5600 (Flir Systems)	FPAs 640x480 InSb, Field of View (FOV) 20°x16°, spectral range 2.5 μm ÷ 5.1 μm
IR Camera SC 7900VL (Flir Systems)	FPAs 320x256 MCT, Field of View (FOV) 11°x8°, spectral range 7.7 μm ÷ 11.5 μm
THZ camera TS4 (ThruVision)	Scaning system, Resolution 124x271, 0.25 THz passive sensing line with +/- 20 GHz bandwidth

Due to the fact that both the thermal camera and the terahertz camera measure the relative temperature of objects, a special attention to certain restrictions related to the possibility of detecting concealed objects should be paid.

Assuming that the scanning object is hidden under clothing for a specified period of time, the object may be heated by the human body. Therefore, it is necessary to determine how large is an impact of the change of the temperature difference between the human body and the hidden object on the detection of hidden object. The temperature difference between the human body and the hidden object can decrease during measurements because of the transition of energy between the object and the human body. Therefore, thermal camera can be used to detect an object covered with a fabric only in certain conditions. The main condition is a value of temperature difference between an object and a surface of the covering material. A parameter conditioning the ability of an imager to distinguish two small values of temperatures is the thermal sensitivity. In order to detect the small temperature difference, the thermal sensitivity of an infrared imager should be as low as possible [10].

The radiation distribution detected by the passive terahertz imager is proportional to the relative temperature of a target and is directly related to the absolute amount of THz radiation emitted by a target [11].

Organization of measurement sessions is presented in Fig. 3. During the measurements, several configurations with various objects (guns, knives, dynamite) and clothes (shirt, T-shirt, sweater) were prepared. A measurement of one single configuration took 30 minutes.

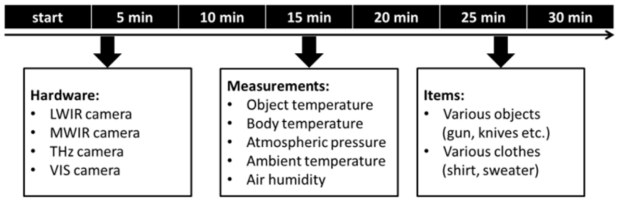


Fig. 3 Organization of measurements

The distance between a human and a set of measurement devices is 5m and is constant during the measurements. A set of data from cameras (four images) and thermoelements were collected every five minutes. For every five minutes, the data package with images, spectral signatures, values of atmosphere parameters (air temperature, humidity and pressure) and values of body and object temperatures was collected.

III. RESULTS

Selected images registered with four cameras (THz, LWIR, MWIR and VIS) and with two test objects (a plastic gun and a metallic tube) and one type of clothing (T-shirt) are presented in Tables II and III.

The images presented in Table II were acquired at the beginning, in the middle and at the end of the measurement session.

TABLE II
RESULTS OF INVESTIGATIONS– LWIR AND MWIR

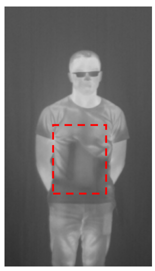
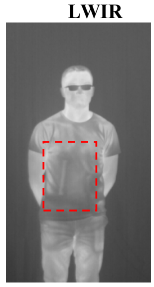
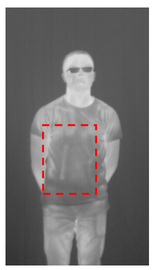
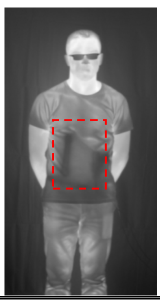
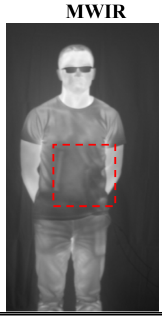
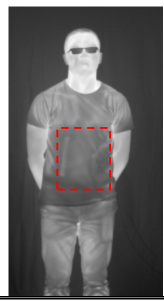
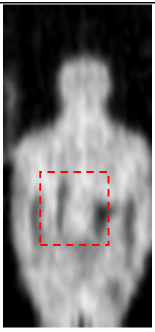
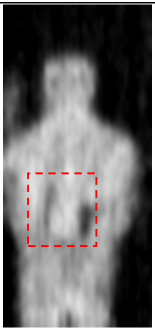
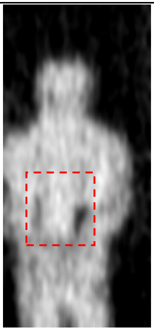
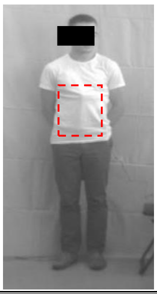
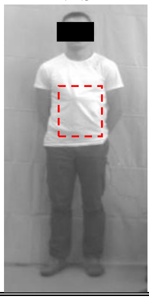
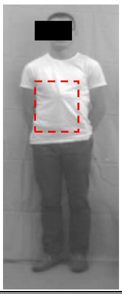
Start	15 min	30 min
	LWIR	
		
	MWIR	
		

TABLE III
RESULTS OF INVESTIGATIONS- THZ AND VIS

Start	15 min	30 min
		
	VIS	
		

IV. ANALYSIS OF RESULTS

The hidden object can be extracted by human sense, however in the case of a security system, the system operator should be provided automatically with clear and understandable information [10], [13].

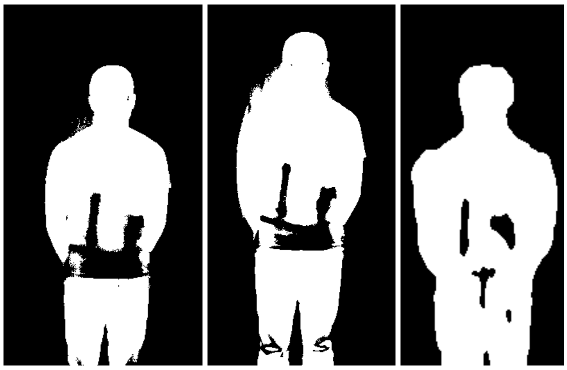
It should be noted that the visibility of the concealed object decreases during time as a result of decrease of temperature difference between the object and the human body. Therefore, the ability to detect the concealed object with a terahertz or infrared camera depends on the temperature parameters of observed objects.

Comparing images registered using infrared imagers it can be noticed that the hidden object is more distinct in the images registered with the MWIR camera. It could be the result of lower value of thermal sensitivity of the MWIR camera.

In order to extract (detect) an object in an image; proper analysis needs to be done. However, to evaluate the capabilities of an imager to detect a hidden object, it is justified to process images in order to extract the hidden object. Image processing is an inevitable element of any surveillance security system. The first analysis of an image in order to an object is to apply segmentation algorithm to an image. The examplary images after binarization are presented in Fig. 4.

Extraction of the detected object from an image requires application of several processing techniques. The images presented in Fig. 4 show the results of the first processing step of extraction of the object. The hidden object is detected; however, the image processing algorithms need to be improved because of the artifacts remaining in the images after processing.

Subjectively, a location of the hidden object is visible in every image except the images acquired with visible light camera. However, the VIS image can be utilized in the image fusion process [14]-[17] as a background image.

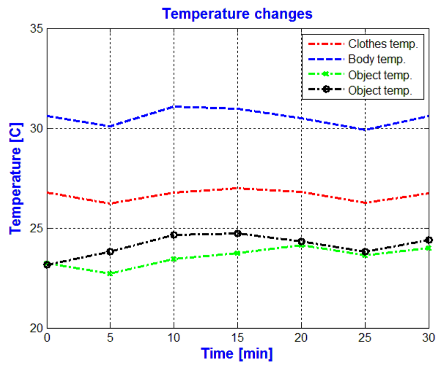


(a) (b) (c)

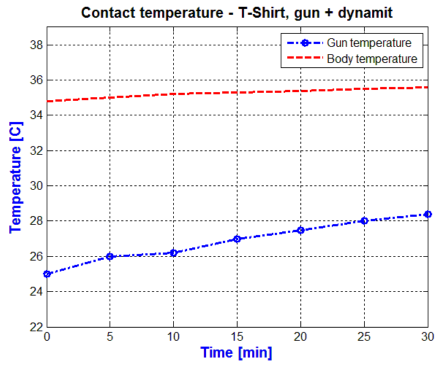
Fig. 4 Processed images; (a) LWIR image, (b) MWIR image, (c) THz image

The emissivity of clothes and weapons were measured using the spectrometer. The value of emissivity of clothes was between 0.92 ±0.03 in MWIR range, and 0.94 ±0.02 in LWIR range. The results were used during the calculations of temperatures.

Values of temperatures measured with MWIR camera and thermoelements are presented in graphs in Fig. 5. In Fig. 5 (a), the values of temperatures of two hidden objects are very similar.



(a)



(b)

Fig. 5 Temperatures of body and objects during measurements: (a) radiation temperatures measured with MWIR camera,(b) contact temperatures

These values are not exactly the values of object temperatures but the values of temperatures of the surface of the clothing. This is an effect of insignificant value of transmittance of infrared radiation in fabrics. The thermal camera measures a radiation temperature of clothing – this is not a direct measurement of a temperature of an object. Values of temperatures measured with thermoelements are presented in graphs in Fig. 5 (b). It can be noticed that values of contact and radiation temperatures of the hidden objects are different. The total change of values of contact temperatures of a gun measured with thermoelement was 3.3K.

V.Summary

The presented results show how the changes of temperature values of human body and the object can influence the camera's ability of detection of the object covered with fabrics. The results presented in the article confirm the fact that it is possible to detect various objects covered with T-shirt placed on a human body using a thermal and terahertz imager in certain conditions.

The results indicate that during the measurements the intensity of pixels presenting the concealed object decreases due to the fact, that during the measurements, the hidden object is heated by a human body and the value of temperature difference between a covering material and an object decreases. Therefore, parameters of imagers are essential for long lasting detection of objects. According to the results, it is not possible to detect the concealed object with single visible light camera.

The detection of objects covered with fabrics strongly depends on the type and thickness of fabric. The thicker the material, the lower the transmission coefficient in infrared as well as in terahertz range. The type of material plays the key role especially for terahertz waves because the values of transmittance of most of fabrics are between 0.9 and 0.6 in the frequency range between 100-300 GHz. The transmittance of infrared in fabrics is very low, considered as zero.

It should be noted that the type of material of the hidden object has a large impact on abilities of detection of the object in the THz range - the detection of metal objects is greater than the objects made of plastic. This is due to the fact that the metal has a very high reflectivity coefficient of THz waves, and some plastics are characterized by a non-zero transmission coefficient.

According to theoretical studies, size and type of material of hidden item are very important factors for the time stability of imager's ability of detection in both infrared and terahertz bands. The specific heat of the material is crucial for the susceptibility to receive the heat from another body.

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