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Verification of the correctness of thermal imaging modelling

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The paper presents a method for verifying the correctness of modelling of thermal imaging of targets by means of the computer faceted thermal target model (FTTM) and the theoretical model of thermodetection system (MTS). It is proved that the computer-produced imaging of the target model is close to the imaging of an actual target obtained by means of a scanning thermodetection system. It is demonstraded that directional temperature characteristics and directional radiative characteristics generated with the use of the FTTM model can replace efficiently actual thermograms of the target and can be applied as input data to theoretical models of thermal imaging by thermodetection systems.

1. Introduction

The development of a decision criterion for a thermodetection system (*e.g.*, a smart ammunition system) requires precise determination of thermal signatures of the target [1]. Using the computer modelling, one can replace costly experimental finding of data sets indispensable for determination of target thermal signatures with cheap and quick computations which, moreover, enable controlled variation in the measuring conditions being simulated and constructional parameters of the device [2]. A portion of the input data for computations can be obtained by means of simple experiments [3].

The paper presents results of comparison of computer modelling of thermal representation of targets by a thermodetection system with the data obtained experimentally. The computer modelling is based on the models developed originally by the authors of this paper: the three-dimensional faceted thermal target model (FTTM) [4], [5] and the model of thermodetection system (MTS) [6]–[8].

The computer FTTM describes target's radiative properties in the infrared spectral region. The model is predestined for simulation of a target in analyses of the influence of thermal-scene conditions on the possibilities of target detection by a thermodetection system. This is a faceted model describing the target as a set of facets. The set of data for the model requires information on the shape and dimensions of the target as well as on distribution of temperature and emissivity coefficient of its surface. The model enables to determination of radiation emission from the target surface for various directions of detection, which makes it possible to obtain the data necessary to design devices for infrared recognition with a limited application of costly experimental investigations.

The theoretical MTS determines thermal images on the basis of an ideal image of target, parameters of an thermodetection system and conditions of the measurement being modelled. It is based on the linear filter theory, which means that the modulation transfer function (MTF) of a whole thermodetection system is expressed as a product of the MTFs of its subsystems, *i.e.*, the objective, detector and electronics. Thermal image of a target emerging at the detection system output is a two-dimensional convolution of the ideal thermal image of the target with the point spread function (PSF) of the thermodetection system. A numerical technique for computing the optical transfer function (OTF) of an objective is based on the wave optics. The model takes into account spectral characteristics of the imaging chain, including transmission of the atmosphere.

2. Idea of the method for verifying the correctness of theoretical modelling

Figure 1 presents a schematic diagram of the method for verifying the correctness of theoretical modelling of thermal imaging. The verification is performed on two levels (A and B).

On level A the computer faceted thermal target model is verified by comparing thermal images of the target generated by means of the FTTM model with images registered experimentally with a measuring thermovision camera for the same conditions of observation [9]. The quantities being compared are: statistical measures of temperature distribution on the target surface and of the background, radiation intensity distributions of the target and background, and distributions of radiance of the target and background. The distributions compared are functions of the observation angle of the target under investigation.

On level B, the computer faceted thermal target model and the theoretical model of thermodetection system are verified by comparing the images (imagings) of a two-dimensional distribution of radiance of the target and background. The images being compared include those determined fully theoretically (by sequential combination of the FTTM model and MTS model), the ones obtained by applying the MTS to the thermogram registered with a thermovision camera, as well as those obtained fully experimentally (with an ST-95 thermal scanner).

3. Statistical measures of thermal characteristics of the target

The assessments of the probability of target detection and the probability of false alarm used commonly in automatic recogniotion systems are based on statistical analysis of the signal and assume a normal distribution of probability of the random variables being considered [10].

The histogram of the background temperature distribution from a thermogram obtained with a measuring thermovision camera (Inframetrics 760) in Fig. 2, and

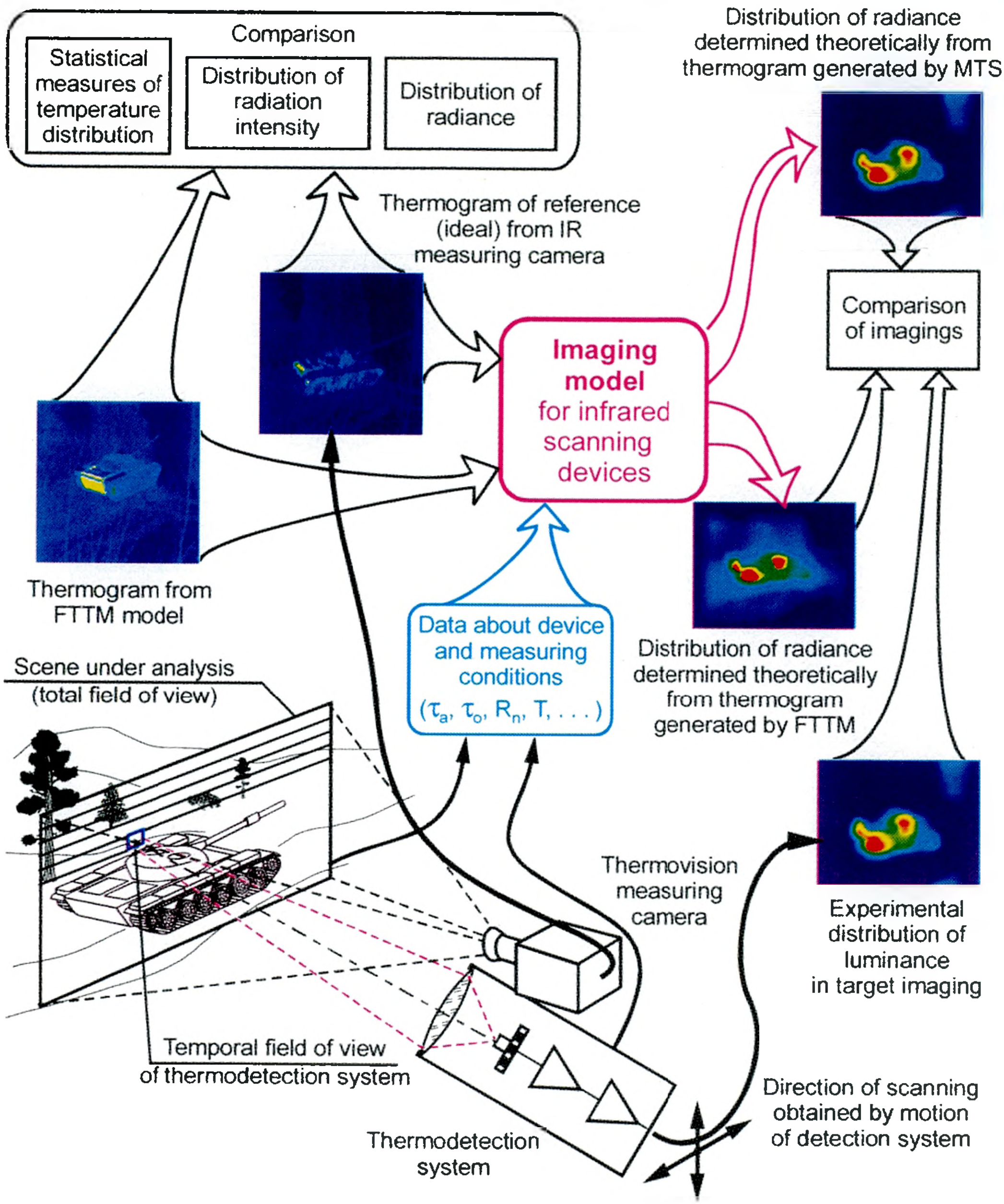


Fig. 1. Schematic diagram of the method for verifying the correctness of theoretical modelling of thermal imaging.

the histogram of temperature distribution on the target surface from a thermogram obtained with using the FTTM model, Fig. 3 show that this assumption is not fully satisfied.

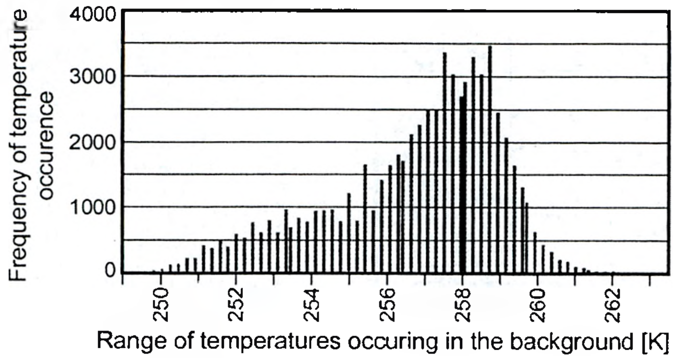


Fig. 2. Histogram of background temperature distribution for the observation angle of 180° (thermovision measuring camera).

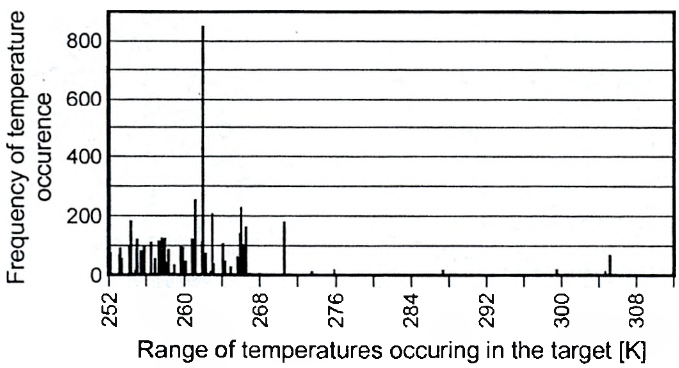


Fig. 3. Histogram of temperature distribution on target surface for the observation angle of 180° (FTTM).

This means that precise analysis of the quantities being investigated should be carried on numerically, and not based on the above assumption. For the first-order approximation, however, it is convenient to use such statistical measures as the average value and standard deviation.

The average temperatures of the target $\bar{T}_t$ and background $\bar{T}_b$ as well as the standard deviation of temperature distributions of the target σ_{T_t} and background σ_{T_b} have been determined for thermograms obtained with the use of the FTTM model (Fig. 4) and those registered with a measuring thermovision camera (Fig. 5). The thermograms from the FTTM model have been determined rotating the target by the round angle with a step of 10 degrees (36 positions of the target in relation to the detecting equipment). The thermograms registered experimentally have been obtained rotating the target by the round angle with a step of 45 degrees (8 positions of the target in relation to the detecting equipment). The manner of carrying out the experiments assumed resulted from temporal and economic limitations.

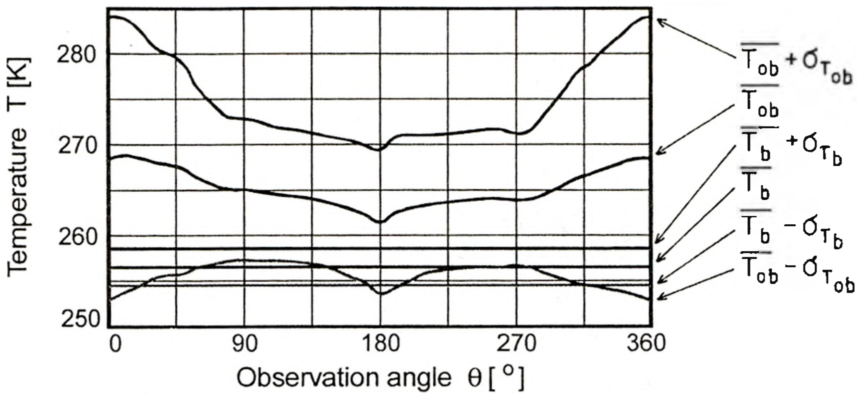


Fig. 4. Statistical measures of temperature distributions of the target (model) and background as a function of the observation angle (FTTM).

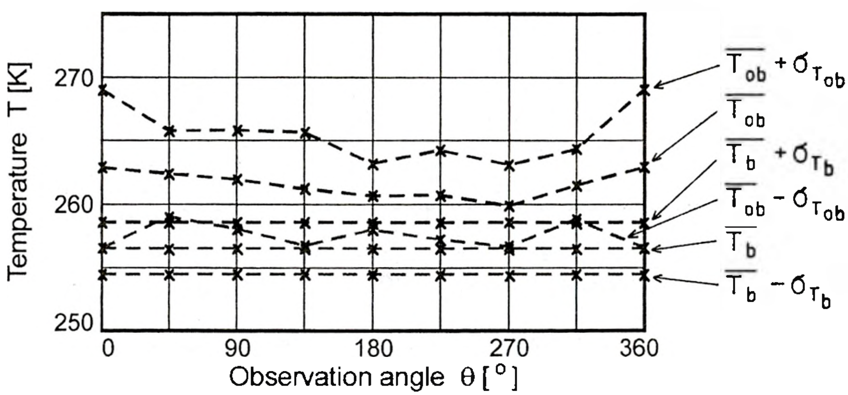


Fig. 5. Statistical measures of temperature distributions of an actual target and background as a function of the observation angle (thermovision measuring camera).

The FTTM program distinguished automatically whether the pixel of a thermogram belonged to the target or to the background. In the case of the thermovision camera, a rectangle circumscribed on the target was cut out from the thermogram, containing about 40% of the background. This influenced underestimation of the values of $\overline{T_t}$ and σ_{T_t} determined in the case of the thermovision camera. An increase in the value of σ_{T_t}, in the case of the FTTM program, was also influenced by quantization of temperatures caused by segmentation of facets of the model.

Taking into account the above remarks, one can state that quite a good consistency has been obtained in the values and course of the dependence of statistical measures of thermograms on the direction of target observation obtained by means of the FTTM program and the thermovision camera.

4. Radiative characteristics of the target

Radiative characteristics are the basis for assessment of detection capabilities (e.g., the signal to noise ratio) of the thermodetection system investigated for a measuring situation being simulated. They are also indispensable during the design stage of the thermodetection system. Figure 6 presents directional characteristics of the radiance of the target and background obtained for the thermograms generated by the FTTM software and those obtained from the thermovision camera.

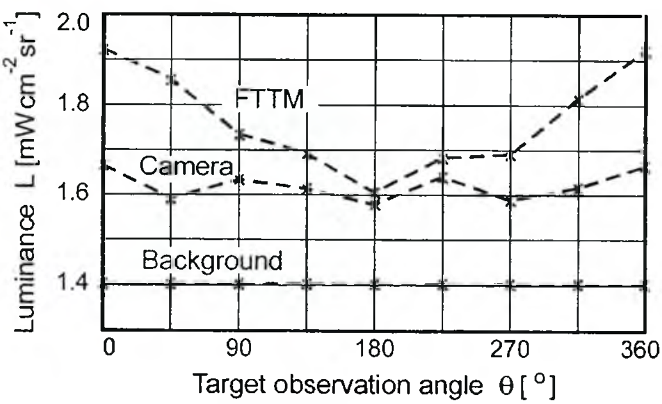


Fig. 6. Radiance averaged over the surface of the target (FTTM), the target "cut out" from thermogram (camera) and background as a function of the observation angle.

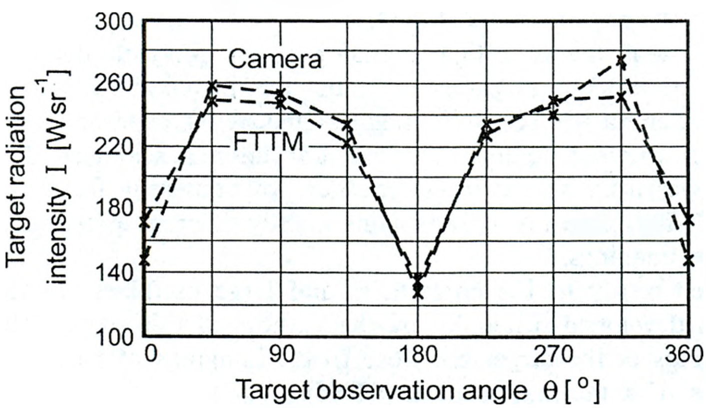


Fig. 7. Radiation intensity of the target (FTTM and camera) as a function of the observation angle.

The target (tank) luminance reaches a maximum for the observation angle of 0° (the target "observed" from behind), and reaches a minimum for the observation angle of 180° (the target "observed" from front). Such a distribution of the luminance results from the fact that the hot engine is located in the rear of the target investigated. Higher values of the luminance for the model assumed result from the effect of covering-up the heat exchangers, located above the engine in an actual target, by additional fuel tanks (the additional fuel tanks have not been considered in the target).

The total intensity of target radiation (Fig. 7) reaches the highest values within the observation angle ranges 45° to 90° and 225° to 270°. For these directions, the "observed" surface of the target is the largest. The maximum intensity of radiation occurs for the observation angle of 315° for which the warmest elements of the target (the engine, heat exchankers, and exhaust manifold) are seen most explicitly. The temperature underestimation near the exhaust manifold for the model of the target (tank) is connected with the fact that the FTTM model does not simulate the exhaust gas.

The slight discrepancy between the target radiation intensities determined theoretically (using the FTTM model) and experimentally (from the thermovision camera) testifies to good representation of the target thermal properties by the modelling.

The comparison, presented below, of the target radiative characteristics determined theoretically and those obtained experimentally allows optimistic thinking about computer simulations of the radiance integrated over the surface of the thermal target.

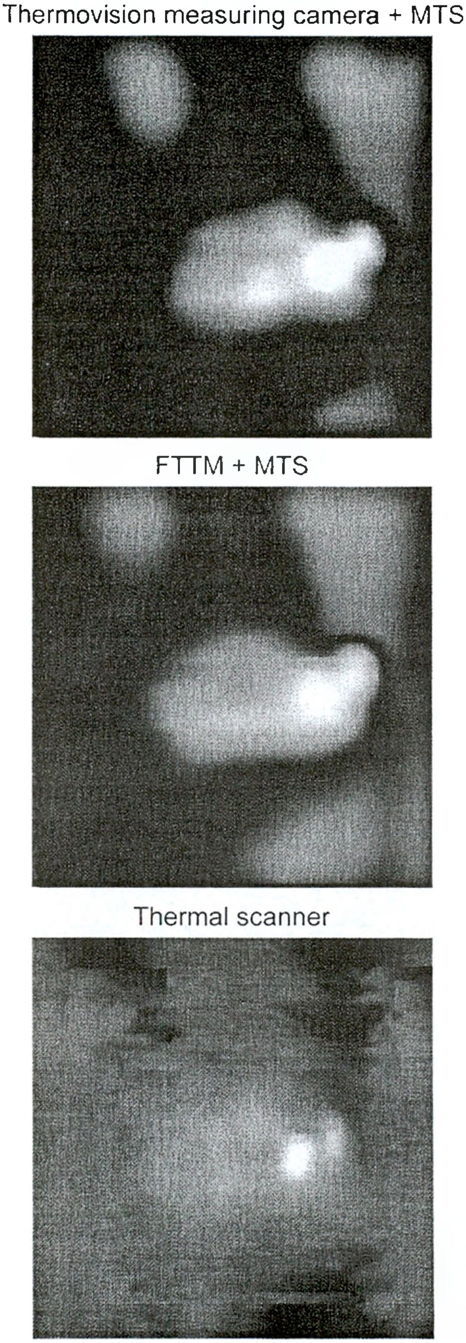
5. Theoretical imaging of the target by thermodetection system

In order to verify further the computer-based FTTM and to demonstrate capabilities of this model in combination with the theoretical MTS, a combination (denoted by FTTM + MTS in the figures) of the two software tools has been applied (Figs. 8 – 11) to determine the theoretical imaging of the target.

For comparison, we show in the same figures analogous imagings obtained by applyin the MTS model to the thermograms from the thermovision measuring camera (the Inframetrics camera + MTS) and imagings registered experimentally obtained by means of a thermal scanner (the ST-95 thermal scanner). The background on the images from the thermal scanner was different from the background used in the FTTM program. This explains slightly different appearance of the background in the imagings.

The imagings presented testify to the correctness and large usefulness of the FTTM and MTS models developed originally by the authors of this paper. The computer-generated imagings of the target are close to the imagings of an actual target obtained by means of a thermal scanner (ST-95).

The similarity of the target imagings determined on the basis of thermograms registered with the thermovision measuring camera and those obtained by means of



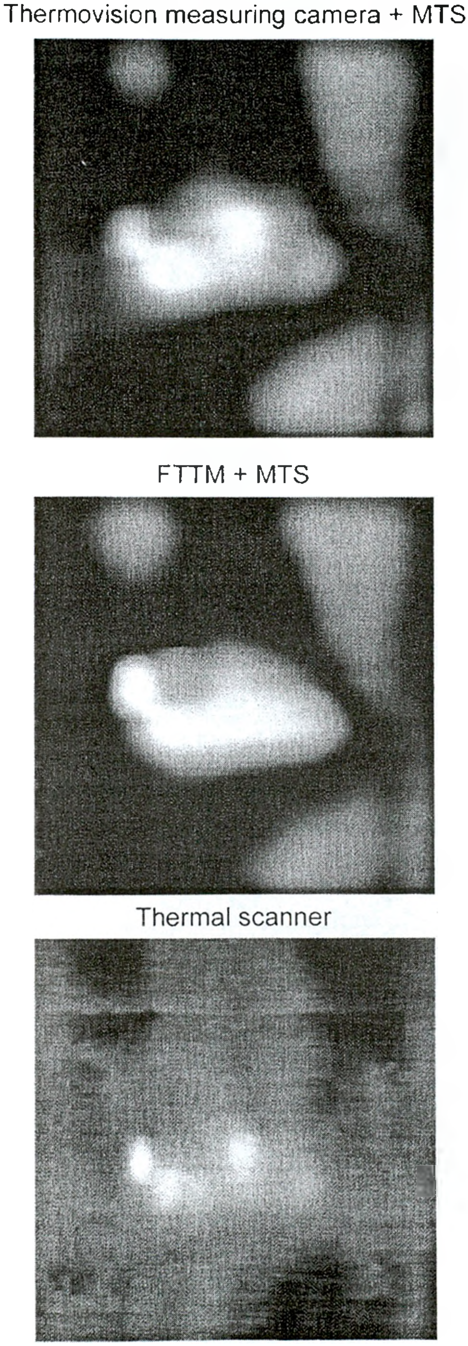


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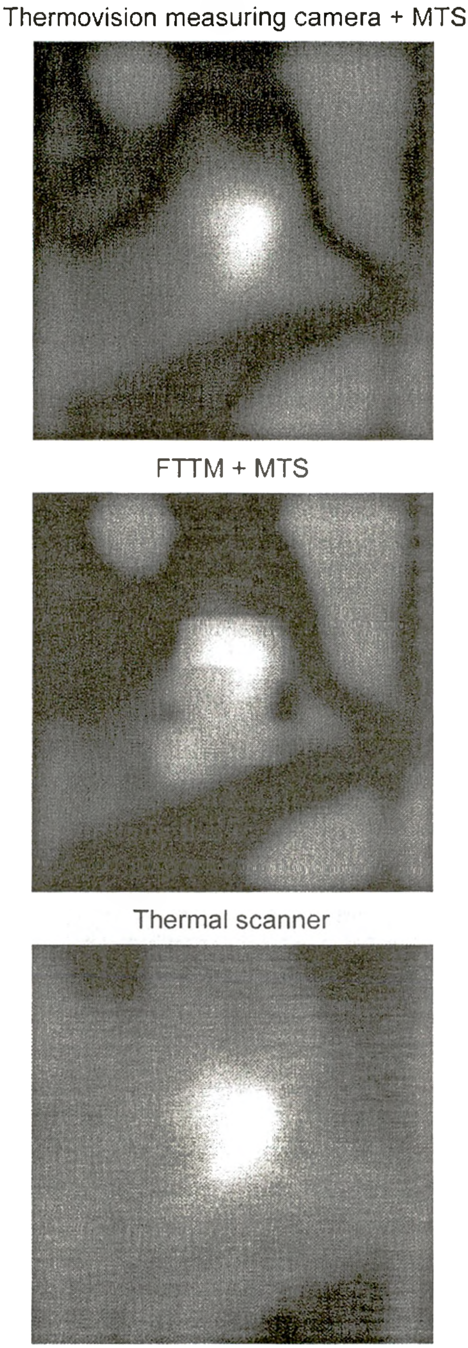
Fig. 8. Target imagings for the observation angle of 270°.

Fig. 9. Target imagings for the observation angle of 90°.



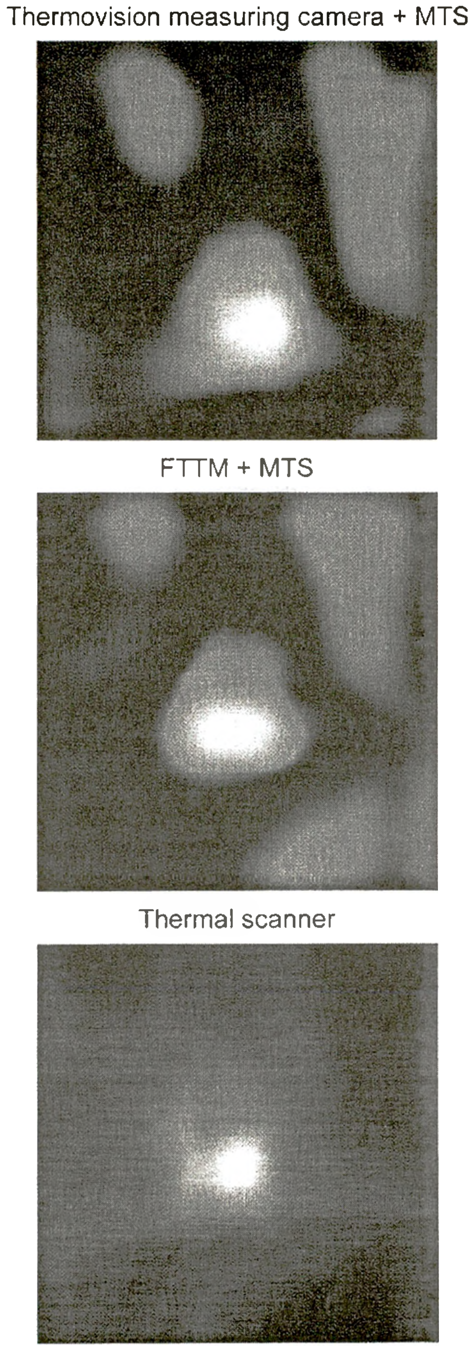


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Fig. 10. Target imagings for the observation angle of 180°.
Fig. 11. Target imagings for the observation angle of 0°.

the FTTM model testifies to good correspondence of the thermal properties of the target model developed with an actual target. This correspondence is an argument confirming the correctness of assumptions of the faceted thermal target model used to determine thermal representation in thermodetection systems.

Two-dimensional images of temperature distributions on the surface of a target generated by means of the FTTM program can replace efficiently actual thermograms of the target as input data for theoretical models of thermal representation by thermodetection systems.

6. Summary

The comparison presented of statistical measures of temperature and radiance distributions on the surface of the target and background, distributions of radiation intensity of the target and background, and target imagings testify to the correctness and usefulness of the FTTM and MTS models developed originally by the authors of this paper. The computergenerated imagings of the target model are close to the imagings of an actual target obtained by means of a thermal scanner.

A striking similarity of target imagings determined on the basis of thermograms registered with a thermovision camera and those obtained by means of the FTTM and MTS models testify for good correspondence of thermal properties of the target model developed and those of an actual target. This correspondence is an argument confirming the correctness of assumptions of the models of a three-dimensional thermal target and a thermodetection system developed.

Two-dimensional images of temperature distributions on the target surface generated by means of the FTTM program can replace efficiently actual thermograms of the target registered during costly and time-consuming experimental investigations. Moreover, the computer modelling enables us to obtain thermal images of a target for such registering conditions and measuring situations which would be difficult or even impossible to accomplish experimentally.

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