

# Modelling of infrared imaging for 3-D objects

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## Abstract

Infrared emission of a 3-D object has been modelled using Faceted Thermal Target Model (FTTM) - fast and user-friendly software based on the geometrical ray-tracing. The methodology of preparation of the faceted target models using CAD software was described. The model takes into account spectral characteristics of the imaging chain (including thermal scanner). The obtained results of simulations for 3-D object have been presented.

## 1. Introduction

Computer simulations of infrared imaging are widely [1,3] used to obtain necessary data without using expensive, time consuming and difficult to control measurements. These simulations are useful in imaging device optimization and object's infrared signature predictions. They are applied in the alerting systems, military systems, tracking control, robotics, and many other research areas.

## 2. Assumptions and the structure of the model

The Faceted Thermal Target Model has been designed to investigate thermodetection of the real-world 3-D objects surrounded by thermal background. FTTM model makes it possible to generate angular temperature and radiation characteristics of the object and/or background.

FTTM describes the object as a set of surfaces with the temperature and emissivity assigned to each of them. Background is modelled as a single plane with a complex distribution of temperature and emissivity. In order to preserve the maximum conformity of shape and size of the model to a real object, the geometrical grid of the model was designed on the base of technical documentation of the modelled object. Temperature distribution and emissivity of the model's surfaces was determined from the experimentally obtained thermal images of the real object. Input data include also the geometry of observation, atmospheric conditions and the thermodetection system parameters. Geometrical ray tracing was used to determine the 2-D projection of the 3-D object on the plane perpendicular to the direction of observation.

Incoherent imaging is linear with respect to the radiance  $L$ , so it should be evaluated in each point of the projection plane. It was assumed that Lambert's cosine law holds so spectral radiance  $L_\lambda$ , dependent on the temperature  $T$  and emissivity  $\varepsilon$  of the object's point, can be expressed by the formula [1,2]:

$$L_\lambda(T) = \frac{\varepsilon}{\pi} M_\lambda(T), \quad (1)$$

where spectral exitance is given by the Planck's law:

$$M_\lambda(T) = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda k_B T} - 1)}, \quad (2)$$

where  $h$  - Planck's constant,  $c$  - vacuum speed of light,  $k_B$  - Boltzmann's constant.

Radiance  $L$  can be obtained by integration of spectral radiance over the whole wavelength range  $\lambda = (0; \infty)$ . In effect, we are interested in the *apparent radiance*  $L_d(T)$ :

$$L_d(T) = C_1 \int_{\lambda_1}^{\lambda_2} L_\lambda(T) \tau_a(\lambda) \tau_o(\lambda) R_n(\lambda) d\lambda = C_2 \int_{\lambda_1}^{\lambda_2} L_\lambda(T) f_\lambda d\lambda, \quad (3)$$

where:  $\tau_a(\lambda)$  - spectral atmospheric transmission,  $\tau_o(\lambda)$  - spectral optical transmission,  $R_n(\lambda)$  - normalized spectral detector responsivity,  $f_\lambda$  - spectral transmission of the imaging chain,  $\lambda_1, \lambda_2$  - boundaries of the effective detection band,  $C_1, C_2$  - normalizing constants.

The product of  $f_\lambda$  and  $L_\lambda$  functions informs about the relative participation of the radiation with a particular wavelength  $\lambda$  to the formation of the output detector signal. Function  $S_\lambda$  (the normalized form of the function  $f_\lambda$ ) is shown in a fig. 1. It is important that the dependence of function  $S_\lambda$  on wavelength is approximately the same for a wide range of the average object's temperature.

### 3. Preparation of data for 3-D objects modelling

Geometrical computer model of 3-D object is built with quadrangular faces. There is a possibility to take advantage of technical documentation of modelled object made in the CAD format. Data must be pre-processed before loading into the simulation software (reduction of some faces, replacing convex faces with concave ones, approximation of the face shapes with quadrangular ones). The way in which the object is segmented and the number and a size of faces have a large influence on the agreement of thermal signatures of the model and the modelled object. Using AutoCAD software the list of model's faces was made. The list was transformed into the format accepted by the simulation software FTTM. Fig. 2 shows geometrical grid of tank model made with AutoCAD software.

Temperature of the model's faces was described on the base of thermal images made by the thermal imaging system *Inframetrics 760*. Digital thermal images were transformed into the temperature matrix. Using Spyglass Transform software, the averaged temperature values of the object area were assigned to appropriate faces of the model. Due to experimental results, an average emissivity of object  $\varepsilon = 0,94$  was assumed.

The thermal image of the modelled object obtained with the procedure described above is shown in fig. 3.

### 4. FTTM simulation software

The FTTM simulation software enables to determine two-dimensional geometrical images of the object and the background for any angular field of view as well as for any direction of observation and location of the thermodetection system with respect to the observed object (fig. 4). A view of the control window of FTTM software is presented in fig. 5.

For a given set of input parameters, geometrical ray-tracing is used to determine 2-D projections of the object as well as related temperature and emissivity distribution. These are used to calculate the apparent radiance distributions.

Two theoretical thermal images generated by FTTM software are presented in fig. 6.

### 5. Results

The comparison between the total radiant intensities of the object evaluated theoretically and experimentally (fig. 7) shows that modelling of infrared signatures of 3-D objects using FTTM software is very effective and accurate. The FTTM is very fast and user friendly. The method allows obtaining infrared images without expensive and difficult to control experimental investigations. Currently the method is limited to the case of negligible influence of the Sun radiation.

### REFERENCES

- [1] ASCETA (J. S.), SHUMAKER (D. L.), executive editors - *The Infrared and Electro-Optical Systems Handbook*. Wasington, SPIE Optical Engineering Press, 1993.
- [2] GAUSSORGUES (G.) - *La Thermographie Infrarouge*. Paris, Lavoiser, 1984.
- [3] SEYRAFI (K.), HOVANESSIAN (S. A.) - *Introduction to Electro-optical Imaging and Tracking Systems*, Boston, Artech House, 1993.

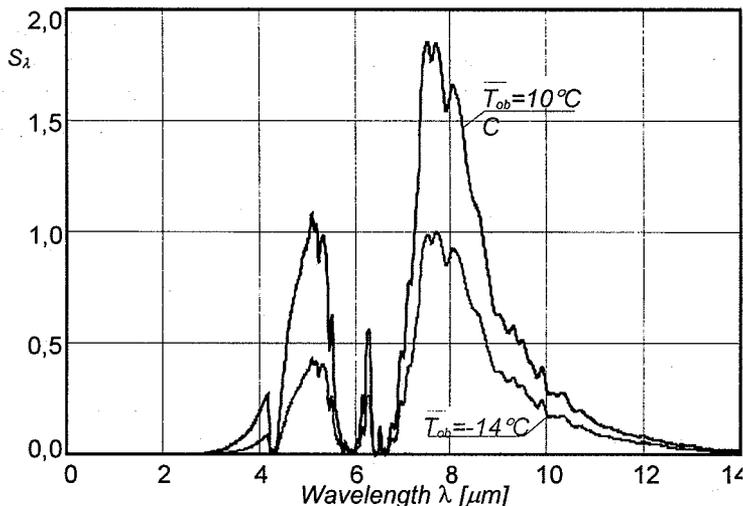


Fig. 1. Graph of function  $S_\lambda$  for two average temperatures of object

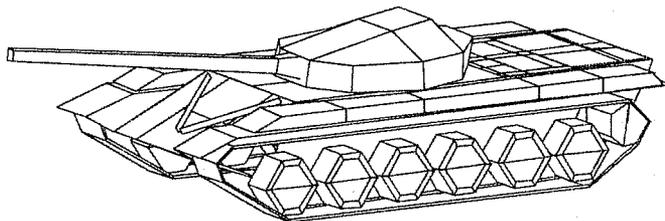


Fig. 2. Geometrical grid for tank model

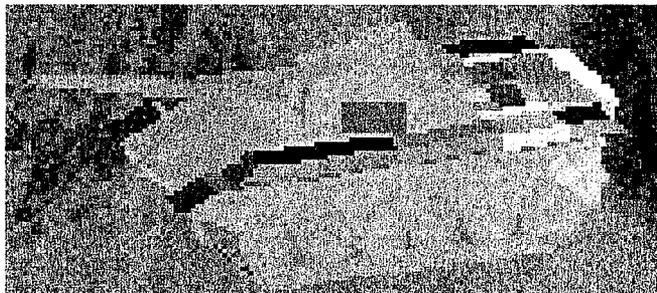


Fig. 3. Thermal image of the object generated using FTMM software

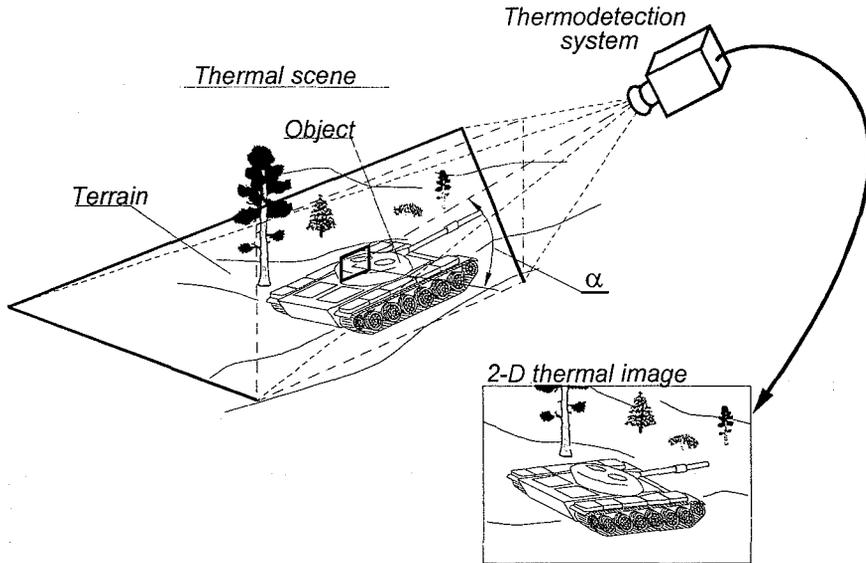


Fig. 4. Scheme of geometrical situation described in FTTM software

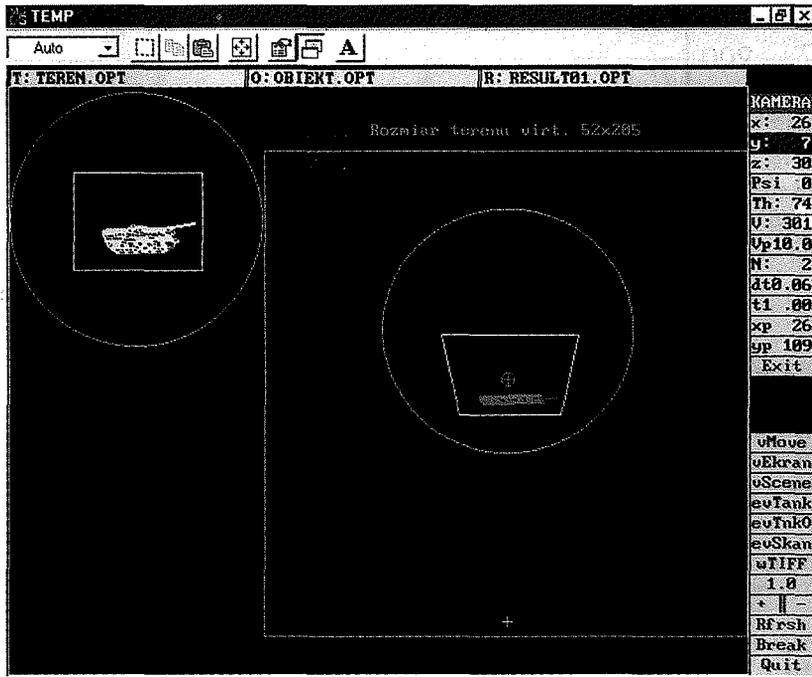


Fig. 5. The control window of FTTM software

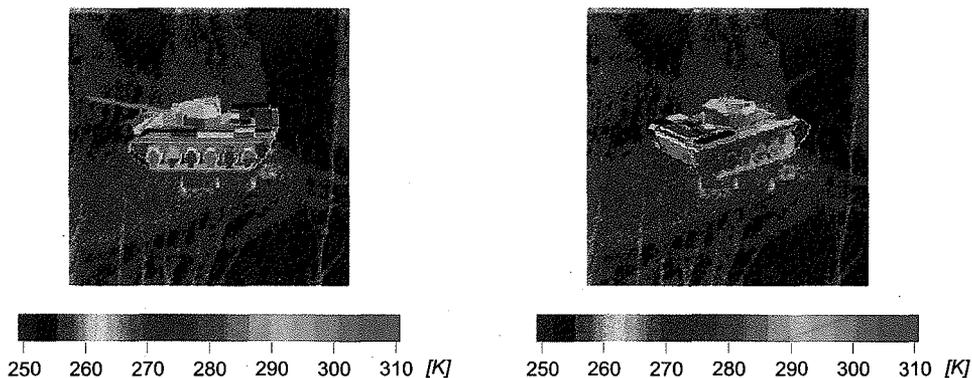


Fig. 6. Thermal images generated by FTTM software

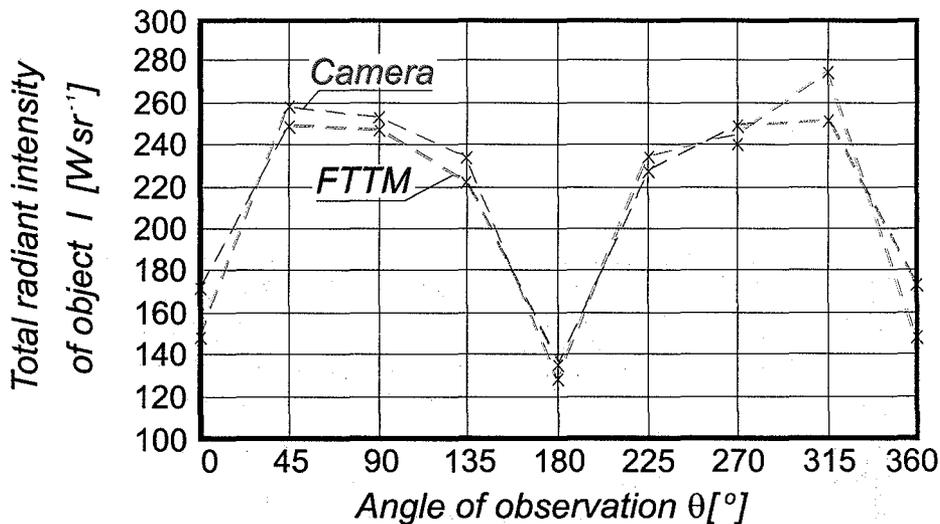


Fig. 7. Total radiant intensity of object simulated by FTTM software (FTTM) and experimentally recorded (Camera)