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Simulation analysis of uncertainty of infrared camera measurement and processing path

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Abstract

The paper deals with simulation analysis of uncertainty of the ThermaCAM 595 infrared camera measurement path and processing algorithm. The uncertainty of the processing algorithm is defined as the measure of the dispersion of the output random variable (the object temperature T_{ob}) around its expected value. It was assumed that inputs of the measurement model are represented by random variables with given functions of the probability density. Further, it was assumed that there are no correlations between inputs. For the analysis purposes it was assumed that the uncertainty of the processing algorithm is modeled by the experimental standard deviation of the output random variable. There are presented results of simulated components of the processing algorithm compound standard uncertainty for two distances between the camera and the object. The results of analysis can be useful in the numerical modeling of temperature distributions.

Keywords: Infrared thermography; Uncertainty; Simulation analysis

1. Introduction

During our contacts with users of thermovision systems, we were often inquired about the following issue: how to estimate accuracy of thermovision measurements when they have to be applied in the analysis of temperature distribution using the finite difference method (FDM), the finite elements method (FEM) or the boundary elements method (BEM) [1]. The answer on this question is not simple. Therefore we decided to write this paper. It is necessary to emphasize, that the problem is not quite solved in the literature. The authors describe it in a different manner. In this paper, the above problem is solved in accordance with the proposition of recommendation of expression of the measurement uncertainty created by International Bureau of Weights and Measures [2,3]. The paper is the first part of solution of this wide problem and it deals with the case, when the input variables of described measurement model are uncorrelated.

The error analysis of the temperature measurement with the use of thermovision system was the

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subject of [1,4,5]. In this work we conduct simulation analysis of the measurement model sensitivity based on the idea of the processing algorithm uncertainty. For the analysis purposes it was assumed that:

(1) The inputs of the measurement model are represented by uncorrelated random variables with given frequency distributions (the influence of correlations between inputs will be concerned in another paper). These variables will be further called input variables.
(2) The uncertainty of the processing algorithm is the measure of the dispersion of the output random variable around its expected value.
(3) The expected values as well as the dispersion of the inputs are modeled by parameters of these variables' distributions: the mean and the experimental standard deviation respectively.
(4) The sample estimators, i.e. the mean and the experimental standard deviation are consistent and unbiased estimators of the expected value and the standard deviation [2,3,6].

The simulations were carried out using original software developed in the Department of Microprocessor Systems, Control Engineering and Thermal Measurements at the Technical University of Częstochowa. The software was developed using MATLAB 6.5 and employs its built-in functions making possible generation of random variables representing the inputs of the model. In this work we investigate how the values of distributions of five parameters (described further) influence the parameters of the probability distribution of the processing algorithm output. In the simulations uniform distribution was used. The components of the processing algorithm uncertainty associated with contributions from individual inputs on the total uncertainty were determined in the research. The simulations made it possible to estimate of the determined distributions' parameters on the assumed confidence levels. The results are presented in data tables and graphs.

2. Processing algorithm. Measurement model

The processing of the measured signal in the infrared camera ThermaCAM 595 can be divided into following stages [7]:

- detection of the infrared radiation by the detectors array,
- linearization and temperature compensation of signals from individual detectors, called calibration of the detectors array or mapping,
- processing the compensated signal in accordance with an appropriate measurement model, conducted by the measurement path-processing algorithm.

In the work we assumed the following measurement model of the thermovision system [1,2]:

$$s = \varepsilon_{ob} \cdot P_{atm} \cdot s_{ob} + P_{atm} \cdot (1 - \varepsilon_{ob}) \cdot s_0 + (1 - P_{atm}) \cdot s_0, \tag{1}$$

where: s—signal corresponding to the overall density of the infrared radiation flux reaching the detector, s_{ob}—signal corresponding to the flux density of the object self-radiation, ε_{ob}—spectral emissivity coefficient of the object, P_{atm}—transmission coefficient of the atmosphere, s_0—detector signal corresponding to the density of the infrared radiation flux of the environment. This model is a basis of the processing algorithm.

The output from the algorithm (object temperature) can be obtained by converting Eq. (1) [2]

$$T_{ob} = \frac{B}{\ln\left(\frac{R}{s_{ob}} + F\right)}, \tag{2}$$

where: R, B, F—calibration constants of the camera, T_{ob}—object temperature. It is necessary to emphasize, that this temperature is not actual object temperature but it is an output from the algorithm. Coefficient P_{atm} plays a significant role in the measurement model (1). It is a function of three variables: relative humidity ω, distance from the object d and the temperature of the atmosphere T_{atm} [1]

$$P_{atm} = f(\omega, d, T_{atm}). \tag{3}$$

There are eight additional coefficients whose values are selected experimentally for each measurement range of the camera. The explicit function form of the model (3) is reserved by the camera manufacturer [8]. It was made available to the authors only for the research purposes and therefore cannot be presented in the full form in the paper.

On the basis of the above, the mathematical model of the temperature measurement can be specified as a function of five variables

$$T_{ob} = f(\varepsilon_{ob}, T_{atm}, T_0, \omega, d), \tag{4}$$

where: ε_{ob}—spectral emissivity coefficient of the object, T_{atm}—the temperature of the atmosphere, T_0—