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Uncertainty Evaluation of Temperature Measurement of Tissue Mimicking Material by Thermographic Cameras

熱画像装置による生体ファントムの温度測定の不確かさ評価

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1. Introduction

The thermographic camera is widely used for the measurement of the temperature elevation and for the determination of the maximum temperature position in the Tissue Mimicking Material (TMM) during the ultrasound irradiation by the ultrasound diagnostic equipment. Although an accurate measurement of the temperature elevation is important in evaluating safety and essential performance of the ultrasound diagnostic equipment, most users do not know about the intrinsic property of a thermographic camera to be considered when measuring temperature accurately. In addition, there is no document that specifies how to estimate the uncertainty during the measurement of temperature elevation of the TMM. Furthermore, IEC 60601-2-37 [1] only specifies the composition of the TMM and there is no data about the emissivity of the TMM, although the emissivity is one of the largest uncertainty source when measuring a surface temperature with a thermographic camera.

In this study, to confirm the intrinsic property of thermographic camera and to establish how to evaluate measurement uncertainty required to measure the temperature elevation of the TMM accurately, two thermographic cameras were evaluated at AIST at the specified temperatures using standard blackbody based on the agreement of the technology consulting with the Japan Electronics and Information Technology Industries Association (JEITA). The size-of-source effect (SSE) was also evaluated to confirm the influence of the source size. The spectral reflectance of the TMM with different surface conditions was also evaluated for the consideration of emissivity.

2. Experimental procedure

A commercially available two thermographic cameras were evaluated. One (TC-A) has a detector elements of 320 (Horizontal (H)) × 240 (Vertical (V)) pixels with a field of view (FOV) of 22° (H) × 17° (V) and the operating spectral range of 8 μm to 14 μm. The nominal measurement uncertainty is 2.0 °C in a temperature range of -40 °C to 120 °C. The other (TC-B) has the same number of detector elements with a FOV of 25° (H) × 19° (V) and the operating spectral range of 7.5 μm to 13 μm. The nominal measurement uncertainty is 2.0 °C in a temperature range of -20 °C to 120 °C. The detector types of both cameras are uncooled focal plane array (FPA) of microbolometers.

The thermographic cameras were evaluated using standard blackbody (Type: 7037, Fluke Corp.). The blackbody cavity has an aperture dimeter of 60 mm, cavity length of 300 mm, and a bottom cone angle of 120°. The inside of the cavity is coated with a black paint, resulting in the effective emissivity of higher than 0.999. The furnace temperature is provided by a calibrated platinum resistance thermometer (PRT), which is traceable to the ITS-90. The thermographic cameras were set in front of the furnace with the focal distance of 450 mm for TC-A and 400 mm for TC-B to become the spatial resolution of approximately 0.55 mm × 0.55 mm. Both cameras were evaluated at 0 °C, 23 °C, and 50 °C. The SSE was evaluated at 50 °C to confirm the influence of the source size.

The Fourier transform infrared spectrometer (FT/IR-6300, JASCO Corp.) equipped with an integrating sphere and a mercury cadmium telluride (MCT) detector was used for the evaluation of the spectral reflectance of the TMM for the wavelength of 2 μm to 15 μm. The reflectance was integrated over all hemispherical viewing directions including both specular and diffusive components. The emissivity was calculated from the following equation: “1 - reflectance = emissivity”. The TMM with the same composition specified in IEC 60601-2-37 was supplied by OST corporation.

3. Result and discussion

Table I shows the evaluation results of the thermographic cameras at 0 °C, 23 °C, and 50 °C and its expanded uncertainty. The uncertainty, presented in Table I, consists of the uncertainty of the standard blackbody furnace system and the evaluation of the thermographic camera. For the uncertainty of the standard blackbody, the standard

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uncertainty of the reference PRT, short-term stability of the furnace temperature, the effective emissivity of the cavity, etc. are taken into account. Details of the uncertainty budget are described in [2, 3]. As for the uncertainty of the evaluation for the thermographic camera, the dispersions of the signals, the repeatability of the measurements, and non-uniformity for the individual detectors are taken into account. The results indicate that those uncertainties are significantly smaller than the nominal measurement uncertainty.

Table I. Evaluation results of the thermographic cameras and its expanded uncertainty.

Eval.	TC-A		TC-B	
temp. (ºC)	Output (ºC)	Expand. Unc. (ºC)	Output (ºC)	Expand. Unc. (ºC)
0.00	1.53	0.30	0.32	0.16
23.00	23.95	0.25	23.71	0.15
50.00	50.64	0.38	50.84	0.17

Although the thermographic cameras were calibrated at the manufacturer before the evaluation at AIST, a large difference from the evaluated temperatures were observed. Differences in calibration conditions at the manufacturer and those at AIST can cause the difference in temperatures. For example, if the aperture size of the blackbody furnace used to calibrate the thermographic camera is different, different radiance signals are observed even at the same temperature. This is known as SSE, which is caused by non-ideal performance of the imaging optics. To confirm the effect of source size, the SSE of the thermographic camera was evaluated. Fig. 1 shows the SSE between each source diameter and the reference diameter of 60 mm for the thermographic camera of TC-B. From the figure, it can be said that if the thermographic camera is calibrated using a blackbody with an aperture size of 24 mm, the output signal obtained by the blackbody with 60 mm aperture gives 0.48 ºC

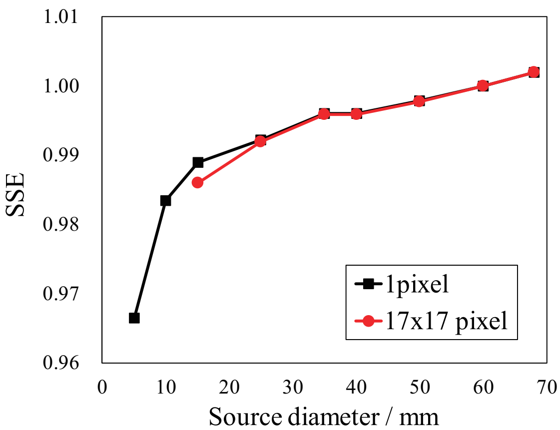

Fig. 1 Measurement result of the SSE for thermographic camera of TC-B.

higher temperature at 23 ºC. If we consider the result of the SSE, the difference observed at the evaluated temperatures can be explained to some extent. It should be emphasized from the results that the size of the radiance source must be considered when the temperature of the TMM is measured by thermographic camera.

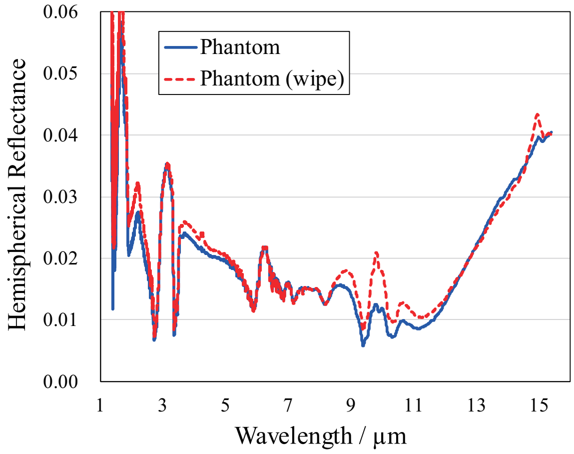

Fig. 2 Hemispherical reflectance of the TMM.

Fig. 2 shows the hemispherical reflectance of the TMM: the one surface was wet with 10 % propanol solution and the other surface was wiped lightly. The TMM with a slightly dry surface shows 1 % higher reflectance at a wavelength of 10 µm. The change in emissivity from 0.99 to 0.98 corresponds to a change in temperature about 0.6 ºC at a measurement temperature of 23 ºC with the same wavelength. This means the change in the surface condition becomes a large uncertainty source to measure the temperature of the TMM.

4. Summary

Two types of thermographic cameras were precisely evaluated using the standard blackbody. It was clarified how the results of the temperature measurement differ at the different measurement conditions, and the evaluated expanded uncertainties were significantly smaller than the nominal measurement uncertainty. The effect of emissivity change on the temperature measurement was also discussed from the results of the spectral reflectance of the TMM with different surface conditions. By taking these results into account, more accurate temperature measurement with precise uncertainty evaluation becomes possible.

References

1. IEC 60601-2-37:2007+AMD 1:2015, Medical electrical equipment - Part 2-37.
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