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Novel free emissivity dual color physics methodology at CIRA in the infrared ranges: applicability study from low to high temperature

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Abstract

Dual colour thermography is a non-intrusive temperature measurement technique based on local grey body hypotheses and on the application of a suitable pair of narrow band filters which allows to obtain the ratio between two input signals to the camera that only depend on the temperature and not on the emissive properties of the investigated surface [1]. The applicability at high temperatures of the dual colour thermographic technique has been also analysed by using an analytical model based on Plank's Law [2] integration and attenuated with the real transmission curves of sensors, optics, filters and attenuators.

1. Introduction

The use of IR thermography as radiometric technique is of great interest due to its potential as contact-less, real time and full filed inspection method. Using radiation techniques for quantitative temperature measurements can be difficult because of the dependency of the surface radiation on its emissivity, ε_{obj}, a surface property that varies with the temperature as well as with the wavelength and direction of radiation and depends on the state of the surface (in terms of roughness, heat or mechanical treatment, etc.) [1].

Dual colour thermography allows to estimate the object temperature without the need to know or assume the value of emissivity.

2. Theory

The total radiance $G_{obj}(T_{obj}, \varepsilon_{obj})$ can be evaluated by integrating the Plank's law for a real surface in the operating spectral range of the IR camera (λ' e λ'') and considering the transmissivity functions respectively for the sensor ($R_t(\lambda)$), for the optic ($R_{ot}(\lambda)$), for the applied filter ($F(\lambda)$) and for eventual attenuators ($A(\lambda)$).

$$G\left(T_{obj},\varepsilon_{obj}\right)=\int_{\lambda'}^{\lambda''}\varepsilon_{obj}\left(T_{obj},\lambda\right)\cdot R_t(\lambda)\cdot R_{ot}(\lambda)\cdot F(\lambda)\cdot A(\lambda)\cdot\frac{2\pi\cdot c^2}{\lambda^5\cdot\left(e^{\frac{h\cdot c}{k\cdot\lambda\cdot T_{obj}}}-1\right)}d\lambda \qquad (1)$$

Where λ is the wavelength of the radiation, c is the speed of light in the vacuum, h is the Planck's constant, k is the Boltzmann's constant and T is the surface temperature of the object. If $G_{n,1}(T)$ and $G_{n,2}(T)$ are the infrared radiations which reach the sensor (with a black body as source) when filters F1 and F2, the calibration curves can be obtained by calculating the ratio: $SR(T)= G_{n,1}(T)/ G_{n,2}(T)$, which under grey-body hypothesis, is a function of only temperature.

3. Materials and Method

The proposed model can be used to replicate the response of any IR camera of which transmission curves are known. Therefore, experimental data for model validation have been obtained by using a micro-bolometric IR detector operating between 7.5 µm and 14 µm (IR camera FLIR A655) and three different black bodies operating in a different temperature range, in order to cover the temperature range (from 50°C up to 2000°C). The analysis were performed in LW, MW and NIR infrared spectral ranges. In particular the first attempt, using the dual color technique, was carried out with two SPECTROGON filters, BP-10400-737 and BP-10500-775 centered respectively at 10.454 µm and , 10.464 µm applied in front of the FLIR A655 camera.

Then in order to perform experimental verification of the MW detected couple of filters, an aluminium plate temperature measurement was carried out. The surface plate temperature was measured using the SC5000 MW thermal camera by means of two narrow spectral band filters and the results compared with ones measured by four K-type thermocouples, taken as reference, positioned around the area focused by the IR camera. Finally in order to increase the sensitivity of the

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ratio between the signals collected at the two near wavelength, a camera with a working range starting from the NIR spectral range (i.e. working in 1.5-5 μm) was chosen. It consists of the multispectral camera FLIR ORION SC 7600 operating in MW and equipped with an integrated filter wheel which can rotate fast enough to switch in such a way to consider the thermal state of the object unchanged, thus, meeting the requirements needed to apply the dual colour technique [4,5,6]. The validated model has been used to determinate a suitable couple of filters to make the FLIR ORION SC 7600 operational in the experimental applications of dual colour technique. In order to achieve this, a virtual camera has been built using technical information provided by the developer. The filters have been selected between the commercially available ones and two attenuators were also chosen for pre-filtering to extend the temperature measurements range.

Together with emissivity curves ε(λ) at different temperatures available in literature for materials with different emissive behaviour, the best hardware configuration has been than implemented in the model to simulate and replicate experimental results. These results have been compared with those obtained by applying dual colour technique and an approach based on the knowledge of an average emissivity (classical technique).

The error analysis has been carried out putting the signals ratio detected by the virtual camera equipped with the filter indicated as F1 (2.097 μm) and F2 (2.210 μm) when the object is at temperature T_{real}, using the actual material emissivity curves, equal to the signals ratio for a black body in the same camera configuration. The dual color temperature T_{dc} derives from the inversion of this equivalence. T_{dc} has been found for several values of T_{real} and for two different couples of filters.

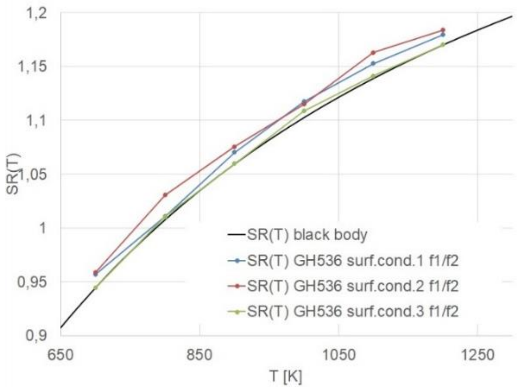

***Fig. 1:** SR curves for the couple of filters f1 and f2 without attenuator, obtained with interpolation of data coming from numerical simulation*

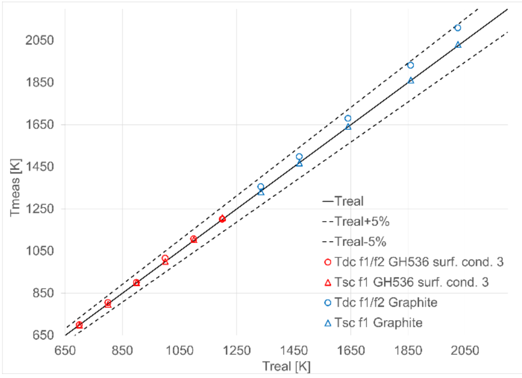

***Fig. 2:** Comparison between the two different approaches for high-emissivity materials*

4. Results

The results have shown that LW range presents limitation, infact the ratio between signals working in this spectral range was too insensitive to be appreciated by the camera. Investigation continued in MW spectral range. The following experimental analysis showed that this novel measurement methodology allows measuring the surface temperature with error lower than 5%, when appropriate narrow wavelength filters with small bandwidths was adopted. Finally in order to increase the sensitivity of the ratio between the signals collected at the two near wavelength, a camera with a working range starting from the NIR spectral range chosen.
The curves in Fig. 1 are obtained with the interpolation of data coming from dual colour simulation using the Orion SC 7600 as reference instrumentation. The goodness of the results can be assessed on the basis of how much better the signals ratio curve obtained analytically for the material approximates the signals ratio curve for a black body. In Fig. 2 is a comparison of the two different approaches. The results have been obtained using dual colour (circular indicator) and the single colour (triangular indicator) with correct average emissivity values. The continuous black line represents the real temperature and an error band of 5% is also reported (dashed black line) to graphically quantify the goodness of the measurements. It is evident that a perfect knowledge of emissivity trends ensures very low errors in temperature measurements with single colour technique, regardless of the emissivity class.

5. Conclusions

The choice of the best thermographic approach depends on the degree of knowledge of emissivity curves, therefore the dual colour technique is preferable in applications at high temperatures for aerospace applications, for which is not possible to characterize the emissive behaviour of materials.

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