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Visualization and Estimation of Temperature from Glowing Hot Object by Artificial Neural Network and Image Analysis Technique

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Abstract

This paper proposes alternative technique to estimate temperature of glowing hot objects with application of artificial neural network (ANN) and image analysis techniques. Regardless of using the cutting edge technology or sophisticated sensor such as 2D thermo-imaging equipment, an approximated thermo-imagery of the glowing hot object can be reconstructed by a well-trained ANN model together with image analysis in RGB color space. By training the model with data along the Blackbody locus from the CIE-1931 chromaticity chart and using three normalized individual monochromatic R, G and B images as inputs, the processed image having correlated color temperature (CCT) is finally obtained. Experimental results show that averaging error of the estimated temperature can be achieved with 10% for the reddish-yellowish hot objects and less than 10% for the bright-yellow one respectively.

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Keywords: Visualization; Image analysis; ANN; Thermo-imaging; CCT

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1. Introduction

Temperature is an important variable in industrial or manufacturing process. It has been used not only in process control but also exploited as monitoring parameter in a task of preventive maintenance. It is also the key observing parameter in power cycle such as combustion process, thermal equipment and heating object[1,2]. There are two approaches of temperature probing, intrusive and non-intrusive techniques. In case of inaccessible places or harsh environment where the object resided or equipment has installed, non-intrusive technique is necessity. It is therefore inevitably to use pyrometer, infrared thermometer or even the cutting edge technology of thermo-imaging camera. Particularly speaking to the devices, they were designed for measurement in point-wise and area-wise applications, i.e., measuring through 1D and 2D optical sensors respectively[3,4]. In addition, by theoretical point of view in black body radiation[5], those are, but only some delicate sensors that were designed to cover a long range of emissive spectrum[6] whereas spatial resolution is another factor that affects quality of measurement. As a result, there are a limited number of applications that such devices could be used appropriately and economically, for example, medical services[7]. Whenever there were requirement of application to visualize surface temperature of glowing hot object with a limit degree of accuracy, an alternative technique of estimating and visualizing temperature by ordinary 2D sensors is of interested[8]. This paper therefore proposes a technique to reconstruct and visualize temperature of glowing hot object in visible region of thermal radiation. By building and training ANN model with data from Blackbody radiation locus on standard colorimetric chart, CIE-1931, colour of glowing hot object in RGB has been used as inputs to the model. It is finally resulting in temperature estimator through image analyser. All relevant techniques, implementation and experimental results are of the following details.

Nomenclature

$B(\lambda,T)$	Spectral radiance as a function of wavelength and temperature, in $W\cdot sr^{-1}\cdot m^{-3}$
h	Planck's constant = $6.626070040\times10^{-34}$ J·s
c	Speed of light = 3.00×10^{8} $m\cdot s^{-1}$

2. Methodology

2.1 Thermal Radiation Model in Visible Spectrum

The object emits electromagnetic wave, as its temperature is above absolute zero in Kelvin scale, was modeled by Planck and known as Blackbody radiation[9] which spectral radiance is defined, i.e.,

$$B(\lambda,T)=\left(\frac{2hc^2}{\lambda^5}\right)\cdot\left(e^{\frac{hc}{\lambda k_B T}}-1\right)^{-1} \tag{1}$$

Where emissivity is equal to 1.0 in case of perfect blackbody and can either absorb or emit all wavelengths including visible spectrum[9]. In applications of non-intrusive thermometry, specific spectral response of optical sensor that complies with emissivity of thermal radiation has to be characterized[10]. However, it is impractical to apply this model directly since emissivity cannot be determined exactly for every wavelength. In contrary to the generic model, a few variant were developed and well approximated to specific spectral ranges rather than the whole spectrum[11]. For the long wavelength, it was approximated by Rayleigh–Jeans model[12,13], i.e.,

$$B_{RJ}(\lambda,T)=\frac{2ck_BT}{\lambda^4} \tag{2}$$

Whereas the case of short wavelength, Wien's law[12,13] is applicable with the promised accuracy, i.e.,