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Temperature determination by thermography: emissivity measurement versus estimation algorithms

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Abstract

Non-contact temperature measurement is very important for the control and inspection in different sectors of industry involving harsh environments, and an accurate measurement depends crucially on the emissivity determination. This work compares two possible methodologies to obtain accurate temperatures. Firstly, the emissivity is rigorously characterised in the laboratory and later used to correct the thermographic images. Secondly, by means of the so-called TES algorithms, approximations of both temperature and emissivity are obtained. Finally, both results are compared and the accuracy obtained together with the operational cost of the two processes and its readiness for industrial implementation are discussed.

1. Introduction

Temperature is perhaps the most critical parameter in many sectors of industry such as metallurgy, manufacturing, nuclear, petrochemical, solar and aerospace. Accurate temperature measurements are essential to manage process control, quality inspection and an overall plant performance, and the benefits of good temperature acquisition and measurement accuracy are numerous. In particular, the harsh environments of some industries require a non-contact temperature measurement, for which the emissivity of the material to be measured becomes an extremely important parameter.

In the TIR (Thermal Infrared) wave range, the resolution of the emissivity spectrum and the target temperature leads to an ill-posed problem where the number of unknown parameters is greater than the number of available measurements. In general, the approaches developed to solve this type of problem are collectively referred to as TES (Temperature and Emissivity Separation). In the industrial environment, these problems are generally treated with probabilistic algorithms, and each solution is usually tailored to a particular problem, what prevents from obtaining a generalisation that would work for all cases.

In this work, we present two approaches to obtain accurate temperature measurements. First, an emissivity function $\varepsilon(\lambda,\theta,T,Surface\_state)$ of the materials to be measured is rigorously characterised previously in the laboratory [1] and then, the temperature of the body is observed and appropriately corrected. Due to the high cost and difficulty of carrying out such a comprehensive and sophisticated analysis in an industrial environment, in the second approach various methods/algorithms (such as [2-4]) widely used in the industrial field are studied to obtain values for both emissivity and temperature with the minimum error at the lowest possible economic cost. Both results are compared among them, as well as with literature data on the emissivity of the studied material.

2. Experimental setup

A thermographic setup has been developed in order to test both approaches on a flat alumina sample of 60x60 mm. A FLIR A655sc long wavelength (8-14μm) thermal imaging camera with a 640x480 pixel resolution and the ResearchIR 4 software have been used to obtain the radiation data and process the images before further analysis. The setup has been designed with a minimum cost for the positioning of the sample, which allows measuring at different viewing angles of the camera from normal to 80°. Besides, two alumina samples with two different surface conditions (polished and ground) have been measured between 50 and 200ºC, placing a heat source at the back. The thermographic images treatment and analysis has been performed with Matlab.

3. Methodology

3.1. Corrections based on an emissivity function from laboratory

The alumina has been measured in the HAIRL radiometer [1] and an emissivity function has been fitted considering temperature, angle, wavelength and the surface state.

Once the emissivity function has been calculated, several experiments have been carried out to obtain the accurate temperature. For this purpose, different thermographic images have been taken in different experimental situations from which the radiance value has been extracted in each case. From these radiance data and by processing these images using the emissivity function in Matlab, the corresponding accurate temperatures have been obtained.

3.2. Correction by estimation of emissivity and temperature

In the last two decades, much effort has been devoted to developing estimation and modelling methodologies capable of providing solutions to cases where the number of unknowns exceeds the number of measurements, such as TES problems. Many of those studies focus on the maximum entropy principle to resolve this uncertainty. Liu, Junchi et al. [2] and Barducci, A et al. [3] argue that the maximum entropy condition is the least compromising hypothesis that can be made to overcome the lack of knowledge in ill-posed problems where it is not possible to obtain an algebraic solution to the problem.

Barducci, A et al. [3] present an algorithm known as MaxEnTES with a complex mathematical formalism where prior information on the expected variability of the temperature and emissivity of the observed targets is required. However, although the MaxEnTES algorithm is an innovative approach and works reasonably well in reconstructing the emissivity spectrum and target temperature, its calculation procedure is still complicated at a certain level.

On the other hand, in Rego et al. [4] work, the temperature calculation is based on a least-squared optimization method that compares the theoretical blackbody radiance from Planck's law and the measured raw data after radiance calibration.

In this work, the algorithms are implemented and the obtained emissivity and temperature values are analysed and compared.

4. Results

The results of both methodologies have been compared in terms of surface condition, temperature and angle, and both the results and their discrepancies between the two variants will be shown. In addition, the temperature accuracy and the economic costs together with industrial readiness of both methodologies will also be discussed.

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