XI National and II International Engineering Thermodynamics Congress

Paper Number: 27742

New methodology for temperature and emissivity estimation by the use of infrared thermography

Rafael Royo[1]

[1]Universitad Politècnica de Valencia, Address: Camino de Vera, s/n, Valencia, 46022, Spain, Phone: 34-618323321
e-mail: rroyo@ter.upv.es

ABSTRACT

A new method for the estimation of both parameters: surface temperature and emissivity is proposed and explained in this paper.

It is for its application on surfaces and materials with specular reflection, which in fact is more common in the infrared spectrum than in the visual range.

The use of the method does not need any type of contact with the surface, or the application of special coatings or putting electrical tapes, it is only necessary a usual calibrated infrared camera.

Some examples of the use of the new method are shown at the paper, and promising new developments are described.

Keywords: *Experimental procedures; temperature measurement; emissivity measurement*

1. Introduction

Infrared thermography use is extended worldwide and for almost every industrial application.

Qualitative thermography is quite useful and more than enough for many users that are interested basically in the analysis of the thermal patterns, for example in building applications to visualize thermal bridges in the façade. However, quantitative thermography is also fundamental, since in many applications the measurement of temperature is absolutely mandatory.

The standard procedure used to determine emissivity is known as the reference emissivity method It consists in coating the surface with a material with known emissivity, take the temperature on its surface and modify the emissivity on the sample of the tested material until the temperature reading coincides with the previous reference surface [1]. A specific method to estimate the emissivity of commercial windows glass is explained at the corresponding norm [2].

An exhaustive discussion about emissivity measurement procedures is presented on reference [3].

In some cases, it is impossible the use of this methods: if simply it is not possible to touch the surface for safety reasons or from any other cause.

This paper describe a new methodology to determine the temperature and emissivity of any surface with mirror like reflection, which in fact is quite most common in infrared range than in the visible one.

Useful advantages of the proposed method are:

- It is non-contact characterization, so it is an intrinsic safe procedure.
- It is not necessary the modification or coating of the surface with any material with known emissivity, as the common PVC electrical tape commonly used in many thermography applications.

2. Radiation fundamentals

First at all, it is necessary to consider that a calibrated infrared equipment only can measure temperature of opaque objects at the infrared range of the electromagnetic spectrum. In this way, the infrared camera could measure, for example, the surface temperature of a window glass, transparent in visible range but opaque in infrared interval, but not of polyethylene films, opaque in visible range but quite transparent in infrared.

The temperature measurement with a thermal camera is absolutely dependent on the compensation parameters, also named as radiometric or “object” parameters, introduced by the own camera user. In fact, the camera measures radiation, and the translation to an accurate surface temperature is determined by:

- Absorption from the atmosphere, the existing air between the surface and the camera
- Reflected radiation from the background, compensated by means of reflectivity and the parameter named as “apparent reflected temperature”
- Emissivity of the own surface

The latest parameters, apparent reflected temperature and emissivity are the fundamental ones to determine the real surface temperature with the infrared camera. The reflectivity value for an opaque surface is determined from the own value of emissivity introduced by the camera user as:

$$\rho = 1 - \epsilon \qquad (1)$$

The effect of both parameters, apparent reflected temperature and emissivity is critical for low emissivity surfaces, the typical situation when polished metal are studied, for example as protection for insulation layers or inside electrical boxes.

The physical relation used by the infrared camera to translate the radiosity *J,* radiation going out from the surface, to the temperature T , unknown surface temperature is the following one:

$$J = \varepsilon\sigma T^4 + (1-\varepsilon)\sigma T^4_{reflected} \qquad (2)$$

Where:

- J is radiosity, exiting or going out radiation from the opaque surface (W/m2)
- ε is the surface emissivity
- σ is the Stephan Boltzmann constant: 5.67E-8 W/m2 K4
- T is the unknown surface temperature (K)
- Treflected is the apparent reflected temperature (K)

Equation (2) is also quite useful, for example, to analyze uncertainties on the temperature measurement process: for example, for what combinations of emissivity, temperature of the surface and the apparent reflected temperature is possible the measurement process with the infrared camera. However, in this paper it is the fundamental expression used on the procedure that will be described.

3. Procedure to estimate emissivity and surface temperature

From the basis of equation (2), a new procedure to estimate emissivity and surface temperature is proposed.

The assumptions for the application of the method are:

- Mirror like reflective surface
- Uniform surface temperature
- Uniform surface emissivity

The first assumption could seem perhaps the most important limitation of the procedure, but it is not so problematic: surfaces are more reflective in infrared than in the visual range.

It is very common that an unfocused image of a reflective surface is confused with a diffuse reflection surface. Take into account that the plane of the surface and the plane of the reflection are not commonly the same ones, if one of them is focused, the other one will appear unfocused.

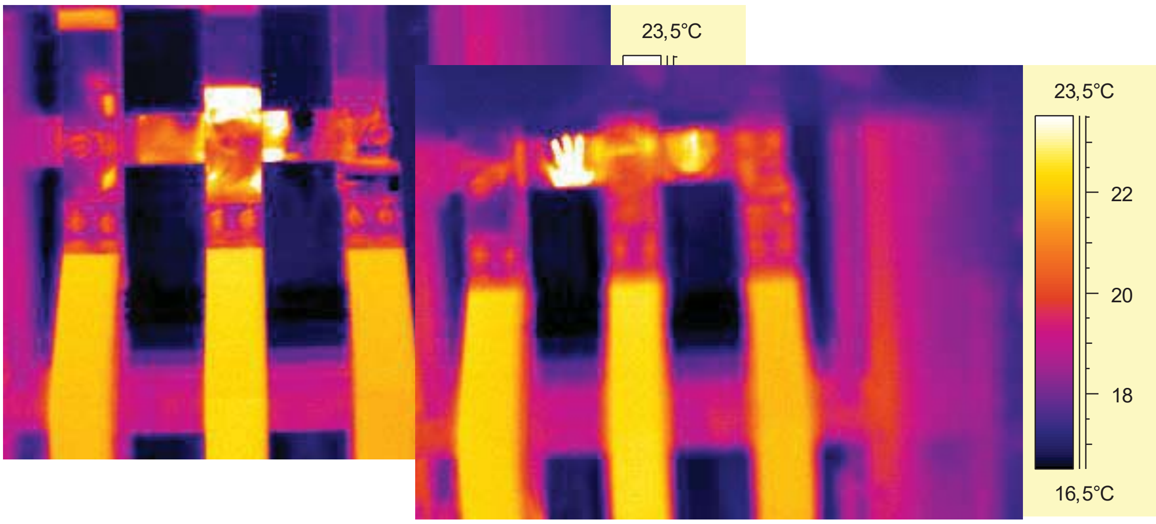

Figure 1. An unfocused image of a reflective surface is commonly confused with a diffuse reflection surface.

At equation (2), J, radiosity, is determined from the thermography, the infrared imagen taken with the thermal camera. T reflected is the apparent temperature of the reflected image source, which is directly measured with the same thermal camera assuming:

- Emissivity as 1
- Distance as 0

As for the definition of apparent temperature measurement describes.

Therefore, in this way, at the equation (2) there are two unknowns: emissivity ε and surface temperature *T:*

$$J = \varepsilon\, \sigma\, T^4 + (1-\varepsilon)\sigma T_{reflected}^4 \qquad (2)$$

If the equation is applied at least to three different cases using the same material but with different values of T reflected, it is could be possible to make a good estimation of emissivity and surface temperature.

This description is the base of the proposed procedure that in the next section will be applied to different examples of reflective surfaces.

4. Procedure to estimate emissivity and surface temperature. Practical case 1: low emissivity surface

Therefore, the procedure consists in applying the equation (2) to the same material surface but in three different situations where reflecting sources with different temperature are used. Therefore, at three different thermographies, the same material surface is reflecting three sources with different temperatures. From the infrared image, it is possible to measure the surface temperature on the sample where the source is being reflected. This surface temperature must be the ambient one, since the sample is not heated or cooled. Emissivity will be modified until the measured value correspond with an ambient temperature, and both values must be the same ones obviously for the three thermographies. With the described method, it is possible to make a good estimation of emissivity and surface temperature.

Firstly, the procedure will be applied to a metal plate, as shown at figure 2. Three different reflection sources are used:

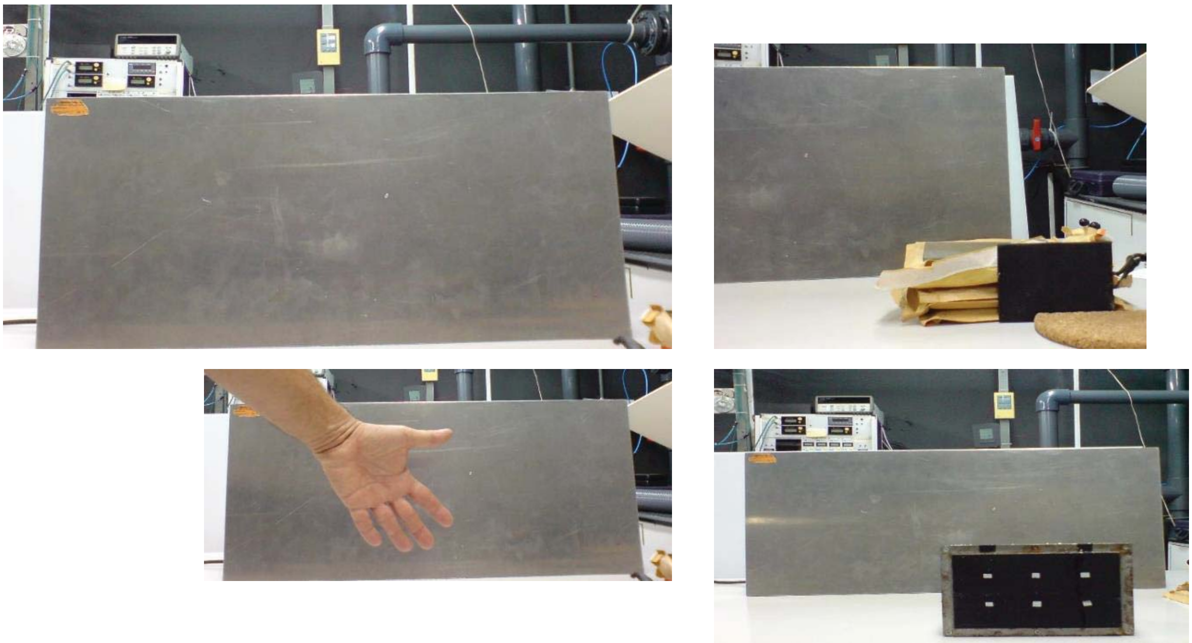

Figure 2. First characterized material: an iron plate. Three different reflection sources use: (1): a metal vessel containing cold water, (2): the own author hand and (3) a plane electrical resistance.

Figure 3. Apparent temperatures of each one of the three reflected references

1. A metal vessel containing cold water
2. The own author hand
3. A hot electrical resistance

Figure 3 shows the apparent temperature measured on the iron plate where every of this samples are reflected.

So from the infrared images the following parameters are known:

Apparent reflected temperature for each of the reflection sources:

- Cold body: 12,4 C;
- Intermediate temperature body: 35 C;
- High temperature body: 69,4 C

Reflected temperature on the surface:

- Cold body: 15,4 C;
- Intermediate temperature body: 33,6 C;
- High temperature body: 53,5 C

Real radiosity on the reflection of each body on the reflective surface:

- Cold body: 393,1 W/m^2;

- Intermediate temperature body: 502 W/m^2;
- High temperature body: 645,5 W/m^2

A simple calculation procedure is implemented in an Excel spreadsheet, where initial assumptions about emissivity and real temperature are carried out:

Estimated emissivity: 0,4 Estimated real surface temperature: 25,5 C

Calculated radiosity with the estimated emissivity and surface temperature:

- Cold body: 406,6 W/m^2;
- Intermediate temperature body: 487 W/m^2;
- High temperature body: 649 W/m^2

A mathematical parameter is implemented: the absolute value of the sum of the relative difference for the three reflection sources with the objective to minimize at the calculation process.

With the estimation used, this parameter is reduced until 4,6%

These results are estimated as reasonable good ones.

5. Procedure to estimate emissivity and surface temperature. Practical case 2: high emissivity surface

A conventional glass to protect a picture will be used as high emissivity surface to check the procedure.

Figure 4. Second material characterized, a commercial glass plate

The same reflection sources as at the previous practical case are used, the metal vessel containing cold water, the hand and the hot electrical resistance.

With the same used procedure, the results obtained are:

Emissivity 0,86 and surface temperature 26,3 C

The final objective of the calculations was to reproduce the measured radiosity with the same values of real temperature and emissivity, as at the previous case.

At this case the module of the sum of the relative error is even lower, 0,46%

These results are also estimated as very reasonable good ones: emissivity of commercial glasses are around 0,85 [3].

6. Conclusions

A new method for the estimation of emissivity and surface temperature from infrared thermography is proposed. The method is applicable for surfaces with specular reflection, which in fact are more common in the infrared spectrum. It is not necessary any type of contact with the surface, or the application of coatings or electrical tapes. Finally, any type of commercial infrared cameras are useful. Not laboratory equipment is necessary.

7. Future proposed developments

The assumption of surface with uniform temperature is fundamental at the described procedure.

To avoid the previous hypothesis that could be not adequate in some situations, it could be possible the superposition over the image of the surface with the reflection, the real image of the object that really is being reflected. Some infrared software are available for this objective.

From calculations, the radiosity of the reflected image will be subtracted from the radiosity of the surface.

The result will correspond exclusively with the real emission from the surface, from which the real temperature of every position of the surface will be at the end determined.

The result could be not uniform temperature if, for example, thermal gradient caused from real heating exist at the surface. This thermal gradients could be hidden at the initial thermography is the surface is highly reflective!

For this alternative procedure could be quite useful to project on the surface a special plate with uniform temperature. In this way, it could be quite simple to subtract the reflected radiation.

Therefore, to reflect a cold and a hot uniform plate could be very convenient to simplify the calculations.

REFERENCES

[1] Vollmer, M.; Möllmann. *Termografía infrarroja. Fundamentos, investigación y aplicaciones*. Editorial Universidad Politécnica de Valencia, 2014, pp. 56-57

[2] UNE-EN-12898 Norma Española. Vidrio para la edificación. Determinación de la emisividad, Julio 2001.

[3] Monchau, J.P. *Mesure d´émissivité por la thermographie infrarouge appliquuée ay diagnostic quantitative des structures.* Autre. Universit_e Paris-Est, 2013. Francais. <NNT :2013PEST1128>. <tel-00952076>

[4] Vollmer, M.; Möllmann. *Termografía infrarroja. Fundamentos, investigación y aplicaciones.* Editorial Universidad Politécnica de Valencia, 2014, pp. 45