THERMOGRAM CALIBRATION FOR INDUSTRIAL MATERIALS THERMOGRAPHY

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Abstract. *Thermography is a high resolution, non-intrusive technique for temperature measurement. In the paper is presented the detailed calibration data for a number of thermographic images made for industrial materials. The calibration will be done using SimTerm and Virtest to simulate a simple image and assess the Minimum resolvable temperature difference (MRTD) for a IR camera, and how it varies with the spatial frequencies. Also, using FLIR Tools to generate a report over an industrial thermogram using the assessed camera.*

Keywords: Thermography, Thermogram calibration

1. Introduction

In industrial applications, quality criteria must be applied to improve the manufacturing process, one of it being the need for equipment working at its maximum capacity.

There is an increasing demand for structural integrity, that is related to the quality of production, and Non Destructive Inspection monitoring and maintenance.

These inspection techniques must be cheap, easy and fast to implement and very reliable, thus as industrial materials are changing, so do these methods.

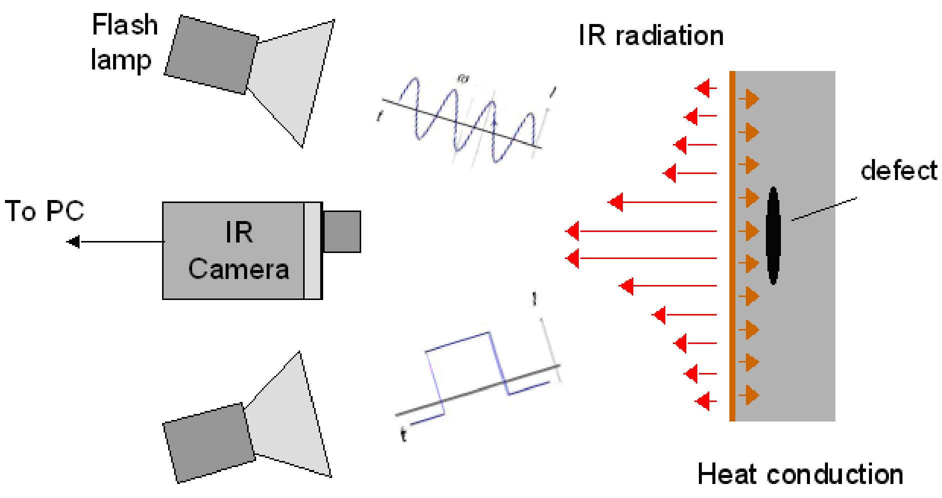

Fig. 1. Active thermography by reflection.

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One of the best methods for industrial inspection is Infrared Thermography (IRT), a non-contact technique which is based on the thermal contrast between the material and the surrounding area, like flaws and surface defects.

The principle behind IRT is to highlight the gradient of temperature that appears because of the imperfections and deteriorations in the material.

It may be used as a passive approach, by observing the surface, or as an active approach, by heating/cooling the material itself and measuring its response.

The active approach can be done either by transmission, or by reflection, depending on the positions of the heat source and the infrared camera with respect to the material that is to be examined.

Reflection is mostly used, as it has the advantage of being used, even if you can only see one side of the inspected item.[1]

2. Fundamental principles of infrared thermography

There are a few fundamental laws of Physics, which IR thermography is based on:

(1) *Planck's law of radiation* that describes the specific spectral radiation M_λ that comes from the idealized black body:

$$M_\lambda(T) = \frac{2\pi h c^2}{\lambda^5 \left(e^{\frac{hc}{\lambda kT}} - 1\right)} \tag{1}$$

where M_λ is the spectral radiant excitance in W·m^{-2}· μm^{-1}, T is the blackbody temperature in Kelvins, λ is the wavelength in μm, $h = 6.626176 \times 10^{-34}$ J·s is the Planck constant, $c = 2.9979246108$ m/s is the speed of the light in the vacuum, $k = 1.380662 \times 10^{-23}$ J·K^{-1} is the Boltzmann's constant.

Measurements and calculations are expressed in a spectral interval equal to the unit in which wavelength is measured. Wavelength in optical radiometry is usually expressed in µm therefore the spectral interval is also expressed in µm. However, we must remember that in practical measurements the spectral interval of the measuring device usually differ from 1 µm.

A blackbody is a body that allows all incident radiation to pass into it and absorbs all the incident radiant energy. This must be true for all wavelengths and for all angles of incidence.

A perfect blackbody at room temperatures would appear totally black to the eye, thus giving it its name.

(2) *Wien's Law* is actually a simplified version of the Planck law, assuming $\exp[(C_2/\lambda T) - 1] \approx [(C_2/\lambda T)]$:

$$M_{\lambda}(T) = \frac{c_1}{\lambda^5 \left({}^{c_2}/_{\lambda T} \right)} \qquad (2)$$

The relative error when calculation excitance using Wien's law is about 1.5% fpr wavelength of maximum radiation.

(3) *Stefan-Boltzmann law*, applied to the emission of a surface over all wavelengths, integrating the Planck Law, stating that the radiant power emitted from the surface of an object at the temperature T is:

$$I\ [\mathrm{W/m^2}] = \sigma T^4 \qquad (3)$$

where $\sigma = 5.67 \cdot 10^{-8}$ W/m^{2}K^4

(4) *Kirchoff's law of thermal radiation* makes a relation between emission and energy absorption, when a body absorbs much energy it also emits much energy.

It introduces the coefficient ε, as the part of the emissivity E, of a real body divided by the E_z of the black body. ε, takes values between 0 and 1 depending on the wavelength, temperature and surface of the body.

(5) *Lambert law* stating that if the radiance of an element of a surface is the same in all directions the next equation is true:

$$I(\theta) = I_n \cos\theta \qquad (4)$$

An ideal surface that fulfills this law is called a Lambertian surface.[2,3]

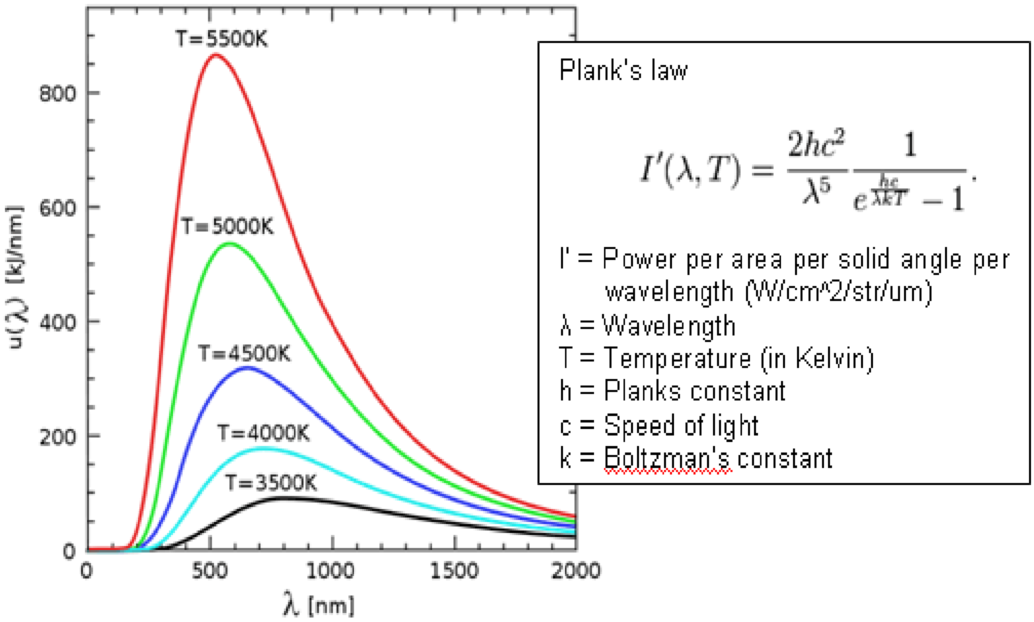

Fig. 2. Typical Blackbody curve described by Plank's Law.[4]

One of the key concepts we will follow in the paper is the Minimum Resolvable Temperature Difference (MRTD).

It is a measure of an infrared camera's ability to resolve a target. It is similar to a resolution test chart for a visible camera.

Usually it is made on a 4 bar target, assessing the minimum temperature difference at which it can be resolved. It changes with the spatial frequency of the bar target used.

It creates a curve of MRTD against spatial frequency which characterizes the performance of the imaging systems.

$$F(x) = \frac{\Delta t(i)}{f_s(i)} \tag{5}$$

$\Delta t(i)$ = array of just resolvable temperature differences,

$f_s(i)$ = array of spatial frequencies.[5]

3. Simulation

Using the computer program Simterm 3.0, a basic calibration thermogram will be generated, by simulating an infrared camera, which is pointed at a 4 bar target.

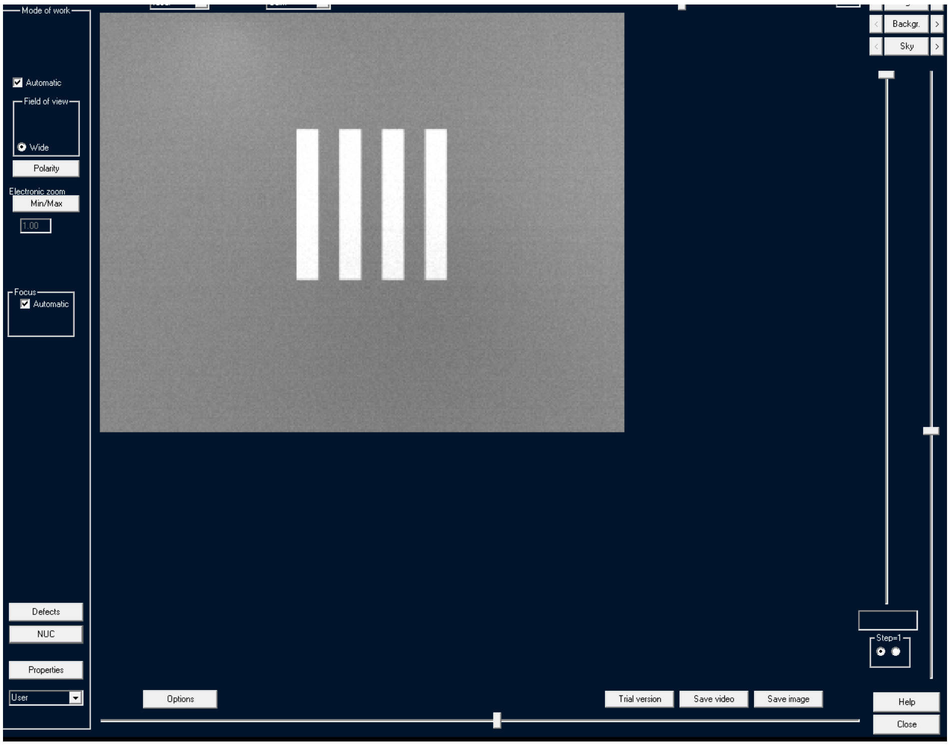

Fig. 3. 4 bar target viewed through an IR camera.

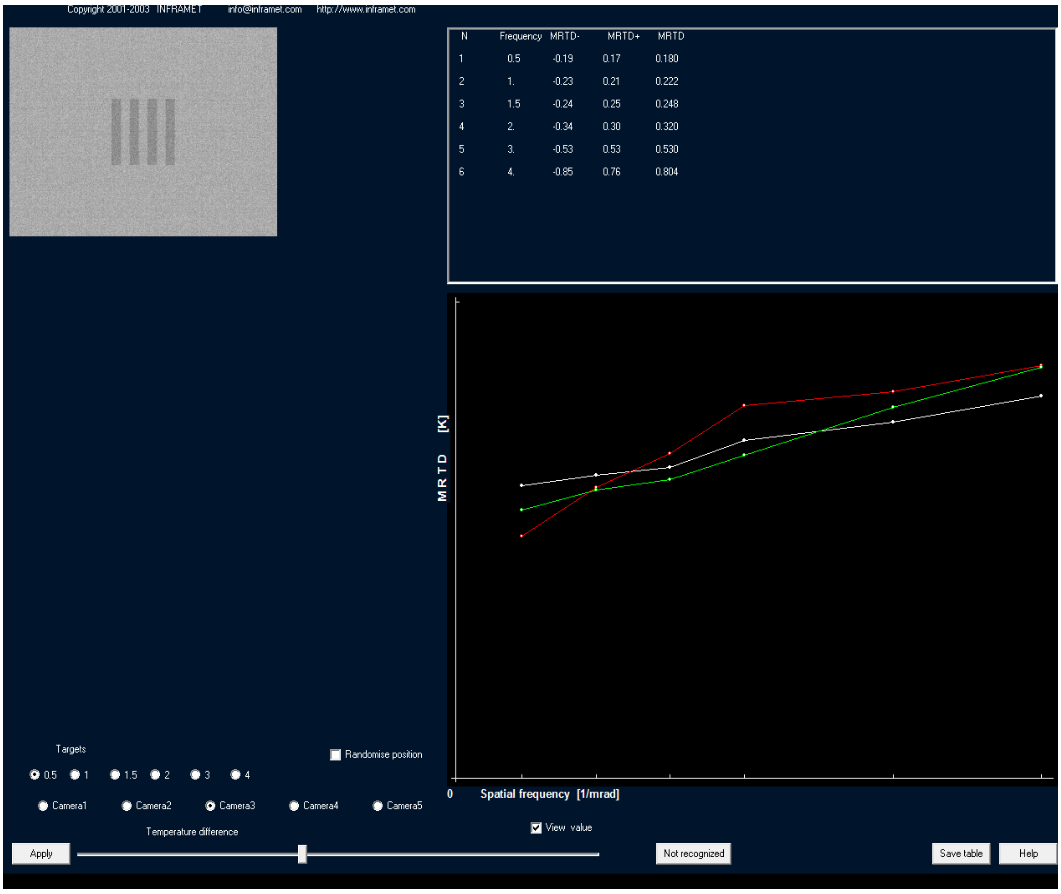

Fig. 4. 3 cameras MRTD curves.

Using VirTest, a test of 3 cameras has been done, showing the MRTD curves for each of them in Figure 4.

For frequencies of .5, 1, 1.5, 2, 3 and 4 cycles/mrad measurements of the temperature difference were done.

The simulation would show the image in the left corner of the screen when the temperature would be enough to be detected by the camera for the given frequency.

The first camera, pictured in white, can resolve frequencies at smaller temperatures for higher frequencies, but it’s worse than the second one, pictured in green, until a frequency of 2 cycles/mrad.

The red camera is the worst of the lot, needing a higher temperature difference to register the same frequencies as the other two.

The tables for the three cameras were as follows:

Table 1. White camera

N	*Frequency*	MRTD-	MRTD+	MRTD
1	0.5	-0.28	0.19	0.232
2	1.	-0.29	0.23	0.260
3	1.5	-0.32	0.24	0.282
4	2.	-0.36	0.38	0.372
5	3.	-0.44	0.46	0.452
6	4.	-0.63	0.56	0.594

Table 2. Red camera

N	*Frequency*	MRTD-	MRTD+	MRTD
1	0.5	-0.14	0.13	0.136
2	1.	-0.25	0.20	0.228
3	1.5	-0.33	0.32	0.324
4	2.	-0.56	0.51	0.536
5	3.	-0.80	0.44	0.622
6	4.	-0.79	0.85	0.820

Table 3. Green camera

N	*Frequency*	MRTD-	MRTD+	MRTD
1	0.5	-0.19	0.17	0.180
2	1.	-0.23	0.21	0.222
3	1.5	-0.24	0.25	0.248
4	2.	-0.34	0.30	0.320
5	3.	-0.53	0.53	0.530
6	4.	-0.85	0.76	0.804

Having chosen a camera based on the MRTD measurements we can calibrate and edit a thermogram, making a report using FLIR Tools.

FLIR is the acronym for Forward Looking InfraRed, the sensors installed in forward-looking infrared cameras use detection of infrared radiation, typically emitted from a heat source, to create a "picture" assembled for video output.

After opening a thermogram with FLIR Tools, we have the option to change the color gradient used to represent the temperatures using the slider at the bottom of the screen, or set it on Auto.

The reporting can be done either by selecting individual maximum and minimum points, like Sp1 – maximum of 53.9 ºC or Sp2 – minimum of 22.7 ºC, or create a rectangle which automatically shows which is the maximum and which is the minimum in the delimited area. Ex: Ar1 with a max of 52 ºC and a min of 26.3 ºC, showing an average temperature of 43.6 ºC

The other parameters of the thermogram are also show in the report, the emissivity, reflection temperature, distance to the object, relative humidity, atmospheric temperature, infrared window temperature and transmission.

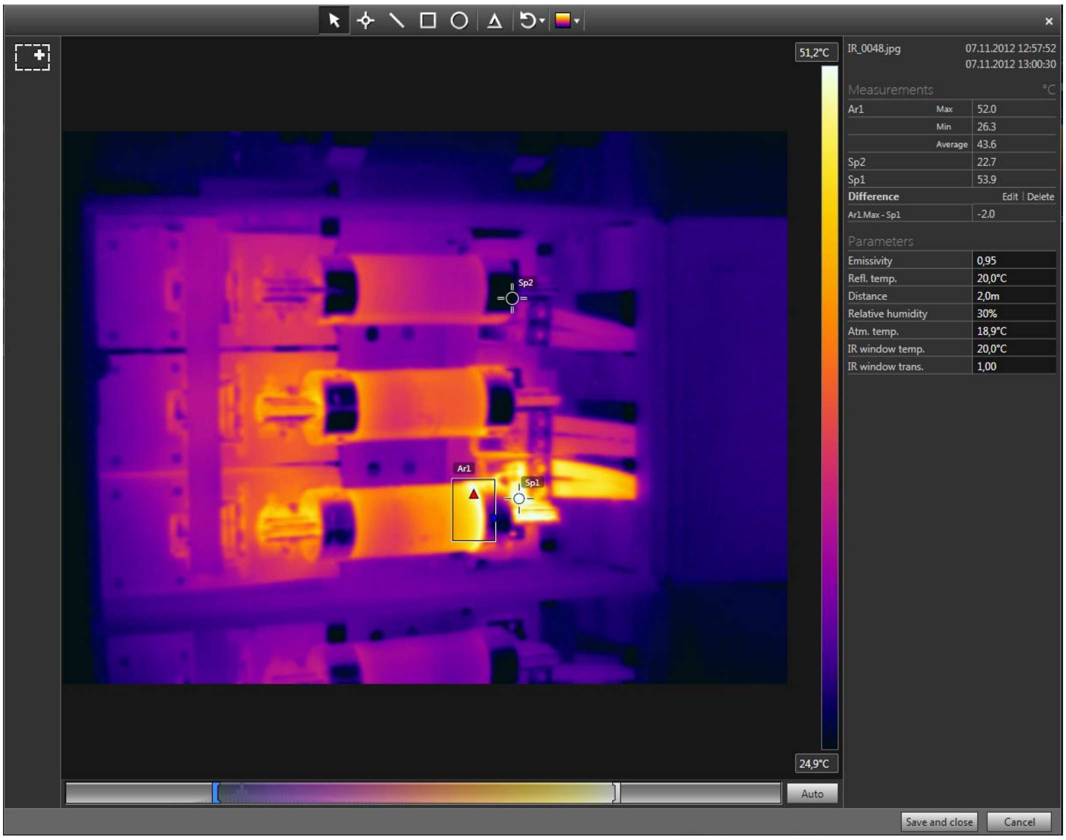

Fig. 5. Thermogram calibration and reporting using FLIR Tools.

R E F E R E N C E S

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