Infrared Thermography Imaging: Evaluating surface emissivity and skin thermal response to IR heating

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Abstract

Thermography imaging uses naturally emitted infrared radiation from the skin's surface. Established and evolving medical applications of thermal imaging include inflammatory diseases, complex regional pain syndrome, Raynaud's phenomenon, fever screening, cancer screening. Temperature distribution on body surface is influenced by a variety of physiological mechanisms and has been proven a reliable indicator of various disorders. The credibility of thermal imaging is subject to the quality assurance and measurement standardization protocols. The purpose of the present study was: a) To experimentally evaluate the emissivity of surfaces behaving in different ways in terms of thermal radiation emissivity, with a thermal camera, as a camera standardisation procedure, and b) To experimentally evaluate the characteristics of skin temperature increase caused by exposure to far infrared radiation. The results indicate a high accuracy of the thermographic method. Temperature increase rate in the anatomical area of the upper limb does not seem to depend on the location of the measurement spot. Absolute temperature values, though, do differ as expected due to different blood perfusion.

Key words: Infrared Imaging, Thermography, IR panels

Introduction

All bodies emit radiation as a function of their absolute temperature. There are four basic laws governing IR radiation emission: Kirchhoff's law of thermal radiation, Stefan-Boltzmann law, Planck's law, and Wien's displacement law. For a body temperature of 300^0K the emitted radiation is between 2 and 20 μm with a peak between 9 and 10 μm, corresponding to the infrared region of the electromagnetic spectrum, that extends between 0.7 and 1000μm [1]. An infrared camera can detect this kind of radiation and relate it with the emitter's temperature. Infrared imaging or thermography has wide applications in a variety of fields: Night vision, building inspection, medical imaging, astronomy, meteorology etc [2,3,4].

A typical thermographic camera detects radiation between 9-14μm and relates intensity of radiation with temperature. However, radiation is influenced by other factors than temperature, fact that limits accuracy of thermography [5]. For example, radiation depends not only on object's temperature, but is also a function of its emissivity. Also, radiation originating from the surroundings is reflected on the object, and both emitted and reflected radiation will also be influenced by the absorption of the atmosphere.

In an attempt to check the influence of a body's emissivity on temperature accuracy as interpreted by the thermal camera, we used a modified version of a typical physics experiment involving a Leslie's cube.

Furthermore, in order to evaluate thermal response of human skin exposed to infrared radiation, we obtained thermograms of human forearms exposed to IR radiation from the panel in different time points.

Materials and Methods

1.1.1. Thermal camera

The Flir T440 camera (FLIR Systems Inc., North Billerica, MA)[6] was used. The camera has a $25^0 \times 19^0$ field of view and an uncooled microbolometer focal plane array of 320×240 pixels. The spectral range of the camera is 7.5–13 μm. The thermal sensitivity is 0.045^0C at 30^0C ambient temperature. The absolute temperature measured depends on factors such as emissivity of the object, the ambient temperature and humidity. (Relevant parameters can be changed in the software after the images are recorded). The temperature accuracy is $\pm 2^0$ C and ±2% if all the variables (emissivity, temperature and humidity) are correctly set. The values selected for the parameters mentioned above are presented in Table I. For all main results of this study, relative temperature changes are used. Therefore, the inaccuracies in absolute temperature, due to dependence on emissivity or any other parameter settings are avoided.

Table I: Selected values of adjustable imaging parameters

Emissivity	1.0
Distance	1.0m
Temperature	29^0C
Relative humidity	50%

1.1.2. Leslie's cube

The original Leslie cube was devised in 1804 by John Leslie (1766–1832), a Scottish mathematician and physicist. It is a device used in the measurement of the variations in energy radiated from different surfaces i.e. for measuring thermal radiation as a function of temperature, colour and surface texture. It consists of a hollow copper cube (10 cm side length) that can be filled with warm water and includes an opening for inserting a thermometer or thermal sensor. The surfaces are: one black, one white, one polished and one unpolished.

1.1.3. IR heating panel

An infrared heating panel (Heatwave IR500), emitting at 10μm, was used as a conventional heating source. Infrared panels emit radiation absorbed by the human body, thus resulting in whole body heating. Their use as heating sources is expanding as they claim to be a cheap and efficient heating method.

The panel's dimensions are 120×40cm, nominal power of operation 500W and thermal efficiency of 90%.

1.2. Experimental setup

1.2.1. Thermal camera response

Leslie's cube was filled with water and then heated with a propane gas canister. The side faces of the cube acquired the same temperature within a short time period. Thermistors were placed to all sides of the cube in order to assess the actual temperature. The IR camera was placed on a tripod in a distance of 1 m from the cube and thermographic images of the cube's surfaces were obtained at 10^0C temperature intervals (as indicated by the thermistors).

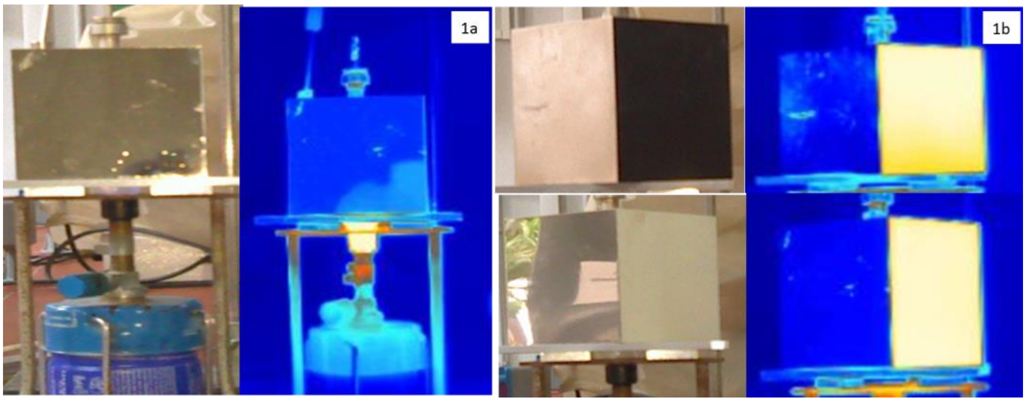

Figure 1. a) Heating of the Leslie cube; b) The four different surfaces of the cube.

1.2.2. Skin temperature variations caused by exposure to far infrared radiation.

The infrared panel was placed at 1.5 m from the volunteer's forearm, which was irradiated for 15 minutes. The forearm was supported on a horizontal surface. Three infrared images were obtained, one before and two 8 and 14 min after irradiation. The IR camera was positioned on a tripod at a distance of 1m.

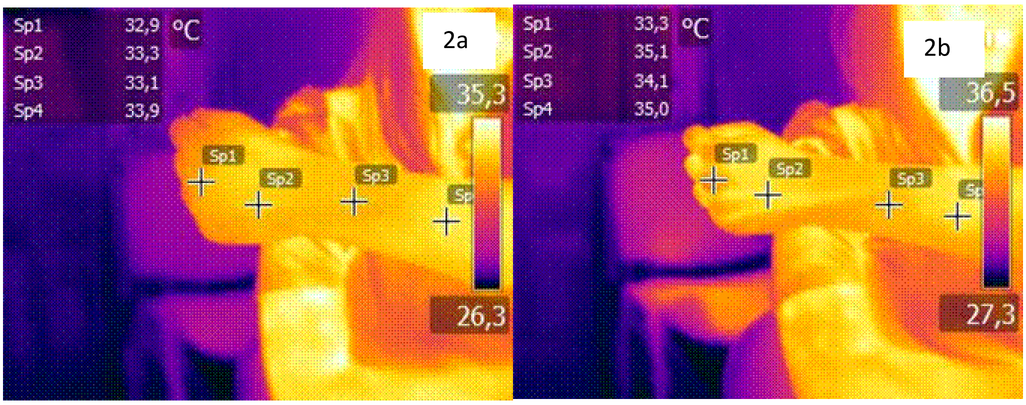

Figure 2. Four different anatomical spots where temperature values were obtained..

Results and Discussion

Figure 3 shows the temperature measured by the thermal camera as a function of the actual temperature of the four Leslie's cube surfaces. The slope of each line represents the emissivity of each surface. The black and the white surfaces have the higher emissivity while the polished and unpolished surfaces have low emissivity values. The black-painted and the white-painted surfaces are the most efficient emitters. Although we would suspect a difference in the absorption factor of the black and white surface due to their different color, their emissivity is virtually the same – an apparent contradiction of Kirchhoff's law. However, the terms white and black refer to the visible spectral range, i.e. the wavelength between 400 and 700 nm. In contrast, the intensity maximum of the emitted thermal radiation is in the wavelength range of about 7000 nm, a completely different spectral range. Table 2 shows the emissivity values for the four surface types obtained by literature.

Table 2. Emissivity values for the four surface types [7]

Surface	Literature values
Copper Polished	0,052
Black Epoxy Paint	0,80
White paint	0.8-0.9
Copper Matt	0,07

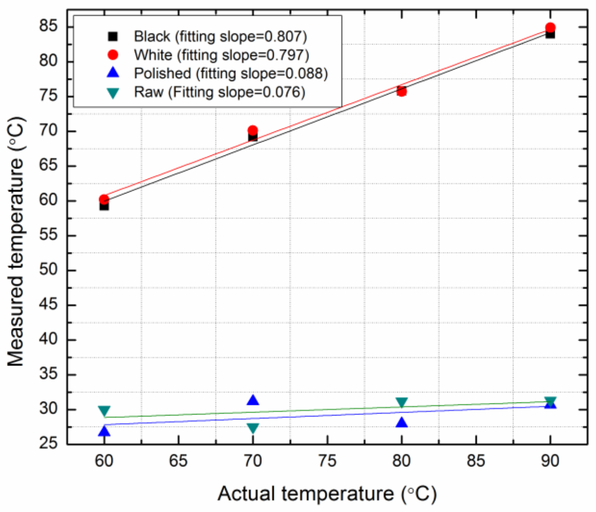

Figure 3. Temperature measured by the thermal camera as a function of the actual temperature (measured by thermistors) of the four Leslie's cube surfaces.

Figure 4 shows the increasing temperature of a volunteer's forehand as a function of exposure time under far infrared irradiation. Temperature values are obtained for four different spots. The rate of temperature increase is almost the same for all spots, indicating that there is no significant difference in IR radiation absorption rate by the different anatomical parts of the irradiated area. The differences in absolute temperature of the four spots is due to different blood perfusion

The surface temperature of the skin is not constant even in healthy subjects. It depends on several factors such as the environment (external temperature, humidity), clothing, the hour of the day, or the sex of the subject [8]. The body surface temperature is actually determined by the heat exchange between the skin and its environment, by the local metabolism and the blood circulation underneath the skin. The external thermal stimulations modify locally the temperature of the skin. Heat diffuses through the skin and along its surface by the mechanisms described above [9].

Human skin behaves like an almost black body with an emissivity of 0.96-0.98. Temperature increase rate in the anatomical area of the upper limb does not seem to depend on the location of the measurement spot. Absolute temperature values, though, do differ as expected. This is not due to the emissivity of the skin. Steketee [10] confirmed that there is no difference in emissivity between black, white or burnt skin. In this case, it is supposed to be due to a good blood circulation, in addition to the thickness and hardness of the cutaneous layer according to the observations made on the subject during the thermal image acquisitions.

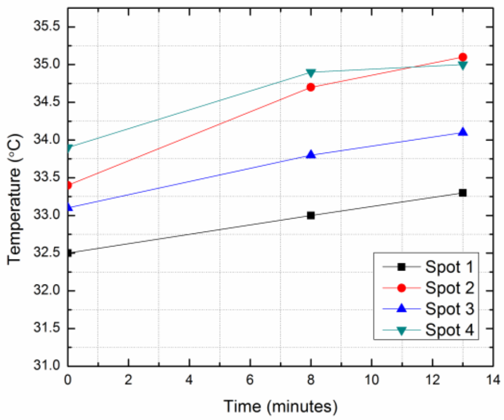

Figure 4. The increasing temperature of a volunteer's forehand as a function of exposure time under far infrared irradiation.

Conclusion

In this work thermograms of a Leslie cube and volunteers' forearms were obtained. Emissivity of the different surfaces of the cube were measured and compared to values available from literature. The results indicate a high accuracy of the thermographic method. Temperature increase rate in the anatomical area of the upper limb does not seem to depend on the location of the measurement spot. Absolute temperature values, though, do differ as expected due to different blood perfusion.

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