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Non-steady-state phenomena inspection through the use of infrared thermography

by Boris G. Vainer

Institute of Semiconductor Physics, Russian Academy of Sciences, Siberian Branch, 13, Lavrentyev avenue, Novosibirsk, 630090, Russia, E-mail: vainer@sun20.isp.nsc.ru

Abstract

One of the considered problems is devoted to the appropriateness of interpretation of diffuse thermal focuses in medical infrared thermography diagnostics. It is shown experimentally that some of usual diffuse foci can be arisen not by inflammation, etc., but by the heat lateral dissipation from the superficial blood vessels. A phenomenon of anisotropic lateral heat transport along the surface of a human body is discovered, and its specific parameters are measured. The variance infrared thermography method is presented. It works effectively when thermographic registration of non-stable, or non-steady-state, thermal objects, or their parts, is required.

1. Introduction

Modern infrared thermography gives possibility to registrate and store thermal patterns of high frame rate, with simultaneous keeping high temperature sensitivity (hundredths parts of degree). Such level of technique allows not only to examine complicated time-dependent processes in the infrared part of spectrum, but also to develop the corresponding thermographic methods themselves. One of important directions, where demands for fast thermographic measurements have been arising, is medicine. With application of computerized FPA-based IR cameras to this region, the potentialities of infrared thermography, as well as the efficacy of reached results, have been noticeably risen [1-3].

From the above, further thermographic study of time-dependent phenomena appears to be actual. A part of the present work is devoted to medical problems. Another one describes a method of acquiring new (additional) information about an investigated object by special mathematical treatment of fast-changed thermograms. This method is applicable not only to medicine, but also to different areas.

2. Interpretation of some diffuse foci of hyperthermia in medical infrared thermography

Analysis of diffuse thermal foci plays an important role in conventional medical infrared thermography. For a long time, physicians didn't pay appropriate attention to peculiarities of vascular patterns mainly due to the absence of apparatus of high spatial resolution at their disposal. Moreover, as far as the objects of about human temperatures is concerned, high spatial resolution (high complexity of FPA) alone is usually not sufficient to recognize small and sharply outlined details in a thermal target. High enough temperature sensitivity and contrast characteristic of the camera are also required. Otherwise the details can be blurred, and an advantage in high complexity becomes lost.

It has been known that diffuse and shapeless area of hyperthermia usually evoked a suspicion on a localized inflammation, or tumor. Examples of such kind of zones are illustrated in Fig.1. It is shown below, that the nature of the aforementioned areas, especially those detected by screening, could be principally different.

Fig.2 illustrates one of examples showing how the sharp pattern of the superficial vessels at a gluteal area is transformed to the diffusely heated region. By cursory examination, the warm zone in Fig.1d could be interpretated as a local inflammation. Actually, it is concerned with a dissipative process, namely, a tangential heat transmission laterally from the

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gluteal superficial venous network. Initially, the veins were filled with a hot blood (Fig.1a) after muscular load applied. Another example is shown in Fig.3.

In the diagnostics, it is well known that hypothermic foci have no less importance than hyperthermic ones (especially it is actual in mammology). From this standpoint, the problem in question could appear to be actual also for interpretation of some diffuse foci of hypothermia. A typical thermogram illustrating a possibility of examination both hot (bright) and cold (black) vessels by modern FPA-based IR detectors is presented in Fig.4. The thermogram is measured with the help of IR thermograph similar to described in [4].

An example which combines both focal and vascular symptoms is presented in Fig.5. In the similar cases, it could be recommended that before thermographic investigation, organs, or tissues, have to be previously loaded. It is needed to reveal correctly the pathological behavior of object.

3. Non-isotropic heat transmission along the surface of a human body

The phenomenon of lateral heat transport (Fig.1,2) gives birth to a question: which of mechanisms is responsible for this. Probably, two effects can play a dominant role. First, it is a usual conductive heat exchange between neighbouring tissues. It could be expected that this mechanism is most likely isotropic due to the fact that the heat conductivity factor of the superficial layer of a human body is uniform enough. Second, it is blood-vessels-aided spread of heat. The last mechanism need not be isotropic.

Fig.6 represents a vertical section of three consecutive thermograms taken from Fig.1. It is intriguing that the propagation of heat front away from surface major vessels is non-isotropic along the surface. In the presented case, propagation vector of heat transfer is directed upwards (i.e. oriented proximally). Analogous graphic, which was plotted for horisontal section, showed that heat front was spread to frontal direction (in thermograms: to the left). On the basis of data shown, the tangential component of the velocity of heat front propagation is estimated as 3.5 mm/min. The average rate of skin maximum temperature decreasing is found to be equal to about 0.4˚C/min.

4. Variance IR thermography

Possibility to use IR camera with the operating speed of at least some tenths frames per second allows to realize thermographic method of measurement which is presented below.

Following the method, each i-th pixel of the displayed image is formed by a mean-square deviation ΔU_i of photo-response U_i received over the time t from the i-th cell of IR detector (variance U_i):

$$\Delta U_i = \sqrt{\overline{U_i^2} - \overline{U_i}^2}$$

Instead of U_i , in the formulas, temperature T_i may appear as converted U_i . The value of t (i.e. the duration of one measurement) is dependent on the speed of observable process. Usually it is of the order of one second. An important point is that with the technique described, in the final picture just variable parts of thermogram stand out sharply against the stable ones. This method can be useful for the investigation of processes in which the fast fluctuations, or monotonous change, of temperature take place in the separate fragments of the target. The examples are an oscillation, or movement, of heated objects, non-uniform heating, or cooling, various of physical bodies, etc. In medicine, the presented method could serve for the quantitative control of the diseases which have included the involuntary importunate motion syndrome.

Two variance-type thermograms are presented in Fig.7. Here, the areas of stable temperature ($\Delta U_i \approx 0$) look black whereas the spatial zones of variable temperature are marked as bright. In Fig.7a, the pronounced profile line resulted from quiver. In Fig.7b, the drying of the preliminarily moistened section of hand has caused a well-defined splash of light.

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5. Conclusion

Modern IR cameras which are characterized by simultaneously high operating speed, themperature sensitivity, contrast of image, and spatial resolution (usually they are the cameras with FPA-type detector) allow to revise some of the former methods in medical infrared thermography. The analysis of thermograms has to be partly switched from terms of diffuse foci to terms of superficial vessels.

Investigations made in the present work have allowed to discover the phenomenon of anisotropic lateral heat transport along the surface of a human body and to estimate a velocity of heat front propagation (3.5 mm/min), and average rate of skin maximum temperature decreasing (about 0.4˚C/min). The application of infrared thermography to the investigation of the above-mentioned non-steady-state processes could bring new information about heat transfer mechanisms in a human body as well as about the peculiarities of blood microcirculation within superficial layer.

The proposed method of variance infrared thermography is effective for eduction of the parts of an object which were affected by temperature changes in the process of measurement. In addition, if during an interval between two consecutive thermograms the object is returned to its initial thermal pattern, the fact of its transitional thermal drift remains unnoticed by the traditional means of measurements. At the same time, the variance method is able to disclose this fact because it is based on the registration of squares of the deviations. It is evident that the described variance method is applicable in some cases not only to IR region of spectrum but also to different spectral sections of electromagnetic radiation.

References

[1] HEAD, J.F., LIPARI, C.A., F.WANG, and ELLIOT, R.L., ”Cancer risk assessment with a second generation infrared imaging system.” In: Infrared Technology and Applications XXIII, Bjorn F. Andresen, Marija Strojnik, Editors, Proc. SPIE, 3061, 1997, p 300-307

[2] VAINER, B.G., “High-resolution medical infrared thermography: new possibilities”, Vrach (Physician), 2, 1999, p 25-27 (in Rus.)

[3] VAINER, B.G., “FPA-based infrared thermography systems in medicine”, Vrach (Physician), 10, 1999, p 30-31 (in Rus.)

[4] KURYSHEV, G.L., KOVCHAVTZEV, A.P., VAINER, B.G., et al., “Medical infrared imaging system based on a 128 x 128 focal plane array for 2.8-3.05 μm spectral range”, Optoelectronics, Instrumentation and Data Processing (Autometria), 4,1998, p 5-10

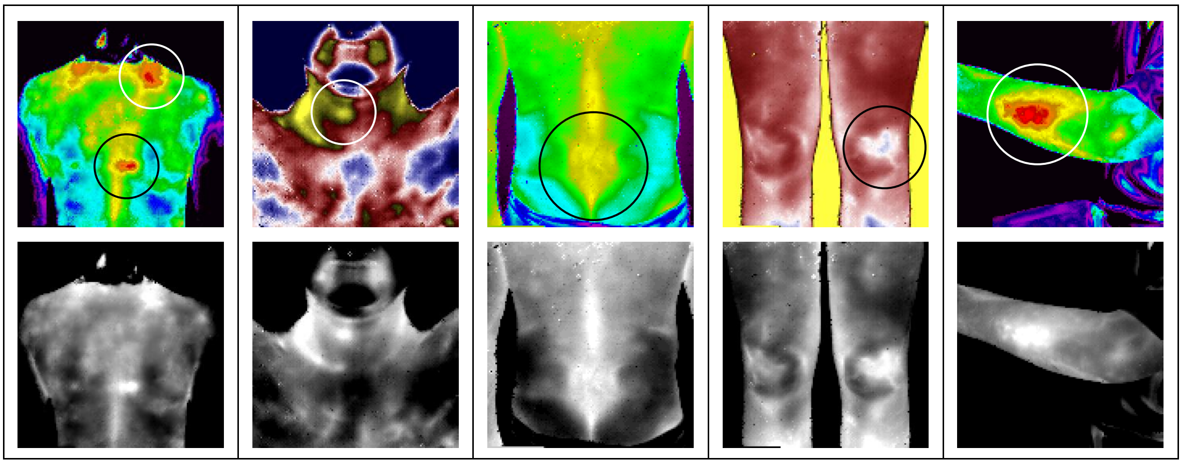

Figure1 : Foci (examples): the centers, or the starting points, of the disease processes.

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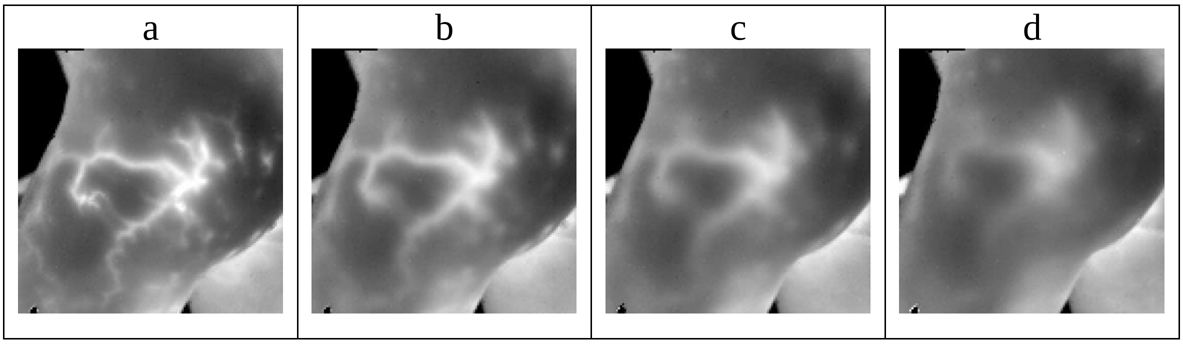

Figure 2 : A heat transport induced by superficial hot veins (the veins was heated in process of muscle exercise).

Figure 4 : White (warm) and black (cold) vessels of the hand.

Figure 5 : Combined (diffuse and vascular) focus in the anterior region of a knee.

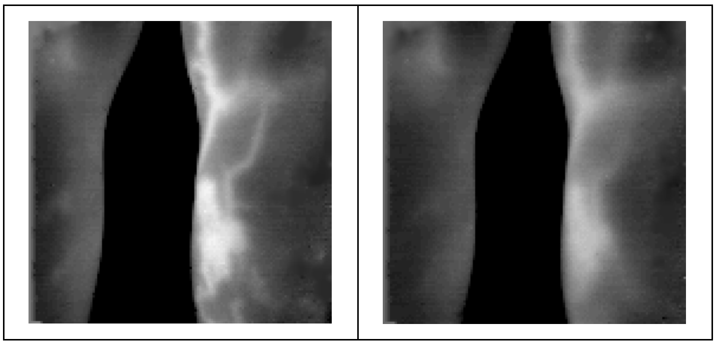

Figure 3 : Lateral heat transport (particular case). Time interval between thermograms is equal to 3 min.

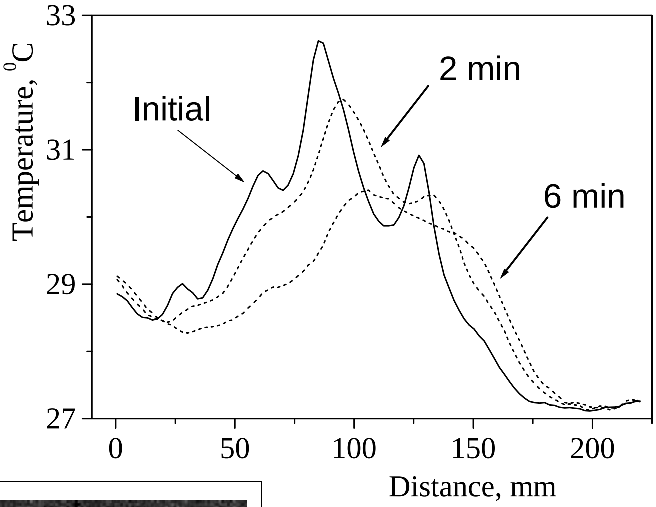

Figure 6 : Time-dependent distribution of skin temperature (constructed from the data of Fig.2).

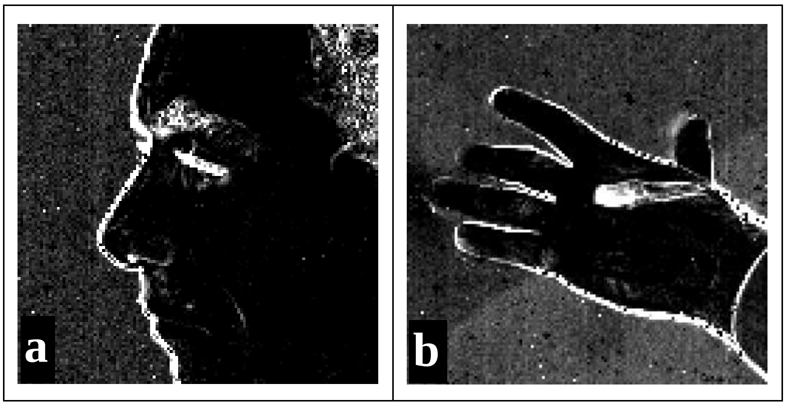

Figure 7 : Two variance-type thermograms. To obtain one, about thirty frames have to be acquired and processed.