Human infrared thermal imaging technology and its clinical applications

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With improvements in infrared camera technology and the promise of reduced costs and noninvasive character, infrared thermal imaging resurges in medicine. The skin temperature distribution of a healthy human body exhibits a contralateral symmetry. Any disease inside body is associated with an alteration of the thermal distribution of human body. So human thermography is of unique value in studying the physiology of thermoregulation, diagnosing some diseases or evaluating the situation of human health. The physical principle of human thermography and its clinical applications are dicsussed. The latest progress of thermography, thermal texture maps (TTM) and its effectiveness are introduced.

OCIS codes: 110.6820, 110.3080, 170.0170.

Human body temperature is a long established healthy indicator. One takes on a thermal symmetry of skin surface temperature in healthy state. Any abnormalities such as malignancies, inflammation and infection may cause a local uniformity in temperature, which show as hot or cold spots. Infrared thermal imaging is a noninvasive technology, which detects the natural thermal radiation from the body and has been used in medicine since early 1970s. However, thermography has declined in medicine in the last two decades probably because of its increasing applications in military attracting too much people's attention. Until 1990s, especially for great improvements in infrared sensor and computer technology, thermal infrared imaging resurges in medicine for its many advantages compared with other imaging technology [2,4]. Clinical use of thermal abnormalities has thus advanced from empirical thermography, which uses thermal images primarily as a qualitative descriptive tool, to the clinical science of thermology, a quantitative tool to study the physiology of thermal behaviour and to elucidate pathophysiologic processes that can not be readily probed by any other means. Thermography can now be used to attain a better understanding of many disease processes that manifest thermal abnormalities, and consequently use thermal imaging information not only to recognize pathology but also to manage disease better[2−7].

All objects at temperatures above absolute zero emit electromagnetic radiation spontaneously, which is known as natural or thermal radiation. The emissive power of a black body E_{b_υ} is the energy of linearly polarized radiation within the frequency interval υ to $\upsilon + d\upsilon$, in watts per steradian per square meter of surface per Hz. By definition, a black body absorbs all incident radiation and radiates in a continuous spectrum according to Planck's law

$$E_{b_\upsilon} d\upsilon = \frac{h\upsilon^3}{c^2(\exp(\frac{h\upsilon}{kT}) - 1)} d\upsilon, \quad (1)$$

where h is Planck's constant, c is the velocity of light, k is Boltzmann's constant, and T is the absolute temperature. The law may also be expressed in terms of wavelength intervals. The Planck energy distribution function has a well-defined maximum at a frequency, which is a function of temperature and decreases quickly on the high frequency side and rather less so on the low frequency side. Integration of the Planck function over all frequencies leads to the Stefan Boltzmann law for the total emissive power from a black body E_b,

$$E_b = \sigma T^4, \quad (2)$$

where σ is the Stefan-Boltzmann constant.

The emissive power of a black body decreases exponentially with temperature, and the wavelength of maximum emissive power moves to longer wavelengths as the temperature falls in accordance with the Wien's law

$$\lambda_{max} T = 0.002897, \quad (3)$$

where λ_{max} is the wavelength (in meters) of the maximum emissive power at temperature T (in K). The emissivity of human skin is more or less constant at a value of 0.98±0.01 between vavelengths from 2 to 14 μm for black skin. Thus, human skin behaves as a physical black body in this wavelength region. Furthermore, Steketee confirmed that there is no difference in emissivity between black, white and burnt skin, whether measured *in vivo* or *in vitro*[4]. An infrared thermograph is a record of the temperature distribution of the outer surface layer of the skin, which is affected by both internal and external factors. The internal factors may be pathological or physiological, while the external factors are a function of ambient conditions, such as temperature, humidity and air flow. The majority of the detected infrared radiation comes from the top layer of the skin, which means that environmental factors are very important. However, if environmental conditions can be adequately controlled, heat emission from the skin surface is mainly determined by the underlying cells metabolism activities. The correlation between skin temperature and underlying diseases was first successively used to identify breast diseases.

In thermal diagnostics, accurate correlation between the thermal image on skin surface and interior human body pathophysiology is desired, in other words, the relationship between the surface skin temperature distribution and interior heat source is desired. Up to now, many numerical methods, such as the finite element method (FEM), the finite difference method (FDM) and the boundary element method (BEM) have been successfully presented to solve this problem[8]. However, all these methods are extremely time-consuming, which limit them to be used in practice. Body surface temperature distribution is the superposition of all kinds of heat sources inside body, which transfer to the surface in some probabilities. It refracts the metabolism status of the cells of human tissue organs. Herein, we discuss a novel approach, thermal texture maps (TTM) technology based on thermal-electrical modeling, which is proposed by Liu *et al.*[1]. Following this method, a relationship between the body surface temperature and the interior heat sources can be easily established.

To describe the heat conduction from the heat source or the heat radiation temperature $T(x)$, a thermal-electrical model shown in Fig. 1 can be made, where the temperature corresponds to the voltage[1]. To describe the heat conduction from the heat source or the heat radiation temperature $T(x)$, a thermal-electrical model shown in Fig. 1 can be made, where the temperature corresponds to the voltage[1].

$$T(x) = \sum_{x=-n}^{n} [U_{\mathrm{S}} - \frac{\sum_{I=1}^{n} R_i}{R_{\mathrm{S}} + R_{\mathrm{A}} + \sum_{I=1}^{n} R_i} \times (U_{\mathrm{S}} - U_{\mathrm{A}})], \tag{4}$$

where n=int$(\frac{D}{R_0 \cos\alpha})$ is the number of resistors, D is the depth of the heat source, and R_0 is the unit heat loss in a certain medium or the heat resistance; U_{S} and R_{S} are the equivalent voltage and heat resistance of heat source respectively; U_{A} and R_{A} are the equivalent voltage and heat resistance of environment respectively; R_n and C_n are the unit heat resistance and heat capacity of tissue along radiation direction. TTM is a structured interpretation technique based on an equivalent heat transfer model — thermal-electrical model, which enables one to visually identify and obtain an approximate strength and depth of an abnormal ball-shape heat source[1,2,6]. TTM is an emerging infrared imaging technology. It has been successfully used in clinic diagnostics or diseases prediction, especially for early state of cancer and the status of human health. Many articles have reported the effectiveness of TTM technology[3,6]. Here, we focus on the method to detect early the prostate disease by use of TTM.

Prostate diseases including hypertrophy and cancer are common in older men. The National Cancer Institute of USA says that more than seventy percent of men with the disease are age sixty-five or older. The W.H.O. says that about two hundred fifty thousand men each year die from prostate cancer. The death rate is about ten times higher in Europe and North America than in Asia.

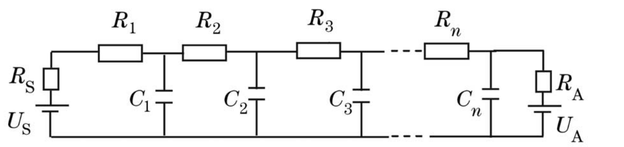

Fig. 1. One-dimensional equivalent thermal-electrical model of heat transfer.

Scientists are not sure what causes cancer of the prostate. But they have found things that can influence the development. For example, prostate cancer appears more common in groups that eat a lot of animal fat, such as red meats and high-fat milk products. Doctors say that one of the most important ways to reduce the risk of death from prostate cancer is to detect the disease early. Herein, we discuss how to use TTM technology to diagnose prostate diseases. If the temperature difference between the right and the left groins is above 0.5 °C, a converse "eight" patter may be detected on the abdomen, which is the main clinic feature of prostate diseases. Two cases are shown in Fig. 2 The results of our study are given in Table 1.

From Table 1, we can know that in all 150 cases 88.6% have a character of a converse "eight" patter on the abdomen. Some show one side, others show double. There are only 17 cases have not this feature. While comparing with the results diagnosed by B ultrasonic, 51 cases are left out. Therefore TTM technology is a more powerful tool than B ultrasonic to diagnose the prostate diseases.

Thermography is an utterly harmless and inexpensive physioloyical probe. Using TTM technology associated with the knowledge of the anatomy and pathophysiology, one can extract information from the thermograms relating to diseases or the state of one's health. In addition, understanding the mechanism of abnormal thermal behavior is key to the optimal use of thermal imaging in clinical medicine. It must be pointed out that without knowledge of the underlying mechanism of each

Table 1. Data of 150 Cases of Prostate Disease Diagnosed by TTM

Relative Difference ΔT (°C)	Cases	Degree	Rate (%)
0.5–1.0	44	Mild	29.3
1.1–1.5	59	Moderate	39.3
1.6–2.5	30	Serious/Cancer	20

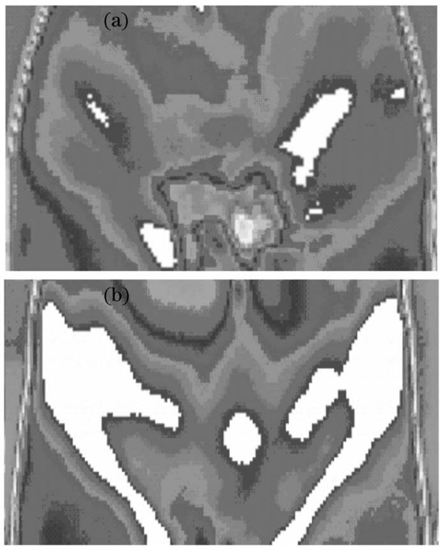

Fig. 2. Prostate disease of a 52-year old man (a) and a 33-year young man (b).

clinical thermal manifestation, application of thermal imaging will remain an anecdotal empirical practice. When medicine is being practiced more and more on the basis of molecular biology and quantifiable physiology, there is little room for a technology that shows just hot or cold spots on the surface of the human body, without a plausible explanation of the underlying causes of these manifestations of pathology. Therefore, to some extend, TTM technology is a unique and powerful tool for diseases prediction or diagnostics, and it will open a new medical field, that is, evaluation or prediction medicine.

The authors thank doctor Ju Zhang, Yanju Xu and Bioyear Inc. for the help. This work was supported by the National Natural Science Foundation of China and the Key Project Science Research Foundation of Fujian Province. H. Yang's e-mail address is hqyang@fjnu.edu.cn.

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