Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Functional Infrared Imaging for Skin-Cancer Screening

Thorsten M. Buzug*, Steffen Schumann, Lucas Pfaffmann, Uwe Reinhold and Jürgen Ruhlmann

***Abstract*—Annually 133.000 people world-wide get sick on malign melanoma, tendency increasing. The purpose of this study is the early diagnosis of malignant skin cancer. At the moment the dermatologists are screening for anomalies at the relevant lesion by examining the skin area with a microscope. To determine changes, another scan has to be taken in a follow-up session after a time period of about 15-20 weeks. Today's visual diagnostic decision is based on the pragmatic ABCD-approach (Asymmetry, Border, Colour, and Diameter). However, there is no adequate and sound non-invasive way to find out, if a skin spot is either malign or benign. If the visual approach corroborates a suspicion of skin cancer, histology is needed to make explicit diagnosis. To avoid unnecessary surgeries (on false positive alarm) and to initiate necessary surgeries in early stages a new diagnostic screening approach is presented here. Based on the fact that malign melanoma have higher metabolism as well as increased blood flow, it has been conjectured that malign melanoma have slightly higher temperature compared to the healthy skin that can be measured by high resolution functional infrared imaging.**

I. Introduction

In the last 20 to 30 years the number of patients who were diagnosed with skin cancer has increased dramatically. However, there is no appropriate and sound way to decide non-invasively, if a skin tumour is benign or malignant. Generally, the diagnosis is made with Stolz's traditional ABCD rule of dermatoscopy based on the four main criteria or lesion parameters: **A**symmetry, **B**order, **C**olour and **D**iameter, with a semi-quantitative score system [1,2]. Frequently, this method is improved by computerised scanning methods based on polarised light surface microscopes [3].

With both methods a suspicious spot has to be observed over a period of time to obtain a reliable result, i.e. the evolution of the spot is important which refines the ABCD method into the ABCDE method [2]. However, for the time being the only way to get an accurate diagnostic finding is an invasive histological examination. To avoid redundant excise of tissue and to detect malignant melanoma in an early stage, a new method is proposed here. Thanks to the facts that malignant melanoma have higher consumption of glucose caused by a higher level of metabolism and an augmented branching of blood vessels, the so called angiogenesis, the temperature should be different to its environment, e.g. the surrounding healthy tissue.

Associated with the increased demand of energy, it is conjectured that malignant melanoma shows a higher temperature (2-4 K) than its surrounding skin [4].

Infrared imaging has a high potential to detect the beginnings of angiogenesis, when cancer cells first try to develop their own blood supply, which is a necessary step before they can grow rapidly and metastasize. To substantiate the conjecture an infrared imaging devices of the latest generation is used.

II. Physics and Instrumentation

Thermographic imaging makes use of the infrared spectral band. The physical formulas describing this topic are Planck's law, Wien's displacement law and the Stefan-Boltzmann law.

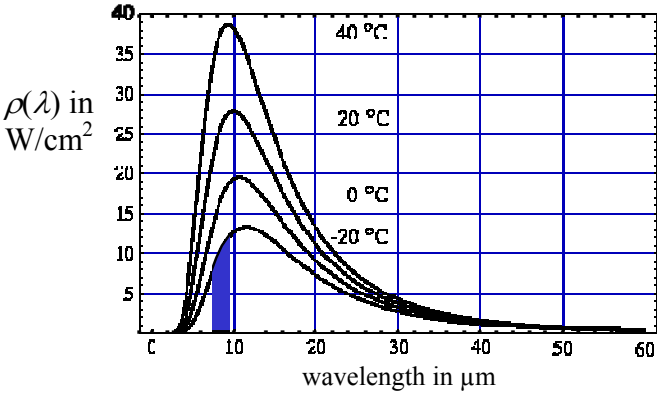

Fig. 1. Spectral distribution of electromagnetic radiation for a so called black body at four different temperatures.

With the Planck's law the relation between the temperature and the wavelength or frequency, respectively, is described (see figure 1). The higher the temperature is, the shorter is the wavelength. Wien's displacement law states that there is an inverse relationship between the wavelength

Manuscript received April 1, 2006; accepted June 20, 2006. *Asterisk indicates corresponding author.*

*T. M. Buzug is with the Department of Mathematics and Technology, RheinAhrCampus Remagen, D-53424 Remagen, Germany, phone: +49-2642-932-318; fax: +49-2642-932-399; e-mail: buzug@rheinahrcampus.de.

S. Schumann and L. Pfaffmann are with the Department of Mathematics and Technology, RheinAhrCampus Remagen, D-53424 Remagen, Germany.

U. Reinhold is with the Dermato-onkologische Praxisklinik Bonn, Friedrich-Breuer-Str. 72-78, D-53225 Bonn-Beuel, Germany.

J. Ruhlmann is with the Department of Mathematics and Technology, RheinAhrCampus Remagen, D-53424 Remagen, Germany and with the Medical Centre Bonn, Spessartstrasse 9, D-53119 Bonn, Germany.

of the peak of the emission of a black body and its temperature. The Stefan-Boltzman law helps to calculate the total radiant emittance.

The thermography camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display temperature variations. This is done via the sensitive Stefan-Boltzman law

$$I \propto \int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda,T)\rho(\lambda,T)d\lambda$$

formulated for a narrow wavelength interval (see figure 1 for illustration of the interval). However, the radiation measured by the camera does not solely depend on the temperature of the object but is also a function of the emissivity $\varepsilon(\lambda,T)$.

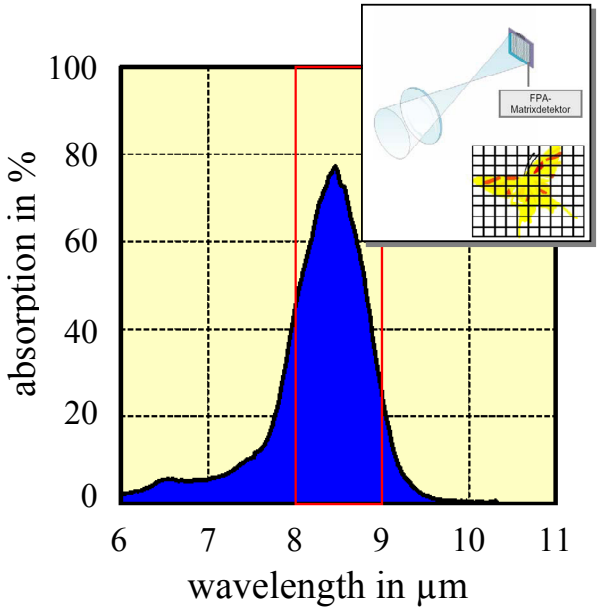

Fig. 2. Sensitivity of the latest FLIR thermographic camera based on QWIP detector technology [6].

Radiation captured with the camera may also originate from the surroundings and is reflected from the object of interest. In the application discussed here the human skin-emission coefficient is $\varepsilon = 0.98 \pm 0.01$ for $\lambda > 2\,\mu m$ [5], therefore, spurious radiation not generated by the skin can be neglected.

The small integration bandwidth is achieved by a so called quantum well infrared photodetector (QWIP) of the latest focal plane array (FPA, see figure 2) thermography camera SC 3000 of FLIR.

While the physical principles of infrared imaging are clear there are a variety of problems one has to cope with in medical applications of thermographic imaging. Typical sources of errors in diagnostic imaging are given in the following list.

- Complexity of an exact model of the medical thermo-regulation process. Even the simple bio-heat equation of Pennes [7]

$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + c_b\, w_m(T)\, \rho_b (T_a - T) + Q_m + P(z,t)$$

(where, ρ, c, k are the density, specific heat and thermal conductivity of tissue, respectively and c_b, is the specific heat of blood, ρ_b is the density of blood, T is local tissue temperature, T_a is a reference temperature – arterial blood –, t is time, Q_m is the metabolic heat production per volume, and $P(z, t)$ is the heat deposited per volume due to spatially distributed heating. In this general form, ω_m is a function of temperature to include the specific case of temperature dependent perfusion [8]) is an ill-posed problem.

- patient-depended variability of the thermo-regulation process due to different bio-feedback time constants,
- spectral specification as well as accuracy and resolution of the infrared camera,
- there is no definition of a standard in active thermography concerning the methodology of thermal excitation or provocation, respectively,
- vagueness of determination of thermal characteristic of skin cancer, i.e. a variation of the emissivity coefficient of the suspicious moles,
- only the surface temperature is imaged,
- unknown relation between thermo-regulative time constants and amount of applied energy in active thermography,
- inhomogeneity and speed variation of energy transfer in active thermography,
- spurious reflection of background radiation,
- insufficient patient acclimatisation before imaging (patient induced uncertainty: E.g. time of patient's most recent warm meal, as well as ambience induced: E.g. instable thermoregulation of the examination room, etc.).

For a discussion of some of these points see [9]. However, in the past decades strong emphasis is given to the detection of malign tumours especially mamma carcinoma with thermographic imaging.

Many research groups find out indications for breast cancer [10-12 and the papers cited therein]. But it seems that the spatial cutaneous temperature signature of a breast tumour can be detected in a late cancer state only. Therefore, the cancer-diagnosis application carried out in this paper exclusively focuses on malign skin processes.

And – it is worthwhile to focus on this application of thermography, because medical infrared imaging is the only diagnostic method that is purely passive and, therefore, inherently is without any dose limitation. Additionally, it is a low-cost system – compared to MR or PET – that yields functional information.

III. Functional Infrared Imaging

To be accepted in clinical routine a simple, reproducible measurement protocol of the thermographic image acquisition and patient preparation has to be set up. In the first trials shown in this paper an functional thermography strategy has been established. The main point of protocol is that the skin spot under suspicion is investigated dynamically.

To get the characteristics or temperature signature, respectively, the relevant skin area has to be provoked. Generally, two directions are possible. On one hand the skin can be warmed up and, on the other hand, the skin can be cooled down. One major risk of the warming-up method is that the denaturising process of the proteins starts when the skin temperature exceeds 42°C. For that reason the cooling-down method is used in our experiments that produce a substantial temperature difference within a few minutes.

The cooling is carried out using direct contact with cooled gel packs. An area of about 10 cm by 10 cm is cooled down to 20° C. After this patient-preparation step the signature of the thermo-regulation process is recorded by the FLIR SC 3000 camera with a temperature resolution of 0.03 K.

A sequel of 300 images is taken in a total time interval of five minutes. However, in practice that interval depends on the level of cooling and the type of skin lesion. The camera is placed directly in front of the lesion using a macro lens.

A difficulty in the evaluation of the thermo-regulation process is that a spot cannot be automatically detected on the basis of the temperature image alone, because at the starting point of thermo regulation the entire skin region of interest has a homogeneous temperature distribution.
To overcome this problem a marker is attached to the skin and a normal digital photo is taken prior to the thermo-graphic session.

By comparing the marker of each image with the digital image, motion of the patient can be compensated. This is important because a small motion in an image acquisition with a macroscopic lens can cause errors in the correlation between the frames of the thermographic sequel. Without stable motion compensation an automated comparison of the temperatures of skin and spot is not possible.

IV. Image Processing

A few elementary image processing steps are required for the automated evaluation of the temperature signature of the thermo-regulation process:

- Detection of bore holes of the fiducial marker (that can be seen even in the thermographic sequel.) using the generalized Hough transformation.
- Estimation of motion parameters based on the homologous landmarks obtained in the first step.
- Segmentation of suspicious skin spot in the digital photo using an active contour.
- Mapping of spot boundary, i.e. the active contour, to each of the thermographic frames using the motion model of the second step.
- Evaluation of thermo-regulation process inside and outside the skin area defined by the active contour of the third step.

V. Results

The clinical study is still ongoing. However, two examples of the first trials are given in this paper.

A. Basaliom

In the first case, a basal-cell carcinoma, the skin has been cooled down to 27 °C. The subsequent thermo-regulation process is observed to 5 minutes taking infrared frames in intervals of 1 s. The healthy skin regulates its temperature to 36 °C within 5 minutes. Figure 3 shows the digital photo and the corresponding infrared image after completes thermo regulation.

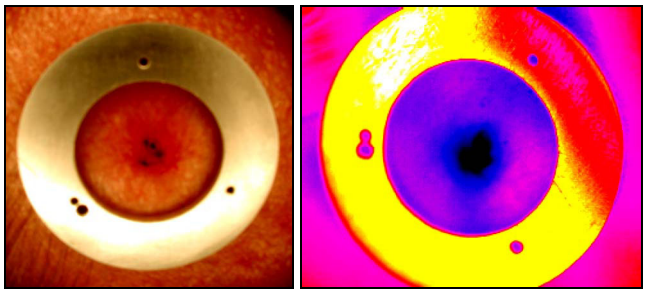

Fig. 3. Original and temperature image of a basaliom.

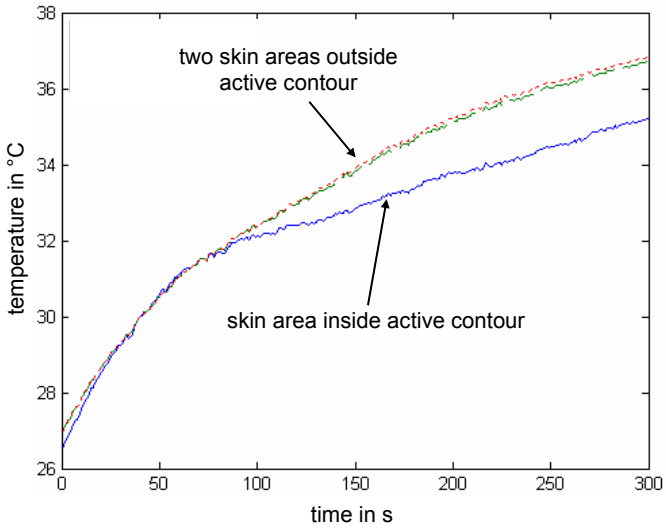

Fig. 4. Signature of thermo regulation of a basaliom.

The signature of the curves is exponential. However, focusing on the thermo regulation of the spot it can be seen that there is a synchronous warm up to 32 °C in the first

90 s. As can be seen in figure 4 the temperature of the basaliom is increasing slower than the surrounding healthy skin when the temperature exceeds 32 °C. The basaliom is not visible at the temperature image in the first 90 s of the recording; however, it is clearly recognizable in the end.

One possible explanation for the lower temperature is based on the physiological characteristics of a basaliom. A basaliom is created from the cells which can produce an isolation layer, like it is already mentioned in a study from Maleszka et al [13] who saw this effect for psoriatic arthritis.

B. *Dysplastic Nevus*

In the second case, a dysplastic nevus, the skin lesion is invisible in the temperature image during the entire recording sequence. Figure 5 shows the digital photo and the corresponding infrared image after a time interval of 5 min.

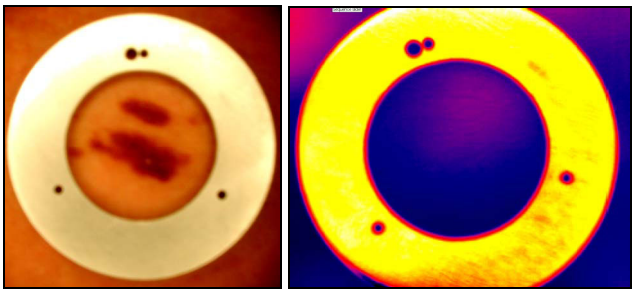

Fig. 5. Original and temperature image of a dysplastic nevus.

In this case the dysplastic nevus is semi-malignant as histology proves. As can be seen in figure 6 the temperature of the dysplastic nevus is increasing synchronously with the surrounding healthy skin.

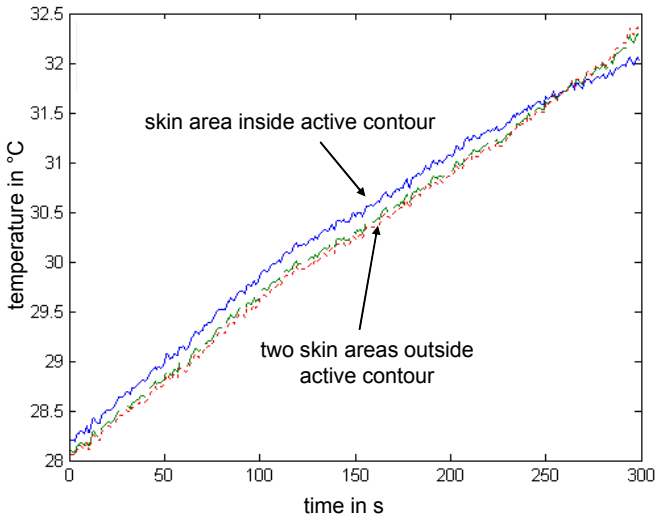

Fig. 6. Signature of thermo regulation of a dysplastic nevus.

VI. Conclusion

During our first clinical trials the method of thermography-based evaluation of skin lesions turns out to be promising. Especially in the case of a basal-cell carcinoma the method yields a clear diagnostic result.

It seems that the well known principles of thermography, that had been rejected some years ago and is recently raised to interest by detector advances, gives a powerful tool for dermatologist's diagnosis.

However, the recording protocol needs an improved standardisation due to patient-individual variation of the acquisition conditions and, in addition to the novel procedure, the traditional ABCD lesion features should support the thermographic evaluation.

VII. References

[1] W. Stolz, D. Hölzel, A. Riemann, et al., *Multivariate analysis of criteria given by dermatoscopy for recognition of melanocytic lesions*, Book of Abstracts, Fiftieth Meeting of the American Academy of Dermatology, Dallas, Texas, December 1991.

[2] R. A. Fiorini, G. Dacquino and G. Laguteta, *A New Melanoma Diagnosis Active Support System*, Proceedings of the 26th Annual International Conference of the IEEE EMBS San Francisco, CA, September 1-5, 2004, 3206-3209.

[3] G. Zouridakis, M. Doshi, and N. Mullani, *Early Diagnosis of Skin Cancer Based on Segmentation and Measurement of Vascularization and Pigmentation in Nevoscope Images*, Proceedings of the 26th Annual International Conference of the IEEE EMBS San Francisco, CA, September 1-5, 2004, 1593-1596.

[4] O. Dössel, *Bildgebende Verfahren in der Medizin*, Springer, Berlin, 2000.

[5] N. Schuster, V. G. Kolobrodov, *Infrarotthermographie*, Wiley-VCH, Berlin, 2000.

[6] FLIR Inc., SC 3000 Handbook.

[7] H. H. Pennes, *Analysis of tissue and arterial blood temperatures in the resting human forearm*, Journal of Applied Physiology, vol. **1**, no. 2, 1948, 93–122.

[8] T. R. Gowrishankar, D. A. Stewart, G. T. Martin and J. C. Weaver, *Transport lattice models of heat transport in skin with spatially heterogeneous, temperature-dependent perfusion*, BioMedical Engineering OnLine 2004, **3**:42.

[9] A. Z. Nowakowski, *Limitations of Active Dynamic Thermography in Medical Diagnostics*, Proceedings of the 26th Annual International Conference of the IEEE EMBS San Francisco, CA, September 1-5, 2004, 1179-1182.

[10] R. N. Lawson, *Implications of SurfaceTemperatures in the Diagnosis of Breast Cancer*, Can. Med. Assoc. J. **75**, 1956, 309.

[11] M. Gautherie and C. Gros, *Breast thermography and cancer risk prediction*, *Cancer*, **45**, 1980, 51.

[12] N. Scales, C. Herry, M. Frize, *Automated ImageSegmentation for Breast Analysis Using InfraredImages*, Proceedings of the 26th Annual International Conference of the IEEE EMBS San Francisco, CA, September 1-5, 2004, 1737-1740.

[13] R. Maleszka, M. Rosewicka, M. Parafiniuk, A. Kempinska, D. Mikulska, *Trial of thermographic investigations application in patient with psotriatic arthritis*. (Polish) Dermatol Klin **5**, 2003, 11-15.