12^{th} National Congress of the Polish Association of Thermology, 28^{th}-30^{th} March 2008, Zakopane

Programme

28^{th} March 2008. Friday

19:00 Opening of the conferrence

19:10 - 20:00 Opening lecture
Chairman: Prof. A. Jung.

Prof Ring E.F.J. New developments and opportunities for infrared thermal imaging in health science.

29^{th} March 2008, Saturday

9:00-10:45 Session I
Chairman: Prof. K. Ammer, Prof. J. Mercer.

1. Renkielska A., Nowakowski A., Kaczmarek M., Grudzinski J., Stojek W - Termiczna odpowiedz oparzonej i nieoparzonej skóry na pobudzenie zimnem. - Thermal response of burned and unburned skin to cold excitation

2. Ammer K. - Identification of hot spots in infrared images using a set of three isotherms.

3. Nica S.A., Mologhianu G., Murgu A., Ojoga F., Sirghii B., Ilie S., Meila A. - Thermography study of patients with stroke in the post-acute stage treated in a rehabilitation department.

4. Hidden P., Fuller A., Fick L., Mercer J.B.- Infrared Thermography in semi-free running domesticated African Elephants (Loxodonta africana) - preliminary results from a pilot study.

5. E.F.J. Ring, A. Jung, J. Zuber, P. Rutkowski, B. Kalicki, U. Bajwa - Examination of fever in Children by Infrared Thermography.

Coffee break

11:15 - 13:00 Session II
Chairman: Prof. F. Ring,

1. Vardasca R., Ring E.F.J., Plassmann P., Jones C.D. - Thermal symetry and temperature values of healthy volunteers on elbow, neck, shoulder and wrist.

2. Berz R. - MammoVision and BIRAS - a semi automatic evaluation system for female breast health assess.

3. Siniewicz K., Wiecek B., Pasnik J., Zeman K. - Diagnostyka termowizyjna u dzieci z hiperplazja grasicy w przebiegu zapalenia pluc.- Thermovision investigations in children with thymus hyperplasia during pneumonia.

4. Moderhak M. - Problems of analysis of thermal processes in breast tumor diagnostics. / Problemy analizy zjawisk termicznych w diagnostyce nowotworów piersi.

5. Klosowicz S.J., Czuprynski K.L., Jaremek H., Stepien J. - New approach to early cancer screening by using of specific thermographic markers for preliminary differentiation of pathologies with hypo- and hyper-thermic expression vizualized on Continuous Liquid Crystal Film Termographic Tester.- Nowe podejscie do wczesnego wykrywania raka sutka z uzyciem markerów termograficznych dla wstepnej diagnostyki patologii o hipo- and hipertermiczne ekspresji obrazowanej za pomoca testera cieklokrystalicznego.

15:00- 17:00 Training course
Chairman: Prof. S. Klosowicz, Dr med. B. Kalicki

1. Rutkowski P. - Praktyczne aspekty badan termograficznych. - Thermography examination in medical diagnostics.

2. Wiecek B. - Wielospektralne systemy termowizyjne.- Multicolor quantum- well infared detectors and their applications.

3. Nowosci z zakresu sprzetu i mozliwosci zastosowan w badaniach termograficznych.. News in thermology equipment.

30^{th} March 2008, Sunday

10:00-12:30 Session III
Chairmen: Prof. B. Wiecek, Dr med. J. Zuber

1. Cicchanowska K., Lukowicz M., Weber-Zimmermann M., Szymanska J., Zalewski P. - Thermovision examination of treatment methods within physical medicine. - Termowizyjna analiza oddzialywania termicznego zabiegów leczniczych w zakresie medycyny fizykalnej

2. Wiecek B. - Wybrane aspekty przetwarzania obrazów do zastosowan medycznych.. Chosen aspects of thermal image processing- software for medical image classification.

3. Zalewski P., Lukowicz M., Ciechanowska K., Pawlak A., Pawlikowski J. - Thermovision examination of high intensity laser therapy - HILT thermal effects in relation to radiation energy doses, wavelength and application technique.- ermowizyjna analiza oddzialywania termicznego laseroterapii wysokoenergetycznej- HILT w odniesieniu do dawki energii promieniowania, dlugosci fali oraz techniki aplikacji.

4. Suchowirski M. - System do nadzoru temperatury badanego obiektu w aktywnej termografii dynamicznej.

5. Seweryn P., Laszczynska J. - Rozklad temperatury powirzchni ciala czlowieka po ekspozycji na szybka zmiane cisnienia barometrycznego (o róznym czasie trwania dekompresji) w obrazie termowizyjnym -/ Distribution of human body surface temperature following exposition to rapid change of barometric pressure (with different decompression time) in thermovision image.

Abstracts

NEW DEVELOPMENTS AND OPPORTUNITIES FOR INFRARED THERMAL IMAGING IN HEALTH SCIENCES

E.F.J.Ring

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Since the early days of medicine, the importance of temperature assessment has been recognised. When thermal imaging became accessible to medicine in the late 1950's, the prime interest seemed to be in the possible use for breast cancer diagnosis. Yet more successfully, the cancer specialists and dermatologists found a good application in the screening of myelomas on the skin for malignancy. Many other applications were also used in a research application, including the assessment of burn injuries, the viability of skin grafts and even amputation levels. Few of those applications have been taken up on a wider scale. There is still a more widely used application in rheumatology, for inflammation and nerve damage, and for examination of the hands for Raynaud's phenomenon.

Modern camera systems have advanced, with reduction in physical size, improved optical resolution and stability, enhanced computer processing and lowered cost.

Has this contributed to a wider spectrum of use in health care sciences? Undoubtedly, some applications for thermal imaging in the surgical operating room have shown good value, in heart and circulation procedures. Smaller cameras can be mounted overhead, now that nitrogen cooling is not essential. New health screening possibilities have been tested in Poland recently. An initiative for screening in shopping malls is underway with a target of 28 cities across Poland. Thermal Imaging of the face is used to look for sinusitis in subjects who could benefit from simple drug therapy. Also, the ISO committee is currently working on a proposed guideline for the use of thermal imaging for fever detection, especially in airports. This was used during the SARS crisis in China, and a new generation of a thermographic screening camera may emerge to meet any future threat of a pandemic influenza virus infection. Interestingly, both the latter screening programs are using images of the face, which can be easily imaged, and is least influenced by varying ambient conditions.

THERMAL RESPONSE OF BURNED AND UNBURNED SKIN TO COLD EXCITATION

A. Renkielska[1], A. Nowakowski[2], M. Kaczmarek[2], J. Grudzinski[1], W. Stojek[3]

[1] Department of Plastic Surgery and Burns, Gdansk Medical University, Gdansk, Poland
[2] Department of Biomedical Engineering, Gdansk University of Technology, Gdansk, Poland
[3] Department of Animal Physiology, University of Gdansk, Gdansk, Poland

This study was devoted to the question if cold excitation may be effectively used in active dynamic thermal imaging (ADT) for diagnostics of skin burn depth. The experiments on animals presented quantitatively the reaction of healthy and burned pigskin to forced cold excitation.

We used high quality IR camera Flir SC 3000, quantum well FPA LW of 25 mK resolution and 60 Hz acquisition rate. For external cold excitation cryogenic CO_2 rehabilitation instrumentation with specially designed applicator to get uniform cooling of tested skin was applied. Histopathological confirmation of burn depth was done on the contra lateral wounds, not tested with ADT, to avoid the influence of the biopsy on the thermal state of the wound. The study compared thermal transients of healthy and burned fields of controlled depths.

The measurement results showed that increasing the time of cooling we obtained stronger decrease of the temperature drop (T) and visible increase of the thermal time constant ( ) at the surface of tested skin. We also observed that for wounds healing within 3 weeks after burn (shallow)   was shorter comparing to unburned skin. Wounds not healing within 3 weeks (deep) were characterized by longer   than unburned skin.

The results confirmed high value of cold stress in ADT in burn depth evaluation and good correlation of heat flow mechanisms with the physiology of the living skin.

THERMOGRAPHY STUDY OF PATIENTS WITH STROKE IN THE POST-ACUTE STAGE TREATED IN A REHABILITATION DEPARTMENT

Adriana Sarah Nica, Gilda Mologhianu, Andreia Murgu, Florina Ojoga, Brindusa Sirghii, Svetlana Ilie, Ana Meila

University of Medicine and Pharmacy, Bucharest, Romania

INTRODUCTION. After the central neurological injury, zhe patient with stroke develops secundary problems relateded to the central and especially peripheral thermal adaptation system in the affected area of the body.

The consequences are clinical, symptomatical and objective and they can be studied in the vasomotor and thermal context.

The application of infrared thermography for the detection of local pathologies on the upper and lower limb used to observe some is generally recognized, but the systemic and local changes of patients with stroke may be a new issue in thermographic research.

MATERIAL: We have studied 100 in-patients with recent stroke, using an EDP medical thermograph in standard evaluation conditions.

METHOD: We applied a standard program of physical therapy using electrostimulation, ultrasounds, massage and kinesotherapy.

We recorded thermograms before and after each procedure. We have studied temperature gradients for single areas, we have compared the temperature gradients between the left and the right part of the body, and finally we have observed the therapy effect in time.

RESULTS:The results were biostatistically transformed and interpreted They underline different degrees of circulatory problems and different types of response in relation to the severity of the neurological damage.

IDENTIFICATION OF HOT SPOTS IN INFRARED IMAGES USING A SET OF THREE ISOTHERMS

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Medical Imaging Research Group, Faculty of Advanced Technology, University of Glamorgan. Pontypridd, Wales, UK

Hot spots in thermal images are important features for assisting the diagnosis in breast disease, epicondylitis and fibromyalgia. However, the reproducibility of identified hot spots is poor.

A novel approach to improve the reliability of hot spot identification is based on the use of a set of 3 isotherms, 0,5 degrees apart. Moving this set over the total range of temperature within a thermal image, can easily detect hot spots as the temperature difference between the 1st isotherm with the lowest threshold and the 3rd isotherm with highest threshold is at least equivalent to the chosen temperature between the isotherms.

This approach was tested in a set of 10 thermal images previously used for testing of the reproducibility of hot spot identification. All images were evaluated twice on different days by the same reader, who was blinded at the second evaluation to the results of the first reading.

Figure 1 shows an example of a typical set of isotherms. Figure 1 shows an example of a typical set of isotherms. The reproducibility of hot spot identification was good (Single Measure Interclass Correlation: 0.699; 95% confidence interval: 0.138 to 0.917, Reliability Coefficient alpha: 0.807). The reproducibility of hot areas was poor (Single Measure Interclass Correlation: 0.14; 95% confidence interval: -0.162 to 0.580, Reliability Coefficient alpha: 0.413).

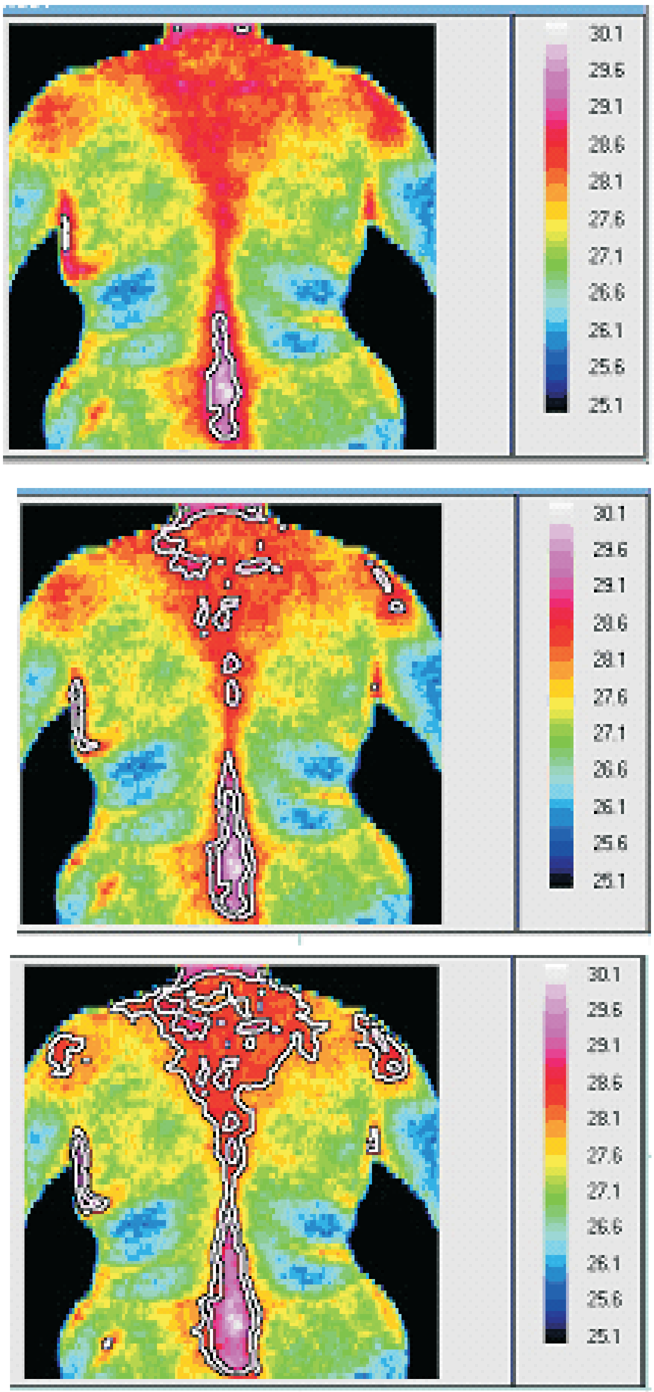

Figure 1
3 isotherms were defined at an temperature interval 0,5 degrees ranging from 29.0 to 28.0°C. 2 hot spots and one hot area were identified

The rather disappointing low degree reproducibility may be caused by several causes. Firstly, the maximum size of a hot spot and the minimum size of a hot area were not cleary defined. This might have caused false classifications of big sized hot spots as a hot areas and vice versa. The threshold for the isotherms with the highest and the lowest temperature differed between the two readings. Finally, very small hot spots may have been overlooked, particulary in the range of lower temperatures and when located close to an irregular shaped isotherm.

INFRARED THERMOGRAPHY IN SEMI-FREE RANGING DOMESTICATED AFRICAN ELEPHANTS (LOXODONTA AFRICANA) - PRELIMINARY RESULTS FROM A PILOT STUDY.

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*Department of Medical Physiology, Faculty of Medicine, UiTø, Tromsø, Norway

Infrared (IR) thermal images of semi-free ranging domesticated African elephants were taken at selected intervals over a 24 hour period during summer (March). The animals belonged to a small herd consisting of 5 adults and a 6-month old juvenile housed at the Letsatsing Game Reserve, North West Province, South Africa. The reserve includes a visitor's centre situated beside a wallow plus stabling and maintenance facilities. The adults are used for elephant back riding safaris that run only in the morning and late afternoons. The herd spends much of the rest of the day-light hours browsing naturally, pursuing a lifestyle similar to wild elephants. At night time the animals are kept in individual concrete stalls in an open sided high roofed stabling area. In addition to recording IR-thermal images, body core temperature in 2 individuals was continuously measured using ingested temperature data loggers. The data loggers were recovered from the faeces following a passage time through the intestinal tract of ca. 42 and 72 hours respectively. Meteorological data, including air temperature, black globe temperature and solar radiation were continuously measured from a local field station. Written details of the animals behavioural patterns were also recorded throughout the daylight hours. The IR-images were taken using a FLIR ThermaCam S65 and FLIR SC3000 cameras (FLIR Systems AB, Boston,MA, USA). All images were electronically stored and afterwards processed using image analysis software ThermaCAM Researcher Pro 2.8 SR-1 (FLIR Systems AB). IR thermal images of the elephants were taken at different times of the day and included activities at the wallow, while grazing in the bush, before and after the rides, and in the stables shortly before sunrise and shortly after sun-down. Preliminary results will be presented in which the thermal state of the animals as shown in the IR-thermal images will be related to both body core temperature and the meteorological data throughout the 24 hour period

EXAMINATION OF FEVER IN CHILDREN BY INFRARED THERMOGRAPHY

EFJ Ring [1], A Jung [2], J Zuber [2], P Rutkowski [3] , B Kalicki [2], U Bajwa [1]
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Recent interest in fever detection for airport screening of passengers has shown the lack of data, outside conventional clinical thermometry. Increasing use is now being made of simple ear radiometers for routine clinical temperature measurement. These devices are known to have limitations, and the technique and the variability of the human auditory canal add to the uncertainty of results.

This study has been conducted at the Paediatric Department of a major Hospital in Poland. The aim of this study is to investigate the possibilities of thermal imaging of the face being used as a reliable indicator of fever in children. In the screening context, thermal imaging has many advantages over other methods, given the need for rapid and objective evidence to exclude a travelling passenger with a raised temperature from increasing the risk of spread of infectious disease (such as H5N1 or similar viruses). In earlier reports on the SARS outbreak temperatures over 38^{0}C were classified as febrile, and made to undergo a simple clinical examination and have temperatures confirmed by thermometry.

To date, 174 children aged from 3 months to 16 years have been tested in the clinical using a clinical thermometer in the axillary, under arm position, and thermal imaging of the anterior face. The ambient temperature has been maintained at 22 – 23^{0}C. The subjects were seated before the camera, and in front of a cloth screen. Thermal images were recorded, and regions of interest around the eyes and centre forehead were used. Mean and maximum temperatures from these regions of interest were determined.

RESULTS: In total, 160 of 174 subjects recorded temperatures in the normal range (defined as <37.5^{0}C) axillary, and had no direct disease or clinical problem affecting their temperature. Fourteen children had raised temperatures >37.5 with 7 being 38°C and over. Forehead temperatures were consistently lower in value than the inner canthi of the eyes.

AFEBRILE CHILDREN			FEBRILE
Anat.site, n=160	Mean temp°^{0}C	S D	Temp.Range n=14
Forehead	34.85	0.64	36.3 – 37.2
Inner Canthi	36.4	0.52	35.5 – 38.6
Axilla	35.9	0.81	37.5 – 39.0
Ear tymp, n=64	35.96	0.49	

A moderate correlation was found between the canthus eye temperatures and the forehead temperatures from the analysis of the frontal face thermograms. r=0.66

Thermal Imaging of the face in children is an efficient means of identifying the presence of fever. Potential artefacts caused by sinus infection, even prolonged crying in children, and may elevate the maximum temperatures recorded over the inner canthi of the eyes. However, the use of a carefully placed clinical thermometer (oral or axillary site) is sufficient to exclude the presence of clinical fever. Further data is being collected on healthy and febrile children. Thermal imaging for screening of travelling passengers may prove to be a suitable and rapid tool, with the inner canthi being the measurement site of choice

THERMAL SYMMETRY AND TEMPERATURE VALUES OF HEALTHY VOLUNTEERS ON ELBOW, NECK, SHOULDER AND WRIST

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Medical thermal imaging is an objective screening modality for investigating skin temperature in arthritis, neuromusculoskeletal injury and circulatory pathology, 100% safe, highly accurate involving no radiation or contact. Its use is increasingly growing. Most parts of the body are thermally symmetrical, being that indicator an important factor on the supportive information to the clinician when assessing abnormalities in specific pathologic state.

Some injuries or syndromes commonly related with upper limb work related disorders affect articulations of the body like elbow, neck, shoulder and wrist, documented information about thermal symmetry on these areas of the body is needed. The object of this study is to analyse the collected data following a standard protocol and using the software package CTHERM to study thermograms of 40 healthy volunteers.

Results have shown that the acceptable values for thermal symmetry on the upper body articulations is 0.5° C difference between the mean temperature of two areas of interest divided by the longitudinal axis of the human body with a standard deviation of no more than 0.3° C.

MAMMOVISION® AND BIRAS® – A SEMIAUTOMATIC EVALUATION SYSTEM FOR FEMALE BREAST HEALTH ASSESSMENT

Reinhold Berz

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Despite widespread adoption of screening programs there is still an increase of breast cancer in European and other countries. Traditional screening methods are able to detect breast cancer lumps with at least 5 mm in diameter. However they generally will not detect smaller cancers or breast cancer in pre-clinical stages, which may take about 5 to 10 years to be detectable with such technologies. Thus unless other methods are used, there may be a lack of clinical information regarding the risk of developing breast cancer or other breast diseases.

Infrared thermography applying a physiological cooling stimulus (IRI = Infrared Regulation Imaging) is an innovative method that could fill the gap between early signs of breast metabolism deregulation and the manifestation of breast cancer lumps. The multi-patented MammoVision® examination is based on a grid system for each breast including several statistical functions for automatically generated evaluations and an expert rating of the breast vascular pattern.

More than 8 years of clinical application demonstrate that there is a correlation between severe thermal signs of altered breast metabolism and the occurrence of breast cancer. A recent study including more than 50 cases of breast cancer indicated that all these cases show clear signs of enhanced and altered breast metabolism calculated from the MammoVision® expert system. False negative results are very low, tending to zero, however there are many women without breast cancer also showing altered and enhanced breast metabolism. If the focus of the screening is on disease (“breast cancer”), some results could be considered false positives. However if the screening focuses on “deviation from breast health”, these suspicious results of women not having breast cancer can actually indicate the need or opportunity for a preventive strategy including early interventional measures which could preempt the disease stage.

In Europe, MammoVision® (and ReguVision® for full body thermal imaging) are the only officially registered infrared imaging systems for medical purposes that entirely comply with the MDD (Medical Devices Directive, CE certified).

PROBLEMS OF ANALYSIS OF THERMAL PROCESSES IN BREAST TUMOR DIAGNOSTICS

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Department of Biomedical Engineering

The aim of this work is to discuss problems of breast tumor diagnostics by the analysis of thermal processes forced by external excitation and observed by thermal IR camera. The history of breast tumor diagnostics by means of thermography goes back to the early sixties of the recent century. The value of breast diagnostics with use of classic mammography, thermal mammography, microwave and near IR examinations is still an up-to-date problem. The basics of thermal flow analysis and simulation forced by external excitation with the aim of medical diagnostics will be discussed. Basic thermal models and the procedures of active dynamic thermography (ADT) examination in breast diagnostics will be presented. Also the course of further research, especially with use of ADT and thermal tomography, will be introduced.

NEW APPROACH TO EARLY BREAST CANCER SCREENING USING SPECIFIC THERMOGRAPHIC MARKERS FOR PRELIMINARY DIFFERENTIATION OF PATHOLOGIES WITH HYPO- AND HYPER-THERMIC EXPRESSION VISUALIZED ON CONTINUOUS LIQUID CRYSTAL FILM THERMOGRAPHIC TESTER.

S. J. Klosowicz[1], K. L. Czuprynski[1], H. Jaremek[2], J. Stepien[3]

[1] Military University of Technology, Warsaw, Poland
[2] GREHEN Ltd, Poland
[3] Glammeron Manner Ltd, Poland Division

Liquid-crystalline contact thermography (LCCT) has been developed for at least 40 years, mainly in medical applications. It would seem that rapid development of thermovision revealed some disadvantages of this method. However, very recently some new concepts regarding its technology and usage has been introduced.

As early as 1976, at the Third International Symposium on Detection and Prevention of Cancer in New York, thermography was established by consensus as the highest risk marker for the possibility of the presence of an undetected breast cancer. It had also been shown to predict such a subsequent occurrence. The Department of Advanced Technologies and Chemistry of the Military University of Technology (MUT) presented a summary of its long-term researches and findings in the area of Liquid-crystalline Contact Thermography, which has remained undisputed. This, combined with other reports, has confirmed that persistently abnormal thermogram should be treated as the highest risk indicator (early marker) for the future development of breast cancer (in a study of 58.000 women screened with thermography, Gros et. al. followed 1,527 patients with initially healthy breasts and abnormal thermograms for 12 years - of this group, 40% developed malignancies within 5 years - this study concluded that "an abnormal thermogram is the single most important marker of high risk for the future development of breast cancer

In medical applications the LCCT seems to be considerably undervaluated, however, the most recent discoveries and significant technological progress in the area of liquid crystal engineering, including one-molecular layer imposition and polymer-hermetization elaborated in the laboratories of the MUT allow on mounting of an advanced thermosensitive compound that may be suitable for precise breast's thermoimaging. The aim of current researches is to develop an objective Breast-Health Test for frequent personal use also in out-of-clinic conditions, due the simplified examination and improved evaluation methodology (with remark that such self-diagnosis should be confirmed by other objective methods interpreted by physician).

New diagnostic methodology is developed on innovative concept based on separation of all thermographic pathologies into two groups (thermopathologies with hypothermic expression usually not-malignant, like degeneratio fibro-cistica, and thermopa thologies with hyperthermic expression - typically for malignant processes, like fast growing ductal carcinoma). The clinical validation studies with participation of scientists from the Military Medical Institute in Warsaw are already initiated with intend to provide solid data to confirm the usefulness of such a thermographic test for screening examination (positive/negative thermograms), especially in a group of patients with BRCA1/BRCA2 gene expression, with strong indication to continuous breast monitoring but at the same time with contraindication to make X-Ray mammography.

SOME ASPECTS OF THERMAL IMAGE PROCESSING - SOFTWARE FOR MEDICAL IMAGE CLASSIFICATION

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[2] Laser Diagnostic and Therapy Center at Technical University of Lodz

The main aim of the paper is to show the usefulness of 2D wavelet transform in thermal image processing for medical applications. Wavelet transformation is actually used in many domains, such as telecommunication and signal processing for compression and to extract quantitative data from a signal. In image processing it can be employed to get new features, representing both global and detail information. Wavelet transformation is based on image filtering represented by rows and columns using low and high pass linear filters (Fig. 1). After filtering, decimation is used to reduce number of pixels. The procedure can be repeated

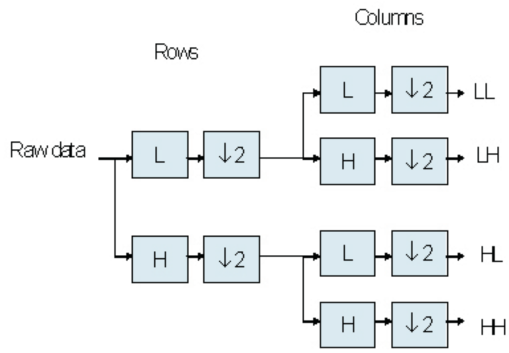

Figure 2.
Neural network example with input, single hidden and output layer

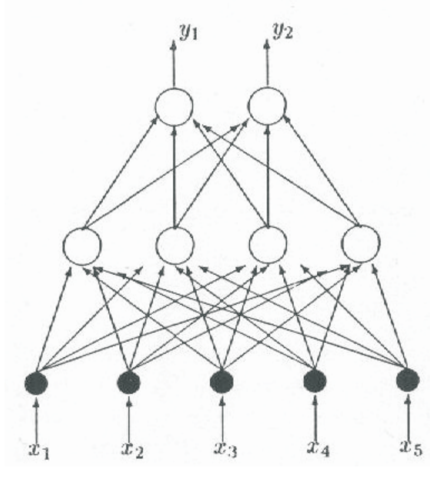

Figure 1
Wavelet transformation of an image

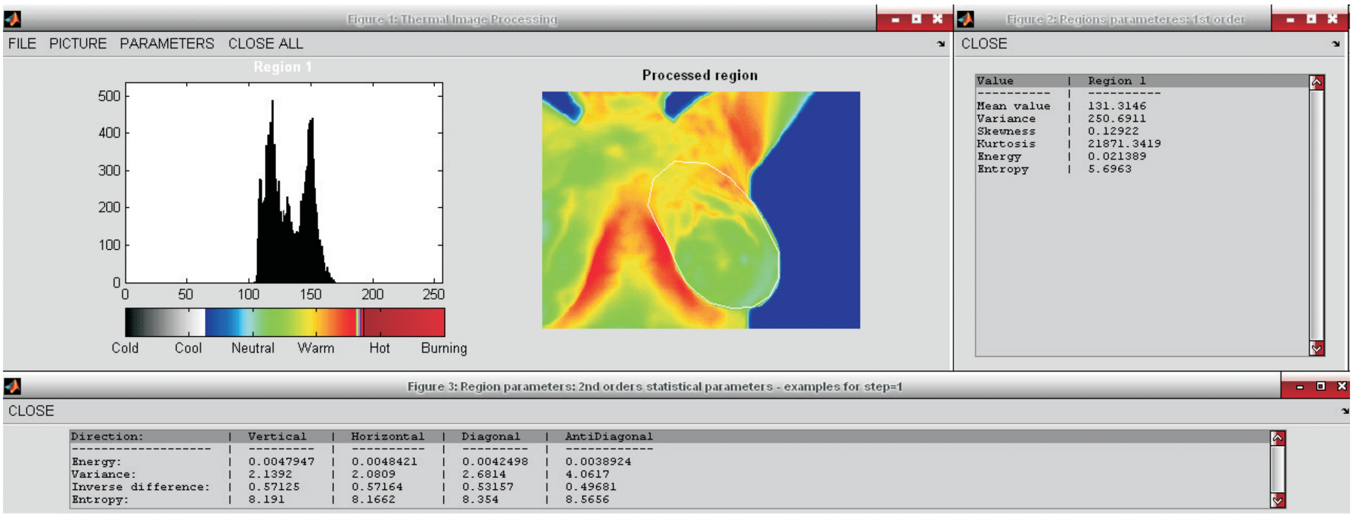

Fig.ure 3.
Histogram and calculated features of a thermal image

until 1x1 images are obtained. Practically, the processing is stopped earlier, after 2-4 steps, and then the features are derived from the filtered subimages.

The next aim of the paper is to present the artificial neural network as an effective tool for image classification. The selected image features has been used as inputs. It means that the number of inputs nodes if the neural network is equal to the number of features. Number of neuron in the first hidden layer can be equal or lower than the number of features in the classification, as shown in Fig. 2. ANN can have user-defined next hidden layers which allow additional nonlinear processing of the input features. As ANN is the nonlinear system and such technique allows the additional decorrelating and data reduction, what finally improves the classification. Such approach is known as Nonlinear Discriminant Analysis (NDA) [3].

It is well known that the training of ANN is the very important step in the entire protocol. It is an multivariable optimization problem typically based on backpropagation technique. In the general case, it can lead to wrong solutions if the there is no single minimum of the error function. That is why we need enough data during learning phase, and sometimes it is necessary to repeat training of ANN with different initial values of the neuron weight coefficients.

In order to verify the research assumptions, novel software was created in MATLAB environment (Fig.3). In Laser Diagnostic and Therapy Center, at Technical University of Lodz, the laboratory for diagnosis of breast diseases using mammography, ultrasonography and thermography in parallel, was created. In the same place and in the same time patient can make thermography, digital mammography, and ultrasonography. In our laboratory, a screening program has been started, so we hope to collect enough images for learing Artificial Neural Network. The software which is discussed in the paper is suitable for feature extracting and image classification for either X-ray, acoustic or thermal images.

References

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[2] Ng E.Y.K., Ung L.N., Ng F.C., Sim "Statistical Analysis Of Healthy And Malignant Breast Thermography" Journal of Medical Engineering & Technology, vol. 25 no6 p. 253-263

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[4] Jakubowska T., Wiêcek B., Wysocki M., Peszyñski-Drews C. „Thermal Signatures for Breast Cancer Screening Comparative Study" Proc. IEEE EMBS Conf. Cancun, Mexico, Sep 17-21, 2003.

MULTICOLOR QUANTUM-WELL INFRARED DETECTORS AND THEIR APPLICATIONS

B. Wiecek
Technical University of Lodz, Institute of Electronics, Poland

In this paper the review of cooled multicolor QWIP (Quantum Well Infrared Photodetector) detectors is briefly presented. Different types of QWIP detectors are mentioned. The limits of detectivity and potential applications of photon detectors are discussed as well as the technological construction of mutiband QWIP detectors.

By changing quantum well size, it is possible to vary the wavelength of absorption. Stacking vertically two QWIPs, multiband detector can be realized (Fig. 1). Ohmic contacts of 0.5µm thickness are made from highly doped GaAs. Each QWIP is fabricated as 20-period GaAs/AlxGa1-xAs structure [7]. At the bottom of the pixel, optical coupler is realized to achieve high quantum efficiency. In some applications, random reflector is successfully used. The important precautions have to be considered to isolate readout circuit from the sensing device by epoxy layer.

Another solution of multicolor IR detector is so-called interlace dual-band structure, where the sensing elements are placed in odd and even rows one after another [7]. One row of pixels de-

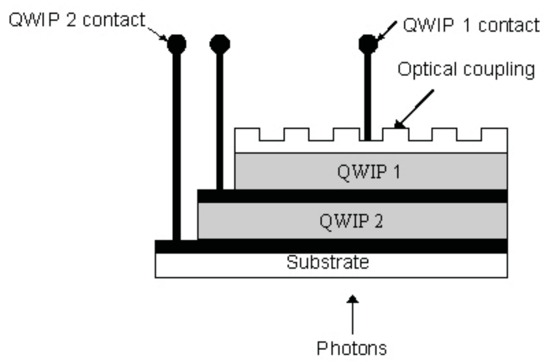

Figure 1
Vertically stacked dual-band IR detector [1]

tects 8-9μm LWIR radiation, while the following one is sensitive to 14-15μm VLWIR spectrum as shown in Fig. 2.

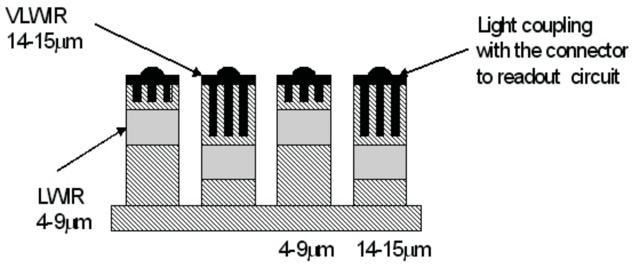

Fig.ure 2
Interlace dual-band IR detector matrix [9]

The typical operating temperature of QWIP detectors varies between 40-100K, mainly realized using Stirling coolers. Bias of each detector should be adjusted separately for both detectors to obtain the maximum responsivity, which is typically in the range of 300-350 mA/W [7]. Unfortunately, the quantum efficiency reaches the level of 10% only. for 20-period MQWIPs. In contrast, such efficiency for MCT detectors is better than 70%. Typical value of NEDT (Noise Equivalent Differential Temperature) at 24mK and 35mK for blue (MWIR) and red (LWIR) sensors has been obtained [7]. In addition to above figures, it is necessary to mention that the lifetime of thermally generated carriers for QWIP detectors is rather short (10ps) in comparison to MCT structures (1μs), what results in much higher integration time, which reaches the level of ms [7]. It is a direct consequence of slowing down the QWIP cameras and their limited applications for fast thermal processes investigations. Detectivity of QWIPs is of 2 orders of magnitude lower than for HgCdTe detectors, and it is at 2×1010cmHz $^{1/2}$ W^{-1}. Reassuming, comparing the figures of merit for MCT and QWIPs, one can conclude that the detectors and IR cameras based on HgCdTe composite semiconductors are much better. It is the truth, but on the other hand, there are undoubted advantages of using QWIPs, such as very high spatial resolution and multicolor applications. Additionally, the cost of QWIP's production should be much lower for high-dense focal plane arrays, due to the low cost, massive production of large bandgap semiconductor devices and integrated circuits, the QWIP detectors are based on.

Temperature measurement with emissivity correction is one of the possible applications of the multicolor thermal detectors. Let's assume, that signal generated by thermovision equipment is a function of wavelength, temperature and the object's emissivity. Typically, the system responsivity depends the wavelength as well, what has to be taken into account by the calibration procedure (Fig. 3).

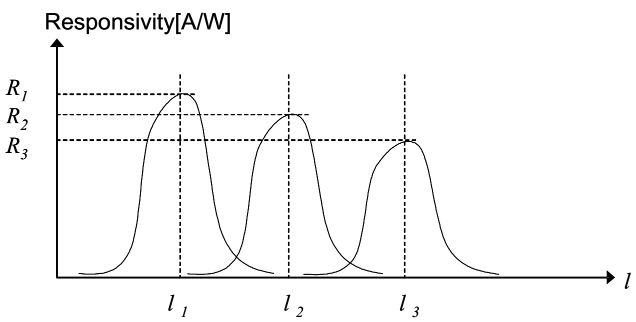

Fig.ure 3
.Spectral characteristics of multiband thermal system

Having the multispectral measurement possibility, according Planck's formulae, the camera generates different signals for a given wavelengths (λi) – egn.(3).

$$S(\lambda_i, T) = A_i \varepsilon(\lambda_i) \frac{2\pi hc^2}{\lambda_i^5 \left(e^{\frac{hc}{\lambda_i kT}} - 1 \right)} \approx \varepsilon(\lambda_i) \frac{2\pi hc^2}{\lambda_i^5 e^{\frac{hc}{\lambda_i kT}}} \qquad (1)$$

where: h=6,6260755·10^{-34} J·s, k =1,3806·10^{-23} J/K – Planck's and Boltzmann's constants, while A_i is the apparatus constant for a given wavelength λ_1. Wien approximation presented in the egn. (1) is valid for λT<0,003m·K, what denotes that for objects at T=300K, λ<10μm. For T=3000K, wavelength should fulfill the condition λ<1μm. Assuming, that emissivity does not depend on wavelength i.e.: $\varepsilon(l_i)$=const, for double wavelength thermal system we can easily derive the following equation to get the temperature value:

$$T = \frac{\frac{hc}{k}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1} \right)}{5\ln\left(\frac{\lambda_1}{\lambda_2} \right) + \ln\left(\frac{S_1}{S_2} \right) + \ln\left(\frac{A_2}{A_1} \right)} \qquad (2)$$

where: S1=S(λ_1,T) and S2=S(λ_2,T) are the system output signals for the chosen wavelengths, respectively. It denotes that the temperature readout from the system is regardless from the emissivity, and depends on the ratio S1/S2 only.

For long wavelength range, i.e: for λT?>0,778m·K, the Rayleigh-Jeans is valid. In this case, the formulae describing the signal obtained from the camera takes a form:

$$S(\lambda_i, T) = \frac{2\pi ckT}{\lambda_i^4} \qquad (3)$$

More advanced applications assume that the emissivity dependence on the wavelength is a given function, e.g.: power or exponential ones [8]. To increase the precision of emissivity compensation, it possible to acquire the thermal images for more then 2 bands, e.g. 3-4 wavelength systems already exist in practice [10]. For example, let's assume that we have 3-band thermal system operating for λ_1, λ_2, λ_3 and the emissivity varies according the following relation: $\varepsilon(\lambda_1)/\varepsilon(\lambda_2)=\varepsilon(\lambda_2)/\varepsilon(\lambda_3)$. It denotes that value of emissivity depends linearly on the wavelength. For such a case, the temperature can be evaluated without emissivities, as:

$$T = \frac{\frac{hc}{k}\left(\frac{2}{\lambda_2} - \frac{1}{\lambda_1} - \frac{1}{\lambda_3} \right)}{5\ln\left(\frac{\lambda_1\lambda_3}{\lambda_2^2} \right) + \ln\left(\frac{S_1 S_3}{S_2^2} \right) + \ln\left(\frac{A_2^2}{A_1 A_3} \right)} \qquad (4)$$

Emissivity compensation during the thermographic measurements is the only one possible application of multiband thermal systems. There are much more very useful applications of multiband thermal systems, such as watching through smoke and fog, or object detection and recognition.

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DISTRIBUTION OF HUMAN BODY SURFACE TEMPERATURE FOLLOWING EXPOSITION TO RAPID CHANGE OF BAROMETRIC PRESSURE (WITH DIFFERENT DECOMPRESSION TIME) IN THERMOVISION IMAGE

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Within the scope of training (according to STANAG 3114) in aviation medicine, conducted by the Military Institute of Aviation Medicine the pilot's organism is exposed to rapid change of barometric pressure (decompression). Literature data suggest that such a changes in physical conditions of the environment may cause life threatening physiological incidents with signs and symptoms of decompression illness. In body systems and organs, decompression provokes a range of functional and anatomical disturbances. The study was conducted to assess organism's adaptive reactions to decompression with thermovisual imaging of skin blood flow distribution in response to rapid environmental pressure changes.

The study was carried on 12 healthy volunteers (men aged 24±6 years; BMI = 21,8±2,8), qualified to the study by Aero Medical Board Warsaw. The subjects were studied in the low-pressure chamber with decompression effect (Ta = 22°C). In order to minimize the risk of decompression illness, each examination was preceded by nitrogen desaturation, achieved by breathing with pure oxygen for 30 minutes. During subsequent study days, subjects underwent decompression from the simulated altitude of 3000 meters above sea level to 7000 meters above sea level, lasting 2 seconds (profile I) and 14 seconds (profile II). Thermographs were recorded (AGEMA 900) immediately before and after decompression. HR, SBP, DBP and SpO_2 were monitored throughout the examination.

Following decompression, a transient increase of monitored haemodynamic parameters was observed. Duration of decompression did not significantly influence these changes. Thermographs revealed symmetrical body temperature distribution, with isothermal lines distribution of highest temperature ("T") characteristic to adult humans. During decompression lasting 14 seconds, rapidly subsiding, insignificant decrease of mean body surface temperature was noted on the area of thorax.

Decompression of 2 and 14 seconds duration did not cause any significant changes of the temperature distribution in human adult body surface.