15th Congress of the Polish Association of Thermology

and

Certifying course: "Practical application of thermography in medical diagnostics"

Zakopane, March 18 – 20, 2011

Scientific Committee:
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Polish Association of Thermology
Paediatric, Nephrology and Alergology Clinic
Military Institute of Health Service

Scientific Programme

Saturday, March 19, 2011

09:00 – 11:00 Session I
Chairman: Prof. Francis Ring, Prof. James Mercer

1. Kalicki B, Jung A, Ring F, Saracyn M, Niemczyk S.	Thermographic Monitoring of the Hands in Renal Dialysis Patients. Comparison of High and Low resolution Cameras.
2. Ammer K.	Infrared Thermography as a diagnostic tool and outcome measure in patients suffering from Raynaud's Phenomenon.
3. Mercer JB, de Weerd L.	Abdominal skin perfusion following breast reconstruction with a free abdominal flap anastomosed to the internal mammary vessels evaluated with Dynamic Infrared Thermography (DIRT).
4. Murawski P.	Tele Med Net programme.
5. Vardasca R., Ring F.	HAVS objective procedure assisted by medical thermography.

11:30 – 13:30 Session II
Chairman: Prof. Kurt Ammer, Prof. Boguslaw Wiêcek

1.Cholewka A, Stanek A, Kwiatek S, Sieroñ A, Drzazga Z.	Thermovision applications in physical medicine.
2.Domaniecki J, Wysoczañski B.	Thermal study of changes in pain intensity after surgery in cryochamber.
3.Pawlak J, Zalewski P, Klawe JJ, Tafil-Klawe M, Lewandowski A.	Thermovision analysis of skin surface temperature in subjectsexposed to a whole-body cryotherapy.
4. Strakowska M., Strzelecki M., Wiêcek B.	Automatic measurement of human body temperature in eye canthus using thermovision camera.
5. Strakowski R., Wiêcek B., Strakowska M	Microbolometer thermovision camera for medical applications.

15:00 – 16:00 Session III – Training course
Chairman: Prof. Ricardo Vardasca, Prof. Anna Jung

1. Więcek B — Importance of Radiation Heat Transfer In IR-Thermography
2. Rutkowski P. — FLIR

16:00 – 17:00 EAT board meeting

Abstracts

ABDOMINAL SKIN PERFUSION FOLLOWING BREAST RECONSTRUCTION WITH A FREE ABDOMINAL FLAP ANASTOMOSED TO THE INTERNAL MAMMARY VESSELS EVALUATED WITH DYNAMIC INFRARED THERMOGRAPHY (DIRT).

James B. Mercer[1,2] and Louis de Weerd [3]

[1]Cardiovascular Research Group, Department of Medical Biology, Faculty of Health Sciences, University of Tromsø, Tromsø, Norway. [2] Department of Radiology and [3]Department of Plastic Surgery and Hand Surgery, University Hospital of North Norway, Tromsø, Norway

Introduction: Breast reconstruction with a free flap from the lower abdomen has become increasingly popular. After transfer of the free abdominal flap to the thoracic wall, the vessels of the flap are preferably anastomosed to the internal mammary vessels in order to reestablish the flap's blood circulation. As the name suggest, the internal mammary vessels perfuse the mammary glands. However, these vessels continue caudally as the superior epigastric artery and vein, an important source of blood for the abdominal wall. Little is known if the removal of this blood source following the anastomotic process has an impact on the skin circulation of the abdomen.

Methods: Dynamic infrared thermography (DIRT) was used to monitor indirectly skin perfusion of the lower abdominal area in patients that have undergone autologous breast reconstruction with a free abdominal flap anastomosed to the internal mammary vessels. DIRT was performed at the end of surgery by examining the thermal recovery patterns following washing of the skin with saline at room temperature. On day 1, day 3 and day 6, DIRT was performed following a mild thermal challenge (short period of fan cooling). All IR-images were taken using a FLIR ThermaCAM S65 HS, FLIR Systems infrared camera. For processing the electronically stored IR digital images we used image analysis software ThermaCAM Researcher Pro 2.8 SR-1 (FLIR Systems AB, Boston, MA, USA).

Results: Immediately at the end of the operation skin temperature patterns of the lower abdominal area showed a clear asymmetry that was caused by a decrease in skin perfusion on the same side of the used internal mammary vessels. This asymmetry became less visible during the following days. In most patients a clear improvement in skin blood circulation was evident on the 3 day. On the 6 post surgical day, the majority of patients showed thermal distribution patterns of the lower abdominal area that were more symmetrical

Conclusion: The use of the internal mammary vessels in autologous breast reconstruction with free abdominal flap results in a temporary reduced skin perfusion of the lower abdomen on the operated side of the body.

THERMOGRAPHIC MONITORING OF THE HANDS IN RENAL DIALYSIS PATIENTS. COMPARISON OF HIGH AND LOW RESOLUTION CAMERAS

Kalicki.B, Jung A, [1]Ring F, Saracyn M. Niemczyk S.

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Introduction: Renal is a medical process that becomes necessary when the normal functions of the kidneys become compromised by failure. The process involves filtering the blood of excess fluid, , and waste when the kidneys can no longer perform this function efficiently. An arteriovenous shunt is surgically implanted to enable the regular haemodalysis to take place, As this is carried out on a regular basis on patients with chronic renal failure, problems can occur with the peripheral vascular system. When this becomes evident, it is necessary to relocate the shunt. This study has been set up to investigate the possibility of using infrared thermal imaging during dialysis to detect changes in peripheral temperatures of hands or feet to provide an objective and non-invasive indicator of the status of peripheral circulation. After repeated use the fistula can cause a blockage in blood flow.

Methods: Two low cost infrared cameras were used FLIR i5 and FLIR i7. To fully evaluate the temperature distribution a FLIR P640 high resolution camera with a combined visible light recording was used. The main differences between the two low-cost cameras were that i5 has an 80x80 pixel resolution image, i7 has 120x120 pixels. The P640 gives a better image with 640 x480 pixel image. However the higher resolution camera is almost 2kg in weight whereas the small cameras are 0.35kg each.

Performing thermal imaging of the extremities in the dialysis unit is not always simple. The patients are immobile, and the tubes conveying blood to and from the patient to the dialysis unit are often overlaying the patient. The camera needs to be mobile, and recoding images should be performed in minimal time. Wherever possible the sites to be imaged, hands or feet should be well clear of the tubes that are at blood heat. Internal storage of the images in the camera digital memory is an advantage, enabling later image analysis after computer download.

Regions of interest were drawn over the coldest finger tips of the hands and a larger region of interest selected over the dorsal and palmar area. The maximal temperature difference was calculated from the central (palmar or dorsal) region to the coldest finer tip. The i7 data was better than from the lowest resolution i5. These were compared with the identical measurements obtaiued from the P640 camera. The visible images from the latter were helpful in interpretation of the thermograms

Results: 9 patients were studied, with a total of 60 readings compared, using both the dialysed limb and the contralateral region.

The maximal differences were obtained from the palmar surfaces of the hands. The mean palmar temperatures were 33.0C from the P640, the same data from the i7 gave a mean temperature of 32.6C, a mean difference of 0.4 CWith more pixels in the image, this is an expected finding. Tthe close comparability of data was reassuring that the low cost i7 camera can be considered suitable for monitoring temperature changes in dialysis patients.

INFRARED THERMOGRAPHY AS A DIAGNOSTIC TOOL AND OUTCOME MEASURE IN PATIENTS SUFFERING FROM RAYNAUD´S PHENOMENON

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Diagnosis of vasospastic finger disease, described for the first time by Maurice Raynaud in 1862, is based on clinical signs such as colour changes of fingers when exposed to cold and/ or psychic stress. A primary form of Raynaud´s phenomenon is differentiated from vasospastic attacks secondary to an underlying disease. Slightly different diagnostic criteria exist for the primary and the secondary vasospastic disease. The British criteria used for the epidemiology of Raynaud´s phenomenon include neurological symptoms such as numbness or pins and needles while the screening criteria from US are restricted to colour changes.

Criteria for the thermographic diagnosis of Raynaud´s phenomenon are not yet established. Different procedures for temperature measurement have been published and provocative tests to elicit a vasospastic attack vary in temperature and duration of exposure. However, a combined temperature gradient (CTG) combining the differences of the temperature at the finger tip minus the temperature of the dorsum of the hand, prior and post a mild cold challenge seems to be a sensitive and reproducible measure for diagnosing Raynaud´s phenomenon by infrared thermal imaging. The CTG can clearly differentiate patients with Raynaud´s phenomenon from healthy subjects, but can not separate primary from secondary vasospastic disease.

Only two studies investigated the correlation between clinical and thermographic signs of Raynaud´s. Both investigations applied the British criteria and related them with baseline temperatures of the finger tips and reported a diagnostic sensitivity of 70% of thermal imaging for clinical signs of Raynaud´s phenomenon.

Thermal imaging was used as outcome measure in some trials for Raynaud´s phenomenon including drug treatments with prostaglandin E, prostacylin, tri-iodothyronine, fluoxitine or, nitroglycerine tape and non pharmacological therapy with low level laser or impregnated gloves. While change of fingertip temperature appeared to be an outcome of good responsiveness, the combined temperature gradient showed only a moderate sensitivity to change.

HAVS OBJECTIVE PROCEDURE ASSISTED BY MEDICAL THERMOGRAPHY

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Background: Hand-Arm Vibration Syndrome is an occupational condition that needs an accurate quantitative and objective diagnostic test to aid clinicians in the judgment of the degree of injury and correspondent treatment.

Aim: An objective assessing method is needed to provide a permanent evidence record of the degree of injury.

Methods: Medical thermography was used with a developed objective mechanic provocation test involving vertical vibration exposure of hands, for 2 minutes at 31.5Hz of vibration frequency and 36 mm/s of vibration magnitude, which was followed by a vascular provocation challenge of the hand for a period of 1 minute at 20°C. In order to assess the peripheral temperature changes of the hand a computational model was developed and the images standardised and analised.

Results: It was possible to discriminate between degrees of injury groups ($p<0.05$) but not individuals.

Conclusion: The proposed method is objective and repeatable, can provide information of the evolutionary stage of the condition. Medical thermal imaging can be used as diagnostic tool to provide evidence of occupational condition affecting upper limbs in support to medical history in medico-legal liabilities

THERMOVISION APPLICATIONS IN PHYSICAL MEDICINE

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In chosen physical medicine therapeutic applications: whole body cryotherapy, hyperbaric oxygen therapy (HBO) and Fotodynamic therapy (PDT) thermovision was used as a non-invasi ve diagnostic technique.

All studies were performed by thermovision camera Flir A40.

Volunteers were divided into three groups: 6 patients suffered from *spondyloarthrosis* treated at the Provincial Centre of Rheumatology and Rehabilitation in Gocza³kowice Zdrój (WORR) where whole body cryotherapy was applicated, 19 patients suffered from trophic ulceration of tibias treated by HBO in Burn Treatment Center in Siemianowice Œl¹skie, and 7 patients suffered from *basal cell carcinoma* (BCC) treated by PDT in Chair and Clinic of Internal Diseases, Angiology and Physical Medicine in Bytom.

Results of the studies showed that diagnostic value of thermal imaging increases due to different physical factors. This effect was especially seen after body cooling where temperature contrasts enhance was obtained and more details were visible in thermograms performed after cold impact than before one. Moreover it was confirmed that increased of oxygen pressure used in hyperbaric oxygen therapy also caused the differentiation of skin temperature gradient. In this case healing process induced by hyperbaric oxygenation improves the neoangiogenesis especially in the periphery of the wound changing metabolism and the thermal skin map. Some skin temperature changes were also observed for patients suffering from BCC due to PDT and metabolism changes caused by cancer development.

Obtained results confirmed that thermovision can be useful as a diagnostic technique in chosen physical medicine applications. It seems that thermal imaging may give also some information about therapeutic effects.

THERMAL STUDY OF CHANGES IN PAIN INTENSITY AFTER TREATMENT IN A CRYO-CHAMBER

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The etiology of pain is multisystemic. This phenomenon is difficult to assess objectively. Despite this, the definition of change in the level of pain is one of the determinants of the physical therapy progress.

The purpose of this study was to determine the relationship between changes in body temperature at the spot of pain, and the subjective feeling of pain in patients.

Study subjects were 18 persons of both sexes, aged from 32 to 64, reporting pain in the area of the lumbar and thoracic spine. Before the treatments, they were examined by a doctor and a physiotherapist.

Patients underwent a series of treatments, using the cryo-c hamber. The temperature in the main chamber was set at -130°C. Treatments were taking place once a day for 10 days. After each cooling, the patients were subjected to warming exercises.

Before the treatments, and after the series, a value of subjective pain using Visibility Analog Scale (VAS) was set. Additionally, pictures were taken, using thermal imaging camera Flir A325 and ThermaCam Researcher Professional version 2.9 software system. The biggest pain points were marked on the thermograms.

Results: 15 patients reported reduced pain after surgery (difference in VAS after surgery was 1.2 or 3 points). In twelve cases thermography indicated a reduce of the temperature of the most painful areas, and in two other, the temperature rose by 0.2 and 0.7 degree, and one patient's temperature did not change at all.

Two respondents reported an increase in pain after surgery (1 point on the VAS. In both cases the temperature of the painful areas increased).

One patient did not observe any changes in pain intensity, and the thermograms did not show changes in surface temperature of his body.

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THERMOVISION ANALYSIS OF SKIN SURFACE TEMPERATURE IN SUBJECTS EXPOSED TO A WHOLE-BODY CRYOTHERAPY

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Introduction: Whole body cryotherapy is a stimulating use of extremely low temperatures ranged from -100 C to -160 C, within 2-3 minutes. The effects of systemic cryotherapy can be registered by thermo-visual methods. The aim of the present work was to evaluate the dynamics of body surface temperatures changes in healthy people, within 6 hours after whole body cryotherapy.

Material and Methods:25 healthy men aged 22 to 49 years (31,5 +/-) were included in examinations. The patients were subjected to single whole body cryotherapy procedure. The research group stayed in a chamber during 3 minutes in temperatures ranged from -100 ^{0}C to -120 ^{0}C. The distribution of temperatures was registered before procedure (01), within a first minute after (02), following 45 minutes (03), within 3 hours after (04) as well as 6 hours from whole body cryotherapy (05). Body surface subjected to analysis was divided into 28 areas (thermograms – marked from R01 to R28), whereas 16 thermograms were subjected to statistical analysis.

The registration of surface temperature variations was performed by means of Flir System Inc. thermovisual camera *ThermaCAM P640*.

Results: As a result of intense cooling of the whole surface of the body, the statistically significant differences between mean temperature before procedure (01) T and after (02) T were noticed, for each analyzed area. The considerable lower temperature was still captured between mean temperature before the procedure (01) T and mean temperature registered 45-55 min after cryotherapy (03) T, for some of considered areas (p<0,05). Within 3 hours after whole body cryotherapy (04), the increase of body surface temperature was noticed with relation to values achieved before the procedure, in every considered area. Nevertheless, the statistically significant difference of temperature registered in 3 hours after the procedure (04) T with respect to temperature before entering into examination (01) T was registered only in case of two considered areas (p<0,05). After 6 hours from termination of whole body cryotherapy (05), the further increase of temperature was affirmed. Within some areas subjected to analysis, the statistically significant differences between temperature registered before the procedure (01) T and temperature captured within 6 hours after cryotherapy (05) T ,were still noticed. At the same time, despite the further increase of temperature within the majority of considered areas, the statistically significant differences between mean temperature of examined areas after 3 hours (04) and temperature noticed within 6 hours after the procedure (05) (p>0,05), were not revealed.

Conclusions: The statistical analysis of registered thermograms of skin surface revealed the intensive cooling after whole body cryotherapy. The compensation of thermal energy loses within determined areas proceeded gradually, with distinctive differences of the process dynamics. The increase of temperature after 3 hours from the procedure, revealed in case of each examined area, as well as further increase of temperature within the consecutive 6 hours, noticed for most areas, with respect to values measured before cryotherapy, is very significant. This increase of temperature, proved in a course of each stage of thermovisual measurements, was observed in case of trunk region and the proximal parts of limbs. In case of distal parts of limbs, the phenomenon maintained during consecutive 3 hours after cryotherapy procedure, and then stabilized, despite the temperature of skin surface of these areas stayed increased with respect to the value before the procedure.

AUTOMATIC MEASUREMENT OF HUMAN BODY TEMPERATURE IN EYE CANTHIS USING THERMOVISION CAMERA

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Technical University of Lódz, Institute of Electronics, Poland

Last researches show that human body core temperature can be measured in eye canthis using thermovision camera [1]. Automatic detection of eye canthis on thermograms can be useful tool to separate healthy people and people with fever. It is extremely important in crowded places such as airports or railway stations. The proposed system could protect from spreading dangerous illnesses.

An algorithm which automatically measures the human body temperature using thermovision camera was elaborated. The program written in Matlab selects people whose temperature is higher than normal. Implemented algorithm of finding eye canthis on thermograms mainly uses morphological operations. At first, the face is detected. Then, an ellipse is created which surrounds the face. The next step uses the morphological operations to find the local maximums and extract smaller regions of interest. Using the ellipse shape, the next selection of ROIs is performed. The region below the smaller ellipse axis is deleted, and the eye canthis are recognized by finding 2 areas that are the closest ones to the center of mass of the ellipse.

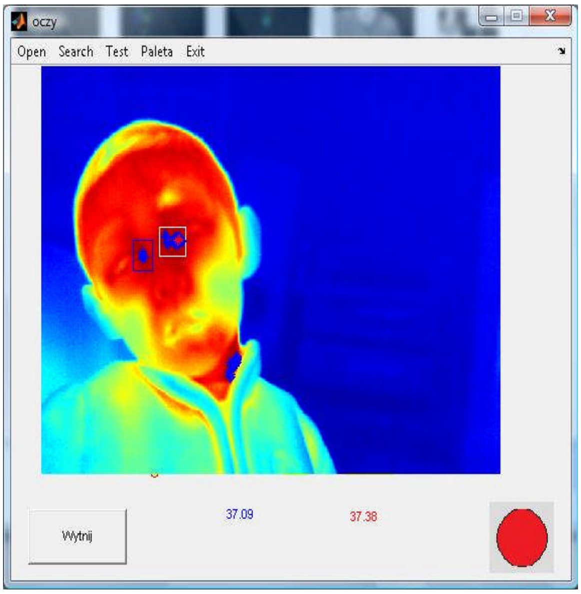

Figure 1
The example using the method of detecting eye canthis and the measuring temperature of human body

Efficiency of the algorithm	84%
Efficiency of the algorithm after deleting 2 thermograms containing 2 persons	92%
Efficiency of working the algorithm after zooming the human face in thermograms	100%

The efficiency of the algorithm is estimated by the number of cases of good detecting eye canthis in comparison to all ones. It the first test, the efficiency was equal to 84%. After deleting two pictures on which there were 2 people (child and parent), the efficiency was increased to 92%. Finally, after zooming the pictures in order to get only the human face in the thermo- grams, all eye canthis were detected. The efficiency was 100%. The improvement of working the algorithm can be done by taking pictures from the closer distance.

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MICROBOLOMETER THERMOVISION CAMERA FOR MEDICAL APPLICATIONS

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The significant growth of applications using thermography for medical diagnosis could be observe in the last years. Though, on the market there is lack of specialized and certified thermovision cameras for that type of use. In Electronic Circuits and Thermography Division at Technical University of Lodz, the uncooled thermovision camera for medical applications was constructed. Designed camera works with uncooled microbolometer detector made from vanadium oxide (VO), which works in long range of infrared radiation (8-14µm). The focal plane array of 288x384 microbolometer detectors with thermal resolution of NETD@ 300K<50mK, allows acquiring 25 frames per second. Detector's parameters together with appropriate temperature span for calibration and non-uniformity correction were selected to achieve the best measure parameters for medical applications. For the purpose of obtained thermographs analysis the dedicated software ThermalScope has been created. This environment give users access to wide range of thermal image pro- cessing tools e.g.: calculating basic and complex statistical parameters, wavelet transform, analysis using artificial neural networks and calculating Fourier transform of thermal image sequence. The software allows using camera for passive or active thermography. Actually the camera is under the certification process, which is required for medical devices.

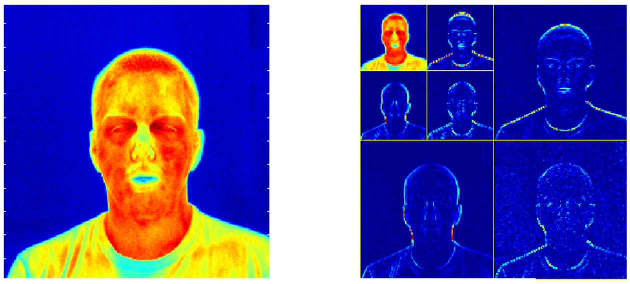

Figure1
The use of ThermalScope software for thermograph analysis – wavelets transform

IMPORTANCE OF RADIATION HEAT TRANSFER IN IR THERMOGRAPHY

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What does IR camera measure?

Relative heat transfer plays the key role in thermal imaging in every thermovision camera. The first problem mentioned in this communication is the radiative temperature measurement of the objects located at different positions versus the camera axis – fig.1. Typically the radiation intensity varies with the angle according the Lambert cosine law. The larger the angle ? between the camera axis and the object's normal direction, the smaller the intensity *I*.

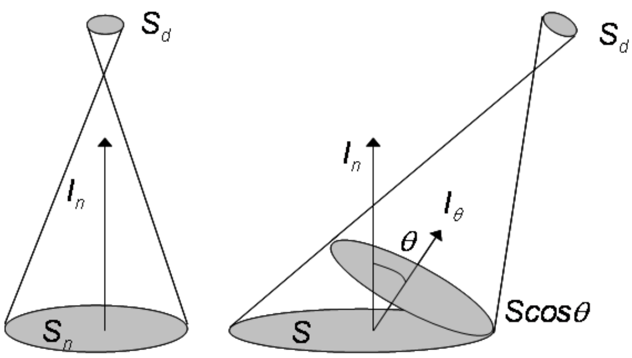


Fig.ure 1
Camera measurement with different observation angles

For larger angles, the smaller radiation intensity in compensated by increased emission area. It proves the thermovision temperature measurement regardless of the observation angle. It's valid both for the photon-cooled and bolometer-uncooled cameras. When the angle is greater than 50?, the directional (angular) emissivity changes the emissive power, and the camera calibration is no valid anymore [1].

Object's emission and reflection

Typically, the emissivity of the object is smaller than 1. It denotes that the real bodies are not the black ones, and they emit less energy one can evaluate using Max Planck law. The lower emissivity results in the object's reflection. Because the surrounding objects have typically the ambient temperature, they can be reflected from the measured surface like in a mirror – fig. 2. The reflection coefficient is estimated as *1-?*. In consequence, the radiation failing on the IR detector consists of two components: emitted and reflected from the body.

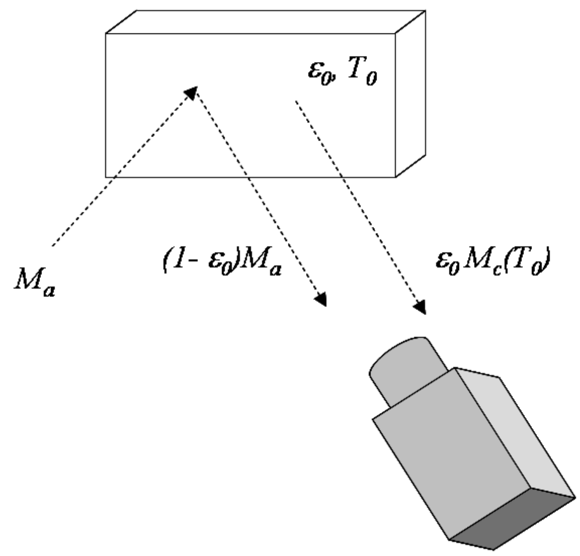


Figure. 2.
Emissivity influence on the radiation partition measured by IR camera

In addition, the radiation is attenuated by the atmosphere having the transmission coefficient τ. Every camera has to recalculate the object's radiation as it is presented by eqn. (1).

$$M_c(T_o) = \frac{M}{\varepsilon_o \tau} - \frac{(1-\varepsilon_o)M_a}{\varepsilon_o} \qquad (1)$$
$$M = \varepsilon_o \tau M_c(T_o) + (1-\varepsilon_o)\tau M_a$$

where: M - radiation exitance, T_0 – object's temperature, ? – transmission of optics and atmosphere, ?0 – object's emissivity.

How to make a black body

In many practical cases, such as camera calibration and non- uniformity correction, the black body with very high emissivity has to be used. In order to design the black body, one needs to apply the theory of radiation configuration (geometry) factors. Let's assume the conical cavity as shown in fig. 3 [1]. The incident radiation is almost fully absorbed by the cone due to the multiple reflection and partial absorption. In effect, the emissivity of the structure significantly grows. This is a principle of construction of black bodies.

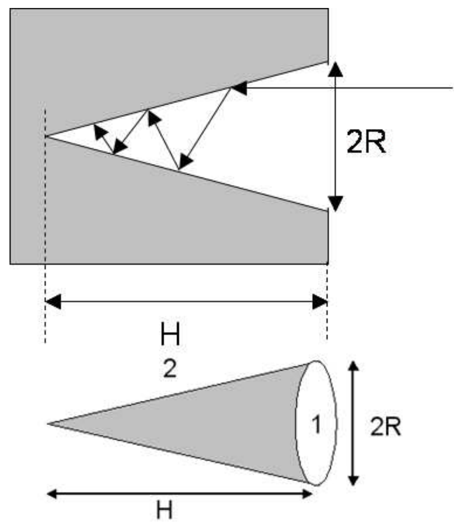


Figure 3
Conical black body

The apparent emissivity for conical geometry can be calculated using egn. (2).

$$\varepsilon_z = \frac{\varepsilon}{1-(1-\varepsilon)F} \qquad (2)$$
$$F = 1 - \frac{R}{\sqrt{R^2+H^2}}$$

where: ε_z =apparent emissivity, ε=real body emissivity *and* F =geometry factor

For real material emissivity ε = 0.9 and $H = 10R$, geometry factor equals to F = 0,9004, and apparent emissivity ε_z = 0,989.

Bolometer detector

The last but not least is the problem of theoretical limits in the operation of microbolometr detectors. The bolometer detector absorbs the radiation energy and coverts it into heat – figure 4. In effect, the heat augments the temperature of the detector, and it changes the electrical resistivity, dielectric polarization or Seebeck voltage in resistive, pyroelectric and thermoelectric devices, respectively.

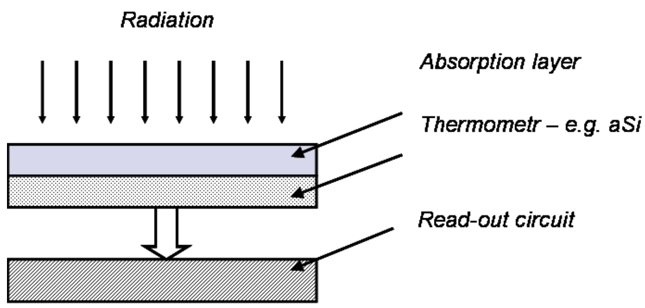


Figure 4.
A structure of microbolometr

The basic equation that governs the heating (cooling) of the bolometer describes the energy balance. The incident radiative power P is divided into the accumulation of heat in the detector and leakage of energy to the ambient – eqn. (3).

$$C_{th}\frac{dT}{dt} = \eta P - G_{th}(T - T_a) \qquad (3)$$

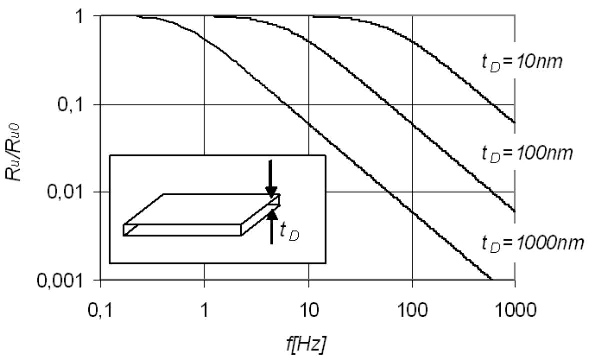
where C_{th} – thermal capacitance, G_{th} – thermal conductance between the detector and ambient, ? – absorption of IR radiation, T – detector temperature, T_a – ambient detector.

In consequence, the detector responsivity R is be essentially decreased when the heat leakage and the thermal inertia (capacity) are too high – eqn. (4).

$$R_v = \frac{\eta I_b \frac{dR}{dT}}{\sqrt{G^2{}_{th} + \omega C^2{}_{th}}} \qquad (4)$$

where I – the bias current, R – electrical resistance of a bolometer, T – temperature.

As a conclusion, one can say, that the bolometer generates a signal dependent upon the radiation flux frequency [2]. With higher rate of radiation variation, the detector responsivity dramatically decreases – fig. 5. The high responsivity can only be achieved for thin (~100 nm) detectors, low thermal process variation rate (~10 Hz) and the detector encapsulated in a vacuum package.



Even if all conditions mentioned above are fulfilled, for typical microbolometer detector 25x25 μm, assuming the radiative thermal leakage only (perfect vacuum) and very small thickness (~100 nm), the thermal time constant is equal to 26 ms – eqns (5).

$$\begin{aligned} &S = 25\mu m \ x \ 25\mu m \\ &d = 100nm \\ &R_{th} = \frac{1}{\alpha_r S} = 0{,}26 \cdot 10^9 \frac{K}{W} \\ &C_{th} = c_v S d = 0{,}1 \cdot 10^{-9} \frac{J}{K} \\ &\tau_{th} = R_{th} C_{th} = 26ms \end{aligned} \qquad (5)$$

The direct consequence of long thermal time constant is the low frame rate of bolometer cameras. If someone wants to investigate high speed thermal processes, he has to buy the photon cooled camera which can easily generate more than 500 frames per second. In addition, the thermal camera has to be equipped with the opaque shutter to compensate a thermal drift. It stops the image stream, what can be inconvenient in various applications. The shutter has to be very uniform, because it generates a radiation flux which compensate the drift for every single detector in the matrix. If the thermal camera is moved from/to warm/cold ambient, the user has to wait a sufficient time in order to stabilize the temperature inside the camera.

References

[1] Siegel R, Howell JR. Thermal Radiation Heat Transfer, 3rd ed., Taylor & Francis, Hemisphere Publishing Corporation, 1992, ISBN 0-89116-271-2.

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