ISSN-1560-604X
Thermology international

Thermology International

Volume 17 (2007)
Number 3 (July)

Quality, Reliability and Maintenance
Guest Editor: Dr Roderick A.Thomas

Conference Abstracts
10th National Congress of the Polish Association of Thermology

Published by the
European Association of Thermology
and the
Austrian Society of Thermology

This journal is indexed in
EMBASE/Excerpta Medica

THERMOLOGY INTERNATIONAL

Volume 17 (2007) **Number 3 (July)**

Published by the
Austrian Society of Thermology
and European Association of Thermology

Indexed in
Embase/Excerpta Medica

Organ of the American Academy of Thermology

Organ of the European Association of Thermology

Organ der Deutschen Gesellschaft für Thermologie

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Für Mitglieder der Österreichischen Gesellschaft für Thermologie, der Deutschen Gesellschaft für Thermologie und der Amerikanischen Akademie für Thermologie ist die Zeitschrift im Mitgliedsbeitrag inkludiert.

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(2) International Committee of Medical Journal Editors. Additional statements from the International Committee of Medical Journal Editors. Can. Med Assoc J 1997;156; 571-4.

Uhlen Verlag Wien,
Ingeborg Machyl, Fachzeitschriftenverlag
Gusenleithnergasse 28a/1, A-1140 Wien
Thermology international
ISSN-1560-604X

Internet: http://www.uhlen.at/thermology-international

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The journal "Thermology international" (formerly "European Journal of Thermology") is published four times/year. Annual Subscription rate is 38.- €, a single copy costs 12.- € plus mailing costs (4.50 €/copy; outside Austria).

The journal is supplied free of charge to members of the American Academy of Thermology, the Austrian Society of Thermology and also to members of the German Society of Thermology.

References:

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Uhlen Verlag Wien,
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Internet: http://www.uhlen.at/thermology-international

Quality, Reliability and Maintenance - an opportunity to exchange expertise in thermal imaging between industry and medicine

Roderick A Thomas

QRM Mission

QRM is an organisation that organises Biennial Condition Monitoring Conferences at St Edmund Hall, University of Oxford. Established by Professor G J McNulty (University of Southampton, University of Sheffield and Sheffield Hallam). The first conference was organised at Clare College Cambridge in 1995 and since then at St Edmund Hall, Oxford. The QRM Conference Series has developed and flourished since the inaugural meeting in 1995 into well-established biennial meetings at the University of Oxford.

The interdisciplinary nature of QRM is exemplified by the 41 papers published in the current proceedings of the 6th International QRM conference held at St Edmund Hall, University of Oxford March 2007. Headings include, Quality Management, Reliability Analysis, Medical Thermography, Condition Monitoring techniques, Research Applications, and Computer Modeling. The material gathered in these proceedings rates some of the best of current practice and research in QRM, which is published in the hardback volume by Coxmoor Ltd, Oxford and has the seal of approval of the co-sponsors The Institution of Engineering and Technology (IET).

The aim of the conference in Quality Reliability and Maintenance (QRM) is to provide a forum of excellence so that the latest research findings can be open to scrutiny from both their peers and specialised international referees. Successful acceptance of the participants' work will be published in the book of proceedings (1,2). The proceedings were originally published by the Institution of Mechanical Engineers (IMechE). The IMechE distributes the proceedings world wide to Universities Libraries and research institutions. Published papers were predominately electrical, electronic and computer based applications

In 2004 Dr RAThomas CEng, FIEE, became conference organiser and is keen to continue to promote the integration of disciplines by widening access and the recent move of the IEE to IET fits perfectly the mission of QRM

A further objective is to keep costs low so that research workers, scientists and engineers of limited means can publish their research. The conference organisation therefore depends on voluntary professional personnel. In this way overheads are kept to a minimum.

Publications

Publications are rated highly in the priorities of these conferences. QRM endeavours to help research workers and research students to have their work exposed to international scrutiny. Papers are restricted to one author for every registration. However, in exceptional circumstances where an author has a further paper with excellent referees' reports, the paper may be deemed a possibility for inclusion in the QRM proceedings at a modest funding cost along with the author's first paper. The condition is that the authors of the extra paper must be from third world or new developing countries.

QRM proceeding papers are accepted for several leading international journals (3,4,5). Appropriate papers are published as special editions in the journals after presentation at QRM.

Previous conferences have been successful both in numbers and academic excellence, the latest proceedings is the 6th in the series representing a total to date of 369 papers from 21 nations. QRM encourages many aspects of condition monitoring particularly infrared thermography mainly industrial but there is a growing number of joint industrial/medical projects. Examples of research areas include:

- Infrared Thermography
- Vibration Analysis and digital Fourier Transforms
- Integrated approaches to Condition Monitoring
- Computation analysis in Condition Monitoring
- Non-Destructive Testing
- Education, Training, Standards and Competences

QRM 2007

Six papers have been selected, two medical and four industrial representing the latest in infrared developments. Greg McIntosh reviews generic methodologies for application of infrared thermography focusing on the methodology for conducting the inspection with an infrared imager and post inspection image analysis (6). Although this approach starts from industrial use of infrared images, the generic principles are also applicable in medicine and biology. My own paper is dealing with industrial applications of infrared thermography in more detail (7), discussing the advantages and disdvantages of infrared imaging as diagnostic condition monitoring technique. John Snell proposes a practical methodology for the evaluation of electrical systems with infrared thermography (8). His approach based on credibility of temperature measurements (which must be both accurate and precise) is combined with two levels of diagnostic questions, which lead to reliable diagnosis and prediction of the actual condition of the system investigated. The final paper from the industrial section reports the findings in evaluation of defects in automotive windscreens using photoelastic stress and thermographic measurements (9).

In the medical section, Kevin Howell and collegues review their experience with infrared imaging in the evaluation of diseases characterised by microcirulatory changes (10). The paper from the Anglo-Polish Database Group analyses clearly factors and procedures, which lead if left uncontrolled to serious errors and misinterpretation of thermal images in medicine (11).

In conclusion, it is quite obvious that thermographers in the field of industry and maintenance, but also in applications in medicine or biology face similar problems Thermal images just provide a two-dimensional map of temperature distribution on the surface of the object of interest. However, any procedure leading to accurate and precise temperature data will allow a correct assessment of the condition imaged if carefully matched with other sources of information. In medicine, diagnosis cannot be solely based on thermal images. The same statement is true for the condition assessment in maintenance of electrical systems (8). However, information on temperature levels of the subject/object evaluated, facilitates the decisions for procedures which may counteract or improve the condition under evaluation.

The quality of papers in the current volume of QRM2007 is in line with the high standards and technical content, which is a tradition of the QRM conferences. They reflect the rapid changes in technology together with the demands for Quality standards from governments and international bodies. The wide spectrum of interests reflects the all embracing and unique message inherent in the QRM philosophy.

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Generic methodologies for utilizing infrared thermography

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SUMMARY

It is essential that before an Infrared (IR) inspection procedure of a particular electrical, mechanical or process is developed, that consideration be given to the methodology that will be employed. In order to be both efficient and effective, different methodologies need to be employed for electrical, mechanical and process apparatus. This paper describes the fundamental generic methodologies which can be applied, their characteristics and how they can be properly implemented in a procedure or predictive maintenance program.

KEY WORDS: Infrared thermography, methods. maintenance

ALLLGEMEINE METHODIK ZUM EINSATZ DER INFRAROTTHERMOGRAPHIE

Bevor ein Plan für die Infrarot-Untersuchung von elektrischen, mechanischen oder Prozess orientierten Anlagen entwickelt wird, ist es bdeutsam dass die eingesetzte Methode sorgsam überlegt wird. Um sowohl effektiv als auch effizient zu sein, müssen für die Überprüfung von elektrischen, mechanischen und Prozeß orientierten Apparaturen unterschiedliche Methoden angewendet werden. Diese Arbeit beschreibt die Charakteristik und Anwendung allgemeiner und grundlegender Methoden, und wie diese in eine vorausschauendes Instandhaltungsprogramm implementierte werden können.

Schlüsselwörter: Infrarotthermographie, Methodik, Instandhaltung

Thermology international 2007; 17(3): 55-58

Introduction

Infrared cameras are, for the most part, quite simple to operate in order to get a reasonable thermal image. And, infrared software is designed to take that imageand easily and rapidly create a report. But in striving for universal ease of use and rapid report writing, two extremely important functions can be overlooked: a sound methodology for conducting the inspection; and post inspection image analysis. When one or both of these functions are forgotten a number of problems may arise:

- the results are not repeatable
- problems are missed;
- non-problems are identified as problems
- the severity of the problem is misjudged
- items which should be inspected are not flagged for re-inspection
- root cause of the problem is not identified and systemic problems reoccur.

Irrespective of the methodology employed there are also two classifications of Infrared Inspection: Qualitative and Quantitative. Qualitative assessments, or those not involving temperature measurement, are performed by Level One thermographers and fundamentally pertains to analyzing the image for identification of thermal anomalies. A quantitative assessment is typically performed by Level Two thermographers and pertains to radiometric temperature measurement and problem severity assessment.

Inspection Methodologies

For both qualitative and quantitative inspections there are different infrared inspection methodologies that can be implemented depending on the equipment type, history, criticality, purpose and analysis required. These methods can be categorized into five general methodologies: Exception Method, Baseline Method, Comprehensive Method, Trending Method and Troubleshooting Method.

Exception Method

The thermographer scans the equipment looking for a thermal anomaly based upon pattern or temperature. Thermal image data is collected only when a suspected problem is located. Equipment that is operating according to the required inspection criteria (e.g.: adequate load, low wind, etc.) is recorded as within acceptable limits. This is often denoted as a 'Green' condition and the inspection of that component is deferred until the next routine interval. If the inspection criteria cannot be met (e.g.: insufficient load, no access, poor weather, etc.) then equipment is recorder as 'not inspected'. This is often denoted as a 'Yellow' condition indicating that a subsequent scan should be performed on this item. The exception method is the most common method for inspection of electrical contacts. The exception method can be extremely efficient and rapid allowing thousands of components to be scanned in the time period of a week. Typical components scanned eligible for this type of inspection include (but are not limited to) electrical disconnects; motor control centres, distribution panels, switch gear, and outdoor substations, distribution and transmission line components. The disadvantage of this type of the inspection method is that the thermographer must have both sufficient training and experience to be able to identify and properly document a thermal problem under varying field conditions. One other significant disadvantage of this method is the temptation to only document the problems found, and to skip the tedious, but essential task of documenting the equipment that was not inspected for reasons such as: the equipment was not running; insufficient load; unsafe access; inappropriate ambient conditions, etc.

Baseline Method

The thermographer scans the equipment making comprehensive recording of all surfaces and data related to the thermal performance of the equipment and the environment (1). The data is archived in an equipment baseline report which may easily be retrieved for future reference. Baseline data is only complete when all performance conditions (seasonal, load, ambient etc) have been collected. Baseline documentation need not be sophisticated or formal. The raw (12 or 14 bit) thermal data is archived, along with operational and environmental data at the time for some future reference. Baseline inspections should be carried out on all critical electrical and mechanical when:

1) An infrared program starts.

2) When operating conditions on a piece of equipment changes significantly.

3) When equipment has had significant repairs or modifications performed.

4) When new equipment is purchased and commissioned.

Comprehensive (Comparison) Method

This method is similar to the baseline method in that images are recorded on a regular basis (e.g. monthly or quarterly) and brought back to the office for analysis. The images are compared to the previous scan, or a similar piece of equipment operating under similar conditions. A comparison is made between the data with an attempt to normalize or account for variables (e.g. load; convection; ambient temperature; etc.) Comparisons may be qualitative (pattern based) or quantitative (temperature based) although every attempt should be made to quantify (such as using a histogram to characterize the pattern) Comprehensive inspection is the most common method for mechanical inspections. Typical components scanned eligible for this type of inspection include (but are not limited to) refractory lined vessels; motors; generators, gearboxes, electrical transformers, pumps, and heat exchangers.

Trending Method

This method is similar to the comprehensive method only the thermal data obtained from multiple successive inspections of the same piece of equipment is trended with time. This method may help to identify the variables which may be influencing the thermal pattern or temperatures and develop a thermal condition trend. This methodology is typically implemented when a Yellow mode (low priority or

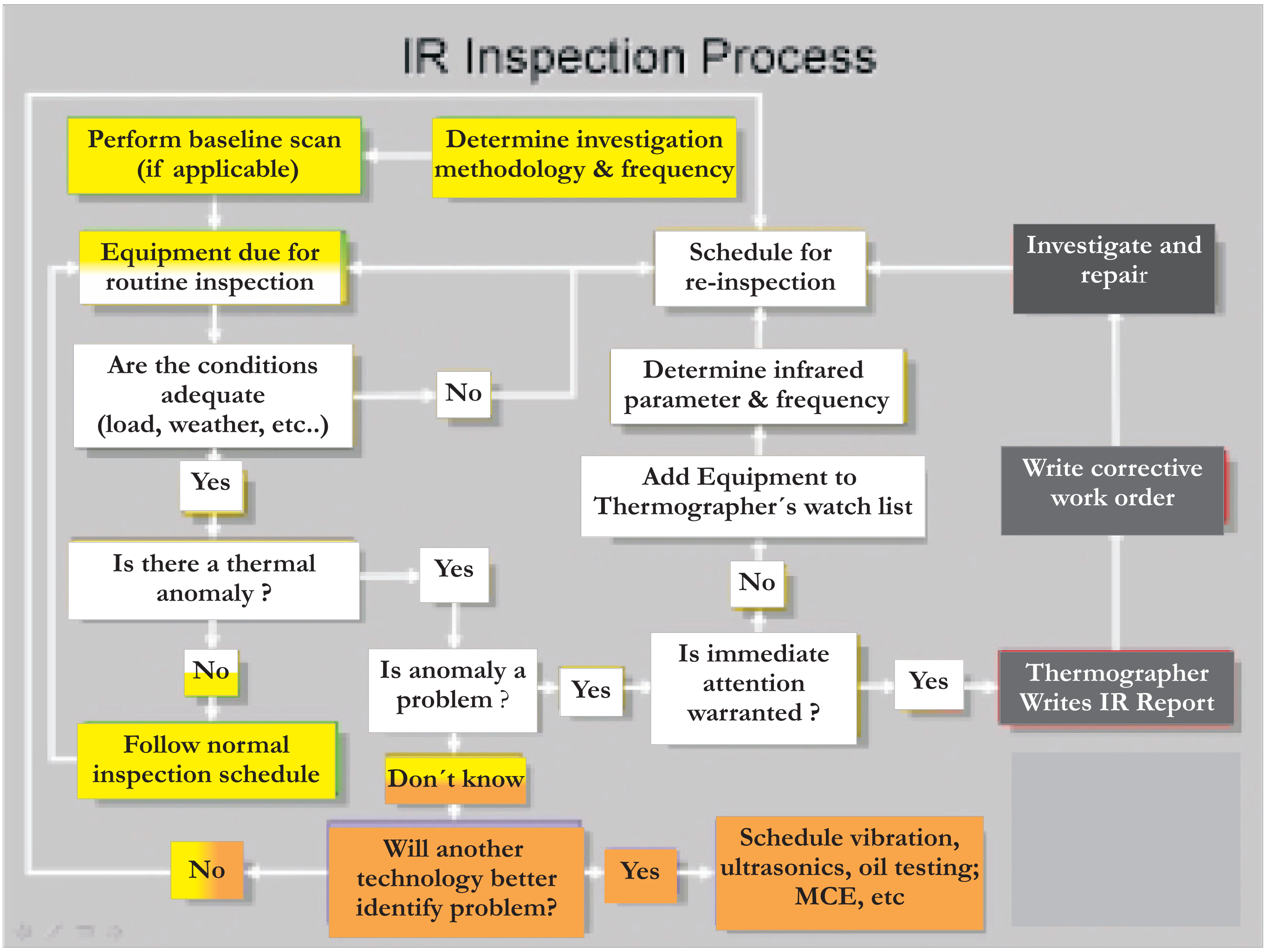

Figure 1
Infrared Inspection Process Flowchart

Table 1
Various Equipment Categorized by Methodology

	Exception	Baseline	Comprehensive	Trending	Troubleshooting
Data Collection	Only thermal anomalies are recorded	Composite thermal imagery of equipment is recorded under various operating conditions	Images of specific equipment locations are recorded	Specific images, data points, or statistics are recorded	Data is recorded as per a baseline
Frequency	Monthly to Yearly	Program start-up New equipment Operation changes Modifications	Weekly, monthly Monthly to quarterly	As situation dictates, increasing frequency asindicated trend	As Required
Route Based	Yes	No	Yes	Yes	No
Report	Image + Photo	Image catalogue Thermal mapping may be employed	Image comparison	Image and data trending	Varies
Target Applications	Most electrical components	High value assets Critical assets Chronic problems	Most mechanical components	Components that have history of problems, or an thermal anomaly of unknown origin or severity	Processess and products
Examples	Electrical panels, disconnects,Connectors, capacitors,v-belts, couplings chain drives, low speed bearings.	Motors generators, Transformers, Refractory- blowers,lined vessels, furnaces, Process heaters,Boilers, extruders,Papermachines.	Motors, pumps,gearboxes,compressors, generators, exciters, transformers,Oil filled circuit breakers, lightning arrestors, isophase bus-duct, heat exchangers, hydraulic systems.	Any equipments for which a detedted anomaly can be quantified for trending	Line blockages leaks, valve operations, Heating cooling problems, moisture Detection, insulation deficiencies, effluent discharge.

unclassified) anomaly is detected. The inspection frequency should be influenced by the slope of the trend. Figure 1 shows an inspection process flowchart which incorporates trending after a thermal problem has been classified 'Yellow'.

Troubleshooting Method

This is a very typical type of inspection but can be extremely difficult. It is a general method in which the thermographer is asked to assist in the identification of an unknown problem on a piece of equipment on which the comprehensive method cannot be used because there is no baseline of similar equipment to compare to. In this case the thermographer uses knowledge obtained from engineers, operations, maintenance and other diagnostic techniques to understand the thermal pattern and its potential causes, preferably in real-time.

There are different means to try and make the Troubleshooting Method 'scientific'. These include:

1) Inducing a thermal transient in the equipment or process.

2) Watching how the steady state thermal patterns change with load.

3) Observing the thermal contrast on the equipment.

4) Looking for thermal symmetry.

5) Knowing the material thermal limits.

6) Making sure there are no unexplained hot or cold spots.

Conclusions

Table 1 summarizes the different methodologies applied to various type of equipment.

Utilizing thermography with systemic methodology and analysis is essential for development of best practices for writing procedures, conducting inspections, and creating a lasting high value inspection program (2). Recognizing that different methodologies, analysis techniques and inspection intervals need to be employed for different types of equipment is also essential. Without sound methodology and adequate analysis the results obtained with thermography may lack repeatability, findings can be inconclusive and wrong decisions made (3). More than one Fortune 500 company (4) has found that programs conducted in this manner are doomed to failure after as little as 4 to 5 years once the obvious thermal anomalies have been repaired.

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Industrial applications of infrared thermography

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SUMMARY

Thermography is essentially a diagnostic condition monitoring technique, operating at two levels firstly, qualitative, where the radiant heat patterns emitted from a machine or component are a measure of condition. Secondly, Quantitative where the radiometric temperature measurements are able to determine regions, or points, of increased or reduced heat emission which can indicate the presence of an anomaly that can lead to predicting machine or component condition and likely failure.

KEY WORDS: qualitative thermography, quantitative thermography, condition monitoring

EINSATZ DER INFRAROT-THERMOGRAPHIE IN DER INDUSTRIE

Im Wesentlichen stellt die Thermographie eine Technik zur Beurteilung beim Warten von Anlagen dar, die auf zwei Stufen funktioniert. Stufe 1 ist die qualitative Beurteilung, bei der das Muster der von der Anlage oder einer ihrer Komponenten abgestrahlten Wärme als Zustandsbeschreibung dient. Die quantitative Beschreibung ist die Stufe 2 , bei der auf Grund radiometrischer Temperaturmessungen Stellen und Regionen e endeckt werden, an denen eine verstärkte oder verminderte Wärmeabstrahlung eine Anomalie anzeigen, welche den Funktionszustand und das mögliche Versagen der Anlage oder deren Komponenten voraussagen können.

SCHLÜSSELWÖRTER: qualitative Thermographie, quantitative Thermographie, Wartung

Thermology international 2007; 17: 94-99

Plant availability

An efficient maintenance strategy can save industry from the danger and expense of catastrophic failure. For example, the cost of unplanned shutdowns and other interruptions in 2005 cost Chevron 1.8 Billion dollars, Chairman Mr Steve O' Reilly, at the 4th Annual Operational Excellence Forum (1). Recent research into the economics of possible cost savings suggest; Half of the electrical failures could be prevented with regular maintenance, unplanned downtime due to equipment failure costs manufacturers up to 3% of their revenue, predictive maintenance can save 8 - 12% over reactive maintenance.

Insurance statistics have revealed that loose connections cause 25% of all failures in electrical equipment such as switchboards, switches, circuit breakers and cables (2). This means that failures attributable to temperature increases within some industries can directly affect the efficient operation of maintenance, and consequently the profitability of those industries (3). It is an established fact that the application of condition monitoring can increase machine reliability and hence reduce catastrophic failure. This results in optimised plant availability and improved safety. There is no strict rule as to the application of an appropriate maintenance strategy. It is often dependent on the type of plant and machines, their criticality levels, method of operation and maintenance. Reliability Centred Maintenance (RCM) is one such technique that addresses all these issues and is currently experiencing a resurgence in its application across Europe. Traditional machine condition monitoring tends to rely heavily on various contact type transducers particularly with reference to vibration monitoring. There are some challenges with this type of monitoring including:

- Problems with background noise on slowly rotating machines.
- Susceptible to distortion via mechanical impedance (as the mechanical impedance of the machine will determine how the vibration transducer will respond to the vibration forces and can significantly alter the characteristic of the measured signal). The vibration signal of some large-massed machines such as turbines are distorted due to low elasticity.
- Difficult to calibrate, because this generally requires removal from machine.
- Mechanical design can lead to a reduction in performance over a period of time, particularly with reference to velocity transducers.
- Could be influenced by vibrations transmitted from surrounding equipment.
- Accelerometers require integration that is susceptible to noise.
- Accessibility problems in very hostile environments, e.g. hazardous to safety, require expensive hard-wiring.

Non-contact thermal condition monitoring

Non-contact infrared (IR) thermal monitoring provides the means to scan the thermal emmissions of complete machines, components or processes in a very short time and display a radiant heat pattern representing temperature distribution (Figure 1).

Thermal imaging instruments in condition monitoring continue to develop in diagnostic capability, simplicity of

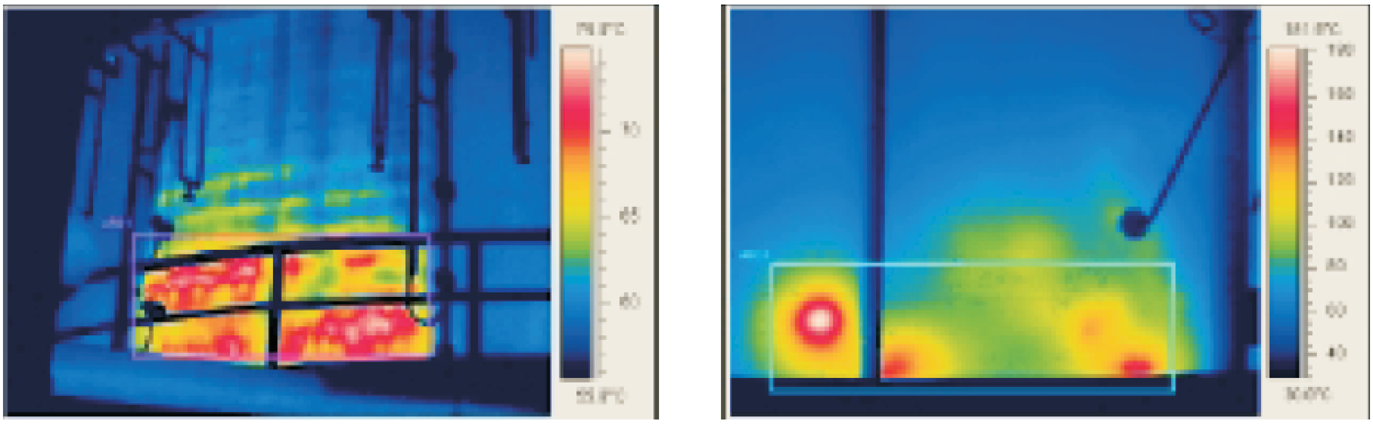


Figure 1 Heat pattern on furnace walls

operation and at reducing costs. Two types of system currently dominate the market: Qualitative and Quantitative instruments.

With the former are lower cost and simpler operation and the later is with enhanced diagnostic capability including for example, simultaneous digital and thermal image recording, multiple emisivity correction in a single image and real-time or faster data acquisition as in the NDT requirement . There are a variety of advantages when adopting infrared thermal imaging as part of an optimized maintenance strategy:

- Wide measurement range (dependent on camera and filter).
- Safe and non-hazardous to personnel and the workplace.
- Does not interfere or make contact with surface being measured.
- Can be used in explosive environments (via coating on camera body or using an intrinsically safe camera).
- Immune to electromagnetic noise.
- Can store and recall images as part of a route based activity.
- Can retrieve and analyse on site.
- Invariably conducted in real-time.
- Reliable, because the components have a semi-infinite lifetime expectancy.

Whilst thermography is a proven diagnostic tool there are instances of good practice where an integrated approach to condition monitoring is required via the combination of visual, vibration, lubricant and wear debris analysis, performance monitoring, motor current analysis and IR Thermography. In particular bearings and gears would benefit from this approach.

The major advantage of thermography is the large number of industrial applications (Table 1).

Challenges of infrared thermography

The current challenges associated with IR thermography are declining. The reasons for this relate to more reliable hardware and user friendly software although, a significant requirement is still the need to carry out training. The other considerations relate to radiometric measurements and an understanding of heat transfer. An objects emissivity must be known or calculated.

Table 1
Machine faults and condition indicators

Machine Fault	Temperature	Pressure	Flow	Oil	Vibration
Electrical – cooling systems, earth faults, circulating currents, laminations,cracking insulation, commutators and brushes	X				X
Commutators, brushes and sliprings	X				X
Ancillary equipment – fuses, loose connections, overload or unbalanced load, pitted relay contacts, switchgear, distribution boards, transformers	X				
Electronic systems – discrete components, printed circuit boards and bonding	X				
Mechanical - Misalignment, bent shaft	X				X
Damaged rolling element bearings, gears	X			X	X
Inadequate or insufficient lubrication	X				X
Damaged journal bearings	X	X	X	X	X
Loose components	X			X	X
Energy systems - boilers, steam systems, flues, heat exchangers and regenerators. Refractory insulation, buildings and roofing. Thermal efficiency of vessels, buildings and materials (NDT)	X X	X	X	X	X
Medical and Research	X	X	X		

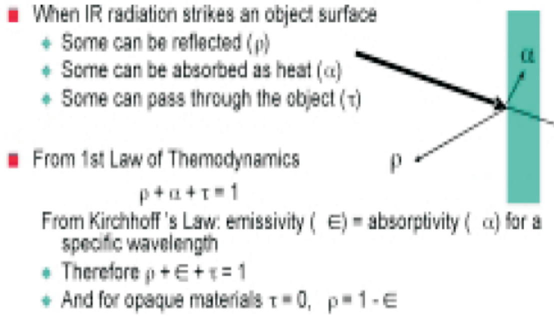
$Qe = \sigma\varepsilon A T^4$ [W/m²]

σ = S-B Constant 5.67 10^{-8} $W/m^{-2}K^{-4}$, T = Surface Temperature [Kelvin], A = Area, ε = Emissivity

Kirchhoff 's law states that for any uniform medium in thermal equilibrium, the emissivity and the absorption coefficient, α_v , for any spectral region equals the ratio of the object's surface emissive power to the emissive power of a black body; this relationship serves to define the emissivity, ε_v , of an object:

$$\alpha_v = \frac{E_v}{E_{bv}} = \varepsilon_v$$

The object surroundings should have a homogeneous (ambient) temperature and should not include hot areas so positioned, that the radiation can be reflected by the object. Atmospheric influences/attenuation - distance, composition (clear, misty etc) and ambient temperature can also affect quality of detail.



Appropriate training is considered an important requirement to successful implementation at all levels. There are many documented applications of IR monitoring in the Steel, Power Generation, Building Services, Automotive, Paper, Cement, Offshore, Glass, Electronic Industries (4). Examples of engineering systems that can be monitored include; Electrical machines and systems, Mechanical machines and systems, electronic systems and components, energy systems, thermal efficiency of vessels, buildings and materials (NDT) and medical diagnostics and research.

Electrical systems are subject to a number of conditions that can directly affect the life of the system namely localized overheating and unbalanced loads. Localized overheating phenomena will result in a discernable Delta Temperature (ΔT) with the magnitude and direction indicating the severity of the problem. This applies to direct measurements and after emissivity correction, compensation for any temperature reflections, convection etc. Electrical connections subject to overheating can be calculated by Joule's Law:

$P = I^2R$ [Watts]

where P is the heat generated (Watts) and is a measure of the heat dissipated, I is the load current consumed (Amps), R is the electrical resistance (Ohms).

Figure 2
Localised overheating in the direction of the connection

When a connection overheats there are a number of reasons why this occurs including, loose, damaged, dirty or connections subj ect to fatigue, produce a unique radiant heat pattern (Figure 2). Localised overheating results in the following scenario:

R (L3) > R (L2 and L1)

where R is the electrical resistance (Ohms), L1-L3 Electrical Phases

Manual manipulation of the thermal image both level and span highlights the local overheating. Further understanding of localized heating reveals that when two conductors come together a contact is made and due to the roughness and deformation of the surfaces this contact is limited to a certain number of points known as 'elementary contacts'. This condition of contact is also affected by the construction resistance (this is the reduction in contact area causing increased resistance to current flow) and the film resistance (development of resistive oxide layers as a result of oxidation). The deterioration of contact through an increase in electrical contact resistance (the sum of the construction and film resistances) will produce 'thermal hot spots'. However the rate of deterioration substantially increases with time. Ideally the trended temperature measurements should be performed in conjunction with current measurements where the load is variable. This will enable the temperature rises to be corrected to a reference current value for a valid comparison (5):

$$\Delta T_r = \Delta T_m \left(\frac{I_r}{I_m} \right)^2$$

where ΔT is the temperature rise at the reference current value (K), ΔT_m is the measured temperature rise (K), I_r is the reference current (Amperes), I_m is the measured current (Amperes).

Unbalanced loads tend to be common place in many industries and again produce a unique radiant heat pattern (Figure 3), where:

I (L2)> I (L1, L3)

Class	Maximum Temperature			
	Internal		External	
	°C	°F	°C	°F
A (Small)	105	221	85	185
B (Medium)	130	266	110	230
C (Large)	155	311	135	275
D (Turbo)	180	356	160	320

Figure 3 a
Maximum permissible temperatures

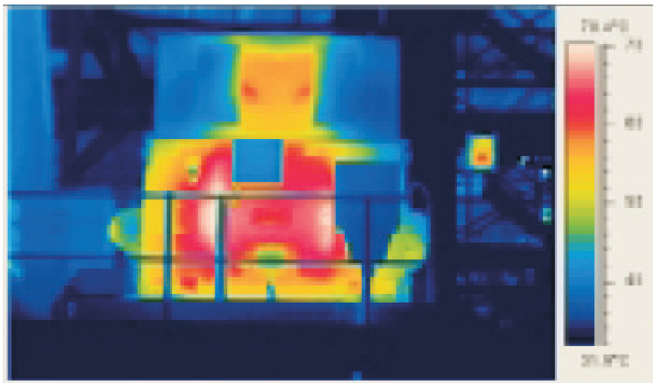


Figure 3
Class B Motor normal temperatures

where I is the load current consumed (Amps), L1-L3 Electrical Phases

There are a number of electrical control and distribution components that can be monitored using IR cameras including: Control equipment, contacts, cables and connections, transformers, fuses and fuse holders, switchgear including contactors, relays, isolators, circuit breakers and various switches, motor control centres with panel door open and many more.

The use of perspex in electrical cabinets is on the increase. Often perspex is opaque to infrared radiation so drilling (and opening the panel door) or removing the Perspex (and using IR windows with the panel door shut) are options to enable thermal imaging.

Industrial applications

Rotating electrical machines are an essential item within many industries. They are however subject to a number of possible failures. Typical failures identified (6) include rotor body defects, rotor winding faults, water coolant faults, stator winding faults, winding insulation defects, stator core defects. When applying condition monitoring to electrical machines there are three sources of possible problems:

- Mechanical sources; bearings, rotor unbalance, looseness, misalignment, end winding damage, brush / brush holder vibrations.
- Aerodynamic sources; turbulence, blade-passing frequency and fan problems.

Table 2
Infrared condition monitoring on electrical machines

Motor	Condition
Machine enclosure	Overheating and cooling. Defective cooling system. Poor electrical connections.
Frame	Overheating
Stator	Stator core - lamination hot spot. Stator windings Stator end winding portion – cracking insulation
Bearing and seals	Overheating

- Electromagnetic sources; static air gap eccentricity, dynamic air gap eccentricity, air gap permeance variations, open or shorted windings, unbalance current phase, broken rotor bars, torque pulses and magnetostriction.

During motor defect monitoring the following condition monitoring parameters have been established as appropriate; temperature, vibration, motor speed, axial flux and stator current. When applying infrared thermography to electrical machines the following component conditions can be determined (Table 2).

From Table 3 it can be seen that thermal imaging of rotating machines can reveal many aspects of machine deterioration such as cooling, commutation, connections, stator condition, bearing and coupling conditions (see next section) and provide verification after repair. An electrical machine's rating is generally fixed by its size (Kilowatt rating) and maximum permissible temperature which the machine can withstand temperature and it is therefore an alarm setting tool:

The temperature rating is the maximum rise over ambient, for example, a Class B Motor has a temperature rating of 90C over 40°C ambient resulting in a 130C maximum internal temperature.

Electronic and microelectronic system condition have benefited via thermographic methods of inspection, particularly with reference to printed circuit boards (PCBs) and individual components including heat sinks, power supplies, regulators, fans etc. The biggest challenge is determining the emissivity that is why a qualitative technique is the preferred option. It is a well known fact that high operating temperatures of electronic components result in a reduced operating life, with the failure rate increasing almost exponentially,

Thermography can be applied to the inspection of discrete components, particularly the effect of thermal run-away leading to catastrophic failure. In the design of PCBs the individual effect of combined components must be taken into consideration including various cooling components such as heat sinks. PCBs are notoriously difficult to monitor thermal patterns in-situ, due to the lack of space. By quick removal of a circuit board these temperatures can be closely monitored and thermal profiles produced. Schneider (7) suggests the following steps to identify problems on whole PCBs. Thermography can also be used in the nonde-

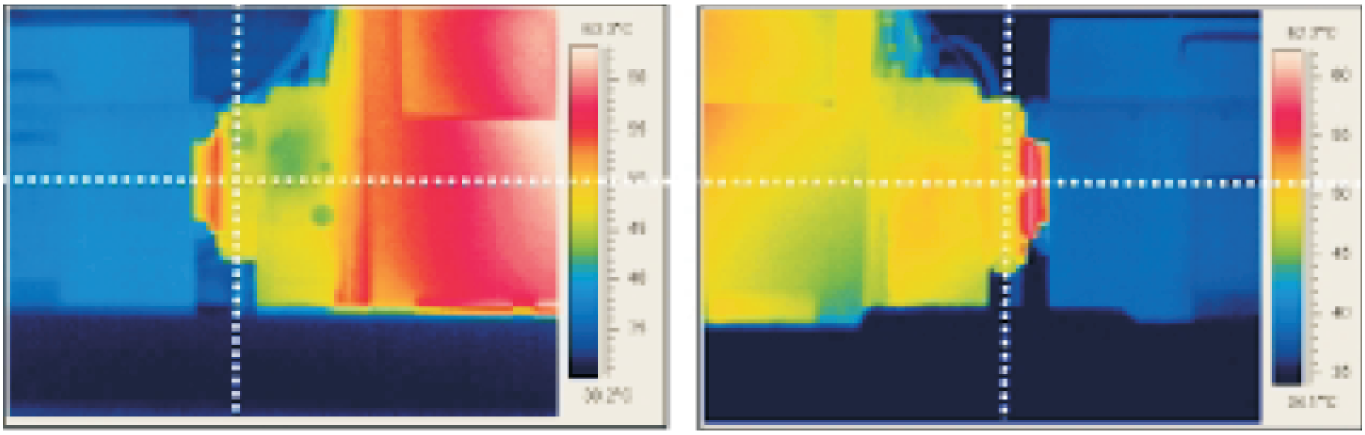


Figure 4
Bearing housing temperatures

structive test inspection of bonds on integrated circuits. This is achieved where induced heat creates a thermal pattern. However the test must take into consideration the exact geometry of the components to be tested, positioning of the component, acceptable temperature and component variations. Recently IR Thermography has been used to investigate the thermal environment within digital track controllers in the train industry by viewing through the cooling fan grating.

Mechanical systems represent a large proportion of industrial equipment used in most industries. These systems include mechanical rotating and reciprocating machines that consist of a large number of mechanical components and have in common that heat is generated as a result of friction caused by defective components. Possible reasons for mechanical machine problems include:

- ·Over and under lubrication leading to overheating.
- Increased loading on the bearings thereby reducing bearing life, Thermal Image 3 (although the heat pattern is dependent on the type of bearing and how it is maintained) Figure 4.
- Increased stress on the machine components leading to fatigue problems.
- Increased forces applied to a machine, such as loose foundations. o Inertia effect leading to imbalance in rotating parts.

All mechanical rotating and reciprocating machines have in common is that in operation they create friction (the load should be in excess of 40%) which is the result of normal or excessive wear. Friction can lead to catastrophic failure, caused by various deteriorating components and is often linked to no or improper maintenance. Examples of mechanical components include: Bearings, couplings, seals, shafts, pulleys, conveyors, pumps, fans, gears, chain drives. Clutches, belts, flywheels, constant velocity joints, steam traps, heat exchangers, tank levels and many more.

Some examples of mechanical machine deterioration include; unbalance, misalignment, looseness, damaged bearings, gears, vanes, blades, belts and chains, eccentricity, aerodynamic and hydraulic problems. For example misalignment can cause expensive energy losses in electrically rotating machines resulting in imbalance, looseness, bearing deterioration and finally catastrophic failure. Thermography can also be used to identify gross misalignment as significant temperature rises across the coupling occur (although the heat pattern will depend upon the type of coupling and how well it is fitted and maintained). Pushing and pulling forces are important and need to be taken into consideration, for example in Figure 4; the horizontal dotted centre line depicts the axial forces or 'float' and the horizontal mounting. The dotted vertical line depicts the vertical forces in the radial direction emanating from the bearing. It is important when examining all machines that due consideration is taken of all the probable consequence of failure and deterioration in this case, looseness, unbalance, misalignment of shafts and bearings, overheating stator windings or insufficient cooling.

Hydraulic component condition monitoring using thermography is generally not common, perhaps one of the reasons for this is the high pressure and fast fluid flow fluctuations that can make diagnosis complex and difficult. However temperature in hydraulic systems can vary to some degree during normal operation of the system due to wear, malfunction, increases in leakage and have been documented (8) as illustrated in Table 3.

Table 3
Thermal problems in hydraulic systems [8]

Hydraulic component	**Thermal problem**
Cylinder	Leakage of piston or rod sealing.
Valves: Pressure valves Directional valves Check valve Valve packages Valve blocks	Leakage through failure, leakage, jammed spool. Solenoid failure, leakage, jammed spool. Brake valve, etc. leakage. Leakage, solenoid failure. Leakage near surface.
Pumps and motors	Leakage (volumetric efficiency), failure, bearings.
Pipes, hoses, fittings	Leakage, clogging.
Complete system	Failure, wrong settings, too high warming of system, small leakage of oil outside of system.

Sometimes it is difficult to locate defects within hydraulic components using simple visual monitoring techniques. For instance, a hot spot on a pressure cylinder may coincide with a physically small defect in the hydraulic actuation system. Hydraulic systems often have dirty components, coated with hydraulic oil this can improve the emissivity of the material. The detection of faulty hydraulic components in the British Steel Industry has proven successful. A defective seal with a small axial incision was installed in a hydraulic cylinder which was then used in an experiment to prove the accuracy of thermography. The fault was quickly picked up on the thermal image as an anomaly resulting from a high pressure (around 500psi) fluid escaping from the incision. Other examples of industrial research include; automotive radiator design, thrust engine exhaust testing (in full reheat) and space shuttle testing and design. There is continued pressure for improved energy conservation particularly in light of 'global warming' and to protect the environment particularly with electrical power generation. This can only be achieved through a further commitment to energy conservation and pollution control. For example the efficiency of space heating in industrial, commercial, retail or domestic environments is reliant upon high standards of insulation installation and adequate maintenance to ensure and to reduce the possibility of leaks to the system. Generally, defective insulation, fluid and air leaks are identified as local increases in temperature whereas blocked pipes are detected as differential temperatures across a pipe. Other examples include:

Identifying defective valves steam traps, e.g. if steam is passing through the diaphragm of the trap, the trap may not operating correctly, fluid leaks, blocked pipes and radiator, and damaged refrigerators sections of a heat exchanger.

Energy efficiencies within all industries has never been so great. Many Governments throughout the World have imposed an energy level, so that those companies who demonstrate improved energy efficiency are given a tax advantage. Steam systems and distribution is common place in British Industry particularly within the manufacturing and process industries such as steel, tinplate and automotive, where large amounts of steam are consumed and condition monitoring plays an extremely important role. The temperature range requirement of refractory structures such as kilns and furnaces can be between 0-1600 C and thermal patterns can reveal internal problems. Inspection can be carried out whilst the plant is operating to predict condition and to plan any remedial maintenance. The temperature distributions from furnaces and sometimes the product itself can indicate furnace and product condition. In the steel industry location of steel strip within a furnace can be monitored by fixed thermal cameras and insulation of the furnace walls with portable thermal imaging cameras. Other examples include monitoring condition of torpedo cars and BOS (Basic Oxygen Steel-making) vessels, operation of water-cooled elements and even measuring the actual product temperatures.

Conclusion

The technological development associated with IR cameras has resulted in two types of systems. Firstly those that are extremely accurate and can capture data at video or higher speeds with large amounts of analytical capability. Secondly those where extreme accuracy is not necessary but are driven by a simple to use software system for predictive maintenance purposes. Both these systems require training to widen application, improve diagnostic capability and reduce the occurrence of error.

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Thermography in the microvascular laboratory

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SUMMARY

We describe our experience with infrared thermography (IRT) in a rheumatology microvascular laboratory. The role of IRT for the detection and assessment of Raynaud's phenomenon (RP) is discussed, along with our recent work on the thermographic evaluation of localised scleroderma (LS). As thermographic equipment becomes cheaper and the quality management (in particular standardisation and calibration) of medical IRT techniques improves, the use of this imaging modality in the microvascular laboratory should increase.

KEY WORDS: infrared thermography, microvascular laboratory, Raynaud's phenomenon, localised scleroderma, quality management

THERMOGRAPHIE ZUR UNTERSUCHUNG DER MIKROZIRKULATION

Die Autoren beschreiben ihre Erfahrungen mit dem Einsatz der Infrarot-Thermographie (IRT) im Rahmen einer rheumatologische orientierten Untersuchungseinheit zur Beurteilung der Mikrozirkulation. Die Rolle der IRT für die Diagnose und Beurteilung des Raynaud-Phänomens (RP) wird diskutiert und es wird ein rezentes Forschungsprojekt zum Einsatz der thermographischen Beurteilung der lokalisierten Sklerodermie (LS) berichtet. Da die Thermographie-Kameras billiger werden und das Qualitätsmanagement (insbesondere die Standardisation und die Kalibrierung der Geräte) sich in der medizinischen Thermographie verbessert, sollte auch der Einsatz dieses bildgebenden Verfahrens zur Beurteilung der Mikrozirkulation zunehmen.

SCHLÜSSELWÖRTER: Infrarot-Thermographie, Mikrozirkulation, Raynaud-Phänomen, lokalisierte Sklerodermie, Qualitätsmanagemen

Thermology international 2007, 17: 100-102

Introduction

Medical IRT describes the imaging of the surface temperature of the human skin by non-contact, radiometric means i.e. an infrared thermal camera. It has a history extending over 40 years, beginning with the earliest work on breast cancer detection (1), and continuing through to the present day with equivocal attempts to screen for severe acute respiratory syndrome (SARS) (2). In the UK, however, the most enduring use of IRT has undoubtedly been for the assessment of peripheral blood flow. After a brief explanation of medical IRT principles, we will describe two applications of IRT in the microvascular laboratory and discuss the importance of quality management.

Principles of medical infrared thermography

Skin temperature may be influenced by many factors, both physical and physiological. The pattern of temperature distribution across the body depends on local skin blood flow and underlying tissue temperature. Skin may be heated, for example, by conduction through tissue due to warm underlying structures, provided these are not too deep. This is the principle behind the use of IRT to assess inflammation in peripheral joints or to detect early superficial breast tumours (1). Skin temperature may also rise in response to energy delivered to the skin surface, making IRT a useful technique to monitor energised surgery techniques (3)or measure dose response in dermatological laser treatments (4). The relationship between blood flow in small skin vessels and skin temperature is complex and non-linear, Figure 1, and therefore skin temperature is unfortunately not an ideal surrogate measure of skin microcirculatory blood flow.

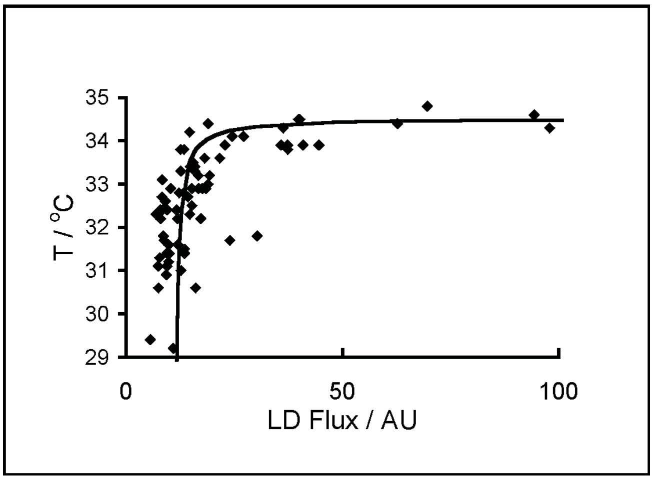

Figure 1.
Blood flux (measured by the laser Doppler technique) versus temperature (measured by IRT) from 7 healthy adult subjects equilibrated to a room temperature of 23 C The data are drawn from skin sites at the leg, arm, back, abdomen and forehead. It can be seen that skin temperature has little dependence on microvessel blood flow at low flux. Some association might exist, however, at higher skin temperatures. The form of the illustrative curve is: $(y-y_m)(x - x_0)=c^2$, where y_m=34.5 °C, x_0= 11 AU and c^2=3.8AU °C. Data from cheek skin (not plotted) has a different relationship between flow and temperature: the cheek exhibits a "blushing" response under sympathetic neurological control

Figure 2a.
Thermogram of hands of a healthy female 10 minutes after cold challenge showing full rewarming.

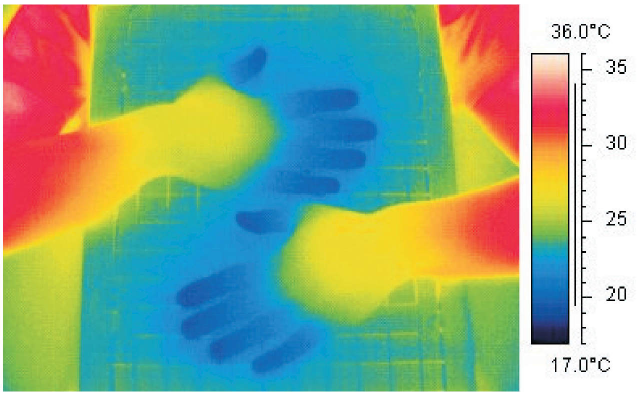

Figure 2b.
Thermogram of hands of a female patient exhibiting Raynaud's phenomenon 10 minutes after cold challenge. The fingers have remained cold over the test period.

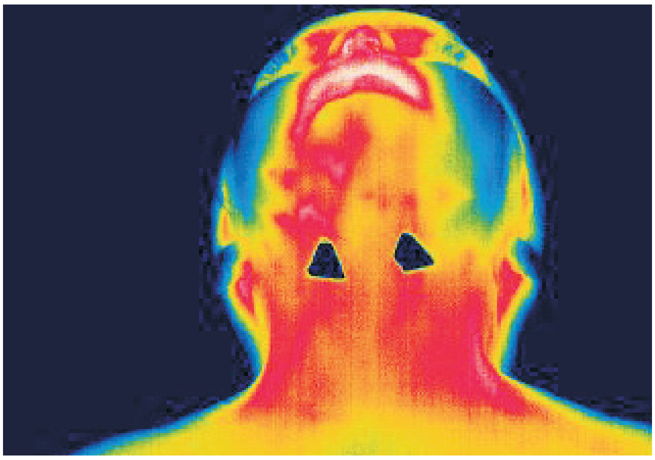

Figure 3a.
Active, hot, LS plaque extending along the right side of chin and neck, before therapy

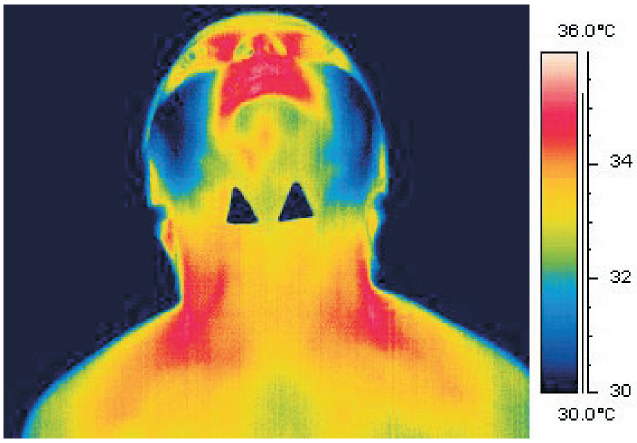

Figure 3b.
Five months after starting treatment, demonstrating a striking reduction in skin inflammation

Despite this, IRT can be a useful investigative tool in medicine due to its ability to image wide areas of skin in real-time. Under carefully controlled ambient conditions ischaemia will give rise to cooler skin, whereas increased blood flow (for example due to localised inflammation) will give a hot area on the thermogram.

Applications of infrared thermography in the microvascular laboratory

Raynaud's phenomenon

In the UK, approximately 10% of the population suffers from Raynaud's phenomenon (RP), with a female predilection over males of around 5:1. The condition is characterised by coldness, numbness, tingling and colour change in the digits triggered by a cold environment. Severe RP may be extremely debilitating, affecting the patient's ability to conduct a normal social and working life.

The diagnosis of RP is clinical and based on the patient's history. The cold challenge test with thermography is an objective test (4) helpful to confirm clinical suspicion and in equivocal cases. The Royal Free Hospital (RFH) is now one of the busiest sites for RP assessment in Europe, performing more than 500 cold challenge tests in a typical year.

Reliably detecting and assessing severe RP is important because an objective judgement in occupational health may lead to a patient being redeployed away from a cold environment. Rarely, but importantly, RP occurs as a clinical manifestation of an underlying connective tissue disease such as scleroderma. In such cases the ability to detect RP as a first sign of more serious complications is an important diagnostic and prognostic value.

The conduct of the cold challenge test is standardised. The patient is acclimatised for 15 minutes at a room temperature of 23°C, before a baseline thermogram of both hands is recorded. The hands are then placed in thin disposable gloves, and immersed in water at 15°C for one minute. Subsequent rewarming of the hands is then recorded by thermography over a ten-minute period (1 frame per minute), Figure 2. The analysis of the test requires that the camera is thermally stable over the test period.

Localised scleroderma (morphoea)

Localised scleroderma (LS) is a rare connective tissue disorder characterised by the progressive fibrosis of areas of skin, termed plaques. The pathological process in active LS plaques is characterised by inflammation. Childhood onset is common: in children, scleroderma lesions can extend to deep underlying tissues including fascia and muscles, leading to localised growth failure with sub sequent limb length discrepancies and joint deformities. Prompt systemic anti-inflammatory treatment may improve the outcome.

Our group at the RFH in association with colleagues at Great Ormond Street Hospital, London (5) have found IRT useful in determining the inflammation in sclerodermatous plaques consistent with active disease, and monitoring the subsequent response to specific antiinflamma tory and disease-modifying treatment, Figure 3. The application of IRT in LS raises two challenges: first, small temperature changes (< 0.5° C) should be determined accurately, and secondly, images spanning several years should be inter-comparable.

Management and Quality Control

Whilst IRT can have several clinical applications, thermal cameras are not manufactured or sold as medical devices (6) but produced for military and industrial applications. This presents a challenge for medical users, as best practice (7) demands that thermal cameras used clinically should be managed as if they were medical devices. The use of industrial equipment in the patient environment generates hazards. Suitable risk assessments should be in place and corrective actions (e.g. the use of a mains isolation transformer) may be needed. Users should ensure that they properly understand the quality of the images produced by their camera (8). For applications requiring absolute temperature measurement a calibrated black body, traceable to the ITS-90 (9) temperature standard, should be in the field of view. In addition, standardised procedures for the set-up of equipment and preparation of the patient must be in place. Working to a quality standard - even if it is implicit rather than externally accredited - is necessary to maintain comparability both within and between clinical thermography centres.

Conclusions

IRT is a highly effective tool in medicine for assessing skin temperature and microcirculatory changes. It needs quality control and rigorous management, to ensure that results have clinical validity and utility.

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Quality assurance for thermal imaging systems in medicine

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SUMMARY

Infrared thermal imaging was first made available to medicine in the early 1960's. Despite a large number of research publications on the clinical application of the technique, the images have been largely qualitative. This is in part due to the imaging technology itself, and the problem of data exchange between different medical users, with different hardware. In 2001 an Anglo Polish collaborative study was set up to identify and resolve the sources of error and problems in medical thermal imaging. Standardisation of the patient preparation, imaging hardware, image capture and analysis has been studied and developed by the group. The collection of normal reference images from a multi-centred study is required, but is dependant in improved reliability and cross calibration of camera systems. This paper specifies the areas found to be the source of unwanted variables, and the protocols to overcome them.

KEY WORDS: thermal imaging, standardisation, reliability, source of error

QUALITÄTSSICHERUNG FÜR THERMOGRAPHIESYSTEME IN DER MEDIZIN

Die Infrarot-Thermographie wird in der Medizin seit den frühen 1960iger Jahren eingesetzt. Trotz einer Großzahl von Forschungspublikationen zum klinischen Einsatz dieser Technik wurden die Wärmebilder meist nur qualitativ beurteilt. Das war teils durch die Bildtechnlologie selbst bedingt und zum Anderen durch das Problem des Datenaustauschs zwischen unterschiedlichen medizinischen Nutzern mit unterschiedlichen Geräten verursacht. Im Jahr 2001 wurde die Englisch-Polnische Kooperationsstudie initiiert, um Fehlerquellen und Probleme in der medizinischen Thermographie zu identifizieren und Lösungsvorschläge zu erarbeiten. Die Vorbereitung der Patienten, die bildgebenden Geräte und die Erfassung und Analyse der Wärmebilder wurden von der Gruppe untersucht und Standards dafür wurden entwickelt. Der Aufbau einer Datenbank von normalen Referenzbildern ist im Rahmen einer multizentrischen Studie ist notwendig. Dies ist jedoch nur bei verbesserter Zuverlässigkeit und gegenseitiger Kalibrierung der Infrarotkameras möglich. Diese Arbeit spezifiert jene Bereiche, die als die Quelle unerwünschter Variabilität gefunden wurden, und beschreibt die Maßnahmen, um sie zu vermeiden

SCHLÜSSELWÖRTER: Thermographie, Standardisierung, Zuverlässigkeit, Fehlerquelle

Thermology international 2007, 17: 103-106

Problems in thermal imaging in medicine

Disease and temperature change has a recognised association since the earliest days of recorded medicine. Fever, one of the earliest observations, was for centuries a subjective assessment on the part of the physician. The introduction of thermometers in the 16-18th century brought the first opportunities to objectively measure fever in man, although the technical limitations, and lack of standards, did not help in the understanding and acceptance of such measurements. Dr Carl Wunderlich in Leipzig in 1868, systemized the measurement of temperature in diseased patients, and introduced the clinical thermometer, showing the value of serial measurements. This situation remained a cornerstone of medicine until the introduction of infrared imaging in the early 1960's (1). Unfortunately, like the early thermometers, satisfactory calibration and standardisation of the imaging systems has taken many years to achieve. As a result many papers have been published on clinical studies, but the acceptance of such studies is limited by uncertainty about the techniques used, the imaging hardware and overall reliability (2,3) The predominant lack of control data over the last 40 years of thermal imaging in medicine has been compounded by the fact that the vast maj ority of publications refer to studies in diseased patients. The limited sources of normal control thermal images are rarely addressed. Similarly, there have been only a limited number of publications on standardisation of technique with thermal imaging (4,5).

The Anglo-Polish database project

Modern computing power, and significantly improved infrared thermal imagers for medicine, led to a new project in 2001 to address the above issues. A multidisciplinary team investigated each of the stages involved in performing a thermal imaging investigation on normal subjects. This team involved, physicians, clinical scientists and computer scientists from established centres of expertise in Poland and the UK. The aim is to investigate the total process of thermal imaging in a clinical environment, and to document all areas in which variables, which may affect the reliability of the process. This initial phase of study was completed at the end of 2003, and is described below. The ultimate aim is to collect a statistical sample of normal men and women (and probably some children) for a reference atlas of the human body thermograms, based on the protocol which has now been presented at some international conferences on thermal imaging in medicine (6). It is anticipated that access to the atlas/database of normal subjects will become possible either for on-line use, or by an electronic or hardware publication.

The standard protocol

The main areas of a clinical thermal imaging procedure that require standardisation are

a preparation of the patient

b standardisation of the thermal imaging system (including calibration)

c image capture protocols

d image analysis protocols

e reporting, archive and storage of images

f education and training of clinical users of the technique

Preparation of the patient.

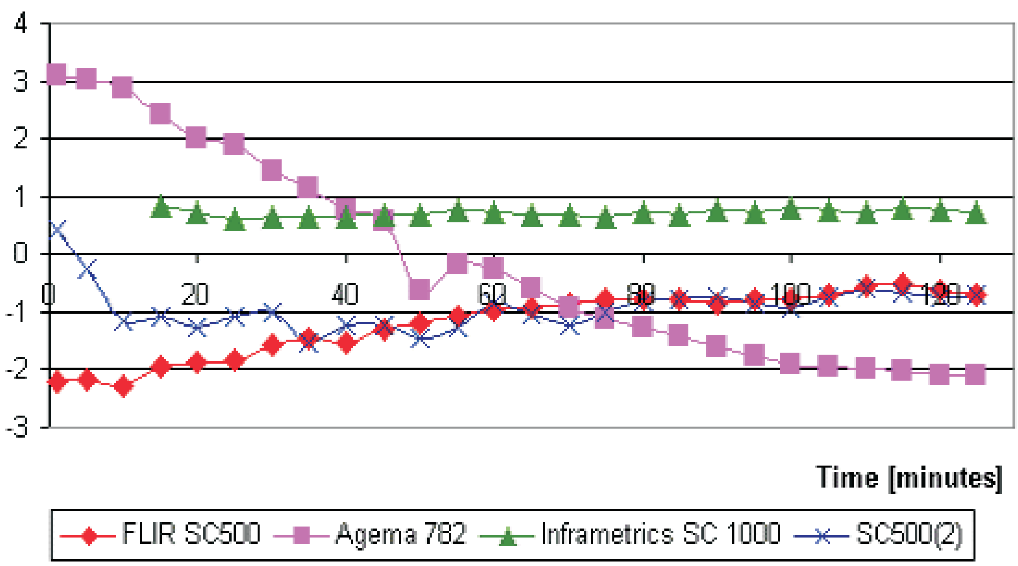
Existing publications draw attention to the key essentials, which may be conveyed to the patient in prior advice regarding smoking, exercise, drugs and cosmetics on the day of examination. The need for stabilisation after removal of essential clothing in a controlled environment (temperature and humidity) has been internationally agreed.

Standardisation of the Thermal Imaging System

There are a number of thermal imagers in medical use, using different detectors and optics. They are not equal in thermal or spatial resolution, and each depend on the manufacturers calibration. It has been found that most camera systems, both cooled and un-cooled detectors require much longer to achieve radiometric stability than stated by the manufacturer. This means that the common practice of setting up a camera just prior to use, is frequently inadequate. Variation in the measurement from a black/grey body radiant source at a known temperature or temperatures must be established for each imaging system, and the minimum warm-up time recorded. In addition, most thermal imagers are calibrated by the manufacturer before delivery, and may not be checked again until a fault is detected. Furthermore, each manufacturer in each country may use a different reference system, resulting in a wide offset range in terms of absolute temperature, Figure 1. In order to correct for this, the project team are collaborating with the National Physical Laboratory, UK in the development of a portable series of temperature standards which can be used to cross calibrate all imaging systems to be used in a multi-centre image collection. A large variable in camera position, caused by conventional photographic tripod use is simply overcome by the use of a large format camera studio stand, which allows vertical adjustment of the camera parallel to the ground.

Image Capture Protocols

We have found image capture to be a maj or source of variability, with varying camera angles and distances. A complete set of standard views was therefore devised, that require the camera to be mounted on a parallax free stand (Figure 1), ideally a heavy-duty studio pillar stand. The cameras than then be maintained at 90to the target, and parallel to the ground. The most useful modification, however, has been the introduction of software generated capture masks for each standard view of the human body. This is an electronic outline written in to the software that automatically appears when each standard view is selected from the menu. The outline ensures that the target fills the frame as much as possible, and that the limits for each view are defined by anatomical description (i.e. visible topographic features). The investigator adjusts the distance between the subject (target) and camera to fit the thermogram of the area to be recorded as closely to the mask outline as possible. This brings the thermogram to approximately the same size for all normal adult subjects regardless of their body size. Figure 3 and four show the description provided for each field of view, and form part of a defined set of 27 such views to cover the



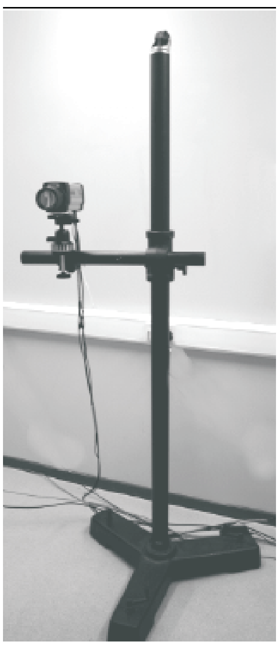


Figure 1.
Shows variable offset in four calibrated IR cameras and camera mount.

body surface which are likely to be of clinical importance in a medical examination. The temperature range and level is kept constant for the standard set of images, although supplementary images can be added if essential to record the full dynamic range of the subj ect.

These standardised procedures allow the collective analysis of groups of subjects within specified age bands placed in decades of life viz.20-80 years of age, male and female.

Image Analysis

Having obtained a standardised image, a set of regions of interest for temperature analysis have been drawn up for each standard view. These are accurately placed, again following anatomical definition, if the image has fitted well to the mask. Minor adjustments can be made if the fit is less good. Figures 2, 3 and 4 show the definitions of regions of interest for three of the standard views, the anterior face, forearm, and anterior total body. Experiments have shown that the usual practice of selecting rectangles or free drawing regions of interest, are poorly reproduced even by the same operator.

However, the policy of following described anatomical landmarks in drawing each region of interest results in very good reproducibility, whether made by the same operator or another (7). Such measures, which ensure that many of the subjective variables in analysis are removed or minimalized, are of critical importance in medicine.

In order to create a mean normal image of each anatomical area, with defined standard deviations, a further process of morphing has been developed. In this way larger numbers of images of the same anatomical area, and for a selected age band, can be merged to derive a mean range of temperature and thermal patterns for each area of the human body.

Reporting, Archive & Storage

Modern software greatly facilitates the reproducibility, from importing the image and the analytical data to a word-processing package. It is important that the images are stored complete with all demographic identification, and the temperature analysis from the standard regions of interest. We are investigating the effects of commonly used compression techniques on the thermal data, and at the present time avoid the use of these methods during the building of the image database. Suitable back up of all files is a standard requirement in medical imaging protocols. Software developments are also in progress to find a range

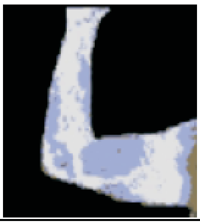
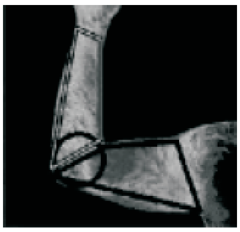
Standard View	LEFT ARM (dorsal view)
Upper	wrist
Lower	below the axillar fold
Other	arm 90° abducted and elbow 90° bent, the outline of the of the deltoidmuscle is within the image
Image	
IMAGE ANALYSIS	
Standard View	LEFT ARM Number of ROIs 3
Description	
ROI 1	Shape: circle Outline of the circle is adjacent to the cubital fold and the lower edges of the elbow.
ROI 2	Shape: trapezoid Upper left corner: cubital fold. Upper right corner: insertion of the deltoid muscle. Lower right corner: axillary fold. Lower left corner: tip of elbow.
ROI 3	Shape: trapezoid Upper left corner: ulnar end of the wrist. Upper right corner: radial end of the wrist. Lower right corner: cubital fold Lower left corner: tip of the elbow.
Image	

Figure 2
Anatomical description of the field of view for image capture of the fore arm

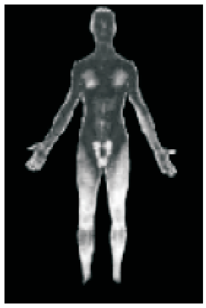
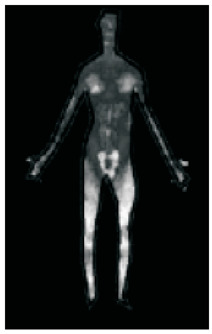
Standard View	TOTAL BODY (anterior view)
Upper limit	the most cranial point of the head
Lower limit	soles of the feet
Other detail	arms and legs slightly abducted, palms point forwards, head is a vertical position, not rotated or tilted to the side
Image IMAGE ANALYSIS	
Standard View	TOTAL BODY (anterior) Number of ROIs 1
Description	Shape: polygon, following the outline of the body
Image	

Figure 3
Anatomical description of the field of view for image capture of the whole body according to the new protocol and the region of interest for image analysis of the anterior surface.

of useful parameters for searching, especially important when the database becomes large enough to be used to compare or subtract a normal thermogram from an unknown undiagnosed medical condition or disease.

Education and Training of Clinical Users of Thermal Imaging

Past experience of clinicians using infrared thermal imaging has been variable, ranging from good sound science to poorly understood technique, and negative results. The aim of the protocol leading to a standard reference database will greatly improve the understanding and reliability of the technique for physicians who have no previous experience in thermal imaging. In all areas of medical imaging, physicians are first taught to recognize normal findings, and only then are they able to learn the features presenting in know diseases or abnormalities. The group have also co-ordinated some archive materials from earlier publications on a CDROM, and published a clinical casebook to aid physicians who may need examples of thermographic abnormalities associated with certain diseases (8). The University of Glamorgan, in Wales UK, also holds regular short residential training courses on the theory and practice of thermal imaging in medicine. This course includes the need for rigorous standardisation of the whole procedure. In addition, specialist conferences are held throughout Europe on a regular basis, and a j ournal which maj ors on thermal imaging in medicine – Thermology international are further aids to this necessary subject of education and communication within clinical science and medicine[9].

Conclusion

After 4 years of collaborative research involving physicians, clinical scientists and academic engineers, the Anglo Polish Project to construct the first normal reference of human body temperature has made important progress. Protocols for standardisation of the medical examination using thermal imaging have been established and have been accepted on an international basis. Further refinements; especially in the camera calibration, and software to aid standard image capture and analysis are being continued or have been completed. The collection of groups of normal males and females volunteer healthy subjects for the database is in the early stages, but some progress has been made.

The wider involvement of clinical centres in the UK and Poland will enable this data collection to be accelerated. The use of modern communication and imaging technology means that larger numbers of subjects can be sampled than would be the case for a single centre. It will also enable the study of any minor ethnic differences that could occur, particularly during the winter season.

It is hoped that this programme will make a substantial contribution to the ultimate wider acceptance and use of infrared thermal imaging in medicine. Furthermore, since thermal images are sometimes used in courts of law, the reduction in variability should improve confidence in their inclusion as objective evidence in medico-legal trials.

Acknowledgments

The authors gratefully acknowledge a 3-year grant from the British Council (Poland), without which this project would not have been possible.

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A practical, effective methodology for evaluating findings from thermographic inspections of electrical systems

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SUMMARY

The value of thermography in Condition Monitoring of machine assets is well known. For many years, however, we have been preoccupied with radiometric temperature measurement while not paying adequate attention to the conditions needed for a successful inspection. The result has been a failure to fully utilize the potential of the technology. This paper discusses a different approach that considers the ambient and system conditions needed to verify asset health and, when relevant, locate thermal signatures associated with abnormal asset health. Radiometric temperatures, when they can be measured reliably, are simply one indicator, of many, for asset health.

KEY WORDS: Condition monitoring, machine asset, thermography, temperature, radiometry

EINE PRAKTISCHE UND EFFEKTIVE METHODE, UM THERMOGRAPHISCHE BEFUNDE VON ELEKTRISCHEN ANLAGEN AUSZUWERTEN

Die Bedeutung der Thermographie bei der Wartung von Maschinenanlagen ist gut bekannt. Allerdings wurden Jahre lang nahezu ausschließlich radiometrische Temperaturmessungen als Begründung zur Wartung verwendet und anderen Bedingungen einer erfolgreichen Inspektion von Anlagen nicht genug Beachtung geschenkt. Das führte dazu, dass das volle Potential der Technologie nicht genutzt werden konnte. Dieses Manuskript diskutiert einen unterschiedlichen Ansatz, der die Umgebungs- und Systembedingungen berücksichtigt, die für die Beurteilung des Zustandes einer Anlage notwendig sind. Relevante thermische Auffälligkeiten werden dann aufgespürt, wenn sie mit einer Fehlfunktion der Anlage einhergehen, da auch die zuverlässig radiometrisch gemessene Temperatur nur einer von vielen Indikatoren ist, die den Zustand einer Anlage beschreiben.

SCHLÜSSELWÖRTER: Wartung, Maschinenanlage, Thermographie, Temperatur, Radiometrie

Thermology international 2007, 17: 107-109

Introduction

A previous paper (1) summarizes the findings of a survey of the work of thermographers throughout the United States more than a decade ago. These results were mixed and quite disappointing. Most thermographers believed that the severity of anomalies located could be determined based on their radiometric temperatures alone. While many problems were located successfully, others were not. Accurate and consistent prediction of the actual condition of those found also proved elusive.

Further investigations, suggest little of substance has changed in the years since, and a majority of thermographers are still primarily concerned with radiometric temperatures with little or no consideration of numerous other significant factors involved.

Present means of evaluating anomalies

Several standards or guides are often referenced in reports, including those of the United States Navy (2), International Electrical Testing Association (NETA)(3), National Fire Protection Association (NFPA) (4), and the Nuclear Maintenance Applications Center (NMAC) (5). These are listed below in Table 1. Closer scrutiny reveals some startling limitations with regard to accuracy and meaning.

None discusses the specifics of how radiometric measurements are made. Emissivity and background correction are not addressed, nor is load, or convective cooling. The thermal gradient -or temperature difference between the internal point of heating and the surface being measured-is also not addressed; all types of equipment are simply lumped together and subjected to the same analysis. In short, none

Table 1.
Temperature Standards (C) and Guides currently in use by thermographers

Action	US Navy[a]	NETA[b]	NFPA[b]	NMAC[c]
Advisory	10-24	1-3	1-3	.5-8
Intermediate	25-39	4-15	4-15	9-28
Serious	40-69	NA	NA	29-56
Immediate	70+	16+	16+	56+

All temperature values in centigrade
[a]Rise over (unspecified) reference. "Normal" operating load.
[b]Load should be 10-40%. Three categories only.
[c]Rise over (unspecified) reference.

is based in science. Most interesting is the fact that language in each implies the thermographer can change the repair priority when a problem seems worse than its temperature suggests! Of course there are no clear directions for how to do this consistently.

One could argue the use of these means of prioritizing findings have been successful. A simple statistical analysis of results suggests this is not true. Problems are missed, false-positives are found, and assessment of found anomalies, using temperature alone, is often inaccurate. Clearly there is a need for as accurate means of prioritizing findings that can be uniformly and simply applied.

What issues contribute to poor results?

There are a number of reasons why the radiometric data collected about the temperature of an anomaly is often inaccurate. Human error is significant; many thermographers have a poor working knowledge of the basics of heat transfer and radiometric physics, yet both are essential with quantitative analysis (6).

While modern radiometers are remarkably accurate in their abilities to measure radiation, they still measure the total radiation from a surface:

$$Qe = \sigma \varepsilon A T^4 - \sigma(1 - \varepsilon_{Bkgrd})\, A T_{Bkgrd}{}^4 \ [w/m^2] \qquad (1)$$

Where σ = S-B Constant 5.67 10^{-8} $W/m^{-2}K^{-4}$, A = Area, ε= Emissivity T = Surface Temperature [Kelvin]

Even when emissivity values and background temperatures are properly characterized, the accuracy of field measurements for low-emissivity surfaces, typical of electrical components, is very low. Because of low emission and high reflection, many anomalies simply fall below the threshold of detection.

Abnormal high-resistance heating of electrical connections occurs beneath the observed surface. Temperature gradients can vary widely. It is not unusual, for example, to find the threads of an electrical connector welded together while the outer surfaces appear relatively undamaged. Coupled to this is the phenomenon of variable emissivity associated throughout the thermal image due to the characteristics different materials, condition, material thickness and temperatures.

Heat output from a high resistance connector varies at the square of current flowing through the resistor. What the temperature of the connector reaches, however, depends on various heat transfer issues. Generally as load increases, so will temperature, but the rate of change is less predictable.

Two particular instances are especially problematic for thermographers. First is the situation where inspections must be made with low loads. Anomalies may be missed and the severity of those found may be underestimated. Loads that will increase in the future also present challenges to interpretation especially if the change is not anticipated. Compounding this problem is another anomaly, convective cooling whose effect can dilute the actual surface temperatures, especially associated with external infrared monitoring but can also occur internally, as in for example electrical basements.

high resistance on one side results in the current being shunted to the other, low resistance side. As a result, heating can occur on the side with normal resistance rather than the side with the problem.

Many thermographers are unclear exactly what temperature difference they should measure. Because of this lack of clarity, rise over ambient and rise over a similar component are often both used interchangeably; in fact, they are typically not interchangeable values. Further, many thermographers work under the illusion that delta measurements are insensitive to errors in emissivity adjustments or variations in convective cooling; again, this misunderstanding can result in dramatic errors.

One must also, consider the limitations of the infrared system with the primary factor considered being re- solu- tion, both spatial and measurement. Most camera suppliers fail to specify measurement resolution. Both these factors are important especially if the IR camera does not have interchangeable lens.

The failure points for various materials related to excessive heating can be determined; in fact information is available on the operating criteria for a number of electrical and mechanical components. However, the data generally pertains to the maximum operating temperature or maximum ambient temperature in which operation may safely occur. This is typically a different alarm temperature than one defined by heating at a single spot of high resistance. More useful alarms are probably melting and annealing temperatures. Many alloys used in electrical components begin to anneal at approximately 100°C (212°F) in a matter of weeks at which point the time to failure can decrease dramatically.

A better approach

Imagine, for instance, a low emissivity connector with a large thermal gradient under light loads and subjected to winter winds. If any abnormal heating is observed, and the heating may not be detectable, one must appreciate that as conditions change failure may be imminent. The truth is that thermographers often inspect when conditions are not favorable to accurate understanding of the true condition of the component. A reliable, repeatable analysis based on science and all relevant factors is required.

Such an approach might suggest asking a series of questions to determine the likelihood of failure. If any "Level One" question is answer in the affirmative, the anomaly is considered a priority for immediate action, either repair or further investigation, examples are illustrated in Table 2.

If all Level One questions are answered in the negative, a series of Level Two questions are prompted. If two of these are answered affirmatively, the anomaly is considered serious and scheduled for repair or further investigation at the next available opportunity; examples are illustrated in Table 3:

Appropriate action may include such management strategies as reducing load or increasing convective cooling until repairs can be made. Whether the anomaly is actually re-

Table 2. Level one condition criteria

Check-list	Conditions
	Is phase-to-phase temperature difference (accurate measurement) >50°F(24°C)?
	Is the absolute temperature >200°F (94°C) (accurate measurement)
	Is there visual indication metal or insulation has melted or degraded
	Is the anomaly on a shiny flat or tubular bus connector
	Is the view of the heat source indirect, i.e. an oil-filled device, bus stab, enclosed bus or inside an unopened enclosure
	Is loading likely to increase by 3X or greater prior to normal repairs
	Is convection >15Mi/Hr (24Km/Hr) and likely decrease to little or nothing

Table 3. Level two condition criteria

Check-list	Conditions
	Is phase-to-phase temperature difference (accurate measurement) >20°F (9°C)
	Are wind/air currents >5Mi/Hr (8Km/Hr) and likely decrease
	Do loads cycle frequently or will loading increase 2X or greater prior to normal repairs
	Does the component have little mass, i.e. smaller than a #10 conductor or lightweight fuse clip
	Is there a history of failure for this or similar components

Table 4

Check-list	Conditions
	Will someone likely be injured if equipment fails?
	Is the equipment critical ?
	What is the probable cost of a failure ?
	Will a failure result in unacceptable environmental consequences ?
	Are personnel and parts available for a repair at this time ?

paired and, if so, when, is a decision best made by a scheduler/planner or manager. That decision is based on consideration of a number of factors, as well as input from the thermographer, such as illustrated in Table 4:

Conclusions

Infrared thermography is a remarkably valuable tool for condition monitoring of electrical systems but results are often not as good they could be. Only by considering all relevant factors and looking at how they interact can the actual condition be reliably predicted. This can be done simply and with repeatable results by using asking a series of questions rather than simply focusing on component temperatures alone. The result will be improved safety and reliability at a reduced cost.

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Photoelastic Stress and thermographic measurements of automotive windscreen defects generated by projectile impact

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SUMMARY

This paper describes an experimental technique to evaluate the stress distribution around an automotive windscreen 'chip', that is created by projectile impact. This stress distribution is measured before and after a typical resin injection repair procedure and the results indicate a significant reduction in the residual shear stress. Concurrent thermographic measurements of the impact region during the repair procedure also suggest that the quality of the repair is dependent on the temperature profile at the time of repair. Preliminary computational modelling of a representative windscreen defect illustrates the predisposition of 'star-shaped' chips to crack-off to a windscreen edge under typical vehicle usage.

KEY WORDS: photoelastic stress, thermography, glass repair, windscreen

THERMOGRAPHISCHE UNTERSUCHUNGEN UND MESSUNGEN DER PHOTOELASTISCHEN SPANNUNG AN AUFSCHLAG VERURSACHTEN DEFEKTEN DER WINDSCHUTZSCHEIBE EINES AUTOMOBILS

Diese Arbeit beschreibt eine experimentelle Technik, um die Spannungsverteilung in der Umgebung einer Aufschlag bedingten Splitterung an der Windschutzscheibe eines Automobils zu erfassen. Die Spannungsverteilung wurde vor und nach einer typischen Reparatur mittels Resin-Injektion gemessen und die Ergebnisse zeigen eine deutliche Reduktion der verbleibenden Scherkräfte an. Während der Reparatur durchgeführte thermographischc Messungen der beschädigten Region sprechen dafür, dass die Qualität der Ausbesserung vom Temperaturprofil während des Reparierens abhängt. Ein vorläufiges Computermodell eines representativen Defekts einer Windschutzscheibe unterstreicht die Prädosposition von sternförmigen Absplitterungen bei typischem Fahrzeuggebrauch zum Rand der Scheibe durchzubrechen.

SCHLÜSSELWÖRTER: photoelastischen Spannung, Thermograpie, Glasreparatur, Windschutzscheibe

Thermology internaional, 2007, 17: 110-113

Introduction

Windscreen 'chips' created by the impact of stones can be repaired by the injection of resin, which, it is claimed, can arrest the further growth of the chip into a non-repairable extended crack. In the UK it is estimated that about 20%of vehicles in a 'car-park' possess chipped windscreens. There is an absence of scientific data regarding resin repair systems and this paper summarises some preliminary work undertaken to show how thermography and photoelastic stress measurements can provide valuable information on the repair process developed by Belron® International Ltd, the world market leaders in windscreen repair & replacement.

Description of the non-destructive testing methods used in the experiments.

Photoelastic stress measurements

A Stress Photonics Inc1,2 'GFP 1200' Automated polariscope system was used to illuminate the damaged area of the windscreen from inside the vehicle. Figure 1 shows a typical arrangement of the apparatus.

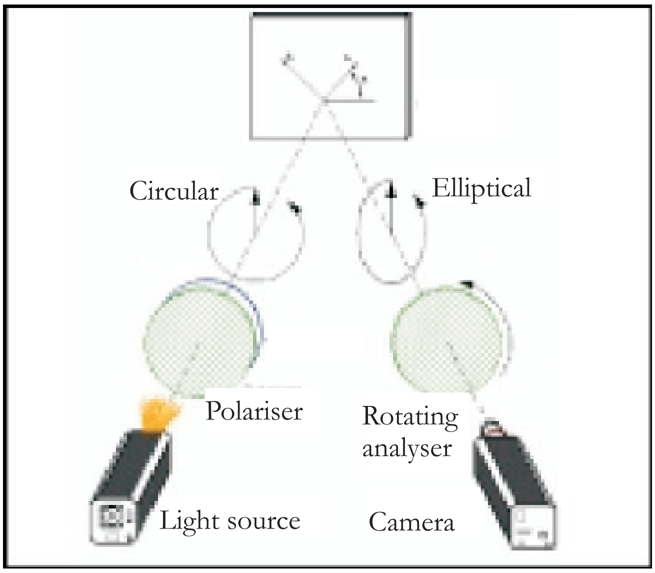

Figure 1.
Experimental configuration of the photoelastic measurement system

When a transparent material experiences stress it becomes birefringent. This means that light polarized along the first principal strain direction will travel faster than light polarized along the second principal strain direction. Photoelastic systems use this effect to measure the difference of the principal strains ε_1, ε_2,in a coating or transparent material (Fig. 2.) The signal is described by:

$S \propto K(\varepsilon_1 - \varepsilon_2)$ where K is the photoelastic constant for the material

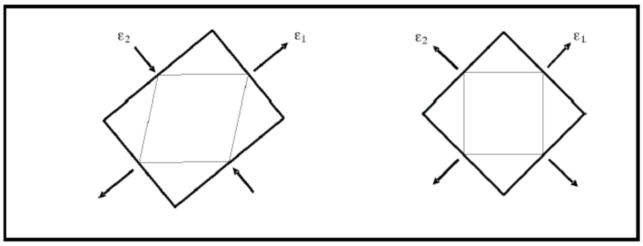

Figure 2. Photoelastic measurements
a) Difference of principal strains b) Hydrostatic Strains

The material element in Fig. 2 is depicted as having equal but opposite normal strain magnitudes oriented at ±45∞. A square drawn on the undeformed element shows how the distortion caused by the normal strains is equivalent to a shear strain in 0/90 reference frame. In fact, the difference of the principal strains is exactly the maximum in-plane shear strain. Equation (1) can be rewritten as:

$$S \approx K\lambda_{max} \quad 2)$$

The hydrostatic strain condition does not induce shear strain in any orientation. In the case of isotropic materials, the difference of principal strains is proportional to the difference of principal stresses. As it is more common to report and compare stresses, this description will focus on stress analysis. Photoelastic systems can also determine the orientation of the principal stresses. The polarimeter generates two images, the τ_0 image and the image τ_{45} As seen in Fig. 3 these two components are sufficient to determine the maximum in-plane shear image, and θ directions of the first principal stresses.

These images can be visualized in several ways. The difference of the normal stresses in a given coordinate system is proportional to the shear stress oriented 45 from axes of the coordinate system. For example:

$$\tau_{45} = \frac{1}{2}(\sigma_x - \sigma_y) \qquad (3)$$

As described by Mohr's circle of Fig. 3

$$\tau_{max} = \frac{1}{2}(\sigma_1 - \sigma_2) \qquad (4)$$

Where

τ_0 Shear stress acting in horizontal and vertical planes Normal stresses acting 45 degrees to horizontal or vertical

τ_{45} Shear stress acting in planes at 45 to horizontal and vertical. Normal stresses acting in horizontal and vertical directions

τ_{max} Maximum shear stress acting in planes 45 to principal stress direction.

The technique requires circularly polarised light to illuminate the damaged area of the windscreen. The camera, which has a rotating analyser in front of it, is focused on the area of interest and for each rotation of the analyser, 16 images are taken. These images, which are at different degrees of polarisation are then superimposed within the polarimeter's software and the amount of retardation of the polarised light calculated. This can then, by using the standard photoelastic optical constant, for glass, be used to calculate shear stresses which are displayed in a colour image format.

Thermographic imaging

An Inframetrics SC 1000 short wavelength Focal Plane Array thermal imaging camera (3) was used to capture the temperature distributions around the chipped area of damaged windscreens during the repair procedure. Care was taken to calibrate the camera (with an emissivity value for the glass of 0.92) and to take account of reflections and

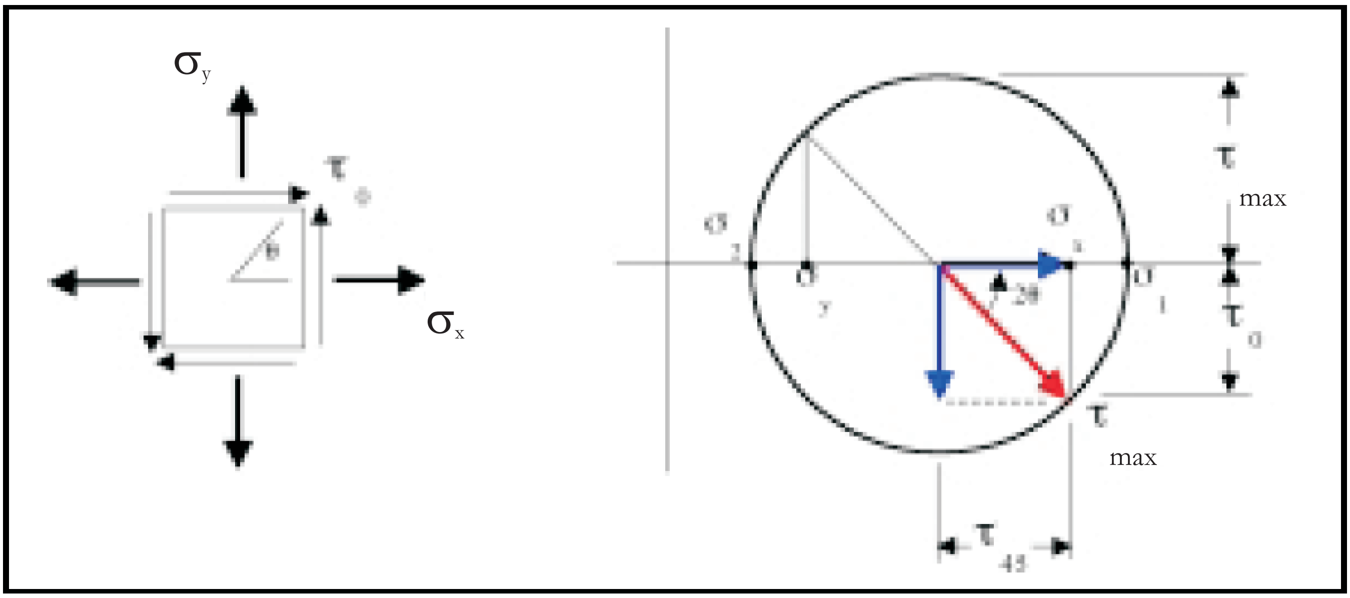

Figure 3
Mohr 's circle representation of the GFP images

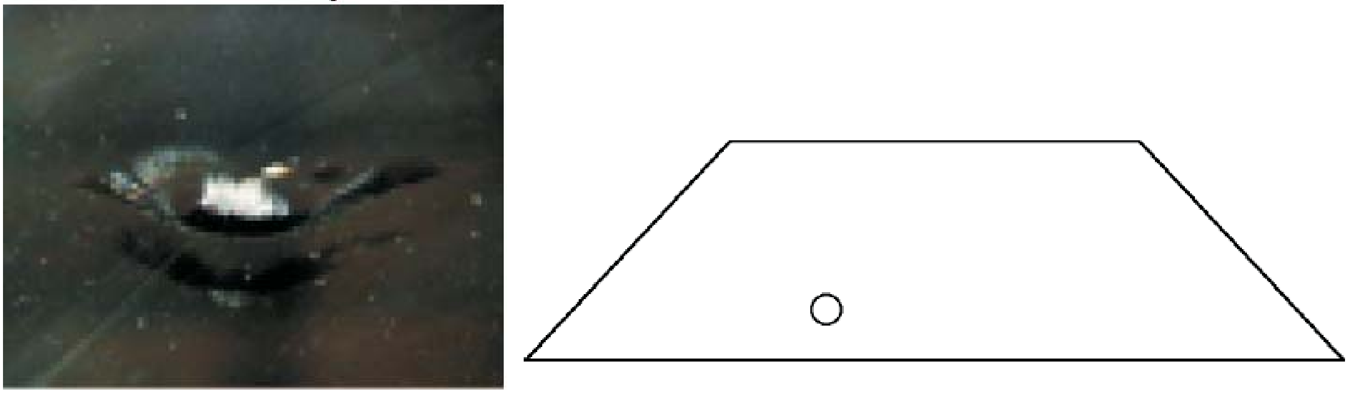

Figure 4
a) Photograph of chip 1 b) Location on windscreen

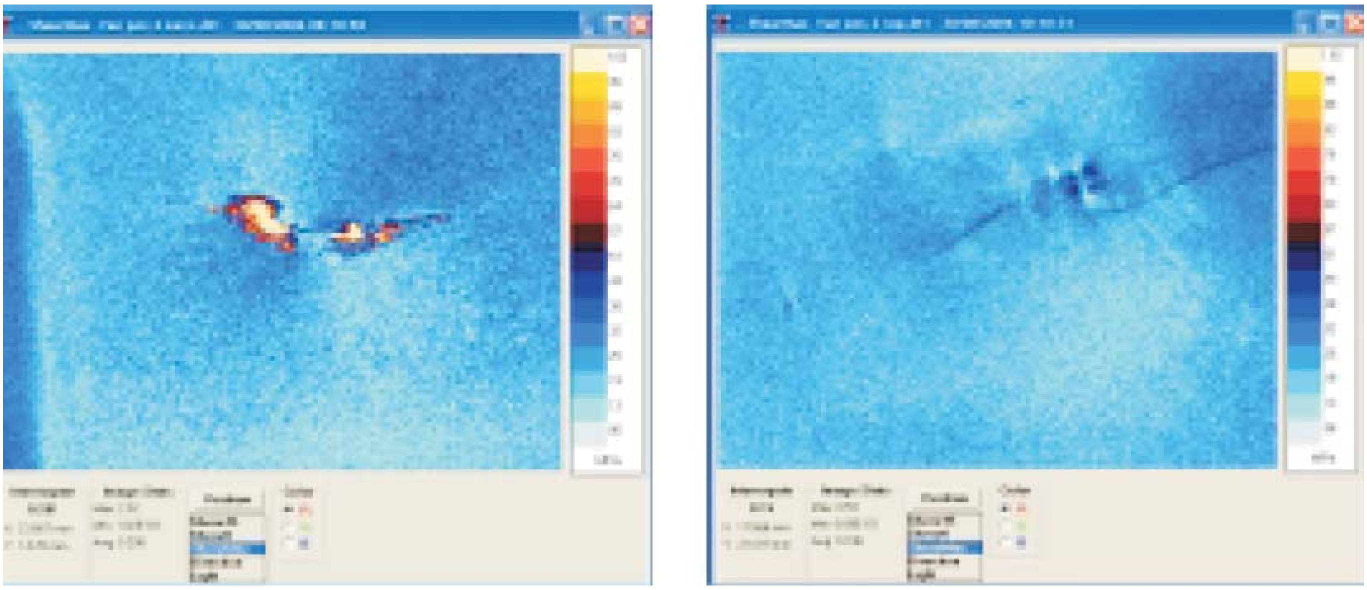

Figure 5
a) Before repair b) After repair

background infrared radiation when measurements were taken. This was accomplished by using the camera's difference engine for ambient and background diffuse radiation and shrouding the windscreen areas to avoid specular I.R. reflections back to the camera.

Results

Figure 4 illustrates a typical windscreen chip, approximately 5 mm wide and its location on the windscreen and Figure 5 shows the distribution of the t_{max} shear stress component before and after the resin injection repair procedure. In order to undertake a clear objective com- parison, the shear stress scale in this figure is kept constant for both images. The maximum shear stress value has been dramatically reduced by over 75% and strongly suggests that the repair procedure reduces the likelihood of crack propagation from the chip area.

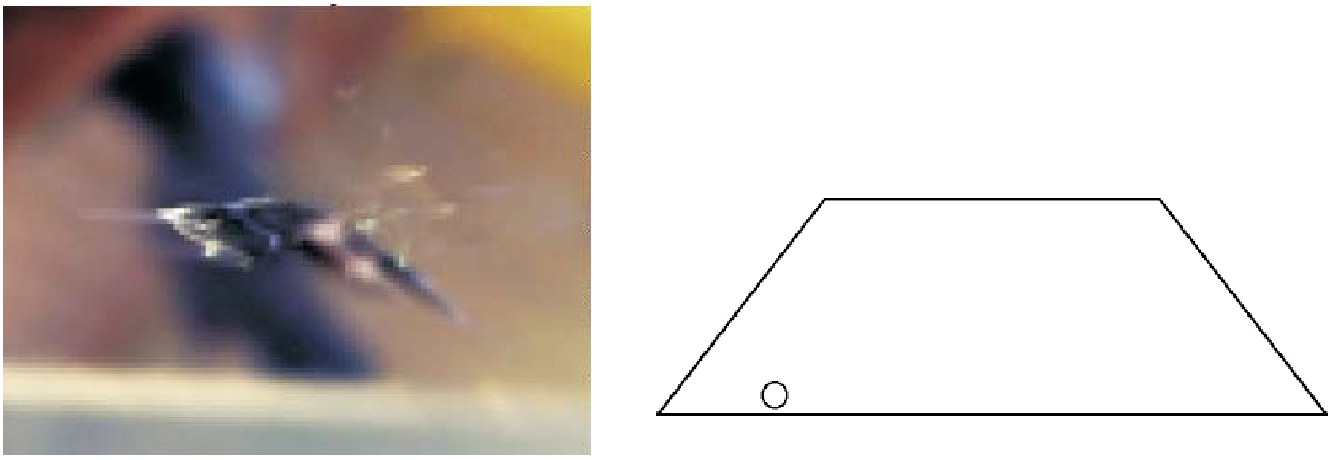

Figure 6
a) Photograph of chip 2 b) Location on windscreen

The results presented here for one vehicle are representative of over twenty similar observations. It is interesting to note that the photoelastic stress measurements consistently revealed a significant residual shear stress component of typically 2 - 5 MPa around a chip defect. The dramatic reduction in this residual stress distribution was consistently repeated.

If the repair procedure is not followed properly, a chip could 'crack-off ' during the repair procedure. Concurrent thermographic measurements have proved invaluable in identifying the conditions where the repair procedure is particularly important. To illustrate this, refer to Figures 6 and 7.

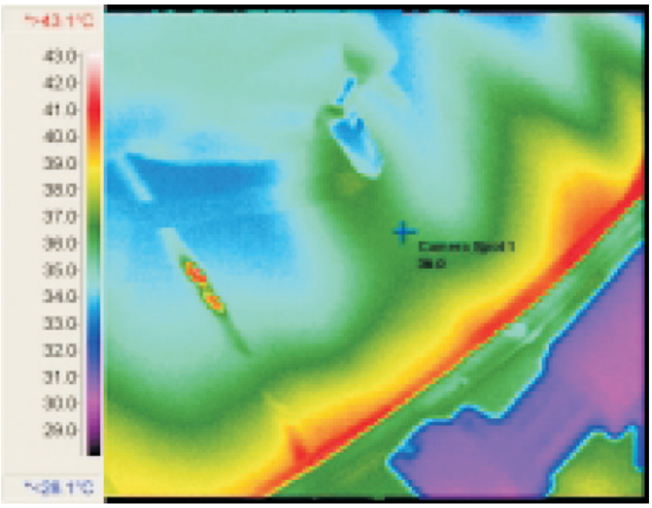

Figure 7
Temperature distribution near chip 2
(cross hairs identifies chip location)

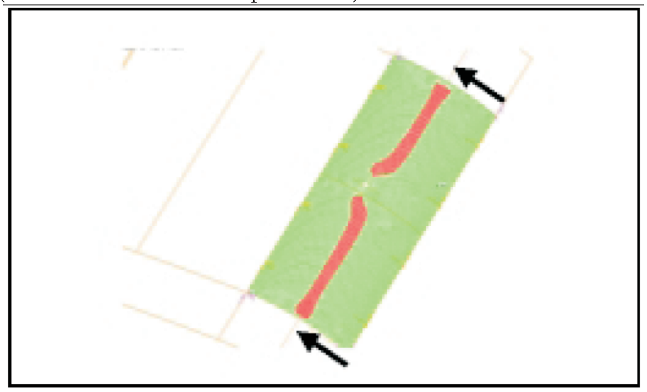

Figure 8.
Stress distribution around a star-shaped crack when the edge is flexed as shown

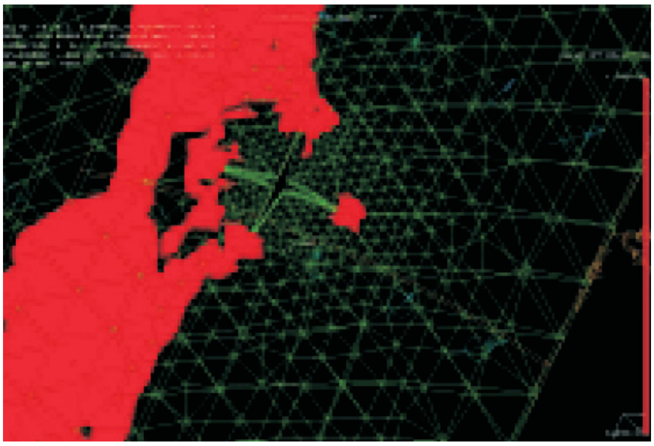

Figure 9.
Mechanical stress due to uniform heat source applied to interior surface of windscreen

Unlike the situation for chip1 in Figure 4, the temperature gradient (Figure 7) from the lower windscreen edge to the chip is significantly higher at the time of repair and the temperature at the chip is at least 5°C higher than the norm. A random error estimate of 0.1°C was obtained from repeated trials.

A programme of experimental and computational modelling work is underway to explore these results in a systematic manner. To illustrate why the chip repair procedure can reduce the likelihood of 'crack-off', a series of simple linear static finite element analyses (FEA) were undertaken (4). Figure 8 shows a selected edge region of basic FEA model of a laminated windscreen, represented by a three layer sandwich of glass (2mm), poly-vinyl-butyrate plastic (1mm) and glass (2mm). A representative star-shaped crack near the right hand side edge has been included. In this figure, the stress distribution around the crack is shown for the condition where the right hand edge is flexed in the direction illustrated.

A second computation is shown in Figure 9, where the same three-layer windscreen model is subjected to a uniform heat source of $5kWm^{-2}$ over the interior surface. This figure shows the resulting mechanical stress due to differential thermal expansion.

Figures 8 and 9 illustrate the preference of star cracks to propagate towards a windscreen edge when subjected to mechanical or thermal excitation.

Conclusions

The experimental study has shown how resin injection into windscreen chipscan significantly reduce the residual shear stress values in the affected area. Concurrent thermographic measurements also show that the efficacy of a repair procedure can be affected by the ambient temperature and also by the temperature gradient around the defect. Future work will consider a brittle fracture model, which will facilitate the modelling of crack initiation and subsequent propagation in windscreens.

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10th National Congress of the Polish Association of Thermology

ZAKOPANE 16th-18th March 2007- Abstracts

FINDINGS FROM ROUTINE THERMAL IMAGING IN SUBJECTS SUSPECTED OF THORACIC OUTLINE SYNDROME

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In 1993 Schartelmüller and Ammer established a protocol for thermal imaging in patients suspected of Thoracic Outlet Syndrome (TOS). With some modification this protocol is routinely used since 1994 for the thermographically assisted diagnosis of Thoracic Outlet Syndrome.

About 1000 subjects underwent this investigation since thermal imaging was included in the diagnostic pathway for TOS. A temperature difference of 0. 5 or more degrees between index and little finger is regarded as a pathological finding. The results in 210 subjects are reported who were studied by thermal imaging between 2000 and 2005. The following classification was made: pathological temperature difference in one position was named “possible TOS”, pathological findings in two positions was regarded as a “probable TOS” and pathological temperature readings in three or four arm position was classified as “definite TOS”. In addition, TOS cases were labeled with “index” or “little finger” with respect to the colder finger.

Between 2000 and 2005, 418 patients (302 females, 116 males) were investigated in total for temperature symptoms of TOS. The thermal images of these 210 cases (156 females, 64 males) were quantitatively re-evaluated. In 115 image series did not show pathological findings and have been classified as normal (55 on the left hand side, 60 on the right hand side). Definite TOS affecting the little finger was detected in 49 left hands and 44 right hands, a definite cold index finger was observed in 6 hands (3 right and 3 left hand side) only. 102 image series showed temperature changes that indicated a probable TOS on the little finger (48 left hand, 54 right hand). A possible TOS (little finger) was seen in 80 hands (42 left hand, 38 right hand). The remaining cases were 9 times classified as probably TOS (index) and as ossible TOS (index) in 15 other cases. There was no significant difference in age between the different classes of TOS, with the exeption that patients with probable or definite cold index finger at the right hand side had a higher age as subjects without symptoms or with TOS symptoms at the little finger. At the right hand, males had also less definite and probable TOS symptoms at the little fingers than females.

A pathological temperature difference between index and little finger is a common finding. Only 23% of the re-evaluated image series had normal distribution of finger temperatures. A small percentage of patients presented with a colder index than little finger. These patients, mostly males, are older than patients with cold little fingers and their symptoms might be caused by compression of the median nerve at the carpal tunnel rather than by irritation of the brachial plexus in the subclavial region.

Thermal imaging is the only method that provides pictorial information of functional changes caused by compression of the brachial plexus. It is a complementary diagnostic test and can be used as outcome measure in clinical trials with patients suffering from Thoracic Outlet Syndrome.

THERMAL SYMMETRY ON EXTREMITIES OF HEALTHY SUBJECTS

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Infrared thermal imaging is being utilized increasingly in the study of neurological and musculoskeletal disorders providing data on the symmetry of skin peripheral temperature. Skin temperature measurements were carried out on 26 healthy subjects’ thermograms. Temperature measurements were obtained using a computer interfaced application developed in past projects of this research unit, CTHERM, this thermographic instrument with the capability of obtaining average temperatures and standard deviation values in corresponding areas of interest on both sides of the body. In the healthy control subjects the overall temperature difference was maximum value 0.19º C on total body view and 0.16 º C on regional views. This study has confirmed with quantitative data from CTHERM software, the thermal symmetry in normal subjects, which can be used to assess thermal changes in specific pathologic states. This work has also compared the usage of total body view (table 1) with the regional views (table 2). No other studies have been carried out with the current generation of higher resolution cameras.

Extremities	Mean Temperature (Right)	Mean Temperature (Left)	Δ Temperature	Standard Deviation (Right)	Standard Deviation (Left)
Upper arm	30.4 °C	30.6 °C	0.2 °C	3.0 °C	3.0 °C
Forearm	30.0 °C	30.0 °C	0.1 °C	3.2 °C	3.1 °C
Hand	28.5 °C	28.5 °C	0.0 °C	3.2 °C	3.2 °C
Upper leg	29.2 °C	29.3 °C	0.1 °C	1.9 °C	1.7 °C
Lower leg	29.1 °C	29.1 °C	0.0 °C	2.4 °C	2.3 °C
Feet	27.4 °C	27.3 °C	0.1 °C	2.2 °C	2.1 °C

Table 1 Results of statistical analysis of Total Body Anterior view

Extremities	Mean Temperature (Right)	Mean Temperature (Left)	Δ Temperature	Standard Deviation (Right)	Standard Deviation (Left)
Upper arm	31.9 °C	31.9 °C	0.0 °C	2,0 °C	2.0 °C
Forearm	31.5 °C	31.5 °C	0.0 °C	2,0 °C	1.9 °C
Hand	31.0 °C	31.0 °C	0.0 °C	2.1 °C	2.2 °C
Upper leg	30.7 °C	30.7 °C	0.0 °C	1.8 °C	1.9 °C
Lower leg	30.9 °C	30.9 °C	0.0 °C	2.4 °C	2.3 °C
Feet	30.4 °C	30.3 °C	0.1 °C	3.0 °C	3.2 °C

Table 2
Results of statistical analysis of Regional Body Anterior views

BURN DEPTH EVALUATION BASED ON ACTIVE DYNAMIC THERMOGRAPHY.

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Proper evaluation of the surface and depth of a burn wound, especially in the case of a severe burn, enables an appropriate choice of treatment to be made. This choice decides subsequently about the success of the entire medical treatment. Clinical assessment is currently the most frequently applied method in burn depth evaluation. Unfortunately the use of this method results in a high number of false diagnoses. Numerous other methods have therefore been introduced and none of them has been fully accepted by clinicians treating burns.

The goal of this work was to evaluate and compare the usefulness in burn depth assessment of two selected modalities of infrared imaging (IRI), namely classical static thermograpy (ST) and active dynamic thermography (ADT), which has not been applied earlier for this purpose. The last method is based on analysis of thermal transients after external tissue excitation using pulse optical heating. Commonly used clinical methods and histopathological assessment were taken as reference methods. The methods presented were employed in *in vivo* animal experiments on 3 young domestic pigs, each weighing approximately 20 kg. Analysis was made of 64 burn wounds for ST and 23 wounds for ADT. The wounds were inflicted according to the modification of Singer's procedure. The analysis also made use of bacteriological methods.

The obtained results were subjected to statistical analysis by means of the Anova variance analysis method and by comparing the average *post hoc* values with Tukey's RIR test. The accuracy, sensitivity and specificity of the methods tested with reference to the characteristic sought, namely healing of the wound within 3 weeks of the burn, have been quantitatively calculated.

Based the bacteriological results, the possibility that the thermographic findings have been influenced by the micro-organisms has been excluded.

The mean values calculated for the synthetic ATD parameter, *ô*, did not differentiate the burn wounds classified into clinical groups at the level of statistical significance. In contrast, however, they did differentiate in this way the groups established according to the histopathological criterion (shallower or deeper than 60% of dermis thickness at the measurement side). When the ADT method is employed, the results of classification based on the histopathological criterion are identical to these based on the clinical criterion "healing within 3 weeks". The calculated threshold value of the time constant ô =10.125s ,accuracy, sensitivity and specificity = 100%, respectively.

ADT as the single method of choice does allow for the objective classification of burn depth on the basis of a quantitative criterion. Possessing all the advantages of ST, ADT is much less subject to the limitations of this method. When all this is taken into consideration it may be claimed that ADT meets to the highest degree the requirements of a modern diagnostic method which will evaluate burn depth and, in consequence, prove useful in the proper choice of treatment.

STANDARDISATION OF THERMAL IMAGING SYSTEMS USED IN MEDICINE

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Infrared thermal imaging was first made available to medicine in the early 1960's. Despite a large number of research publications on the clinical application of the technique, the images have been largely qualitative. In 2001 an Anglo Polish collaborative study was set up to identify and resolve the sources of error and problems in medical thermal imaging. The predominant lack of control data over the last 40 years of thermal imaging in medicine has been compounded by the fact that the vast majority of publications refer to studies in diseased patients. The limited sources of normal control thermal images are rarely addressed. Similarly, there have been only a limited number of publications on standardisation of technique with thermal imaging.

The main areas of a clinical thermal imaging procedure that require standardisation are

A preparation of the patient

B standardisation of the thermal imaging system (including calibration)

C image capture protocols

D image analysis protocols

E reporting, ar-chive and storage of images

F education and training of clinical users of the technique.

Two of these critical areas in medical thermography are described in more detail

STANDARDISATION OF THE THERMAL IMAGING SYSTEM: There are a number of thermal imagers in medical use, using different detectors and optics.

They are not equal in thermal or spatial resolution, and each depends on the manufacturer's calibration. It has been found that most camera systems, both cooled and uncooled detectors require much longer to achieve radiometric stability than stated by the manufacturer.

This means that the common practice of setting up a camera just prior to use, is frequently inadequate. Variation in the measurement from a black/grey body radiant source at a known temperature or temperatures must be established for each imaging system, and the minimum warm-up time recorded. In addition, most thermal imagers are calibrated by the manufacturer before delivery, and may not be checked again until a fault is detected. Furthermore, each manufacturer in each country may use a different reference system, resulting in a wide offset range in terms of absolute temperature. Protocols to test the camera systems used, and to reduce variables have been developed.

IMAGE CAPTURE: Image capture is a major source of variability, with varying camera angles and distances. A complete set of standard views was therefore devised, that require the camera to be mounted on a parallax free stand The most useful modification, however, has been the introduction of software generated capture masks for each standard view of the human body. This is an electronic outline written in to the software that automatically appears when each standard view is selected from the menu. This optimises the position and size of the body region being imaged and greatly improves repeatability.

THERMOGRAPHIC ASSESSMENT OF THERMAL EFFECTS OF THE ERBIUM:YAG LASER IN ORAL EPITHELIUM PHOTOABLATION

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BACKGROUND: Infrared thermography was introduced in dentistry at the end of the last century. Despite of its short history recent studies on thermal imaging system in the field of dentistry seem to be of promising use. The assessment of the thermal effects of the high-power lasers is one of the potential applications.

OBJECTIVE: The aim of this study was thermographic analysis of temperature distribution on the surface of oral mucosa during laser ablation (removal) of the epithelial tissue being inflamed.

MATHERIALS AND METHODS: The study describes the case of women with severe type of bullosus oral lichen planus. Lesions in the form of erosions and blisters were removed with the Er:YAG laser. Temperature elevation at the time of laser irradiation was measured by thermovision.

RESULTS: Thermal images taken during the surgery were analyzed. The assessment included the temperature distribution, the range of temperature changes including the maximum as well as the rate of cooling of oral mucosa at the time of laser application.

CONCLUSIONS: Results obtained in this study suggest, that thermal imaging system is a useful tool for monitoring thermal effects of laser on oral soft tissues. The Er:YAG laser beam can significantly increase the temperature in the interaction site. Monitoring of temperature distribution improves the safety of laser treatment due to control both laser parameters and optical fibre position (i.e. the distance between fibre and the surface of oral mucosa).

LIQUID-CRYSTALLINE CONTACT THERMOGRAPHY IS COMING BACK

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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 about this method. However, very recently some new concepts regarding its technology and usage has been introduced.

The physical principle of LCCT operation is selective light reflection from a cholesteric liquid crystal layer giving a possibility to assign the color of a liquid crystal layer to its temperature. Usually such materials have been used in the form of a thermosensitive foil of multiple usage. In such a foil liquid crystal droplets of micrometer size are embedded in an elastic polymer matrix. In comparison with other thermovision systems LCCT is simpler and cheaper; moreover, it does not include artificial processing of an image. On the other hand, thermographic foil has to be placed on the patient skin, which introduces several problems with interpretation of the thermogram. The measurement standards are the same for both methods.

Recently a new approach to LCCT technology and interpretation of thermal images obtained by this method has been developed. It allows to use LCCT for screening diagnostics made by patients themselves. In fact this application potentially can be adopted as an alternative method for early disclosure of several kinds of cancer. In case of a cancer indications such autodiagnosis should be confirmed by other objective methods interpreted by professionals.

HEART MONITORING BASED ON DYNAMIC THERMOGRAPHY – IN-VIVO EXPERIMENTS ON ANIMALS

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The aim of this study is the development and analysis of application of new tools for continuous inspection of open- heart cardiosurgical interventions, suitable in clinical environment. Our focus is on IR-thermal imaging for monitoring of isurgical interventions such as CABG in treatment of ischaemia and other heart dysfunctions. In this presentation, we discuss.the preliminary results of *in-vivo* experiments on animals using an IR thermal camera and newly developed procedures of dynamic thermography.

MATERIAL AND METHODS: The IR-camera AGEMA THV-900 SW/TE of 0.1°C resolution was used for capturing of thermal images and sequences presented in this paper. It was placed at the distance of 0.75 m from the pig's chest, in the plane perpendicular to it. The steady state temperature distribution on the tested surface is recorded using an IR camera. Next, external thermal excitation is applied to force thermal transients at the tested surface. Recording of temperature allows calculation of such thermal parameters as thermal time constants, dependent on the state of the tested structure. We apply external pulse excitation (step function) lasting several seconds, using halogen lamps for generation of heating or a cryotherapy device (CryoFlow 1000) for cooling. IR camera is applied for capturing of series of thermal images allowing measurements of temperature transients on the tested surface.

The i*n vivo* animal experiments were performed according to all legal regulations and permission by the Gdansk Ethics Commission for Experimentation on Animals. Introduction of ischaemia to the heart muscle was done by clamping the left descending artery (LAD). Thermal state of the heart is monitored using an IR thermal camera and simple recording of radiation emitted by the observed surface of the heart. Additionally, thermal properties of the heart muscle are calculated from active dynamic thermography (ADT) experiments based on external thermal excitation.

RESULTS: Natural re-warming phase for the cooling procedure as well as natural cooling phase for the heating procedure are more suitable for characterisation of tissue by thermal parameters because the heat transfer in these phases is mainly depended on thermal properties of tissues (thermal capacity, thermal conductance) and not on properties of excitation sources. Thermal properties of the heart for the heating excitation (halogen lamps) and cooling excitation (CRYOFLOW) for natural processes (cooling and re-warming phases respectively) for regions K1 and K2 are shown in Figure 1. For both procedures time constants for affected tissue are longer than for healthy tissue (grey cells in Table 2). Heat exchange (transport) in natural way for affected tissue is slower than for healthy tissue mainly due to strongly decreased blood circulation in this affected region. The experiments prove that any impairment in blood circulation in tissue is manifested by slower heat transport and by longer time constants of exponential thermal model.

ACKNOWLEDGEMENTS: This research was performed under the grant 3 T11E 01027 from the Polish Ministry of Science.

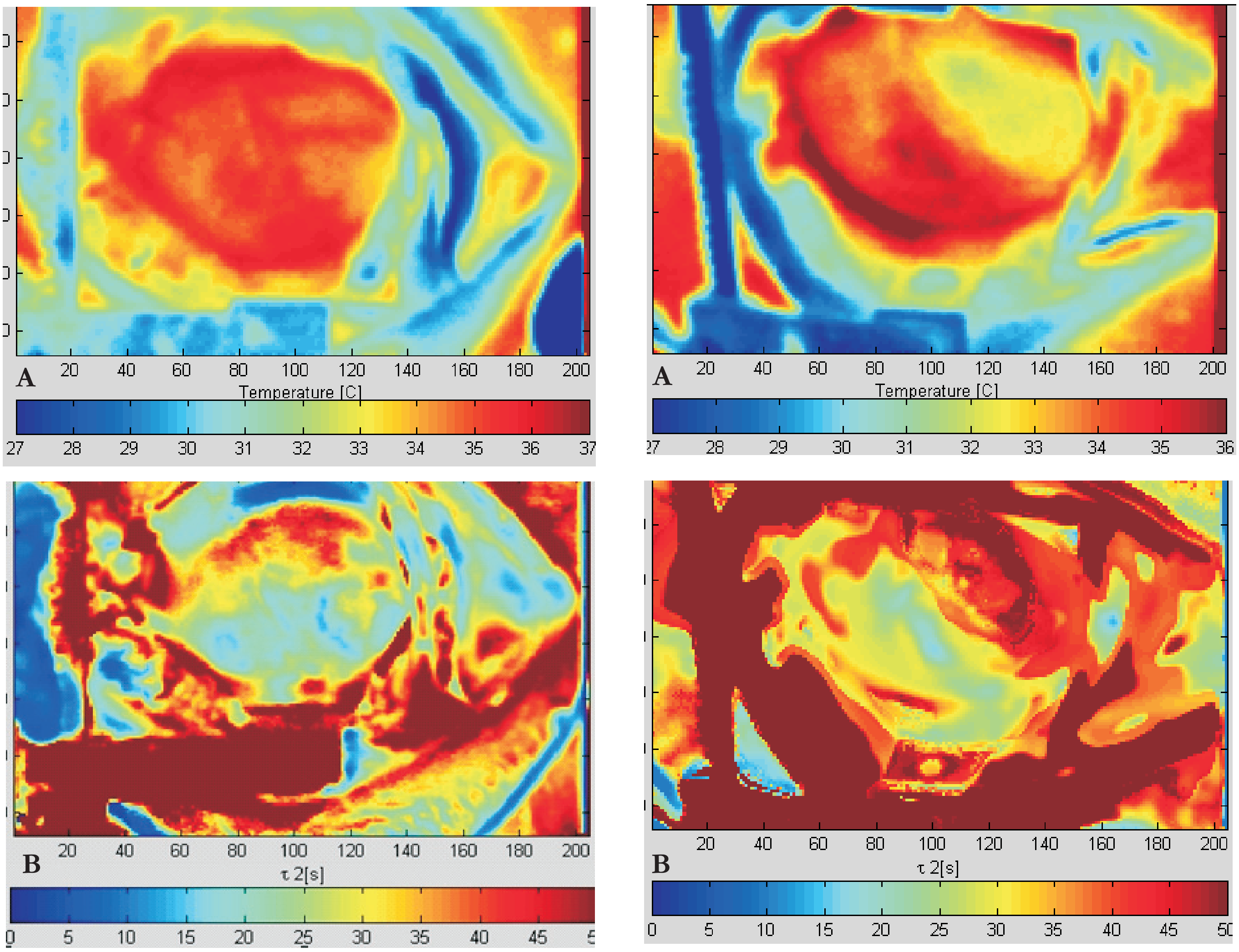

Figure 1 Healthy heart before clamping LAD Heart 25 minutes after clamping LAD

A/ Static IR-images; B/ ADT parametric images for cooling 30 seconds by forced air flow (CryoFlow 1000) of the temperature 5^0C; captured during 90 seconds at the phase of natural recovery (self-re-warming), taken before and 25 minutes after clamping LAD

TEMPERATURE MEASUREMENTS IN CHILDREN FOR FEVER DETECTION

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The interest in the use of thermal imaging as a means of screening passengers for fever, has become a major issue since the SARS epidemic in Asia, and the continuing risks from Avian influenza (H5N1 virus). A convenient target for imaging in this situation e.g. airport, is the human face. Reports from Asia indicate that measuring the temperature of the frontal face can indicate fever when maximum temperatures of 380C are reached. This should be most evident at the inner canthus of the eye. To investigate the temperature of a cohort of children in the Pediatric Clinic in Warsaw, we have performed two short studies of 5 days duration.

METHOD: Children of ages from 3 months to 17 years were examined with the IR camera and their temperatures were measured with a conventional thermometer used in the arm axilla. In the first study (July 2006) 57 subjects were thermogrammed, a full frontal face, using a FLIR Thermacam B series. An external reference source was used to maintain regular checks on the camera. In the second series, November 2006, 38 subjects were examined with the same technique, but using the new Thermacam B640. In the second series some additional temperature measurements were made with a Braun ear radiometer.

RESULTS; In the first series, none of the children tested had active fever at the time of examination. Some had a recent history of raised temperature, but this had resolved by the time they attended the clinic. In the second series there were three readings clearly raised over the 38oC level, and this was found in the auxiliary thermometer reading also. In the first series, no correlation was found between auxiliary and eye temperatures measured by the separate techniques. In the second series however, a better correlation R2 = 0.501 was obtained. The camera software on both occasions provided a direct readout of maximum temperature from a region of interest placed over both eyes during the recording.

The highest temperature was found in one subject (age 6 yrs) with 390C at the arm axilla and 38.60C at the eye. A few hours before, the subject complained of fever symptoms, measuring 37.50C at the axilla and 37.40C at the eye canthus. After two doses of antibiotic her temperature fell to36.70C axilla, and 36.40C eye, both in normal limits. Another subject with tonsillitis (age 2 years) recorded 38.60C at the eye, and 38oC axilla. Another 2 yr old registered 37.7 underarm and 37.3 at the eye. However ear radiometry was lower, 35.6 and 36.0 left and right respectively.

The radiometric measurements from the ear were only performed in 16 subjects, but no correlation was found with the other two methods, probably due to small sampling.

Although the number of fever subjects was small, the data indicate that raised temperatures could be rapidly found with the IRT camera, and raised temperatures were confirmed both by thermometry and clinical diagnosis.

News in Thermology

8th Course on the Theory and Practice of Infra Red Thermal Imaging in Medicine

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The 8th Course on the theory and practice of thermal imaging was held at The University of Glamorgan on 4-6th July 2007 (figure 1). Since the first course at The University was held in 2001, approximately 80 people have completed the course. The have been a number of changes in the course content since that time. This year, again Prof. Graham Machin of the National Physical Laboratory, and visiting Professor, lectured on traceability and calibration of thermal imagers and Dr Rod Thomas from Swansea, visiting Fellow at Glamorgan presented the subject of detectors and cameras. Prof.Kurt Ammer presented thermal physiology and clinical applications of thermal imaging, with aspects of standardisation and technique by Prof. Francis Ring. Dr Peter Plassmann lectured on self testing and quality assurance of thermal imagers, and on the image processing software CTHERM. Practical sessions included image capture (figure 2), and image processing, the latter takes place in a computer-training laboratory (figure 3), where everyone is able to work on a separate workstation, and the instructor can use a projected image for demonstration. The final session of the programme included and overview of the future for thermal imaging and a lecture by Prof. Ammer reviewing past conferences, scientific journals and societies working in thermal imaging for medicine, veterinary science and biology.

This is the only course of its kind, where physicians, engineers, physicists technicians etc. can all benefit from this practical programme. The emphasis of this course is to improve background understanding of the techniques and the correct use of standardised practice to improve re- liability. It does not set out to teach anyone how to diagnose clinical diseases. The short course is recognised by The Faculty of Advanced Technology at the University of Glamorgan.This year, for the first time, a one-day workshop based on the theoretical aspects of the course was given at Auburn University prior to the International conference on Medical Thermology in May. (1) In earlier years,

Figure 1
Participants of the 8th Course

Figure 2
Image capture of both hands in the dorsal view

a course was conducted at Sao Paulo University in Brazil by Prof. Ammer and Ring, and also in the Boltzmann Institute for Physical Diagnostics,Vienna Austria, both attracting a good number of participants. Certified teaching sessions have also been included in the meetings of the Polish Society of Thermology held in Zakopane, Poland.

In the early years, with a lack of textbooks and no formal teaching, medical thermographers required months, even years to gain experience at a time when the imaging systems were large, often unstable, and poorly understood. There is now a wealth of literature, the most comprehensive source

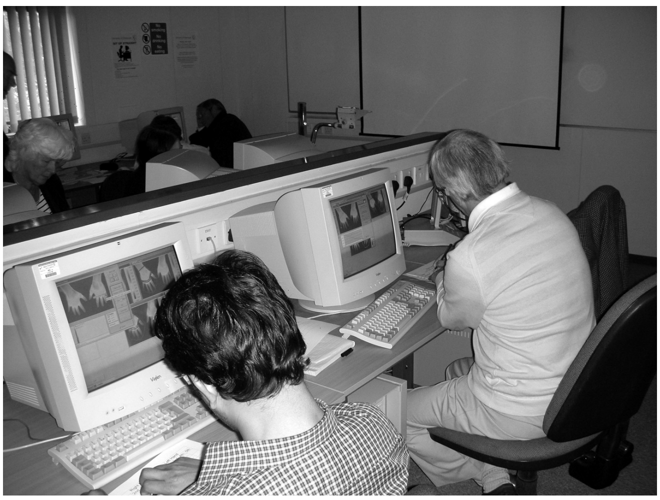

Figure 3
Analysis of captured images in the computer lab

now being the CD of publications and bibliography published by the Medical imaging research group at Glamorgan University. This was initially funded from the USA under the technology transfer programme. It is updated every few years, and the 2007 edition is now available with over 8,000 references (distributed to participants of the Auburn Workshop). In addition, UK course participants receive a copy of the "Casebook of Infrared Imaging in Clinical Medicine" (Jung, Zuber & Ring eds) Medpress Warsaw 2003.

Results from the practical work of previous courses have been published (2,3,4, 5) It was proven by these practical exercises, that even beginners in the technique of thermal imaging can reproduce both standard views and temperature readings from captured images at a high level of reliability.

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An Unofficial Impact Factor for Thermology international

The journal "Thermology international" is not yet tracked and recognised by the Institute of Scientific Information (ISI) which generates the annual impact factor. However, it is indexed since 2002 at Embase and was included in the database of periodicals at Ulrich´s-Web in the category Physics -Heat in August 2005.

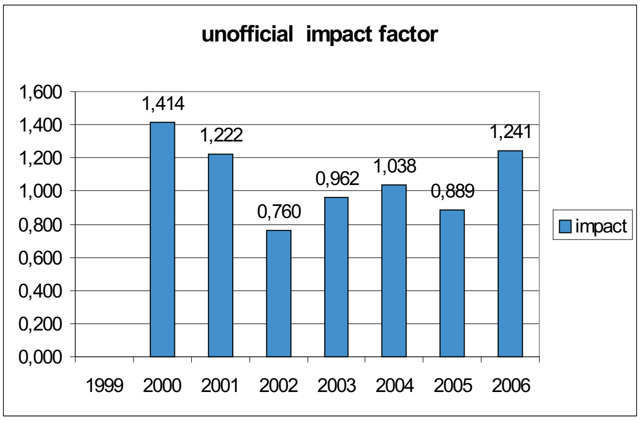
A publication from the Department for Physical and Rehabilitative Medicine of the University Munich dealing with relevant journals in the field of rehabilitation medicine listed Thermology international in the subsection thermotherapy (1).

An unofficial impact factor can easily calculated (2) as the impact factor is "is calculated by dividing the number of current citations to articles published in the two previous years by the total number of articles published in the two previous years." The citing sources used for calculations of the impact factor are not clearly defined (3). They are definitely not restricted to journals already included in the database of ISI

For calculation of an unofficial impact factor the citation statistic of Google scholar was used. This tool accumulates citations over time and does not restrict citations to the 2 years period after publication of the cited article. For Thermology international 24 articles were cited 55 times in other journals. These citations were checked for the time interval between publication of the cited article and the citation. A hand search was performed through all issues of Thermology international to obtain the number of published articles and also of self-citations to articles published in a time period of two years. Table 1 shows the cumulated findings from the search in Google Scholar and in Thermology international.

	articles	selfcited	cited	citations	2 years articles
1999	13	19	3	22	
2000	16	36	5	41	29
2001	11	27	6	33	27
2002	14	15	4	19	25
2003	12	24	1	25	26
2004	14	24	3	27	26
2005	13	15	9	24	27
2006	16	34	2	36	29
2007	16	17		17	32

Figure 1 shows the impact factors based on the data from table 1.



Due to its wide scope of topics, Thermology international fits into various categories of ISI academic journals. The five most appropriate are "Biology", "Biophysics", "Radiology, Nuclear Medicine & Medical Imaging", "Rehabilitation" and "Thermodynamics" The following defintions are provided by ISI for these five categories (4)

Biology
The Biology category includes resources having a broad or interdisciplinary approach to biology. In addition, it includes materials that cover a specific area of biology not covered in other categories such as theoretical biology, mathematical biology, **thermal biology,** cryobiology, and biological rhythm research.

This category includes 64 journals with a median impact factor of 1.135 (5).

Biophysics
Biophysics covers resources that focus on the transfer and effects of physical forces and energy-light, sound, electricity, magnetism, **heat, cold,** pressure, mechanical forces, and radiation-within and on cells, tissues, and whole organisms

This category includes 66 journals with a median impact factor of 2.332 (5).

Radiology, Nuclear Medicine & Medical Imaging;
Radiology, Nuclear Medicine & Medical Imaging covers resources on radiation research in biology and biophysics. Resources in this category focus on interventional radiology, investigative radiology, neuroradiology, radiotherapy, and oncology. Nuclear Medicine resources are concerned with the diagnostic, therapeutic, and investigative use of radionuclides. Medical Imaging resources are concerned with **computerized medical imaging** and graphics

This category includes 85 journals with a median impact factor of 1.665 (5).

Rehabilitation
Rehabilitation covers **resources on therapy** to aid in the **recovery or enhancement of physical**, cognitive, or social abilities diminished by birth defect, disease, injury, or aging.

This category includes 27 journals with a median impact factor of 1.300 (5).

Thermodynamics
Thermodynamics includes resources that focus on the areas of physics examining the transformations of matter and energy in physical and chemical processes, particularly those processes that involve the **transfer of heat and changes in temperature.** Relevant topics in this category include cooling and heating systems, cryogenics, refrigeration, combustion, energy conversion, and thermal stresses.

This category includes 27 journals with a median impact factor of 0.854 (5).

The current unofficial impact factor of Thermology international is 1.241, which is above the median impact of journals in the categories Biology and thermodynamic, slightly below that of rehabilitation journals and definitely below the impact of Radiology, Nuclear Medicine & Medical Imaging and of Biophysics, which shows with 2.332 the highest impact of all categories appropriate for Thermology international.

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3. The PLoS Medicine Editors. The impact factor game. PLoS Med 2006; 3(6): e291

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5. http://portal.isiknowledge.com.

Meetings

August 23-26, 2007

29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society
in conjunction with the biennial Conference of the French Society of Biological and Medical Engineering (SFGBM)
Convention Center, "Cité Internationale", Lyon, France

Track 02: Biomedical Imaging and Image Processing
02.17: Minisymposium / Invited Session:
Recent advances in medical infrared imaging
Chair: Dr. Nicholas Diakides

Thursday 23.rd August, B13

Recent Advances in Medical Infrared Imaging.
Organizer: Diakides Nicholas A., Advanced Concepts Analysis, Inc.

12:45-13:00, Paper ThB13.1
Reaction of Normal and Burned Tissue to Cold Excitation (I)
Nowakowski Antoni Z., Kaczmarek Mariusz - Gdansk Univ. of Tech.
Renkielska Alicja, Grudzinski Jacek - Medical Univ. of Gdansk
Stojek Wojciech - Gdansk Univ.

13:00-13:15, Paper ThB13.2
Forehead Thermal Signature Extraction in Lie Detection (I)
Zhu Zhen, Pavlidis Ioannis.- Univ. of Houston
Tsiamyrtzis Panagiotis - Athens Univ. of Ec. and Business

13:15-13:30, Paper ThB13.3
Thermal Signatures of Emotional Arousal: A Functional Infrared Imaging Study (I)
Merla Arcangelo, ITAB - Inst. of Advanced Biomedical Tech. - Foundation
Romani Gian Luca, Univ. of Chieti-Pescara

13:30-13:45, Paper ThB13.4
Virtual Thermistor
Fei Jin; Pavlidis Ioannis, Univ. of Houston

13:45-14:00, Paper ThB13.5
Thermal Monitoring of the Myocardium under Blood Arrest Preliminary Study (I)

Kaczmarek Mariusz, Nowakowski Antoni Z, Topolewicz,Jerzy - Gdansk Univ. of Tech.
Stojek, Wojciech - Gdansk Univ.
Siebert Janusz, Rogowski Jan, Medical Univ. of Gdansk

14:00-14:15, Paper ThB13.6
Representation of Thermal Infrared Imaging Data in the DICOM Using XML Configuration Files (I)
Ruminski Jacek . Gdansk Univ. of Tech

17th November 2007

20th Symposium of the Austrian Society of Thermology, SAS Hotel Vienna, Austria

Topic: What is the place of thermal imaging in medicine?

Speakers : Prof. F. Ring, University of Glamorgan, U.K
Prof B. Wiecek, University of Lodz, Poland
Prof. Anna Jung, Warsaw, Poland
Prof R. Berz, Hilders/Rhön, Germany
Prof K. Ammer, Vienna, Austria

Deadline for Abstracts: 30th September 2007

Please use the form provided on page 123 for abstracts submission. Electronic submission is preferred and strongly suggested (Email: KAmmer 1950@aol.com)

Information
Prof K. Ammer, MD, PhD
Austrian Society of Thermology
Hernalser Hauptstr 209/14
Email: KAmmer 1950@aol.com

2008

2nd -5th July 2008

QIRT 2008 - 9th International Conference on Quantitative InfraRed Thermography at the AGH University of Science and Technology, Krakow, Poland

Conference Organiser:Institute of Electronics
Faculty of Electrical, Electronic, Computer and Control Engineering of the Technical University of Lodz, Poland
and
Faculty of Mining Surveying and Environmental Engineering AGH University of Science and Technology, Krakow, Poland

The Quantitative Infrared Thermography (QIRT) conference is an international forum, which brings together specialists from industry and academia, who share an active interest in the latest developments of science, experimental practices and instrumentation, related to infrared thermography.

Following conferences in Paris (1992), Sorrento (1994), Stuttgart (1996), Lodz (1998), Reims (2000), Dubrovnik (2002), Brussels (2004), and Padova (2006), the 9th Quantitative InfraRed Thermography conference, QIRT2008, will take place on July 2-5, 2008 at the AGH University of Science and Technology, Krakow, Poland

CONFERENCE FEE

Regular participants: The conference fee is € 300 (before May 15, 2008) and € 400 (after May 15, 2008).

The fee covers Conference Procedings, welcome reception and conference dinner, lunches and coffee break facilities, but not the accomodation.

*Students:*The conference fee is € 150 (before May 15, 2008) and € 200 (after May 15, 2008). Without Conference Procedings, welcome reception and conference dinner, but including lunches and coffee break facilities.

Accompanying persons: The conference fee is € 100. The price includes welcome reception and conference dinner.

Pre-conference course

Preceding the conference, the following courses will be organised:

A - Basic Thermography,

B - Application to Fluids,

C - Application to Solids,

D - Medical Applications.

The Courses are scheduled on Wednesday, July 2, 2008.

The tuition is € 100 for one or more courses. Two courses will be presented in parallel, in the morning (A and B) and afternoon (C and D).

Concerning the QIRT, please consult the QIRT website.

QIRT Journal page: http://qirt.revuesonline.com.

QIRT 2006 page: http://qirt2006.pd.cnr.it.

CONTACT:

Please address inquiries to qirt@p.lodz.pl.

Secretary of QIRT2008
Technical Univesity of Lodz (TUL),
Institute of Electronics, Wolczanska 211/215,
PL 90-924 Lodz, Poland

Phone (+48) 42 631 2656, 2657, 2637
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20th Thermological Symposium of the Austrian Society of Thermology

Vienna, 17th November 2007

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Return this form not later than September 30, 2007 to:

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Thermology International

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This journal is a combined publication of the Austrian Society of Thermology and the European Association of Thermology (EAT)
It serves as the official publication organ of the the American Academy of Thermology, the German Society of Thermology, the UK Thermography Association (Thermology Group) and the Austrian Society of Thermology.
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Thermology International

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Österreich

Diese Zeitschrift ist eine gemeinsame Publikation der Österreichischen Gesellschaft für Thermologie und der Europäischen Assoziation für Thermologie (EAT)

Sie dient als offizielles Publikationsorgan der Amerikanischen Akademie für Thermologie, der Deutschen Gesellschaft für Thermologie, der Britischen Thermographie Assoziation (Thermologie Gruppe) und der Österreichischen Gesellschaft für Thermologie.

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