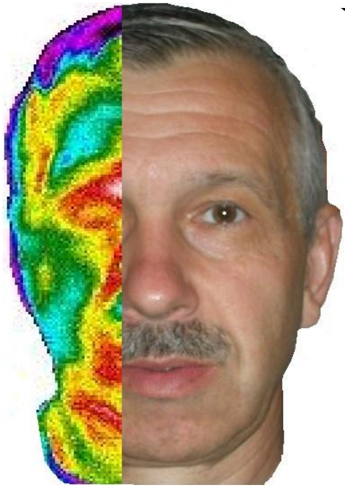
NEW TECHNIQUES IN THERMAL NONDESTRUCTIVE TESTING

- Introduction: Basics of Infrared
- Technical diagnostics
- Active NDT of materials



Prof. Vladimir Vavilov

Tomsk Polytechnic University, Russia

vavilov@tpu.ru

Thermal NDT

Michael Kröning

Basics of Infrared Thermography

TOLMI

The grand five in nondestructive testing:

ultrasonics, X rays, liquid penetrants, magnetic particles & eddy currents

Infrared Thermography

№ 6

What makes IR thermography so useful?

There are, at least, five things which make IR thermography so uniquely useful.

- **It is non-contact – uses remote sensing**
- **It is two-dimensional – produces images**
- **It is accomplished in real time**
- **It senses heat losses which irreversibly accompany human activity**
- **It is applicable to both metals and non-metals**

Thermal NDT

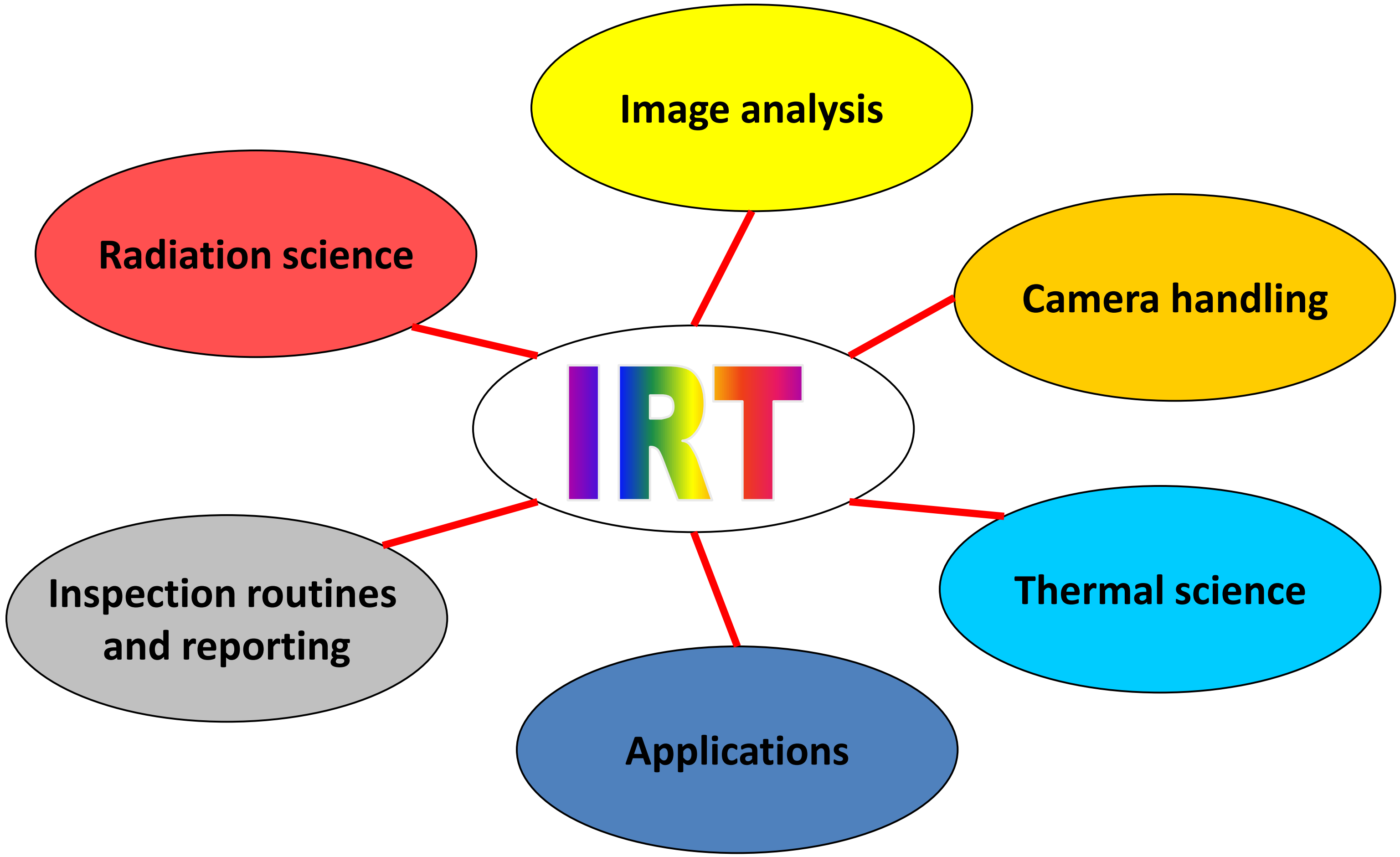


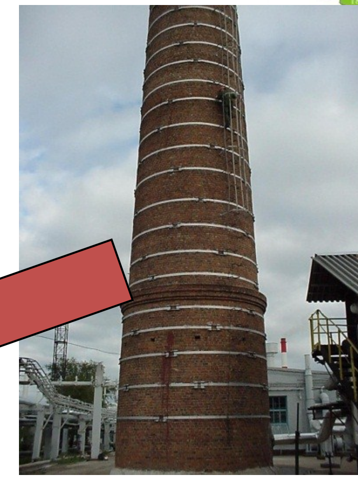
Image analysis
Radiation science
Camera handling
IRT
Inspection routines and reporting
Thermal science
Applications

What is an Infrared System?

Computer

Infrared imager

Atmosphere



Test target

Processing software

Nondestructive Testing (NDT) of Materials (thermal stimulation is required)

Night Vision

Search & Rescue
Surveillance
Alarm systems

Technical Diagnostics

Predictive Maintenance
Condition Monitoring

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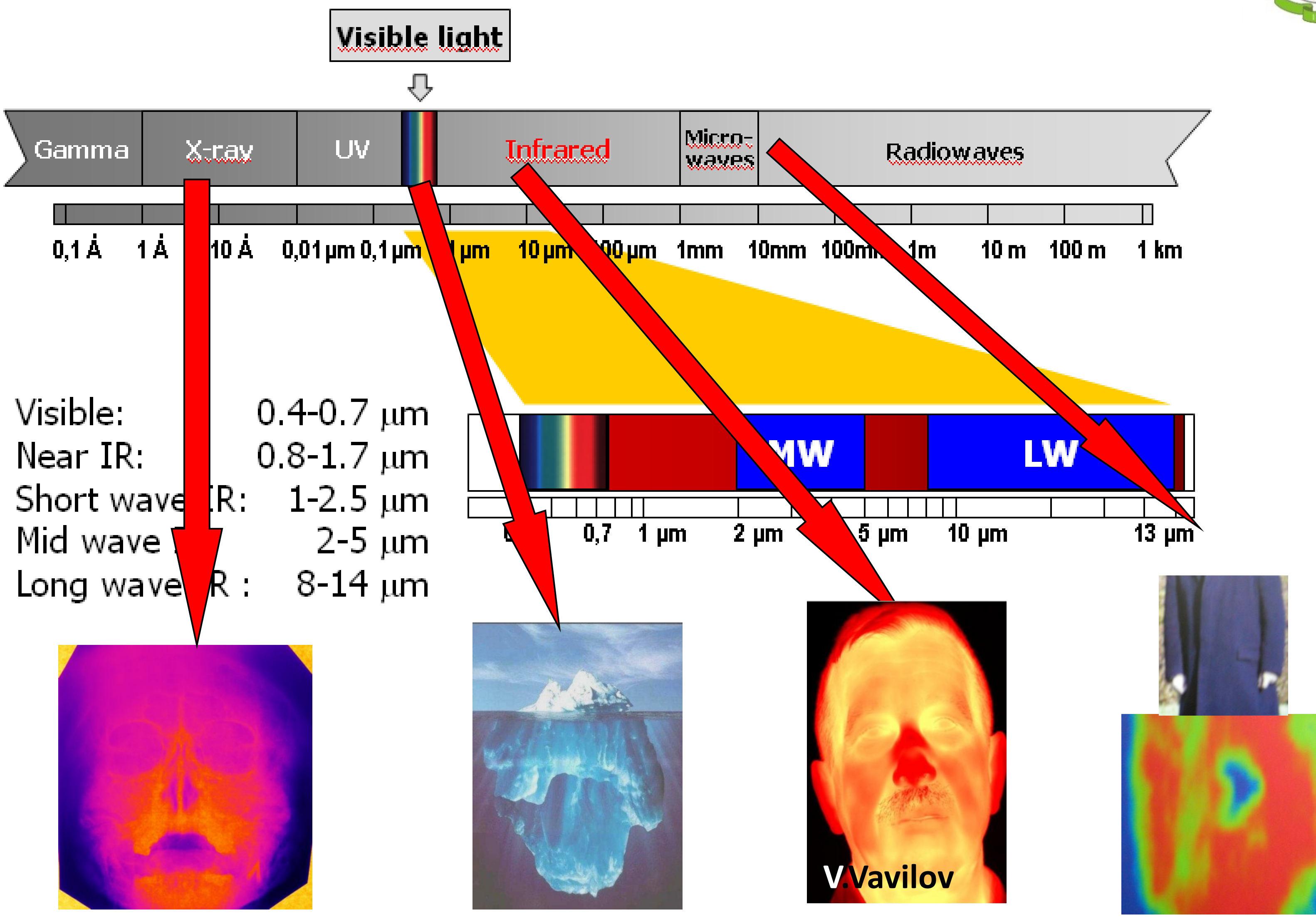
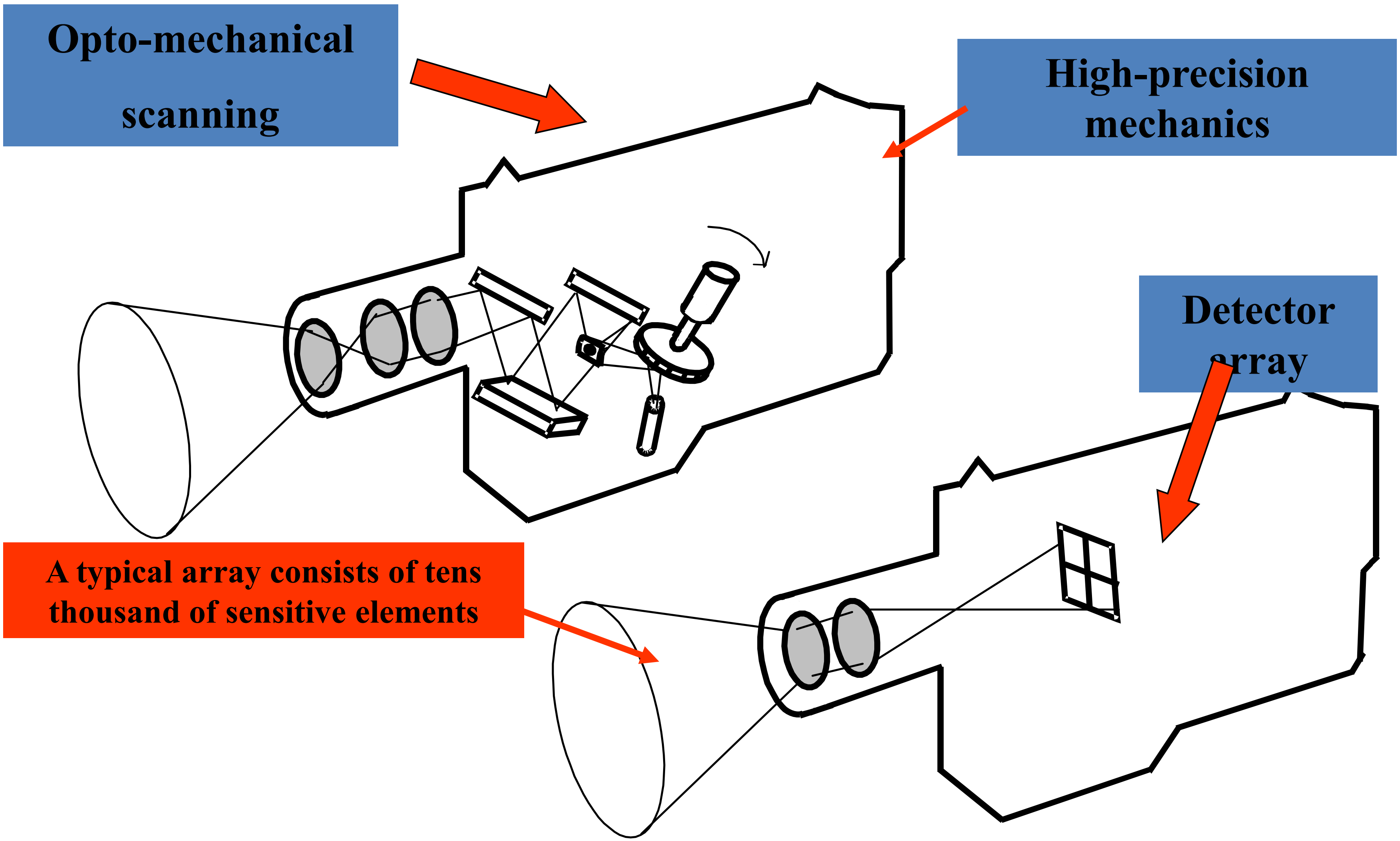
Thermal NDT

TOLMI



3-5 µm (Middle Wave) and 7-13 µm (Long Wave) wavelength bands are typically used in IR thermography

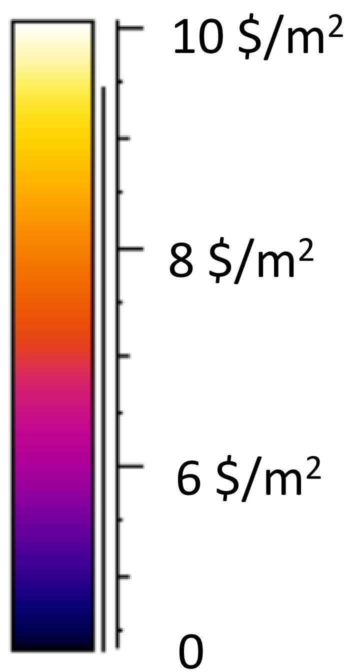
Infrared Imagers

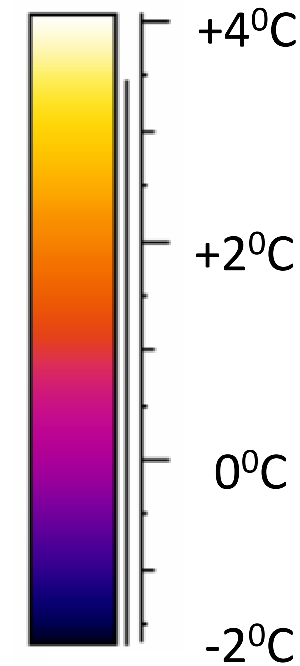


Two Types of IR Imagers

Thermal NDT

Infrared Image





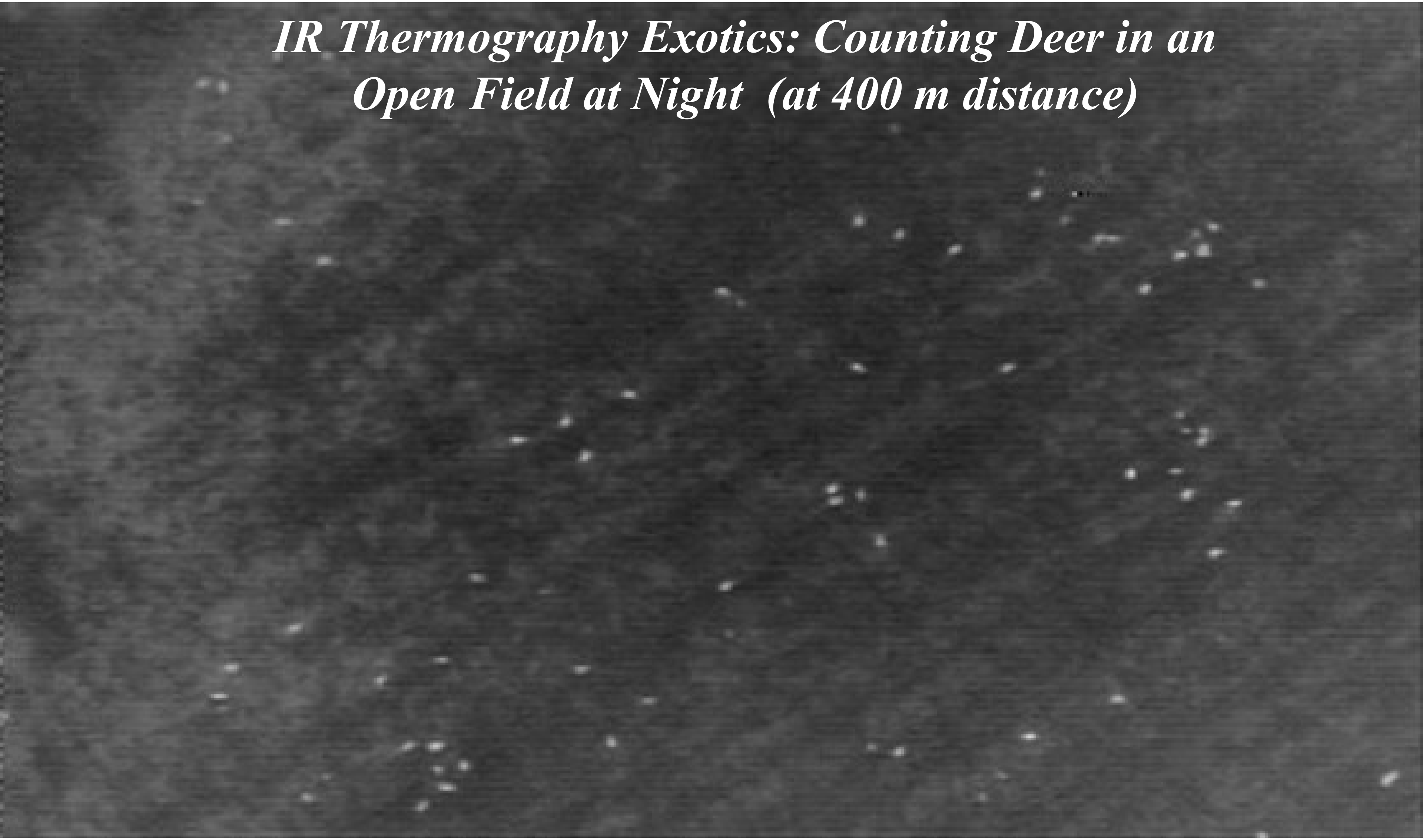
- Dark areas- cold, bright areas - hot
- What does this IR image tell about?

Standard IR images reflect distribution of "radiation" ("apparent", "effective") temperature across a building facade. Special data processing may provide versatile information on issues of interest.

Night vision

Night Vision (Police Operations)

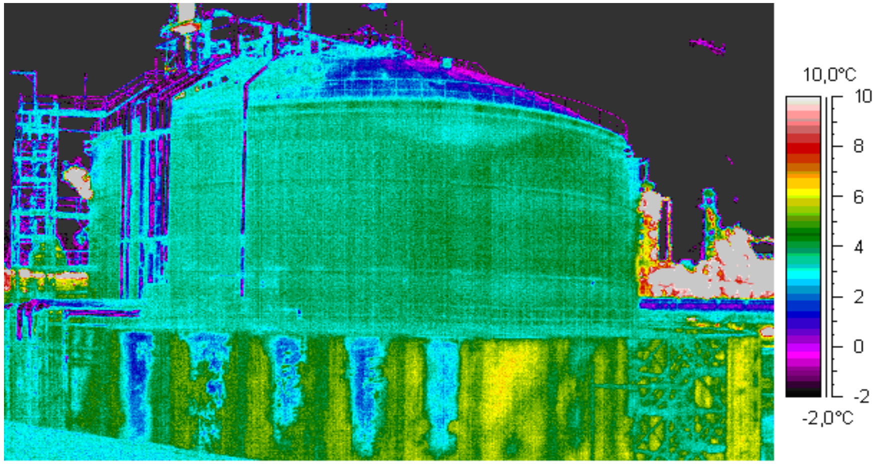
IR Thermography Exotics: Counting Deer in an Open Field at Night (at 400 m distance)



Technical diagnostics

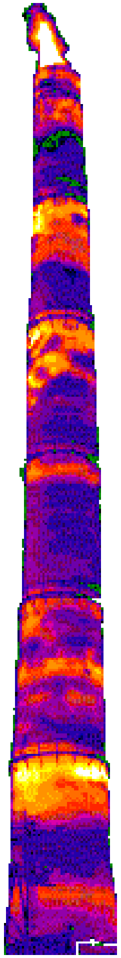
Applications: Technical Diagnostics in Industry

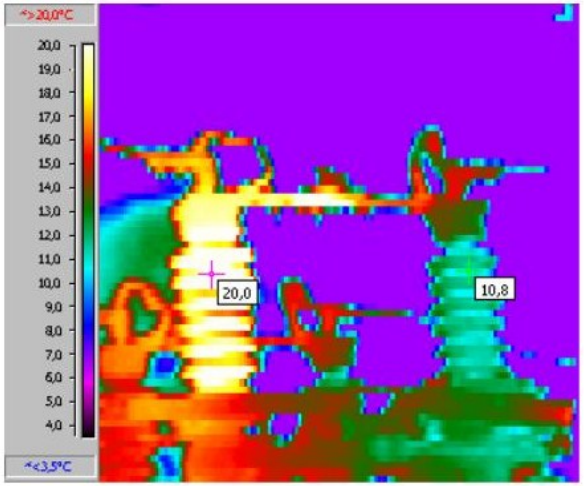
In Russia, IR Thermographic diagnostics of tanks with liquid ammonia is obligatory by law.



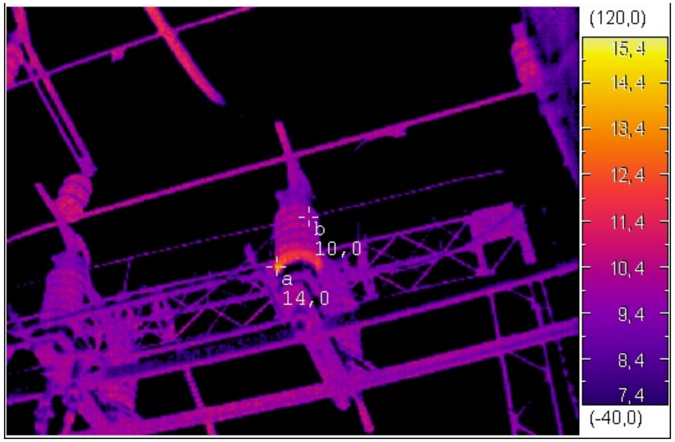
At Tomsk Polytechnic University,

the federal guidelines on the evaluation of industrial chimneys have been developed.

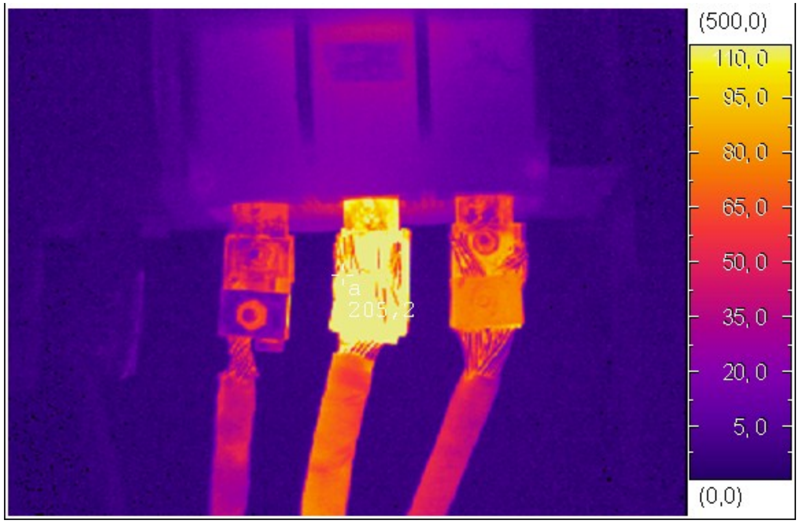




Defective rod insulator: ΔT=10°C



Defective rod insulator: ΔT= 4°C



A typical defect in bolt joints is the absence of washers when connecting copper wires with a flat outlet made of copper or aluminum. It is recommended to perform the IR thermographic inspection of bolt joints once a year because defects appear continuously depending on load, impact of chemical reagents, grade of tightening, etc.

Contact Joints (Bolt, Welded, Compressed)

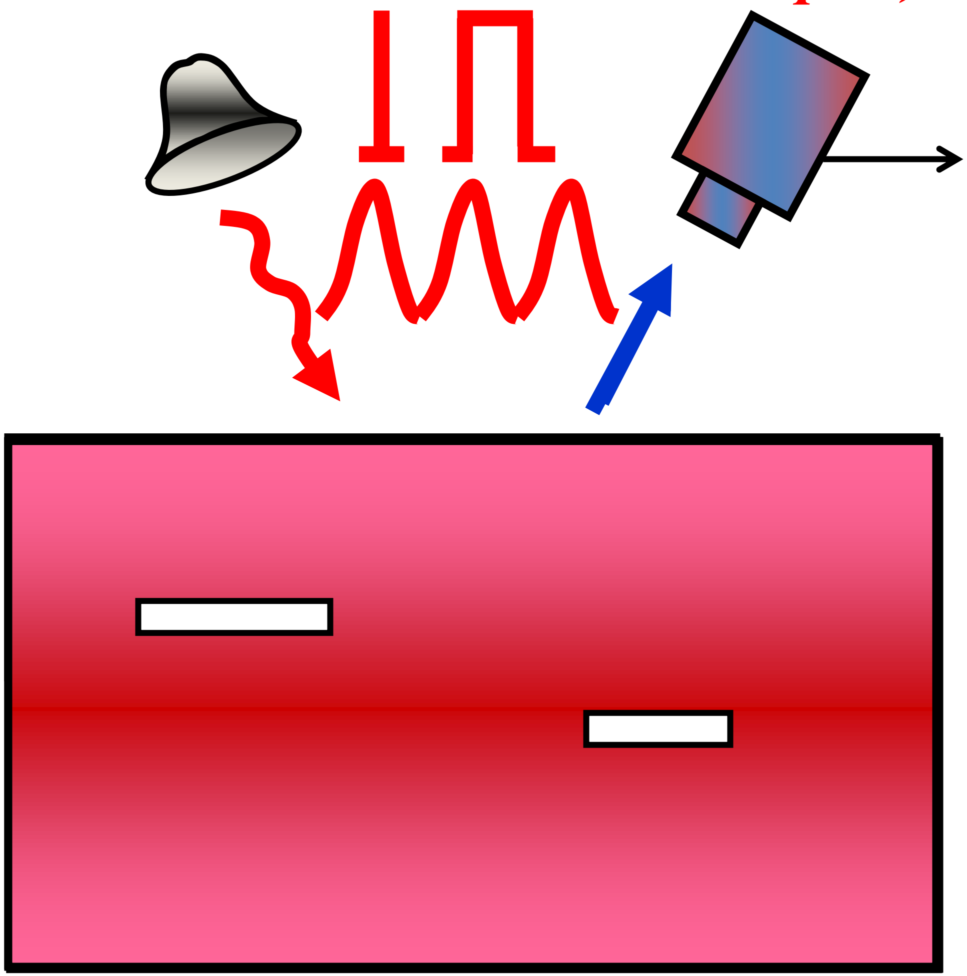

Steam Line Surveys
Manhole Cover
Leak Underground

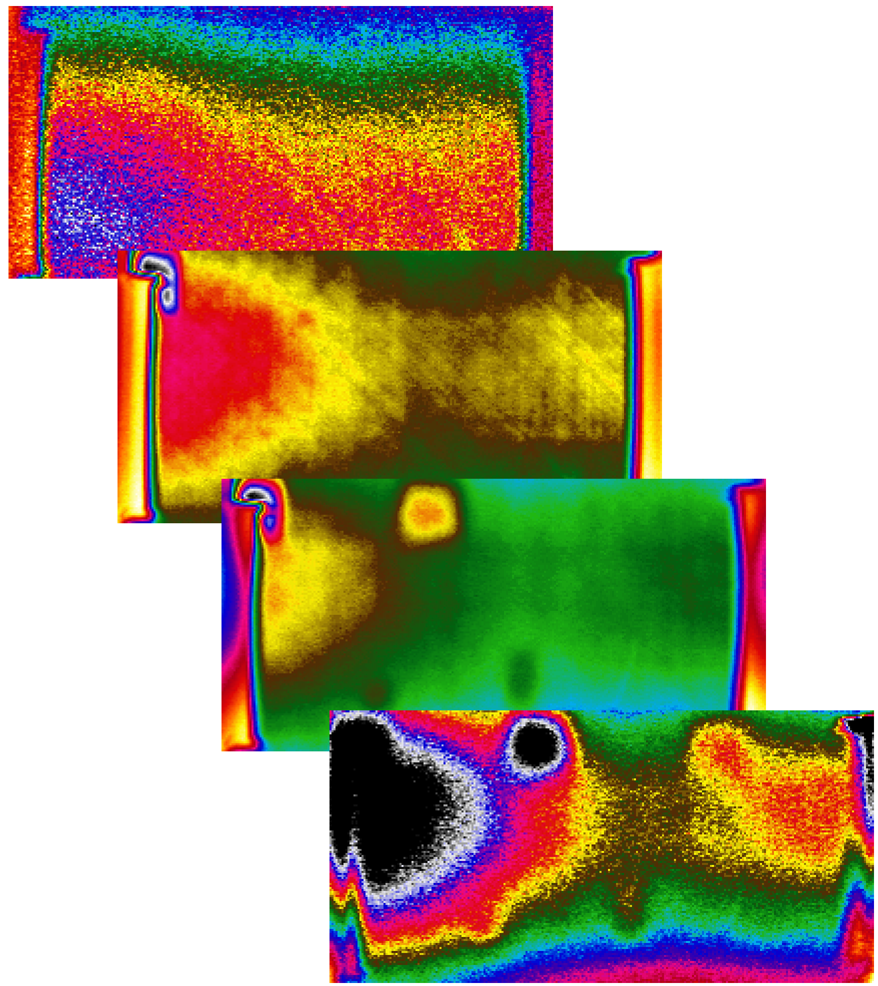
Thermal NDT

Inspection of Trains with Radioactive Wastes (Germany, 2010)

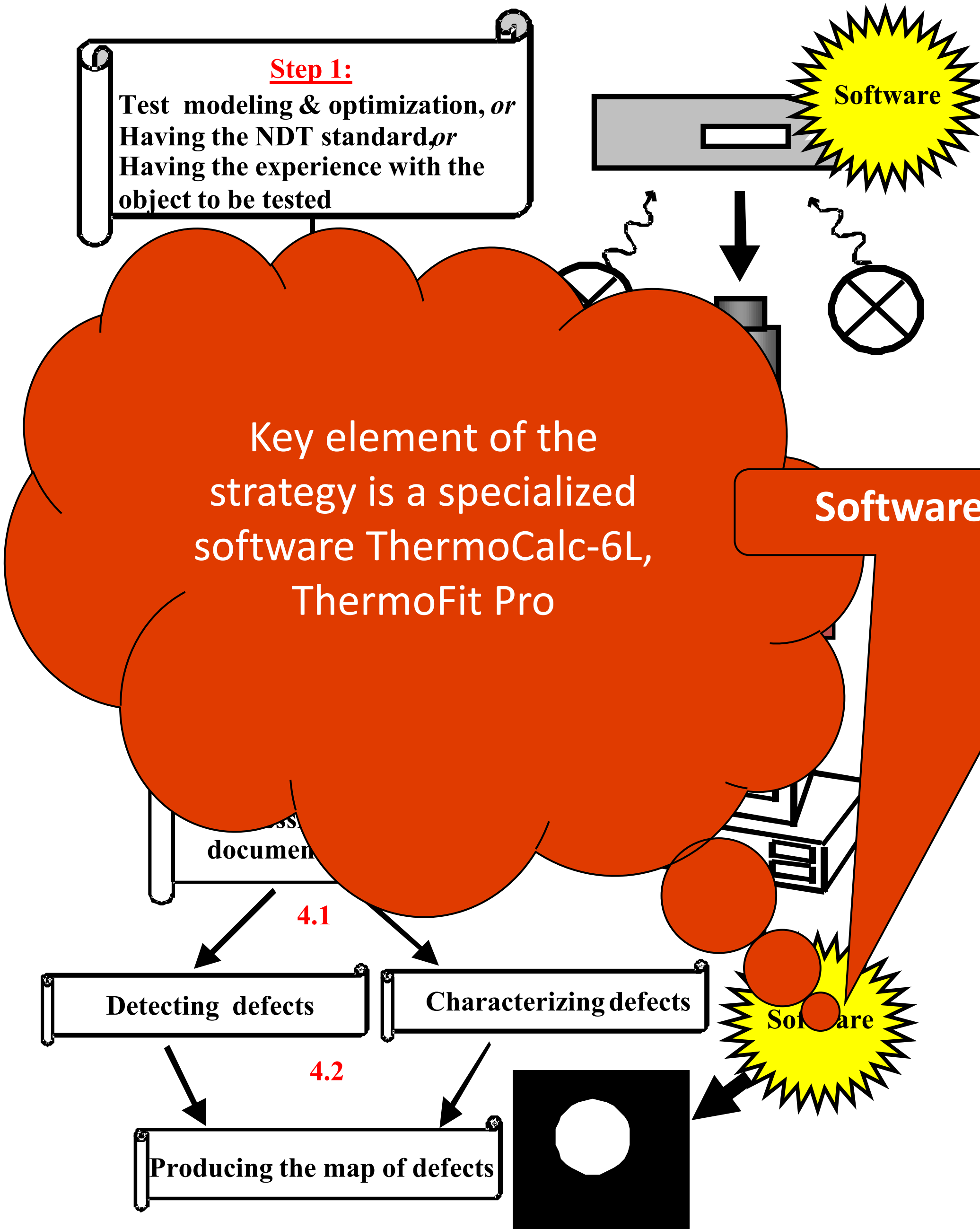
Active NDT of Materials

Active Thermal NDT of Materials (Pulsed & Thermal Wave, or Lockin Techniques): Optical Heating





Basic Inspection Procedure



Key element of the strategy is a specialized software ThermoCalc-6L, ThermoFit Pro

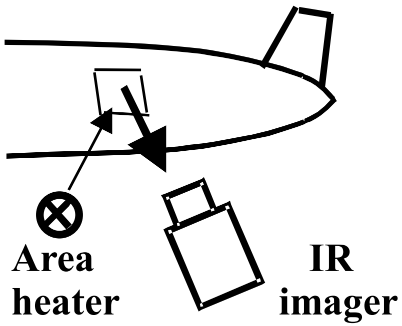
Cylindrical and conical

Software customers: Boeing, NASA

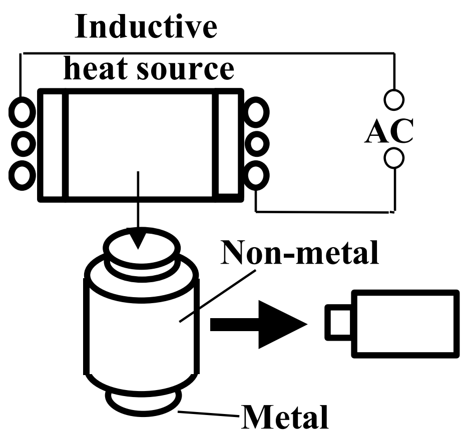
Thermal NDT

Heating Procedures

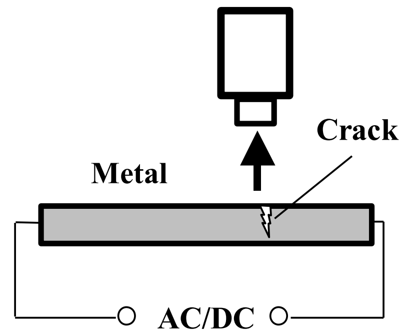
I – Optical Heating



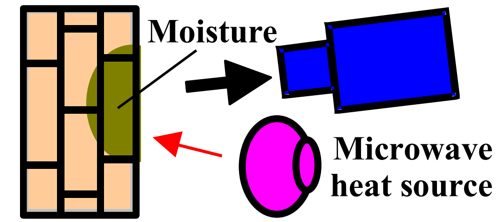
II – Inductive Heating



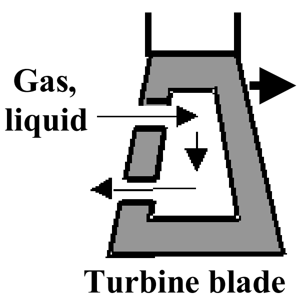
III – Electric Current Heating



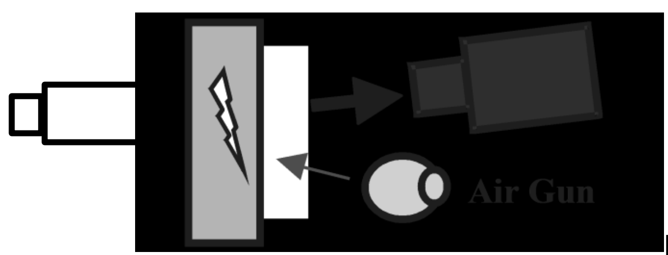
IV – Microwave Heating



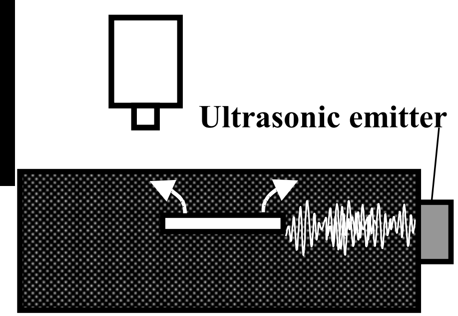
V – Heating with Gas (Liquid)



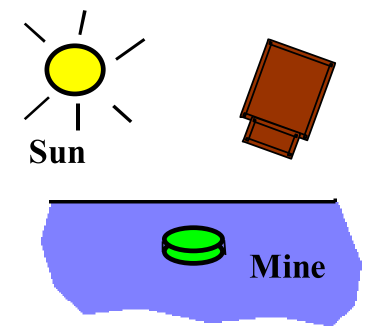
VI – Air Flux Heating

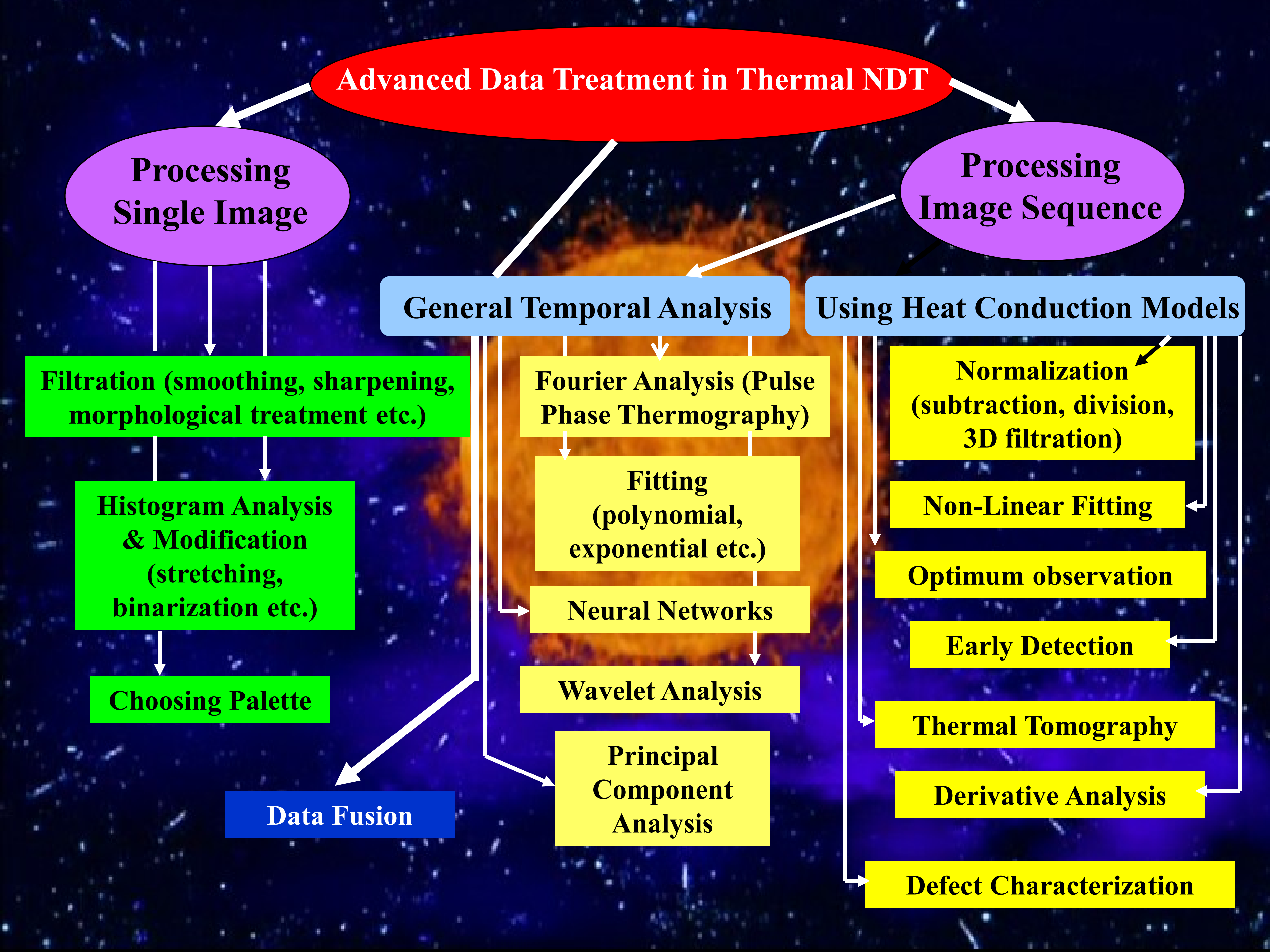


VII – Sonic IR Imaging (Thermosonics, Ultrasonic Lockin Thermography, Vibrothermography)

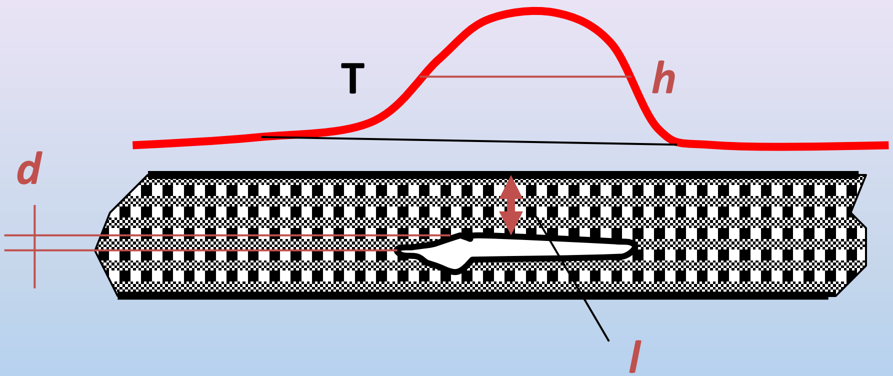


VIII–Natural Heating




Advanced Data Treatment in Thermal NDT
Processing Single Image
Processing Image Sequence
General Temporal Analysis
Using Heat Conduction Models
Filtration (smoothing, sharpening, morphological treatment etc.)
Histogram Analysis & Modification (stretching, binarization etc.)
Choosing Palette
Data Fusion
Fourier Analysis (Pulse Phase Thermography)
Fitting (polynomial, exponential etc.)
Neural Networks
Wavelet Analysis
Principal Component Analysis
Normalization (subtraction, division, 3D filtration)
Non-Linear Fitting
Optimum observation
Early Detection
Thermal Tomography
Derivative Analysis
Defect Characterization

Solving Inverse Problems and Defect Characterization in Thermal NDT



There are **three** defect parameters to be typically evaluated by surface temperature distributions:

•Defect lateral size ***h*** (visual analysis or the Full Width Half Maximum (FWHM) technique

•Defect depth ***l*** (by an inversion technique)

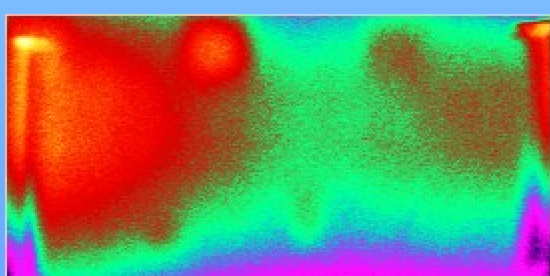
•Defect thickness ***d***, or thermal resistance $\boldsymbol{R_d}$ (by an inversion technique)

Typical accuracy:

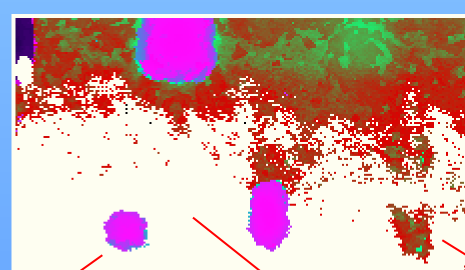
few percent by *h*, *l*,

tens percent by *d*

Source image (CFRP)

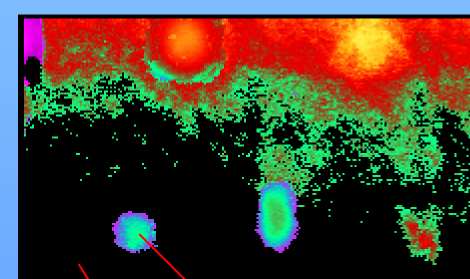


Depthgram



1.36 mm 5 mm 2.56 mm

Thicknessgram

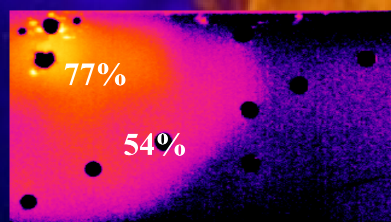


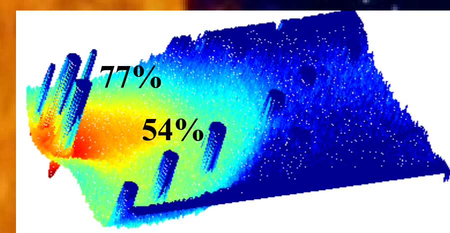
0 0.0039 m^2KW^{-1}

Applications: Detection of Hidden Corrosion in Metals

Aircraft aluminum panel (2 mm), front and rear surface

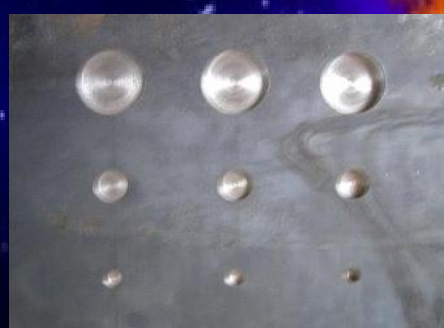
A developed algorithm allows both corrosion detection and quantitative evaluation of material loss

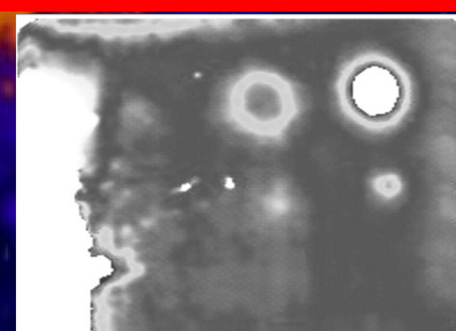




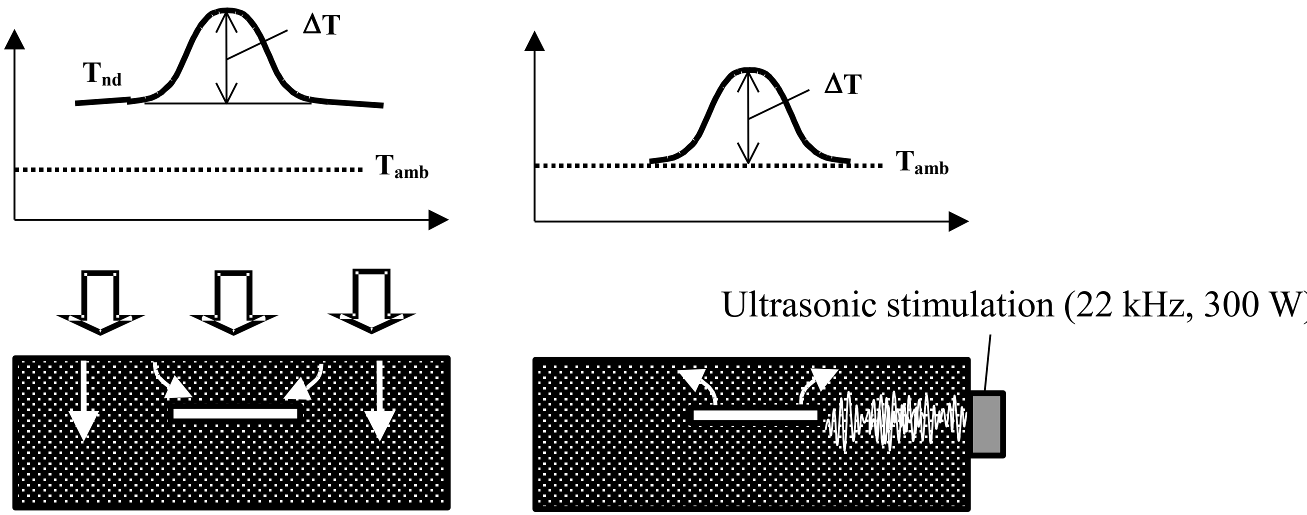
Steel thickness >10 mm

20% material loss – detection limit

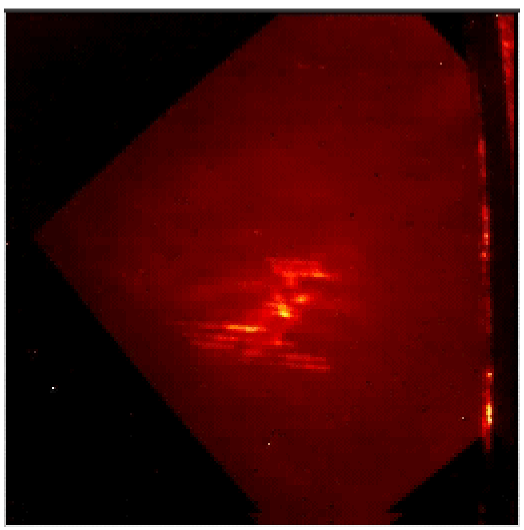


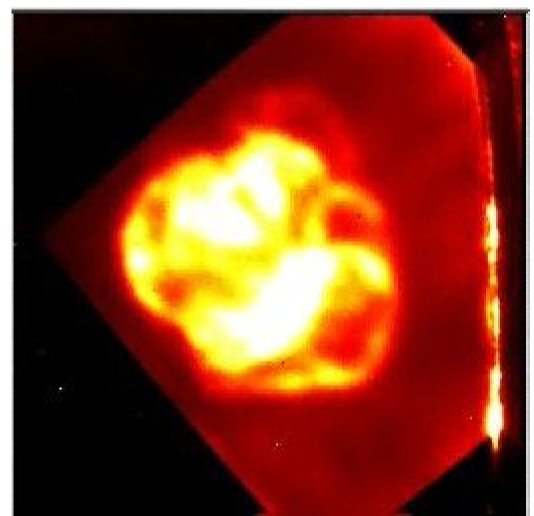


Ultrasonic IR Thermography (Sonic IR Imaging, Thermosonics, VibroIR)



Impact damage in graphite epoxy composite





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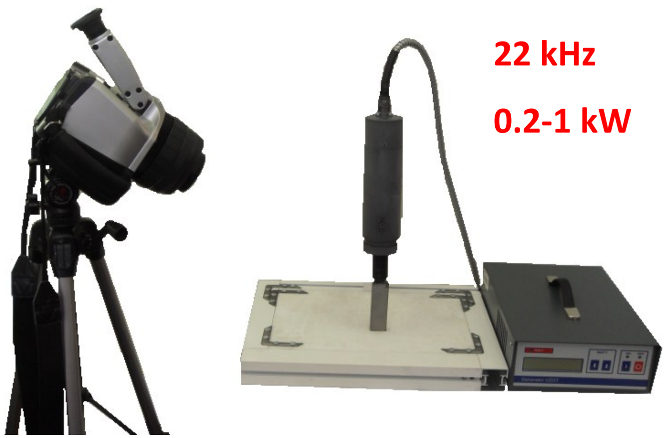
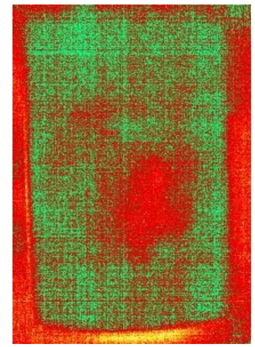
Ultrasonic IR Thermography

TOLMI

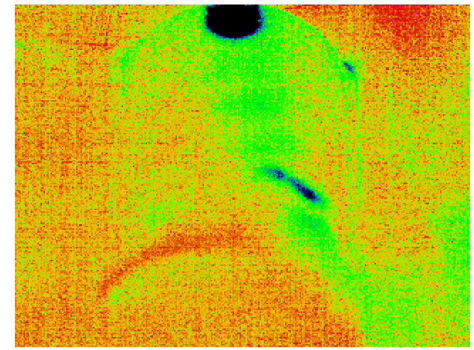


Crack in composite

Optical stimulation

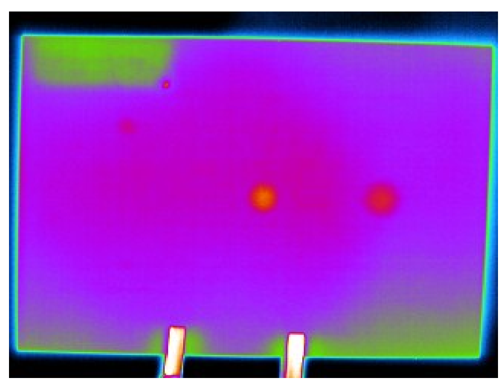


Ultrasonic stimulation

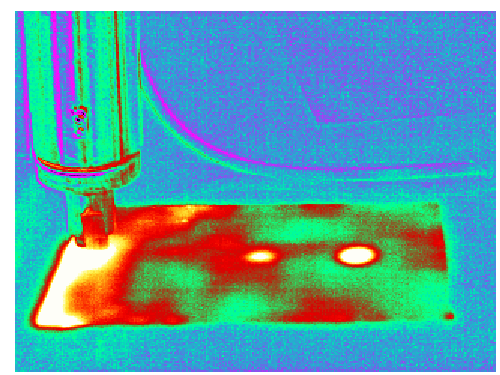


Delamination in graphite/epoxy

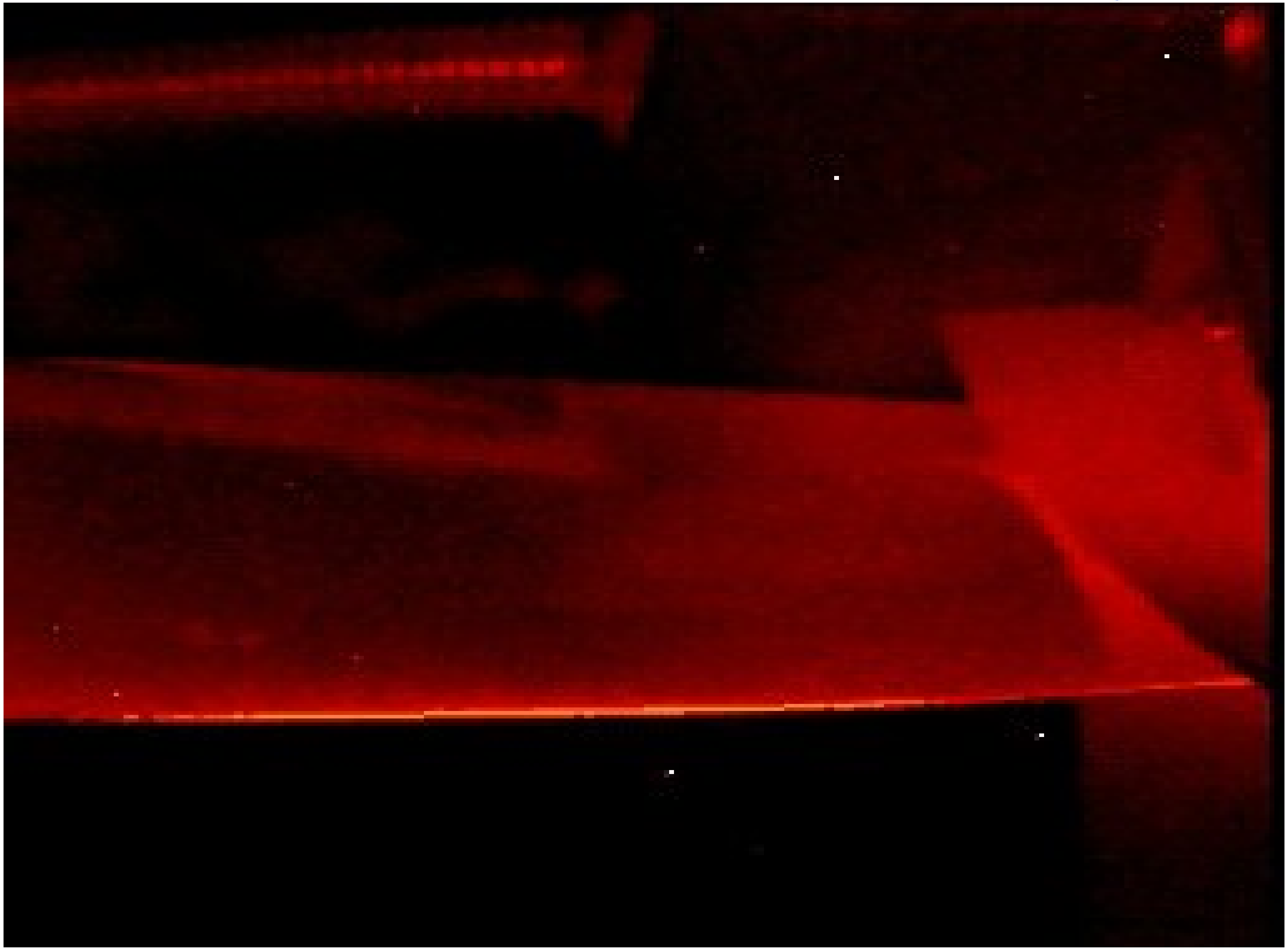
Optical stimulation



Ultrasonic stimulation



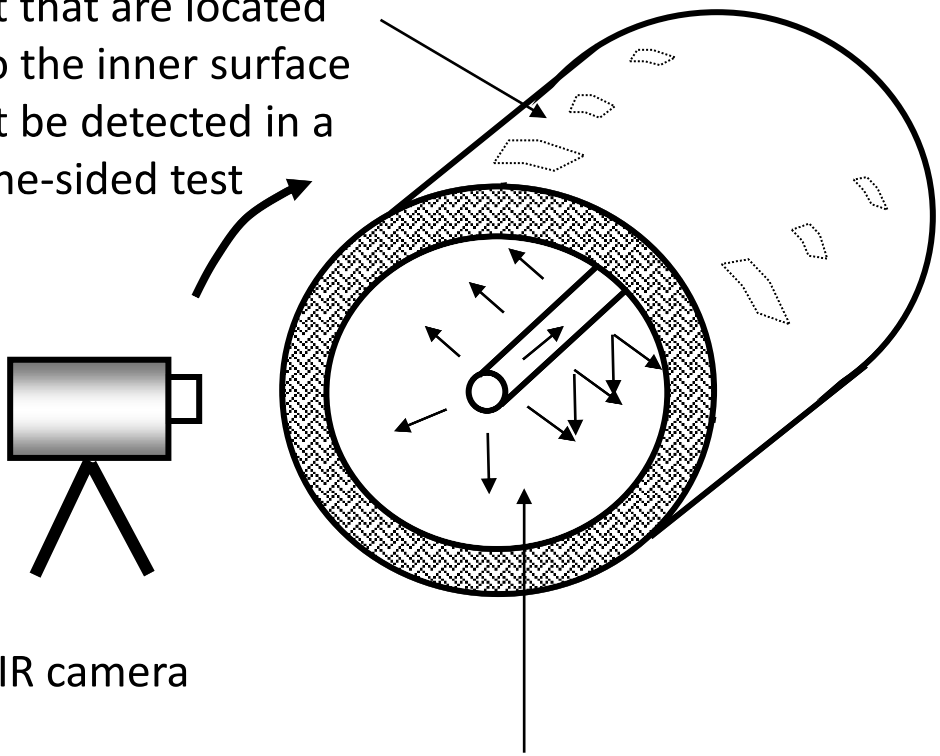
Ultrasonic IR Thermography



Crack in Turbine Blade

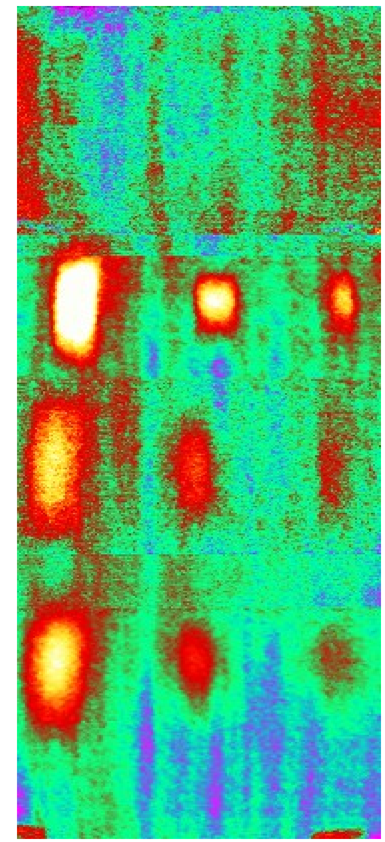
Inspecting 4 mm-thick graphite epoxy composite

Defect that are located close to the inner surface cannot be detected in a one-sided test



IR camera

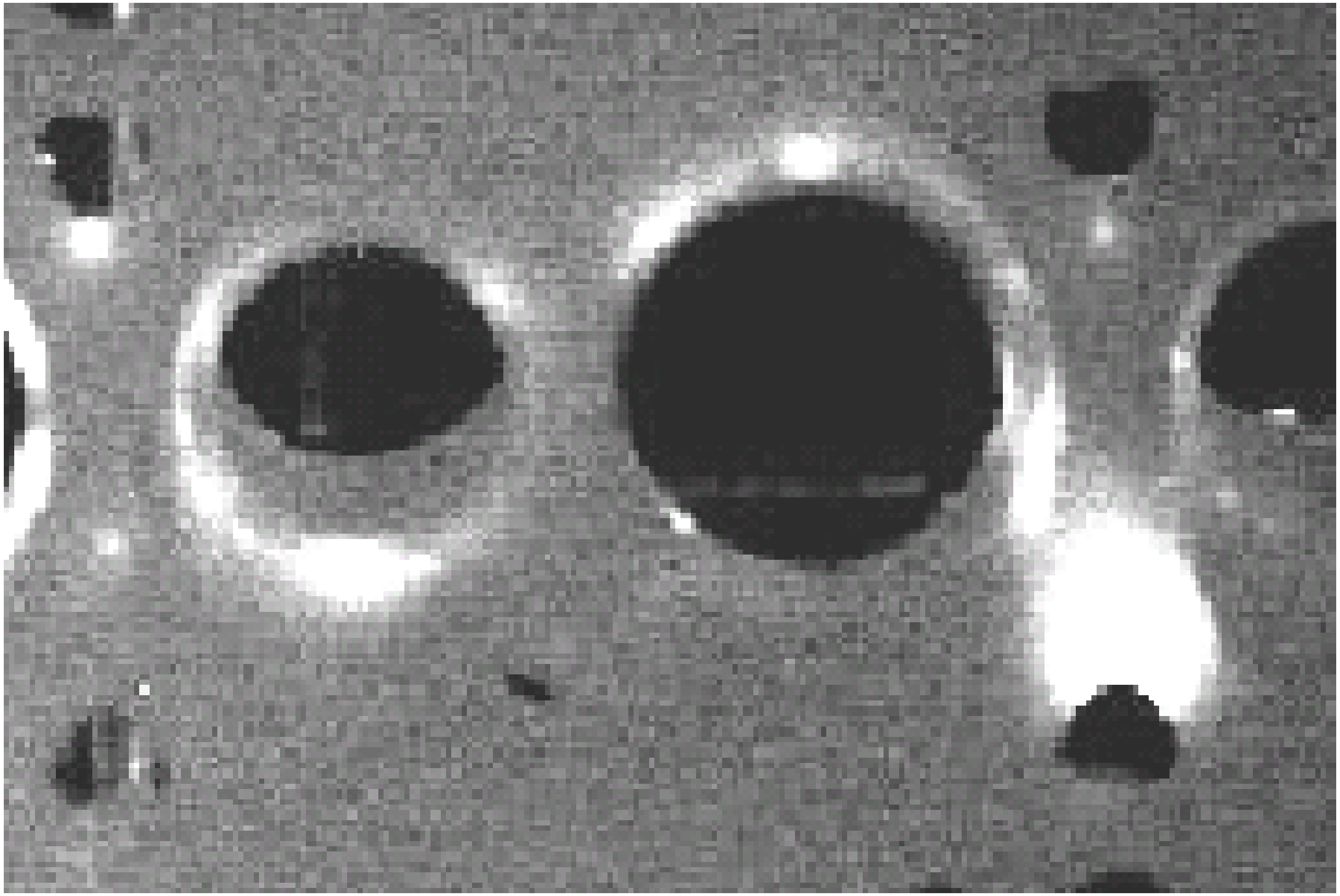
Halogen tubular lamp



Defect map (cylinder evolution, 6 images)

In some cases, one-sided test can be substituted with a more sensitive two-sided test

Ultrasonic IR Thermography



Defects in aluminum car cylinder block

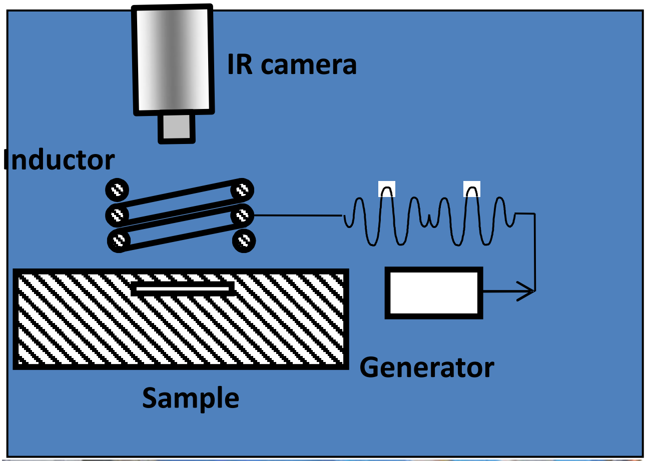
Eddy Current IR Thermography

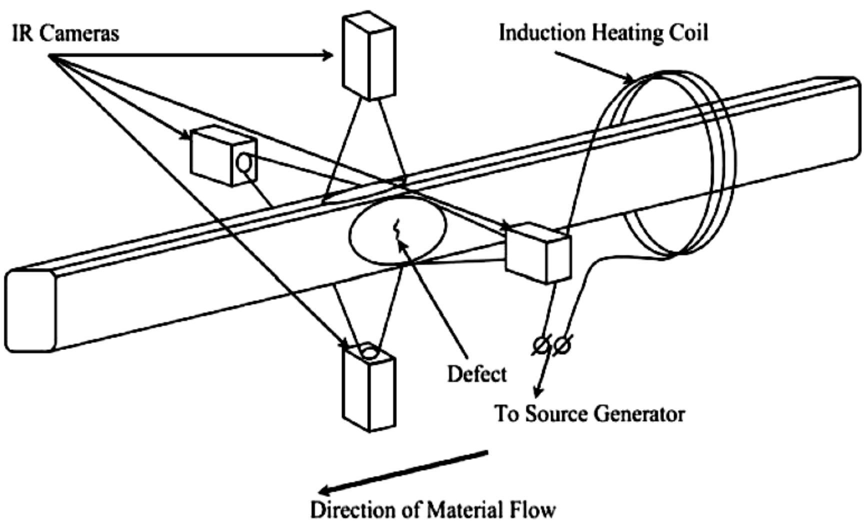
for electrically conductive materials (compressor blades, toothed gear wheels etc.).

Eddy currents are excited by inductors with power up to few kW. The carrier frequency of few hundred kHz is modulated with a frequency of 0.01-1 Hz.

Penetration depth of 100 kHz eddy currents in:

- **steel - 0.07 mm**
- **aluminum honeycombs – 5 mm**
- **graphite/epoxy composite - 50 mm**



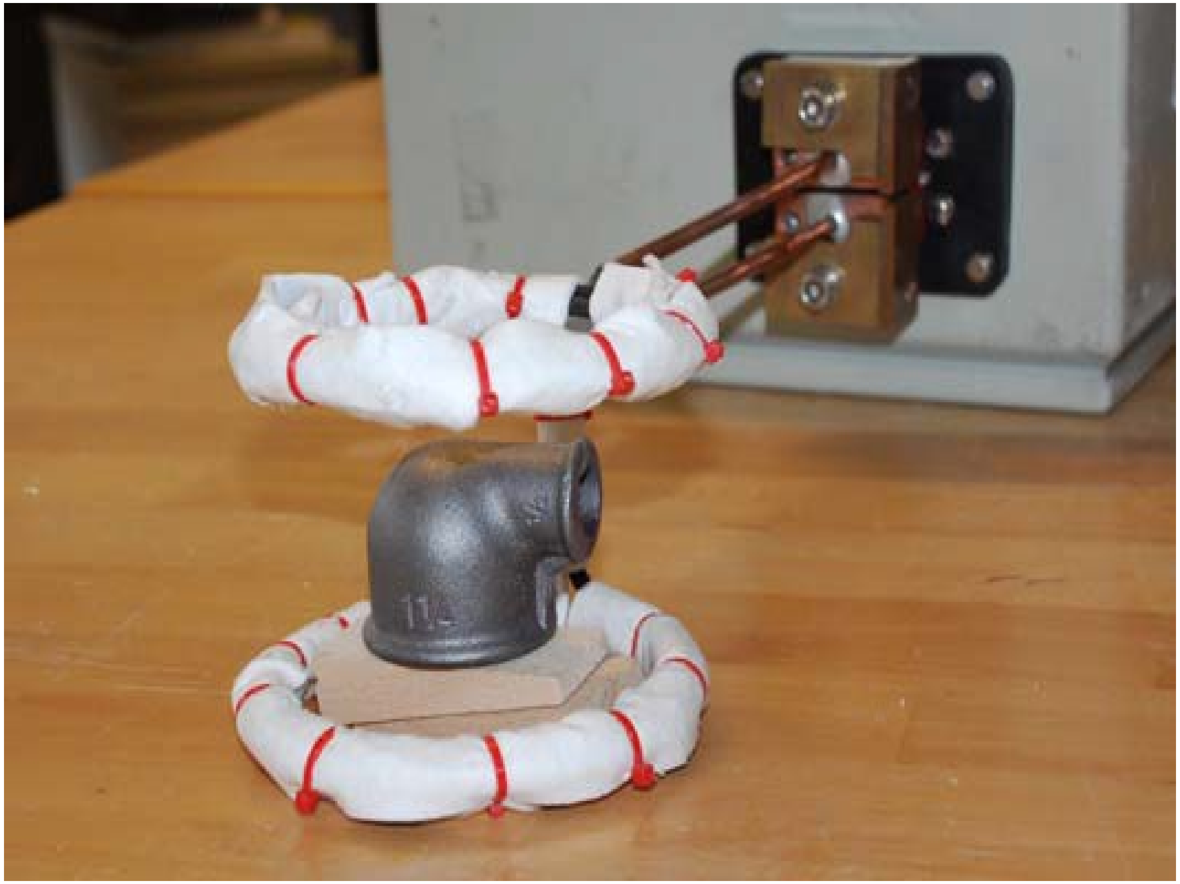


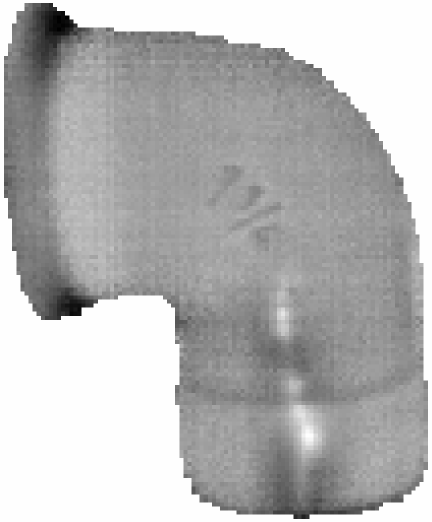
Courtesy: Starmans Electronics, Czech Republic

Steel Bar Inspection in Automotive Industry

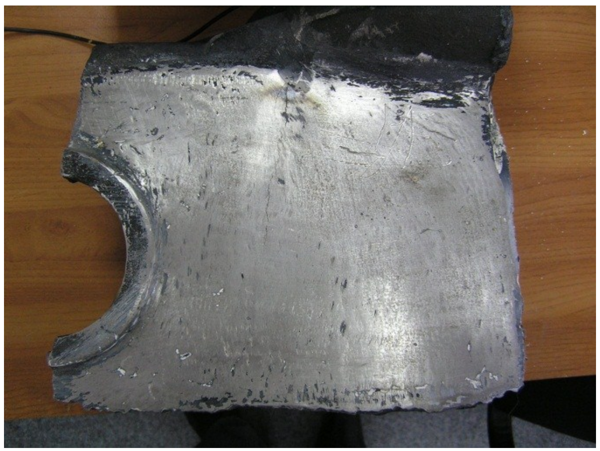
Eddy Current IR Thermography

Steel Casting Samples

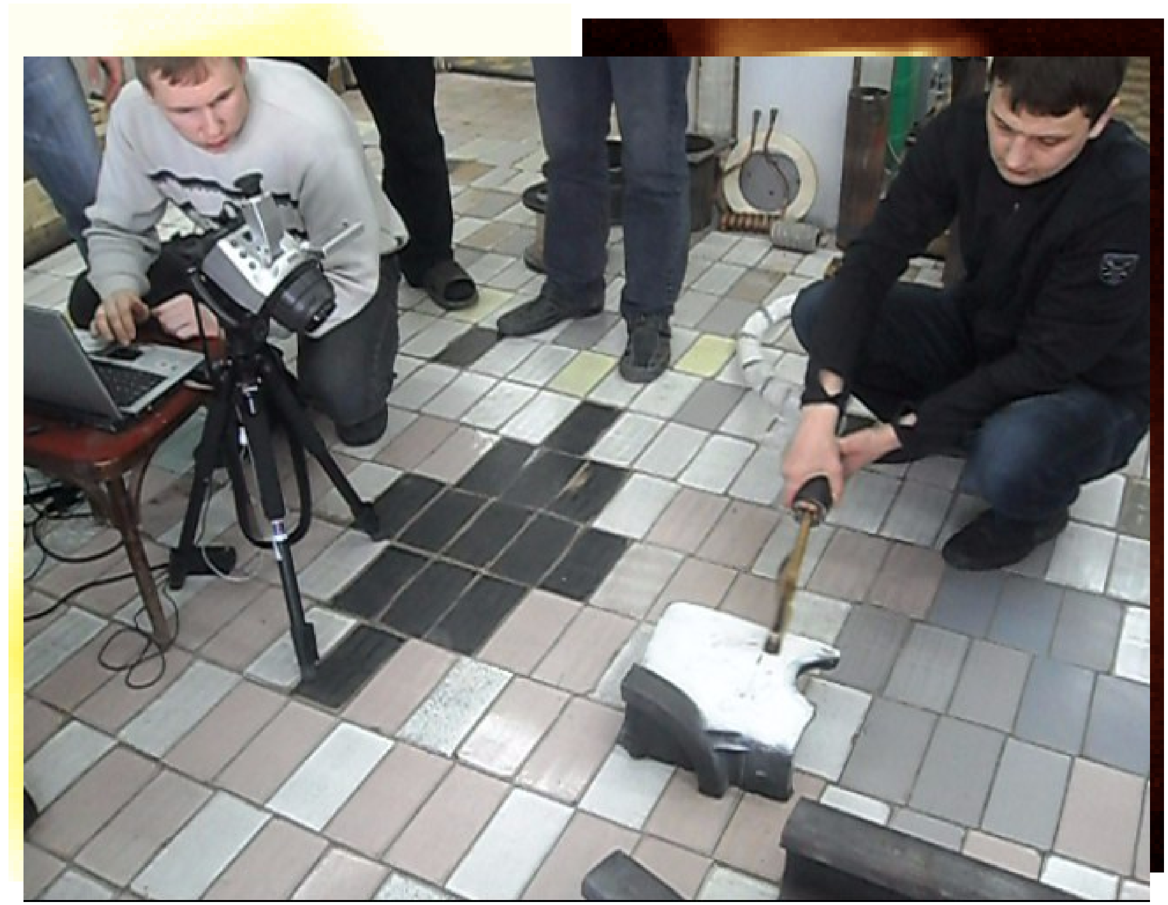




Eddy Current IR Thermography (Tomsk, 2012)



Section of a railway road car truck with a fatigue crack



Original image

After image processing

Eddy Current IR Thermography (Tomsk, 2012)

IR Thermography Stress Analysis (TSA)

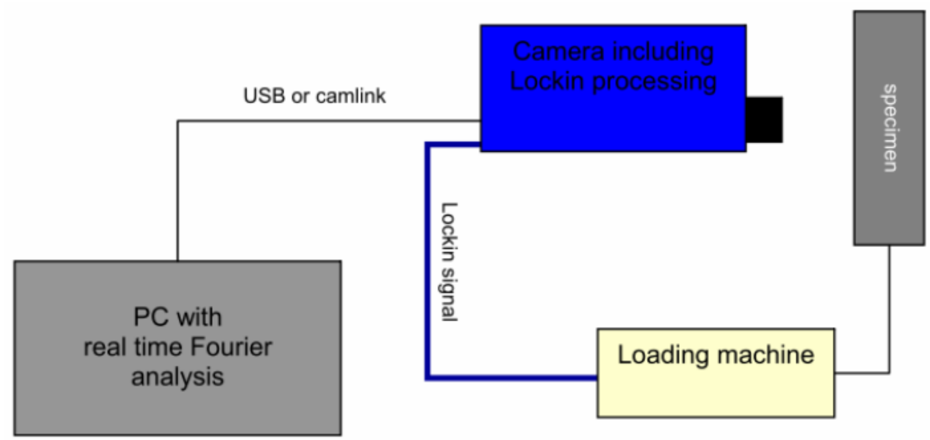
The TSA technique is based on the equation of thermoelasticity that connects changes in mechanical stresses $\Delta\sigma$ that appear in materials under cyclic loading, with temperature changes ΔT. This phenomenon is relatively weak: 1MPa change in stress causes only 1 mK temperature signal in steel. Therefore, IR cameras with very high temperature sensitivity are necessary.

When dealing with harmonic mechanical stimulation, peak values of stresses and temperatures are related by the Kelvin formula:

$$\Delta T = -\frac{\alpha}{\rho C_p} T \Delta\sigma$$

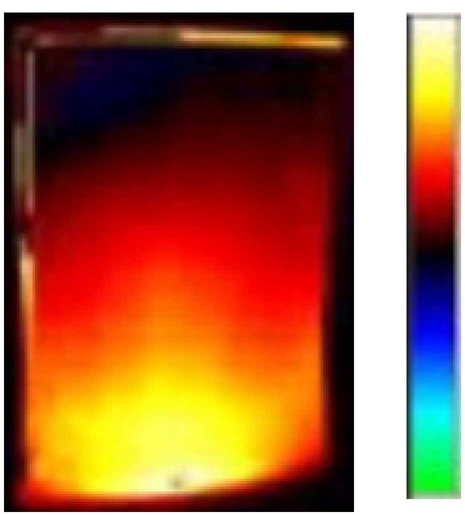
ΔT – temperature signal
α - coefficient of thermal expansion
ρ - material density
C_p - material heat capacity
T - absolute temperature
$\Delta\sigma$ - change in the sum of principal mechanical stresses

IR Thermographic Stress Analysis



Stress distribution in a turbine blade

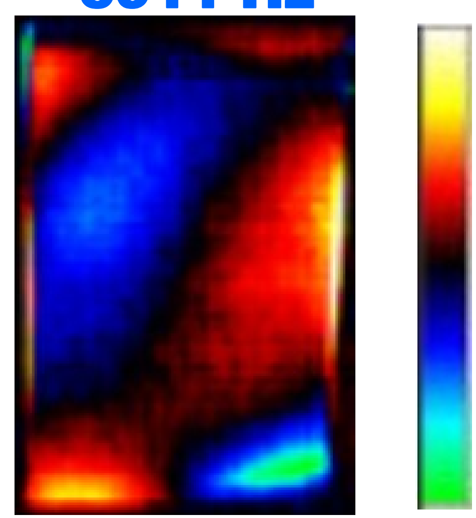
717 Hz



+100 MPa

-100 MPa

5911 Hz

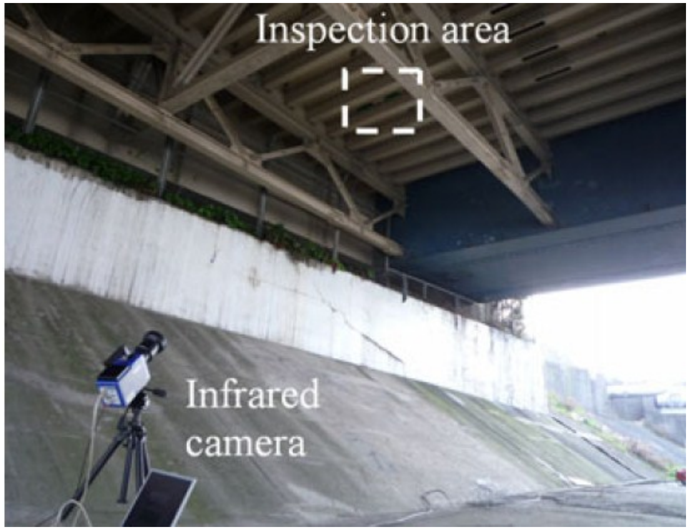


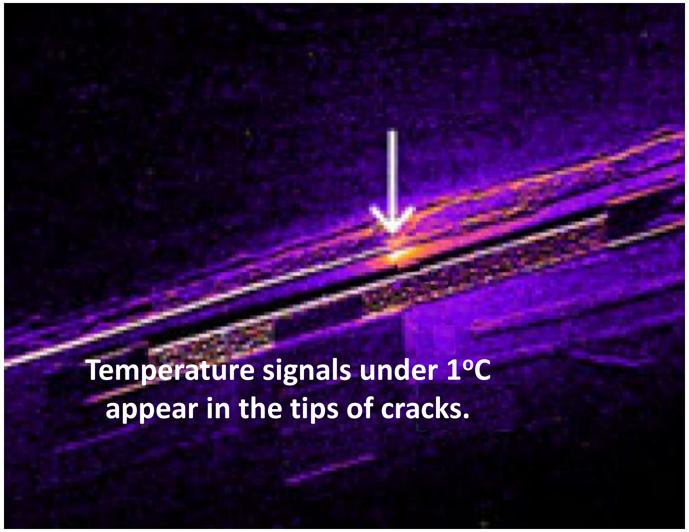
+40 MPa

-40 MPa

Crack propagation in aging structures

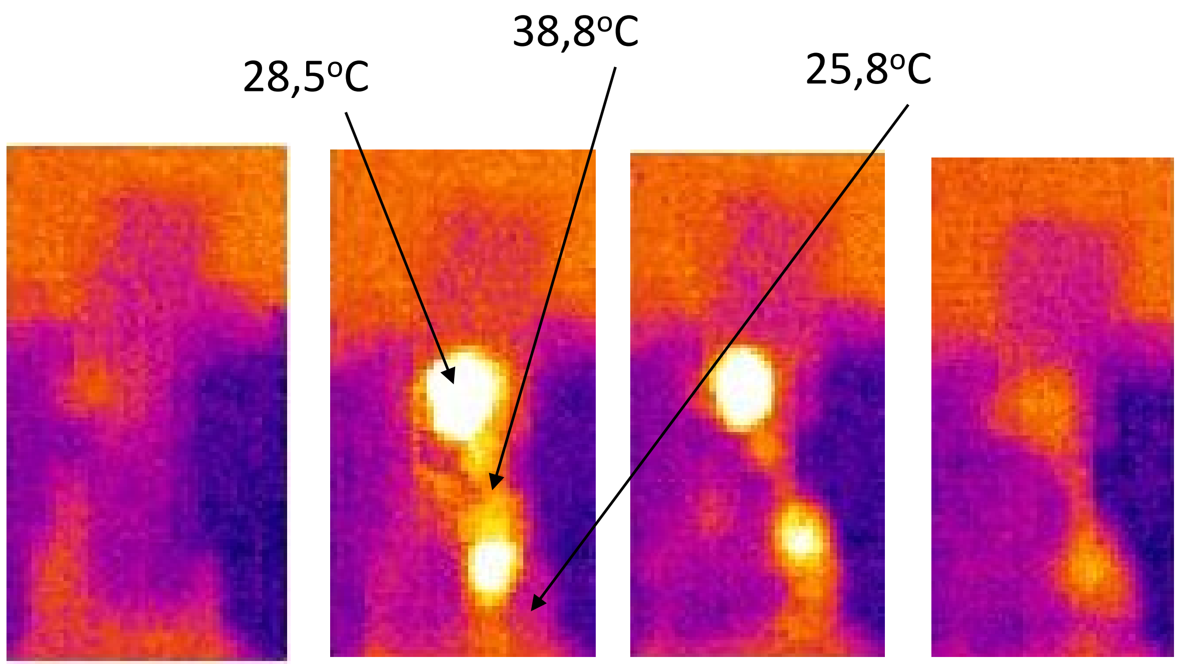
Thermoelastic stress analysis (TSA) provides the opportunity of crack depth and growth rate measurement





In laboratory environment, TSA research has been conducted for a few decades.
Recently, it was implemented outdoors (Sakagami et al., Japan):
Mechanical cyclic stimulation of welded bridge joints was ensured
by regular traffic of heavy trucks.

Analyzing damage of human bones under linearly growing load (Tomsk, 2005)



τ = 0 **160 ms** **320 ms** **3 s**

Thermal NDT Trends

- A definite trend is the further improvement of temperature and spatial resolution and increase of frame frequency of IR cameras. Such hardware will allow the inspection of high-conductive materials.
- Development of novel stimulation techniques will be continued. In some special cases, ultrasonic stimulation of structural inhomogeneities seems to be very attractive. In the case of metals, inductive heating may be a solution. Perhaps, lasers which are rarely used in TNDT could experience revival as powerful and flexible heat sources.
- Image processing will be, as before, forwarded to the better recognition of subsurface defects on the clutter background. The techniques of the Fourier transform, wavelet transform and the principal component analysis might be complemented with neural networks and data fusion.
- Efficient defect characterization approaches will be developed. These algorithms should be essentially 3D to take into account a finite size of detected defects.
- Thermal NDT will probably confirm its role as a screening technique, but, if the problems stated above, will be successfully solved, the thermal method may become unique in particular test cases.

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THANK YOU