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Infrared Thermography in Marine Applications

Review Paper

Infrared (IR) thermography has become a powerful tool for basic and applied scientific research and for the application in various fields such as industry, environment, military and maritime affairs, etc. As a „predictive" maintenance tool, IR thermography has the ability to identify problems before they occur. It is especially helpful for trouble shooting potential electrical overloads, worn or bad circuit breakers and buses. IR thermography can also be used to detect bad bearings, shafts, worn pulleys or any application where heat detection would be beneficial.

This paper has the intention to familiarize researchers, engineers and sea business staff with possibilities of applying IR thermography in the field of maritime affairs. Therefore, basic principles of IR thermography are presented and examples of the tool application are given.

Keywords: *Infrared thermography, marine application, non-destructive testing*

Primjena infracrvene termografije u pomorstvu

Pregledni rad

Infracrvena (IC) termografija postala je snažan alat za temeljna i primijenjena znanstvena istraživanja i primjenjuje se u različitim područjima poput industrije, okoliša, vojske, pomorskim poslovima itd. Kao „predskazujući" alat održavanja IC termografija pruža mogućnost da se problemi uoče prije nego se dogode. To je posebno korisno za probleme izbacivanja zbog mogućih električnih preopterećenja, istrošenih ili loših strujnih prekidača i sabirnica. IC termografija također može biti od koristi za otkrivanje loših ležajeva, osovina, pohabanih remenica ili u bilo kojoj primjeni gdje će otkrivanje topline biti od koristi.

Nakana ovog članka jest približiti, istraživače i osoblje koje se bavi pomorstvom, mogućnosti primjene IC termografije u poslovima pomorstva. Stoga su prikazani temeljni principi IR termografije i prezentacija ilustrativnih primjera primjene.

Ključne riječi: *Infracrvena termografija, primjena u pomorstvu, nedestruktivno ispitivanje*

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1 Introduction

IR thermography is a technique for producing an image of the invisible to our eyes infrared light emitted by objects due to their thermal condition. A typical type of thermography camera produces a live video picture of heat radiation intensities. More sophisticated cameras can actually measure the temperature values of any object or surface in the image field-of-view and produce false colour images that make interpretation of thermal patterns easier. An image produced by an infrared camera is called a thermogram [1].

The properties of measuring heat transmission from objects using a thermography camera are more than an interesting novelty; this information can prove useful in a variety of applications. Defence and law enforcement applications include criminal tracking, land/airborne surveillance of vehicles which have been recently operated, all from a safe distance. With a thermography camera, industrial users can detect flaws in manufacturing or weakened thermal insulators, fire safety professionals can differentiate between full and empty flammable storage containers and use the camera to see through smoke, find lost persons, and localize the source base of the fire, etc.

Originally developed for military use during the Korean War, Thermal Infrared cameras have slowly migrated into other fields of remote sensing uses as varied as medicine and archaeology. A recent advance in IR sensor production and a reduction in prices have helped the infrared viewing technology to be adopted as a cost-effective, non-invasive measuring method. Advanced optics and sophisticated software interfaces continue to add to the variety of Thermal IR cameras. Today, the IR thermography is applied in numerous human activities, such as [2]: astronomy (telescope), fire fighting operations, military and police surveillance, target detection and acquisition, law enforcement and anti-terrorism, predictive engineering maintenance of mechanical and electrical equipment, process monitoring, condition monitoring and surveillance, energy auditing of insulation, roof inspection, masonry wall structural analysis, moisture detection in walls and roofs, medical testing for diagnosis, non-destructive testing, quality control in production environments, research and development of new products, effluent pollution detection, locating of unmarked graves, aerial archaeology, search and rescue operations, etc.

Main advantages of IR thermography are:

- Allowing corrective actions to be taken before electrical, mechanical, or process equipment fails (prevention)

- Getting a visual picture for an analysis and comparison of temperatures over a large area
- Catching moving targets in real time (video rate)
- Measurement in inaccessible areas or areas hazardous for other test methods

Some limitations and disadvantages of IR thermography are:

- Thermal Images need experience and special tools to be interpreted correctly
- Very accurate temperature measurements are hard to make because of changes in material emissivities
- Training for and developing proficiency in the IR scanning is time consuming.

2 Fundamentals of thermography

The three methods by which heat flows from one object to another are radiation, convection and conduction**.** While the major concern of IR viewers is with radiation effects, the effects of the other two cannot be neglected.

Conduction is the way in which heat moves in a solid by transferring thermal energy from molecule to molecule, heating up each adjacent area within the solid. Convection is a faster heat transfer effect, and moves in the the way heat does in a liquid or in a gas. In convection, a medium is used to carry thermal energy and to develop a current in the medium to move it along more rapidly. This is a faster and more powerful thermal energy transfer than conduction. However, the most powerful means of thermal energy transfer is radiation, which moves at the speed of light. These three phenomena do not exclude each other, and in most situations they occur together.

IR energy is emitted by all materials above 0 °K (≈ - 273 °C). Infrared radiation is part of the electromagnetic spectrum and occupies frequencies between visible light and radio waves (Figure 1). The IR part of the spectrum spans wavelengths from 0.7 μm (micrometers, microns) to 1000 μm. Within this wave band, only frequencies of 0.7 μm to 20 μm are used for practical, everyday temperature measurement [3].

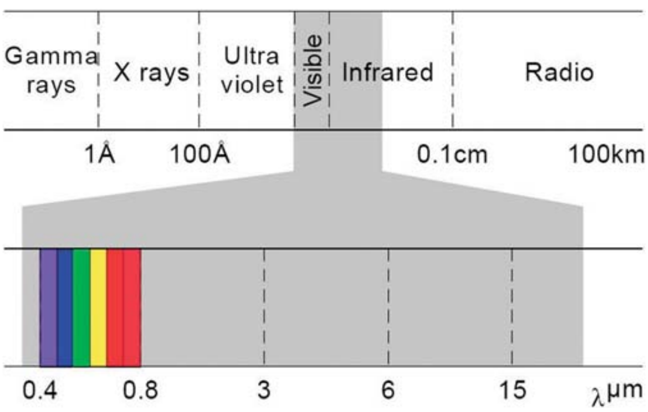


Figure 1 **Electromagnetic spectrum**
Slika 1 **Elektromagnetski spektar**

Though IR radiation is not visible to the human eye, it is helpful to imagine it as being visible when dealing with the principles of measurement and when considering applications, because in many respects it behaves in the same way as visible light. IR energy travels in straight lines from the source and can be reflected and absorbed by material surfaces in its path. In the case of most solid objects which are opaque to the human eye, part of the IR energy striking the object surface will be absorbed and part will be reflected. A certain amount of the energy absorbed by the object will be re-emitted and a certain amount will be reflected internally. This will also apply to materials which are transparent to the eye, such as glass, gases and thin, clear plastics, but here, some of IR energy will also pass through the object. These phenomena collectively contribute to what is referred to as the emissivity (ε) of the object or material optical properties.

Materials which do not reflect or transmit any IR energy are know as black bodies (BB) and are not known to exist naturally. However, for the purpose of theoretical calculation, a true black body is given an emissivity value of 1.0. The closest approximation to a black body emissivity of 1.0, which can be achieved in real life, is an IR opaque, i.e. a spherical cavity with a small tubular entry. The inner surface of such a sphere will have an emissivity of 0.998. The object has an emissivity ε which is the ratio of radiant power form an object to that from a black body at the same temperature.

Different kinds of materials and gases have different emissivities, and will therefore emit IR energy at different intensities for a given temperature. The emissivity of a material or gas is a function of its molecular structure and surface characteristics. It is not generally a function of colour unless the source of the colour is a radically different substance from the main body of the material. Metallic paints which incorporate significant amounts of aluminium are a practical example of such a case. Most paints have the same emissivity irrespective of colour, but aluminium has a very different emissivity which will therefore modify the emissivity of metallized paints. The more highly polished some surfaces are, the more IR energy will be reflected from the surface. The surface characteristics of a material will therefore also influence its emissivity. In temperature measurement, this is most significant in the case of infrared opaque materials which have an inherently low emissivity. Thus, a highly polished piece of stainless steel will have a much lower emissivity than the same piece with a rough, machined surface. This is because the grooves created by the machining prevent a large amount of the IR energy from being reflected. In addition to molecular structure and surface condition, the third factor affecting the apparent emissivity of a material or gas is the wavelength sensitivity of the sensor, known as the sensor spectral response. As stated earlier, only IR wavelengths between 0.7 μm and 20 μm are used for practical temperature measurement. Within this overall band, individual sensors may operate only in a narrow part of the band, such as from 0.78 μm to 1.06 μm, 3.0 μm to 5.2 μm or 7 μm to 14 μm, for reasons which will be explained later (IR attenuated by the atmosphere).

The formulas upon which the infrared temperature measurement is based are old, established and well proven. It is unlikely that most IR users will need to make use of these formulas, but a good knowledge of them will provide an appreciation of the interdependency of certain variables. The important formulas are as follows [4]:

1 Planck's Law

This law describes the relationship between spectral emissivity, temperature and radiant energy from a black body.

$$E_{BB}(\lambda,T)=\frac{2\cdot h\cdot c^2}{\lambda^5}\frac{1}{e^{\frac{h\cdot c}{\lambda\cdot k\cdot T}}-1}\qquad (\mathrm{W/m^2\eta m}),\qquad (1)$$

where: E_{BB} is black-body spectral radiant emittance at wavelength λ (μm) and thermodynamic temperature T (also called absolute temperature) (K), c is velocity of light ($c = 3\cdot10^8$ m/s), h is Planck's constant (h = 6,625$\cdot10^{-34}$ Joule·s) and k is Boltzmann's constant (k = 1,38$\cdot10^{-23}$ Joule/K)

2 Wien's Displacement Law

This law states that the wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature increases.

$$\lambda_{max}\cdot T = 2898\ (\mu\mathrm{mK})\qquad (2)$$

For example, the sun (≈ 6000 °K) emits yellow light, peaking at about 0,5 μm in the middle of the visible light spectrum. At the temperature of 20 °C (≈ 293 °K) the peak of radiant emittance lies at 9.9 μm, while at the temperature of T = 473 °K (≈ 200 °C) the peak is λ_{max} = 6.1 μm (Figure 2).

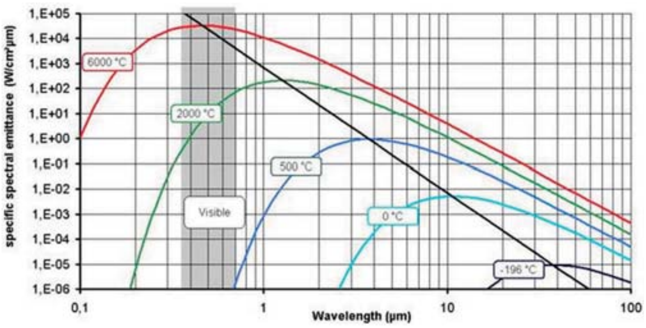


Figure 2 **Distribution and the peaks of radiated energy from objects at various temperatures**

Slika 2 **Raspodjela energije zračenja i maksimuma s objekata različitih temperatura**

3 The Stephan-Boltzmann Law

The hotter an object becomes the more infrared energy it emits.

The Stefan-Boltzmann law, also known as Stefan's law, states that the total energy radiated per unit surface area of a black body in unit time (known variously as the black-body irradiance, energy flux density, radiant flux, or the emissive power), E_{BB}, is directly proportional to the fourth power of the black body thermodynamic temperature T:

$$E_{BB} = \sigma\cdot T^4\ (\mathrm{W/m^2})\qquad (3)$$

The constant of proportionality σ, called the Stefan-Boltzmann constant or Stefan's constant is non-fundamental in the sense that it derives from other known constants of nature. The value of the constant is σ = 5, 6697 · 10^{-8} W/m²K⁴.

4 Kirchoff's Law

When an object is at thermal equilibrium, the amount of absorption will equal the amount of emission. According to Kirchoff's law, for any material the emissivity and absorptance of a body are equal at any specified temperature and wavelength, i.e.:

$$\varepsilon = \mathrm{a},\qquad (4)$$

where a is coefficient of absorptance (the ratio of radiant power absorbed by an object to that incident upon it).

Real objects almost never comply with these laws over an extended wavelength region although they may approach the black-body behaviour in certain spectral intervals. When the infrared energy radiated by an object reaches another body, a portion of the energy received will be absorbed (a), a portion will be reflected (r) and, if the body is not opaque, a portion (t) will be transmitted through. The sum total of the three individual parts must always add up to the initial value of radiation which left the source.

$$\mathrm{a + r + t = 1}\qquad (5)$$

If we have a body which is totally non-reflective and completely opaque, then all the radiated energy received by this body will be absorbed. This type of a body is a perfect absorber and will also be a perfect emitter of infrared radiation. A perfect absorber and hence emitter of infrared energy is referred to as a black body. A black body would not necessarily appear to be black in colour as the words black body are a technical term to describe an object capable of absorbing all radiation falling on it and emitting maximum infrared energy for a given temperature. In practice, surfaces of materials are not perfect absorbers and tend to emit and reflect infrared energy. A non-black body would absorb less energy than a black body under similar conditions and hence would radiate less infrared energy even if it was at the same temperature.

For opaque materials t = 0, and the relation is simplified to a + r = 1. According to Kirchoff's law, ε + r = 1. For highly polished materials ε approaches zero, so that for a perfect reflecting material r ≈ 1 is valid.

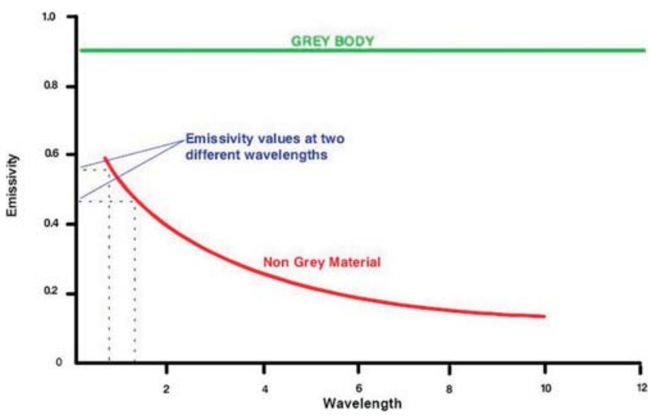
A gray body (GB) has ε less than 1 and constant value wavelenght independent. Taking into account ε for gray-body radiator, the Stefan-Boltzmann formula becomes:

$$E_{GB} = \varepsilon\cdot\sigma\cdot T^4\ (\mathrm{W/m^2})\qquad (6)$$

A real body generally has not a constant value for emissivity (Figure 3) but usually a constant value is taken for a narrow spectral band.

Figure 3 **Spectral emissivity of BB, GB and Non-Grey material (the plot of BB is missing)**

Slika 3 **Emisivnost crnog, sivog i realnog tijela**



The atmosphere is not fully transparent to IR. It attenuates the radiation passing through it and also emits radiation. The atmosphere influence on IR measurements depends mainly on the air density, temperature, visibility and relative humidity (the influence of aerosol). There are some narrow spectral bands called atmospheric windows where the attenuation is not so strong (SW – short wave, 3 – 5 μm; LW – long wave, 8 – 14 μm; Picture 4.) and it is the reason why Thermal IR cameras works in these bands. Modern IR cameras have a computer program for the prediction of atmospheric attenuation and use it in the analysis process.

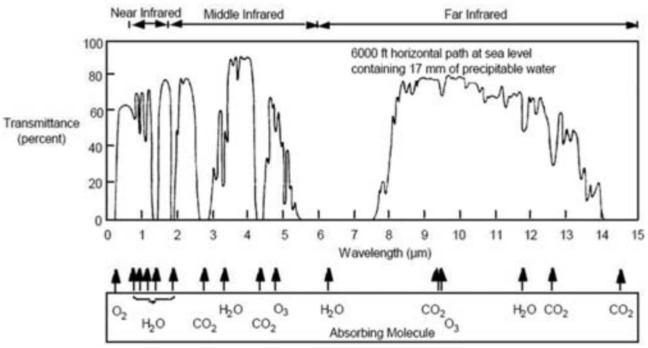


Figure 4 **Atmospheric transmissivity in different wavelenght bands**
Slika 4 **Propusnost atmosfere u različitim spektralnim pojasima**

According to the approaches to measuring, thermography is classified as active thermography and passive thermography. Generally, in active thermography external stimulation is required to generate relevant thermal contrasts in thermal steady state "specimens", while in passive thermography, the actual thermal state of the "specimen" provides enough information to characterize the sought features. Thus, the active thermography presentation elaborates on various stimulation schemes such as pulse, step, and modulated, while special attention is paid to data analysis since the active thermography is often deployed for quantitative characterization. Also, vibrothermography is an active IR thermography technique where, under the effect of mechanical vibrations induced externally to the structure at a few fixed frequencies, heat is released by friction precisely at defect locations (such as cracks and delaminations).

3 IR Thermography measuring

As already mentioned, when viewing an object, a camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. A third radiation contribution comes from the atmosphere between the object and the camera.

This basic description of the measurement situation, as illustrated in Figure 5, is so far a fairly true description of real conditions. What has been neglected could, for instance, be the sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify; however, in most cases they are fortunately small enough to be neglected. In the case when they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, by shielding intense radiation sources, etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

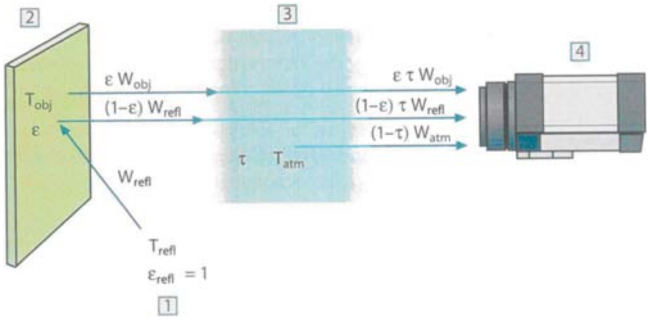


Figure 5 **A schematic representation of a general thermographic measurement situation.**
1: Surroundings; 2: Object; 3: Atmosphere; 4: Camera
Slika 5 **Shematski prikaz situacije općeg termografskog mjerenja.**
1.: okolina; 2.: objekt; 3.: atmosfera; 4.: kamera

The three collected radiation power terms are [5]:

1 - Emission from the object = $\varepsilon\tau W_{obj}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is T_{obj}.
2 - Reflected emission from ambient sources = $(1 - \varepsilon)\tau W_{refl}$, where $(1 - \varepsilon)$ is the reflectance of the object. The ambient sources have the temperature T_{refl}.
3 - Emission from the atmosphere = $(1 - \tau)\tau W_{atm}$, where $(1 - \tau)$ is the emittance of the atmosphere. The temperature of the atmosphere is T_{atm}.

The total received radiation power can now be written as:

$$W_{tot} = \varepsilon\tau W_{obj} + (1 - \varepsilon)\tau W_{refl} + (1 - \tau)W_{atm}$$

According to Stefan's law, from the measured value W it is possible to get the object temperature.

Thermal IR imagers come in different configurations to suit specific needs. Some imagers are designed to give the actual temperature measurement of the scene along with a colour video representation. This type of imager is called "Thermovision" or "Imaging Radiometer" and is used mostly for industrial (predictive maintenance, process control, R&D) and medical (human and veterinary) applications. Other imagers are designed primarily for surveillance and/or target acquisition environments. These cameras can be either hand held or fixed mount remote installations. The main differences in surveillance units are the optical elements and the spatial resolution of the imager. Another use is in the aerial surveillance where the thermal imager is mounted on an air platform. These airborne TIR imagers are mounted to an aircraft in gyro stabilized all weather housings. Typically, they are remote controlled and are either alone or paired with a CCD

TV camera and a Laser range finder. Primarily, these systems are used by defence and law enforcement agencies and electronic news gathering teams.

Instead of CCD sensors, most thermal imaging cameras use CMOS Focal Plane Array (FPA) sensors. The most common types are made of materials like InSb, InGaAs, QWIP FPA. The latest sensor technologies use low cost, uncooled microbolometer FPA devices. Their spatial resolution is considerably lower than that of optical cameras, mostly 160x120 or 320x240 pixels, up to 640x512 for the most expensive models. IR Thermographic cameras are much more expensive than their visible-spectrum counterparts, and higher-end models are often export-restricted. Older bolometers or more sensitive models of sensors, such as InSB, require cryogenic cooling, usually by a miniature Stirling cycle refrigerator or liquid nitrogen.

4 IR thermography in marine applications

In 2004, loyd's Register, the world's most important ship classification and certification body, made the following prediction:"In the near future, mechanical machinery onboard vessels will also benefit from thermal imaging, especially as a pre-docking strategy to identify and target equipment and systems which need attention as well as to eliminate necessary work.". Now IR thermography can do much more and on the market there are numerous companies offering IR thermography services for marine applications [6].

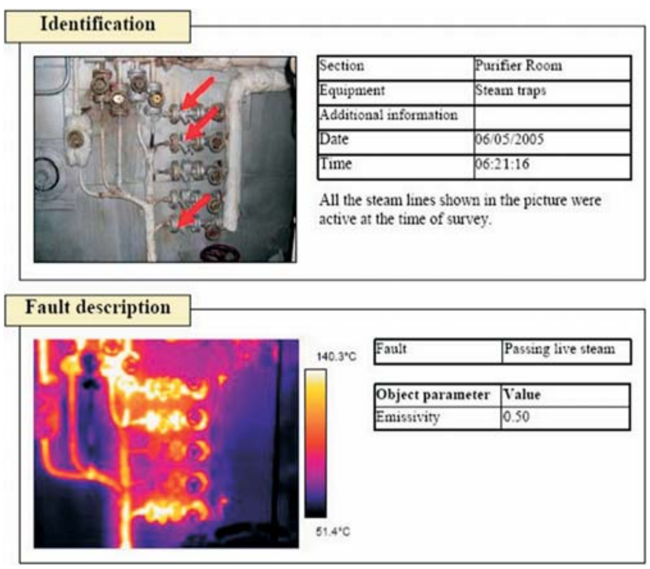
Commercial ships are rewarding objects for thermographic inspections with huge machinery, vast electrical installations, extended electronic systems that can hardly be surveyed by visual inspections. Fire prevention is an important issue and relevant prescriptions are clear. According to the International Convention for the Safety of Life at Sea (SOLAS), the maximum surface temperature of machinery, parts and components in a vessel's engine room should not rise above 220 °C. In order to avoid the ignition and fire development, all surfaces above 220 °C are to be insulated or otherwise protected.

Statistics show that the majority of engine room fires are caused by ruptured fuel or oil pipes which eventually spray fuel/oil on adjacent hot surfaces. This does not happen often, but an engine room fire will have severe and costly consequences for the ship and its cargo, its crew and the shipping company. Smaller deficiencies are numerous, and the piping or cable insulation, as required by the SOLAS rules, often appears to be missing. As engines become more complex and get steered by a growing number of electrical or electronic components, the need for regular inspection and maintenance rises. IR thermography has the advantage of being a non-contact inspection and measurement tool able to display and store exact temperature values as well as visual evidence. Moreover, time-saving becomes an important asset in the shipping business as required inspections have to be done at a fast pace. When something happens to the engines or to other vital installations, the losses by far exceed the investment in such a convincing, time-saving and hence affordable inspection tool as an infrared camera.

Moreover, thermographic inspections with an infrared camera (Figure 6) will instantly show the thermal condition of electrical circuits, electronic systems and other installations and parts onboard. In more general terms, infrared cameras allow fast and secure inspections in line with the tight scheduling in the maritime trade. Sooner or later, all electrical installations will, by nature, develop faults. On board ships, these faults can be attributed to vibrations and to poor quality maintenance by crew and/or shipyard repairs, but may also be attributed to incorrect installation. By utilising the thermographic scanning process, these potential failure areas can be discovered before they become a hazard. Thermography can be used in all types of electrical installations, i.e. fuses, contacts, circuit boards, cable runs and other electrical components. Typical areas for scanning are: switch boards in engine control rooms, emergency generators, galleys, laundries, accommodation fans/air conditioners, lifts, bridge consoles, thrusters, light and power distributors, etc. Thermographic scans of electrical installations are possible while systems are operative, without causing costly downtime. In nearly all cases, this form of troubleshooting is extremely cost effective and in some critical situations, the only method available. For commercial and technical managers, this will avoid additional costs associated with potential fires and/or shutdowns of a large electrical system.

Figure 6 **Using a hand held thermovision camera on board ship**
Slika 6 **Uporaba ručne termovizijske kamere na razvodnoj ploči broda**

Figure 7 **Example page of thermography report (SeaTec)**
Slika 7 **Primjer stranice termografskog izvješća (SeaTec)**



Identification

Section	Purifier Room
Equipment	Steam traps
Additional information	
Date	06/05/2005
Time	06:21:16

All the steam lines shown in the picture were active at the time of survey.

Fault description

140.3°C

51.4°C

Fault	Passing live steam

Object parameter	Value
Emissivity	0.50

Thermography offers the advantage of not interfering with the vessel's operation. Engines must work at their normal loads and temperatures for good inspection conditions. A three to four hour trip at full speed and in full load condition is ideal to get a clear picture of the ship's electrical and propulsion systems. An example of thermography report is presented in Figure 7.

Severity criteria clearly define the ship engine room maximum temperature at 220 °C. Based on this threshold, thermographers utilize a set of severity criteria [7]:

Severity 0: OK (measured temp. < 210.0 °C)

Severity 1: to be monitored (210.0 °C < [measured temp.] < 220.0 °C)

Severity 2: unacceptable deviation (measured temp. > 220.0 °C)

However, severity criteria are void without careful observation and knowledge of the ship's engines. If there is some oil-piping right next to a spot detected as a class 1 spot, the thermographer gives it immediate repair status and upgrades it to Severity 2.

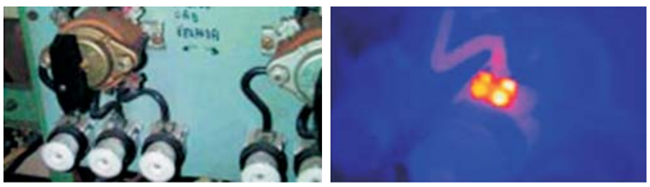
Some results of a thermography inspection done on a passenger ship are presented to illustrate this. The thermography inspection was carried out during the vessel's sea trials by a certified operator from Thermo-protection Ltd, Fredrikstad, Norway (Figures 8 and 9).

digital photo *thermal image*

Location: Engine room
Equipment: Main engines nos. 1–4
Status: Engine parts>220 °C
Date: 13.06.2002
Time: 10:24:42

Maximum temperature: 329 °C
Normal temperature: 204 °C
Temperature difference: 125 °C

Figure 8 **Main engine exhaust**
Slika 8 **Ispuh glavnog motora**



digital photo *thermal image*

Location: Emergency switchboard
Equipment: E-Heizung KL W5
Date: 13.06.2002
Time: 14:54:56

Maximum temperature: 156 °C
Normal temperature: 49 °C
Temperature difference: 107 °C
Category of fault A

Figure 9 **Electrical switchboard**
Slika 9 **Električna razvodna ploča**

Global Switchgear Services Limited uses the versatility of thermal imaging to carry out electrical and mechanical inspections of marine and industrial equipment (Figures 10 to 12). The company has a wide variety of customers including: commercial and royal navy shipping; nuclear, coal, oil, gas and hydro energy industries; pumped storage; rail and heavy industry such as steel mills. Global can quickly identify areas of potential concern that if left undetected could cause damage, fires or be potentially life threatening.

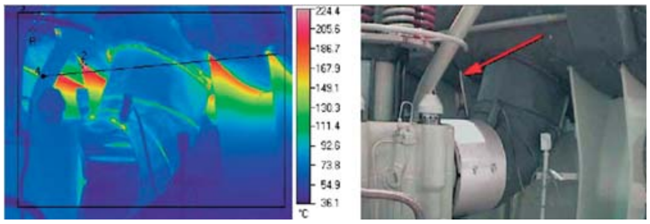


Figure 10 **Thermal and digital image of the ship engine exhaust**
Slika 10 **Toplinska i digitalna slika ispuha brodskog motora**

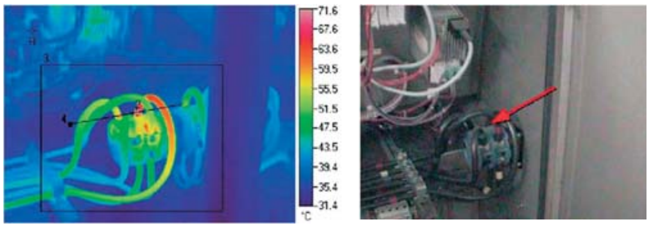


Figure 11 **Thermal image showing that there is poor connection on the main switch insulator**
Slika 11 **Toplinska slika pokazuje da je slaba veza na izolatoru glavnog prekidača**

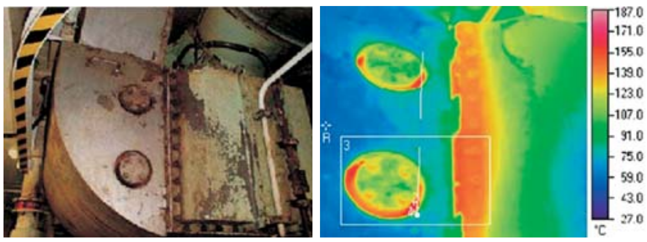


Figure 12 **Thermal image of the main engine charge air cooler showing hot spots on seals**
Slika 12 **Toplinska slika hladnjaka glavnog motora pokazuje vruća mjesta na brtvama**

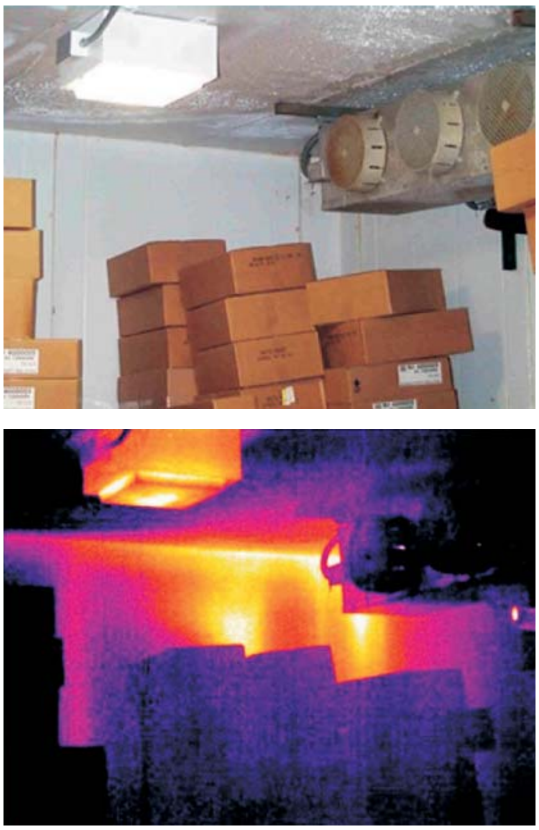
A specialty of Thermowind, a Germany company, is yacht inspection, particularly the search for delamination on the yacht's fibreglass reinforced plastic (FRP) or composite wood-FRP hulls. Delaminations can lead to harmful moisture accumulation within the vessel, which destroys the material and the wooden core of the hull.

The non-destructive nature of thermal imaging was found to be a good tool for yacht service and repair facilities. One of such surveys revealed cracks in both the port and starboard torque boxes in the engine room of a 13.1 m (43-foot) yacht ('PERSISTENCE') [8]. The detection of cracks and their depths was of vital importance in assessing the seaworthiness of the vessel. The information allows the repair facility to give a more comprehensive and accurate estimate as to the cost of repairs, and it also provides the boat owner with visual documentation as to the extent of the damage. In the paper [b], the authors explained the procedures used for determining the presence of cracks, their location with respect to critical areas, and the depth of these fractures in relation to the extent of the damage.

Thermography finds its largest marine application on cargo ships. Typical applications of thermography on cargo ships are not entirely different from those on land-based facilities. The most common application is the electrical system survey A typical electrical survey on a ship would cover such items as switchboards, motor controllers, circuit breaker panels and major junction box connections on motors and generators. There are also typical mechanical surveys performed aboard ships for bearings, shaft alignment, steam lines and steam traps. Many of these mechanical surveys would again not be very different from a common land-based survey.

When it comes to cargo surveys, if there are differences in surface temperatures, a trained operator can interpret thermal patterns. This is helpful in dealing with moisture problems in bulk cargoes. As moisture migrates to the cargo surface, creating temperature differences or only slight evaporation of water, a trained operator will spot the thermal pattern. Deterioration of hold insulation can cause great problems when reefer vessels trade in warm areas; the condition of the insulation of reefer holds or freon and brine piping can be verified by using thermography. When claims arise due to cargo temperature problems during discharge, a thermographer can be of great help. From a thermal pattern of cargo pallets inside the holds or inside the reefer containers, a thermographer can locate the source of the problems [9].

Figure 13 **Early detection of engine / equipment failures on cargo ship using thermography**
Slika 13 **Rano otkrivanje kvarova motora/opreme na teretnom brodu uporabom termografije**



Brodarski institute, Marine Research & Special Technologies, have used modern thermography equipment (FLIR P65) and the appropirate software for the measuring and analysis of electrical and mechanical systems in marine applications [10]. IR thermography relating to other NDT methods can solve various problems.

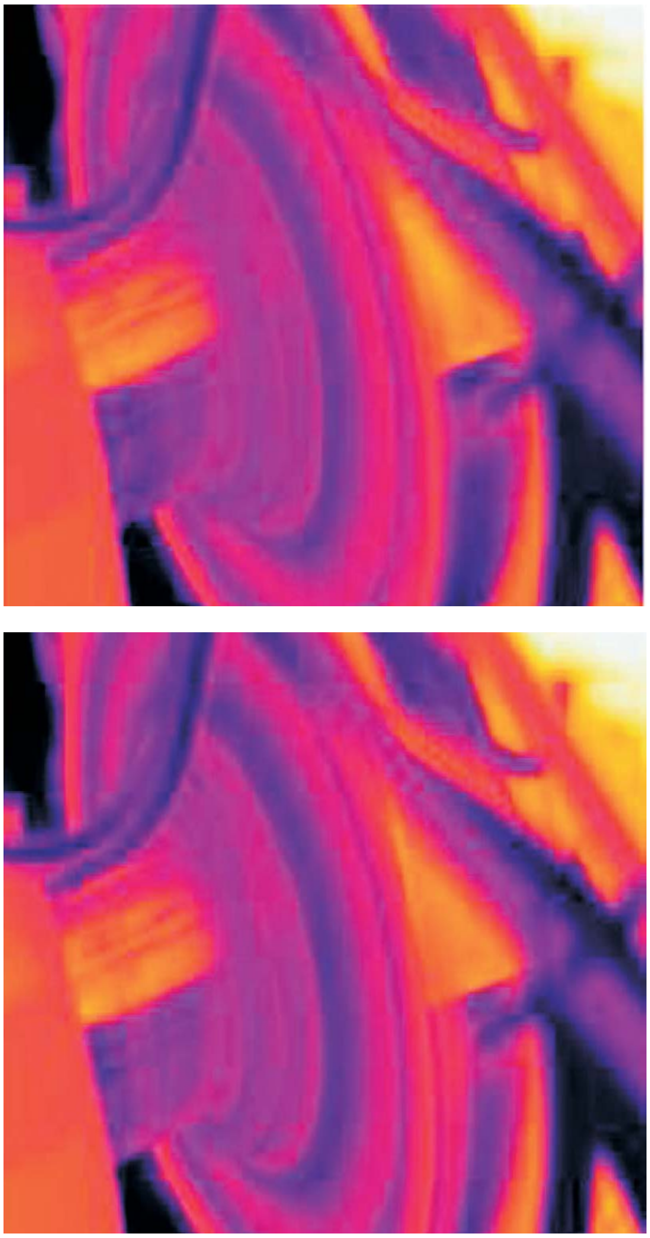


Figure 14 **Example of dynamic investigation of a ship's engine (*Brodarski institute*)**
Slika 14 **Primjer dinamičkog ispitivanja brodskog motora (*Brodarski institut*)**

Thermovisions are used for maritime navigation, search and rescue, and security applications. With thermovision navigators have the ability to see in total darkness, through light fog, and smoke.

Visible image *Thermal image*

Figure 15 **Example of thermovision using for navigation, [11]**
Slika 15 **Primjer uporabe termovizije u navigaciji, [11]**

One of the main tasks in the ecological monitoring of the seas is an operational satellite and aerial detection of oil spillages, determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport. There are several airborne remote sensors for application to oil spill detection and assessment. A common sensor is an IR radiometer or an IR/ultraviolet (UV) system. This sensor class can detect oil under a variety of conditions, discriminate oil from some backgrounds and has the lowest cost of any sensor. UV/IR-scanner together with standard remote sensing equipment like Side Looking Airborne Radar (SLAR), photocameras, Imaging Airborne Laser Fluorosensor (IALFS) and Microwave Radiometer (MWR) are available and has been used during routine plain flight [12].

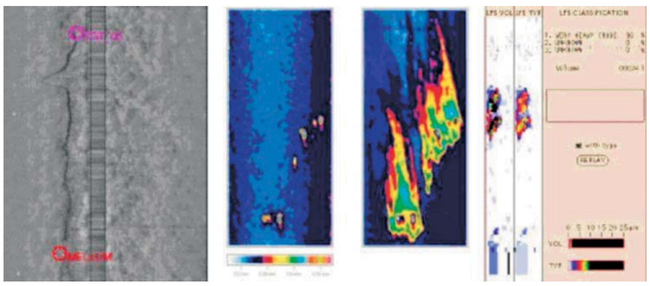


Figure 16 **From left to right: SLAR with oil-slick, MWR, IR and LFS information. [12]**
Slika 16 **Od lijeva na desno: SLAR, MWR, IR i LSF podaci s naftnom mrljom. [12]**

5 Conclusion

IR thermography is a mature and widely accepted maintenance technology. Thermography is increasingly used in marine applications for engineering inspection of electrical and mechanical systems of ships and stationary and mobile marine systems. In addition, IR thermography can be used to monitor the quality of the sea water surfaces and to detect any pollution or hazardous materials.

In addition to saving money and increasing uptime, IR thermography can play a major role in maintaining the safety and reliability of marine facilities where a system failure could lead to the loss of a vessel or its crew.

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