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Making Infrared spectrum visible with infrared cameras: Advantages and applications

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Abstract *As a general physical rule, every system produces heat as the part of losses during the operation. The basic problem in engineering is the method and technique to detect the heat of the system and especially on specific points.*
On early years the heat control and measurement was accomplished with the use of thermal detectors placed on carefully sellected points of the system. Any inspection and estimation is limited around these local points without knowing what happens to every point of the system. This is sometimes unreliable or very complex during testing to estimate the behavior of the system.
The problem has been overcome last years by the development of infrared (IR) cameras. An IR camera is a useful tool for modern applications because we have images of the system produced by the distribution of heat on the surface. For the first time the heat becomes visible. We can see all the points of a system and measure its temperature point by point and detect any thermal stress. Thermal test and control becomes precise and reliable with thermal imaging and each part of the system acquires its own thermal identity.

Keywords: Infrared (IR) camera, thermal imaging, infrared thermography, IR sensor, IR spectrum, microbolometer, photoconductive, photovoltaic, QWIP, MCT

1. Introduction

1.1 Background

Till the very late of last century, the mid of last decade, technology for thermal testing was limited in thermal sensors attached to a system for measuring temperature and controlling its state during operation. The sensors, depending on the operating temperature of the system, were mainly PTC or NTC thermistors, thermocouples, thermal switches, temperature sensors built on IC's etc, with the attribute to change their resistance, to develop a small voltage, to activate a switch or to develop a precise output voltage respectively.
All methods based on the above sensors were localized on a narrow region around the sensor and the disadvantage was the special study of the system to allocate the points of interest to establish sensors and possibly more than one for a reliable and safe thermal testing. Besides that all the testing took place in systems with dimensions from a few cm^3 but not less than 1 cm^3. So thermal analysis was more complicated and mostly it was a practical approach to the real behavior of temperature distribution of thermal sources.
Another serious disadvantage when testing lets say an electronic printed circuit board (pcb) is the absence of real time thermal activity appearance of all the parts on pcb, as they are hundreds. This reduces the factor for fast and effective redesign.
All the above sensors must keep in contact with the body of the system, so limiting controlling and inspection on embedded systems only.

1.2 Blackbody theory and Infrared spectrum

All bodies radiate energy proportional to their absolute temperature, including all wavelengths. Most energy is concentrated around a narrow band extending from 0.3μm to about 20μm and a small fraction from 0.4μm to 0.7μm is the visible region of radiation. Radiation extending beyond 0.7 μm is in infrared region, invisible for human eyes. Black body energy density follows Wien – Planck Law (formula 1) as a function of wavelength λ (in meters) and absolute temperature T (in ^{0}K), where C_1 is the first radiation constant = $3.7415*10^{-16}$ watt/m^2, C_2 is the second radiation constant = $1.43879*10^2$m K. This function is plotted in fig. 1. As it is seen maximum energy radiated from blackbody shifts to shorter wavelengths by

increasing the temperature. The value of that wavelength λ_m is given by Wien's Displacement Law (formula 2)

$$J_{\lambda T} d\lambda = C_1 \lambda^{-5} \left(e^{C_2/\lambda T} - 1 \right)^{-1} d\lambda \quad (1)$$

$$\lambda_m T = b \quad (2)$$

where b = 2.8978*10^{-3} m K. Blackbody is an ideal concept but bodies of real world behave somewhat like it. Science and technology for many decades made a great effort to develop detectors sensitive to the infrared spectrum for detecting IR radiation. The interest was that with such a detector one can receive IR radiation from a distance, like any other kind of electromagnetic receivers. IR thermometers (IRT) were made about forty years ago and they are used up to now in many applications. An IRT measures temperature of a body or of a small area of it, depending on optics, from a distance of some meters to kilometers. IR sensors used on IRT are thermal (thermopiles, thermistor bolometer), photon (photoconductive, photovoltaic), pyroelectric.

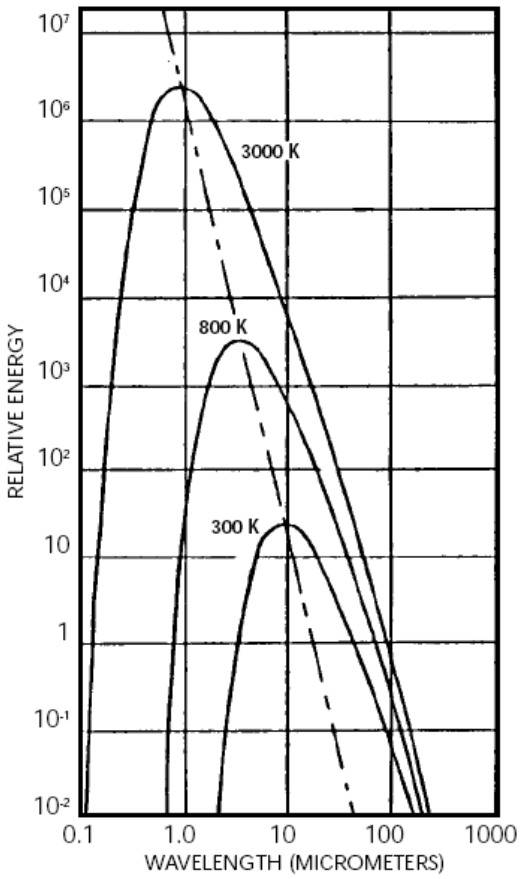


Fig.1: Radiation intensity as a function of wavelength and temperature (Planck's Law)

2 The IR Camera

2.1 Technology and advantages

Infrared camera (IRC) or thermal imaging camera (TIC) is a non-contact device that detects infrared energy (heat) of an area of a body – the field of view (FOV) - and converts it into an electronic signal, which is then processed to produce a thermal image on a video monitor and perform temperature calculations. Heat sensed by an infrared camera can be very precisely quantified, or measured, allowing you to not only monitor thermal performance, but also identify and evaluate the relative severity of heat-related problems. IR cameras appeared widely on the market on the last fifteen years. The mass production of IR cameras was based on the following recent innovations:

- The IR sensor development with increased signal to noise (S/N) ratio, better sensitivity, wide spectral response,
- better fabrication with smaller pixel size and more pixel density for linear arrays and camera Focal Plane Arrays (FPA)
- the great development and experience in Digital Signal Processing (DSP)
- suitably designed and dedicated IC's for DSP
- the advanced algorithms and software support for signal analysis of thermal cameras (Infrared Thermography)
- the advanced cooling systems
- more cost-effective thermal analysis solutions
- the attractive price

They are selected by application needs and divided in four types depending on the region of IR spectrum response. The detectors - photovoltaic or photoconductive - differ accordingly.

- Near Infrared (NIR) camera (0.7 to 1.0 μm) with detectors based on Indium-Gallium-Arsenide (InGaAs), Si material technology
- Short Wave IR (SWIR) camera (1.0 to 3.0μm) with detectors based on Indium-Gallium-Arsenide (InGaAs), InAs, PbS material technology
- Middle Wave IR (MWIR) camera (3.0 to 8.0μm) with detectors based on Indium-Antimonide (InSb), PbSe material or QWIP (Quantum Well Infrared Photodetector)
- Long Wave IR (LWIR) camera (8.0 to 20μm) with detectors based on Barium-Strontium-Titanate, on MCT (Mercury Cadmium Tellurid) material and microbolometer.

All these detectors can achieve outstanding sensitivity of less than 20 mK even at the highest frame rates of IRC. LWIR cameras are made mostly having a cooling system (a liquid nitrogen pump) with temperature down to -196^{o} C and MWIR can have a thermoelectric cooler too, for better sensitivity and lower thermal noise. The detector is responsible for thermal noise, so it is attached to the cooler to keep it in a lower temperature than rest of the system.

IR camera signal depends on point-to-point temperature of the object to be focused. With the help of advanced IR (or thermal imaging) techniques based on novel algorithms and software support, one can visualize and / or filter this signal which is turned in blue to red image from lower to higher temperature respectively. IRC is better if it has a higher definition (resolution), e.g. 640*512 pixels. High definition thermal imaging refers to the fine detail and clarity of a thermal image. It contains a large number of pixels per unit of area. In this case, with a TIC high definition photo one is capable to find significant problems that could be missed with a lower resolution TIC or to focus on smaller problems at greater distances, or can resolve greater detail with smaller targets, while still looking at the larger picture. More pixels mean greater temperature measurement accuracy, particularly for small objects. Thermal systems can measure very small targets, smaller than 7 microns with the help of an IR microscope. Even if you knew where a hot spot was on something this small, you couldn't measure it with a thermocouple, since the heat would sink away.

Infrared Thermography is the method to detect, analyse, estimate, measure temperature and recognise thermal problems from a thermal imaging photo. It is helping to verify thermal performance, detect and quantify thermal problems with precise non-contact temperature measurements, and document them automatically in seconds with professional easy-to-create IR reports. It is of primary importance to select an IRC which responds to thermal range for the respective application. Parameters chosen on thermal applications with IRC and thermography suite software program must be carefully established for better system performance. All these attributes establish a device with great advantages and make IRC an important tool for testing, inspection, controlling, manufacturing, research, diagnosis and much more.

2.2 Applications

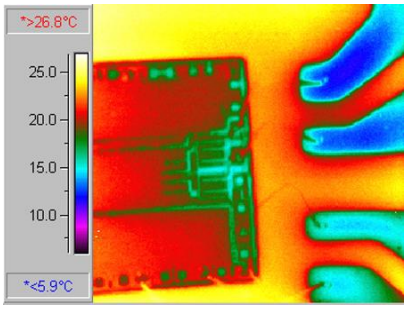
A wide field of applications is based on IRC like non destructive testing, mechanical maintenance and control, electrical and electronic systems, manufacturing, in industry and production, on buildings, agriculture, automotive, medical, biological, military, aerospace, plastics, paper, metals, chemical, food, pharmaceutical, ovens and driers, semiconductor, glass, spectral emissivity, research, target signature analysis, machine vision, scientific imaging, underground leaks, insulation surveys, etc.

Nearly everything that uses or transmits power gets hot before it fails. Cost effective power management is critical to maintaining the reliability of electrical and mechanical systems. And today, infrared thermography is the most effective proven predictive maintenance technology available to quickly, accurately and safely locate problems prior to failure. Finding and fixing a poor electrical connection before a component fails can save you the much greater costs associated with manufacturing downtime, production losses, power outages, fires and catastrophic failures. A high definition thermal imager is ideal e.g. to be used from a distance on substations, switchyard, transmission and distribution lines and improves worker safety. Picture 1 a) shows a thermal photo from a relaxed bolted connection of electric power line which could lead to an overheating, burning and open circuit problem.

Picture 1 b) shows a PCB thermal image with an overheating component which is located very quickly on testing procedure.

Internal observation of Integrated Circuit (IC) chip and of silicone wafer is possible by using a high resolution and high S/N ratio NIR camera which use an infrared microscope. The inside of semiconductor devices is observed using infrared illumination, which passes through silicon. IC internal inspection system can observe condition of metal wiring inside IC, wire bonding, and die bonding, and is the best for the analysis of a flip chip. Wafer complete observation type can observe the voids of bonded wafers, and cracks, internal defects of wafer. Picture 2 shows a thermal image of a microcircuit showing 7 micron leads. Faults even smaller than 7 microns can be detected.

Picture 1: a) Bolted connection problem b) PC board with overheating component.
(Photos from Image Gallery of FLIR Systems)



Picture 2: Thermal image of a microcircuit showing 7 micron leads.
(Photo from Image Gallery of FLIR Systems)

On all pictures a remarkable notice must be given on temperature window with predetermined temperature lower and higher limits that can satisfy the working and specification limits of material or component. It's of primary interest to know thermal profile of every part of a system and its thermal identity for correct estimation of possible defects, otherwise a wrong alarm may happen if predetermined high risk temperature point lies on normal element working temperature or catastrophic failure may occur if predetermined high risk temperature point is far away from real high risk point of element.

On production predictive maintenance and Non Destructive Testing (NDT) techniques, companies making high voltage and high power transformers for Electric Power Stations and substations, test transformers measuring heat and checking heat distribution on these with the help of heat thermography and an IRC. Sometimes an electrician needs to know the defects caused by an unbalanced load on a three phase electrical system or an overloaded line or a loosing screw with a band connection, especially on fuses and switches in electrical power panels, before it fails and the only quick and reliable method for it is an IRC that helps remotely measure and react on a possible thermal problem. In motion control overheating of an electrical power motor is very important during overload conditions. With an IRC a severe damage can be avoided drastically and suitable manipulations on load requirements take place for safe and long lasting of motor health.

Another important application field for IRC is on fire fighting where an invisible man or object can be seen with IRC through the smoke. Warm objects, animals and humans can be seen during night with LWIR cameras.

In agricultural applications single seeds or bulk samples of seeds can be measured. FT-NIR can be used to determine moisture, protein, oil in a wide range of seed grains, beans etc or analyze various components such as protein, fat, moisture, fiber etc in meat, cheese and animal feeds.

3 Conclusion

IR Camera thermal Imaging, IR thermography and the wide field of applications is a revolutionary scientific and technical approach on today's natural and technical world. It promises more safety, easy way for establishing IRC and software suite on computers, can be stand alone or be configured as a network – LAN, WAN, etc - for systems or whole industries management and maintenance. The only we need is to spread its use everywhere, to be familiar with it, and continue research on IRC for expanding applications. A combination of IRC with visible cameras or IR laser spot light promises the best solution for many applications on targeting, recognition, control, safety and surveillance.

References

1. J. C. Richmond and D. P. DeWitt, eds., *Applications of Radiation Thermometry* (American Society for Testing and Materials, Philadelphia, 1985).
2. H. Preston-Thomas, "The International Temperature Scale of 1990 (ITS-90)," Metrologia 27, 3-10 (1990).
3. http://www.flirthermography.com
4. http://www.hamamatsu.com
5. http://www.photonics.com
6. http://www.ircameras.com
7. http://www.mikroninfrared.com
8. http://www.brukeroptics.com
9. Photonics Spectra Volume 41 Issue 4 April 2007: "Infrared Imaging: The Short and the Long of It"