Infrared Thermography-A Review

Rajesh Singh Shekhawat
Research scholar, IIET, Kurukshetra University, Kurukshetra, INDIA

Abstract— *In this paper present a various application of Thermography in various fields like industrial, scientific, and medical applications. With the development of infrared camera infrared Thermography is a major area of research. It is also used for conditioning, monitoring, maintenance and various applications in research and development. Infrared thermal-imaging cameras can be used to detect loss of heat in insulated systems, detect overheating of electrical apparatus, Military and civilian purposes. Thermal imaging is non-contact two-dimensional and three-dimensional tool but it is also use for heat transfer, analysis of thermal properties, testing, diagnosis of diseases etc. Application of infrared radiation is measure the temperature of objects from safe distance. Thermography makes it possible to see everything in environment with or without visible light. The radiation emitted by a body increases with temperature; therefore Thermography allows one to see variations in temperature.*

Keywords—*Infrared radiation, temperature, visible light, Thermal Properties, 2-D Imaging, 3-D Imaging. Thermography,*

I. INTRODUCTION

Infrared thermography is utilized for various purposes such as fault detection of power equipment and observing body temperature of humans and animals. Recently, a lot of work has been done to combine state-of-the art computer vision techniques with the thermal imaging.

The subjects of infrared and related techniques of thermography are still new to every researcher. New research is going on with Smartphone attachable thermal imaging devices.

However, the resolution and the field of view of the thermal cameras are limited and it is difficult to monitor large machines and large areas. Since the cost of these devices is also high, it is difficult to cover large surface. Analysis with the low resolution camera image is also difficult.

II. HISTORY OF THERMOGRAPHY

The infrared as it is often called heat radiation, it discovered by Sir William Herschel (1738-1822) in 1800. Sir William Herschel was searching a new optical material but this discovery was an accident. During this experiment he was find a single material which have a property reduction in brightness and the maximum reduction in heat [1][2]. Italian researcher Marsilio Landiani (1746-1815) had observed much same effect in 1777. It was not Herschel who originated term infrared.

Macedonio Melloni(1798-1854) discovered the naturally occurring rock salt (NaCl) which was available in the form of huge natural crystals to be realised in lenses and prisms is exceptionally transparent to the infrared (rock become a principal infrared optical material). Heat picture became practically realisable in 1840, the result of work by Sir John Herschel. The thermal image on paper, which is called thermograph.[4]

Another milestone created by Samuel P. Landley (1834-1906) in 1880 was inventing the bolometer. An English scientist, Sir James Dewar, introduced the use of liquefied gases as cooling agents in low temperature research. From 1900 to 1920, some inventors of the world discovered the term "infrared". Modern sense of infrared began to be developed during world War-I. Middle of the 1950s and form that time adequate thermal imaging devices finally began to be available to civilians and industry.

Gustav Kirchhoff [1860] formulated the blackbody theorem . Willoughby Smith [1873] discovered the photoconductivity of selenium. Stefan-Boltzmann [1879] law formulated empirically that the power radiation by a blackbody is directly proportional to T^4. Lord Rayleigh and Wilhelm Wien [1880s & 1890s] solved small part of the blackbody equation; Max Planck [1901] published the blackbody equation and theorem. Quantizing the allowable energy transitions problem is solved by Max Planck. Albert Einstein [1905] discovers the theory of the photoelectric effect. Theodore Case [1917] developed the thallous sulfide detector; the first infrared search and track (IRST) device construct by British scientist which is able to detect aircraft in one kilometer range.

In 1935 Lead salts – early missile guidance in World War II. Teau Ta[1938] – predicted that the pyroelectric effect could be used to detect infrared radiation. The Zielgerät [1945] infrared weapon system "Vampir" is indeed the first portable infrared device for military applications. H. Welker [1952] grew synthetic InSb crystals. In [1950s] Honeywell and Texas Instruments indicated infrared images. Nomenclature and radiometric units as termed by Fred Nicodemenus, G.J. Zissis and R. Clark; Robert Clark Jones [1950s and 1960s] defined *D*. W.D. Lawson [1958] discovered IR detection properties of HgCdTe. Falcon and Sidewinder [1958] missiles were developed using infrared technology. J.

Cooper [1961] demonstrated pyroelectric detection. W.G. Evans [1964] discovered infrared thermoreceptors in a pyrophile beetle[6].

First IR Handbook[1965] first general purpose imagers (FLIR Systems Inc.); phenomenology evolved by Fred Simmons and A.T. Stair, U.S. Army's night vision lab formed NVESD (Night Vision and Electronic Sensors Directorate), and Rachets discover detection, recognition and identification modelling. Willard Boyle and George E. Smith [1970] proposed CCD at Bell Labs for picture phone.

In [1972] Common module program started by NVESD. In [1978] Infrared imaging astronomy, observatories planned; IRTF on Mauna Kea opened; 32 by 32 and 64 by 64 arrays discover using InSb, HgCdTe and other materials. On February 14, 2013 researchers[7] developed a neural implant that provides rats the ability to sense infrared light.

III. Theory of Thermography

A. *The Electromagnetic Spectrum*

Electromagnetic spectrum is different regions. These are (i) Radio waves, (ii) Microwaves, (iii) Infrared, (iv) Visible light, (v) Ultraviolet, (vi) X-rays and (vii) Gamma rays. Each region of the EM spectrum has a different wavelength and frequency. The EM spectrum is the range of all types of EM radiation. Radiation is energy that travels and spreads out as it goes. Thermography falls under infrared spectral band. At the short-wavelength end of the spectrum, the boundary lies at the limit of visual perception, in the blood-red zone. At the long-wavelength end of the spectrum it merges with the microwave radio wavelengths falling in the millimetre range.

The infrared band is also divided into four smaller bands, the boundaries of which are also arbitrarily.

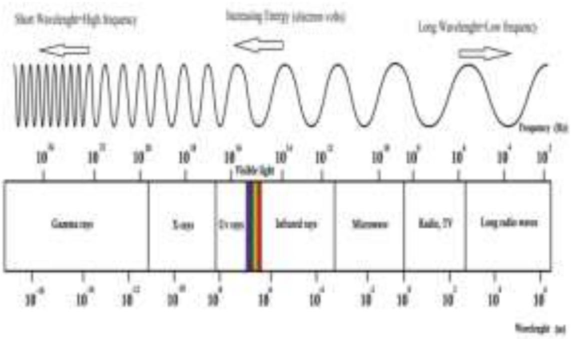

Fig 1 Electromagnetic Spectrum

B. *Infrared Band*

The size of infrared region is approximately 0.8 µm to 1000 µm, which is start from visible light and end at the microwaves. Complete infrared range of the electromagnetic spectrum is not useful in Infrared technology (IRT), because it is blocked by the atmosphere. The some portions define the usable part of the infrared by IRT (i) NIR- Near-infrared from 0.8 µm to 1.7 µm. (ii) SWIR- Short-wavelength infrared from 1 µm to 2.5 µm. (iii) MWIR- Mid-wavelength infrared from 2 µm to 5 µm. (iv) LWIR- Long wavelength infrared from 8 µm to 14 µm. (v) VLWIR- Very-long wavelength infrared 12 to about 30 µm, covered by doped silicon. Out of all of these regions, MWIR and LWIR fall under the most commonly used types of in IRT. There are two reasons: (i) the band of peak emissions and (ii) atmospheric transmittance.

C. *Principle of Thermography*

Infrared imaging technology used in real time measurement of two dimension of surface temperature field. A camera, data acquisition and processing computer are used in infrared thermography. The infrared camera detects energy emitted by the object and convert into electrical signal. All objects above absolute zero temperature emit a radiation which is directly proportional to surface temperature. The energy detect by camera depends upon emissivity coefficient of the surface under measurement. This technology based upon Stefan-Boltzmann law:

$$E_b = \sigma T^4 \text{Watt/m}^2 \quad (1)$$

Where E_b =Blackbody hemispherical emission; σ =The Stefan-Boltzmann constant; T= Absolute temperature.

Real bodies don't exactly obey this blackbody law. A real body emits only a fraction of radiation emitted by a blackbody at the same temperature and at same wavelength and hence a correction factor (ε) must be included in the above equation:

$$E = \varepsilon \sigma T^4 \text{Watt/m}^2 \quad (2)$$

Where ε = Object surface Emissivity. This sates that the total emissive power proportion to the value of ε from the gray body.[14]

IV. Temperature Measurement Formula

Total Energy means energy profile when viewed through a thermal imaging camera. Emitted Energy generally temperature intended to be measured. Transmitted energy means Energy that passes through the object from a remote thermal source. Reflected energy means the total amount of energy that is reflected off from the surface of the object from a remotely located thermal source.

In the physical parameters temperature is one of the easily and accurately measured physical quantities. Temperature measurement provides details regarding the object's internal as well as external energy, so its regulation and monitoring is of paramount importance in many industrial processes [8]. Temperature measurement with the help of IRT, measures the infrared radiations radiated by an object and transforms the energy measured into a temperature value. However, as not all of the radiation received comes from the target device, to measure temperature with utmost efficiency, radiations from other sources (such as surrounding objects or the environment) must be eliminated during the conversion to temperature. This process is called compensation. The total radiation detected by the camera (W_{tot}) is generated from three sources: the emission of the target object (E_{obj}), the emissions from the surrounding environment and rebounded by the object (E_{refl}) and the emissions by the atmosphere (E_{atm}). It can be determined as Equation (3). The process is illustrated in Figure 2.

$$W_{tot} = E_{obj} + E_{refl} + E_{atm} \qquad (3)$$

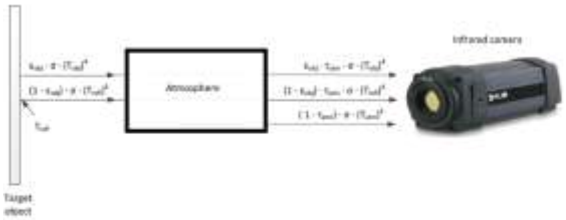

Fig 2 Radiation received by the infrared camera

The first source is the emission from the target object. However, not all radiation released by the target object is detected by the camera; as a function of the transmittance of the atmosphere (τ_{atm}), some of the radiations are absorbed by the atmosphere. Thus, the emission of the target object can be expressed as Equation (4).

$$E_{obj} = \varepsilon_{obj}.\tau_{atm}.\sigma.(T_{obj})^4 \qquad (4)$$

Grey bodies have a reflectivity greater than zero. Thus, they reflect the infrared radiation released by the surroundings. The reflectivity can be calculated from the emissivity$\{\rho_\lambda = (1-\varepsilon_\lambda)\}$. Some part of this reflected radiation is also absorbed by the atmosphere. This is the second component detected by the camera and can be expressed as Equation (5).

$$E_{refl} = \rho_{obj}.\tau_{atm}.\sigma.(T_{refl})^4 = (1-\varepsilon_{obj}).\tau_{atm}.\sigma.(T_{refl})^4 \qquad (5)$$

The third component is the emission of infrared radiation from the atmosphere. This can be exhibited as Equation (6), where (τ_{atm}) is the emittance of the atmosphere.

$$E_{atm} = \varepsilon_{atm}.\sigma.(T_{atm})^4 = (1-\tau_{atm}).\sigma.(T_{atm})^4 \qquad (6)$$

Substituting Equations (4)–(6) in (3), Equation (7) is obtained. Therefore, the temperature of the object can be figured out from Equation (8). Similar equations are used by various camera manufacturing firms to perform temperature measurements [9, 10].

$$W_{tot} = \varepsilon_{obj}.\tau_{atm}.\sigma.(T_{obj})^4 + (1-\varepsilon_{obj}).\tau_{atm}.\sigma.(T_{refl})^4 + (1-\tau_{atm}).\sigma.(T_{atm})^4 \qquad (7)$$

$$T_{obj} = \sqrt[4]{\frac{W_{tot} - (1-\varepsilon_{obj}).\tau_{atm}.\sigma.(T_{refl})^4 - (1-\tau_{atm}).\sigma.(T_{atm})^4}{\varepsilon_{obj}.\tau_{atm}.\sigma}} \qquad (8)$$

In order to solve Equation (16), the following parameters must be supplied: the emissivity of the object (ε_{obj}), the throw back or the reflected temperature (T_{refl}), the transmittance of the surrounding atmosphere (T_{atm}) and the temperature of the atmosphere (T_{atm}).

The transfer emittance of the atmosphere is generally estimated using the distance from the object to the camera and the relative nature of the atmosphere. In general, this value is very close to one. The temperature is measured by using thermometer. However, as the emittance of the atmosphere is very close to zero $(1-\tau_{atm})$, this parameter has some effect on the temperature measurement. On the other hand, the emissivity of the object and the reflected temperature has a very high influence on the temperature measurement and must be measured very accurately.[15]

V. APPLICATION

The primary use for infrared thermography is for predictive maintenance. With this area there are many categories of problems: high electrical maintenance, Hot spot caused by inductive current, open circuit. In the electrical equipments due to high electrical resistance problem is generate that can be identified by using a camera. Power is calculated as ($P = I^2R$). When the resistance is high the power dissipated will be high. For example failures that might be detected with thermal imaging include overheated, bad connections, oxidation on switches and insulation defect. In the low voltage equipments IRT is used detect poor connections, high resistance connections, internal fuse damage, internal circuit breaker faults, internal damage, corroded connections

In the mechanical equipment and installation monitoring problems can be detected, such as overheated motors, lubrication problems, misalignments, overheated motor axles, suspect rollers, overloaded pumps, etc. Typically, when mechanical components become hot and less efficient, the energy dissipated will increase. Due to faulty region temperature of equipment or systems increases rapidly. After more heat is dissipated then system is fail. Further, pipeline faults can be found out including leakage in pumps, pipes and valves, insulation breakdowns and pipe blockages.

VI. CONCLUSIONS

Based on the above study of literature, the conclusion can be put that infrared thermography can be a very useful technique in different application. An infrared camera is a single important instrument that may not only be useful in the measurement of thermal properties, examination of mechanical properties, heat transfer, but also protection of power equipments. The quantitative thermography needs precise knowledge of surface emissivity of the object.

ACKNOWLEDGMENT

This research paper was supported by B. K. Birla Institute of Engineering &Technology, Pilani. We thank to Dr. P. S. Bhatnagar from (Director, BKBIET, Pilani) who provided perceptions and expertise that assisted the research in a very precise manner.

I would also like to show our gratitude to the Dr. Shelly Garg (Principal, IIET) for sharing their pearls of intelligence with us during the course of this research. I am also immensely grateful to Mr. D. N. Yadav (HOD, IIET) and Sweety Sharma (Assiatant Professor, IIET) for their remarks on an earlier version of the manuscript.

REFERENCES

[1] *Herschel, William (1800). "Experiments on the Refrangibility of the Invisible Rays of the Sun". Philosophical Transactions of the Royal Society ofLondon 90:284–292doi:10.1098/rstl.1800.0015. JSTOR 107057*

[2] "Herschel Discovers Infrared Light". *Coolcosmos. Ipac.caltech.edu*. Retrieved 2011-11-08.

[3] Miller, *Principles of Infrared Technology* (Van Nostrand Reinhold, 1992), and Miller and Friedman, *Photonic Rules of Thumb*, 2004. ISBN 978-0-442-01210-6

[4] IR Automation Guidebook: Temperature Monitoring and Control with IR Cameras, USA, Canada and Latin America FLIR Systems Incorporated.

[5] https://en.wikipedia.org/wiki/Infrared#History_of_infrared science.

[6] Evans, W.G. (1966). "Infrared receptors in *Melanophilaacuminata* DeGeer". *Nature* **202** (4928) :211. Bibcode:1964Natur.202..211E. doi:10.1038/202211a0

[7] "Implant gives rats sixth sense for infrared light". *Wired UK*. 14 February 2013. Retrieved 14 February 2013.

[8] Michalski, L.; Eckersdorf, K.; Kucharski, J.; McGhee, J. Temperature Measurement;Wiley: West Sussex, UK, 2001.

[9] FLIR A320, FLIR A325 User's Manual; FLIR Systems: Boston, MA, USA, 2008.

[10] Liebmann, F. Infrared Target Temperature Correction System and Method. US Patent 7,661,876,16 Febuary 2010.

[11] A. Lisowska-List, S.A. Mitkowski & J. Augustyn, "Infrared technique and its application in science and engineering in the study plans of students in electrical engineering and electronic" in 2nd World Conference on Technology and Engineering Education Ljubljana, Slovenia, 5-8 September 2011

[12] Xiangyang Ju, Jean-Christophe Nebel, J. Paul Siebert, on "3D Thermography Imaging Standardization Technique for Inflammation Diagnosis" at Digital Imaging Research Centre, School of Computing & Information Systems, Kingston University Kingston upon Thames, Surrey, KT1 2EE, UK.

[13] W. E. Lorensen and H.e Cline, "Marching cubes: a high resolution 3D surface construction algorithm", ACM Computer Graphics, 21, 1987.

[14] Yasaswi V, Keerthi S, Jainab Begum S , Krishna Sravan Y, Sridhar B"Infrared Thermal Image Segmentation for Fault Detection in Electrical Circuits Using Watershed Algorithm", International Journal of Engineering Trends and Technology (IJETT), V21(9),423-429 March 2015. ISSN:2231-5381. www.ijettjournal.org. published by seventh sense research group.

[15] Infrared Thermography for Temperature Measurement and Non-Destructive Testing Rub´en Usamentiaga 1;*, Pablo Venegas 2, Jon Guerediaga 2, Laura Vega 2, Julio Molleda 1 and Francisco G. Bulnes 1 Sensors 2014, 14, 12305-12348; doi:10.3390/s140712305