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Introduction

The word 'thermal' is pertaining to heat or temperature and in thermal remote sensing, heat radiated by the imaged surface is the main source of data. Thus thermal remote sensing is defined as the branch of remote sensing that deals with the acquisition, processing and interpretation of data acquired primarily in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum. Most commonly used spectrum are the intervals from 3 to 5 µm and 8 to 14 µm, in which the atmosphere is fairly transparent and the signal is only lightly affected by atmospheric absorption (Fig. 1). In Thermal remote sensing, we are interested that how well energy is emitted from the surface at different wavelengths. Thermal remote sensing does not depend on reflected sunlight, so that it can also perform during the night.

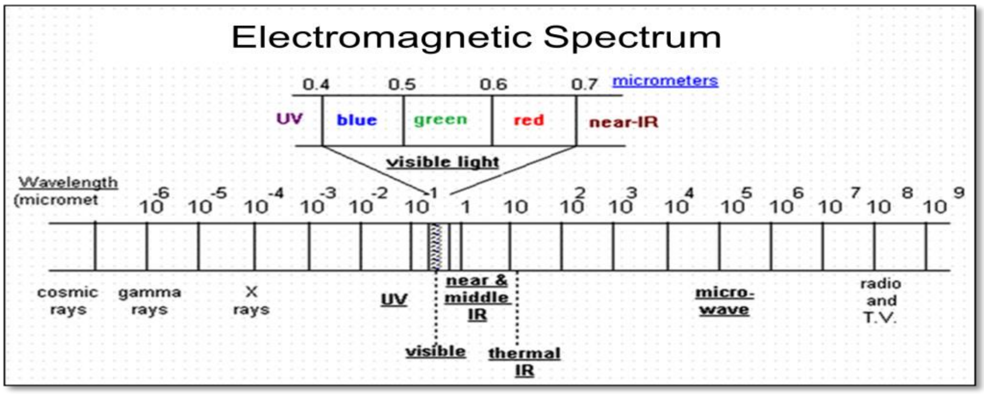


FIG. 1

It is a well-known fact that all natural targets (features) reflect as well as emit radiations. In the TIR region of the EM spectrum, the radiations emitted by the earth due to its thermal state are far more intense than the solar reflected radiations and therefore, sensors operating in this wavelength region primarily detect thermal radiative properties of the ground material. As thermal remote sensing deals with the measurement of emitted radiations, for high temperature phenomenon, the realm of thermal remote sensing broadens to encompass not only the TIR but also the short wave infrared (SWIR), near infrared (NIR) and in extreme cases even the visible region of the EM spectrum (Fig. 2).

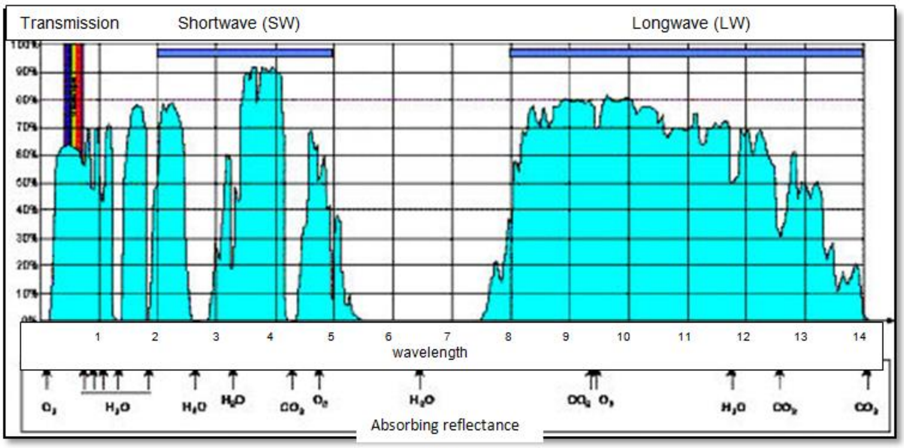


FIG. 2

Basic thermal radiation principles

Spectral Emissivity and Kinetic Temperature

In thermal remote sensing, radiations emitted by ground objects are measured for temperature estimation. These measurements give the radiant temperature of a body which depends on two factors; kinetic temperature and emissivity.

Thermal remote sensing exploits the fact that everything above absolute zero (0 K or -273.15 °C or –459 °F) emits radiation in the infrared range of the electromagnetic spectrum. How much energy is radiated, and at which wavelengths, depends on the *emissivity* of the surface and on its *kinetic temperature*.

Emissivity is the emitting ability of a real material compared to that of a black body and is a spectral property that varies with composition of material and geometric configuration of the surface. Emissivity denoted by epsilon (ε) is a ratio and varies between 0 and 1. For most natural materials, it ranges between 0.7 and 0.95 (Table 1).

Table 1: Emissivity of Common Materials

Material	Emissivity
Clear water	0.98-0.99
Wet snow	0.98-0.99
Human skin	0.97-0.99
Rough ice	0.97-0.98
Vegetation	0.96-0.99
Wet soil	0.95-0.98
Asphalt concrete	0.94-0.97
Brick	0.93-0.94
Wood	0.93-0.94
Basalt rock	0.92-0.96
Dry mineral soil	0.92-0.94
Paint	0.90-0.96
Dry vegetation	0.88-0.94
Dry snow	0.85-0.90

Kinetic temperature is the surface temperature of a body/ground and is a measure of the amount of heat energy contained in it. It is measured in different units, such as in Kelvin (K); degrees Centigrade (°C); degrees Fahrenheit (°F).

The radiant temperature calculated from the radiant energy emitted is in most cases smaller than the true, kinetic temperature (T_{kin}) that could be measure with a contact thermometer on the ground. The reason is that most objects have a Kinetic temperature emissivity lower than 1.0 and radiate incompletely. To calculate the true T_{kin} from the T_{rad} , we need to know or estimate the emissivity. The relationship between T_{kin} and T_{rad} is:

$$T_{rad} = \varepsilon^{1/4} T_{kin}$$

Concept of Black body

An object radiates unique spectral radiant flux depending on the temperature and emissivity of the object. This radiation is called thermal radiation because it mainly depends on temperature and it can be expressed in terms of 'black body' theory.

Black body is a theoretical object that absorbs and then emits all incident energy at all wavelengths. This means that the emissivity of such an object is by definition 1. However, true black-bodies do not exist in nature, although some materials (eg, clean, deep water radiating between 8 to 12µm) come very close (Fig. 3).

Materials that absorb and radiate only a certain fraction compared to a blackbody are called 'grey bodies'. The fraction is a constant for all wavelengths. Hence, a grey-body curve is identical in shape to a black-body curve, but the absolute values are lower as it does not radiate as perfectly as a black-body (Fig. 4).

A third group is the 'selective radiators'. They also radiate only a certain fraction of a black-body, but this fraction changes with wavelength. A selective radiator may radiate perfectly in some wavelengths, while acting as a very poor radiator in other wavelengths. The radiant emittance curve of a selective radiator can then also look quite different from a ideal, black-body curve (Fig. 4).

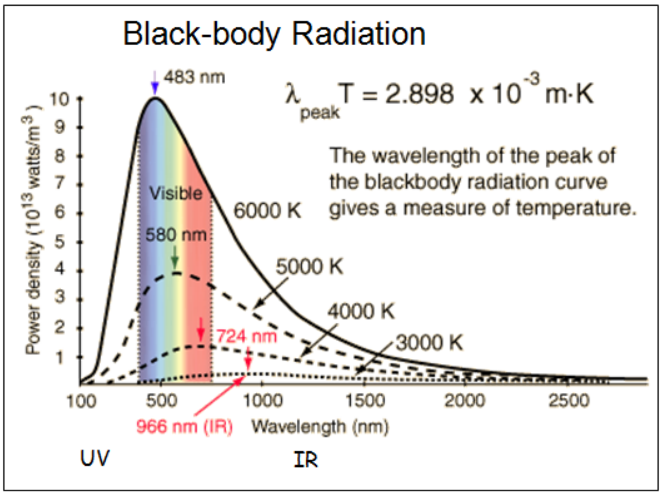


FIG 3

The fraction of energy that is radiated by a material compared to a true blackbody is also referred to as emissivity (ελ). Hence, emissivity is defined as:

$$\text{Emissivity} = \frac{\text{Radiant energy of an object}}{\text{Radiant energy of a black body with the same temperature as the object}}$$

OR

$$\varepsilon\lambda = \frac{M_{T,\lambda}}{M_{\lambda,\mathrm{T}}^{BB}}$$

Where, $M_{T,\lambda}$ is the radiant emittance of a real material at a given temperature, $M_{\lambda,\mathrm{T}}^{BB}$ is a radiant emittance of a black-body at the same temperature.

A black body has

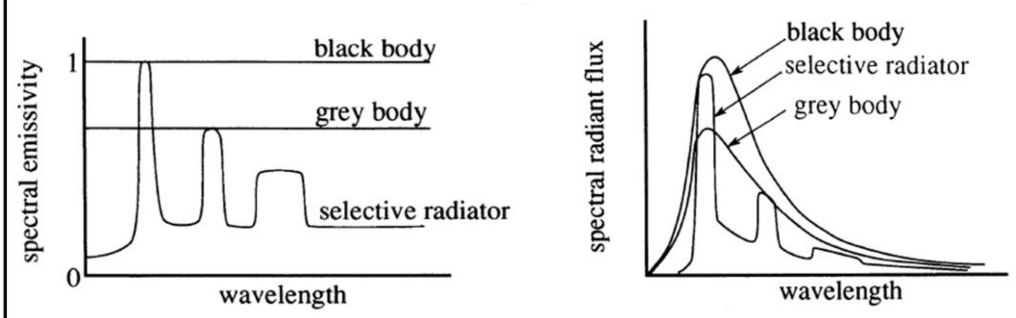
$\varepsilon\lambda$ = 1

A gray body has

$\varepsilon\lambda$ = constant

A selective radiator has

$$\varepsilon\lambda = fn(\lambda)$$



Spectral emissivities and radiant exitances for a black body, a gray body and selective radiator

FIG. 4

Data acquisition: Modes and platforms

There are three different aspects which have to be taken into account while mode of thermal data acquisition is considered:

Active versus passive mode:

Most of the thermal sensors acquire data passively, i.e. they measure the radiations emitted naturally by the target/ground. Data can also be acquired in the TIR actively deploying laser beams (LIDAR). However, these techniques are not well researched and are only in the infancy.

Broad band versus multispectral mode:

For the broad band thermal sensing, in general the 8 to 14 µm atmospheric window is utilised. However, some spaceborne thermal sensors such as Landsat Thematic Mapper Band 6 operates in the wavelength range of 10.4 to 12.6 µm to avoid the ozone absorption peak which is located at 9.6 µm. The multispectral thermal channels, such as those in the ASTER platform, are targeted specially for geological applications.

Daytime versus night-time acquisition:

Thermal data can be acquired during day and night also. For some applications it is useful to have data from both the times. However, for many applications night-time or more specifically pre-dawn images are preferred as during this time the effect of differential solar heating is the minimal. The platforms for such data acquisitions range from satellites, aircrafts to ground based scanners.

Types of scanners used in thermal remote sensing

Following are the scanners used in thermal remote sensing:

A. Across-track thermal scanners and

For Across-track thermal scanners, Daedalus DS-1260, DS-1268, and Airborne Multispectral Scanner are used as thermal Infrared Multispectral Scanners. These scanners provide most of the useful high spatial and spectral resolution thermal infrared data for monitoring the environment. The DS-1260 records data in 10 bands including a thermal-infrared channel (8.5 to 13.5 µm). The DS-1268 incorporates the thematic mapper middle-infrared bands (1.55 - 1.75 µm and 2.08 - 2.35 µm). The AMS contains a hot-target, thermal-infrared detector (3.0 to 5.5 µm) in addition to the standard thermal-infrared detector (8.5 to 12.5 µm).

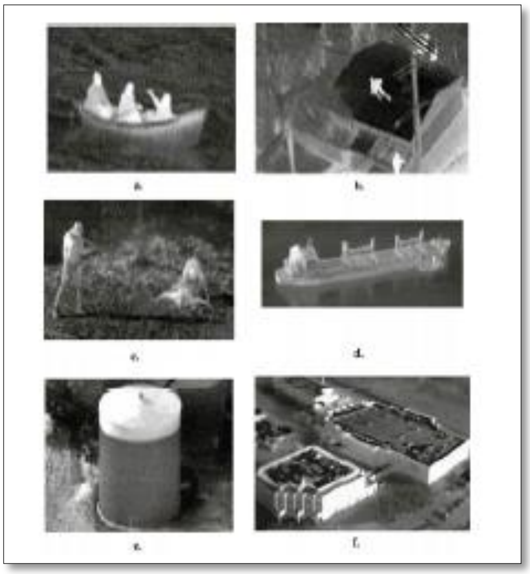
The detectors are cooled to low temperatures (-196 °C; -243 °C; 73 °K) using liquid helium or liquid nitrogen. Cooling the detectors insures that the radiant energy (photons) recorded by the detectors comes from the terrain and not from the ambient temperature of objects within the scanner itself.

B. Push-broom Linear and Area Array Charge-coupled device (CCD) Detectors

For this, solid-state microelectronic detectors are used. Those are smaller in size (e.g. 20 x 20 mm) and weight. They require less power to operate, have fewer moving parts, and are more reliable. Each detector in the array can view the ground resolution element for a longer time, allowing more photons of energy from within the IFOV to be recorded by the individual detector. It helps in improving radiometric resolution (the ability to resolve smaller temperature differences). Each detector element in the linear or area array is fixed relative to all other elements, therefore, the geometry of the thermal infrared image is much improved relative to that produced by an across-track scanning system and some linear and area thermal detectors do not even require the cooling apparatus.

C. Forward-Looking Infrared (FLIR) Systems

Forward-Looking Infrared type systems are calibrated with aircraft that look obliquely ahead of the aircraft and acquire high-quality thermal infrared imagery, especially at night. FLIR systems collect the infrared energy based on the same principles as an across-track scanner, except that the mirror points forward about 45° and projects terrain energy during a single sweep of the mirror onto a linear array of thermal infrared detectors (Fig. 6).



Forward Looking Infrared (FLIR)

FIG. 6

Thermal IR Sensors

Following are the important thermal IR sensors:

i. TIROS (Television IR Operational Satellite): It was launched in 1960. The sensor attached with it is ideal for monitoring regional cloud patterns and frontal movement.
ii. GOES (Geostationary Operational Environmental Satellite): It has 8 km spatial resolution and full-disk of Earth are obtained every 30 minutes both day and night
iii. HCMM (Heat Capacity Mapping Mission): It was launched in 1978 having 600 m spatial resolution with 10.5 – 12.6 micron range.
iv. CZCS (Coastal Zone Color Scanner) fitted on NASA's Nimbus 7 and launched in 1978, that included a thermal infrared sensor for monitoring sea-surface temperature.
v. AVHRR (Advanced Very High Resolution Radiometer): It collects thermal infrared local area coverage (LAC) data at 1.1 x 1.1 km and global area coverage (GAC) at 4 x 4 km.
vi. TIMS (Thermal Infrared Multispectral Scanner): It is Airborne and acquires thermal infrared energy in six bands at wavelength intervals of <1.0 μm
vii. ATLAS (Airborne Terrestrial Applications Sensor): It has 15 channels
viii. Landsat ETM+ Band 6: 10.4 – 12.5 micron range
ix. ASTER (Advanced Spaceborne Thermal Emmission and Reflection Radiometer): It is calibrated on Terra having 5 bands with 8.125-11.65 micron range

Applications of thermal remote sensing

Thermal remote sensing has ability to record minor temperature variations therefore, reserves immense potential for various applications:

Application in Agriculture and Food industry

Thermal remote sensing has potential use in agriculture and food industry that includes:

i. Predicting water stress in crops
ii. Planning irrigation scheduling
iii. Disease and pathogen detection in plants
iv. Evaluating and Predicting fruit maturity and their yield
v. Detection of foreign bodies in food materials

Application in Volcanology

i. Thermal remote sensing is capable of detecting and analysing volcanic heat patterns.
ii. Thermal remote sensing can be used to measure and map active lava flows and to detect new cracks where new gases escape. Thus it helps in improving volcanic warning systems.

Application in Weather forecasting

Thermal remote sensing is being used to determine weather patterns on earth.

Thermal remote sensing is used to track dangerous weather conditions, raining patterns, heat waves and solar activity.

Thermal remote sensing helps in making accurate weather forecasts revealing a range of information like the formation and swirling motion of clouds, sea surface temperature, moisture profile of the atmosphere and the movement of smoke plumes from wildfire.

Thermal Imagine in Border Security

Thermal remote sensing is extremely useful for border surveillance as thermal imagine cameras are capable to detect man sized target at extremely long distances, in darkness and in extreme weather conditions. Thermal imagine cameras are also used in search and rescue operations as with the help of this an officers may be able to search up to 1,500 feet in any direction (Fig. 7).

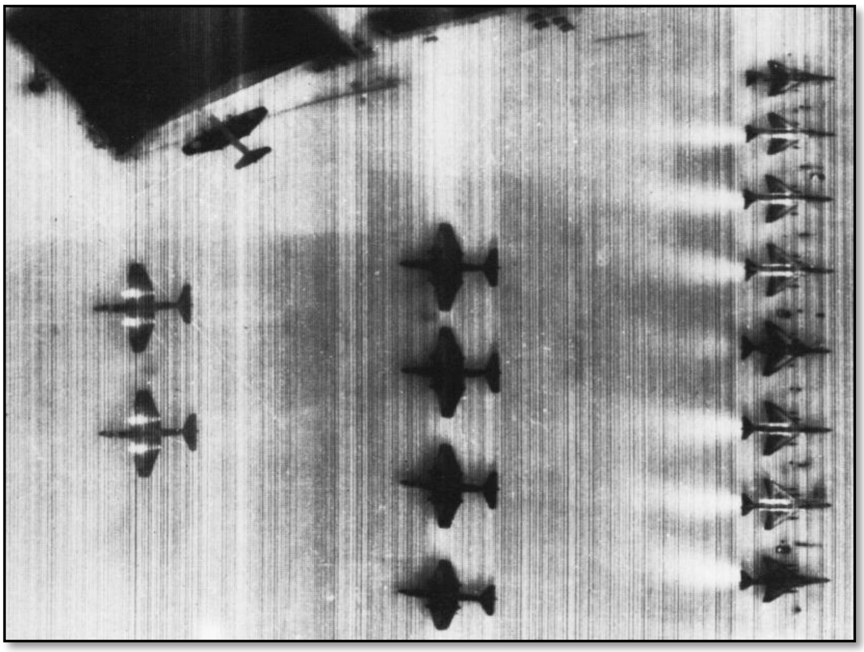


FIG. 7: Night time thermal Infrared imagery of Airport

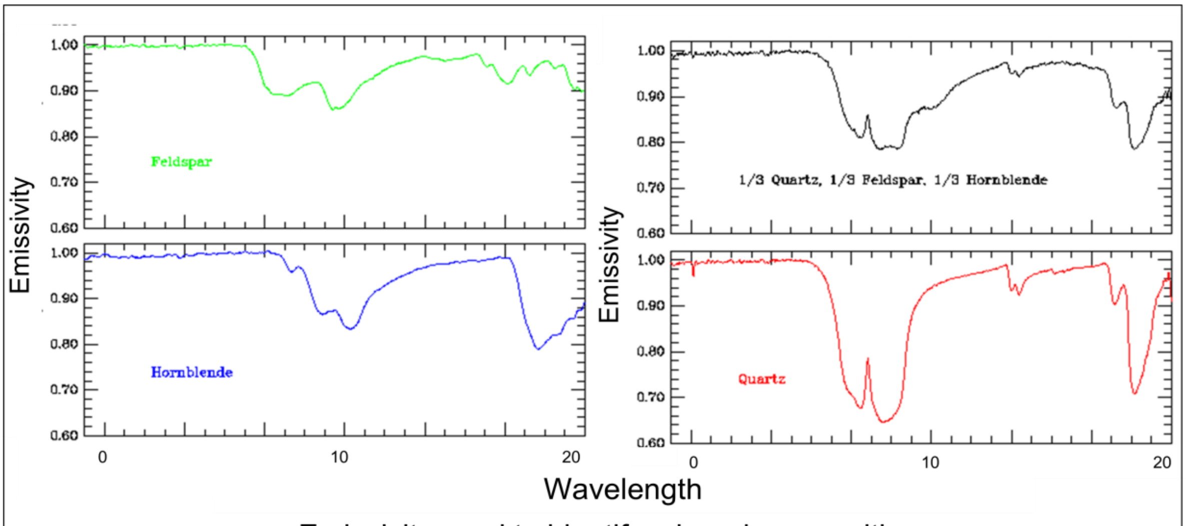
Application in building diagnostics

Thermal remote sensing can be used to scan entire building to detect energy waste, presence of moisture in building, plumbing issues and electrical issues.

Besides these, thermal remote sensing is also used for:

- Identification of geological units and structures
- Soil moisture studies
- Hydrology
- Coastal zones
- Forest fires
- Coal fires
- Seismology
- Environmental modelling
- Medical sciences

- Veterinary sciences
- Identification and exploration of minerals (Fig. 8)



Emissivity used to identify mineral composition

FIG. 8

Summary

Thermal remote sensing deals with acquisition, interpretation and processing of data, acquired primarily in thermal infrared region of the electromagnetic spectrum. Most commonly used spectrum lie in intervals of 3 to 5 µm and 8 to 14 µm, in which the atmosphere is fairly transparent and the signal is only lightly affected by atmospheric absorption. In thermal remote sensing surface temperature is the main factor that determines the amount of energy that is radiated and measured in the thermal wavelengths. Thermal remote sensing does not depend on reflected sunlight, so that it can also perform during the night. Thermal remote sensing exploits the fact that everything above absolute zero (0 K or -273.15 °C or –459 °F) emits radiation in the infrared range of the electromagnetic spectrum. How much energy is radiated, and at which wavelengths, depends on the *emissivity* of the surface and on its *kinetic temperature*. With the help of Planck's law, ground temperature could be directly calculated. Planck's radiation law describes the amount of emitted energy per wavelength depends on the object's temperature. Thermal remote sensing is unique in helping to identify surface materials and features such as rock types, soil moisture, geothermal anomalies etc. Thermal remote sensing reserves immense potential for various applications in agriculture and food industry, volcanology, weather forecasting, border security, identification of geological units and structures, soil moisture studies, forest fires, coal fires, seismology, environmental modelling and identification and exploration of minerals.