6. Thermal Infrared Images

6. Thermal Imaging

6.1Principle of thermal Imaging

All materials, which are above zero degrees Kelvin (-273 degrees C), emit infrared energy (EM energy in 3-14 μm).

Our eyes are only sensitive to visible energy (0.4-0.7 μm). Human sense thermal energy through touch, while detectors (sensors) are sensitive to all EM spectrums.

All objects (vegetation, soil, rock, water, concrete, etc) selectively absorb solar short-wavelength energy and radiate thermal infrared energy.

The infrared energy emitted from the measured object is converted into an electrical signal by the imaging sensor (micro-bolometer) in the camera and displayed on a monitor as a color or monochrome thermal image. The basic principle is explained in lecture two.

6.2Kinetic heat, radiant flux and temperature

The energy of particles of matter in random motion is called kinetic heat (also referred to as internal, real, or true heat).

We can measure the true kinetic temperature (T_{kin}) or concentration of this heat using a thermometer.

We perform this in situ (in place) temperature measurement when we are ill.

We can also measure the true kinetic internal temperature of soil or water by physically touching them with a thermometer. When these particles (have kinetic heat) collide they change their energy state and emit electromagnetic radiation called radiant flux (watts). The concentration of the amount of radiant flux exiting (emitted from) an object is its radiant temperature (T_{rad}).

There is usually a high positive correlation between the true kinetic temperature of an object (T_{kin}) and the amount of radiant flux radiated from the object (T_{rad}). Therefore, we can utilize radiometers placed some distance from the object to measure its radiant temperature which hopefully correlates well with the object's true kinetic temperature. This is the basis of thermal infrared remote sensing.

Unfortunately, the relationship is not perfect, with the remote measurement of the radiant temperature always being slightly less than the true kinetic temperature of the object. This is due to a thermal property called emissivity.

6.3Thermal Radiation Law

Blackbody (perfect absorber and emitter)
Stenfan-Boltzmann Law ($M_B = \sigma T^4$ in Wm^{-2})
Wien's Displacement Law ($\lambda_{max} = 2898/T$)
Emissivity ($\varepsilon = M_R / M_B$) at the same temperature

$$M_B = \sigma T_{kin}^4$$

$$M_R = \sigma T_{rad}^4$$

$$\varepsilon = \frac{M_R}{M_B} = \frac{T_{rad}^4}{T_{kin}^4}$$

The dominant wavelength (λ_{max}) provides valuable information about which part of the thermal spectrum we might want to sense in. For example, if we are looking for 800 °K forest fires that have a dominant wavelength of approximately 3.62µm then the most appropriate remote sensing system might be a 3- 5µm thermal infrared detector.

- MODIS band 20-25 are in3-5 µm

If we are interested in soil, water, and rock with ambient temperatures on the earth's surface of 300 °K and a dominant wavelength of 9.66 µm, then a thermal infrared detector operating in the (8-14µm) region might be most appropriate.

- Landsat image thermal band (6) is in 10.4µm- 12.5µm
- ASTER band 12 and 13 are in (8-14 µm)
- MODIS band 29-30 and 31- 32 are in (8-14 µm)

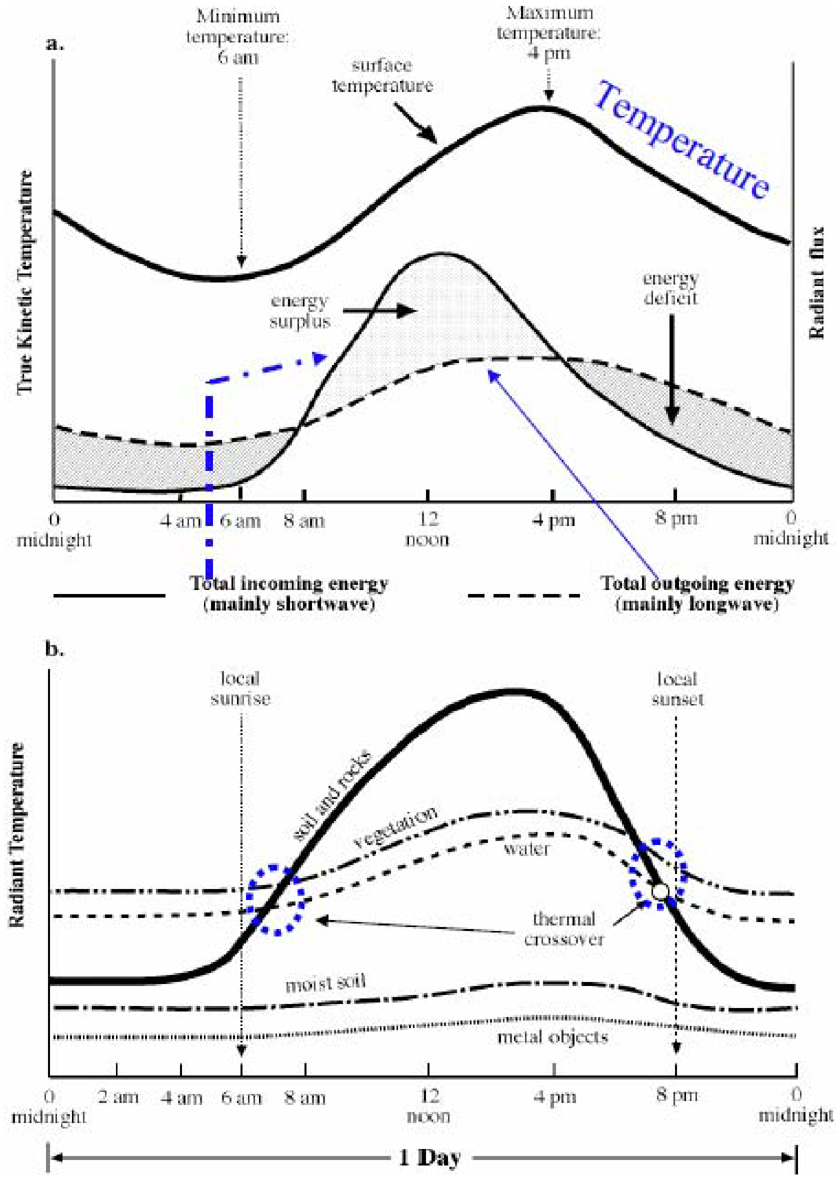
6.4 Diurnal Temperature Cycle of Typical

The diurnal cycle encompasses 24 hours. Beginning at sunrise, the earth begins intercepting mainly short wavelength energy (0.4 -0.7 µm) from the Sun. From about 6:00 am to 8:00 pm, the terrain intercepts the incoming short wavelength energy and reflects much of it back into the atmosphere where we can use optical remote sensors to measure the reflected energy.

However, some of the incident short wavelength energy is absorbed by terrain and then re-radiated back into the atmosphere as thermal infrared long wavelength radiation (3-100µm). The outgoing long wavelength radiation reaches its highest value during the day when the surface temperature is highest.

This peak usually lags two to four hours after the midday peak of incoming shortwave radiation, owing to the time taken to heat the soil.

The contribution of reflected short wavelength energy and emitted long wavelength energy causes an energy surplus to take place during the day. Both incoming and outgoing shortwave radiation become zero after sunset (except for light from the moon and stars), but outgoing long wave radiation continues all night



Peak Period of Daily Peak Outgoing Long-wave Radiation and the Diurnal Radiant Temperature of Soils and Rocks, Vegetation, Water, Moist Soil and Metal Objects

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Water and vegetation have higher thermal capacity. In different time of thermal images, there are different performances even the materials.

6.5Emissivity

The intensity of the emittance is a function of the temperature of the material. In other words, the higher the temperature, the greater the intensity of infrared energy that is emitted.

As well as emitting infrared energy, materials also reflect infrared, absorb infrared and, in some cases, transmit infrared. When the temperature of the material equals that of its surroundings, the amount of thermal radiation absorbed by the object equals the amount emitted by the object.

Two rocks lying next to one another on the ground could have the same true kinetic temperature but have different radiant temperatures when sensed by a thermal radiometer simply because their emissivities are different. The emissivity of an object may be influenced by a number of factors, including:

1. Color -darker colored objects are usually better absorbers and emitters (i.e. they have a higher emissivity) than lighter colored objects which tend to reflect more of the incident energy.
2. Surface roughness-the greater the surface roughness of an object relative to the size of the incident wavelength, the greater the surface area of the object and potential for absorption and re-emission of energy.
3. Moisture content-the more moisture an object contains, the greater its ability to absorb energy and become a good emitter. Wet soil particles have a high emissivity similar to water.
4. Compaction-the degree of soil compaction can effect emissivity.
5. Field-of-view-the emissivity of a single leaf measured with a very high resolution thermal radiometer will have a different emissivity than an entire tree crown viewed using a coarse spatial resolution radiometer.
6. Wavelength-the emissivity of an object is generally considered to be wavelength dependent. For example, while the emissivity of an object is often considered to be constant throughout the (8 -14 μm) region, its emissivity in the (3 -5 μm) region may be different.
7. Viewing angle-the emissivity of an object can vary with sensor viewing angle

We must take into account an object's emissivity when we use our remote radiant temperature measurement to measure the object's true kinetic temperature. This is done by applying Kirchoff's radiation law

Kirchhoff's radiation law

$\Phi_{i\lambda} = \Phi_{r\lambda} + \Phi_{\tau\lambda} + \Phi_{\alpha\lambda}$

$1 = r_\lambda + \tau_\lambda + \alpha_\lambda$

Kirchoff found in the infrared portion of the spectrum $\alpha_\lambda = \varepsilon_\lambda$

Most materials does not lose any incident energy to transmittance, i.e. $\tau_\lambda = 0$, so we can get

$1 = r_\lambda + \alpha_\lambda = r_\lambda + \varepsilon_\lambda$

This means reflectivity and emissivity has a inverse relationship; "good absorbers are good emitters" and "good reflectors are poor emitters"

Black body radiation (W $m^{-2}\mu m^{-1}sr^{-1}$) using Planck equation:

$$E_{Black\ body}\ (\lambda, T) = \frac{2hC^2}{\lambda^5} \cdot \frac{1}{e^{hc/_{\lambda.k.T}} - 1}$$

T- is the physical (kinetic) temperature

Through radiance recorded by a remote sensor, if we use the Planck equation, we can get a temperature, which we call **brightness temperature** T_b, which is less than the real physical (or surface) temperature T.

$$R(\lambda, T_b) = \frac{2hC^2}{\lambda^5} \cdot \frac{1}{e^{hc/_{\lambda.k.T_b}} - 1}$$

$$= \varepsilon_\lambda . E_{Black\ body}\ (\lambda, T) = \varepsilon_\lambda \cdot \frac{2hC^2}{\lambda^5} \cdot \frac{1}{e^{hc/_{\lambda.k.T}} - 1}$$

$$T = \frac{h.c}{k.\lambda.\ln(1 - \varepsilon_\lambda + \varepsilon_\lambda\, e^{hc/_{k\lambda T_B}}}$$

6.6Thermal Sensing Systems

Thermal scanner is one of the most important thermal sensing systems, a particular kind of across track multispectral scanner which senses in the thermal portion of the electromagnetic spectrum by means of inbuilt detectors. These systems are restricted to operating in either 3 to 5 I-lm or 8 to 14 µm range of wavelengths. The operation and the efficiency of this type of scanning systems are based on the characteristics of the detectors. Quantum or photon detectors are typically used to detect the thermal radiation. These detectors operate on the principle of direct interaction between photons of radiation incident on them and the energy levels of electrical charge carriers within the detector material. The spectral sensitivity range and the operating temperatures of three photon detectors which are common in use are as follows:

Type	Abbreviation	Useful spectral range (µm)
Mercury-doped germanium	Ge:Hg	3 - 14
Indium antimonide	In Sb	3 – 5
Mercury Cadmium telluride	Hg cd Te (MCT)	3 - 14

Fig. below illustrates schematically the basic operation of a thermal scanner system. A thermal scanner image is a pictorial representation of the detector response on a line-by-line basis. The usual convention when looking at the earth's surface is to have higher radiant temperature areas displayed as lighter toned image areas.

Geometrical characteristics of both along track and across track scanner imageries, and radiometric calibrations of these sensing systems should be considered in the design of the thermal scanning systems. The geometrical characteristic of across-track scanner imagery, such as like spatial resolution and ground coverage, tangential scale distortions, resolution cell size variat ions and one-dimensional relief displacement, are some of the geometrical parameters to be considered in the design of thermal and multispectral scanners. Radiometric calibration of thermal scanners can be performed through a number of approaches and each has its own degree of accuracy. Methods used are internal blackbody source referencing and air-to-ground calibration.

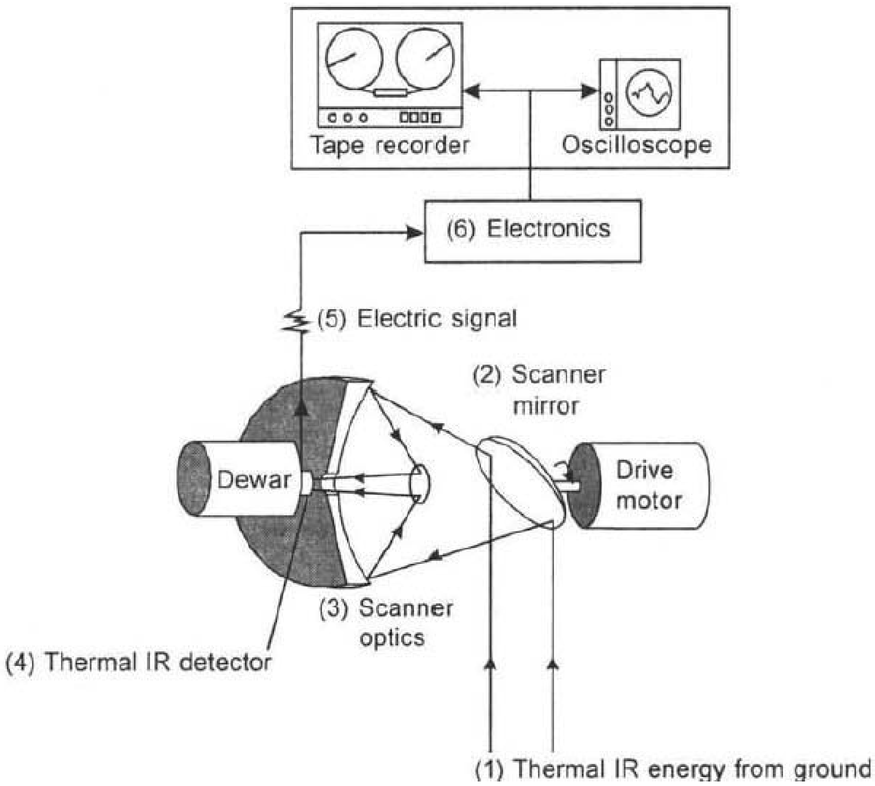


Fig. Across-track thermal scanner schematic

6.6.1 Factors effecting to separate the target from background :

- Temerature , the temperature of man-made targets is often higher than the temperature of most of background .Therefore the radiation from the target is often higher than the radiation from the background . Both man-mande and natural objects have rather high emissivity in the part of the spectrum concerned . By paint , the targets can be given similar emissivity as the background.
- Size , the size of target can sometimes be advantageous for detection. If the target itself is small and hot or if it contains small and hot spots these can easily be detected by special filtering techniques.

6.6.2 Advantage & disadvantage of Thermal Imaging System

6.6.2.1 The advantages of thermal imaging systems are:

1) They are passive; i.e. no revealing radiation is emitted by the system.
2) They operate day and night, i.e. they do not dependent on sun or start illumination.

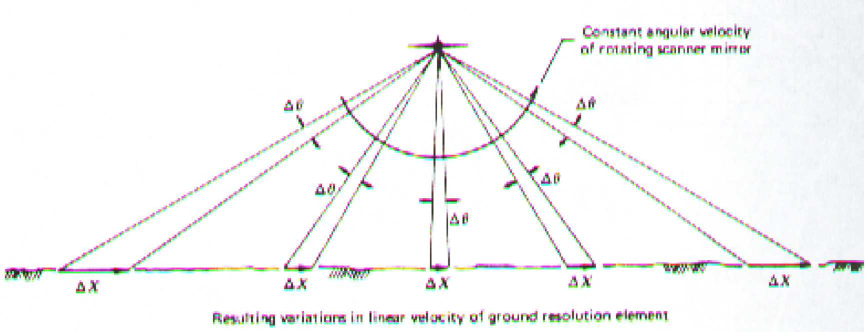
6.6.2.2 The main disadvantage

1) Is the need for reasonably good visibility conditions due to scattering in fog and rain.
2) The interpretation of picture takes a trained person because emitted thermal radiation , and not the ordinary reflected solar radiation, is used to produce the picture.

6.6.3 Factors affecting the imagery (Thermal Image)

1. Solar gain. During the daytime direct sunlight differentially heats objects according to their thermal characteristics. This can be an advantage in looking for specific differences in tonal signature from differing materials. However, there is the problem of shadowing by trees, buildings and other objects, which causes thermal shading, and orientation, which leads to differential heating, patterns on slopes.
2. Air temperature. The stability and variation in the temperature range throughout the expected survey period can have a significant bearing upon the interpretation. This is particularly important for examination of building heat loss where the maximum difference between internal and external temperature is required. For this application, the air temperature is required to below $+6^{\circ}C$.

3. Wind. Wind speeds are required to be below 15 knots and preferably around 5 knots. There are two reasons for this firstly, low wind speed reduces the amount of buffeting the aircraft receive; secondly, high winds result in strong wind shadows and differential cooling and an increase in the convective rather than radiative temperature loss.
4. Look angle. The scanner scans the ground perpendicular to the line of flight and as such only the area directly beneath the scanner is viewed vertically (see figure). Away from the nadir the scanner "Looks" at an angle to the ground surface, and for buildings a compressed view of walls is achieved.



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5. Survey timing. The mission planning is an important factor in terms of type of results required. For example, the scanning of hot water from a power station must be completed during the period of power generation. Effects of tides and currents, for example also have to be taken into account.