MODULE – 1 LECTURE NOTES – 5

SPECTRAL REFLECTANCE CURVES

Electromagnetic energy incident on the surface features are partially reflected, absorbed or transmitted through it. The fractions that are reflected absorbed or transmitted vary with material type and the condition of the feature. It also varies with the wavelength of the incident energy. Majority of the remote sensing systems operate in the region in which the surface features mostly reflect the incident energy. The reflectance characteristics of the surface features are represented using spectral reflectance curves.

This lecture covers the spectral reflectance characteristics of some of the important surface features.

Understanding spectral reflectance curves for different features at different wavelengths is essential to interpret and analyze an image obtained in any one or multiple wavelengths.

1. Spectral Reflectance Curve for Vegetation

Spectral reflectance curve for healthy green vegetation exhibits the "peak-and-valley" configuration as illustrated in Fig. 1. The peaks indicate strong reflection and the valleys indicate predominant absorption of the energy in the corresponding wavelength bands.

In general, healthy vegetations are very good absorbers of electromagnetic energy in the visible region. The absorption greatly reduces and reflection increases in the red/infrared boundary near 0.7 μm. The reflectance is nearly constant from 0.7-1.3 μm and then decreases for the longer wavelengths.

Spectral response of vegetation depends on the structure of the plant leaves. Fig. 1 shows the cell structure of a green leaf and the interaction with the electromagnetic radiation (Gibson 2000).

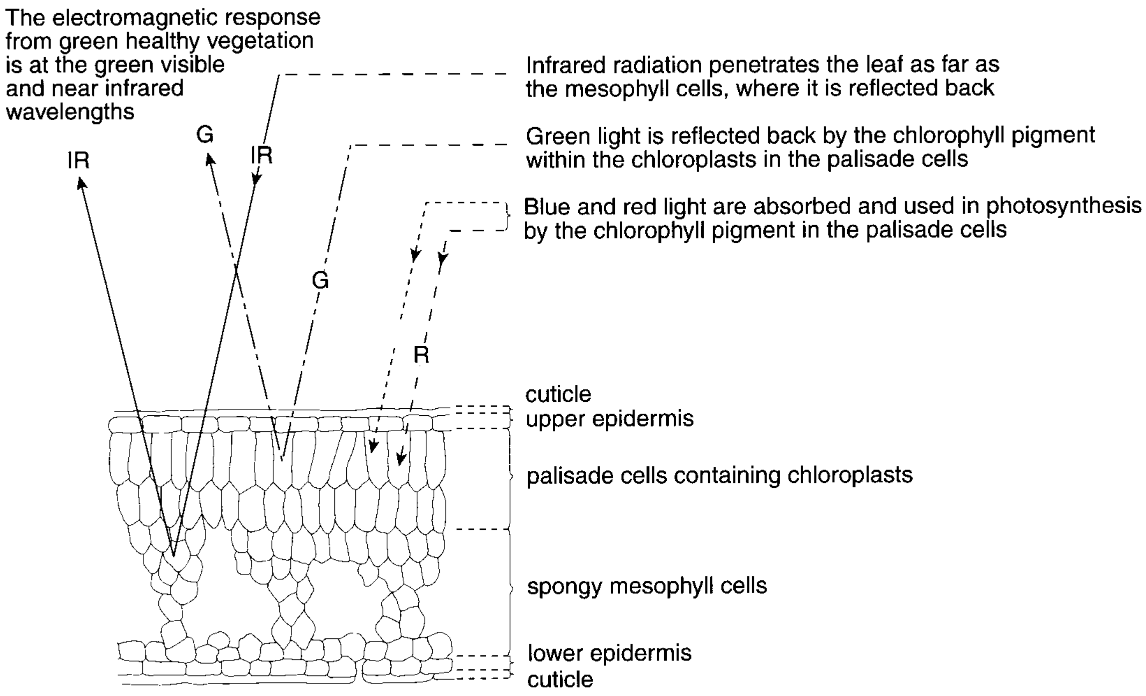

Fig.1. Cell structure of a green leaf and interactions with the electromagnetic radiation (Gibson, 2000)

The valleys in the visible portion of the spectrum are due to the pigments in plant leaves. The palisade cells containing sacs of green pigment (chlorophyll) strongly absorb energy in the wavelength bands centered at 0.45 and 0.67 μm within visible region (corresponds to blue and red), as shown in Fig.2. On the other hand, reflection peaks for the green colour in the visible region, which makes our eyes perceive healthy vegetation as green in colour. However, only 10-15% of the incident energy is reflected in the green band.

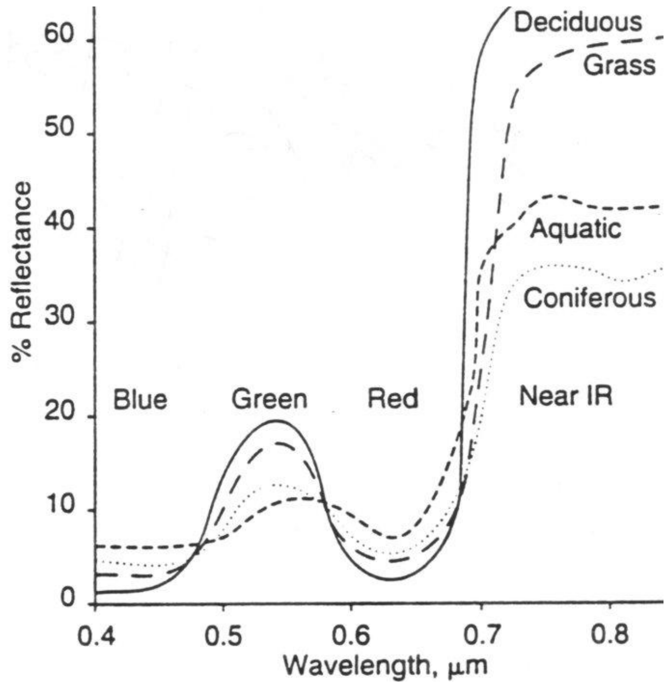

Fig. 2. Spectral reflectance of healthy vegetation in the visible and NIR wavelength bands
http://www.geog.ucsb.edu/

In the reflected infrared portion (or near infrared, NIR) of the spectrum, at 0.7 µm, the reflectance of healthy vegetation increases dramatically. In the range from 0.7 to 1.3 µm, a plant leaf reflects about 50 percent of the energy incident upon it. The infrared radiation penetrates the palisade cells and reaches the irregularly packed mesophyll cells which make up the body of the leaf. Mesophyll cells reflect almost 60% of the NIR radiation reaching this layer. Most of the remaining energy is transmitted, since absorption in this spectral region is minimal. Healthy vegetation therefore shows brighter response in the NIR region compared to the green region. As the leaf structure is highly variable between plant species, reflectance measurements in this range often permit discrimination between species, even if they look same in visible wavelengths as seen in Fig. 3.

If a plant is subjected to some form of stress that interrupts its normal growth and productivity, it may decrease or cease chlorophyll production. The result is less absorption in the blue and red bands in the palisade. Hence, red and blue bands also get reflected along with the green band, giving yellow or brown colour to the stressed vegetation. Also in stressed vegetation, the NIR bands are no longer reflected by the mesophyll cells, instead they are absorbed by the stressed or dead cells causing dark tones in the image (Fig. 3)

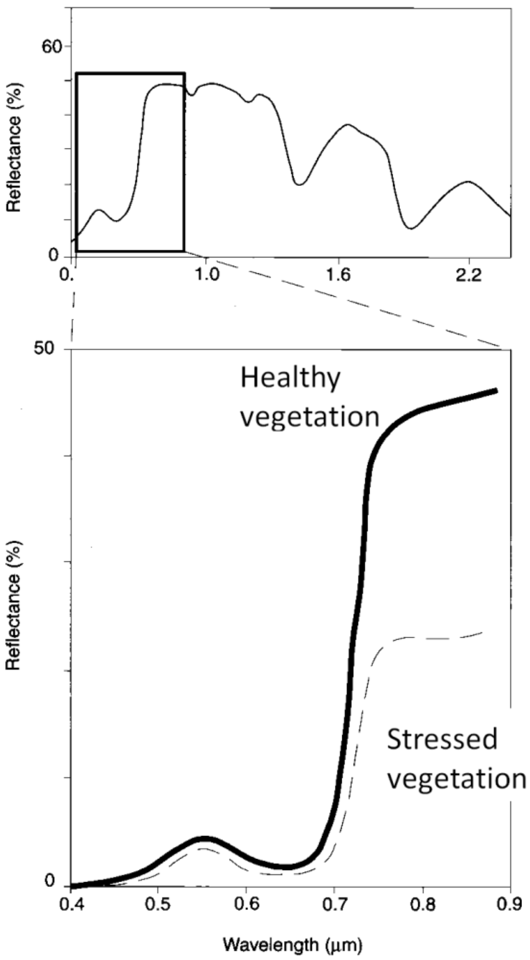

Fig. 3 Spectral reflectance curve for healthy and stressed vegetations (Gibson, 2000)

Beyond 1.3 µm, energy incident upon the plants is essentially absorbed or reflected, with little to no transmittance of energy. Dips in reflectance occur at 1.4, 1.9, and 2.7 µm as water in the leaf strongly absorbs the energy at these wavelengths. So, wavelengths in these spectral regions are referred to as water absorption bands. Reflectance peaks occur at 1.6 and 2.2 µm, between the absorption bands. At wavelengths beyond 1.3 µm, leaf reflectance is approximately inversely related to the total water present in a leaf. This total water is a function of both the moisture content and the thickness of the leaf.

Similar to the reflection and absorption, transmittance of the electromagnetic radiation by the vegetation also varies with wavelength. Transmittance of electromagnetic radiation is less in the visible region and it increases in the infrared region. Vegetation canopies generally display a layered structure. Therefore, the energy transmitted by one layer is available for reflection or absorption by the layers below it (Fig. 4). Due to this multi-layer reflection, total infrared reflection from thicker canopies will be more compared to thin canopy cover. From the reflected NIR, the density of the vegetation canopy can thus be interpreted.

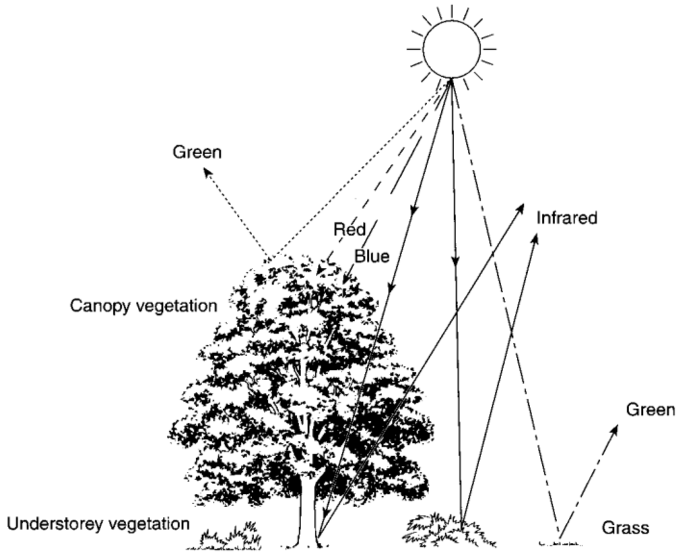

Fig. 4. Reflectance from dense forest and thin vegetation canopies (Gibson, 2000)

As the reflectance in the IR bands of the EMR spectrum varies with the leaf structure and the canopy density, measurements in the IR region can be used to discriminate the tree or vegetation species. For example, spectral reflectance of deciduous and coniferous trees may be similar in the green band. However, the coniferous trees show higher reflection in the NIR band, and can be easily differentiated (Fig.5). Similarly, for a densely grown agricultural area, the NIR signature will be more.

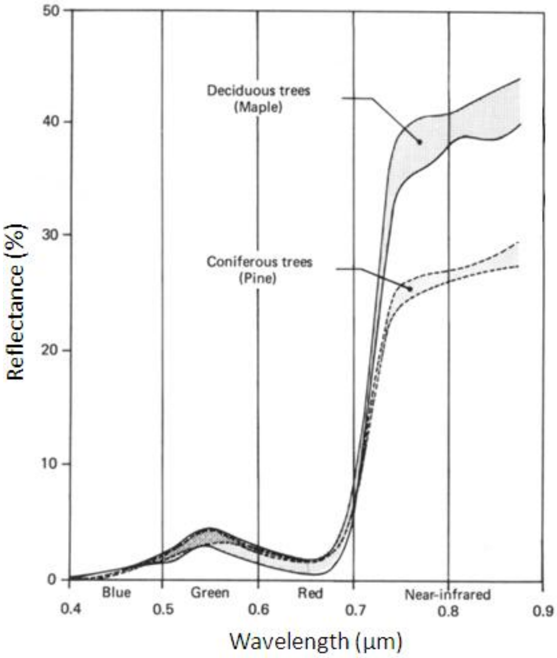

Fig. 5 Spectral reflectance curves for deciduous and coniferous trees (Lillesand et al., 2004)

2. Spectral Reflectance of Soil

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Some of the factors effecting soil reflectance are moisture content, soil texture (proportion of sand, silt, and clay), surface roughness, presence of iron oxide and organic matter content. These factors are complex, variable, and interrelated.

For example, the presence of moisture in soil decreases its reflectance. As with vegetation, this effect is greatest in the water absorption bands at 1.4, 1.9, and 2.7 μm. On the other hand, similar absorption characteristics are displayed by the clay soils. Clay soils have hydroxyl ion absorption bands at 1.4 and 2.2 μm.

Soil moisture content is strongly related to the soil texture. For example, coarse, sandy soils are usually well drained, resulting in low moisture content and relatively high reflectance. On the other hand, poorly drained fine textured soils generally have lower reflectance. In the absence of water, however, the soil itself exhibits the reverse tendency i.e., coarse textured soils appear darker than fine textured soils.

Two other factors that reduce soil reflectance are surface roughness and the content of organic matter. Presence of iron oxide in a soil also significantly decreases reflectance, at least in the visible region of wavelengths.

3. Spectral Reflectance for Water

Water provides a semi-transparent medium for the electromagnetic radiation. Thus the electromagnetic radiations get reflected, transmitted or absorbed in water. The spectral responses vary with the wavelength of the radiation and the physical and chemical characteristics of the water.

Spectral reflectance of water varies with its physical condition. In the solid phase (ice or snow) water give good reflection at all visible wavelengths. On the other hand, reflection in the visible region is poor in case of water in liquid stage. This difference in reflectance is due to the difference in the atomic bond in the liquid and solid states.

Water in the liquid form shows high reflectance in the visible region between 0.4μm and 0.6μm. Wavelengths beyond 0.7μm are completely absorbed. Thus clear water appears in darker tone in the NIR image. Locating and delineating water bodies with remote sensing data is done more easily in reflected infrared wavelengths because of this absorption property.

For example, Fig. 6 shows a part of the Krishna River Basin in different bands of the Landsat ETM+ imagery. The water body appears in dark colour in all bands and displays sharp contrast in the IR bands.

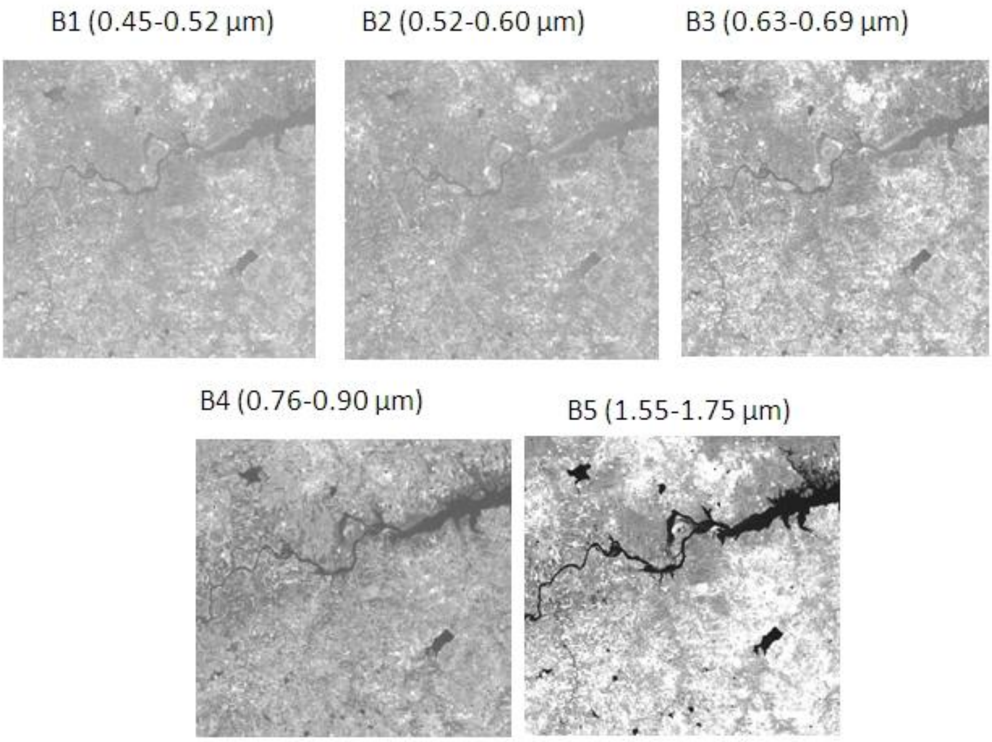


Fig. 6 Landsat ETM+ images of a part of the Krishna river basin in different spectral bands

(Modified from Nagesh Kumar and Reshmidevi, 2013)

However, various conditions of water bodies manifest themselves primarily in visible wavelengths. The energy/matter interactions at these wavelengths are very complex and depend on a number of interrelated factors (Fig. 7). For example, the reflectance from a water body can stem from an interaction with the water's surface (specular reflection), with material suspended in the water, or with the bottom surface of the water body. Even in deep water, where bottom effects are negligible, the reflectance properties of a water body are not only a function of the water, but also of the material in the water.

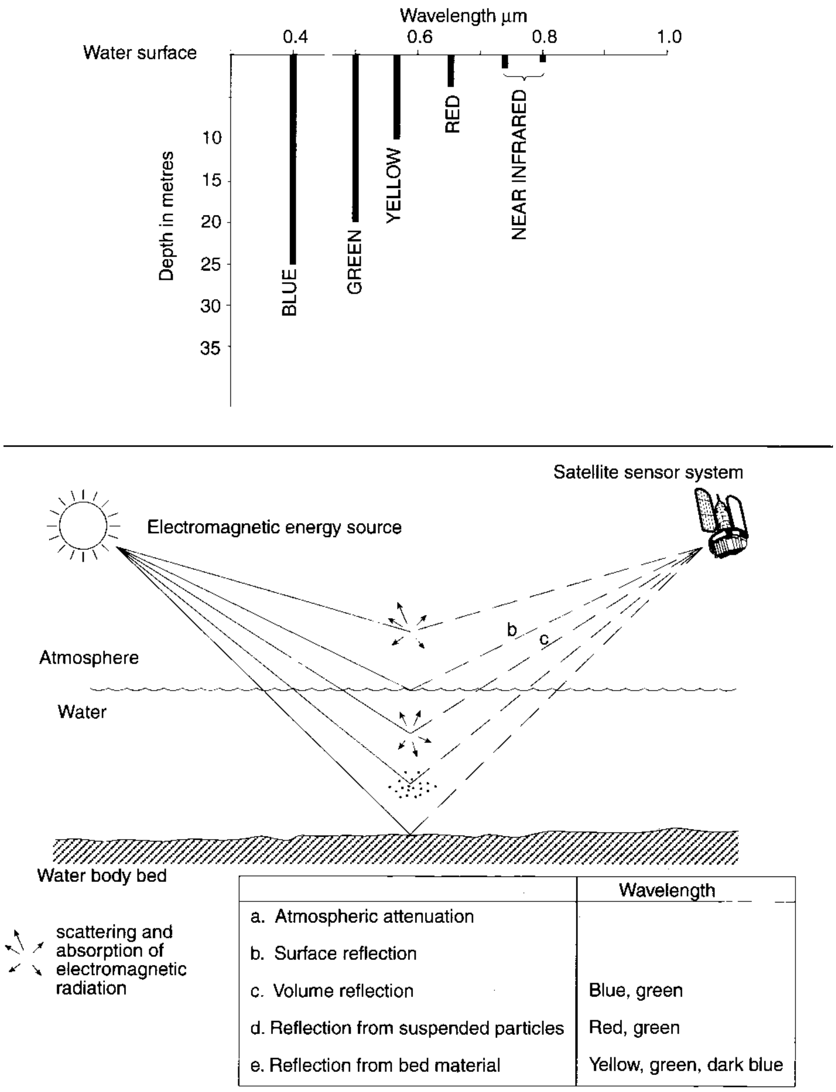


Fig. 7. Complex spectral response from a water body (Gibson, 2000)

Clear water absorbs relatively less energy having wavelengths shorter than 0.6 μm. High transmittance typifies these wavelengths with a maximum in the blue-green portion of the spectrum. However, as the turbidity of water changes (because of the presence of organic or inorganic materials), transmittance and therefore reflectance change dramatically. For example, water bodies containing large quantities of suspended sediments normally have much higher visible reflectance than clear water. Likewise, the reflectance of water changes with the chlorophyll concentration involved. Increase in chlorophyll concentration tends to decrease reflectance in blue wavelengths and increase reflectance in green wavelengths. These changes have been used in remote sensing to monitor the presence and to estimate the concentration of algae. Reflectance data have also been used to determine the presence or absence of tannin dyes from bog vegetation in lowland areas, and to detect a number of pollutants, such as oil and certain industrial wastes.

Many important characteristics of water such as dissolved oxygen concentration, pH, and salt concentration cannot be observed directly through changes in water reflectance. However, such parameters sometimes correlate with observed reflectance. Thus, there are many complex interrelationships between the spectral reflectance of water and particular characteristics.

Variation in the spectral reflectance in the visible region can be used to differentiate shallow and deep waters, clear and turbid waters, as well as rough and smooth water bodies. Reflectance in the NIR range is generally used for delineating the water bodies and also to study the algal boom and phytoplankton concentration in water. More details on the remote sensing applications for monitoring water quality parameters can be found in Nagesh Kumar and Reshmidevi (2013).

Further details on the spectral characteristics of vegetation, soil, and water can be found in Swain and Davis (1978).

4. Spectral Reflectance of Some Natural Features

Sample spectral reflectance curves of some of the natural features like snow, healthy vegetation, stressed vegetation, dry soil, turbid water and clear water are given in Fig. 8.

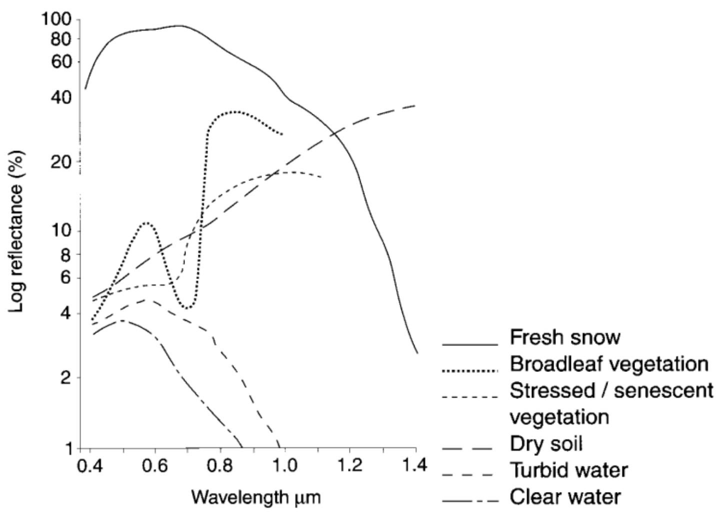
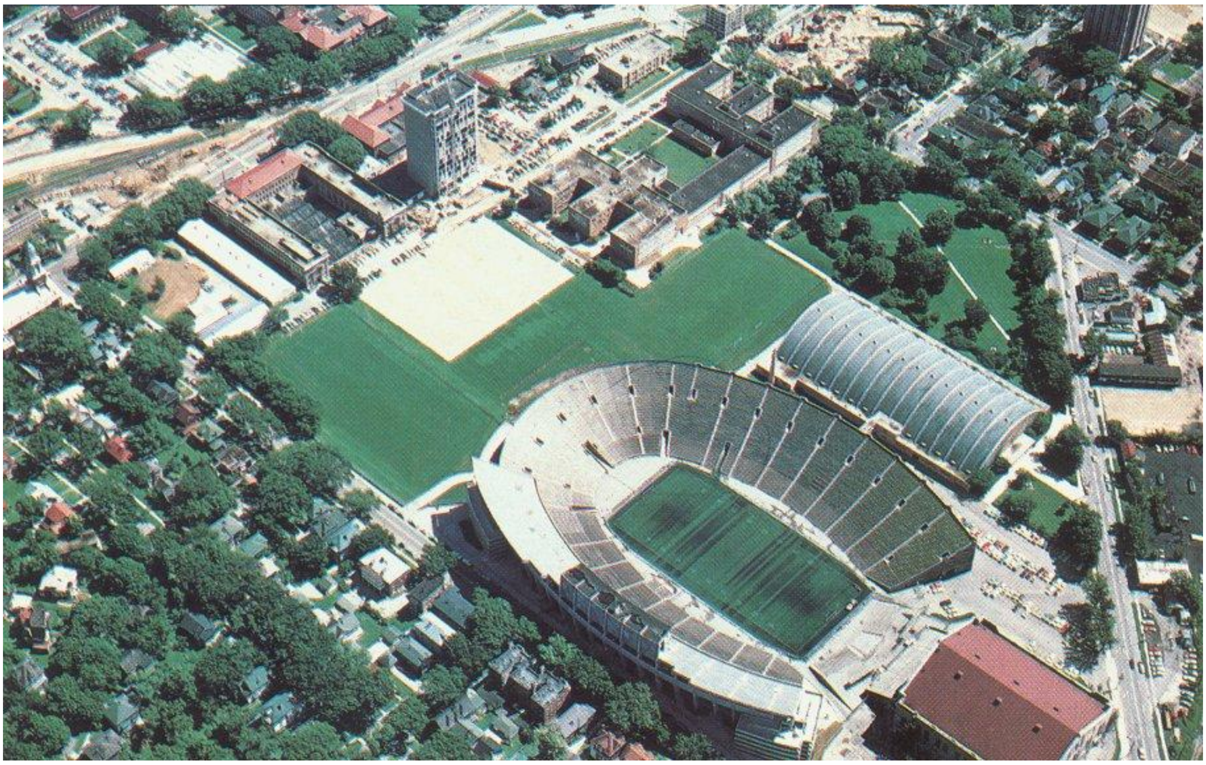


Fig. 8 Sample spectral reflectance curves for natural features

In a multispectral image, multiple sensors are used to sense the reflectance in different wavelength bands. Reflectance recorded in multiple bands are analysed to find how the spectral reflectance varies with wavelength. Using the average spectral reflectance curves as the basic information, the spectral reflectance variation is used to identify the target features.

For example, in Fig.9 aerial photographs of a stadium in normal colour and colour IR are shown. In normal colour photograph, the artificial turf inside the stadium and the natural vegetation outside the stadium appear in the same colour. On the other hand, the IR colour photograph helps to differentiate both very clearly. The artificial turf appears dark in tone, whereas the natural vegetation shows high reflectance in the IR region. Spectral reflectance curves of the natural vegetation and the artificial turf are shown in Fig. 10. (Images are taken from Lillesand et al., 2004).

(a)



(b)

Fig. 9 Aerial photograph of a football stadium with artificial turf (a) normal colour photograph (b) colour IR photograph (from Lillesand et al., 2004)

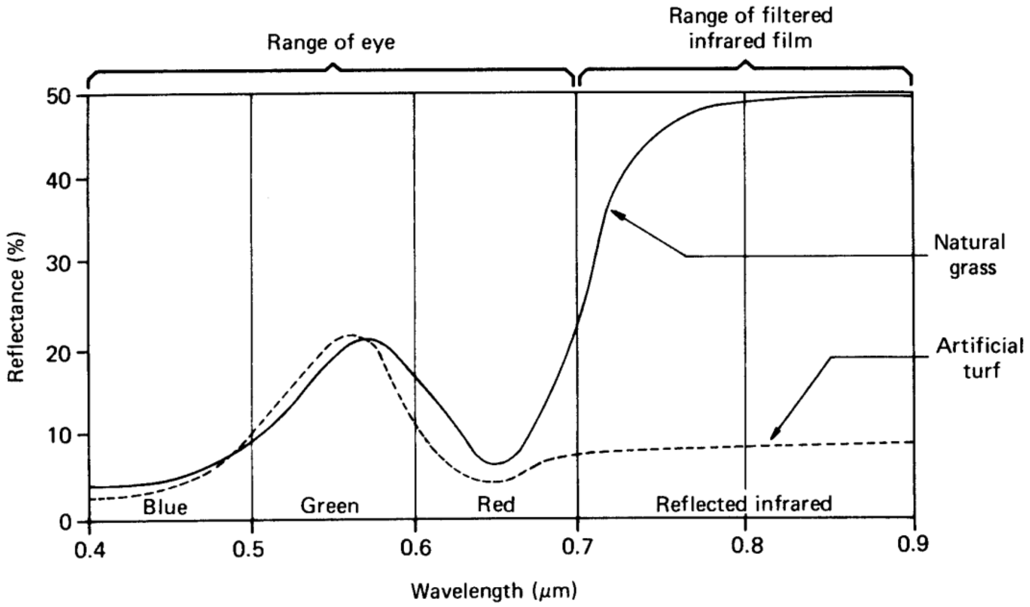


Fig. 10 Spectral reflectance curves of the natural vegetation and the artificial turf (From Lillesand et al., 2004)

Bibliography / Further Reading

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