

MODULE 3.

FACTORS AFFECTING 3D LASER SCANNING

Learning Outcomes:

This module discusses factors affecting 3D laser scanner performance. Students should be able to explain the impact of various factors on 3D laser scanning and plan field operations accordingly.

Lecture Contents:

3.1 *Atmospheric Conditions*

See Section 2.2 of module 2.

3.2 *Reflectance (Albedo)*

Reflection is one of the key elements in electronic distance measurement. In general, there are two types of reflections: specular and diffuse, and they are illustrated in Figures 3.1 and 3.2. Specular reflection occurs when light ray hits a smooth surface such as polished glass, plastic or metal. The direction of the reflected light ray is predictable in this type of reflection since the incoming (incident) light and the reflected light form equal angles with the normal of the surface. The prisms or targets used in EDM generally provide smooth surfaces and therefore an EDM system using them involves specular reflection. Diffuse reflection, on the other hand, occurs when light bounce off rough surfaces. Since most natural surfaces are not smooth, vast majority of reflections are diffuse type. Laser scanning, for the most part, involves this type of reflection. In diffuse reflection, the direction of the reflected light is difficult to predict because of the orientations of the micro-surfaces that make up the rough surface.

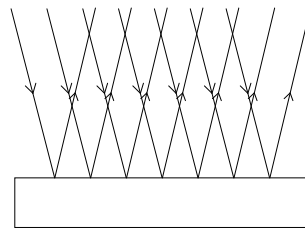


Figure 3.1 Specular Reflection

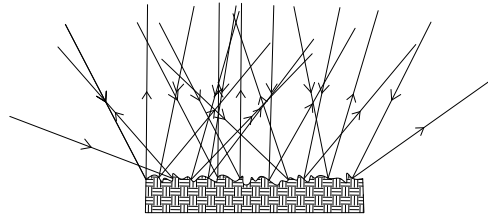


Figure 3.2 Diffuse Reflection

The amount of reflection can be measured by a parameter called reflectance which is the ratio of the intensity of reflected light to that of the incident light. Reflectance depends on the finishing and material of the surface and the wavelength of the EM radiation. In 3D laser scanning for surveying, the common types of surfaces are soil, vegetation, concrete, rock and asphalt, and the types of lasers range from green to infrared.

Soil is the common type of material encountered in topographical scanning. Its optical properties depend on its water contents, composition, and surface texture. In general, the reflectance decreases as the water content increases in the soil due to the decreased contrast of refractive index between the soil particles ($n \approx 1.5$) and the surrounding medium when air ($n=1$) is replaced by water (Twomey et al., 1986). The relationship can be described by an exponential function (Duke and Guerif, 1998):

$$R = R_s + (R_d - R_s)e^{-cw} \quad (3.1)$$

where R_s , and R_d are the reflectances for saturated and dry soil, respectively, c is the constant and w is the water content. All values in Eq. 3.1 are wavelength dependent except the water content. Lobell and Asner (2002) tested four types of soil with different organic C and water contents under various EM radiations. Figure 3.3 shows the relationships between water content and reflectance for a radiation with $\lambda=600$ nm from their study.

The results indicate that regardless of soil types, as the water content increases the reflectance decreases. The change is most profound in the lower water content range (<20%). In the study, four types of soils were used: Aridisol, Andisol, Mollisol and Entisol with organic C contents, 0.19%, 3.69%, 5.58% and 0.57%, respectively. Studies have shown that the impact of water content on soil reflectance is similar over the entire spectrum from 500 nm to 2500 nm as shown in Figure 3.4. The ratio between the reflectance at two different wavelengths, therefore, can be regarded as independent of the water content.

Soil with high organic C contents generally tends to be dark and has lower reflectance and vice versa. Figure 3.5 shows the changes of reflectance as a function of wavelength for soil with different organic C contents (Batholomeus). Minerals in the soil such as iron oxide may also impact the reflectance of soil.

Surface roughness is also a factor affecting soil reflectance. A rough surface generally has lower reflectance due to self-shadowing effect and multiple scattering.

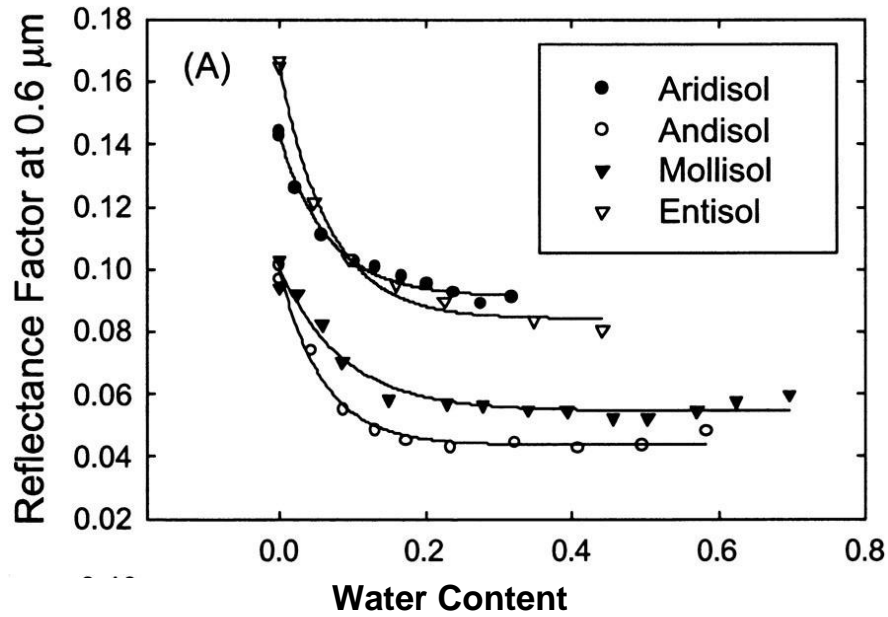


Figure 3.3 Soil Reflectance as a function of water content for soils with various organic C contents for different radiations, $\lambda=600$ nm. (Lobell and Asner, 2002)

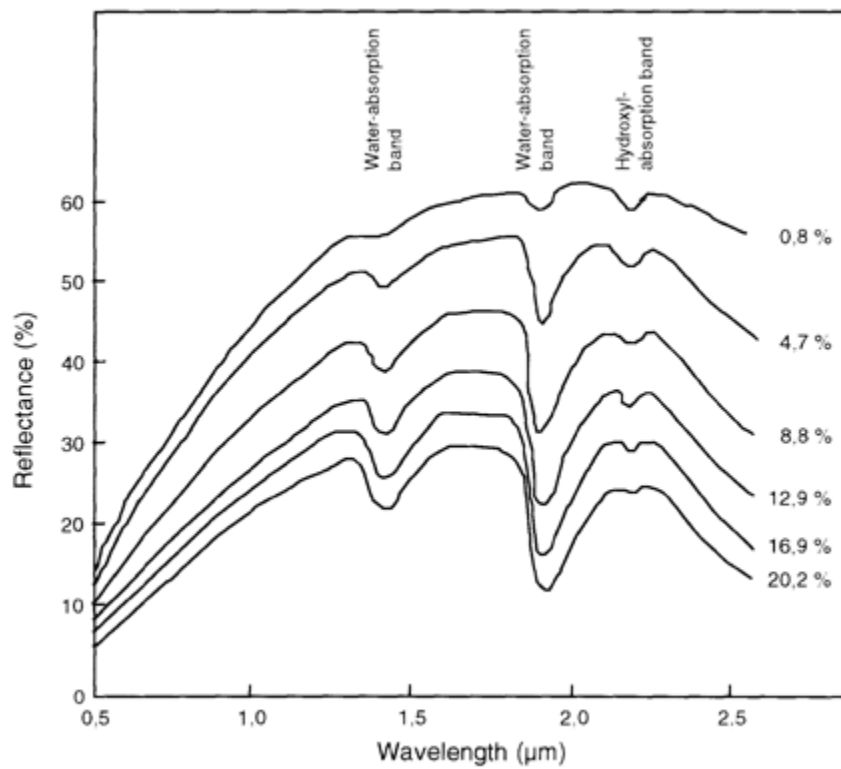


Figure 3.4 Soil reflectance as a function of wavelength at various water contents. (Leblon, 1996)

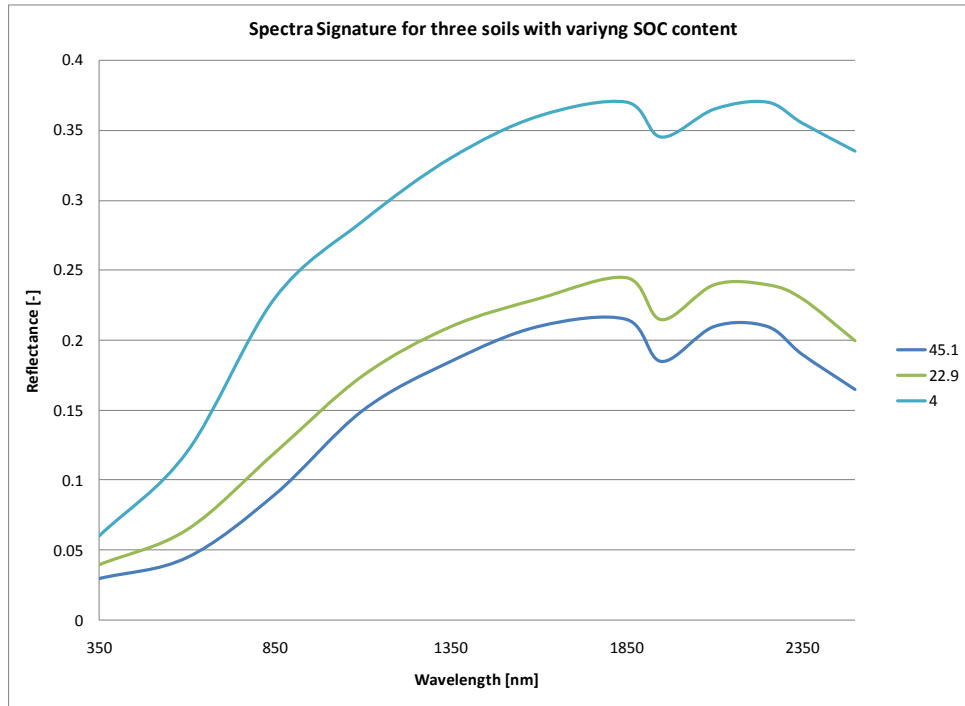


Figure 3.5 Impact of soil organic C content on reflectance (Batholomeus)

Figure 3.6 shows the relationship reflectance (albedo) and surface roughness obtained by Matthias et al. (2000) for two types of soil (Gila and Pima) tested in Arizona. The general trends for both dry and wet soils are similar.

Vegetation is another common type of surface encountered in surveying scanning. In general, optical properties of plant leaves are the same regardless of species. A typical spectral reflectance curve of a healthy green leaf is shown in Figure 3.7. The curve can be divided into three segments: visible, near-infrared and shortwave infrared. The visible band (400-700 nm) has low reflectance (15% maximum) because of the dominance of light-absorbing pigments. Within this band, there are two relatively stronger sub-absorption bands around 450 nm (blue) and 670 nm (red). This is caused by the presence of chlorophyll a and b, which account for 65% of the pigments in healthy green leaves, absorb more blue and white light than green and hence reflect more green light. This is the reason why green leaf appears green and chlorophyll is called the green pigment. In the near-infrared region (700 – 1300 nm), leaf cell structures control the optical properties, and absorption in this band is low (10% maximum), but reflection and transmission are high with reflectance up to 50% and transmittance, 40%. For land surveying, the purpose is to measure the ground surface, not the vegetation canopy, it may be advantageous to use NIR laser since it can penetrate the leaves and “see” the ground. In the shortwave Infrared band (1300 to 2500 nm), absorption by leaf water

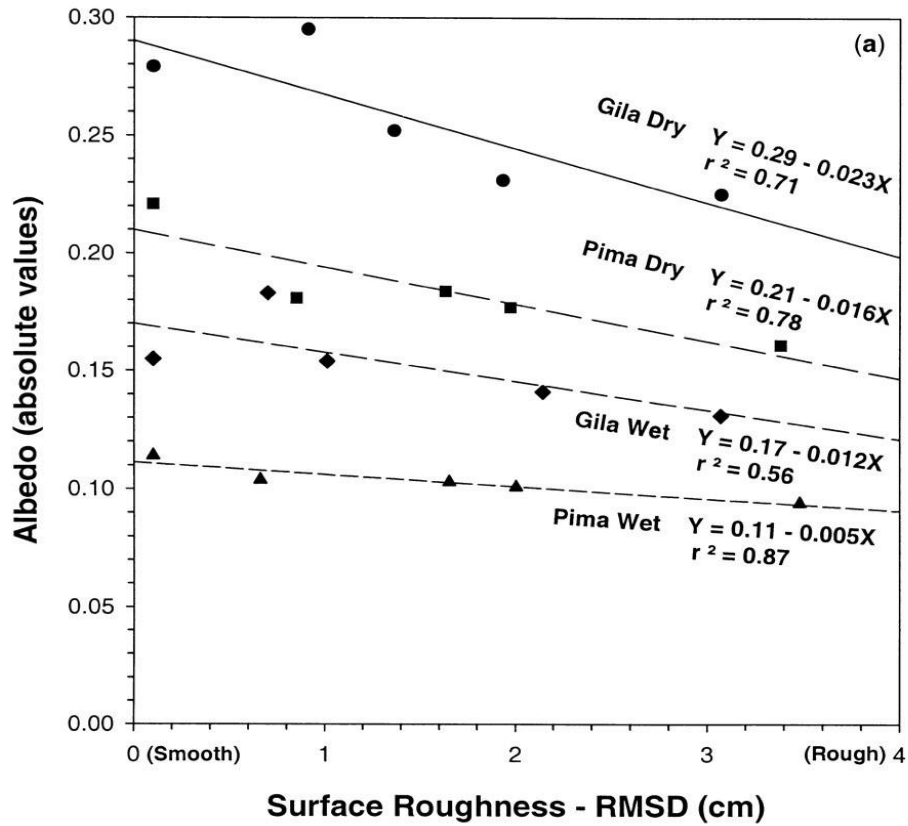


Figure 3.6 Soil Reflectance (albedo) as a function of surface roughness (Matthias et al. 2000).

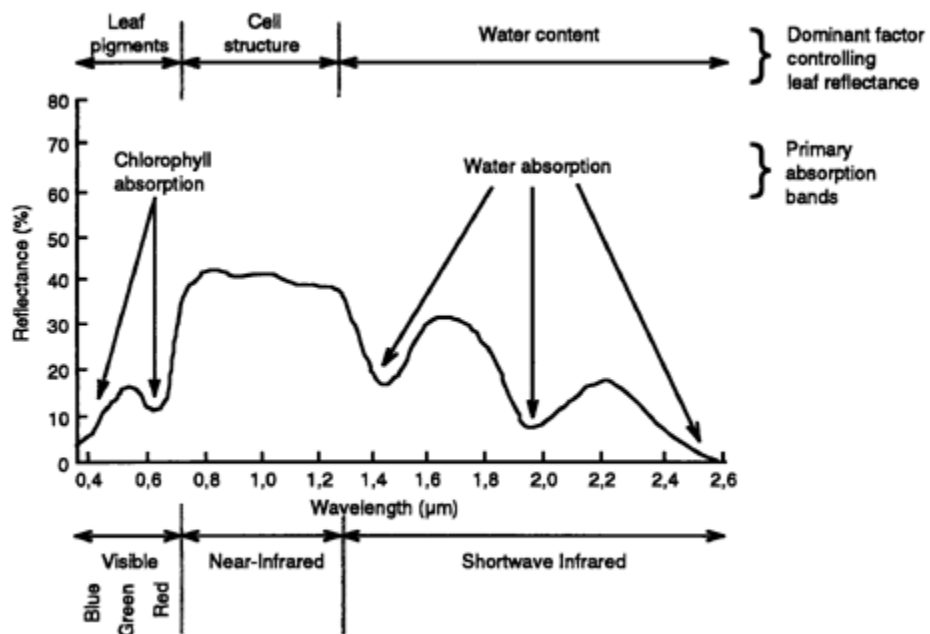


Figure 3.7 Typical reflectance curve of a healthy green leaf ((Leblon, 1996)

becomes a controlling factor and there are three strong absorption band around 1450, 1950 and 2500 nm. Regardless of wavelength, other factors such as age, water status, mineral stresses and healthiness of a leaf also affect the leaf reflectance.

Concrete and asphalt surfaces are also encountered in laser scanning, especially in urban areas. Studies show that concrete and asphalt surface such as parking lot, roads and sidewalks could make up 30 to 45 percent of the urban surface area. The reflectances for these types of surfaces vary considerably in accordance with concrete and asphalt types and ages. Table 2.4 shows the solar reflectance of typical gray Portland Cement concrete and asphalt pavement. In general, reflectance of concrete surface decreases with time as the surface gets rougher and/or darker and reflectance of asphalt increase with time since the surface gets lighter.

Table 2.4 Solar Reflectance for Concrete and Asphalt (After VanGeem, 2002)

Surfaces	Solar Reflectance
New Asphalt	~0.05
Aged Asphalt	~0.1
Aged Concrete	0.2-0.3
Concrete	0.4-0.5

Solar reflectance is an aggregate measure since the solar spectrum ranges from 300 to 2500 nm. A more accurate measure should be the reflectance at a particular wavelength. Figure 3.8 shows the reflectance for a type of aged concrete and asphalt as a function of wavelength in the visible range (400-700 nm). The general trend is similar to that of soil in this spectrum range though the values are different.

Occasionally, laser scanning surveying may also encounter rock surface such as surveying in mountain areas and scanning stone buildings. Reflectance of rock varies considerably from 10% to 55% in accordance with rock composition and color.

3.3 Beam Divergence

Although laser beam is highly collimated in comparison with natural light, it does diverge with distance. The divergence is negligible in many applications, but may not be ignored for precise, long-distance measurement. Beam divergence is a function of wavelength and initial beam diameter. Longer wavelength has larger divergence, and bigger initial beam diameter results in smaller divergence. The relationships can be described with the following formula:

$$\gamma = \beta \frac{\lambda}{D}$$

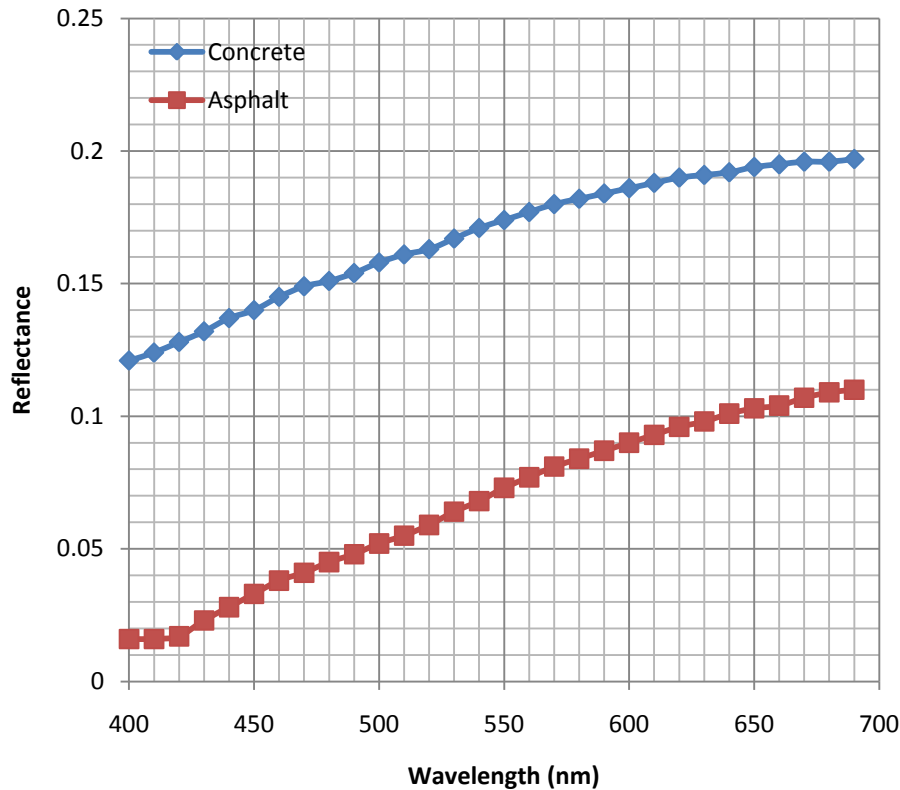


Figure 3.8 Reflectance of concrete and asphalt as a function of wavelength in the visible range. (After Adrian and Jobanputra, 2005)

where γ is the divergence angle in mrad, λ the wavelength, D the initial beam diameter and β a constant. Theoretically, β is greater than 2.44. The divergence angle is illustrated in Figure 3.9.

Beam divergence for terrestrial 3D laser scanner varies with manufacturers. For example, the divergence angles for RIEGL™ series of terrestrial scanners range from 0.15 mrad to 0.3 mrad. Leica™ HDS6000 has a divergence angle of 0.22 mrad. Datasheet of Trimble™ GX 3D scanner did not specify the divergence angle, but based on the spot sizes given at 5m and 15 m, it was calculated that the divergence is 0.06 mrad. In general, one mrad corresponds to a 100mm spot size increase over 100 m distance.

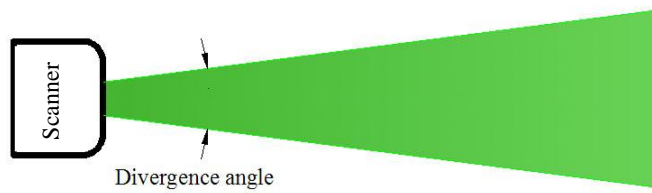


Figure 3.9 Divergence of laser beam

Questions:

1. What is the impact of water content on reflectance?
2. Discuss the reflectances of various surface materials.
3. Calculate the laser spot size 70 meters away from the instrument for a green laser (532 nm) with a initial beam diameter of 1 mm assuming that $\beta=1.5$.