10 Radar Imaging

Active sensors provide their own source of energy to illuminate the target. Active sensors are generally divided into two distinct categories: imaging and non-imaging. The most common form of active imaging sensor is RADAR.

Non-imaging sensors include altimeters and scatterometers. Radar altimeters transmit short microwave pulses and measure the round trip time to targets to determine their distance from the sensor (Canadian Centre for Remote Sensing 2004). Scatterometers are used to make precise quantitative measurements of the amount of energy reflected from targets (Canadian Centre for Remote Sensing 2004). The amount of reflected energy is dependent on the surface properties (roughness) and the angle at which the energy strikes the target.

Radar consists of a transmitter, a receiver, an antenna, and an electronics system to process and record the data (Sabins 1987, Tikhonov 1997, Navalgund, et al. 2007, Lakshmi 2013). The transmitter generates successive short bursts (or pulses) of microwave energy at regular intervals, which are focused by the antenna into a beam. The radar beam illuminates the surface obliquely at a right angle to the motion of the platform and reflects back to the source, similar to the flash of a camera. The antenna receives a portion of the reflected energy (or backscatter) from various objects within the illuminated beam (Sabins 1987). By measuring the time delay between the transmission of a pulse and the reception of the echo from different targets, their distance from the radar and thus their location can be determined (Sabins 1987, Canadian Centre for Remote Sensing 2004).

10.1 Radar Imaging

When discussing microwave energy, the polarisation of the radiation is important. Polarisation refers to the orientation of the electric field. Most radar systems are designed to transmit microwave radiation either horizontally polarised or vertically polarised. Similarly, the antenna receives either the horizontally or vertically polarised echoed energy. There can be four combinations of both transmitted and received polarizations:

1. HH - for horizontal transmit and horizontal receive,
2. VV - for vertical transmit and vertical receive,
3. HV - for horizontal transmit and vertical receive, and
4. VH - for vertical transmit and horizontal receive.

The first two polarisation combinations are referred to as like polarised because the transmitted and receive polarisations are the same. The last two combinations are referred to as cross-polarised because the transmitter and receiver polarisations are opposite of one another.
Both wavelength and polarisation affect how radar interacts with the surface. Therefore, radar imagery collected using different polarization and wavelength combinations may provide different and complementary information about the targets on the surface (Canadian Centre for Remote Sensing 2004).

The imaging geometry of a radar system is different from the framing and scanning systems commonly employed for optical remote sensing. The microwave beam is transmitted obliquely at right angles to the direction of flight illuminating a swath (Avery and Berlin 1992). Range refers to the across-track dimension perpendicular to the flight direction, while azimuth refers to the along-track dimension parallel to the flight direction. This side-looking geometry is typical of imaging radar systems.

The portion of the image swath closest to the flight track of the radar platform is called the near range while the portion of the swath farthest from the flight track is called the far range. Figure 10.1 shows the geometry of an imaging radar system. The incidence angle is the angle between the radar beam and ground surface (A), which increases, moving across the swath from near to far range. The look angle (B) is the angle at which the radar “looks” at the surface (Canadian Centre for Remote Sensing 2004). At all ranges the radar antenna measures the radial line of sight distance between the radar and each target on the surface. This is the slant range distance (C). The ground range distance (D) is the true horizontal distance along the ground corresponding to each point measured in slant range (Canadian Centre for Remote Sensing 2004).

![Figure 10.1: Incident angles.](image)

Unlike optical systems, radar’s spatial resolution is a function of the specific properties of the microwave radiation and geometrical effects. If a Real Aperture Radar (RAR) is used, a single transmit pulse and the echoed signal are used to form the image (Avery and Berlin 1992). In this case, the resolution is dependent on the effective length of
the pulse in the slant range direction and the width of the illumination in the azimuth direction (Canadian Centre for Remote Sensing 2004). The range or across-track resolution is dependent on the length of the pulse \( P \). Therefore:

\[
R_s = \frac{P}{2}
\]  

(10.1)

Therefore, two distinct targets on the surface will be distinguished from one another if their separation is greater than half the pulse length as seen in Figure 10.2. However, when projected into ground range coordinates, the resolution in ground range will depend on the incidence angle. Thus, for fixed slant range resolution, the ground range resolution will decrease with increasing range.

Range resolution is defined as:

\[
P_r = \frac{P \cdot c}{2 \cos \theta}
\]  

(10.2)

where \( P \) is the pulse length in seconds, \( c \) is the speed of light and \( \theta \) is the depression angle, which is the angle between horizontal and bottom of radar beam (i.e. \( 90^\circ - B \)).

The azimuth or along-track resolution is determined by the angular width of the radiated microwave beam and the slant range distance, as shown in Figure 10.2. This beam-width is a measure of the width of the illumination pattern and depends on the radiation pattern and gain of the radar antenna. As the radar pulse travels away from the sensor, the azimuth resolution becomes worse. Azimuth resolution is defined as:

\[
R_a = \frac{0.7S\lambda}{D}
\]  

(10.3)

Where \( S \) is the slant range distance in metres, \( D \) is the antenna length and \( \lambda \) is the microwave wavelength.

Finer range resolution can be achieved by using a shorter pulse length. Finer azimuth resolution can be achieved by increasing the antenna dimensions; however, the actual length of the antenna is limited by what can be carried on an airborne or space-borne platform. For airborne radars, antennas are usually limited to one or two metres in size while for satellites they can be from 10 to 15 metres in length (Canadian Centre for Remote Sensing 2004).

To overcome this size limitation, the forward motion of the platform and Doppler analysis of the echoes are used to simulate a very long antenna and thus increase
azimuth resolution (Avery and Berlin, 1992). This process is called Synthetic Aperture Radar (SAR).

**Figure 10.2: Azimuth resolution.**

### 10.2 Image Distortion

As with all remote sensing systems, the viewing geometry of radar results in certain geometric distortions in the resultant image. However, there are key differences for radar imagery, which are due to the side-looking geometry, and the fact that the radar is fundamentally a distance-measuring device (Canadian Centre for Remote Sensing 2004).

Slant-range scale distortion occurs because the radar is measuring the distance to features in slant-range rather than the true horizontal distance along the ground. This results in a varying image scale, moving from near to far range (Figure 10.3). This causes targets in the near range to appear compressed relative to the far range. Using trigonometry, ground-range distance can be calculated from the slant-range distance and platform altitude to convert to the proper ground-range format.

Similar to the distortions encountered when using cameras and scanners, radar images are also subject to geometric distortions due to relief displacement. As with scanner imagery, this displacement is one-dimensional and occurs perpendicular to the flight path; however, the displacement is reversed with targets being displaced towards, instead of away from the radar flight path (Canadian Centre for Remote Sensing 2004). Radar foreshortening and radar layover are two consequences, which result from relief displacement. Layover occurs when the radar beam reaches the top of a tall feature before it reaches the base. The return signal from the top of the feature will be received before the signal from the bottom (Canadian Centre for Remote Sensing 2004).
Both foreshortening and layover result in radar shadow. Radar shadow occurs when the radar beam is not able to illuminate the ground surface (Canadian Centre for Remote Sensing 2004). Shadows occur in the down range dimension (i.e. towards the far range), behind vertical features or slopes with steep sides.
10.3 Target Interaction and Image Appearance

The brightness of features in a radar image is dependent on the portion of the transmitted energy that is returned back to the radar from targets on the surface. The magnitude or intensity of this echoed energy is dependent on how the radar energy interacts with the surface. This depends on the particular characteristics of the radar system (frequency, polarization, viewing geometry, etc.) as well as the characteristics of the surface (land cover type, topography, relief, dielectric properties etc.). Because many of these characteristics are interrelated, it is impossible to separate out each of their individual contributions to the appearance of features in a radar image.

For the purposes of discussion, these characteristics can be grouped into three areas, which fundamentally control radar energy/target interactions. They are:

1. Surface roughness of the target
2. Radar viewing and surface geometry relationship
3. Moisture content and dielectric properties of the target

The surface roughness of a feature controls how the microwave energy interacts with that surface or target and is generally the dominant factor in determining the tones seen on a radar image. Surface roughness refers to the average height variations in the surface cover from a plane surface. Whether a surface appears rough or smooth to radar depends on the wavelength and incidence angle. A surface will appear smooth if the height of any features is less than the Rayleigh criterion, which is defined as:

\[ h_r = \frac{\lambda}{8 \sin \theta} \]  

(10.4)

Where \( \lambda \) is the microwave wavelength and \( \theta \) is the depression angle.

Incidence or look angle in relation to viewing geometry and how changes in this angle affect the signal returned to the radar have already been discussed. However, in relation to surface geometry, and its effect on target interaction and image appearance, the local incidence angle is a more appropriate concept. The local incidence angle is the angle between the radar beam and a line perpendicular to the surface at the point of incidence. Thus, local incidence angle takes into account the local slope of the terrain in relation to the radar beam. With flat terrain, the local incidence angle is the same as the look angle of the radar. For terrain with any type of vertical relief, this is not the case. Generally, slopes facing towards the radar will have small local incidence angles, causing relatively strong echoes, which results in a bright-toned appearance within an image (Canadian Centre for Remote Sensing 2004). Conversely, slopes facing away from the radar will appear to be darker.

The presence (or absence) of moisture affects the dielectric properties of objects (Sabins 1987). Changes in the dielectric properties influence the absorption,
transmission, and reflection of microwave energy; therefore, the moisture content will influence how targets and surfaces reflect energy from radar and how they will appear in an image (Sabins 1987). Generally, reflectivity (image brightness) increases with increased moisture content (Canadian Centre for Remote Sensing 2004).

If the radar energy does manage to penetrate through the topmost surface, then volume scattering may occur (Canadian Centre for Remote Sensing 2004). Volume scattering is the scattering of radar energy within a volume rather than from an outer surface, and usually consists of multiple bounces and reflections from different components within the volume. For example, in a forest, scattering may come from the leaf canopy at the tops of the trees, the leaves and branches further below, and the tree trunks and soil at the ground level. Volume scattering may decrease or increase image brightness, depending on how much of the energy is scattered out of the volume and back to the radar (Canadian Centre for Remote Sensing 2004).

10.4 Airborne versus Space-borne Radar

Like other remote sensing systems, an imaging radar sensor may be carried on-board either an airborne or space-borne platform. There are trade-offs between the two. Regardless of the platform used, a significant advantage of using a Synthetic Aperture Radar (SAR) is that the spatial resolution is independent of platform altitude (Canadian Centre for Remote Sensing 2004); therefore fine resolution can be achieved from both airborne and space-borne platforms.

Although spatial resolution is independent of altitude, viewing geometry and swath coverage can be greatly affected by altitude variations. At aircraft operating altitudes, an airborne radar system must operate over a wide range of incidence angles, perhaps as much as 60 or 70 degrees, in order to achieve relatively wide swaths; therefore foreshortening, layover, and shadowing will be subject to wide variations, across a large incidence angle range (Canadian Centre for Remote Sensing 2004). On the other hand, space-borne radar operating at altitudes of several hundred kilometres has a much narrower range of incidence angles, typically ranging from 5 to 15 degrees (Canadian Centre for Remote Sensing 2004). This provides for more uniform illumination and reduces undesirable image variations across the swath due to viewing geometry.

Although airborne radar systems may be more susceptible to imaging geometry problems, they are flexible in their capability to collect data from different angles and directions. Space-borne radar does not have this degree of flexibility, as its viewing geometry and data acquisition schedule is controlled by the pattern of its orbit.

As with any aircraft, airborne radar will be susceptible to variations in velocity and other motions of the aircraft. Thus the radar system must use sophisticated positioning equipment to compensate for these variations. Space-borne radar is not affected by motion of this type. Indeed, the geometry of their orbits is usually very
stable and their positions can be accurately calculated; however, geometric correction of imagery from space-borne platforms must take into account other factors, such as the rotation and curvature of the Earth (Sabins 1987).

10.5 Ground Penetrating Radar

Ground penetrating radar (GPR) has been used for over twenty years at chemical and nuclear waste disposal sites as a non-invasive technique for site characterization. More recently GPR is being used in the horticultural industry to map the distribution of tree roots for better orchard and landscape management. Standard GPR surveys are conducted from the surface of the ground providing geotechnical information from the surface to depths of between 2 and 15 m, depending on GPR frequency of operation and soil conductivity. Commercially available GPR systems operate over the frequency range 50 MHz to 1000 MHz. Lower frequencies provide better penetration but poor resolution, while the higher frequencies give poor penetration but good resolution.

Soil water content is a key control for plant growth and health. Recent studies have shown that careful irrigation management can have beneficial effects on many crops, including almonds, citrus, prunes, pistachios and wine grapes. In particular, moderate water stress on grapevines early in the growing season can have a positive impact on grape quality. Hubbard et al. (2005) used 900 MHz GPR ground-wave travel time data, to estimated soil water content distribution in the top 15 cm of soil in a Californian Vineyard. Comparison with conventional ‘point’ soil moisture measurements, obtained using time domain reflectometry (TDR) and gravimetric techniques revealed that the estimates of GPR-obtained volumetric water content estimates were accurate to within 1 % by volume (Hubbard, et al. 2005).

Barton et al (2009) have used GPR to investigate tree roots (Barton and Montagu 2004) and wood decay (Butnor, et al. 2009) in living trees. They found that tree roots could be successfully mapped using GPR operating at 500 MHz (Barton and Montagu 2004). When using GPR to assess wood quality, they also demonstrated that near-surface wood decay, air-filled voids and desiccated boles had unique electromagnetic signatures, which could be separated from other defects. GPR successfully estimated the percent area of air-filled cavities and was not significantly different than results from destructive sampling (Butnor, et al. 2009).

GPR can also be used to map soil properties around agricultural landscapes; however GPR systems are not common and can be expensive. The next chapter will explore the use of electromagnetic survey systems for mapping soils.
References


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