NASA Computational Case Study
SAR Data Processing: Ground-Range Projection

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NASA Science Application: Earth Sciences, Planetary Sciences, remote sensing, radar and SAR data processing.
Computational Algorithms: Projection and interpolation.

Abstract- Radar technology is used extensively by NASA for remote sensing of the Earth and other Planetary bodies. In this case study, we learn about different computational concepts for processing radar data. In particular, we learn how to correct a slanted radar image by projecting it on the surface that was sensed by a radar instrument.

1   Introduction

Remote sensing refers to collection of information about an object without being in physical contact with it [5]. This information can be gathered via satellites, cameras on airplanes, or sensors that are distributed over an area. Depending on the data acquisition method used, there are various ways of processing and interpreting the obtained information. *Radio Detection and Ranging (Radar)* is a widely used technology in remote sensing, which was originally developed for military applications during World War II [1]. This technology is based on sending and receiving radio signals, recording each signal's travel time to and from the target, and estimating the target's location based on this accurate measurement. Radar measurements are desired for remote sensing applications because they can pass through clouds without significant loss of their information, and they work the same way at different illumination levels (e.g. day vs. night time) [1].

Figure 1 shows a typical side-looking radar instrument. *Azimuth*, or *along-track*, direction is a vector parallel to the sensor's motion vector, while *nadir* is a point on Earth's surface directly under the sensor [1,2]. The direction along which the radar beams are sent is called the *range* direction. More specifically, the distance from the radar to a ground point within the measurement area is called the *slant range* to that point [3]. The distance from nadir to any ground target point is that point's *ground range* [3]. From an image analysis point of view, the slant range resolution image is not of interest, rather its projection onto a ground range resolution [4].

After collecting the radar measurements and processing them (some of which you will learn about in this case study), one can obtain a two-dimensional image, along range and azimuth directions, of the area over which the radar instrument's signals were sent to and received from. Each pixel in that image represents a physical location on earth. The corresponding physical length of the side of an image pixel along the range direction is its *ground range resolution*. The ground range resolution, r_g (pixel size on ground), is given by

$$r_g \quad = \quad \frac{C\tau}{2\sin(\theta_{Look})}, \tag{1}$$

where C is the velocity of light measured in meters per second, τ is the pulse duration in seconds, and θ_{Look} is the signal's look angle as shown in Figure 1 [4]. A signal's bandwidth, B, is the inverse of its transmission
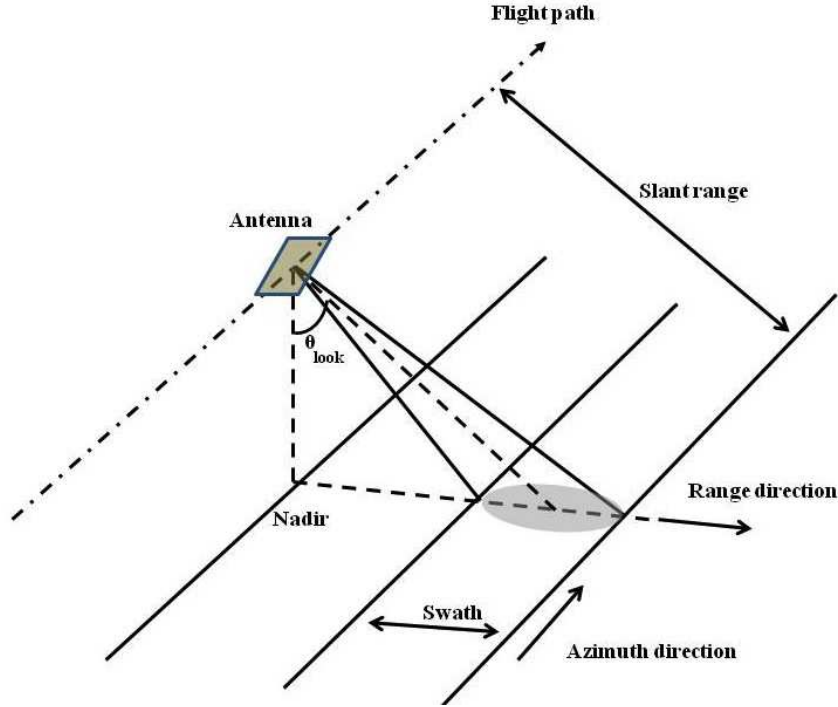
Figure 1: A typical side looking radar, flown on an aircraft or satellite, pointing perpendicular to the flight path.

duration, and is measured in units of *hertz*. The hertz a unit of frequency representing the number of cycles a pulse with τ duration has in a second. Thus, the above relationship is also often represented as

$$r_g \quad = \quad \frac{C}{2B \sin\left(\theta_{Look}\right)}. \tag{2}$$

The slant range is directly related to how fast a signal travels to the target from the antenna and back. In other words, it is a function of the radar's frequency and the velocity of light, C. The slant resolution r_s is calculated as

$$r_s \quad = \quad \frac{C}{2B}. \tag{3}$$

Question 1: How does the ground resolution change at larger incident angles?

Similarly, the corresponding physical length of each pixel along the azimuth direction is called the *azimuth resolution*. The azimuth resolution is calculated as

$$r_a \quad = \quad \frac{R_0 \lambda}{l}, \tag{4}$$

where l is the antenna length, or aperture, in the along-track dimension. R_0 is the distance between the antenna and the target, and λ is the wavelength of the signal [2, 4].

Question 2: What would be the azimuth resolution for a signal transmitted at a range of 2km and 40cm

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wavelength from a 5m antenna? What size antenna should be used in order to get a forty meters azimuth resolution for the same signal? What would be the size of an antenna yielding a one meter azimuth resolution for the same signal? How does changing the antenna aperture affect the azimuth resolution?
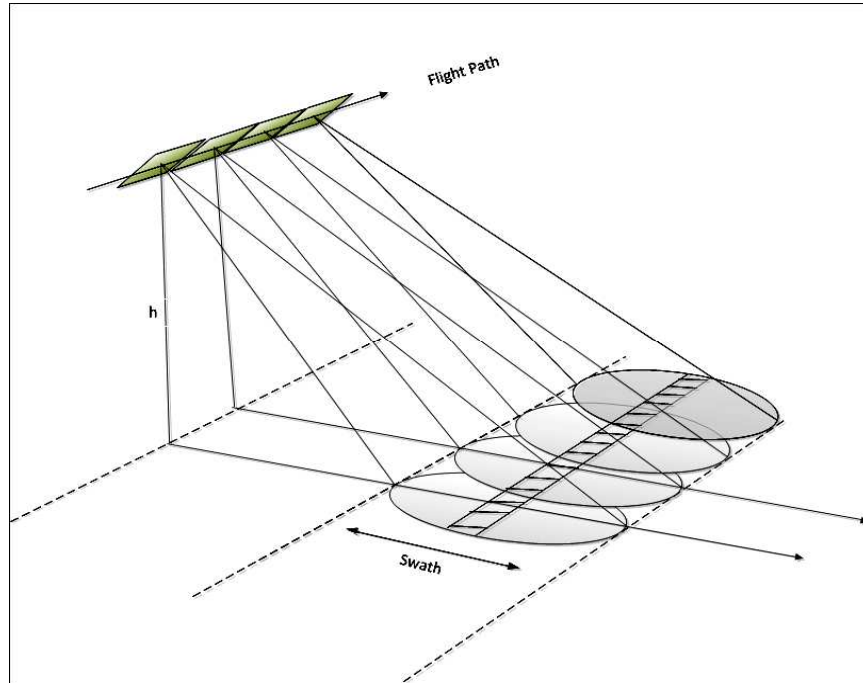

Figure 2: Synthetic generation of a large antenna by moving a small antenna in azimuth direction.

Building, operating, and flying or launching large antennas are expensive, impractical, and at times impossible. In order to overcome the limitations of having a large antenna, a *Synthetic Aperture Radar (SAR)* technique is used to give the effect of a long antenna, or so-called synthetic aperture, without having one [4]. This approach essentially utilizes the motion of the antenna along the azimuth direction during transmission of the ranging pulses. Figure 2 demonstrates this idea. There are different ways of synthetically generating the effects of a very large antenna. For example, in *Stripmap SAR*, the antenna's pointing direction is held constant while its platform moves [1]. In *ScanSAR*, the antenna's pointing direction moves in order to cover a larger imaged width or *swath*. In this case study, we are concerned with processing data that was captured in ScanSAR mode.

2 Problem Description

In this section we will learn how to convert the slant range SAR data to its ground range projection. Before doing so, we practice calculating various quantities, illustrated in Figure 3.

Question 3: Suppose the radar's Look angle, θ_{Look}, is 30 degrees, and the antenna's beamwidth, θ_{Beam}, is 19.5 degrees. The antenna's height is 3950 meters. Calculate R_{far}, the slant range from the antenna to the farthest pixel, in meters. Similarly, calculate R_{near}, the range from the antenna to the closest pixel.

Question 4: What would be the length of R_g, the range from nadir to the closest pixel, in meters for the radar described in Question 3?
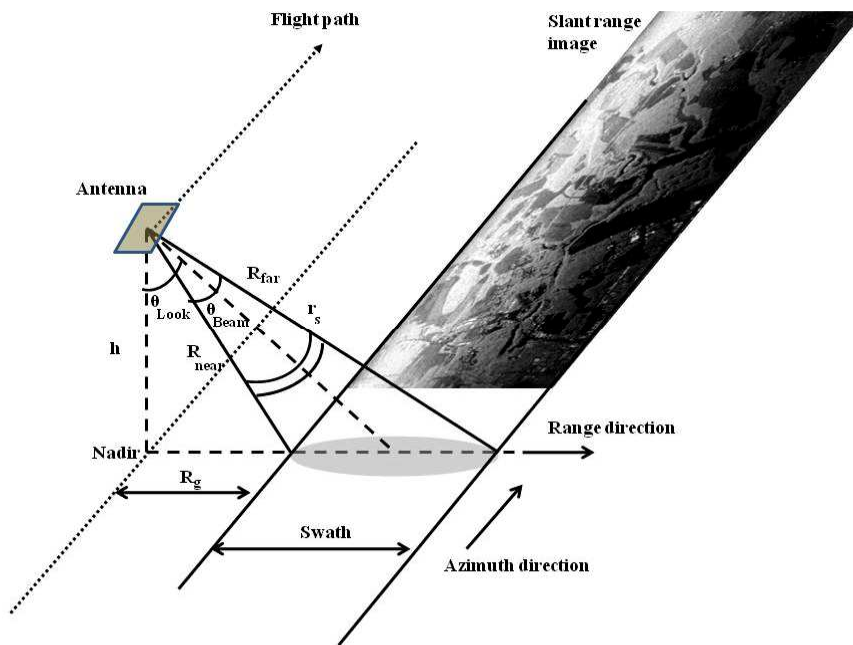
Figure 3: The antenna and slant range image properties. Radar measurements are made in the range direction, resulting in a slanted observed image in that direction. ....Slanted images have to be corrected for their representations on the ground.

Question 5: What would be the total *ground range*, the distance which is measured along the surface of the Earth for the same radar? In other words, if near range is the first point on the ground that was sensed, and far range is the sensed ground point at the greatest distance normal to the flight path, what is the distance between the near range and the far range in meters?

Now that you know how to calculate various quantities for SAR data processing, let's start working with some SAR data. This data was obtained with an antenna flying on a ScanSAR mode, with a bandwidth of 20 megahertz (10^6 hertz). The distance of the instrument from nadir is 3950 meters. The radar started scanning from a 16.5 degree *start angle*. That is the angle between the antenna and R_{near} in Figure 3 is 16.5 degrees.

Question 6: What is the slant resolution of the above mentioned radar in meters?

Activity 1: Load the two-dimensional SAR data for this problem stored in Matlab data format file titled 'singleLookAvg.mat'. Report the name, size, and type of data that you have just loaded. Display the two dimensional SAR data in gray scale. Save the results in a .jpg file. How does this image look to you?

Hint: You can alternatively read the data from a text file called 'singleLookAvg.txt'. This file contains 10 numbers on each line. The image data is written column by column, and each column has 20,000 values.

Activity 2: Convert the intensity values of the SAR data to *Decibel (dB)* and display the result. Decibel is a logarithmic unit for the ratio of two physical quantities. For example, for a power density value x, its decibel conversion relative to its unit is calculated as $20 \log_{10}(x)$. This is how SAR data is often displayed and for the rest of this case study, we continue to display our results in this manner.

Activity 3: Calculate the corresponding ground location for each pixel of the image. How many of such conversions you should perform for a SAR image of size $r \times c$, where r and c represent number of rows and columns respectively?

Hint: Use the radar's slant resolution and start angle.

Activity 4: Convert the slant range radar data to its ground range projection so that each pixel's resolution is 20 meters. How does the final number of pixels in ground range compare to the original number of pixels in slant range data? Display the results.

Hint 0: Process the data in one dimension, one row at a time.
Hint 1: Consider the triangle formed by h, R_g, and R_{near} in Figure 3. Calculate R_g. This is the ground location of the first pixel.
Hint 2: Similarly for other pixels, consider a right triangle with the vertical right side h, and a hypotenuse that increases in length by r_s, the slant resolution, from one pixel to the next. Calculate the ground location for each pixel using such a triangle.
Hint 3: How many pixels of size 20 meters will fit within the swath, the width of the imaged area on the ground?
Hint 4: Now you have ground locations of all the pixels. What is the distance between the first two pixels? How about the last two? How would you map the pixels to equidistant pixels of size 20 meters each? What would you do if more than one pixel in the slant image map to the same 20-meter pixel on the ground?

Activity 5: Convert the slant range radar data to its ground range projection so that each pixel's resolution is 10 meters. How does the final number of pixels in ground range compare to the original number of

pixels in slant range data? What did you have to do differently this time compared to the previous Activity? List computational issues you faced and describe how you resolved them. Display the results.

Extra Activity: Produce the ground range image of the provided data so that each pixel's resolution is 4 meters. Did you have to make any changes to your initial algorithm in order to improve the quality of the result or the algorithm's running time? If so, report how you overcame your initial algorithm's limitations for obtaining better results (faster). Display the results.

References

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