

Airborne SAR radiometric calibration using point targets

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Abstract. The trihedral corner reflector, with high stability, large RCS and little change within a wide angle range, is widely used in SAR radiometric calibration. Results from airborne SAR overflights of corner reflectors are utilized to compute calibration constant, transfer function of the system and backscattering coefficient of different targets. The key step of SAR calibration is the derivation of calibration constant. In this paper, we used two methods, the peak and integral method, to compute the calibration constant. Through real flight data, we found that, using point target for SAR calibration is simple and practicable.

1. Introduction

The quantitative use of SAR data requires accurate calibration^[1]. SAR images acquired from different sensors, different temporal or spatial can be comparative after calibration. The calibration can be divided into internal and external calibration. Internal calibration technology was designed within the SAR system used in upload machine monitoring some system parameters, such as transmit pulse power; external calibration technology refers to the use of precision calibration equipment arranged in the calibration field of ground to measure SAR system parameters, such as coefficient scaling constant and system transfer function^[2].

The calibration program can be divided into two categories: the calibration based on the point targets or the distributed target. Point targets in airborne SAR radiometric calibration is much simpler than the use of distributed targets, and can achieve the necessary calibration accuracy, so point target calibration method becomes a commonly used method^[3]. For point targets, two different methods have been used to relate the scattering cross section of the point target to the received energy: the peak method and the integral method. Both the methods have its merits and demerits^[4].

We carried out an experiment to discuss the practicability of the two methods. The signal-to-clutter ratio (SCR) was discussed and the backscattering coefficient of typical objects were computed at last.

2. SAR calibration Models

According to the radar equation and SAR imaging principle, the SAR image pixel power, if corresponds to the average output power of the signal, can be described as follows:

Point target average output power:

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$$P_p = \frac{P_t g^2 G^2(\theta, \phi) \lambda^3 G_s \tau_p f_s f_{PRF}}{2(4\pi)^3 R^3 V \rho_a} \sigma \quad (1)$$

Distributed target average output power:

$$P_d = \frac{P_t g^2 G^2(\theta, \phi) \lambda^3 G_s \tau_p f_s f_{PRF} \rho_r}{2(4\pi)^3 R^3 V \sin \theta} \sigma_0 \quad (2)$$

Where P_t is the transmit signal power; $g^2 G^2(\theta, \phi)$ is two-way antenna pattern; G_s is system receiver gain; λ is the wavelength of the transmitted signal; R is the slant range of the synthetic aperture radar and target; τ_p is pulse width; f_s is the distance in the sampling frequency range; V is flight speed; f_{PRF} is radar platform for pulse repetition frequency, ρ_a, ρ_b is azimuth and slant range resolution; σ is radar cross section; σ_0 is backscattering coefficient.

From the formulas above, we find that there are many common elements between them. In the process of mutual comparison, these common elements can be eliminated, thereby deriving out a condensed calibration equation.

3. Calibration constant

Using corner reflector for SAR calibration, you need first set up a series standard angle reflectors with known scattering cross section on the ground calibration field. Through the image of the calibration field, we can relate the theoretical scattering cross-section of the standard angle reflectors (σ_{ref}) to the corresponding image power (\mathcal{E}_p)^[5], the calibration constant:

$$K_i = \frac{\mathcal{E}_{p_i}}{\sigma_{ref} \sin \theta_i} \quad (3)$$

Where, \mathcal{E}_{p_i} is the energy associated with the point target i ; σ_{ref} is the theoretical radar cross-section of the corner reflector; θ_i is the incidence angle of the target i .

In order to improve the precision, the number of samples should be as much as possible. Using the average of the measured values corresponding to the point targets as the final measurement result of the calibration, i.e. calibration constants were determined as follows:

$$K = \frac{1}{N} \sum_1^N K_i \quad (4)$$

From the description above, we can see that the key step of measuring calibration constant is how to extract the point target pulse response energy. Usually there are two methods, namely the peak method and the integral method. The peak method obtains the energy by multiplying the response peak and the equivalent resolution cell area; the integral method adopts energy by integrating a specific area of the impulse response.

3.1. Integral method

We described the point target as a 15 rows \times 15 samples region centered with the peak point. The structure and size of the integration region are shown in Fig. 1.

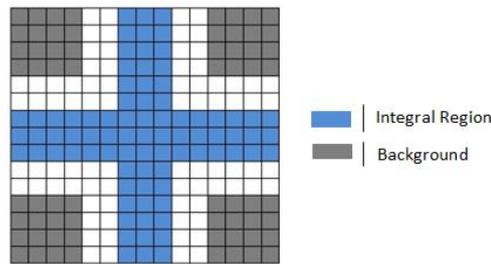


Figure 1. Integral method sketch map. Blue is the energy integral region, gray as the background area.

In Fig.1, the smallest square stands for a pixel. Among them, the blue area is the energy integral region, the number of pixels is N_A ; the gray region is the background area, the number of pixels is N_B ; the pixel spacing respectively is $\delta_a \delta_b$, the total energy of the integral region is:

$$\varepsilon_p = \left(\sum_{i \in A} DN_i^2 - \frac{N_A}{N_B} \sum_{i \in B} DN_i^2 \right) \delta_a \delta_b \quad (5)$$

Where, DN_i^2 is the image power associated with pixel i .

3.2. Peak method

In contrast to the method recommended above, one cannot avoid the explicit consideration of the range and azimuth resolution when using the estimated peak value of a reflector in an SAR image. SAR image resolution is the 3dB antenna main lobe width of impulse response. Weighted case, IRW fair width is about 20%, namely 1.2 to 1.5 pixels^[6].

$$\varepsilon_p = DN^2 ab \delta_a \delta_b \quad (6)$$

Where, a b is the IRW fair width in range and azimuth.

The reference [4] discussed the advantage and disadvantage of both the methods above. In this paper we had not compared the two methods, but used the ratio of the result computed in the two different methods to examine the result.

4. Radiometric calibration

After we got the calibration constant (k), it was easily to acquire the final calibrated image, then we detected the signal-to-clutter ratio (SCR) and the backscattering coefficient of some typical surface features to examine the accuracy of the calibration result.

4.1. Determination of sigma-nought

After relative radiometric calibration of SAR image, the image pixel power has a linear relationship with the target backscatter coefficient. The SAR images after calibration constant correction became images of backscattering coefficient, whose pixel power was a direct reflection of the target backward scattering coefficient. The system transfer function is:

$$\sigma^0 = \frac{DN^2}{K} \cdot \sin \theta \quad (7)$$

Where, DN is pixel value; K is calibration constant.

4.2. Detection of signal-to-clutter ratio

We considered the maximum calibration error using a point target in a background random scene and showed it to be determined by the signal-to-clutter ratio (SCR):

$$SCR = \frac{\sigma_{pq}^T}{\sigma_{pq}^c} = \frac{\sigma_{pq}^T \sin \theta_i}{\langle \sigma_{pq}^0 \rangle P_a P_r} \quad (8)$$

Where σ_{pq}^T is the point target RCS and $\langle \sigma_{pq}^c \rangle$ the average background clutter RCS, which is related to the normalized average clutter RCS $\langle \sigma_{pq}^0 \rangle$.

To measure the target signal-to-clutter ratio from an actual SAR image, the ratio of the peak power in the target impulse response to the mean background clutter power, estimated from an area located close to the target, is often used. In Fig.2, we describes the SCR compute region. If you want to obtain a precisely calibration result, the SCR should great than 20dB.

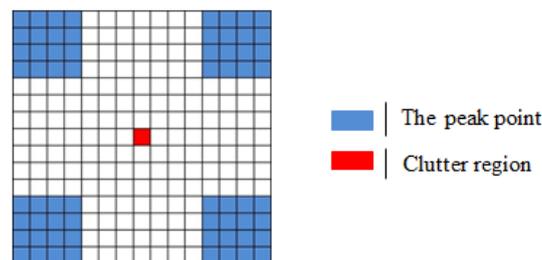


Figure 2. SCR compute region. The red pixel is the peak point, the blue pixels are the clutter regions.

4.3. Typical surface features detection

SAR data becomes σ^0 image after calibration. We compared some typical surface features with the records in the book “Handbook of Radar Scattering Statistics for Terrain” [7], to check the calibration precision.

5. Calibration experiment

5.1. Introduction of calibration field

We used an airborne X-band SAR image acquired in Rizhao Golden Sands beach, January, 2013. The X-SAR system parameters are summarized in Table1.

Table 1. System parameters of the X-band SAR

Wavelength	0.033m
Azimuth sampling distances	0.3582m
Slant range sampling distances	0.375m
Flight height	2998.3m
Incedent angle	70degree
Flight velocity	59.6414m/s

We used two corner reflectors with side length of 0.3706m and 0.4159m.

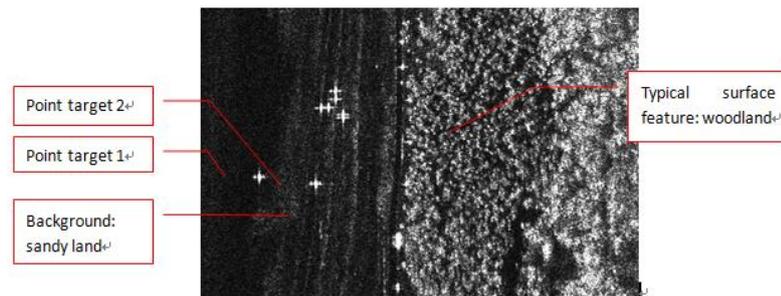


Figure 3. Calibration field, the two bright spots on the lower left are the point targets used for this calibration experiment.

The left of the image, just like the marked region on the image above, with a little gray is sandy land; in the right of the image, where it is obviously rough and a little bright, is the woodland.

5.2. Experiment result

Table.2 shows the calibration constant computed using the peak method.

Table 2. Calibration constant using peak method

Point target	Peak point target energy(ε_p)	Point target theoretical RCS(σ_{ref})	Calibration constant(k)
1	60538.75	72.557503	30.326715
2	74247.06	115.08437	29.209833
Mean calibration constant(k)		29.7683 dB	

The peak method requires knowledge of the equivalent rectangle system resolution which is sensitive to system focus. While the integral method is independent of actual resolution. Table.3 shows the calibration constant computed using the integral method.

Table 3. Calibration constant using integral method

Point target	Point target energy(ε_p)	Point target theoretical RCS(σ_{ref})	Calibration constant(k)
1	156872.23	72.557503	34.461842
2	195702.88	115.08437	33.419012
Mean calibration constant(k)		33.9404 dB	

After calibration constant $K = 33.9404$ dB determined, the transfer function $\sigma^0 = \frac{DN^2}{K} \sin \theta$ will also be determined. The image center incidence angle is a system parameter. If the incident angle between the short-range point and the distant point is too different, we need to consider in the changes during the entire image calibration.

Table.4 shows the SCR of the two points with their nearby region. The result, $RCS = 27$ dB illustrates that the calibration field meets the requirements of SAR calibration.

Table 4. Signal-to-clutter ratio (SCR)

Point target	Point target relative coordinate	Point target theoretical RCS(σ_{ref})	Clutter average RCS
1	(80 234)	18.606823 dB	-8.3639755 dB
2	(157 243)	20.610163 dB	-7.3699951 dB
Mean signal-to-clutter ratio(SCR)		27.4755 dB	

Fig.4 is the calibrated σ^0 image. We selected a part of woodland in the calibrated σ^0 image, as the typical surface feature detection region, and computed the average of the σ^0 . The result, $\sigma^0 = -6.66287$ dB which meets the value of woodland backscattering coefficient recorded in the book “Handbook of Radar Scattering Statistics for Terrain” [7].

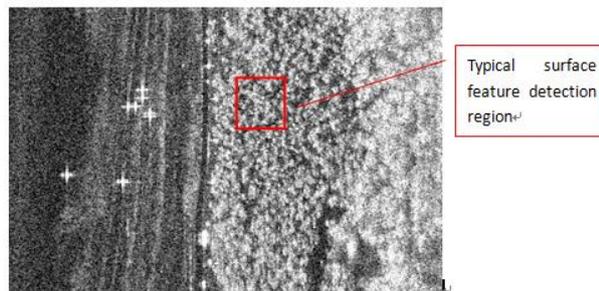


Figure 4. The calibrated σ^0 image. The region of the red rectangle is a part of forest, which has a stable scattering intensity.

6. Conclusion

SAR radiometric calibration technology is the premise of any quantitative analysis for the study of the measured data. The quantitative relationship between the measured data and the calibrated data can be obtained through the calibration of the measuring equipment. The calibrated data laid the foundation for the application of the SAR image from different equipment, different time and different space. In this paper, we derived methods that using point targets known scattering cross section to calculate the backscatter coefficients, the system calibration constant and the system transfer function by the integral and peak method. Through the real flight data, we obtained the final image, the SCR and the average sigma nought of some typical surface features. The experiment result suggests that our calibration method is feasible. Usually airborne SAR calibration needs the correction of antenna pattern. In this X-SAR system, we had got a high precision of antenna pattern through internal calibration, so we did not detected the antenna pattern this time. In the next experiment we will do some work on the estimate of antenna pattern through external calibration to further improve the accuracy of calibration.

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