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APPROACH FOR ABSOLUTE RADIOMETRIC CALIBRATION OF RISAT-1 SAR DATA USING STANDARD TARGET

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Abstract

Just like any other mechanical instrument SAR sensorsalso add its own noise to the received signals. Also even putting the best efforts in precaution and post-caution of SAR sensor design, development and satellite launch; once the sensor is in orbit its resulting data will fluctuate from laboratory tests. This fluctuation amount varies from sensor to sensor. Also each SAR sensor's transmit power levels may vary which results in different received power for same illuminated area from different sensors (keeping all system and target properties same). Calibration provides a solution to above problems. Radiometric calibration procedure of SAR data provides a reference mechanism to SAR amplitude data and calibration constant is the key to get a radiometric calibrated SAR image. By using this calibration constant digital numbers are converted to backscattering coefficient. Using standard targets is the most efficient way to perform radiometric calibration of SAR data. Impulse response function is generated from deployed standard targets which initiates the process to derive calibration constant.

This paper uses integral box method as an approach to derive calibration constant of RISAT-1 SAR data. Also an equation has been derived to calibrate various beam modes of RISAT-1 SAR data using the derived calibration constant.

Keywords—Absolute Radiometric Calibration, Calibration constant, Impulse Response Function, RISAT-1, Standard Target, Synthetic Aperture Radar

Introduction

Almost a century later after Heinrich Hertz proved that Maxwell's theory of electromagnetic radiation was correct, radar remote sensing community was gifted by the launch of first spaceborne SAR sensor Seasat, in 1978 AD. However due to unavailability of any other space borne SAR sensor most of the analysis done with Seasat data was qualitative. Today SAR community is having huge amount of data from various retired and currently operational SAR satellites e.g. SIR-A, SIR-B, SIR-C/X, ERS-1/2, JERS, Envisat, ALOS-1/2, RISAT-1, TerraSAR-X, Tandem-X and lots of SAR sensors are planned to be launched in near future e.g. RISAT-3, RADARSAT-3, DESDynl, BioSAR, NISAR, SMAP. Also due to globalization and advancement in communication technology data from any satellite can be very easily accessed. This huge amount of data from various satellites and bundled information within the data itself (viz. phase as well as amplitude) assigns a responsibility to users too to check whether SAR data values from different sensors, for a given area are within same range or not (keeping system and target properties kept identical). Being assured that different sensors are providing identical data, quantitative analysis can be performed. Making amplitude information from different sensors identical involves a mechanism called radiometric calibration and dataset is referred as radiometrically calibrated data. Calibrated SAR data has helped developing number of hypothesis and lots of them converted to established theories [1-3].Radiometrically calibrated SAR data has also helped to compare results from various sensors [4-6], which in turn provided opportunity to develop parameter retrieval models for various applications [7-15]. For a given SAR image, the digital number (DN) is proportional to the received voltage [16]. Therefore, the image intensity I, is proportional to the received power Pr. The process to retrieve SAR backscattering coefficient from the observed SAR image intensity is known as radiometric calibration [17]. Radiometric calibration procedure provides a reference mechanism between SAR DN values and known Radar Cross Section (RCS) of a deployed standard target or distributed target [18-20].

SAR calibration can be carried out by analyzing standard targets response as well as reference distributed targets analysis [20-23]. Amazon Rainforest is an established distributed target for SAR data calibration as announced by SAR subgroup of Working Group on Calibration and Validation (WGCV) of Committee on Earth Observation Satellite (CEOS). Canadian Boreal forest is also being used by researchers as distributed target for SAR calibration [24, 25]. There are various standard point targets for SAR data calibration which can be classified based on their nature of functionality viz. active and passive standard targets. In active domain active radar calibrator (ARC) and polarimetric active radar calibrator (PARC) are used whereas in passive domain dihedral corner reflector (DHCR), triangular trihedral corner reflector (TTCR), square trihedral corner reflector (STCR), luneburg lens are used.

This paper provides an approach for calibration of RISAT-1 SAR data from deployed passive standard targets [26, 27]. For this approach integral box method is used. Using this method calibration constant is derived with the help of Impulse Response Function (IRF) of deployed standard targets.

Characteristics of Standard Target Deployment Site

As briefed in [28] to deploy standard targets for calibration of SAR data it is required to first select the sites on the basis of pre-established parameters.

A.Surface roughness

The area should be very homogeneous in context of roughness. If selecting an agricultural field it should be taken into account that it should not be ploughed. When selecting open grounds it should be cared that ground should not be rough or having big stones fluctuating rms height of the ground.

B. Background Contribution

Apart from roughness it should also be taken care that the selected field should be very dry and there should not be any vegetation in the ground. The basic concept is that SAR should getlow or no backscatter from the groundsurrounding the deployed standard target.

C. Dimensions of a Typical Deployment Site

The selected area should be sufficiently large so that it can contain main lobe as well as side lobes of the standard target. It should contain at least 10 resolution pixels of the SAR data being calibrated in azimuth as well as range direction. An ideal field fulfilling all the above mentioned criteria is shown in Fig.2.

Fig. 2: Ideal site for standard target deployment

RISAT-1

Radar Imaging SATellite (RISAT-1) is India's first indigenously developed space borne SAR sensor. This C-band active antenna based, multi-mode SAR payload was launched on 26th April 2012 by PSLV-C19 flight. After positioning at 536 km sun-synchronous dawn-dusk circular orbit it was operated on May 1, 2012. RISAT-1 mission is designed to provide SAR images with a repetivity period of 24 days. Its orbit design takes the space craft crossing the equator in its descending path (north to south) at 6 AM and crosses the equator in its ascending path (south to north) at 6 PM. RISAT-1 SAR sensor transmits a series of electromagnetic pulses of radiation in C band using an active array antenna of 576 transmit receive modules mounted in panel of ~6m X 2m. The electromagnetic pulses strike the earth surface and the backscattered signal is received by the receive modules mounted in the antenna and by time correlated processing of this signal, information about the earth surface is deciphered. RISAT-1 is not only capable of acquiring data in multi polarization mode, including quad linear polarization, but it is also first of its kind to operate in hybrid circular polarimetric mode for earth observation [24, 25]. Fig.1 shows a diagram of RISAT-1 SAR beam modes. Specifications of RISAT-1 SAR beam modes are given in Table 1.

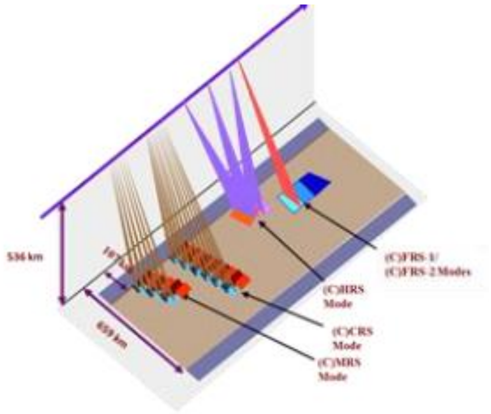

Fig.1: Different beam modes of RISAT-1

Table 1. Specifications of RISAT SAR Beam modes

Altitude		536 Km				
Frequency		5.35 GHz				
Imaging Modes		HRS/ C-HRS	FRS-1/ C-FRS-1	FRS-2/ C-FRS-2	MRS/ C-MRS	CRS/ C-CRS
Swath Coverage		Selectable within 100 – 700 KM off-nadir distance on either side (200 – 600 KM region is qualified, the rest is unqualified)				
Inc angle coverage	Qualified	200-490 (200-600 Km)				
	Total	100-540 (100 –700 Km)				
Swath/ Spot Km	Defined	10x10	30	30	120	240
	Experimental	100x10	---	---	---	---
Applicable Polarization combinations		Single/ Dual (co+ cross)/ (CH& CV*	Single / Dual (co + cross) / (CH & CV)*	Quad / (CH &CV)*	Single / Dual (co + cross) / (CH & CV)*	Single / Dual (co + cross) / (CH & CV)*
Resolution (Az x slant range)		1m x 0.7m	3m x 2m	9m x 4m	21-23m x 8m	41-55m x 8m
Minimum sigma naught (dB) (Qualified Region)		-16.3	-17	-18	-18	-18
Total no. of beams		64 on each side of the flight track: total 128				
Azimuth and Range ambiguity		< -20 dB				

RISAT-1 Radiometric Calibration Approach

In order to carry out absolute radiometric calibration of SAR it is required to deploy standard point targets with known Radar Cross Section (RCS) accurately pointing towards the SAR sensor over a low clutter region [26, 27]. Once the point targets are imaged, integrated power from two dimensional IRF of deployed standard target is analyzed after removing clutter noise. From IRF, calibration constant is generated.

A. Scientific Basis behind Derivation of Calibration Constant

Calibration constant can be derived by using radar equation [19-20, 29]. For a SAR imageDN value is proportional to the received voltage. Therefore image intensity I is proportional to the received power P,

$$I = G_p \times P = G_p \times DN^2 \qquad (1)$$

Where, Gp is the gain of the processor.

For an area extended target, the mean received power is given by the radar equation

$$P_r = \frac{P_t G^2 \lambda^2 \sigma^o A}{(4\pi)^3 R^4} \qquad (2)$$

Here P_t is the power transmitted by the antenna, G is gain of the antenna, λ is the wavelength of the microwave signal, R is the slant range distancebetween the antenna and the target, σ° is the backscattering coefficient of the target under consideration and A is the illuminated area.

For radiometric calibration, the standard target is deployed in the uniform background. Using the radar equation given in eq. (2), the power received for the standard target (Pc) can be written as

$$P_c = \frac{P_t G^2 \lambda^2}{(4\pi)^3 R_c^4}(\sigma_c + \sigma_b^o A)(3)$$

Where, $\sigma_b^o$is the backscattering coefficient of the background and$\sigma_c$is the RCS of the calibration target and $R_c$is the slant range distance between sensor and the calibration target. The equation can be rewritten as

$$P_c = \Omega\,(\sigma_c + \sigma_b^o A)(4)$$

Once the background effect are ignored or subtracted from the main power, the equation can be rewritten as

$$P_c = \Omega\sigma_c(5)$$

Thus for standard targets the intensity given in eq. 1 can be written as

$$I_c = G_p P_c = G_p \Omega\sigma_c(6)$$

For a distributed target the received intensity given in eq. 1 can be written as

$$I_u = G_p P_u = G_p \Omega(\sigma^o A)(7)$$

Thus, the backscattering coefficient for a uniform target can be obtained as

$$\sigma^o = I_u / G_p \Omega A(8)$$

Value of G_P can be obtained from equation (6) as

$$G_p = I_c / \Omega\sigma_c(9)$$

Substituting this value of G_P in equation (8) leads to

$$\sigma^o = I_u / (I_c / \Omega\sigma_c)\Omega \mathrm{A}(10)$$

i.e.

$$\sigma^o = \frac{I_u \sigma_c}{I_c A}(11)$$

Replacing I_u and I_c from equation (6) and equation (7) we get

$$\sigma^o = \frac{P_u \sigma_c}{P_c A}(12)$$

The illuminated area, A is dependent on the angle of incidence and when normalized at scene center, we get

$$\sigma^o = \frac{P_u \sigma_c \sin\alpha \sin\theta_{center}}{P_c A \sin\theta_{center}}\ (13)$$

Considering calibration constant C_c

$$C_c = \frac{P_c A}{\sigma_c \sin\theta_{center}} \quad (14)$$

Equation (14) can be re-written as

$$\sigma^o = \frac{P_u \sin\alpha}{C_c \sin\theta_{center}}(15)$$

Calibration constant depends on the characteristics of the standard target and the angle at which the target is deployed. Standard target deployment is shown in Fig.3. Once the calibration constant is arrived at, SAR DN values can be converted to the backscattering coefficient for that SAR processor using equation (15).

Fig.3: Standard target deployment

In Integral method, power from a standard point target is taken by integrating the power from all pixel values corresponding to the point target to arrive at the calibration constant [29].In order to arrive at the interpolated integrated power from the point targetP_{ii}, two directional interpolation is done on the power image with an interpolation factor f_{int} in both, range and azimuth direction to get point target impulse response function (IRF) as shown inFig. 4. Impulse response from a standard target is distributed over 20 resolution cells spread around the standard target. Integrated power from two dimensional impulse responses is analyzed for estimating main lobe and side lobe energy received from the point target. Main lobe energy is calculated from IRF by integrating an area of 2 times the resolution cell, spread around the peak of the IRF. The side lobe energy is calculated by integrating the area of 20 resolution cells spread around the peak of IRF, by excluding the main lobe energy. The image interpolation is done in frequency domain using available FFT routines. The FFT of the sub imagesurrounding the point target is interpolated f_{int}times in frequency domain and then inverse FFT is performed to obtain interpolated data.

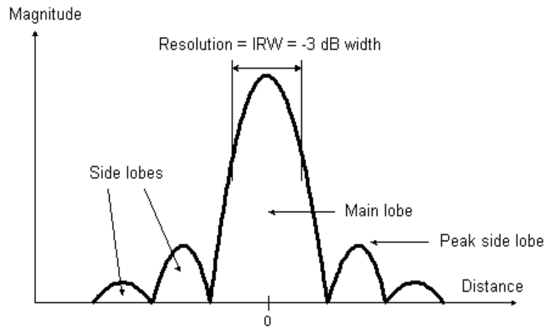

Fig 4: Standard point target impulse response function [30]

Once the impulse response function is obtained for all the point targets, next task is to calculate calibration constant. In case of the integral method, the resolution area A is estimated as

$A = \delta_r \delta_a$(16)

Where,δ_r and δ_a are the pixel spacing in range and azimuth direction [19]. Power integralsP_{ii} is obtained by integrating over a square area surrounding point target and noise power is determined using an area surrounding the standard target. For the interpolated values of pixels equation 14 and 15, will be modified to the equations for the integral approach as

$$\sigma^o = \frac{P_u \sigma_c sin\ \alpha \sin \theta_{center}}{(P_{ii}/f_{int}^2)\, \delta_r \delta_a \sin \theta_{center}} \quad (17)$$

$$C_{ii} = \frac{(P_{ii}/f_{int}^2) \delta_r \delta_a}{\sigma_c Sin\theta_{center}} \quad (18)$$

Where,f2int is the interpolation factor in both range and azimuth direction.
Finally the calibration constant is derived using equations (18). After deriving the calibration constant, backscattering coefficient can be derived as

$$\sigma_i^o = 10log10(DN_i^2) - C_{ii} + 10log10\ Sin\theta_i - 10log10(Sin\theta_{center}) \quad (19)$$

Using equation (18) once the calibration constant isarrived; equation (19) can be used to convert SAR DN values to backscattering coefficient for that SAR processor.

Conclusion

In this paper an approach for absolute radiometric calibration of RISAT-1 SAR data has been presented. This approach is based on calibration constant calculated from impulse response function of deployed passive standard targets. One equation has also been presented for RISAT-1 radiometric calibration. This equation can be adopted for absolute radiometric calibration of various beam modes ofRISAT-1 SAR data.

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