Correction of Radiometric Errors by Multi-Look Processing with Extended Number of Looks

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Abstract—**The application of the clutter-lock technique in case of fast and significant instabilities of the antenna orientation leads to strong geometric distortions in SAR images. In the paper we propose a radiometric correction approach which could be used with SAR processing algorithms without clutter-lock. The technique has been tested by using a Ku-band airborne SAR system, installed on a light-weight aircraft.**

Keywords-synthetic aperture radar; airborne SAR; radiometric errors; radiometric correction; multi-look processing

I. Introduction

The clutter lock technique is usually used to avoid strong radiometric errors in SAR images [1-2]. According to this technique, the azimuth reference functions are built adaptively to track time variations of the Doppler centroid caused by instabilities of the antenna orientation. The application of the clutter lock guarantees that the SAR beam of the central look is pointed exactly to the center of the real antenna beam and all SAR look beams are within the main lobe of the real antenna pattern, as shown in Figure 1. However, the usage of the adaptive, time-varying SAR reference functions lead to geometric distortions in SAR images. The clutter lock technique is very effective if variations of the antenna beam orientation are slow in time and small in comparison to the antenna beam width in azimuth. In this case, the geometric distortions in SAR images can be easily corrected by re-sampling of SAR images to the correct rectangular grid.

Tracking the Doppler centroid in case of strong and fast variations of the antenna beam orientation leads to unbearable geometric distortions in SAR images that cannot be corrected by re-sampling of SAR images. This problem is most critical for SAR systems with a narrow antenna beam and for SAR systems installed on light-weight aircrafts. For such systems, the geometric accuracy is the first-priority problem. The built-in correction of geometric distortions, proposed in [3], is an efficient solution of this problem. However, the method does not use the clutter lock and SAR beams may be pointed to ground areas which are not illuminated by the antenna beam, as illustrated in Figure 2.

In order to track the illuminated spot on the ground and, thus, to correct strong radiometric errors, we have proposed to use the multi-look SAR processing with an extended number of SAR looks. In such approach, some of the SAR look beams are always within the real antenna beam as shown in Figure 3. Because of instabilities of orientation, the antenna beam illuminates different SAR looks at different times. It can be imaging as the SAR image "migrates" though different looks.

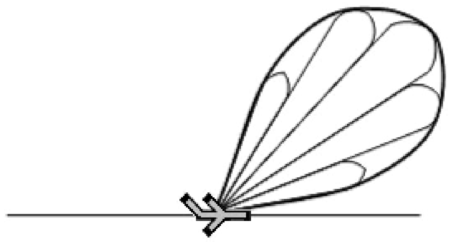

Figure 1. Multi-look SAR processing with clutter-lock.

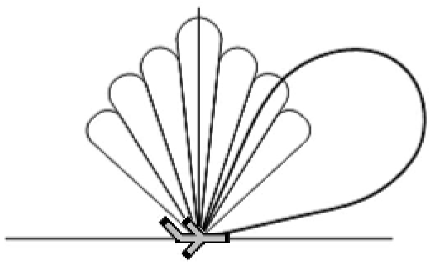

Figure 2. Multi-look SAR processing without clutter-lock.

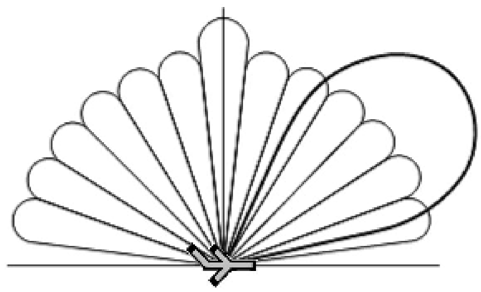

Figure 3. Multi-look SAR processing with extended number of looks.

In this paper we show how these looks can be combined to obtain the SAR image without radiometric errors. The proposed approach has been tested with a Ku-band SAR system installed on a light-weight aircraft [4].

II. MULTI-LOOK RADIOMETRIC CORRECTION

A. Principle of the Approach

Let us denote the error-free SAR image to be reconstructed as $I_0(x, y)$. The obtained SAR look images, $I(l; x, y)$, l is the look index, are corrupted by speckle noise $N(l; x, y)$ and distorted by the radiometric errors $0 < R(l; x, y) \le 1$. The SAR look image can be written as

$$I(l; x, y) = I_0(x, y) \cdot N(l; x, y) \cdot R(l; x, y) . \quad (1)$$

The speckle noise in a single-look SAR image is a multiplicative noise with an exponential probability density function with the mean and variance

$$\mu\{N(l; x, y)\} = 1 , \ \sigma\{N(l; x, y)\} = 1 . \quad (2)$$

The proposed radiometric correction procedure consists of two main steps.

1) Compose "the best SAR look images".

Each part of the scene is always presented in several SAR look images. We should select the most bright (best-illuminated) parts of the scene among all L_{Ext} extended SAR look images and compose "the best SAR look images". The number of these best SAR looks denoted as L_{Best} is less than the number of looks within the real antenna beam L.

In order to estimate the brightness of SAR images we should apply a two-dimensional low-pass filter to suppress speckle noise. This smoothing filter should preserve variations of the illumination (the radiometric errors) caused by the instabilities of the antenna beam orientation.

We should design an appropriate low-pass filter $\mathbf{F}$, which splits the radiometric error function into the high- and the low-frequency components

$$\mathbf{F}\{R(l; x, y)\} = R_{LF}(l; x, y) , \quad (3)$$

$$R_{HF}(l; x, y) = R(l; x, y) - R_{LF}(l; x, y) , \quad (4)$$

so that the high-frequency component is negligibly small:

$$R_{HF}(l; x, y) << R_{LF}(l; x, y) . \quad (5)$$

We shall assume also that the most of the speckle noise power is contained mainly in the high-frequency component of the speckle noise function:

$$S_{HF}(l; x, y) >> S_{LF}(l; x, y) . \quad (6)$$

We can apply the low-pass filter to the SAR look image:

$$\mathbf{F}\{I(l; x, y)\} = I_{LF}(l; x, y) . \quad (7)$$

Taking into account assumptions (2), (5) and (6) we can write approximately:

$$I_{LF}(l; x, y) \approx I_{0LF}(x, y) R_{LF}(l; x, y) . \quad (8)$$

Here $I_{0LF}(x, y)$ is the low-pass-filtered component of the SAR image to be reconstructed.

The low-frequency component $I_{LF}(l; x, y)$ (8) contains information about the scene illumination. It is distorted by the radiometric errors but almost not corrupted by speckle noise.

For radiometric correction we should store in memory two related sequences of images: the composed best SAR look images, $I_{Best}(l; x, y)$, and the corresponding filtered (smoothed) best SAR look images, $I_{Best\,LF}(l; x, y)$. These sequences are kept in ascending order with respect to brightness:

$$I_{Best\,LF}(l; x, y) < I_{Best\,LF}(l+1; x, y) . \quad (9)$$

The algorithm of forming of these sequences is as follows. We take the SAR look image (one-by-one, all of L_{Ext} looks) and smooth it by the low-pass filter. Then we compare the brightness of the obtained smoothed SAR look image (pixel-by-pixel) with the already composed smoothed best SAR looks trying to insert the pairs $\{I(l; x, y), I_{LF}(l; x, y)\}$ into the sequences $\{I_{Best}(l; x, y), I_{Best\,LF}(l; x, y)\}$ preserving the ascending order in brightness (9).

2) Correct radiometric errors and build multi-look SAR image.

The idea of radiometric correction by multi-look processing with extended number of looks is based on the fact that at least one of many looks is pointed very close to the center of the real antenna beam. This look demonstrates the maximum power (the brightest image) and does not suffer of radiometric error.

Due to ascending ordering (9), the best SAR look with index L_{Best} will be the brightest look which contains only correctly-illuminated samples. For this look $R(l; x, y) \approx 1$, and, according to (8), we can use it as the reference to estimate the error-free low-frequency component of SAR image:

$$I_{0LF}^{Est}(x, y) \approx I_{Best\,LF}(L_{Best}; x, y) . \quad (10)$$

Now from (8) we can find the radiometric error functions as

$$R_{LF}^{Est}(l; x, y) \approx \frac{I_{LF}(l; x, y)}{I_{0LF}^{Est}(x, y)} . \quad (11)$$

Figure 4. A single-look SAR image built with clutter lock.

Figure 5. Multi-look SAR image built without clutter-lock by ordinary averaging of all SAR look.

The correction of radiometric errors is performed as

$$I^{RC}(l;x,y)=\frac{I(l;x,y)}{R_{LF}^{Est}(l;x,y)}=I(l;x,y)\frac{I_{0LF}^{Est}(x,y)}{I_{LF}(l;x,y)}. \quad (12)$$

Finally, applying the above radiometric correction, we can build the multi-look SAR image as

$$I_{L_{Best}}(x,y)=\frac{1}{L_{Best}}\sum_{l=1}^{L_{Best}} I_{Best}(l;x,y)\frac{I_{0LF}^{Est}(x,y)}{I_{Best\,LF}(l;x,y)}. \quad (13)$$

Some practical aspects of data processing that deserve attention are discussed in the next subsection.

B. Practical Aspects of the Approach

We can use the accurately tracked Doppler centroid values to prevent the synthesis of those SAR look beams which are obviously beyond the real antenna beam at the moment. It allows us to reduce the computation burden. It is especially important when the variations of the antenna beam orientation are larger than the antenna beam width, and we have to increase the number of SAR looks considerably, although a few of SAR looks are illuminated simultaneously.

To improve the signal-to-noise ratio in the final multi-look SAR image, we should not sum up those SAR looks, which is illuminated less than, for example, -10 dB with respect to maximum illumination. Such poorly-illuminated SAR looks could introduce significant additional receiver noise to the final image. Actually, this threshold limits the possible number of the composed best SAR looks L_{Best}.

The low-frequency components of SAR look images can be obtained by using a simple smoothing filter, but excluding from averaging all bright points representing artificial objects since the radar cross section of artificial targets could demonstrate significant variations from one look to another.

In case of very fast variations of the antenna beam orientation, some ground areas could be illuminated less time than it is required to achieve a desired azimuth resolution. In this area some de-focusing will be observed, but also these areas will be darker than it should be. In order to correct such radiometric errors, the reference low-frequency component could be composed of SAR looks which are intentionally built with lower resolution to reduce the required time of synthesis.

III. Example of Radiometric Correction

The application of the clutter lock in case of strong and fast instabilities of the antenna beam orientation leads to the considerable geometric distortions in SAR images. Figure 4 shows a single-look SAR image built by using clutter lock. One can see apparent geometric distortions caused by fast and significant instabilities of the antenna beam orientation.

If we perform ordinary averaging of all SAR look images (geometrically correct) built without clutter lock we obtain multi-look image with radiometric errors and non-uniformly suppressed speckle noise, as illustrated in Fig. 5. Instabilities of the antenna orientation lead to non-uniform illumination of the scene. As a result, one can see dark and light strips in the image. The dark areas were illuminated for shorter time, the SAR image is presented only on a few SAR looks, the real antenna footprint quickly moved to the neighbor area. The light areas were illuminated for longer time, the SAR image is presented on many SAR looks.

Multi-look SAR image shown in Fig. 6 was built by applying the radiometric correction described in this paper. One can see that radiometric errors have been corrected.

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Figure 6. Multi-look SAR processing with extended number of looks.