Azimuth and Range Scaling for SAR and ScanSAR Processing

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Abstract - This paper presents new range and azimuth scaling functions which can be introduced into the processing of SAR and ScanSAR data for automatic geometric scaling in range and azimuth directions. These new phase functions have been implemented into the extended chirp scaling algorithm for air- and spaceborne SAR data processing. Several examples using the scaling functions are presented and results of the data processing are shown to verify the validity of the proposed algorithms.

I. INTRODUCTION

SAR processing requires normally an interpolation for the correction of the range cell migration. It consists of two components (linear and quadratic term), which must be corrected in order to perform an accurate azimuth compression. Since both terms are varying as a function of the range distance, the migration correction must be updated for each range position.

The interpolation for range cell migration correction (RCMC) can be circumvented by means of the chirp scaling operation [1]. The chirp scaling principle is based on the fact that the positioning of the impulse response function after compression is determined by its phase center position before compression. Since a linear scaling is required for RCMC, a linear frequency modulated function can be used to shift the phase center of the range chirps, whereby the amount of the shift is proportional to the distance to a reference range r_{ref}. In the case of SAR processing, the chirp scaling correction is applied in the range-Doppler domain, since the targets at a given range distance will have the same RCM trajectory independent of their azimuth position.

In this paper, the chirp scaling principle has been further exploited for several other applications. In addition to the traditional range chirp scaling, which equalizes the range cell migration in the processing, the following applications have been investigated:

- Range scaling. It performs a geometric scaling of the image in the range direction and is incorporated within the range chirp scaling operation. It can be used for automatic range co-registration of interferometric image pairs obtained in a multi-pass scheme. The range scaling can also be used to modify the sampling interval in the final image.

- Azimuth chirp scaling. Its principle is similar to the range chirp scaling but additional operations are required to accommodate the hyperbolic phase history in the azimuth direction. It can also be used for automatic azimuth co-registration of interferometric image pairs obtained in a multi-pass scheme with different PRF's and/or velocities as well as to selected the final sampling interval in a stripmap SAR image.

- Azimuth scaling. It is used to select the final azimuth sampling interval of ScanSAR or Spotlight data. In opposite to the azimuth chirp scaling, the basic scaling is applied in the range-Doppler domain due to the burst operation of ScanSAR and Spotlight imaging modes.

In section II of this paper, the scaling in the range direction (range chirp and range scaling) is presented. Section III shows the theory of the azimuth (chirp) scaling for stripmap and ScanSAR/Spotlight case. Several results of data processing are presented in section IV for demonstration of the geometric scaling in the final image. Section V concludes the paper.

II. SCALING OF THE RANGE SIGNAL

The basic idea is to combine the scaling of the image in the range dimension with the RCM equalization operation (range chirp scaling) of a chirp scaling processor into a single operation. This is possible since both operations represent a linear scaling of the range signal. This implies that their combination can be performed within one single step and is in fact also a chirp scaling operation but with a modified scaling factor:

$$a_{scl}(f_a) = \frac{1 + a(f_a)}{\alpha_{rg}} - 1 \qquad (1)$$

where $a(f_a)$ is the traditional chirp scaling factor known from [1] and α_{rg} is the desired scaling of the processed image in range dimension. For $\alpha_{rg} = 1$ no scaling occurs and $a_{scl}(f_a) = a(f_a)$. The full derivation of a_{scl} is given in [2]. Also the full derivations of the phase functions H_1,H_2,H_3 and H_4 (see fig. 1) are given there. Here we will concentrate on some essential discussions:

- Since the new chirp scaling factor a_{scl} is used instead of a within the first phase function H_1, this impacts all other phase functions.

- The second phase function H_2 performs RCM correction with the traditional chirp scaling factor a, since the natural curvature of the azimuth signal was not changed by the range and range chirp scaling operation, but for the compression of the range signal a modified rate according to a_{scl} must be considered.

- The phase correction H_3 which must be applied after

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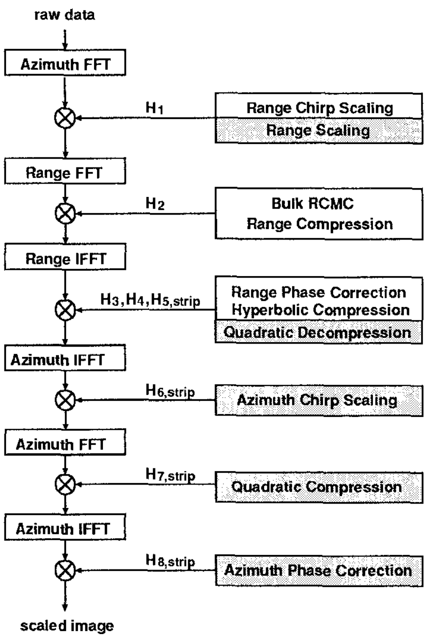

Figure 1: Signal flow of the Extended Chirp Scaling algorithm for processing of one block of stripmap data with modified/additional functions for the range and azimuth chirp scaling.

range compression in the range-Doppler domain is dependent on a_{scl} and a and is given explicitely by:

$$H_3 = exp\left[j4\pi\cdot \frac{k(f_a;r_{ref})\cdot a_{scl}\cdot (1+a)^2}{c^2\cdot (1+a_{scl})}\cdot (r_0 - r_{ref})^2\right], \quad (2)$$

where k is the modified chirp rate from [1] and r_0 the range distance.

Finally, special care must be given to the update of H_4 with range since at this step of the processing the image is already scaled in the range dimension.

Using this approach the co-registration of interferometric image pairs in the range dimension during processing is possible without any additional computation load. For wavenumber processors a similar approach with some additional computations was already presented in [3]. Another application of range scaling is the processing of highly squinted data [2]. Any desired resampling of the image in the range dimension can also be achieved by using this approach.

III. SCALING OF THE AZIMUTH SIGNAL

Stripmap case

The chirp scaling principle is also adaptable for scaling the azimuth dimension of stripmap SAR data. In order to obtain a very precise scaling, the natural hyperbolic phase history must be substituted by its quadratic approximation. The grey boxes of the signal flow in fig. 1 show that three additional phase multiplies and two FFT operations are needed to obtain a precisely scaled image in azimuth. The function $H_{5,strip}$ performs the decompression of the focused azimuth response in the range-Doppler domain and can be applied together with the phase correction function in range H_3 and the hyperbolic compression function H_4. It should be updated with range as follows:

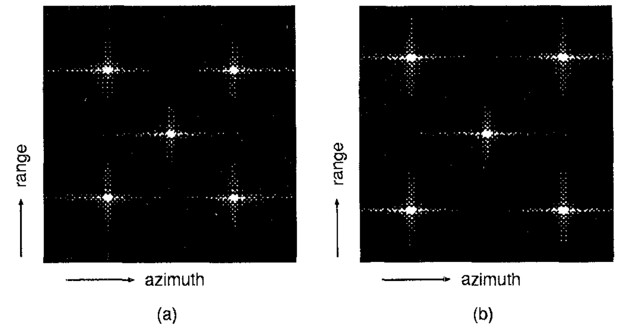

Figure 2: Simulated response of 5 point targets of stripmap SAR data processed with the extended chirp scaling algorithm: no scaling (a), phase preserved scaling of 20% in range and azimuth dimension (b)

$$H_{5,strip}(f_a;r_0) = exp[j\cdot \pi/k_a(r_0)\cdot f_a^2], \quad (3)$$

where f_a is the azimuth frequency. At this stage the natural modulation of the azimuth signal is substituted by a quadratic modulation of rate k_a allowing the use of the chirp scaling principle:

$$H_{6,strip}(f_a;r_0) = exp[j\cdot \pi\cdot a_{az}\cdot k_a(r_0)\cdot (t - t_{ref})^2] \quad (4)$$

The azimuth chirp scaling factor $a_{az} = 1/\alpha_{az} - 1$ is zero for $\alpha_{az} = 1$. The quadratic compression with modified modulation rate and the phase correction follow immediately:

$$H_{7,strip}(f_a;r_0) = exp\left[j\cdot \pi\cdot \frac{f_a^2}{k_a(r_0)\cdot (1+a_{az})}\right], \quad (5)$$

$$H_{8,strip}(f_a;r_0) = exp\left[j\cdot \pi\cdot \frac{a_{az}\cdot k_a(r_0)\cdot a_{az}}{1+a_{az}}\cdot (t - t_{ref})^2\right] \quad (6)$$

The best choice for the reference position t_{ref} is the azimuth block center. Relative to this position the azimuth chirp scaling will be performed.

This approach is exact and phase preserving, but the additional computation load is not negligible. In cases where the amount of scaling is small (e.g. ERS-1), the azimuth chirp scaling can be performed at the beginning of the processing without substituting the hyperbolic phase by its quadratic approximation. For this case the additional computation load reduces to two phase multiplications [4].

ScanSAR case

For ScanSAR processing we have introduced subaperture processing into the extended chirp scaling algorithm combined with an improved SPECAN approach [2].

The azimuth processing starts in the range-Doppler-domain after range processing, RCMC and radiometric correction by applying the new azimuth scaling function:

$$H_{5,scan}(f_a; r_o) = exp[j\cdot 2\cdot \pi\cdot (t_c(r_{scl}) - t_c(r_o))\cdot f_a]\cdot$$
$$exp\left[\frac{j\cdot 4\cdot \pi\cdot r_o}{\lambda}\cdot(\beta(f_a)-1)\right]\cdot exp\left[\frac{j\cdot \pi}{k_{a,scl}}\cdot f_a^2\right], \quad (7)$$

where $k_{a,scl}$ is the linear Doppler rate at the properly selected scaling range r_{scl}. The first factor is essential for avoiding time shifts before deramping, which would lead to wrap around effects. The azimuth scaling function improves the SPECAN approach by eliminating the hyperbolic azimuth phase history (second factor in eq. 7) and introducing a quadratic one (third factor). Since the quadratic modulation is constant over range, no azimuth interpolation is required. The scaling factor is selected depending on the chosen scaling range. In order to avoid wrap around effects during the final FFTs an additional azimuth time extension is applied before the first azimuth FFT.

The deramping is performed in the time domain according to:

$$H_{6,scan}(t; r_o) = exp\left[j\cdot \pi\cdot k_{a,scl}\cdot t^2\right]\cdot$$
$$exp[j\cdot 2\cdot \pi\cdot k_{a,scl}\cdot (t_c(r_{scl}) - t_c(r_o))\cdot t]. \quad (8)$$

Because of the azimuth scaling all azimuth signals are multiplied with the same inverted quadratic phase function for the scaling range (first exponential term in eq. 8). The second term is related to the first term of $H_{5,scan}$ and introduces an azimuth time shift in order to relocate the targets according to their Doppler zero position. The final step of the azimuth processing is an azimuth FFT, which compresses the azimuth signals.

IV. SIMULATION RESULTS

Five simulated point targets were used to verify the performance of the scaling approachs in strip mode.

In fig. 2a the processing was performed with a normal chirp scaling approach and the targets appear at their natural position. In fig. 2b the processing steps were like in fig.1 including a range scaling with $\alpha_{rg} = 1.2$ and an azimuth chirp scaling of $\alpha_{az} = 1.2$. The reference range r_{ref} and the reference time in azimuth t_{ref} used for the processing are according to the target in the image center. Thus the image appears as scaled by 20 percent in both directions, leaving the position of the middle target unchanged. The phase of the targets remains unmodified in any case.

For the ScanSAR case the extended chirp scaling algorithm has been implemented including the described azimuth scaling approach. Fig 3 shows the results of the processing of 6 simulated point targets. A group of 3 point targets is located in near range, while the second group of three point targets is located in far range. Due to the decrease of the Doppler rate as a function of range, the far range point targets are compressed in the azimuth direction and the near range point targets are distanced, if the azimuth scaling is not used (see fig. 3.a). This effect can be corrected by means of the azimuth scaling, as shown in fig. 3.b. In this case, the reference sampling distance in azimuth has been fixed to that of the near range point targets, so that their scaling remains constant.

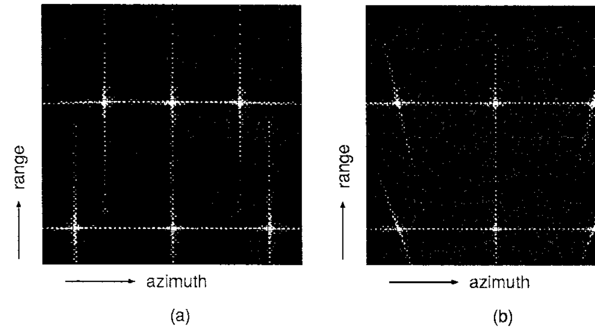

Figure 3: Simulated point targets of a burst of ScanSAR mode data processed with the extended chirp scaling algorithm without (a) and with (b) azimuth scaling

V. DISCUSSION

In addition to the presented applications for the range and azimuth (chirp) scaling, the same principle can be used in connection with subaperture processing of airborne SAR data with strong motion errors. By means of the azimuth chirp scaling, the velocity variations can be compensated in each subaperture by scaling the azimuth signal to the same reference velocity. By means of the range scaling, the deviations from the linear flight path in line of sight direction can be precisely corrected instead of using a simple linear shift. These extensions of the range and azimuth scaling will be subject of future research.

VI. REFERENCES

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