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New Approach to Strip–Map SAR Autofocus

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Means for removing phase errors induced in spotlight mode synthetic aperture radar (SAR) imagery are now well–established. The Phase Gradient Autofocus (PGA) algorithm ([1],[2]) has been shown to be robust over a wide range of spotlight mode imagery and phase error functions. These phase errors could have their origin either in uncompensated platform motion or random propagation delays incurred, for example, from tropospheric turbulence. The PGA technique, however, cannot be directly applied to imagery formed in the conventional strip–mapping mode. In this paper we show that if the fundamental ideas of PGA are modified in an appropriate way, the phase errors in strip–map imagery can be effectively estimated and compensated.

The PGA algorithm for focusing spotlight mode imagery (see top diagram of Figure 1) involves identifying individual point-like targets in the defocused image, "windowing" and shifting each such image segment to the image center, and Fourier transforming the windowed data in cross-range to obtain individual target signatures in the *aperture domain*, where the data are compressed in range but dispersed in cross range. Each signature thus produced consists of a complex constant (a_i in Figure 1), corresponding to the point reflector chosen, multiplying a complex exponential whose phase is the common phase error function $\psi(t)$. The clutter captured in the window appears as additive white noise. Since all targets thus selected have been produced by the *same synthetic aperture* in the spotlight collection process, the phase error function is the same across each reconstructed aperture, and an estimate of the common phase errors can be constructed by averaging aperture domain data from a variety of range lines. Actually, first differences of phase from pulse to pulse across the aperture are first estimated, as a necessary step to handle the unknown complex constants a_i associated with individual targets. The phase differences are then integrated across the aperture to produce an estimate of the phase error function. Finally, the estimated phase error is removed from the image and the entire sequence of steps is iterated.

A conventional development of strip–map SAR views each point target in the image domain as having arisen from a certain linear FM chirp response in the range–compressed domain. Compression in cross–range to form the image is accomplished by convolution with a conjugate chirp waveform. This is in contrast to the spotlight mode case, in which the equivalent step is accomplished via Fourier transformation. Thus in order to obtain range–compressed aperture signatures to which a phase estimation procedure similar to PGA can be applied, each point-target response in the image domain should be isolated, windowed, and convolved with an appropriate FM chirp (refer again to Figure 1). This will reconstruct the original chirp signal form which the image was produced, combined with noise arising from clutter included in the window. Multiplication by the known conjugate chirp will yield a complex exponential involving the phase error function, again multiplied by the constant a_i associated with the target. In this case, however, each target in general has been produced from a different aperture, so each reconstructed aperture signal must be positioned accordingly before it can be combined with others to estimate the phase error. A set of selected image targets produces a set of displaced apertures which collectively span the duration of the strip-map collection, as depicted in the lower diagram of Figure 1.

The range compressed aperture data used to estimate the phase error function can be computed much more efficiently than by actually performing the chirp convolution procedure described above. The alternative is to simply Fourier transform the windowed and center shifted image data and then position the resulting signature in the aperture domain coincident with the image-domain target position. One

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way to argue the validity of this method is to utilize a theorem stating that a chirp convolution followed by a conjugate chirp multiply is equivalent (for large time-bandwidth product) to a Fourier transform. A second view is that the Fourier transform of the windowed image segment surrounding a certain target directly gives the aperture data from which the target was formed, since this is a consequence of any aperture synthesis imaging system, independent of how the actual compression is performed. The result is that strip-map autofocus may be performed with steps very similar to the spotlight mode PGA algorithm. One difference is that the individual target apertures must be positioned in accordance with the positions of the targets in the image domain.

Another important distinction in the strip-map autofocus algorithm is that it involves estimating the second difference of phase instead of the first difference (gradient) used in spotlight-mode PGA. The reason for this required departure is a consequence of the fact that individual targets come from different but partially overlapping apertures, each of which spans only a portion of the SAR collection interval. As a result of inaccurate target position estimation in the image domain, individual aperture signatures may contain unknown linear phase components, which will cause first differences in phase not to coincide from one target aperture to the next. Second differences, or curvature, however will coincide for overlapping target apertures and may be used as the basis for coherent averaging. A double integration of the phase curvature is then employed to recover a phase error estimate used to correct the image, and the whole process is iterated. This paper shows results from both simulated as well as real SAR imagery successfully refocused using the new algorithm.

[1] P. H. Eichel, D. C. Ghiglia, and C. V. Jakowatz, Jr., "Speckle processing method for synthetic-aperture radar phase correction", *Optics Letters*, 14, 1-3, January, 1989.

[2] C. V. Jakowatz, Jr., and D. E. Wahl, "Eigenvector method for maximum-likelihood estimation of phase errors in synthetic aperture radar imagery", *JOSA-A*, vol. 10, No. 12, December, 1993.

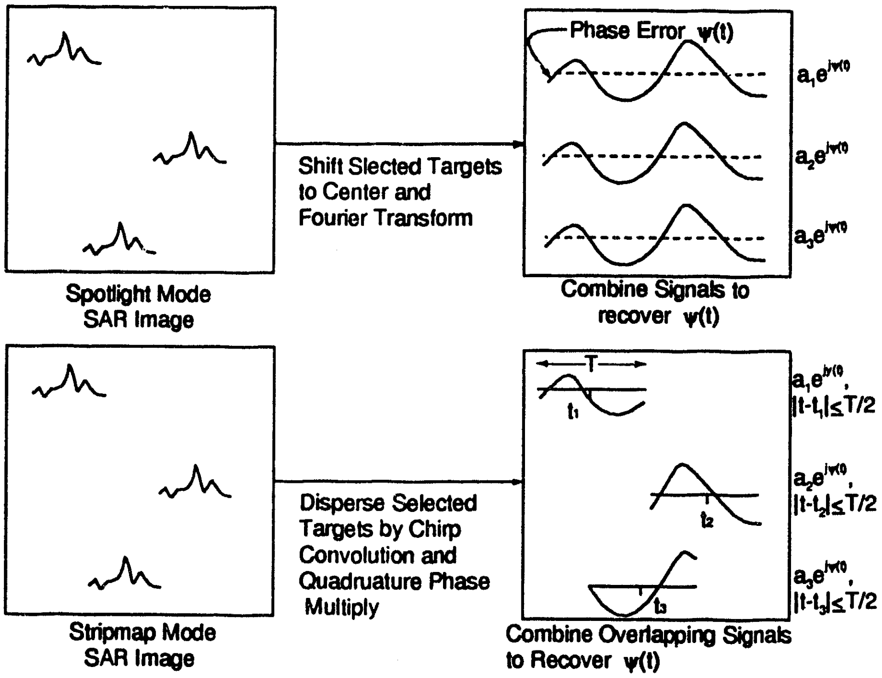

Figure 1: Image domain and range-compressed domains for spotlight and strip-map SAR

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