Performance of the Polar Formatting Algorithm for SAR Image Formation on Wide Aperture Collections

Charles V. Jakowatz, Jr.
Sandia National Laboratories
Albuquerque, NM
cvjakow@sandia.gov

Paul A. Thompson
pathomp@sandia.gov

Neall E. Doren
nedoren@sandia.gov

Daniel E. Wahl
dewahl@sandia.gov

June 8, 2000

1 Introduction

In this paper we describe the performance of the well-known polar formatting algorithm (PFA) for formation of spotlight-mode synthetic aperture imagery from phase history data, under conditions of large-angle synthetic apertures. Such conditions typically occur when the SAR center frequency is low and/or the azimuthal resolution is is very high. Traditional wisdom states that PFA is not desirable for large aperture angles (say on the order of 60 degrees) because either: 1) the polar-to-Cartesian interpolation step is typically implemented as two separate one-dimensional filters and the resulting interpolation errors lead to unacceptable quality in the reconstructed image; or 2) the polar-to-Cartesian conversion is implemented as a fully two-dimensional interpolation and ends up consuming excessive computation time. Here we show that the traditional wisdom is incorrect, i.e., we show that the conventional polar-to-Cartesian interpolation implemented as two separable 1-D steps does yield acceptable image quality even for very wide-angle aperture collections. In addition, we dispell a second notion that PFA is inadequate in imaging scenarios wherein range curvature effects are significant. In fact, the defocus induced by range curvature in PFA in many situations can be corrected via post-filtering of the formed SAR image, and the calculation time for the refocus is quite reasonable. We will demonstrate these results by way of PFA formation of SAR imagery from synthetic target data and will contrast the PFA results with those from the CBP (convolution/back-projection) algorithm. CBP is often considered to be superior to PFA for wide-aperture or near-field imaging scenarios, because CBP avoids the step of 2-D interpolation of phase history data and also can be easily modified to account for curved wavefronts in the near-field scenario. The downside of CBP is that it is generally much less efficient computationally than PFA. Our conclusion is that PFA with post-filtering for correction of near-field effects is the algorithm of choice for many (but not all) practical spotlight-mode SAR imaging scenarios involving wide-angle synthetic apertures.

2 Interpolation Effects in the Polar Formatting Algorithm (PFA)

We first demonstrate that the ill-effects on quality of the formed SAR image induced by the interpolator used in classic PFA are essentially negligible, even for cases of very wide angle apertures.

The interpolator employed here amounts to two separable one-dimensional interpolators, one in the range direction followed by another in cross-range. A sinc interpolation filter suited for this purpose is carefully detailed in Chapter 3 of [1], and won't be discussed further here. Experience suggests that the number of coefficients required for the filter to yield acceptable image quality is 16. Figure 1(a) shows an ideal point target reconstructed using PFA on synthetic spotlight-mode phase history data from a collection of ideal point targets, for the case of a 60^o-wide synthetic aperture. The imaging parameters used to generate these data are shown in Table I. In this case we have chosen the range to be sufficiently large that no near-field effects are present, so that we can isolate the effects of the polar-to-Cartesian interpolator. A 40-dB Taylor weighting function was used in both polar dimensions to reduce the sidelobes, as is commonly done in practice. Note that because the phase history annulus is of such large angular extent, the major sidelobes of the IPR do not lie in the cardinal directions. Although the impulse response does vary as a function of position in the scene (generally degrading as we move the point target further away from scene center), the one shown here is typical for the majority of target positions in the scene. Figure 1(b) shows the impulse response for the same imaging scenario when the CBP algorithm is used. The two IPR's are virtually the same. The only position in the image for which the IPR's from PFA and CBP appear to differ is at the extreme corner of the scene, i.e., at extreme range and cross-range location. The IPR's from this position are shown in Figures 1(c) and (d). Figure 2 shows the result of convolving the IPR's from the two algorithms with an actual SAR image. Note that any differences in the IPR's are virtually undetectable in the resulting imagery. (This is true even though we have used the worst IPR for the PFA result, i.e., that of Figure 1(c), to obtain Figure 2(a)).

Parameter	Value
Range	1000 km
Center frequency	500 MHz
Bandwidth	500 MHz
Image resolution	0.3 m x 0.3 m
Scene diameter	1000 m
Aperture angle	60^o
Image size	5000 x 5000 pixels

Table I: Imaging parameters used to generate synthetic phase history data

3 Correction of Range Curvature Effects in PFA via Post-Filtering

In typical wide-aperture spotlight-mode SAR imaging scenarios, the near-field effects of wavefront curvature may be present. PFA in its original form cannot accommodate this situation, because it is derived on the assumption of strictly planar wavefronts. The result of wavefront curvature is to introduce a spatially-varying defocus distortion into the formed imagery (a detailed discussion of this is presented in [1]). It is possible, however, to post-process such an image formed via PFA with the appropriate space-variant filter to remove the defocus effects, because the form of the required filter can be derived analytically, using the known imaging parameters. The demonstration of this concept and its associated implementation issues are discussed fully in [2].

Figures 3(a), (b), and (c) show the result of reconstructing computer simulated phase history data for point targets located at three positions in the scene using PFA without the post-filter

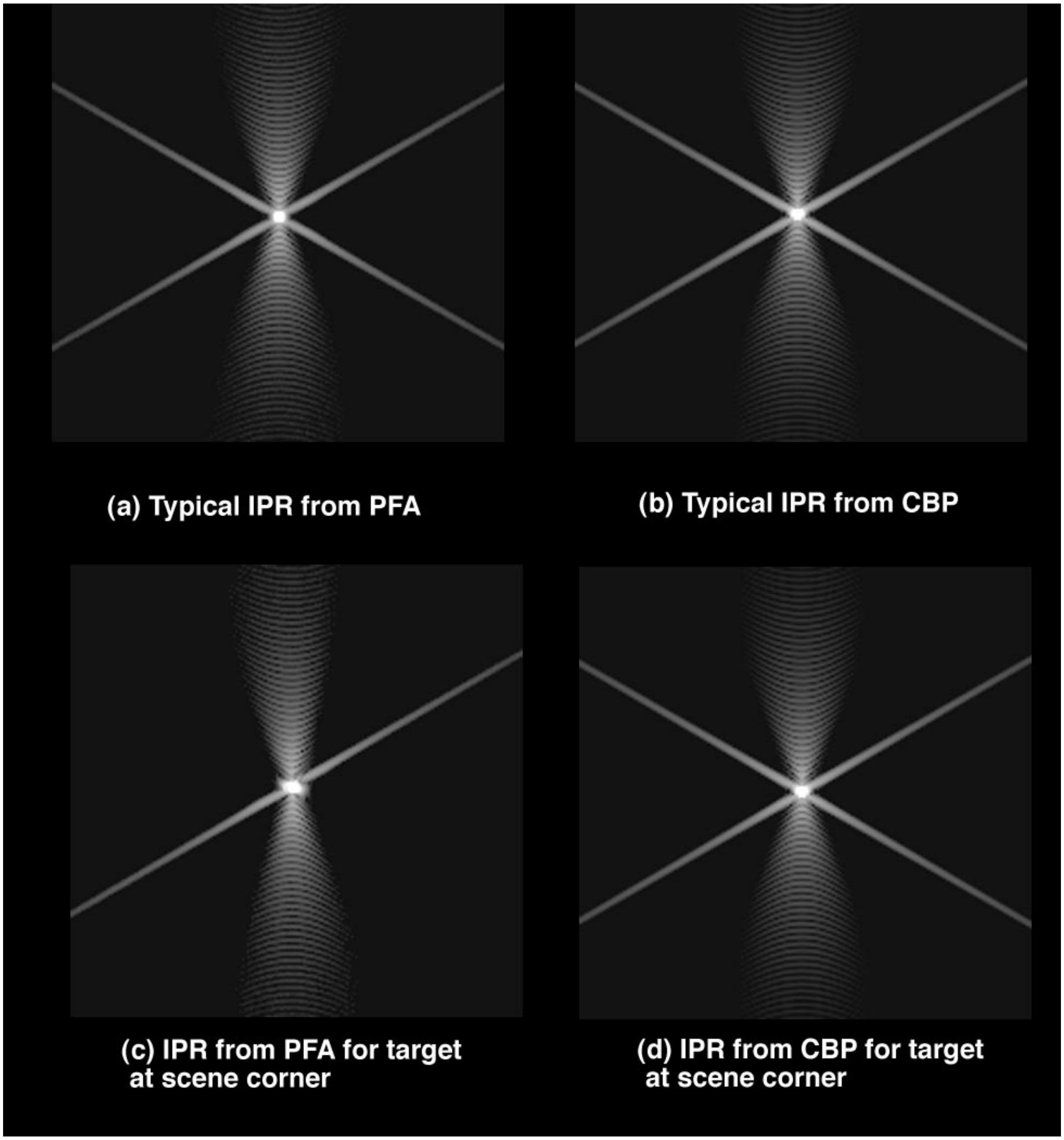

Figure 1: Impulse response functions (IPR) using 40-dB Taylor weighting from reconstruction of synthetic SAR phase history data. Aperture is 60^o wide. (a) Result for typical mid-image position using PFA (b) Result for typical mid-image position using CBP (c) Result for scene corner position using PFA (d) Result for scene corner position using CBP

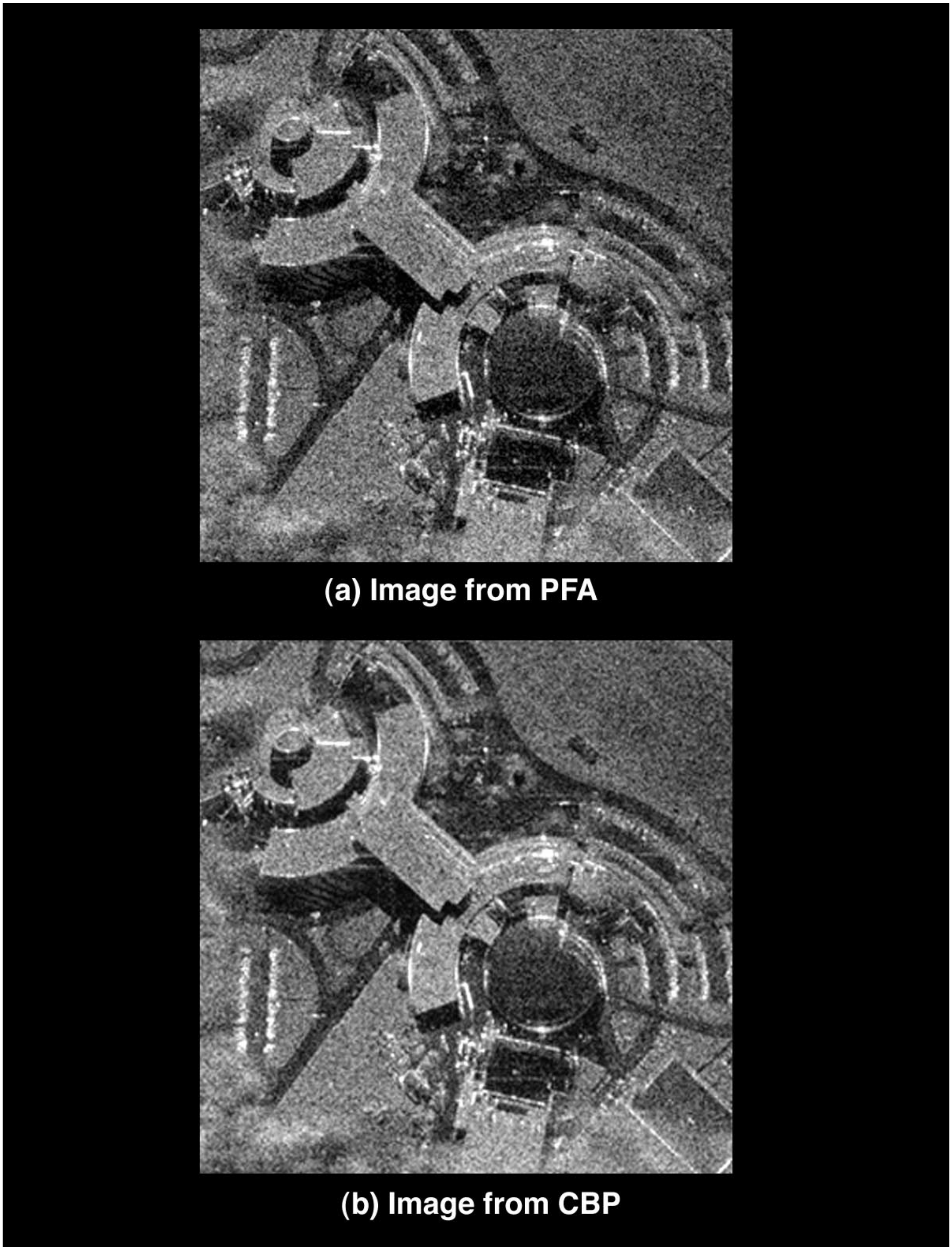

Figure 2: SAR imagery convolved with IPRs of Figure 1. (a) Result from PFA (b) Result from CBP

for refocus. In this case, the imaging parameters are the same as those used to generate data for the images of Figure 2 (see Table I), but with the standoff range reduced substantially (from 1000 km to 20 km), so as to cause significant near-field effects. The space-variant defocusing caused by wavefront curvature is easily seen from these three IPR's. Figures 3(d), (e) and (f) show that application of the appropriate space-variant post-filter does indeed completely restore the image to correct focus. (Note that Figure 3 (e) corresponds to the point position at the scene corner and comparison with Figure 1(c) indicates that the refocus is correct.) The additional compute time needed to perform the refocus is approximately equal to the PFA image formation time in this particular situation.

4 Summary and Conclusions

We have demonstrated that the polar formatting algorithm (PFA) for formation of spotlight-mode SAR imagery from phase history collections is robust for imaging scenarios that involve very wide-angle synthetic apertures. The conventional interpolator used to re-format polar samples in the phase history data onto a Cartesian grid, namely a series of two one-dimensional interpolators, performs quite adequately even for synthetic apertures as wide as 60^o. For situations wherein wavefront curvature causes defocus in wide-aperture collections, a post-filter may be applied to the image formed via PFA to restore the image to full focus. In many (but not all) cases of practical interest, the additional compute time required to implement the filter is on the order of PFA image formation time, and is therefore not prohibitive. In order for CBP to present a viable alternative to PFA in imaging scenarios such as this one, a "fast" version of CBP that results in computation times on the order of PFA with post-filtering must be discovered.

5 References

(1) Jakowatz, Charles, et. al., Spotlight-Mode Synthetic Aperture Radar: A Signal Processing Approach, Kluwer Academic Publishers, Boston, 1996.

(2) Doren, N. E., Jakowatz, C. V., Wahl, D. E., Thompson, P. A., "General formulation for wavefront curvature correction in polar-formatted spotlight-mode SAR images using space-variant post-filtering", presented at 1997 IEEE Signal Processing Society International Conference on Image Processing, October 26, 1997, Santa Barbara, CA.

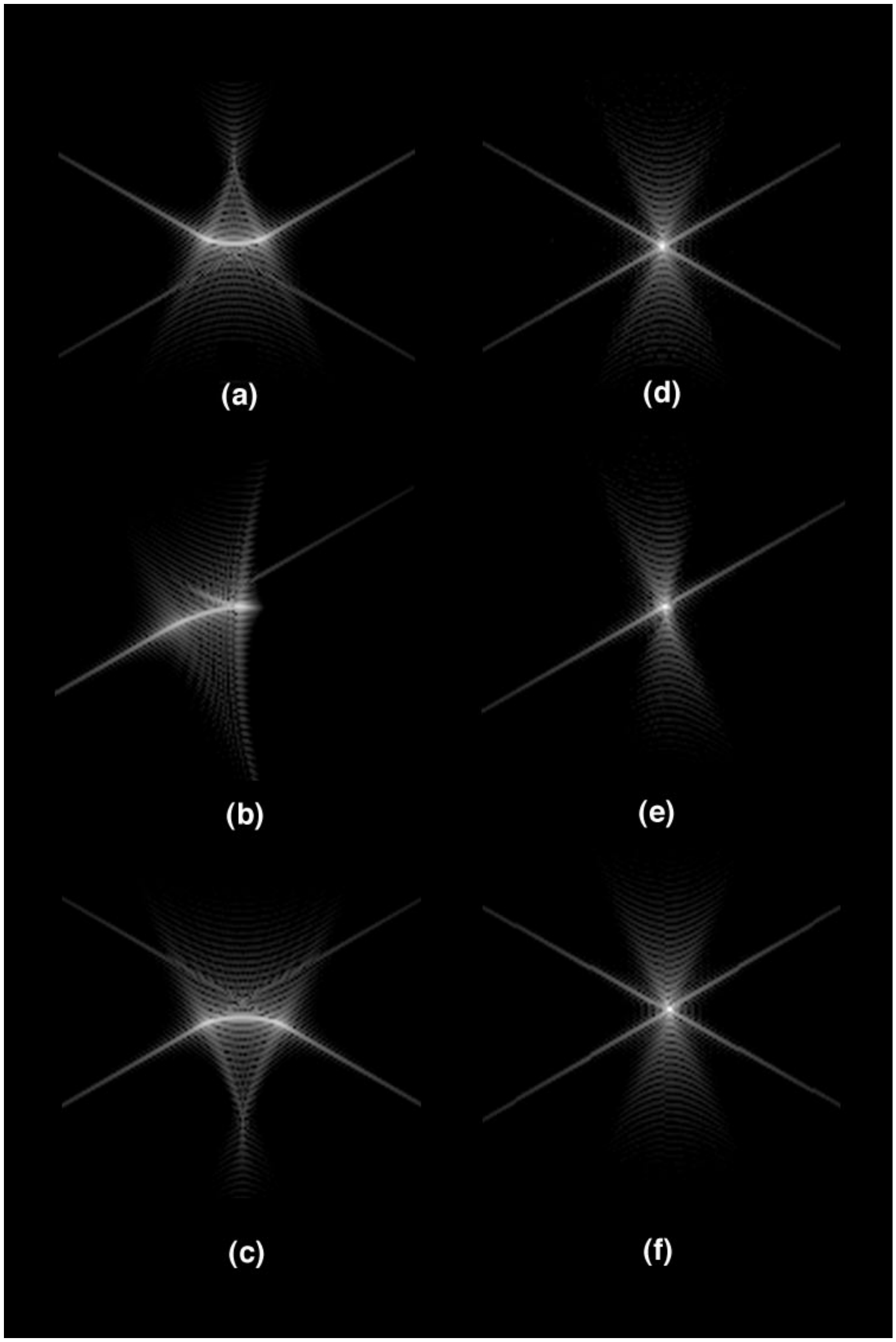

Figure 3: Result of PFA image formation from wide-aperture synthetic target data using parameters that result in significant range curvature. Images (a), (b), and (c) show IPR's from point targets at three different positions when standard PFA (no post-filter) is used. Images (d), (e), and (f) are the same points after the appropriate space-variant post-filtering is performed. Refocusing of the entire scene for this particular case requires additional compute time that is approximately equal to the normal PFA time.