Extending the Phase Gradient Autofocus Algorithm for Low-Altitude Stripmap Mode SAR

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Abstract— The Phase Gradient Autofocus (PGA) algorithm has been widely used in Spotlight Synthetic Aperture Radar (SAR) to remove motion-induced blurs in the images. The PGA algorithm has been proven to be a superior autofocus method. This algorithm is extended for application to low-altitude stripmap mode SAR. Standard PGA algorithms are formulated only for spotlght-mode SAR. We describe a new algorithm which allows PGA to be applied to stripmap-mode SAR. Three SAR images with different characteristics are used in demonstrating this algorithm.

INTRODUCTION

Full focusing of SAR images generally requires some type of autofocus routine. The Phase Gradient Autofocus (PGA) algorithm has proven to be a superior method for higher order autofocus because it does not assume a model for the phase error [1, 2]. Standard PGA algorithms are designed only for spotlight-mode SAR systems, yet there are many stripmap-mode systems which could benefit from the autofocusing. One method of applying PGA ideas to stripmap-mode data has been proposed previously [3]. Our algorithm differs from theirs in that we modify the stripmap data so that it can be used in a PGA algorithm with little modification, while they modify the main PGA algorithm.

This paper describes a new algorithm which allows PGA to be applied to stripmap-mode SAR data. The following section describes our algorithm. The next section shows the results of simulations using phase errors applied to actual SAR data.

STRIPMAP PGA

Our stripmap PGA algorithm performs a set of preprocessing steps, then uses a slightly modified PGA algorithm for the actual autofocus. The preprocessing steps convert the stripmap data to a format similar to spotlight data so that little modification is necessary to the final PGA algorithm. These steps will be described in turn, along with discussion of the differences between spotlight-mode and stripmap-mode data which make these steps necessary. Note that in this discussion we neglect range migration and consequently ignore the polar formatting algorithms commonly used in spotlight mode processing.

Step 1: Segment. The stripmap data is segmented so that points in the image segment will have phase histories covering most of the segment. One of the significant differences between spotlight-mode and stripmap-mode data is that the phase history for any point in a spotlight image covers the entire data set. In stripmap data the phase history is limited by the antenna beamwidth to a very short span of the image. Another difference is the signal bandwidth. Spotlight-mode systems are able to get high-resolution images at relatively low sample rates because the dechirping reduces the bandwidth before sampling. To use the same dechirping method for stripmap data requires either short segments or extreme oversampling. Thus for our algorithm, the maximum segment length is determined from the frequency content of the data and the system azimuth sample rate.

Step 2: Dechirp. The data is dechirped by multiplying by the conjugate of the azimuth chirp. Probably the most significant difference between stripmap and spotlight data is that the spotlight image is the Fourier transform of the range-compressed data. The corresponding processing step in stripmap data is correlation, which does not easily lend itself to a PGA formulation. Once the segmented data is dechirped, the resulting data is related to the corresponding image by a Fourier transform, the same as spotlight data. If the segments are too long, the dechirping can lead to aliasing; thus it is important to stay within the maximum segment length.

Step 3: Fourier transform. The data is Fourier transformed to form a pseudoimage. The term pseudoimage is used here because the segmented, dechirped data is only used to estimate the phase error and not to produce an actual image. The position of any given target in the pseudoimage does not necessarily correspond to its position in the final image. Positioning of targets in the pseudoimage, as in spotlight-mode images, is determined by the linear phase terms left from the dechirping. These linear terms depend on actual target position, azimuth chirp rate, azimuth sample rate, and segment length.

If we assume a wide-beam SAR, the chirp rate is range dependent. Thus the azimuth positioning of targets in the pseudoimage will be range dependent, causing a warping effect. This has little effect on our estimation. We can calculate how each target will map into the pseudoimage from system parameters. If we find which azimuth positions the edges of the segment are mapped to at each range, then we know that only that data between those positions corresponds to actual targets in this segment.

Step 4: Modified PGA algorithm. The modified PGA algorithm is applied to the pseudoimage, with the principal modification in the circular shifting step. As described in the previous paragraph, only a portion of the pseudoimage corresponds to actual targets and contains the phase history. The circular shifting step must exclude those portions of the pseudoimage

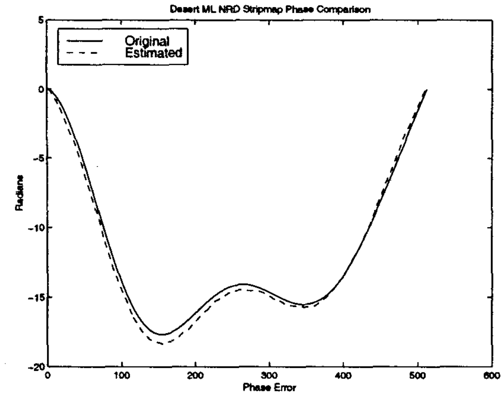

Figure 1: Applied and estimated phase errors for the desert image using the non-range-dependent ML PGA phase estimator.

which do not contain the phase history. This is accomplished by cutting each line to the proper length, performing the circular shift, then zero-padding the data back to the original length. With this modification, the PGA algorithm is applied to the pseudoimage. This can be the standard PGA algorithm using the maximum likelihood (ML) phase estimator [4], or it can be a range-dependent PGA algorithm using our phase-weighted estimator (PWE) [5] or a similar estimator. The result frcm the PGA algorithm in this step is the estimated phase error, not the focused image. The focused pseudoimage is discarded and we return to the original stripmap data in the next step to remove the phase error.

Step 5: Remove phase error. Finally the estimated phase errors from the different segments are combined and used to remove the phase error. In order to avoid discontinuities in the phase error estimate between segments, the mean of the phase gradient of each segment is removed before integrating and combining segments. This somewhat corresponds to the center shifting step of the spotlight PGA algorithm because both serve to remove constant linear terms from the estimate.

SIMULATION RESULTS

This algorithm has been simulated on actual SAR data. In these simulations, a well-compressed complex SAR image is used as the synthetic truth image. This image is convolved with simulated azimuth chirps to form a range-compressed stripmap-mode SAR image. Phase errors are applied, and the stripmap PGA algorithm is used to estimate and remove these errors.

These algorithms are tested on images with three different types of characteristics: a desert image with few significant features, a mountain image with distributed targets, and an urban image with various types of targets. Simulations were performed using both range-dependent and non-range-dependent artificial phase errors. For simplicity, we only show non-range-

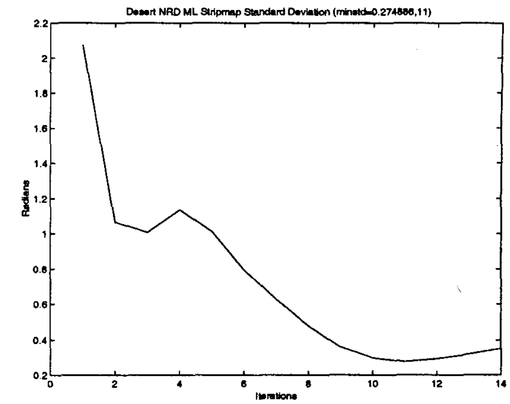

Figure 2: The standard deviation of the phase estimation error for the non-range-dependent desert image using the ML PGA phase estimator.

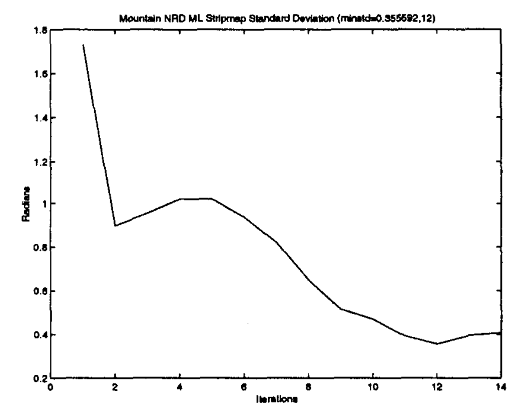

Figure 3: The standard deviation of the phase estimation error for the non-range-dependent mountain image using the ML PGA phase estimator.

dependent simulations using the standard ML PGA phase estimator.

Figure 1 shows an example of the applied and estimated phase error with the desert image. Figure 2 shows the phase estimation error standard deviation as a function of iteration for the same example. Figure 3 shows the phase estimation error standard deviation as a function of iteration for the mountain image with the same applied phase error. Figure 4 shows the phase estimation error standard deviation as a function of iteration for the urban image. We note from these plots that the algorithm generally converges within 10-15 iterations, and that this convergence is affected by the scene imaged.

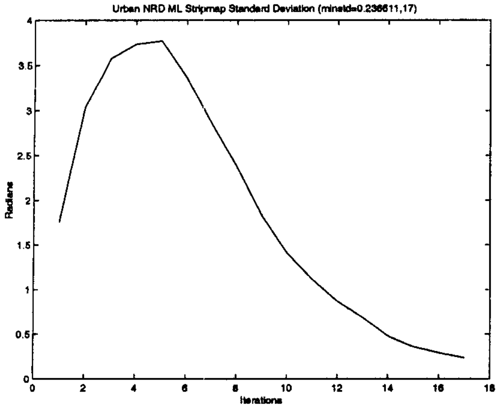

Figure 4: The standard deviation of the phase estimation error for the non-range-dependent urban image using the ML PGA phase estimator.

CONCLUSIONS AND FUTURE WORK

The PGA algorithm has been widely used in spotlight SAR images to remove motion-induced blur. PGA has been proven to be a robust, computationally superior autofocus algorithm. The conventional PGA algorithm is formulated only for spotlight-mode SAR data. We have introduced a new algorithm which makes the PGA algorithm applicable to stripmap-mode data. We have demonstrated that these algorithms can be successful at removing range-dependent and non-range dependent phase errors.

We are continuing active research on this topic. We are working to better understand and compensate for the effects of the image segmentation and recombination of the estimates. In some simulations of range-dependent phase errors in stripmap data it has been observed that the estimation accuracy depends on the applied phase error functions to some degree. We are working to understand and correct this phenomenon.

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