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FINAL REPORT

PROCESSING OF POLARAMETRIC SAR IMAGES

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for

Lawrence Livermore National Laboratory
Contract No. B218804
Livermore, California 94550

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Final Report for:
Lawrence Livermore National Laboratory Contract B218804.

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Abstract - The objective of this work was to develop a systematic method of combining multifrequency polarized SAR images. It is shown that the traditional methods of correlation, hard targets, and template matching fail to produce acceptable results. Hence, a new algorithm was developed and tested. The new approach combines the three traditional methods and an interpolation method. An example is shown that demonstrates the new algorithms performance. The results are summarized suggestions for future research are presented.

1 Introduction

Radar, developed in the early 1940s, has proven to be one of the most useful technologies. It is used in a wide variety of applications, including topological mapping and detection of patterns. Typically, radar systems are narrowband and operate with a fixed center frequency. Further, the receiving array is typically fixed, and hence has a fixed aperture.

There have been several improvements, or modifications, of the early radar systems. It is well known that the resolution of a radar system is dependent on the aperture of the receiving array. To increase the resolution, the array aperture must be increased, which requires a longer array. One technique that is often used to improve the resolution of the radar system is to synthetically increase the array length. The increase can be accomplished via smart signal processing methods and does not require modifications of the existing hardware. Radar systems that use this smart processing method are called synthetic aperture radar (SAR) systems.

Other modifications of early radar systems include the use of multiple center frequencies and polarization. In SAR systems, the antenna orientation of a simple two-element array can be configured as vertical-vertical (VV), vertical-horizontal (VH), HV, or HH. Further, instead of using a single receiving array designed for a specific wavelength, many SAR systems now use multiple antennas, each designated for a different frequency band. Thus, for each fixed center frequency four distinct images or waveforms can be measured.

Clearly, in a SAR imaging systems, the original data can consist of many images at different polarizations and perhaps, at different center frequencies. Further, each of these images will contain noise. Therefore, it is desirable to remove the noise and to reduce the data as much as possible, without destroying the information of interest. A new technique to accomplish this task is presented herein. In the following section, the conventional methods are introduced and shown to be ineffective with multi-frequency images. Then, the new technique is introduced and an example presented. The report closes with suggestions for future research.

2 Registration of Single-Frequency SAR Images

It is well known that the signal-to-noise (SNR) ratio of an array processing system can be increased by a factor proportional to the number of sensors, if the measurement data can be coherently added (and the noise is white). However, it is also known, that the alignment of the waveforms must be precise to coherently add the signal. If the alignment contains errors, then the signal will not be coherently added, and the resulting SNR may be much different than expected. In SAR imaging systems, it is desirable to coherently add, or to register, the images to improve the SNR and reduce the amount of data.

In a typical narrowband array processing system, if the received waveform is a plane wave and the noise white, then the waveforms received at the different sensors can be delayed in time, or equivalently, a phase change can be applied, and the results summed to accomplish the coherent addition. This simple processing can be used because the received waveform is narrowband, hence a delay in time results in a constant phase change. For single-frequency polarized SAR images, the registration can be accomplished essentially in the same way. That is, the registration can be accomplished by determining the appropriate shift in pixels, and then summing the images together.

There are several different methods that are used to determine the appropriate shift for single-frequency polarized SAR images. One method uses "hard targets". That is, the location of known and fixed object is determined for each image. Then, the images are added so that the known objects are overlaid perfectly. This technique will produce an accurate registration (pixel accuracy) if hard targets are present. A second method that is used for registration is to correlate two images. When the images are perfectly aligned, the correlation function will be a maximum. A third method used for image registration is often called the template matching method [1, 2]. It is similar to the "hard target" technique, however, a template is correlated with the second image. The template serves as the hard target. The template is typically formed from an external process and is not generated from the images to be registered.

3 Registration of Multifrequency SAR Images

As with single-frequency SAR images, the amount of speckle noise can be reduced in multi-frequency SAR images if these images are properly combined [3, 4, 5]. Several different techniques for registering single-frequency SAR images were presented in the previous sections. However, these techniques are not effective when the images are formed with different wavelength systems. As a simple example, note that an image, just like a temporal waveform, will look different at different frequencies. Hence, the use of hard targets, correlation, or template matching may not produce acceptable results. As with temporal signals, the frequency domain structure of a time-delayed signal has a linear phase change, relative to the original signal. Therefore, different wavelengths are rotated (in phase) by differing amounts. In the context of SAR images, this means that a single shift cannot align the images.

One of the objectives of this research was to determine if the common methods of image registration can be applied to multifrequency SAR images that are primarily water. The correlation method and the hard target methods were applied to multifrequency test images to determine if these techniques would allow for accurate registration. The method of correlation yielded very small correlation coefficients. Further, the value of the coefficients was dependent on the exact data used. Even a small perturbation in the the region could result in significant differences in the correlation coefficient. The method of hard targets was equally disappointing. The images of interest are primarily open water images, hence the number of hard targets is small. In addition, the hard targets that were present could not be aligned to pixel-level accuracy. The results of these tests was not unexpected.

In fact, it can be shown, that even over small regions, the hard target, template matching [3, 4, 5], and correlation methods fail to provide the necessary accuracy for registration of multifrequency images. Finally, unlike single-frequency SAR images, the sampling grid and hardware associated with the production of images for the different frequencies may produce images of differing resolution or sizes.

3.1 Multifrequency Registration Algorithm (MRA)

A new technique that combines the hard target, template matching, and correlation methods with that of interpolation [6, 7, 8] (used to overcome linear warping effects and differences in resolution and/or size) is presented. The method has been shown to work well if a hard target is present in the template area.

3.1.1 Step 1 - Determination of Shift Values

It was stated earlier that a single shift can not be used when multifrequency images are to be registered. Therefore, the objective in the first step is to identify a set of

regions that contain distinguishable features and to determine the optimal shift values for each region.

For the MRA to be implemented, it is necessary that a rough, visual registration be possible. The algorithm will determine the proper pixel-level registration. The initial step to extract alignment information from each image as follows:

- 1.1 For each image, identify and extract a set of small regions in which a distinguishable feature (i.e. coastline or ship) is present. We call these extracted regions the template-images.
- 1.2 For each template-image, form two absolute images. One being the absolute value of the real part the other being the absolute value of the imaginary part of the template-image.

It was shown that the correlation of the noisy template-images selected in Step 1.1 had a very low correlation. To decrease the sensitivity to the noise and other variations due to wavelength, the magnitude of the real and imaginary portion were first computed. Then, a *binary* template was formed. The generation of binary template was performed as follows:

- 2.1 For one image, select one pair of absolute complex images formed in Step 1.2. (Select for example, the two L-band complex images).
- 2.2 Apply a 3×3 median filter to the two template-images selected in Step 2.1. The median filter is used to reduce the number of outliers.
- 2.3 Apply a threshold, determined by the statistical properties of the image, to the filtered template-images. The result will be a pair binary template-images.
- 2.4 Re-apply the 3×3 median filter to remove outliers formed from Step 2.3. The final binary images are called the templates.

The last step in the procedure is to correlate the binary templates (formed from the real and imaginary absolute images) with the template-images for all images not selected in Step 2.1. The correlation was implemented as:

- 3.1 Correlate the binary templates determined in Step 2.4 with each of the absolute complex images. The binary template formed from the real absolute image-template is correlated with the real absolute image-templates, while the binary template formed from the imaginary absolute image-template is correlated with the real absolute image-templates.

3.2 Locate the peak of the correlation which is selected as the appropriate shift for that sub-image.

3.1.2 Step 2 - Interpolation

The polarimetric SAR images used for test data were collected by JPL in 1991. The "distance" between objects in different images will not be constant, in general, due to the different frequency bands used to collect the images. The JPL images contain a small amount of "linear warping" that can be compensated for by linear or bilinear interpolation.

When the warping is only range-dependent, a linear interpolation scheme can be used. However, a bilinear method must be applied when both the range and azimuth are linearly warped. For linear interpolation, two sets of two points are selected as the basis for the interpolation. For bilinear interpolation, three sets of significantly separated points (that do not fall on a line) are used as the foundation for the interpolation.

4 Multifrequency Registration Example

To demonstrate the effectiveness of the MRA, consider the problem of aligning the L-band and the P-band SAR images shown in Figures 1 and 2. Each of the original images are 500×2400 pixels, however, the horizontal axis was decimated by a factor of 8 which produces 500×300 size images.

4.1 Shift Values

To test the algorithm for determining the shift values, consider the L-band and P-band images in Figure 1 and 2. We selected a region on the upper-left of both images that contained a section of coastline. The L-band and P-band absolute template-images are shown in Figure 3(a) and (b). The binary templates were formed from the L-band absolute template-images are shown in Figure 3(c). The template-image was selected to be a region of size 32×512 .

Three other regions were also selected for testing. Figure 4 (a) and (b) illustrate the complex template-images for the L-band and P-band images, when coastline from the upper right hand side is selected. In Figure 5 the region selected was the middle lower coastline and in Figure 6 the ship was selected. In Figures 3 through 6, parts (a) and (b) show the original template-image while part (c) illustrates the binary templates. All templates were formed from the L-band template-image. For Figures 1 through 4, the template-image was selected to be a region of size 32×512 ; whereas for Figure 5, the template-image was of size 64×256 and for Figure 6, the template-image was of size 32×256 .

	Image Only		Image and Template	
	optimal shift	correlation	optimal shift	correlation
Region 1	(-4,3)	0.102841	(0,2)	0.189722
Region 2	(1,3)	0.105228	(0,3)	0.155684
Region 3	(0,3)	0.210776	(0,3)	0.327400
Region 4	(0,3)	0.522132	(0,3)	0.490300

Table 1: Correlation results for four regions of the image

The optimal shift values as determined by correlating the binary templates with the template-images are shown in Table 1. In regions with distinct features, the results for the correlation of the images by themselves and the template matching produce consistent results. In Region 4, a ship is present and the correlation of the images without using the template is 0.52. However, it may not be necessary to use template matching. When the hard target is not as well defined, as in Regions 1 and 2, the template matching method does produce the correct ship whereas the correlation technique does not.

4.2 Interpolation Results

When applying the template matching procedure, it was found that the shift values of the images considered had a very small dependence on location (less than one pixel over the entire image). For these images, the interpolation procedure, either linear or bilinear, did not change the result and was omitted.

4.3 Image Enhancement

Once a set of images has been properly registered, they can be combined. The computer algorithm biota was used here for the combining procedure. The results are shown in Figure 7.

The overall shape of the wake is more defined in the combined image. For example, the lower arm of the L-band image and upper arm of the P-band image are very faint. However, in the combined image both arms are clearly visible. This result is illustrated quantitatively in Table 2 for four regions of the image using the signal to noise ratio (SNR). It is seen that the SNR values for the L-band and combined image have a similar SNR for the upper arm near the ship which is significantly larger than the SNR for the P-band image. Similarly, the P-band and combined images have a similar SNR for the lower arm far from the ship, which is significantly larger than the L-band image. However, there was not a significant improvement for the upper arm far from the ship and the lower arm near the ship were both the L-band and P-band

	Upper Arm Near to Ship	Upper Arm Far from Ship	Lower Arm Near to Ship	Lower Arm Far from Ship
L Band	19.3	25.5	15.7	11.1
P Band	13.9	22.5	15.6	16.1
Combined	19.8	25.6	14.9	18.0

Table 2: SNR for four regions of the ship wake

had similar SNR.

5 Summary

An algorithm for registering and combining multifrequency polarized SAR images was presented and demonstrated with the combination of an L-band and a P-band image. This new approach does require the ability to visually determine a coarse registration, however, this is not an unreasonable assumption. Further, the method combines the conventional methods that are used for the registration of single-frequency SAR images.

There are several variations of the algorithm presented that could be examined. For example, the real and imaginary portions of each image were separated to form two images. It may be more reasonable to neglect the phase and to use the magnitude of the original images to form binary templates. Second, the construction of the binary template has not been optimized. The size of the median filter and the threshold used will affect the structure of the binary template.

One of the problems of the approach used herein is the use of templates. If the images are of open ocean, it may not be possible to determine segments of images that contain the same distinguishable feature. Thus, an alternative approach should be considered. In the context of the problem studied herein, one of the main objectives was not the registration of images per se, but instead, the identification of wakes present within these images. The registration was a means to improve the image quality and therefore the ability to identify wakes, when they are present.

If the problem of wake detection in open water SAR images is considered, then perhaps, an alternative method should be examined. If we examine an open water image, with and without a wake, the key difference is that a wake is a structured object. It looks roughly like a V, however, the size (or scale), the location, and the orientation are completely dependent on orientation. Thus, a wake can be viewed as a known shape with unknown parameters. These unknown parameters are the scale, location, and angular rotation. If the speckle is Gaussian, then it should be possible

to determine if a wake is present, its size, its angular rotation, and its location by using a sliding, scaling, and rotating matched filter.

The use of scale and shift in analysis is becoming more common with the introduction of the wavelet transform. In the last few years, there have been conference and journal papers that present results where the wavelet transform has been applied successfully to SAR imaging problems. See for example, [9, 10, 11, 12] [13, 14, 15, 16, 17]. The results in [14] show that speckle noise can be reduced and images segmented using wavelet methods. These results encourage the implementation of a detection method for wakes that use a wavelet transform with an appropriately chosen mother wavelet.

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Figure 2. P-band Polarized SAR Image.

Figure 1. L-band Polarized SAR Image.

Figure 3. Region 1 - Upper left.
 (a) L-band absolute complex images;
 (b) P-band absolute complex images;
 (c) Binary template images.

Figure 4. Region 2 - Upper right.
 (a) L-band absolute complex images;
 (b) P-band absolute complex images;
 (c) Binary template images.

Figure 5. Region 3 - Lower center.
 (a) L-band absolute complex images;
 (b) P-band absolute complex images;
 (c) Binary template images.

Figure 6. Region 4 - Ship.
 (a) L-band absolute complex images;
 (b) P-band absolute complex images;
 (c) Binary template images.

Figure 7. Combined L-band and P-band images.