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Improving Line Detector by Wedge Filtering in the Fourier Power Spectrum Domain*

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Abstract— This paper reports on the work being performed for the ship wake detection effort. We show that improvements in the detectability of line features in noisy images, using the correlation-spectral line detector, can be achieved through the judicious choice of a wedge filter in the Fourier power spectrum (FPS) domain.

I INTRODUCTION

IN OUR previous work [1], we demonstrated the effectiveness of the correlation-spectral [2] method for detecting lines in images. This procedure generates a one dimensional "feature vector" from a two dimension signal. The feature vector consists of the probability of a line feature in the image as a function of angle. The greater the probability at a particular angle, the greater the likelihood of a line at that angle in the image.

Subsequent study has shown that trends in the image result in artifacts in the feature vector that mask the peaks due to line features. Also, noise could result in false alarms. To reduce these artifacts we developed a wedge filter, applied in the Fourier power spectrum domain, to eliminate those spectral components associated with image trends and noise.

II FILTER DESIGN

The filter is designed to favor those spectral components associated with a wake or wake segment over those associated with noise. A simple approach to determine the location of the Fourier components of the wake is to consider a two dimensional sinusoid:

$$f(x, y) = \sin[2\pi k_0(\cos(\theta)x + \sin(\theta)y)]. \quad (1)$$

This is a plane wave propagating at an angle θ to the X-axis with wavelength $1/k_0$. Its FPS has two impulses located a distance k_0 radially from the origin at angles θ and $\theta + \pi$. Assuming a wake segment is nearly a plane wave, it has its spectral components located in the area of the plane wave impulses.

Our detection procedure is to segment large SAR images into overlapping tiles and to process the tiles with the correlation-spectral method to determine the existence of line features [1]. With the above assumption that, local to a tile, a wake segment propagating at an angle θ has wavelengths on the order of $1/k_0$, then the FPS of the tile will have wake components located in the regions of the plane wave impulses. Non-zero tile spectral components, located in other regions, are due to noise and can be ignored.

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Our filter design procedure is to estimate the spread in wake wavelength using several SAR images to determine lower and upper bounds, $[\lambda_{\min}, \lambda_{\max}]$. This fixes the inner and outer radii of the FPS domain filter to be $1/\lambda_{\max}$ and $1/\lambda_{\min}$ respectively.

Since wakes can be oriented at all angles we allow the angular extent of the filter to be $[0, 2\pi]$. This filter is an annulus. For simplicity we choose it to be unity within its range and a step cutoff to zero at the limits.

In some of our SAR images, the use of an annular filter is not sufficient to isolate the wake components. In these images, taken from an airborne platform, there is a trend in the direction perpendicular to the direction of flight. This trend is along the vertical axis of the images and has its FPS components lying solely along the vertical axis. To remove them, we notched out a 4° wedge about $\theta = \pm\pi/2$.

III APPLICATION OF THE FILTER TO THE AUTOCORRELATION

For a tile of size M by N , the steps of the line detection procedure, used in our previous work, are:

1. Pad out the tile to $2M - 1$ by $2N - 1$;
2. Take its D.F.T.;
3. Compute its Fourier power spectrum;
4. Inverse Fourier transform to yield the autocorrelation;
5. Perform the correlation-spectral line detection on the autocorrelation.

The filter is applied between steps 3 and 4. This is summarized in Figure 1. Note, estimating wavelengths from images to determine the filter radial bounds was involved and error prone. It was easier to choose the bounds by successively increasing the inner radius, decreasing the outer radius, applying the filter to a few selected tiles, and processing them. By observing the resulting feature vectors, we tuned the filter bounds. In this manner we determined the bounds on the filter to be 5 and 10 pixels for a 128 point transform, and 10 and 20 pixels for a 256 point transform.

To understand the benefits of the filter we compare four cases:

1. no padding, no filtering;
2. no padding, and filtering;
3. padding, no filtering;
4. padding, and filtering.

Since all input signals are 128 by 128 pixels, padding is out to 255 by 255. Thus the two Fourier transform sizes are 128 and 256.

We use two baseline cases: a 2 Hz biased sine propagating at an angle of 120° and the same sine with an additive ramp of slope .1 in the vertical direction. These signals are described by:

$$f_0(x, y) = \sin[4\pi(x \cos(120) + y \sin(120))] + 1 \quad (2)$$

$$f_1(x, y) = \sin[4\pi(x \cos(120) + y \sin(120))] + 0.1y + 1 \quad (3)$$

The results are presented in Figures 2 to 7. They were generated by the same VIEW[3] macros and thus are identical in layout but represent different input signals. The figures are divided into two parts: (a) and (b). The (a) figure shows the input signal in the upper left hand corner; the 128 point filter and its transform across the middle top; the table in the upper left corner lists the inner and outer radii of the filter in pixels for each transform size; lastly, across the bottom, the autocorrelations. From left to right they are the result of padding the signal, padding and filtering, not padding, and not padding and filtering.

The (b) figure shows the input signal again and the four feature vectors resulting from the four autocorrelations. The two top graphs are the results from the un-filtered autocorrelations, the bottom ones are from the filtered. The 256 point transforms are on the left, the 128 on the right.

Figures 2a and 2b show the results for $f_0(x, y)$. Note the peak in probability at 30° along the lines of constant phase in the image. For this case there is no significant difference between the filtered and un-filtered cases. The ringing in the feature vectors of the 128 point transform is due to aliasing effects.

Figures 3a and 3b show the results for $f_1(x, y)$. Note in Figure 3a how the linear trend washes out the sinusoidal aspect in the un-filtered autocorrelations. Figure 3b clearly demonstrates the effectiveness of the 4° notch in the filter. As seen in the feature vectors of the un-filtered cases, the trend obscures the peak at 30° . The feature vectors from the filtered autocorrelations go to zero at 0° and 180° . This is to be expected because of the notch. This is the drawback of the filter because a vertically oriented wake segment would not show up in the feature vector. The 256 filtered transform feature vector show small, isolated peaks at 0° , 90° , and 180° . These are artifacts from the filter and can be seen to arise from the dark and light patches around the horizontal and vertical axes at the edges of the 256 filtered autocorrelation in Figure 3a.

Figures 4 and 5 show the results for a ramped sine with additive Gaussian noise. The signal to noise ratios are 5000 (74db) and 1000 (60db) respectively. The SNR is computed as

$$SNR = \frac{\sum (signal)^2}{\sigma_{noise}^2} \quad (4)$$

Solving for σ_{noise} in terms of the given signal and desired SNR, we generated zero mean noise and added it to $f_1(x, y)$:

$$f_{SNR}(x, y) = \sin[4\pi(x \cos(120) + y \sin(120))] + 1 + 0.1y + n(x, y) \quad (5)$$

where $n(x, y) \sim \mathcal{N}(0, \sigma_{noise})$. The images are labeled "nrs5000" and "nrs1000" for noisy ramped sine with the given SNR.

Note the sinusoidal aspect of the image is no longer visible and is only revealed in the filtered autocorrelations. The 128 point transform ringing in the feature vectors is enhanced by the noise. The feature vector maximum is still at 30° .

Figures 6 and 7 show the process applied to real wake data. The tiles are extracted from two different wakes oriented along the horizontal axis. The tile in Figure 6 is near the apex of the wake and includes both arms. This is seen in the two peaks of the feature vector. Figure 7 shows a tile with one wake segment.

Throughout all of the examples presented, the filtered padded and un-padded results are similar. In some cases the contrast between a line feature peak and the rest of the feature vector is greater in the un-padded case. This leads us to conclude the use of the filter eliminates the need for padding.

IV CONCLUSIONS

The use of a wedge filter dramatically improves the detectability of line features in correlation-spectral feature vectors. It eliminates the trend in the SAR images but with the expense of a blind spot along the direction of the trend. It also eliminates the need for padding of tiles thus reducing the size of the required Fourier transform and computation time.

In designing the filter we assumed the spectral components of a wake segment were similar to those of a plane wave. Obviously a wake is not a plane wave so a more accurate filter could be designed knowing the dispersion relation of the wake.

V ACKNOWLEDGEMENTS

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Fig. 1. Autocorrelation and filter block diagram.

Fig. 2a. Autocorrelation results for $f(x,y) = \sin[4\pi(\cos(120)x + \sin(120)y)] + 1.0$

sine

Fig. 2b. Feature vectors for $f(x,y) = \sin[4\pi(\cos(120^\circ)x + \sin(120^\circ)y)] + 1.0$

Fig. 3a. Autocorrelation results for $f(x,y) = \sin[4\pi(\cos(120)x + \sin(120)y)] + 1.0 + 0.1y$

ramped_sine

Fig. 3b. Feature vectors for $f(x,y) = \sin[4\pi(\cos(120)x + \sin(120)y)] + 1.0 + 0.1y$

Fig. 4a. Autocorrelation results for the noisy ramped sine with SNR of 5000

nrs5000

Fig. 4b. Feature vectors for the noisy ramped sine with SNR of 5000

Fig. 5a. Autocorrelation results for the noisy ramped sine with SNR of 1000

Fig. 5b. Feature vectors for the noisy ramped sine with SNR of 1000

Fig. 6a Autocorrelation: results for real wake segment. Note the tile is near the apex of the wake and contains both arms

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Fig. 6b. Feature vectors for real wake segment with both arms

Fig. 7a. Autocorrelations results for real wake segment

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Fig. 7b. Feature vectors for real wake segment

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