SIDELOBE APODIZATION FOR HIGH RESOLUTION OF SCATTERING CENTRES IN ISAR IMAGES

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Abstract - Inverse Synthetic Aperture Radar (ISAR) image processing is useful in identifying and isolating dominant scattering centres of a target for subsequent placement of Radar Absorbing Material (RAM). ISAR image construction artifacts have the potential of obscuring low intensity scatterers in the image as well as blurring regions where closely separated scatterers occur. Spatially variant sidelobe apodization (SVA) is a technique that reduces sidelobe levels in a Fourier image while maintaining the image resolution that would be obtained using the rectangular window. In this paper, we investigate the application of 2 versions of SVA to the ISAR image of a ship; these are the standard cosine-on-pedestal SVA and the new Kaiser window version of SVA. It is found that either SVA approach is able to find and isolate scattering centres. We also found that when polar reformatting is required, neither SVA version is a substitute for it, but applying SVA after polar reformatting gives excellent results.

1. SPATIAL SIDELOBE APODIZATION

Sidelobe reduction techniques have been proposed in ISAR imaging [1, 2, 3]. Spatially Variant Apodization (SVA) is based on the use of the cosine-on-pedestal weighting function to reduce the sidelobe level from one frequency bin to the next. This weighting function is described as $w(n) = 1 + 2\alpha_c \cos(2\pi n/N)$ and its discrete Fourier transform is given by $W(k) = \delta_{k,0} + \alpha_C(\delta_{k,-1} + \delta_{k,1})$ for a window length N, where $\delta_{k,j}$ is the Kronecker delta function. The rectangular and Hann windows are obtained by setting $\alpha_C = 0$ and $\alpha_C = 0.5$ respectively. In ISAR imaging the window is applied in the spatial frequency domain and the particular choice of α_C determines the resolution and sidelobe levels in the final image (*i.e.* in the spatial domain).

Denoting the original complex-valued image as [1] $g(m) = I(m) + iQ(m)$, we get, after convolving with $W(k)$: $g'(m) = \alpha_C(m)g(m-1) + g(m) + \alpha_C(m)g(m+1)$, where $\alpha_C(m)$ is selected for each m so as to optimize the effective window given the two neighbors of $g(m)$. In order to reduce sidelobes while retaining the resolution of the rectangular window, α_C is chosen by minimizing $|g'(m)|^2$ subject to the constraint $0 \le \alpha_C(m) \le 0.5$ (constraining the window to lie between the rectangular and the Hann).

The SVA method can be implemented using the real and imaginary channels of $g(m)$ jointly or separately. As shown by Stankwitz *et al.* [1], the implementation reduces in either case to simple equations obtained by solving $|g'(m)|^2 = 0$ for α_C. In terms of taking $I(m)$ and $Q(m)$ jointly, the procedure yields

$$\alpha_C(m) = -\frac{\{I(m)[I(m-1) + I(m+1)] + Q(m)[Q(m-1) + Q(m+1)]\}}{[I(m-1) + I(m+1)]^2 + [Q(m-1) + Q(m+1)]^2}. \tag{1}$$

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Thus, the convolved image is

$$g'(m) = \begin{cases} g(m), & \alpha_C(m) < 0 \\ g(m) + \alpha_C(m)[g(m-1) + g(m+1)], & 0 \le \alpha_C(m) \le 0.5 \\ g(m) + 0.5[g(m-1) + g(m+1)], & \alpha_C(m) > 0.5 \end{cases} \quad (2)$$

For closely spaced signal components located around pixel m, the values of α_C will be close to or equal to zero. Thus, the operation is equivalent to applying the rectangular window. Otherwise the value for α_C is calculated so that the lowest possible sidelobe is obtained by considering an infinite number of cosine-on-pedestal window shapes. When $\alpha_C > 0.5$, the Hann window is applied as stated in (2).

Using the real and imaginary channels of $g(m)$ separately yields a simpler implementation of the SVA method with similar results when the method is applied one dimension at a time (in the 2-D case).

2. SVA USING THE KAISER WINDOW

As noted by Lee and Munson [2], SVA is a version of the minimum variance spectral estimator with a restricted set of weighting functions using a simple estimate of the covariance function. Other weighting functions (Poisson, Gaussian, Tukey, Kaiser, and Cauchy) can be used as an estimate of the covariance function for sidelobe apodization purposes [6]. Among these weighting functions, the use of the Kaiser window has shown excellent results when compared to the cosine-on-pedestal SVA method. Such a method was recently presented by Thomas *et al.* [8] and will be given in outline here.

The Kaiser window [4] can be defined by

$$w(n) = I_0(\pi\alpha_K\sqrt{1-(2n/N)^2})/I_0(\pi\alpha_K),\ 0 \le |n| \le N/2 \quad (3)$$

where $I_0(x)$ denotes the modified zero order Bessel function, and α_K is the parameter of the window that changes resolution and sidelobe levels as in the case of α_C in the cosine-on-pedestal function. The DFT of the Kaiser window [5] can be expressed as

$$W(k) = \frac{N}{I_0(\alpha_K\pi)}\frac{\sin(\sqrt{\alpha_K^2\pi^2-(Nk/2)^2})}{\sqrt{\alpha_K^2\pi^2-(Nk/2)^2}},\ \text{for } k = -\pi, \ldots, -\frac{2\pi}{N}, 0, \frac{2\pi}{N}, \ldots, \pi \quad (4)$$

Thus, the use of $W(k)$ in the image domain using a convolution is not as simple as in the case of the Kronecker delta functions for the cosine-on-pedestal SVA method. Kaiser [4] found the following empirical relations between the sidelobe attenuation levels (ATT) and the value of α_K:

$$\alpha_K = \begin{cases} 0.1102(ATT\text{-}8.7), & ATT > 50 \\ 0.5842(ATT-21)^{0.4} + 0.07886(ATT-21), & 21 \le ATT \le 50 \\ 0, & ATT \le 21 \end{cases} \quad (5)$$

From (5), it can be seen that for $\alpha_K > 30$, an attenuation greater than 300 dB is possible. With this in mind, by setting this attenuation as a boundary, only few samples around $k = 0$ in (4) are seen to considerably contribute to the output of the convolution implementation of the weighting function. Thus, we can modify the image and implement the convolution as

$$g'(m) = \sum_{i=-n}^{n} W(2\pi i/N)g(m-i) \qquad (6)$$

with just a few samples of (6). For $n = 1$, the same number of Kronecker delta functions are used as in the cosine-on-pedestal SVA approach. For larger n better results are obtained, however, we still need to find the best α_K for every pixel. Furthermore, solving for $|g'(m)|^2 = 0$ using (6) requires the use of a numerical analysis tool to find the value of α_K that guarantees a minimum sidelobe level. Though we are using only a few samples in (4), the increased complexity compared to the Kronecker delta functions in the cosine-on-pedestal SVA approach makes the Kaiser window SVA approach significantly slower [8].

3. EXAMPLES OF APPLYING SVA TO ISAR IMAGES

We now show the effects of using these two SVA approaches on an ISAR image of a ship. The synthetic scattering data for the ship was obtained using RAPPORT (Radar signature Analysis and Prediction by Physical Optics and Ray Tracing). This program calculates the RCS of complex objects by using physical optics and ray tracing and can deal with shadowing and an arbitrary number of reflections. The version of the code was developed by TNO Physics and Electronics Laboratory and modified at DREO for the specific computational needs. RAPPORT requires the object to be a union of polygonal facets, each of which is defined in an input file by coordinates of its vertices along with the normal vector. A schematic of the faceted ship which was input into RAPPORT is shown in Figure 1.

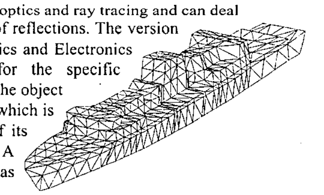

Figure 1. Faceted ship input into RAPPORT

The left image in Figure 2 shows an ISAR image created using 195 aspect angles at 0.0051° steps over a total aspect angle of 1°, and 129 frequencies at roughly 1 MHz steps between 11.1375 and 11.2626 GHz. The Hann window was used in the Fourier inversion. Both SVA approaches were applied to the image by simply applying the 1D algorithms described herein to each column and row of the image separately. The right image in Figure 2 shows the results when the cosine-on-pedestal SVA approach is applied to the complex image data, whereas the centre image shows the result for the Kaiser SVA approach. The background signal level between point scatterers in the image is indicative of how sidelobes yield undesired effects on target images. Note that the target's point scatterers are clearly discernible when using both SVA techniques but especially when using the Kaiser window SVA. This is the result of improvement in the suppression of sidelobes. Note that the SVA was applied to the complex valued images without the use of polar-reformatting. Polar-reformatting is typically required with a total aspect change greater than 3° in order to focus the image [7]. Applying polar-reformatting to the 1° aspect angle image shown in Figure 2 would result in little improvement and would increase the computational time required to obtain the image.

Several other cases were tested and all yielded positive results. When the total aspect angle of the scattering data used to reconstruct the image was increased beyond 3° it was found that polar-reformatting was required in order to focus the scattering centres which are blurred due to motion artifacts. The application of either SVA technique after polar-reformatting yielded similar excellent results as in the 1° case shown in Figure 2. The increased resolution allows us to determine more precisely the location of the scattering centres on the ship. The strongest scattering centres can then be covered with RAM.

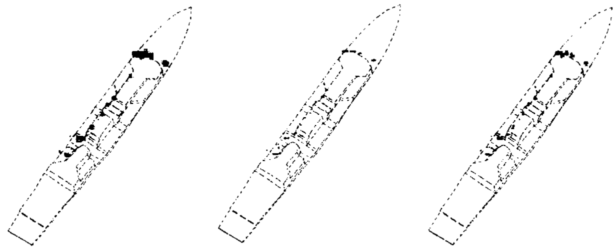

Figure 2. Example of sidelobe apodization using high resolution ISAR data.
Left: Hann window, Middle: Kaiser SVA, Right: cosine-on-pedestal SVA.

4. CONCLUSIONS

Both the cosine-on-pedestal and Kaiser window spatially variant sidelobe apodization techniques have been shown to reduce sidelobes in ISAR images and thereby help to expose weaker scattering centres which are hidden by sidelobes of the stronger scattering centres. The sidelobe reduction is greater in the case of the Kaiser window but the application of the Kaiser window SVA is not as simple as in the case of the cosine-on-pedestal window. The computation of optimal window parameters requires a substantial effort and some future work will target how such calculations can be made more efficient.

5. REFERENCES

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