Optical Aperture Synthesis Object’s Information Extracting Based on Wavelet Denoising

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Abstract. Wavelet denoising is studied to improve OAS(optical aperture synthesis) object’s Fourier information extracting. Translation invariance wavelet denoising based on Donoho wavelet soft threshold denoising is researched to remove Pseudo-Gibbs in wavelet soft threshold image. OAS object’s information extracting based on translation invariance wavelet denoising is studied. The study shows that wavelet threshold denoising can improve the precision and the repetition of object’s information extracting from interferogram, and the translation invariance wavelet denoising information extracting is better than soft threshold wavelet denoising information extracting.

1. Introduction
As a new research field, OAS imaging observation is an indirect imaging. Showed in figure 1, image-plane interference pattern is used in OAS imaging observation. Light coming from observation object comes through telescopes, optical distance compensation instruments, tip-tilt mirrors and combiner, finally, the two beams of light effect each other and an interferogram comes forth in image-plane. Here is The mathematical model of interferogram [1],

\[ I_0(x, y) = 2I_1(x, y)(1 + |r_{12}(0)|\cos(\phi_0 + 2\pi(u_0x + v_0y))) \]  (1)

Where \( |r_{12}(0)| \) is object’s Fourier modulus, and \( \phi_0 \) is object’s Fourier phase, and \( I_1(x,y) \) is the intensity distribution in image-plane by using single telescope, and \( u_0 \) and \( v_0 \) is a constant concerned with wavelength and focus. OAS object’s information extracting means to extract parameter \( |r_{12}(0)| \) and \( \phi_0 \) from interferogram. Extracting object’s Fourier information is a precondition to construct object image. There are three kinds of information extracting method, phase-modulation method, Fourier analysis method and least-squares method [2].

2. Object’s Fourier information extracting method
During image-plane detector sampling periods, an added optical distance is used to modulate two beams of interferometric light by using a PZT mirror, and phase included in interferogram is modulated. This is phase-modulating method. OAS interferogram has a good frequency spectral property, and the main energy of interferogram is the position of object’s u-v point. By designing a filter, object’s Fourier information can be extracted. This is Fourier analysis method. Least-squares method of extracting object’s information is based on polynomial fitting, which can extract object’s Fourier modulus and Fourier phase by curve fitting or surface fitting.
Figure 2 is OAS interferogram without noise. The Fourier modulus and phase included in interferogram is respectively -0.0702 and 0.9532. Figure 3 shows object’s Fourier phase distribution graphic that is extracted with Fourier analysis method and least-squares method from interferogram added with noise. Figure 4 shows object’s Fourier modulus distribution graphic that is extracted by phase modulation method and Fourier analysis method. Figure 3 and figure 4 shows that the precision and the repetitition of the extracted object’s Fourier information is effected badly by noise.
3. Object’s Fourier information extracting based on wavelet denoising

The observation interferogram inevitably embody many kinds of noise. Traditional denoising method have an inconsistency between protecting image’s partial features and restraining noise. Wavelet transformation pioneers a new approach to denoise by its good time frequency feature. Among the many wavelet denoising methods, the Donoho nonlinear wavelet threshold denoising method is widely used [3-5], and it can get a approximative optimum estimation to original image. But the method will make Psuedo-Gibbs where is incontinuous [6]. In the paper, translation invariance wavelet threshold denoising based on Donoho wavelet soft threshold is researched and used to denoise for extracting OAS object’s information.

3.1. Translation invariance wavelet threshold denoising

Wavelet transform will produce oscillation at singular points of interferogram. There are Pseudo-Gibbs at singular points of interferogram when wavelet threshold denoising is used. So according to the characteristic that Pseudo-Gibbs are relative to singular point, a correct approach is used to remove Pseudo-Gibbs. By shifting the position of interferogram’s pixels, singular points’ positions will change and oscillation will be removed. This is translation invariance wavelet threshold denoising.

In order to explain translation invariance wavelet threshold denoising, a one-dimension singal \( \tilde{x}(i)(0 \leq i \leq N-1) \) is used to express interferogram. There are Pseudo-Gibbs at singular points of interferogram when wavelet threshold denoising is used. So according to the characteristic that Pseudo-Gibbs are relative to singular point, a correct approach is used to remove Pseudo-Gibbs. By shifting the position of interferogram’s pixels, singular points’ positions will change and oscillation will be removed. This is translation invariance wavelet threshold denoising.

\[
\tilde{x}(i) = S_{\tilde{x},h} W^{-1} ((Th(W(S_{\tilde{x},h}(\tilde{x},i)))))
\]

So a best denoising purpose means a optimum shift parameter \( h \).

To a certain interferogram, there always is a optimum shift parameter \( h \) to make least oscillation and minimum Pseudo-Gibbs. But when there are many singular points, there is a optimum shift parameter \( h \) only fitting in with a certain singular point , and maybe badly fitting in with the other singular point. So it is impossible to get a optimum shift parameter \( h \) to fit in with all singular points. In order to resolve the problem, a average operation will be used.

3.2. Translation invariance wavelet denoising object information extracting

When OAS wavelet denoising object information is extracted, wavelet function effects the result enormously. To select wavelet function, a comparability principle is used. That is to say, wavelet function is similar to image in different scales. The more similar the wavelet function to image, there are a better denoising effect. By simulation, Biorthogonal wavelet transform can get a better denoising effect. Figure 5,figure 6 and figure 7 shows the denoising effect. The figures show that image quality improve remarkably after translation invariance wavelet denoising is used. Table 1, table 2 and table 3 shows the effect of wavelet denoising by simulating 200 times. The tables show the precision and repetition improves after wavelet denoising is used, and there is a better effect by translation invariance wavelet denoising.

4. Result

The precision and the repetition of object’s information extracted from interferogram improves by wavelet threshold denoising, and there is a better effect by translation invariance wavelet denoising. Unconspicuous effect comes forth to phase modulation mode by wavelet denoising. Because there are four images to extract object’s information with phase modulation mode, and phase modulation mode have a good anti-noise. Wavelet denoising markedly improves the information extracting with least-squares mothod.
Table 1. Statistics of object’s information extracted with wavelet denoising phase modulation method.

|                      | Without denoising | Soft threshold denoising | Translation invariance wavelet denoising |
|----------------------|-------------------|--------------------------|-----------------------------------------|
| Noise variance       |                   |                          |                                         |
| $\sigma = 0.001$     | 0.0702            | -0.0702                  | -0.0702                                 |
|                      |                   |                          |                                         |
| $\sigma = 0.01$      | -0.0698           | -0.0699                  | -0.0703                                 |

Table 2. Statistics of object’s information extracted with wavelet denoising Fourier analysis method.

|                      | Without denoising | Soft threshold denoising | Translation invariance wavelet denoising |
|----------------------|-------------------|--------------------------|-----------------------------------------|
| Noise variance       |                   |                          |                                         |
| $\sigma = 0.001$     | -0.0701           | -0.0703                  | -0.0701                                 |
|                      |                   |                          |                                         |
| $\sigma = 0.01$      | -0.0708           | -0.0708                  | -0.0705                                 |

Table 3. Statistics of object’s information extracted with wavelet denoising least squares method.

|                      | Without denoising | Soft threshold denoising | Translation invariance wavelet denoising |
|----------------------|-------------------|--------------------------|-----------------------------------------|
| Noise variance       |                   |                          |                                         |
| $\sigma = 0.001$     | -0.0697           | -0.0699                  | -0.0853                                 |
|                      |                   |                          |                                         |
| $\sigma = 0.01$      | -0.0715           | -0.0713                  | -0.0713                                 |
References

[1] Fan weijun and Xia liangzheng 2004 Mathematical model of optical aperture synthesis image plane interference and computer simulation Journal of Infrared and millimeter Waves 23 143-147

[2] Fan weijun and Xia liangzheng 2004 Information extract and computer simulation for optical aperture synthesis destination Journal of Data Acquisition & Processing 19 56-60.

[3] Donoho D L. 1995 Adapting to unknown smoothness via wavelet shrinkage [J] J Amer Statist Assoc. 90 1200-24

[4] Donoho D L and Johnstone I1995 Wavelet shrinkage asymptopia [J] Journal of Royal Statistical Society 57 301-369.

[5] Donoho D L. 1995 Denoising by soft-thresholding [J] IEEE Transaction on Information 58 613-627

[6] XIE Jie-cheng, ZHANG Da-li and XUWen-li 2002 Overview on Wavelet Image Denoising 7 209-208.