Fusion of sub-aperture overlapping areas based on wavelet transformation

Yiwei Chen (陈一巍)[1,2*], Yongxin Sui (隋永新)[1], and Huaijiang Yang (杨怀江)[1]

[1]*State Key Laboratory of Applied Optics, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China*

[2]*University of Chinese Academy of Sciences, Beijing 100049, China*

**Corresponding author: cyw198788@163.com*

Received January 26, 2013; accepted May 31, 2013; posted online August 2, 2013

A new sub-aperture overlapping area fusion algorithm based on wavelet transformation is proposed to retain high-frequency components as much as the measurements in the sub-aperture overlapping areas. The principles of sub-aperture stitching are briefly introduced, and the fusion algorithm based on wavelet transformation is demonstrated. The results of the experiment indicate that the new algorithm improves the retention of high-frequency measurement components.

OCIS codes: 220.4840, 120.3180, 120.6650, 120.4630.

doi: 10.3788/COL201311.082201.

With the development of modern science and technology, large-aperture optical systems have become widely used[1,2]. Thus, determination of methods by which to analyze large-aperture optical components have become a challenge for researchers. An interferometer with an aperture larger than the optical flat under study is necessary to investigate large-aperture optical flats directly. However, the manufacture of large-aperture interferometers is expensive and highly impractical. To address this problem, Kim *et al.*[3] proposed the use of a sub-aperture stitching method to test large-aperture optical components in 1982. The sub-aperture stitching method measures a large-aperture optical flat using an interferometer with a smaller aperture. The aperture under study is covered by several smaller sub-apertures, which can be directly measured by the interferometer. To cover the aperture under study and correct for location errors, adjacent sub-apertures feature overlapping areas[4]. These sub-aperture overlapping areas must be fused to obtain the results of the full aperture. The sub-aperture overlapping area fusion algorithm currently used is a weighted-average algorithm[5], which leads to stabilization of the fusion results. However, location errors may decrease the high-frequency components of measurements in the weighted-average algorithm; these components are highly important in some cases[6]. Therefore, another algorithm must be developed to fuse sub-aperture overlapping areas. The new algorithm may be adapted from the image fusion domain[7−9]. Image fusion based on wavelet transformation is a mature technique that can sufficiently retain high-frequency components[10−12]. Thus, the fusing of sub-aperture overlapping areas based on wavelet transformation may be feasible. The theory of sub-aperture stitching is given briefly. The sub-aperture overlapping area fusion algorithm based on wavelet transformation is demonstrated. A comparison between the new algorithm and the average algorithm is provided through experiments.

Wavelet analysis is a multi-scale technique. Therefore, wavelet transformation is a highly useful tool in image processing. Discrete wavelet transform (DWT) preserves all of the information of an image. The use of DWT is a major breakthrough in the field of image fusion. Initial image decomposition by DWT results in four regions (Fig. 1): LL represents low-frequency coefficients, whereas LH, HL, and HH represent high-frequency coefficients.

After compensating for relative tilt, piston, and mechanical location errors, sub-aperture overlapping areas must be fused to obtain full aperture results. Firstly, the images of overlapping areas are decomposed by three-level DWT (Fig. 2): lyLL3 represents low-frequency coefficients, whereas LH3, HL3, HH3, LH2, HL2, HH2, LH1, HL1, and HH1 represent high-frequency coefficients. Low-frequency coefficients contain approximately the same characteristics as the images of overlapping areas. Thus, an average rule can be used to fuse these overlapping areas together[13]. Larger absolute values of the coefficients correspond to sharper brightness changes[14]. To retain as much of the salient features in the images as possible, including edges, lines, and regional boundaries, the choose-max scheme, which involves simple selection of coefficients with large absolute values and discarding others, is widely used in image

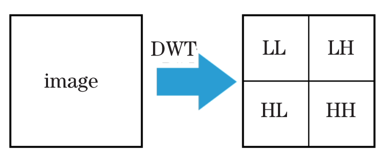

Fig. 1. Discrete wavelet transform (DWT).

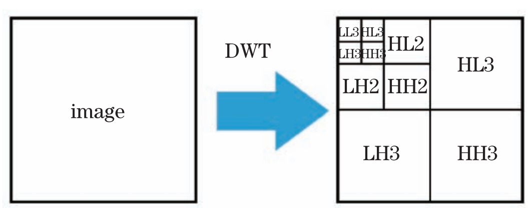

Fig. 2. Three-level DWT.

fusion[14]. However, the goal of fusing sub-aperture overlapping areas is to retain high-frequency components as much as the measurements. Thus, high-frequency coefficients are fused using the choose-randomly scheme, which involves randomly selecting a coefficient and discarding others. Although high-frequency components are not retained as "real," these parameters indicate the number of high-frequency components that exist in a certain area, which is our real concern. Finally, the fused image of the overlapping areas is obtained using inverse DWT (IDWT). Fusion of sub-aperture overlapping areas based on wavelet transformation is shown in Fig. 3.

Using the lattice design shown in Fig. 4, a flat surface is measured by a sub-aperture stitching interferometer.

After compensating for relative tilt, piston, and other mechanical location errors, the sub-aperture overlapping areas are fused using two methods: by calculating their average values (the old algorithm, Fig. 5) and by using the algorithm introduced in the following (the new algorithm). The full-aperture results are shown in Fig. 6.

The results obtained from both methods do not appear to have notable differences. However, after high-pass filtering, differences may easily be detected (Fig. 7).

The old algorithm clearly reduces the high-frequency components of the measurements in the sub-aperture overlapping areas, whereas the new algorithm retains the high-frequency components nearly as much as the measurements in the sub-aperture overlapping areas. Moreover, after high-pass filtering, the measurement root mean square (RMS) obtained in the sub-aperture overlapping areas is 0.0007537λ, the full-aperture RMS obtained using the old algorithm in the sub-aperture overlapping areas is 0.0005609λ, and the full-aperture RMS obtained using the new algorithm in the sub-aperture overlapping areas is 0.0007419λ.

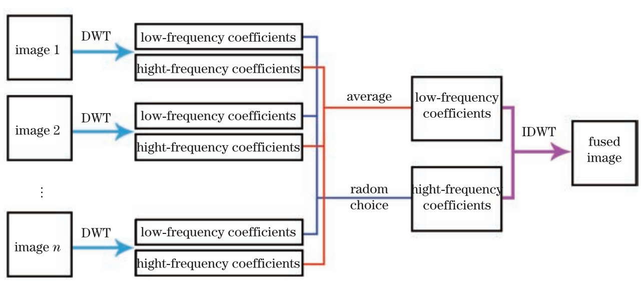

Fig. 3. Fusion of sub-aperture overlapping areas based on wavelet transformation.

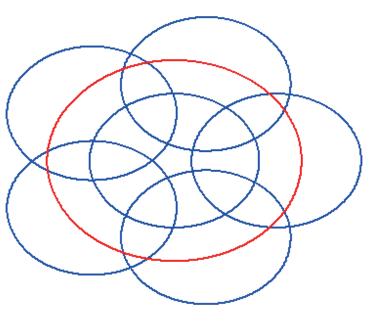

Fig. 4. Lattice design.

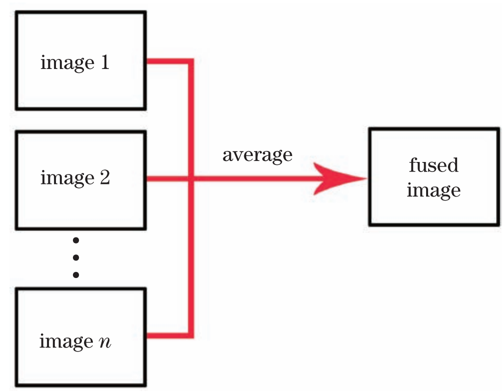

Fig. 5. Old algorithm.

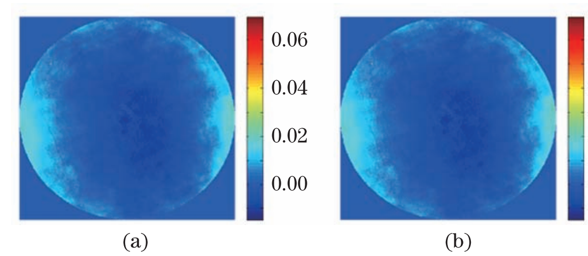

Fig. 6. Full-aperture results obtained by using (a) the old algorithm and (b) the new algorithm. Unit: wavelength.

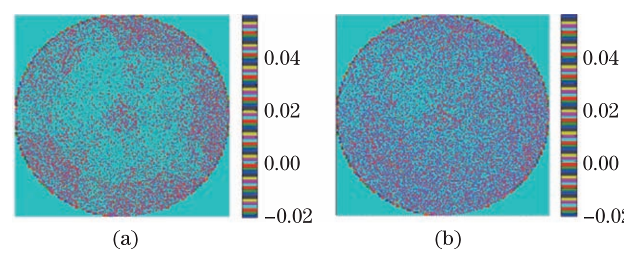

Fig. 7. Full-aperture results obtained by using (a) the old algorithm and (b) the new algorithm after high-pass filtering. Unit: wavelength.

In conclusion, a new sub-aperture overlapping area fusion algorithm based on wavelet transformation is proposed to retain high-frequency components nearly as much as the measurements. Experiments show that the old sub-aperture overlapping area fusion algorithm reduces the high-frequency components of measurements, whereas the new algorithm retains the high-frequency components as much as the measurements.

References

1. J. M. Hill, Appl. Opt. **49,** D115 (2010).
2. C. Guan and Z. Wang, Appl. Opt. **31,** 205 (1992).
3. C. J. Kim, Appl. Opt. **21,** 4521 (1982).
4. M. Otsubo, K. Okada, and J. Tsujiuchi, Opt. Eng. **33,** 608 (1994).
5. M. Sjödahl and B. F. Oreb, Opt. Eng. **41,** 403 (2002).
6. U. Dinger, G. Seitz, S. Schulte, F. Eisert, C. Muenster, S. Burkart, S. Stacklies, C. Bustaus, H. Hoefer, M. Mayer, B. Fellner, O. Hocky, M. Rupp, K. Riedelsheimer, and P. Kuerz, Proc. SPIE **5193,** 18 (2004).
7. Q. Miao, C. Shi, P. Xu, M. Yang, and Y. Shi, Chin. Opt. Lett. **9,** 041001 (2011).

8. Y. Yuan, J. Zhang, B. Chang, H. Xu, and Y. Han, Chin. Opt. Lett. **9,** 011101 (2011).
9. S. Gao, W. Jin, and L. Wang, Chin. Opt. Lett. **10,** 081101 (2012).
10. H. Wang, Z. Jing, and J. Li, Chin. Opt. Lett. **1,** 523 (2003).
11. Z. Li, Z. Jing, and S. Sun, Chin. Opt. Lett. **2,** 578 (2004).
12. G. Qu, D. Zhang, and P. Yan, Opt. Express **9**, 184 (2001).
13. R. Aguilar-Ponce, J. L. Tecpanecatl-Xihuitl, A. Kumar, and M. Bayoumi, *IEEE International Symposium on Circuits and Systems* 2658 (2007).
14. G. Pajares and J. M.l de la Cruz, Pattern Recognition **37**, 1855 (2004).