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*

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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.

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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

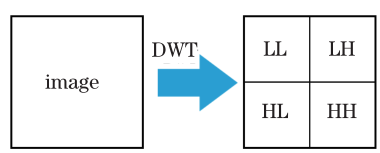

Fig. 1. Discrete wavelet transform (DWT).

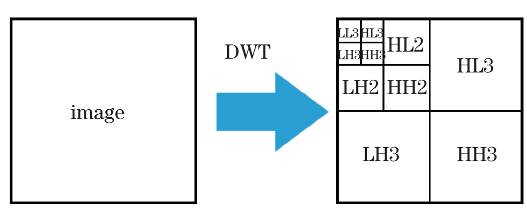

Fig. 2. Three-level DWT.

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.

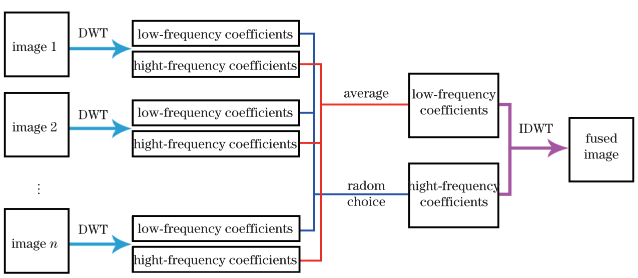

Fig. 3. Fusion of sub-aperture overlapping areas based on wavelet transformation.

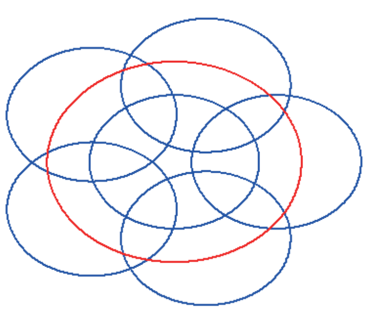

Fig. 4. Lattice design.

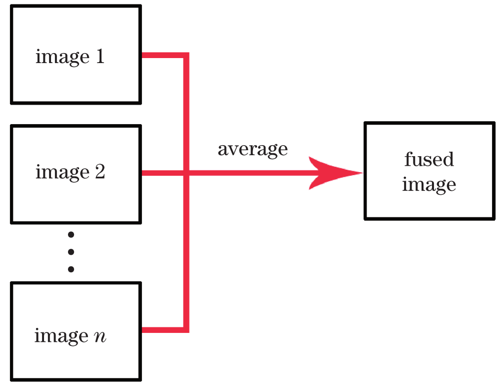

Fig. 5. Old algorithm.

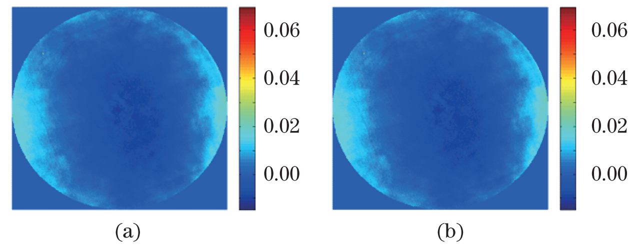

Fig. 6. Full-aperture results obtained by using (a) the old algorithm and (b) the new algorithm. Unit: wavelength.

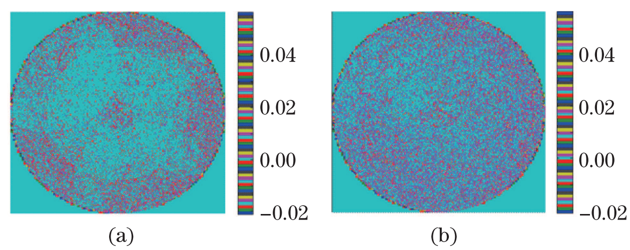

Fig. 7. Full-aperture results obtained by using (a) the old algorithm and (b) the new algorithm after high-pass filtering. Unit: wavelength.

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.

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