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Modified image fusion technique to remove defocus noise in optical scanning holography

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ABSTRACT

In sectional image reconstruction based on optical scanning holography (OSH) system, tomographic images are always contaminated by defocus noise. Though lots of methods have been proposed to solve this problem, some unsatisfactory results remain. In this article, a modified image fusion method is presented based on wavelet transform and connected component algorithms to deal with the defects in a random-phase OSH system where different sectional images usually have a relative displacement, rotation and loss. The method can fully utilize redundant information and affine transformation to repair the defects, and the defocus noise can be removed well. The final sectional images are more visible.

1. Introduction

Optical scanning holography (OSH) has been used in many fields, such as microcopy [1,2], three-dimensional (3-D) display [3], image encryption [4,5] and remote sensing [6,7]. It is a digital holography technique that records 3-D information by a 2-D optical heterodyne scanning. While the technique has the advantages of non-contact and high-resolution, the quality of in-focus section is usually degraded by the defocus noise, which comes from the reconstruction of other sections. To eliminate the defocus noise, various methods, such as Wiener filter [8], inverse imaging [9,10] and nonlocal means filtering [11], have been proposed. However, there are always some shortcomings in these methods.

Zhou put forward another way to tack with the problem, in which a random phase pupil is introduced to transfer the defocus noise into speckle-like patterns [12]. Then the speckle-like noise can be eliminated by a filter. Based on Zhou, Ou proposed a frame difference and connected component (FDCC) method [13], through which the speckle-like noise can be removed completely. However, when FDCC is applied in actual OSH experiment, it may not perform as satisfactorily as in numerical simulation. Because in actual OSH experiments, it is inevitable that there are some offsets between the two frames used for FDCC, especially when a significant vibration exists in the mechanical scanning process of OSH system and a displacement and rotation may occur compared to the last frame. And if the threshold of binarization in the connected component process is not set properly, there may be some loss in the original reconstructed holograms. That means in an actual experiment the position of sectional object in the two frames may be not as accurate as in simulation. There are usually slight relative displacement, rotation and loss. When these sectional images with inevitable relative changes are used, the reconstructed object may lose its original appearance, which cannot be tolerated in FDCC reconstruction. And defects would appear in reconstructed object caused by relative changes between original reconstructed images. For solving these problems, in this paper, we present a method of image fusion and connected component (IFCC) in random phase OSH system. With affine transformation introduced for image pre-registration, the relative displacement and rotation can be repaired perfectly and the different reconstructed images from the same sectional object can be fused better. In addition, the fusion can make full use of redundant information to fix the loss of an image. The simulation and experiment results testify that IFCC method is steady and can eliminate the speckle-like noise perfectly.

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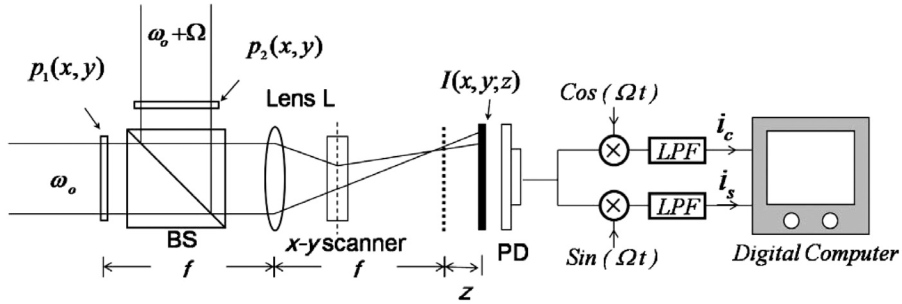

Fig. 1. [12]. Schematic of OSH. $p_1(x,y)$ and $p_2(x,y)$ are pupil functions; $I(x,y,z)$, object transmittance intensity function; f, focal length of lens L; z, distance of object from focal plane of lens L; PD, photodetector.

2. Optical scanning holography system

As described in Ref. [12], there are two stages in the process of random phase OSH, which we call them encoding and decoding stages. Both stages utilize the typical architecture shown in Fig. 1 [12]. Two pupils $p_1(x,y)$ and $p_2(x,y)$, illuminated by lasers of frequencies centered at ω_0 and $\omega_0+\Omega$ respectively, are located at the focal plane of lens L. The combined laser beam is applied to scan the object, located at a distance of $f+z$ away from the lens L, whose transmittance intensity function is $I(x,y,z)$. The transmitted light would be collected by the photodetector (PD) for further electronic and computer processing. In the encoding stage, the object is recorded as a hologram, which is used later to reconstruct object in decoding stage.

However, in an actual OSH experiment, some problems may be caused by utilizing mechanical scanning. For example, structure gaps cause vibration in the mechanical scanner and scanning speed is not consistent absolutely, both of which would lead to offsets in a reconstructed image. That means even when we scan object twice in succession, there is still offset, displacement and rotation, etc. In accordance with the feature of mechanical scanner itself, the offset is usually pixel-level. And in the reconstruction process of FDCC, these offsets can lead to a partial loss of the reconstructed image if an improper threshold is set.

3. IFCC method

IFCC method is composed of image fusion (IF) and connected component (CC) labeling. Image fusion has been widely used for computer vision [14], medical image fusion [15] and remote sensing [16]. The method can combine relevant information from two or more images into a single image. The resulting image will be more informative than any of the input images. It means that even though a part of one image has some loss while the corresponding parts of other images are complete, the fusion image will still have a good quality. Thus, we conduct IF method based on modified wavelet transformation algorithm to suppress the defocus noise partly and reserve the image details, and affine transformation is introduced to restore relative displacement and rotation. Through affine transformation and image fusion, the defects (displacement, rotation, loss) can be repaired firstly. Then similar as in FDCC, the connected component labeling, which is a basic process during computer vision, pattern recognition and image analysis [17,18], is applied to further remove the noise based on binary image analysis because it can distinguish the difference between images based on features, such as area, contour and perimeter. In random phase OSH system, there are obvious differences between the reconstructed object and speckle-like noise, which means they can be easily distinguished by CC labeling. Finally, considering image energy losing, which rises from the process of reconstructing and binary, and motion blur caused by mechanical scanning affecting the edge of an image, we add a step of edge-preserving for image reconstructing, at last.

In short, with IFCC, the defects of displacement, rotation and loss can be repaired well, and the defocus noise is suppressed to a certain extent by wavelet filter. Then CC labeling is used to remove the speckle-like noise further. By combining the two methods, we expect to get a fusion image more complete, at the same time, the defocus noise can be eliminated perfectly.

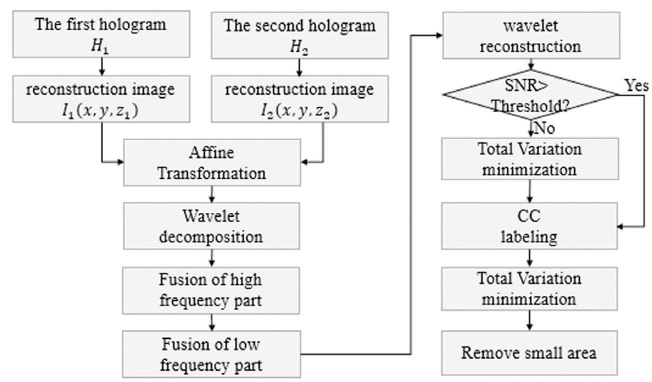

Fig. 2. Flow chart of IFCC algorithm.

Fig. 2 shows the flow chart of IFCC method. The steps of the algorithm are as follows:

1. Generate two holograms, $H_1(x,y)$ and $H_2(x,y)$, with the same or different random phase mask.
2. Get the reconstruction of ith section, $I_1(x,y,z_1)$ and $I_2(x,y,z_2)$, respectively.
3. Pre-register $I_1(x,y,z_1)$ and $I_2(x,y,z_2)$ by affine transformation, selecting $I_1(x,y,z_1)$ as the reference image in affine transformation.
4. Fuse the pre-registered images, $I_1(x,y,z_1)$ and $I_2(x,y,z_2)$.
5. Compare the values of average SNR between the two holograms, $H_1(x,y)$ and $H_2(x,y)$, with a threshold which we set as 1dB here. When the value of SNR is smaller than the threshold, then go to step 6, otherwise, go to step 7.
6. Preserve the edge of binary image using Total Variation minimization method [19], and stop iteration until the value of SNR larger than the threshold.
7. Use CC labeling and remove the connected component whose area s is smaller than the threshold we set. Here, the threshold is set as $0.1 * s_{max}$ and s_{max} is the maximum area in all the connected components [13].
8. Preserve the edge with Total Variation minimization method. Usually, the more number of iteration, the smoother of the image.

As for affine transformation, we draw on projections onto convex set (POCS) model [20]. In this paper, only two images are used. One of them is not deformed and chosen as reference frame, but it is not interpolated as the method of super-resolution image reconstruction while the other steps are the same as Ref. [20].