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Digital holographic image fusion for a larger size object using compressive sensing

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ABSTRACT

Digital holographic imaging fusion for a larger size object using compressive sensing is proposed. In this method, the high frequency component of the digital hologram under discrete wavelet transform is represented sparsely by using compressive sensing so that the data redundancy of digital holographic recording can be resolved validly, the low frequency component is retained totally to ensure the image quality, and multiple reconstructed images with different clear parts corresponding to a laser spot size are fused to realize the high quality reconstructed image of a larger size object. In addition, a filter combing high-pass and low-pass filters is designed to remove the zero-order term from a digital hologram effectively. The digital holographic experimental setup based on off-axis Fresnel digital holography was constructed. The feasible and comparative experiments were carried out. The fused image was evaluated by using the Tamura texture features. The experimental results demonstrated that the proposed method can improve the processing efficiency and visual characteristics of the fused image and enlarge the size of the measured object effectively.

1. Introduction

The digital holography has been widely applied in the measurement of surface topography, deformation and vibration [1–3]. The redundancy of recording data, the size limitation of the laser spot and the disturbance of zero-order term are main problems of the digital holography that directly affect the accuracy and efficiency of measurement. For the redundancy of holographic recording data, compressive sensing is usually used to execute data compression processing [4–7]. For example, Rivenson et al. gave a one-dimensional free-space propagation formula in the Fresnel approximation. The matrix-vector form of the discrete Fresnel transform is transformed as the approximate model of compressive sensing [4]. Rivenson et al. proposed a method to obtain a 3D object by utilizing a 3D-2D forward propagation model and demonstrated that compressive sensing approach yields improved sectioning of the planes of different depths [5]. Memmolo et al. proposed a robust method to suppress the noise components in digital holography using compressive sensing that does not consider any prior knowledge or estimation about the statistics of the noise [6]. Rivenson et al. provided an overview of the theoretical aspects and presented examples of application of compressive sensing theory in digital holography. And the near field model and the far field model was described, respectively [7]. These researches on digital holography focus on how to sparsely extract the whole image using compressive sensing when the image is reconstructed. However, the useful information will be removed when the whole image is sparsely extracted. Therefore, this compression of whole image often reduces the image quality because the useful information of digital hologram is compressed together with redundant data compression. Due to the size limitation of laser spot, digital holography is usually used to measure tiny objects. Mosaic methods are usually applied for the measurement of large size objects and the original image quality cannot be improved in mosaic methods. Some time, it is difficult to extract suitable feature points from the intersection of stitched images when the definitions of the holograms distribute irregularly. However, image fusion can improve the image quality [8,9]. Javidi et al. proposed a method for multi-spectral holographic three-dimensional image fusion using discrete wavelet transform [8]. Do et al. presented multifocus holographic 3-D image fusion based on independent component analysis (ICA). ICA technique is used to fuse multiple reconstructed holographic images at different distances [9]. The above methods can only fuse multiple images of the measured object that is in the range of the laser spot. Furthermore, these images to be fused are fused directly without compression. Thus, the efficiency of image fusion will be affected due to a large amount of measured data. In addition, phase-shifting method, mean value method and frequency domain filtering method are mainly used for removing the zero-order term. The phase-shifting method needs using a robust optical system in a laboratory and records multiple

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holograms by changing the phase of reference wave. Only the real image is obtained through the mathematical process [10]. The mean value method [11] needs subtracting the mean intensity of a hologram from every pixel value of the hologram in order to remove the zero-order term. However, the zero-order term cannot be completely eliminated when the intensity of the object wave was uneven. The frequency domain filtering method requires converting a hologram from the spatial domain to the frequency domain [12,13]. The hologram is filtered by setting a filtering window to remove the zero-order term. For example, a single high pass filter has been applied in the digital holography. Zhang Y. P. et al. formulated the theoretical basis for obtaining the spectrum distribution of hologram. A method that carries out high-pass filtering processing without zero-order diffraction interference upon digital hologram is proposed [14]. However, high pass filter can only filter out the low frequency noise and many high frequency background noises cannot be filtered out. In addition, because the spectral position of the real image locates on one side of the spectrum of the zero-order term, it is difficult to set an accurate filtering window. Thus, to obtain an appropriate filtering window often adjusts the parameters of the filtering window repeatedly.

To address the problems mentioned above, an image fusion for a larger size object using compressive sensing is proposed. The high frequency component obtained by means of discrete wavelet transform (DWT) is compressed and the low frequency component is retained to ensure the quality of the reconstructed image. The fusion method of multiple holograms with different clear parts is adopted to realize high quality of the reconstructed image of a larger size object. The zero-order term and background noises of hologram are removed by combining the high-pass and low-pass filters. Therefore, the image quality and the processing efficiency can be improved greatly. The principle of the proposed method is described in Section 2. Experiments are performed in Section 3 to demonstrate the efficiency of the proposed method. At last, the conclusion is given in Section 4.

2. Measurement principle

2.1. Algorithm framework

The reflective optical layout of off-axis Fresnel digital holography is shown in Fig. 1. Due to the size limitation of laser spot, only a part of a measured object can be clearly recorded in a single digital hologram. The plane mirror M_3 is finely adjusted to make the object wave project onto different positions of the measured object. As a result, multiple digital holograms including different clear parts of the measured object are recorded by CCD. The reconstructed images of the digital holograms are decomposed separately by using DWT. Then the low and high frequency components of the digital holograms can be obtained simultaneously.

Because the low frequency component reflects main useful informa-

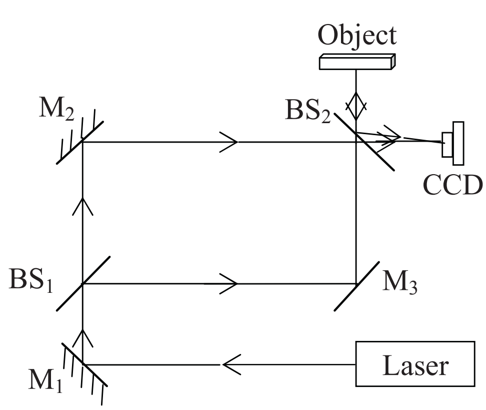

Fig. 1. Schematic of the reflective off-axis Fresnel digital holography.

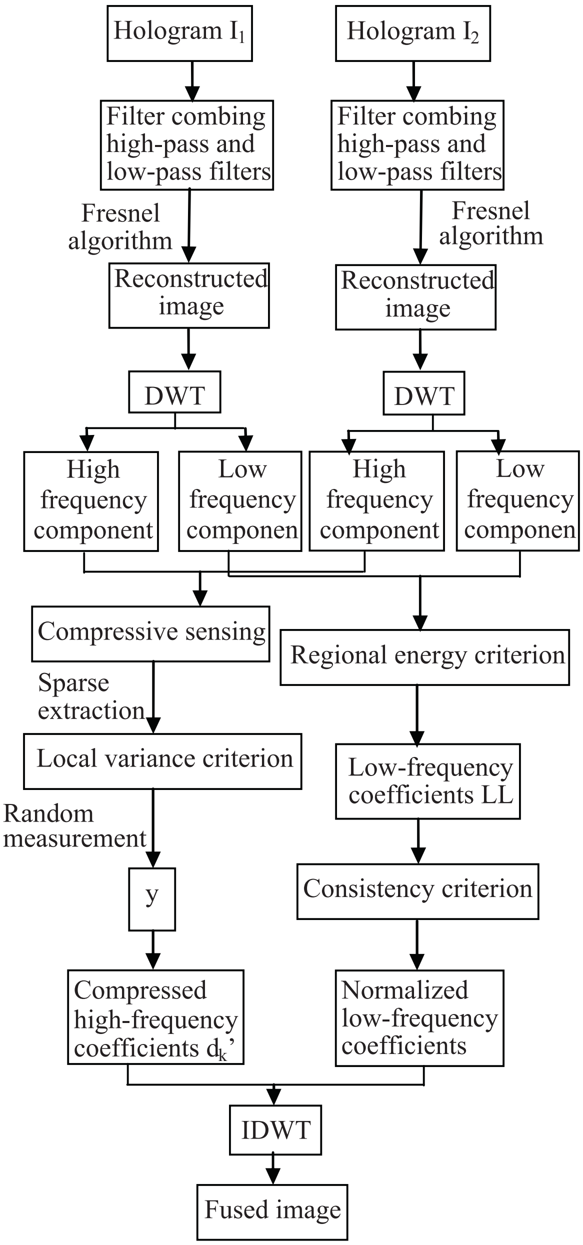

Fig. 2. The algorithm framework of holographic image fusion using compressive sensing.

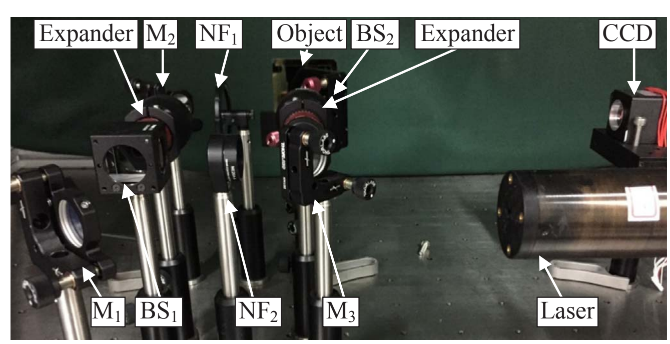

Fig. 3. The experimental setup.

tion of the digital hologram, the quality of the reconstructed image will be affected if they are compressed. Thus, the low frequency component needs to be retained totally to ensure the image quality. The criteria of regional energy and consistency are employed to normalize the low frequency component so as to equalize the gray distribution of the fused