Aberration-free reconstruction of digital holograms in arbitrary tilted planes

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Holography is a technique to perform 3-D imaging. In this method, the 3-D information is recorded in the interference hologram of the object wave and the reference wave. Recently, digital holograms are captured by a video camera and reconstructed by a computer by means of a diffraction integral, unlike conventional holograms using photographic recording and optical reconstruction.[(1),(2)]

For quantitative analysis of a 3-D object, scanning confocal microscopy and optical coherence tomography have been developed. These methods need mechanical scanning process to evaluate the dimensions of the object structures quantitatively. It limits the time of acquisition of 3-D images, because mechanical movement of an optical element or the object is very time-consuming process. And additional operating units make the system complicated. One of many advantages of digital holography is that focusing can be adjusted freely to yield images in arbitrary positions. This point makes it possible to measure the real-time images and quantitative informations of specimen without any mechanical moving parts in measurement system.

Because the most procedures of measuring process are performed by numerical calculation, it's very important for high image quality and accuracy, which algorithm is chosen to reconstruct a 3-D image in the given situation. A diversity of reconstruction algorithms for various environments of measurement have been studied. These algorithms are including several useful characteristics such as flexible magnification, numerical aberration compensation and viewing angle variation, which are difficult to be realized in conventional optical microscopy.[(3)~(6)] In view of the results so far achieved, digital holography is expected as a new 3-D imaging technique. It has already been applied to a variety of fields such as MEMS and Biology.[(7)~(9)]

To extract the 3-D informations from the measured holograms, several algorithms have been proposed such as Single Fresnel Integral(SFI), Convolution Method(CM) and Plane Wave Expansion Method(PWEM) according to the decrease in the reconstruction distance. These algorithms allow the images and the phase-maps to be reconstructed on the image plane which parallels with the hologram plane.[(10),(11)] In the case of 3-D structures, however, it would be interesting to investigate other sections such as non-parallel planes. The algorithms above mentioned need an amount of efforts to carry out the image reformation that can be occurred with the various viewing angles in conventional holography which has used the holographic films. In 2000, Yasuhiro Takaki and Hitoshi Ohzu discussed this image reformation in off-axis digital holography on their paper, following that, Lingfeng Yu and D. Lebrun proposed reconstruction methods on non-parallel plane in in-line digital holography, in 2002 and 2003, respectively.(12)~(14) Their algorithms make an application of fresnel approximation so that the dimensions of specimen are much smaller than those of hologram. However, Lingfeng Yu and Myoung K. Kim clarified on their recent research that established algorithms may fail to reconstruct images without aberration and phase noise in the case of the closer regions inside fresnel region in which large Numerical Aperture(NA) can be achieved for high image resolution or diffusive objects that can't be ignored the effects of higher order diffractions.(15) Furthermore, in digital holographic microscopy using micro-objective lenses for micro-object inspection, the dimensions of the magnified object is not smaller than those of hologram. In their algorithms, moreover, the pixel resolution of the reconstructed image varies as the reconstruction distance and the viewing angle. It requires the usage of the additional algorithms for magnification control to compare the two states of the object pixel by pixel.

In this paper, we propose a new reconstruction algorithm for arbitrary tilted image plane without any mathematical approximation using PWEM. Contrary to other methods, we established a coordinate transform in wave-vector space, which will be suggested in the next chapter, and exhibited the possibility of applying Nonuniform Discrete Fourier Transform(NDFT) to perform the coordinate transform and preserving or magnifying the pixel resolution irrespective of the reconstruction distance and the viewing angles in our algorithm. And then we will verify the accuracy and effectiveness compared with the results using preexisting algorithm.

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