A new method of digital holographic reconstruction  
based on EALCD and CCD

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Abstract

As a fast, simple and robust method for the field of non-destruction and non-contact testing and recording, digital holography has made great progress in recent years. Digital holographic reconstruction, an important part of digital holography, is also rapidly developing. In this paper, a new digital holographic reconstruction method is described, which is based on electrical addressed liquid crystal display (EALCD) and charged coupled device (CCD). Some properties of liquid crystal have been given in detail. Due to the digital devices mentioned above, it is not only convenient to improve the quality of the reconstructed image, also it has many advantages. On the basis of theory analysis, the new method is described in detail and has been carried out by optical experiment successfully.

Keywords: digital holographic reconstruction, CCD, EALCD, digital image processing

1. Introduction

Holography was firstly put forward by Dennis Gabor in 1948[1]. Now, it has become the most important technique in the field of 3D reconstruction and dynamic deformation testing of objects.

1.1 Traditional holography

The traditional holography is usually called optical holography. The process is very complex and trouble, as following Fig. 1.

![Fig. 1 The traditional holography](image)

1.2 Digital holography

With the occurrence of digital optical sensitive devices, such as charged coupled device (CCD), particularly with the improvement in the resolution and sensitivity of CCD and the development in the computer technology in recent years, digital holography (DH) obtains many advantages and has been developing rapidly. The process of digital holography can also be divided into two steps, which are similar with the traditional holography, including a hologram digitally recorded by CCD and numerically reconstructed by computer, as following Fig. 2.

![Fig. 2 The digital holography](image)
In fact, digital holography is simulation process of holography by computer. The wet chemical processing is left out. Therefore, it is more convenient than traditional holography and has the advantage of real time.

2. The properties of EALCD

Electrical addressed liquid crystal display (EALCD) is one of the most useful of spatial light modulators in optical information processing and optical computing.

Liquid crystal devices consist essentially of a thin layer of liquid crystal between two substrates with conducting electrodes. At least one of those electrodes must be transparent and generally have a thin coating to align the liquid-crystal molecules. The electrodes are usually etched to form appropriate geometrical patterns. Because liquid-crystal displays modify the ambient light instead of emitting light of their own, they use less power than light-emitting displays.

Liquid crystal is organic polymer compound, which has both properties of crystal reorientation and liquid liquidity. Liquid crystals are true liquid-with viscosities comparable to light machine oils-but with long range order in the orientation of their molecules. The ordering is determined by a delicate balance of intermolecular force, so that even small external stimuli, such as weak electric fields, can produce dramatic changes in the macroscopic properties of the liquid. The orientation of liquid crystals is an important aspects of the behavior of liquid crystals and it is an critical aspect to device performance. The alignment of a liquid crystal by substrate depends on both the nature of the liquid crystal and the substrate. The topography of the substrate as well as its chemical composition determines the orientation of the liquid crystal at the surface; the orientation at the surface then controls the orientation in the bulk by the same intermolecular forces responsible for the long-range orientational order in the first place \(^{(1)}\).

The EALCD has a sandwich structure consisting of a photoconductor layer, a dielectric mirror layer, a liquid crystal layer and two transparent electrode layers \(^{(2)}\) (Fig. 3). Liquid crystal molecules have the ordinary and the extraordinary index of refraction. The basis for the liquid-crystal devices is a molecular reorientation induced by applied electric fields. The intensity transmission is a function of the birefringence of the EALCD under the different external voltage applied to the display.

![Fig. 3 The EALCD configuration](image)

1. 7—glass substrate 2. 6—transparent electrode 3. 5—coating to align the liquid-crystal molecules 4—liquid crystal layer 5—power K—switch

3. The basic principle of digital holography

3.1 Basic theory of holographic recording

Goodman presented digital holography in 1967, the basic
principle of which is holograms recorded by CCD\textsuperscript{[2]}. The recording light path is the same as traditional optical holography, as following Fig. 6:

\begin{center}
\includegraphics[width=0.7\textwidth]{fig6.png}
\end{center}

Fig. 6 Coordinate system of digital holography

Where the object-plane is expressed \(x_0, y_0\), its optical field distribution is termed \(U_0(x_0, y_0)\) near the surface and \(x, y\) is represented the plane of CCD. The distance between two planes is denoted \(d\). When the recording condition satisfies the Fresnel approximation, object recording light intensity distribution at CCD surface can be expressed as:

\[
O(x, y) = \frac{1}{j\lambda d} \exp(jkd) \exp\left[\frac{jk}{2d} (x^2 + y^2)\right] \times \int \int \sum O(x_0, y_0) \exp\left[\frac{jk}{2d} (x_0^2 + y_0^2)\right] \exp\left[-\frac{jk}{2d} (x_0x + y_0y)\right] dx_0 dy_0
\]

(1)

The assumption that the distribution of the reference light is expressed \(R(x, y)\), when the Two light waves interfere, at \(x, y\) plane, hologram recorded on light intensity distribution by CCD can be written as follows:

\[
I(x, y) = |O(x, y) + R(x, y)|^2 = |O(x, y)|^2 + |R(x, y)|^2 + R^*(x, y)O(x, y) + R(x, y)O^*(x, y)
\]

(2)

3.2 Basic theory of reconstruction\textsuperscript{[5]}

In linear conditions, the transmission coefficient of hologram can be written as follows:

\[
t = t_0 + \beta I(x, y)
\]

(3)

\(t_0\) can be neglected, when recording hologram by CCD.

When employing optical method to realize reconstruction, we use original reference beam illuminates hologram, the complex amplitude distribution of the transmitted light behind hologram can be simplified as follows:

\[
tR(x, y) = \beta I(x, y)R(x, y)
\]

\[
= \beta |O(x, y)|^2 + |R(x, y)|^2 R(x, y) + \beta R^*(x, y)O(x, y)
\]

(4)

In the formula (4), the first term is the zero-order diffraction, whose amplitude has been minified by \(\beta |O(x, y)|^2 + |R(x, y)|^2\); the second term is the description of the reconstructed image of object wave, which is the 1st order diffraction; the third one is the description of the reconstructed conjugate image of object wave, which is the -1st order diffraction.

Due to the linearity of CCD exposure, high orders diffraction does not exist, which is useful to record and reconstruct hologram\textsuperscript{[5]}.

4. The reconstruction of digital holography

In this paper, a new digital holographic reconstruction is brought forward, which obtain some own features, using optical method, based on digital devices, CCD and EALCD.

In the first step of holography, we use the CCD to record the hologram, which is the same with the digital holography. The recording configuration is as following fig. 7. The distance between object and CCD is near. Therefore, the hologram is Fresnel hologram.
Then in the second step, we adopt the approach that hologram is transferred to digital media—electric addressed liquid crystal display (EALCD) to light up in order to realize the reconstruction. At first, the hologram recorded by CCD is carried out A/D conversion by the image acquisition card. And then the hologram converted is stored in the computer in digital form and then inputted the hologram into EALCD for the reconstruction.

At last, we place the lens and the CCD behind the EALCD to record the reconstructed image. The reconstruction configuration is as following fig. 8.

5. The results of the experiment

In real experiment, the object used in experiment is a coin: RMB 1 JIAO with the dimension of 18×18 mm. We adopt the off-axis holography to record hologram. The CCD camera with the light sensitive pixels of 2048(H)×2950(V) and the pixel sizes of 3.5 μm(H)×3.5 μm (V) is used to record the hologram and the reconstructed image. (Fig. 9). A He-Ne laser with the wavelength 632.8 nm is adopted and the max output power is 5 mw. The EALCD is produced by England (SVGA3VX) with the resolution of 1024(H)×768(V), the pixel sizes of 13 μm (H)×10 μm (V) and effective area of 18.5mm (H)×13.9 mm (V). (Fig. 10) (Note: H expresses lateral and V expresses longitudinal)

In order to obtain maximum energy in the system, we do not use polarizer. A microscope objective with magnification of 40× has been set in the setup to expand the beam. The beam splitter is used to provide object beam and reference beam.

In practical experiment, we obtain the reconstructed images by a lens fixed behind the EALCD. The angle between object beam and reference beam was measured as 10 degrees, which corresponds to a spatial frequency of the CCD used in the experiment.

Both of them are reconstructed from the hologram of Fig. 11. And Fig. 12 and Fig. 13 are reconstructed images of hologram of Fig. 9 in two different position.
5. Summary

The new method of reconstruction mentioned above not only has the features of traditional holography, but also has the advantages of digital holography. The wet chemical processing has also been left out. In addition, it is faster and more convenient than traditional holography and need not home position.

Then the new method of reconstruction has some merits that other digital holography does not have. For example, it is real optical experiment rather than simulated by computer in other digital holography. Therefore, more scientific observations can be carried out and some new phenomena may be discovered. Also, the new method of reconstruction is more convenient to observe from different angle and orders, does not like the single image simulated by computer in other digital holography. Also, it is real-time, automatically recording and inputting to EALCD by computer. This method and the optical path are very flexible, which has great potential in actual engineering application.

However, the low resolution of EALCD and CCD has limited the developing of this method. If the resolution of the CCD and EALCD could be greatly improved, the method is very good for 3D reconstruction of digital holography, further 3D deformation measurement.

Reference
2 Zhiwen Lu*, Yingjie Yu, Yunfang Jiao Deformation measurement based on digital holography 20072
3 Frederic J.Kahn The molecular physics of Liquid-crystal devices Physics Today 70-74 May 1982
4 Takashi Kurokawa, Seiji Fukushima Ferroelectric Liquid Crystal Spatial Light Modulators And Their Applications Ferroelectrics, 1993, vol.149, pp.245-254
5 Wensheng Wang, Testing Technique of Interference