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REAL TIME MICRODISPLACEMENTS TESTING BY OPTO-DIGITAL HOLOGRAPHIC INTERFEROMETRY TECHNIQUE

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Résumé

Contrairement à holographie classique, l'étape d'enregistrement dans l'holographie opto-digitale est basée sur l'utilisation de capteurs CCD et l'étape de restitution est basée sur l'utilisation d'afficheurs à cristaux liquides (LCD) ou des barettes à miroirs digitaux (DMD). L'inconvénient majeur de ce genre de composants étant la taille de leurs pixels qui reste assez grande devant celle des grains des plaques holographiques classiques. C'est pourquoi, il n'était pas possible de réaliser des hologrammes d'objets volumineux. L'évolution rapide dans la technologie de ces éléments d'imagerie ces dernières années, permet de trouver, actuellement, des éléments avec des tailles relativement petites (environ 4µm dans le cas des CCD et 7µm dans le cas des LCD). Il est donc possible d'augmenter le volume des objets holographiés et d'améliorer la qualité des hologrammes obtenus. Nous montrons dans ce travail qu'il est possible d'enregistrer et de restituer en temps quasi réel des hologrammes d'objets de quelques cm².

Etant donné que tout le processus est contrôlé numériquement, il est donc possible de suivre en temps réel et en utilisant les techniques d'interférométrie holographique à double exposition, en temps réel ou en temps moyenné, tout changement sur l'échantillon à étudier et de pouvoir enclencher ou arrêter le processus au moment voulu à l'aide de logiciel adapté. Ceci peut être réalisé par soustraction d'une image de référence à l'aide du logiciel adéquat directement sur la caméra CCD. Nous montrons aussi l'aptitude de la technique à l'étude en temps réel de tout phénomène évolutif.

Mots clés: Holographie digitale, Holographie Optodigitale, Interférométrie holographique, Contrôle non destructif

Abstract

In opposite of classical holography, the opto-digital holography recording step is based on CCD (charge coupled device) sensors and the optical reconstruction step is based on LCD (liquid crystal displays) or DMD (digital mirror displays) devices. Knowing, that the important disadvantage of these elements was their pixel size which was relatively high comparatively to the classical photoplate's grains size, it was not possible to make holograms of large objects. The quick evolution of these imaging devices, these last few years, permits to find, such devices with relatively low pixel size (nearly 4 µm for CCD and 7 µm for LCD). It is then possible to work on voluminous objects and to get best holograms quality. We show in this work that it is possible to record and reconstruct holograms of objects having several cms square.

Since all the process is controlled numerically, it is possible to follow in real time using the holographic interferometry techniques, double exposure, real time or time average, any changes in the object under study and to start and stop the process at any time by adequate software. This can be done by subtracting a reference image by suitable software directly on the CCD camera. We show also, the ability of the technique to study in real time all evolutional phenomena.

Keywords: Digital holography, Opto-digital holography, Holographic interferometry, Non destructive testing

ملخص

عكس الهولغرافيا الكلاسيكية،فإن مرحلة التصوير في الهولغرافيا البصرية الرقمية تعتمد على مجسات CCD أما مرحلة تركيب الصورة فتعتمد على شاشات البلورات السائلة (LCD) أو المرآت الرقمية (DMD). العائق الرئيسي لهذه المركبات هو كبر الخلايا الذي يبقى مرتفعا مقارنة ببلورات الألواح الهولغرافية الكلاسيكية. لذلك لم يكن ممكنا الحصول على هولغرامات لأشياء ذات أحجام كبيرة. لكن مع التطور التكنولوجي الملحوظ خلال السنوات الأخيرة لهذه المركبات حيث أصبح من الممكن إيجاد مركبات ذات خلايا أصغر(حوالي 4 مكرومتر بالنسبة لـCCD و 7 مكرومتر بالنسبة ل LCD). لذلك أصبح من الممكن الحصول على هولغرامات لأشياء ذات أحجام كبيرة مع تحسن في نوعية الصور. نبين من خلال هذا العمل أنه من الممكن تصوير و تركيب صور، في زمن شبه حقيقي، لأشياء ذات مساحات بعدة سنتمترات مربعة.

بما أن كل العملية مراقبة رقميا، فمن الممكن إذا المتابعة في الزمن الحقيقي بواسطة تقنيات التداخل الهولغرافي المضاعف، في الزمن الحقيقي أو الزمن المتوسطي كل تغير على الأشياء المدروسة مع إمكانية تشغيل أو توقيف العملية في أي وقت بواسطة نظام تحكم مواتي. هذه العملية يمكن إجراؤها بواسطة طرح صورة معلميه عن طريق نظام التحكم المواتي مباشرة من خلال آلة التصوير CCD. نبين كذلك قابلية التقنية لدراسة كل الظواهر المتغيرة في الزمن الحقيقي.

الكلمات المفتاحيـــة **:** الهولغرافيا الرقمية، الهولغرافيا البصرية الرقمية، التداخل الهولغرافي، المراقبة الغير محطمة

INTRODUCTION

Holography [1, 2] is a technique for recording and reconstructing optically complete object's information, as amplitude and phase variations, by interfering on the sensitive plane of an optical detector an object wave with a refrence one. The detector (photoplate) records the resulting distributed intensity given by the following equation:

$$I = I_{ob} + I_{ref} + 2\sqrt{I_{ob} I_{ref}} \cos(\varphi_{ob} - \varphi_{ref}), \qquad (1)$$

Where I_{ob} is the object wave intensity variation, I_{ref} is the reference wave intensity variation, φ_{ob} and φ_{ref} are respectively the object phase and reference phase variations.

As interference phenomena are observed under define conditions, mainly, the coherence of the light for which, lasers are the most convenient and used light sources.

The saving medium widely used till several years ago, was photosensitive materials (mainly those made from silver halide crystals). This kind of media is chosen for its high resolution (more than 2000 lines/mm) comparatively to ordinary photographic films (500 lines/mm). The main disadvantages of these media are their necessary chemical processing and the fact that the information is not quickly ready to handle. Furthermore several aberrations are introduced during these operations. To avoid such disadvantages and in order to make this technique automatic, several authors [3, 4, 5, 6] tried to use CCD sensors and computers as recording media (digital holography).

After many attempts at different laboratories, Schnars and Jüptner [3] show the possibility to record a hologram using a CCD camera and to reconstruct the image in a numerical manner. It is then possible to reconstruct the image at any time and space and make any transformation or calculation such as phase distribution determination [4] or interfere holograms numerically [4, 5].

The main problem was the resolution and the surface size of the CCD detectors (nearly 100 lines/mm), which is less than that of ordinary films. To fulfill the sampling theorem and resolve the interfering fringes between object and reference beams, the maximum angle θ (2) between the object and reference beams must be in the range of several degrees only. That was the reason why only small objects placed at large distances can be recorded.

$$\theta \leq \arcsin \frac{\lambda}{2\Delta x}, \qquad (2)$$

Where λ is the light wave length and Δx the pixel pitch of the CCD sensor.

To overcome the CCD resolution problem, several set-ups were proposed and discussed [6]. Experimental applications were also carried out with relatively small and microscopical objects [7].

In the same time, liquid crystals displayers (LCD) directly addressed by computer made possible the optical reconstruction of the hologram [8].

If the CCD technology has grown enough these last few years, so that, it is possible to find different megapixel cameras, but in term of pixel pitch the situation still be always the same (8 – 9)µm. Recently, it becomes possible to find on the market CCD cameras with less than 5µm pixel pitch. With such resolution it is possible to make holograms of relatively large objects using of axis configuration. In the same time the resolution of liquid crystal displays (LCD) has also known a very interesting achievement. We show in this work that it is possible to see in real-time relatively good holograms of macroscopical objects, as it is also possible to see in real time any changes on the object by holographic interfermetry in an opto-digital manner.

Real time opto-digital holography

Opto-digital holography is a new field of holography where the hologramm of any object is recorded digitally and the three dimensionnal image is reconstructed optically.

As all steps are controlled by computer, the reconstructed image is observed in quasi real time. It is made of two steps as in classical holography; the recording step, were the light scattered by the object surface is superposed to the reference illumination at the plane of the CCD sensor. The interference pattern (1) is digitized and recorded according to the sampling theorem [4]:

$$(I)_{CCD} = (I).rect\left[\frac{x}{L_x}, \frac{y}{L_y}\right] \sum_{k,l=-\frac{N}{2}}^{\frac{N}{2}} \delta(x - k\Delta x, y - l\Delta y), \qquad (3)$$

Where L_x, L_y are the sizes of the CCD ship following x and y coordinates;

N, k and l are respectively the pixel numbers and pixel coordinates following also x and y axes.

The resulting image is stored in the host memory of the computer and then addressed on a liquid crystal display giving rise to a hologram transparency [9]:

$$(T)_{LCD} = (I)_{CCD} \left\{ rect\left[\frac{X}{L_X}, \frac{Y}{L_Y}\right] \sum_{k,l=-\frac{M}{2}}^{\frac{M}{2}} \delta(X - p\Delta X, Y - q\Delta Y) \right\} \qquad (4)$$

Where L_X, L_Y are the sizes of the LCD ship following X and Y coordinates;

ΔX, ΔY are the pixel sizes of an LCD;

M, p and q are respectively the pixel numbers and pixel coordinates following also X and Y axes.

The LCD should be then illuminated by a laser beam to reconstruct, by phase modulation in order to enhance the diffraction efficiency, at a distance d, the three dimensional image of the recorded object.

By adequate software it is possible to address directly the interference pattern recorded by the CCD camera on the LCD, the technique is called real time opto-digital holography. For such purpose the following set-up was built (fig. 1):

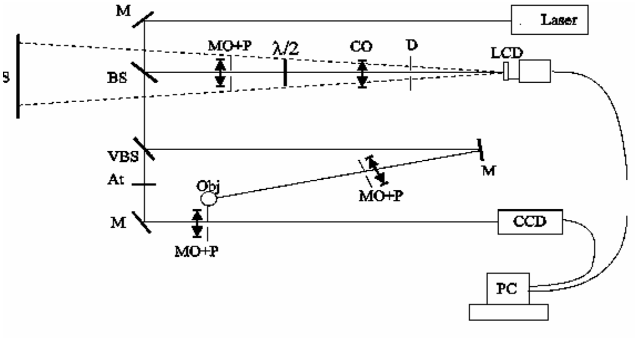


Figure 1: Real time opto-digital holographic set-up scheme M, mirror; BS, beam splitter; VBS, variable beam splitter; At, attenuator; MO, microscope objective; P, pinhole; D, diaphragm; CO, camera objective; S, screen

The green laser light coming from a frequency doubled YAG laser, is splitted using mirrors and beam splitters in three beams. One as object beam which is enlarged with a convenient microscope objective in order to illuminate the whole object under study. The second as reference beam is passed through a microscope objective to focus it on a pinhole in order to get the Fourier configuration. The third as a reconstructing beam via the LCD, it is also enlarged and collimated.

The CCD camera used, was a KAPPA DX2N with a photosensitive surface 6,5 x 4,8 mm² made of (1384 x 1032) pixels with (4,65 x 4,65) µm pixel size. The LCD was a WUXGA reflective LCoS display having the following features: 1936 x1216 pixels; amplitude or phase modulation; pixel pitch: 9.5 µm; 2 π Phase Shift between 400 and 650 nm; fill factor: 92 %; imaged array: 19.01 x 11.40 mm²; addressing: 8 Bit. In order to test our set-up, an alarm clock of 5x5 cm² was used as object; the reconstructed image is as follows (fig. 2).

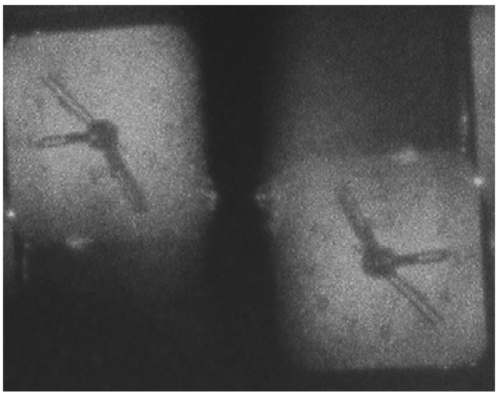
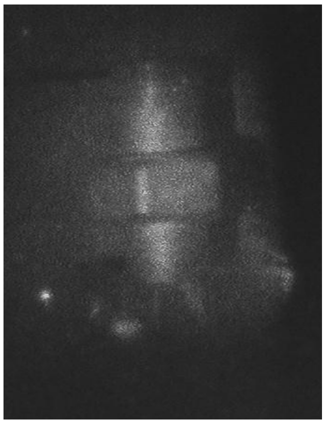


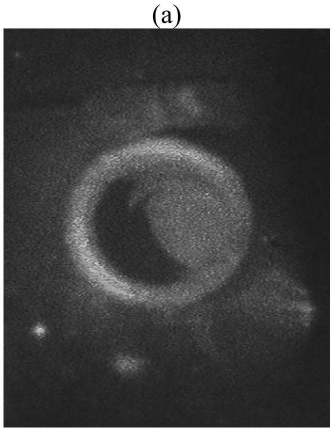
Figure 2: Real time reconstructed image of an alarm clock hologram

We can see clearly the whole area of the watch and the shadow of its hands. The twin images are clearly visible and the sharpness is relatively equal on all the area, of course speckle degrades a little bit the quality of the image. The zero order blocked here with an obstacle degrades the image quality.

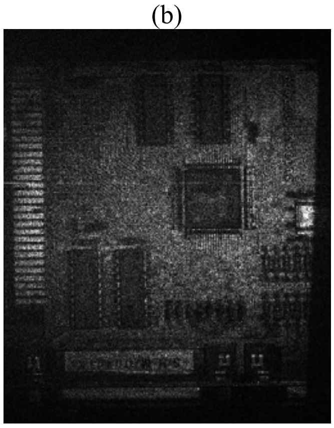
Several other elements with different natures were also taken as objects and their reconstructed images are presented in figure (3).



(a)



(b)



(c)

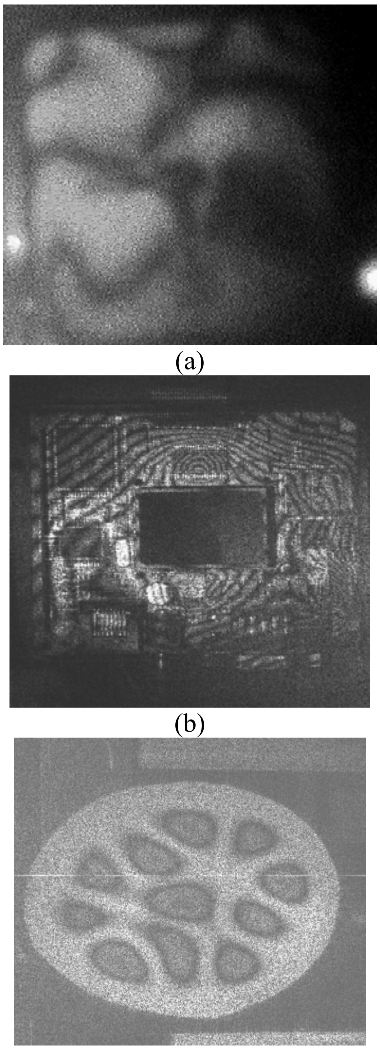
Figure 3: Real time reconstructed holograms of different technical objects: a- Mechanical end piece; b- Flanged side outlet tee; c- Electronic board.

From these images, one can see the efficiency of such technique for observing different kinds of elements and possibly directly in their using set-ups.

Real time opto-digital holographic interferometry

If in holography the three dimensional characteristics of the observed image constitutes an important event, holographic interferometry was the motor development of holography in specialized laboratories, since it can visualize and permit to evaluate microdisplacements and deformations on studied objects. It takes a very important place as a non destructive testing technique.

Holographic interferometry is a technique consisting of superposition of two or more holograms on the same observed support. Such superposition gives rise to interference fringes showing micro displacements or deformations occurring on the object under study between the different expositions. Several techniques are usually used such double exposure technique, real time technique, integrated time technique. In classical holographic interferometry, it was necessary to develop chemically, the photoplate and see after that the occurring fringes. With optodigital holography, it is possible to see in quasi real time the resulting interferogram. In our case it is possible to see in real time on the screen any change on the studied object (displacements or deformations) as defiling fringes by putting a reference image in the buffer of the CCD camera. The following images show such possibility (fig. 4).



(a)

(b)

(c)

Figure 4: Opto-digital holographic interferograms a- double exposed interferogram of an alarm clock under ring; b- real time interferogram of an electronic board under voltage; c- integrated time interferogram of a vibrating membrane.

The above interferograms show clearly the changes on the object as fringes. The rings of the alarm clock let the object suffering of vibrations. The feeding of the board card under voltage lets the temperature changes with increasing time. A membrane under vibration lets appear different resonance frequencies. These images are only examples of several results obtained with this technique, which means that the technique is useful for any application and any kind of object.

CONCLUSION

We have shown in this work the ability of optodigital holography for reconstructing real time holograms of different kind of objects. It was pointed out that this goal depends closely on the suitable CCD camera in order to work on relatively volume objects, several cm² in our case. We have shown also the possibility to make real time holographic interferometry. This new possibility permits to follow any deformation process using a video camera to record all the process and to study it after that, step by step in order to predict failures and cracks.

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