ap

Asian Journal of Physics Vol. 24, No 2 (2015) 269-274

Despeckle methods and their new application to laser LCOS projector

Suganda Jutamulia

University of Northern California

Biomedical Engineering Department

1300 Valley House Drive, #100-7, Rohnert Park, CA 94928

Early despeckle methods are revisited. In earlier problem, speckles are caused by the diffused holographic object, and in current problem, speckles are caused by the diffused projection screen.

Keywords: Despeckle; hologram; laser projector; LCOS

1 Introduction

The paper is to honor Professor Francis Yu, who has made significant contributions to information optics [1].

About four decades ago, there were a number of studies related to the speckle reduction or "despeckle" as we will use the terminology in the paper. Various despeckle methods were proposed and demonstrated. One of them was Yu method [2]. Yu method and others were aimed to reduce speckles that were generated in holographic reconstruction using lasers. In another example demonstrated by Jutamulia *et al* [3], speckles generated in optical coherent processing could be reduced. A general analysis of speckle reduction in optical coherent processing is given by Iwai and Asakura [4].

Currently, digital image processing is preferred over optical coherent processing. Holographic display using laser for reconstruction is also not widely available. However, recently, laser based projectors become commercially available, especially small footprint laser projector modules using liquid crystal on silicon (LCOS) display are introduced for their inclusion in mobile phones and other portable projectors [5]. Since lasers are used to illuminate and project the displayed image on the LCOS display, speckles unavoidably arise. Thus, despeckle methods are back in demand. In the paper, Yu [1] and van Ligten [6,7] despeckle methods are revisited, which may be adopted for the sake of new applications.

Speckles are usually recognized as objective and subjective speckles. Objective speckles are speckles generated on an observation plane, independent of the observer. Subjective speckles are speckles generated on the retina of the observer when the observer looks at the observation plane. Thus when two observers are looking at the same observation plane, the two observers may observe two different speckle patterns over the same image of the observation plane. Speckles perceived by an observer looking at the laser projected image on a projection screen are subjective speckles.

2 Yu Despeckle Method

According to Yu [1], speckle noise in the hologram image has been commonly regarded as the number one enemy. The speckle subjectively arises from a hologram in which a diffused object is recorded. Historically, almost as soon as lasers had become available, this image granularity or sparkling effect was already reported. In Yu method, the hologram image speckle can be reduced by spatially random sampling of the hologram aperture. The sampling procedure can be performed by a movable random mask. If the sampling function is made to be uncorrelated in subsequent spatial sampling, the speckle effect in the hologram image can be eliminated.

Corresponding author :

e-mail: suganda@sbcglobal.net (Suganda Jutamulia)

In most holographic processes, the objects to be holographed are generally not perfectly smooth in surface (i.e., diffused). In the conventional off-axis wavefront recording as shown in Fig 1, the light scattered from the object can be regarded as composed of a large number of infinitesimal point radiators having random phases. The complex light field distributed on the recording aperture can be written as the summation of the interferences of the reference wavefront and wavefronts originated from point radiators on the diffused surface with random phases.

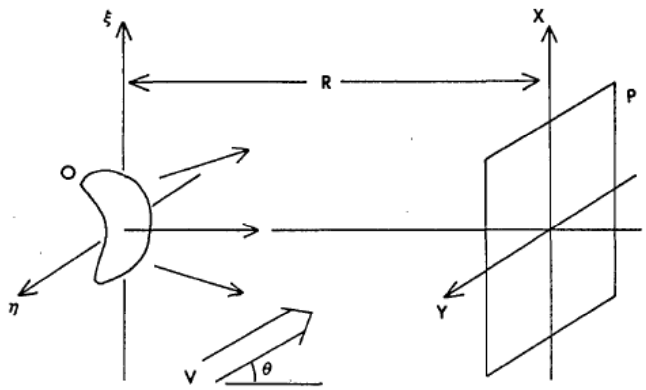

Fig 1. An off-axis wavefront recording. O, diffuse object; P: photographic plate; v: oblique reference wave [2].

When the hologram is reconstructed, the complex light field for the real image reconstruction can be determined from the Fresnel-Kirchhoff theory. The interference patterns of point radiators with random phases will produce a random interference pattern known as speckle noise over the reconstructed image of the diffused object. However, this type of speckle effect can be reduced by means of random spatial sampling of the hologram.

With reference to Fig 2, let us assume a spatially sampling function (i.e., random masking) is 1 over the open aperture and 0 otherwise at a time, for example, t1. The sampling function is located at the front of the hologram during the reconstruction process. The complex light field illuminating the hologram can be seen proportional to the spatial sampling. The complex light field at the back focal distance of the

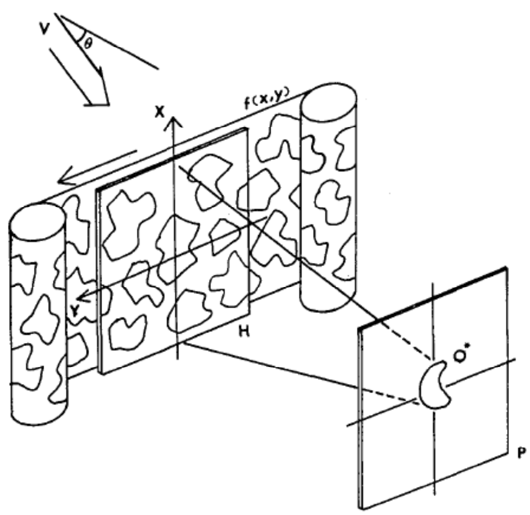

Fig 2. Schematic diagram of speckle reduction by random spatial sampling. f(x,y), the sampling function; H:hologram; v: monochromatic illumination; P: photographic plate [2].

hologram can be written by the convolution between the Fourier transform of the sampling function and the Fresnel-Kirchhoff integral of the hologram. At a time t1, a speckle pattern is generated, which differs from the speckle pattern generated by different sampling function at another time t2. By moving the sampling function while the hologram is stationary and taking integration from t1, t2, …. to tn, the speckle effect in the hologram image can be eliminated. Thus it may be seen a reduction of speckle effect in hologram image, posterior to the holographic recording, is possible.

3 Van Ligten Despeckle Method

In van Ligten method [6,7], when the hologram (19) is recorded, the object (17) is illuminated by multiple point sources (43), each of which is coherent with the reference point source (29), as shown in Fig 3. During the reconstruction as shown in Fig 4, the object wavefront contains separate subwavefronts corresponding to each point source (43). These subwavefronts are now separated in time of presentation to the observer. This separation is achieved by imaging, using a lens (54), the Fourier transform plane (52) of the object (53) in real spac (55), and placing a mask (60) in the image plane (55).

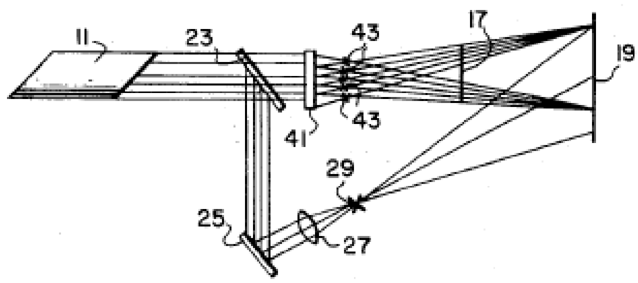

Fig 3. Recording hologram using multiple object beams [7].

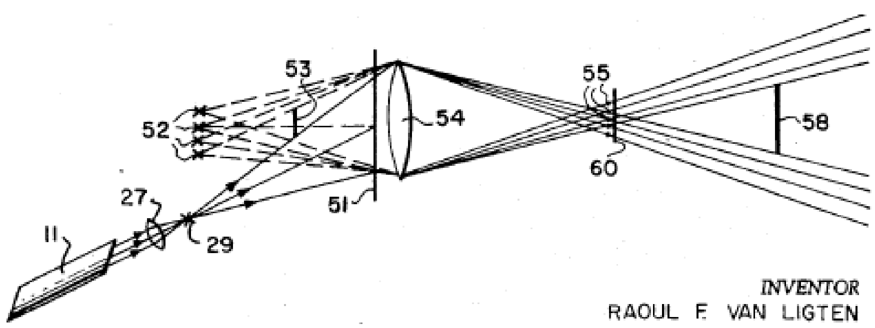

Fig 4. Reconstruction of hologram. Object subwavefronts are separated in real space (55). A moving mask (60) is placed in theimage plane (55) [7].

The mask (60) is opaque except for a round hole whose center coincides with one of point sources (43). The mask (60) is now moved in time from one position to another. The speckle pattern associated with a position of the mask is different from the speckle pattern associated with another position of the mask. The effective image that the human observer or any other time-integrating mechanism sees can be obtained by adding the intensities of each image present during the integration time. The resultant image appears as an image of the object illuminated by mutually incoherent wavefronts. Speckles are eliminated in the time-integrated observation.

4 LCOS Display

As the technology advanced, currently liquid crystal on silicon (LCOS) display are commercially available [5,8]. LCOS displays are primarily divided into two classes, displays for rear-projection TV (RPTV) and displays for pocket and pico projectors. Pocket projectors are portable stand-alone projectors as small as a mobile phone. Pico projectors are designed to embed into a mobile phone. LCOS displays are small, typically about 3 inches in diagonal for RPTV having HD resolution 1920x1080 pixels, and about 0.2-0.9 inch in diagonal for pico projector having from VGA resolution 640×480 pixels, to SXGA resolution 1280 ×1024 pixels and HD resolution 1920×1080 pixels. LCOS displays are mostly used for projection display, but they can be also used for near-to-eye (NTE) direct display.

The main difference between LCOS display and active matrix TFT LCD is that while active matrix TFT LCD forms thin-film-transistors (TFT) on a glass substrate, LCOS display forms the transistors and other electronic circuits directly on a silicon substrate using microelectronics manufacturing technology. Accordingly, a tiny pixel in the order of 6 μm can be formed. Thus a HDTV format of 1920×1080 pixels with 8 μm pixel pitch has been demonstrated in a LCOS display having active area of 15.36×8.64 mm^2. The display size is 0.7 inch in diagonal.

LCOS displays include a layer of liquid crystal sandwiched between a top sheet of glass coated with a transparent electrode, and a pixelated silicon substrate backplane made by the complementary-metal-oxide-semiconductor (CMOS) fabrication process. Note that the CMOS fabrication process is capable of forming a pixelated structure having 1.5 μm pixel pitch. However, the pixel of this small dimension may not have sufficient liquid crystal to alter the light polarization.

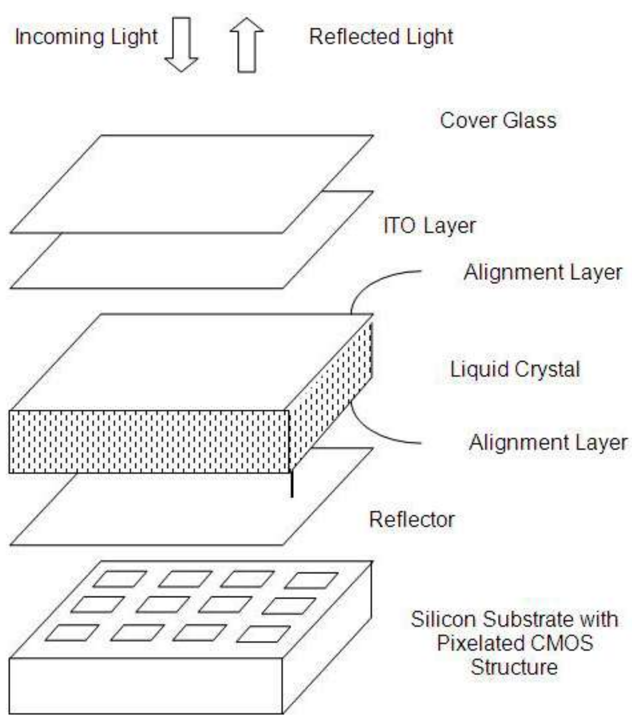

Fig 5. Structure of LCOS display

In many cases, LCOS displays are reflective. A reflector may serve as a mirror element for each pixel, with the strength of the reflection controlled by the amount of light transmitted through the liquid crystal layer above. Transmissive LCOS display is also possible, by making the silicon substrate thin enough for light transmission. However, this configuration is less efficient, since the electronic circuits and other structure behind the reflector must be properly design in order not to block the transmitted light. In a reflective LCOS display, since the transistors and electronic circuits are underneath of thereflector, they can be made under the pixels, thus the fill factor can approach 100% in theory. Usually, a reflective LCOS display is referred as simply LCOS display.

An LCOS display is depicted in Fig 5 [8]. The incoming light passes through a cover glass and transparent indium-titanium-oxide (ITO) electrodes, enters the liquid crystal layer, and finally is reflected by a reflector. A pixelated CMOS structure may be underneath the reflector. The electric field between the ITO electrode and the pixel controls the polarization modulation in the liquid crystal layer. Thus the reflected light is polarization modulated by each pixel in the silicon substrate. Using a pair of polarizers, the polarization modulated light is transformed to intensity or phase modulated light.

Applications of LCOS displays include projection display, near-to-eye (NTE) direct display in which the eye directly views the display (LCOS display), and as spatial light modulator in scientific application not for display. For example, a pure phase LCOS SLM is available from Hamamatsu (Japan), which can be used in adaptive optics to correct the random phase variation for retina imaging.

5 Despeckle of laser projector

A typical laser projector [9] is depicted in Fig 6. A laser is collimated by a collimating lens. The collimated laser light illuminates a reflecting type LCOS display through a beam splitter. Light after passing through and being modulated by the LCOS is projected by a projection lens on a projection screen. An observer looks at the projected image on the projection screen. The projection screen is not smooth, i.e., having topographical structure.

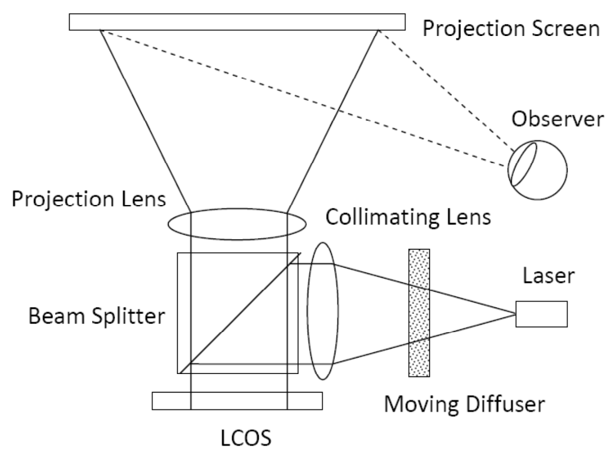

Fig 6. Schematic diagram of a typical laser projector using LCOS display.

Limited by the pupil of the observer, the associated point spread function on the screen may include multiple elements of the topographical structure as shown in Fig 7. Each element has random height such that light reflected has random phase. At the retina of the observer, the multiple interference of light of random phases from elements of the topographical structure in each point spread function, will produce a subjective speckle pattern.

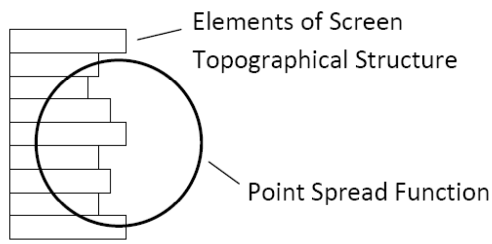

Fig 7. Each point spread function on the projection screen includes multiple elements of topographical structure.

To reduce the speckles perceived, it is commonly used a moving diffuser located between the laser and the collimating lens as shown in Fig 6, following a method suggested by Martienssen and Spiller [10] almost five decades ago. The diffuser effectively generates multiple sources having random phases from the laser light. Elements of the topographical structure in each point spread function are illuminated by the generated multiple sources. As the diffuser is moving, the phases of light at each element of the topographical structure originating from the generated multiple sources change randomly. Consequently, the generated speckle pattern changes randomly. Thus, in time integration, the perceived speckle pattern is eliminated.

6 Conclusion

Yu and van Ligten despeckle methods have replaced the method based on the rotating diffuser of Martienssen and Spiller for holographic speckle reduction. Therefore, Yu and van Ligten despeckle methods, and various methods, which are available, may be adopted to solve the current problem associated with laser projectors. In earlier problem, speckles are caused by the diffused holographic object, while in current problem, speckles are caused by the diffused projection screen.

References

1. Part of this paper was presented at Optics & Photonics Taiwan International Conference, OPTICS (2012), National Taiwan University, December 6-8, 2012, Sepecial Session on Optical Information Processing Honoring Professor Francis Yu and Celebrating his 80th Birthday.
2. Yu F T S, Wang E Y, Speckle reduction in holography by means of random spatial sampling, *Appl Opt*, 12(1973)1656-1659.
3. Jutamulia S, Asakura T, Ambar H, Reduction of coherent noise using artificial incoherent sources, *Optik*, 70(1985)52-57.
4. Iwai T, Asakura T, Speckle reduction in coherent information processing, *Procd IEEE*, 84(1996)765-781.
5. Bleha W P, Lei L A, Advances in liquid crystal on silicon (LCOS) spatial light modulator technology, *SPIE Procd,* 8736(2013)87360A.
6. van Ligten R F, Speckle reduction by simulation of partially coherent object illumination in holography, *Appl Opt*, 12(1973)255-265.
7. van Ligten R F, Simulation of an extended incoherent object source in holography so as to eliminate speckle noise, U.S. Patent 3,640,599 (Feb 8, 1972).
8. Armitage D, Underwood I, Wu S-T, Microdisplays move outside the box, O E Magazine, November 2002, 28-30.
9. Janssens P, Malfait K, Future prospects of high-end laser projectors, *SPIE Procd*, 7232(2009)72320Y.
10. Martienssen W, Spiller E, Coherence and fluctuations in light beams, *Am J Phys*, 32(1964)919-926.

[*Received*: 01.02.2015 ; *accepted*: 03.02.2015]