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Rapid Defect Inspection of Display Device with Optical Spatial Filtering

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ABSTRACT

We present a fast inspection method of machine vision for in-line quality assurance of liquid crystal displays (LCD) and plasma display panels (PDP). The method incorporates an optical spatial filter in the Fourier plane of the imaging optics to block the normal periodic pattern, extracting only defects real time without relying on intensive software image process. Special emphasis is on designing a collimated white light source to provide a high degree of spatial coherence for effective real time Fourier transform. At the same time, a low level of temporal coherence is attained to improve defect detection capabilities by avoiding undesirable coherent noises. Experimental results show that the proposed inspection method offers a detection accuracy of 15% tolerance, which is sufficient for industrial applications.

Key Words: Pattern inspection, optical spatial filtering, Fourier optics, white light

1. Introduction

Display devices such as Liquid Crystal Display (LCD) and Plasma Display Panel (PDP) are made up of a thin glass substrate on which array of electrode pattern is deposited. The detection of defects in periodic structures is an important aspect of manufacturing of display device which consist of repetitive pattern array of hundreds of thousand pixels. For in-line quality assurance of such display devices, a drastic improvement in throughput can be made by incorporating Fourier optics in which only defective patterns can be extracted by optical spatial filtering in a fast manner without relying on time consuming software image processing with machine vision technology.

It has been known long that optical Fourier transformation coupled with subsequent spatial filtering provides a fast means of parallel processing in inspecting a large target area of periodic pattern.[1] This inspection method is drawing attention these days as its industrial demand is growing together with widely available machine vision technology. So far several attempts have been made in such areas as integrated-circuit patterns, [2,4] lithography photo masks,[3] and textured materials.[5] Along with the practical applications of Fourier optics, increasing efforts are being made on developing effective spatial filters such as photographic plates,[2,5] emulsion mask,[3] holography plates,[4] gelatin pin holes[6] and photorefractive filters.[7]

But, the use of coherent light in the spatial filtering cannot avoid coherent noise and it decreases defect detection capability. Particularly in inspecting patterns on glass substrate of display device such as LCD and PDP, the thickness variation and tilt motion of the substrate and the multi-reflection from the surfaces produce interference patterns, which act as background noise on a spatially filtered image of the object. A collimated white light source is used to yield low temporal coherence to improve defect detection capabilities by avoiding the undesirable coherent noise and we investigated the effect of the spatial coherence of illumination on the system and spatial coherence is released to use efficient power of the light source. Also, For a spatial filter, we used low pass filter that is immune to rotation of the input object and can discriminate an opaque and a transparent defect for efficient inspection.

2. Basic principles of white light optical Processing

The white light processing is similar to a coherent processing system except for the use of white-light source[8]. If we place a signal transparency s(x,y) in the input plane P_1 as shown figure 1, the complex light field for a wavelength λ_n behind the lens L_1 is

$$= CS(p_n, q_n) \qquad (1)$$

where the integral is over spatial domain of the input plane, (p_n, q_n) denotes the angular spatial frequency coordinate system. $S(p_n, q_n)$ is the Fourier spectrum of s(x,y), $p_n = (2\pi/\lambda_n f)\alpha$, and $q_n = (2\pi/\lambda_n f)\beta$, (α, β) is the linear spatial coordinates system of (p_n, q_n). Also, f is the focal length of the lens L_1 and C is a complex constant and we drop the constant for simplicity of the analysis. If we put a spatial filter, $H(p_n, q_n)$, in the spatial frequency plane, then the complex light field behind the spatial frequency plane is

$$E_f(p_n, q_n : \lambda_n) = S(p_n, q_n) H(p_n, q_n) \qquad (2)$$

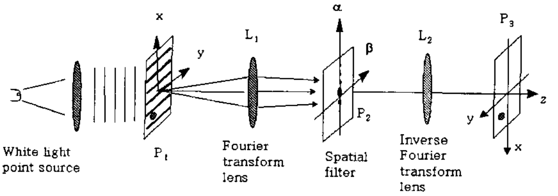


Fig. 1 Optical configuration of spatial filtering with white light source.

The corresponding complex distribution at the out plane P_3 of the process for each λ_n is

$$= s(x, y : \lambda_n) * h(x, y : \lambda_n) \qquad (3)$$

where the integral is over the spatial domain, * denotes the convolution operation and $h(x,y:\lambda_n)$ is the spatial impulse response of the filter $H(p_n, q_n)$.

For the entire spectral band of the light source, the output light intensity distribution can be approximated as

$$I(x,y) \cong \sum_{n=1}^{N} \left| g(x, y : \lambda_n) \right|^2 = \sum_{n=1}^{N} \left| s(x, y : \lambda_n) * h(x, y : \lambda_n) \right|^2 \qquad (4)$$

The above equation is the typical incoherent addition form where resultant intensity is the sum of the squares of the individual wave distribution $g(x,y:\lambda_n)$. Since the output intensity is the sum of the mutually incoherent narrow-band irradiances, the annoying coherent noise can be suppressed.

3. Optical spatial filtering

Figure 2 shows a finite periodic object and its diffraction pattern. The diffraction pattern is the product of two functions. One is the diffraction pattern of unit cell and the other is the interference function which is the diffraction pattern of the infinite arrays and aperture function.

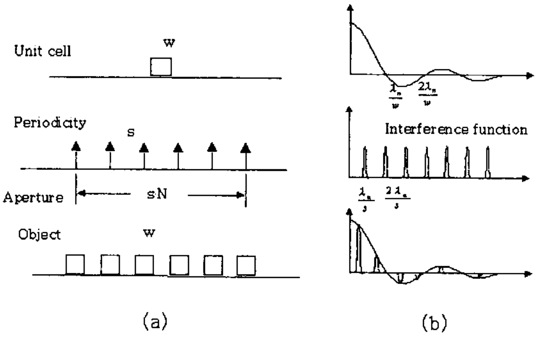


Fig. 2 Frequency Spectrums of periodic signals;(a) input pattern (b) Fourier transform of the input

For an array, the intensity in the Fourier plane is[9]

$$- {}_0\angle_{\lambda_n} \left\lfloor \overline{N \sin(\pi sp / f\lambda_n)} \right\rfloor \left\lfloor \overline{\pi pw / f\lambda_n} \right\rfloor \qquad (5)$$

where *N* is the number of patterns; *s* the period of the array; *w* the width of a unit cell; I_o the intensity of the center of the diffraction pattern; and *f* the focal length of the lens. The diffracted pattern of a periodic object is a series of spikes and the size of the spikes is governed by the first sinc function of the equation (5). By defining the spike diameter S_n for each wavelength ,λ_n, as twice of the distance to the first maxima of

$$N\,sin(\pi sp / f\lambda_n) \tag{6}$$

$$S_n = 2f\lambda_n / Ns \tag{7}$$

The spike diameter decreases as the number of features, N, in the array increases and the wavelength ,λ_n, decreases. The spike distance h for each wavelength is

$$h_n = f\lambda_n / s \tag{8}$$

The side-lobe of each spike contribute to the edges of the overall envelope in which N of pattern is included and the high frequency spikes contribute to the edges of each unit cell in the pattern. Therefore, only the central peak of each spike contains information of periodic pattern and the side-lobe does not contain any information of its periodicity.

Filtering of the diffraction pattern is achieved by placing a spatial filter which attenuates all the central peaks of the spikes for the entire spectral band of the light source at the spatial frequency domain. The filter should block off the central peaks of every light spikes of each wavelength and is thus an array of opaque dots whose separation is

$$h_a = f\lambda_a / s \tag{9}$$

where λ_a is the average wavelength of the light source spectrum. The diameter of the dot ,D, should be large than the distance of two central peak of maximum and minimum wavelength and is expressed as

$$D \geq h_{\lambda\,max} - h_{\lambda\,min} = f(\lambda_{max} - \lambda_{min}) / s \tag{10}$$

where λ_{max} and λ_{min} is the maximum and minimum wavelength of the light source respectively.

4. Spatial filter design

If an incremental rotation is applied to the object, the same amount of rotation is induced in its Fourier pattern, because of the angle conservation principle of the Fourier transform. Thus the spatial filtering system must be furnished with costly fine angular setting mechanism to block out the periodic signal. Also defect information carrying lights are apt to bunch around dc, having a symmetric sinc function profile with zero means. Therefore simple low pass filter whose pass band is below the first spike at the spectrum domain. The cut-off frequency is given by

$$H \leq f\lambda_{min} / s \tag{11}$$

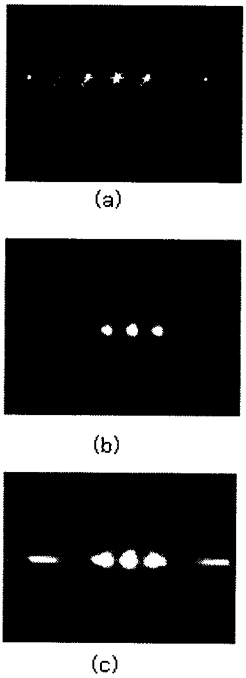
As the dc component is passed at the filter plane, the output pattern preserves defect type information ,i.e. the filtered image can discriminate an opaque and a transparent defect, which is dark and bright spots respectively.

The white light is passed through pin-hole and collimated to make a plane wave or quasi plane wave to be used in defect inspection with optical spatial filtering because the light spikes at the Fourier transform pane should be separated at the back focal plane of the Fourier transform lens. If the size of the pinhole is very small, collimated beam gets plane wave, but the light power is not strong enough to provide a sufficient illumination of large area, which is needed for inspection of display device whose size is over ten inches at its diagonal. Also as the size of pinhole gets larger, the collimated beam become less spatially coherent and also it has good effect on reducing the coherent noise in addition to the temporal incoherence of the white light. Therefore as long as the light spikes are separated and the sufficient defect signal can be passed through the spatial filter, large pinhole is good at defect inspection with white light.

Figure 3a shows the Fourier transform pattern of 1 dimensional periodic pattern with He-Ne laser. The diameter pinhole of the laser beam expander is 8 μm and the shape of the spike is very small. Figure 3c shows the result when 0.5 mm pinhole is used and the size of the spike is very larger than that of laser. Figure 3b shows when 150 nm band pass filter is placed in front of the white light source and the size of the spike is smaller than the that of whole white light spectrum. The size of spike is also affected by the pinhole size and the magnification ratio of collimating lens and Fourier transform lens because the pinhole plane and the back focal plane of the Fourier transform lens are optically conjugated. To use a low pass filter as a spatial filer, we need to consider the pinhole size effect at the cut-off frequency that determines the hole size of the filter through which the signal can pass. The cut-off frequency is

$$H \le (f\lambda_{min} / s) - (fb / 2f_c) \qquad (12)$$

where, f_c is the focal length of the collimating lens and b is the diameter of the pinhole.


(a)

(b)

(c)

Fig. 3 Fourier transform pattern of a line grating with various light sources; (a) He-Ne laser (b) Tungsten lamp with band pass filter (c) Tungsten lamp.

5. Experiments

Figure 4 shows the optical configuration set up in this investigation. The object under inspection is illuminated by a collimated beam of Tungsten arc lamp and the pin hole size before the collimating lens is 0.5 mm. A Fourier-transforming lens is placed in front of the object. In addition a circular low pass made of aluminum foil is located at the back-focal plane of the lens, where the Fourier-transformed image of the object appears. The cut-off frequency of the spatial filter is adjusted to block off the high frequency terms dominated by the pitch of the holes, so that only low frequency terms passes through. The transmitted beam is then inversely Fourier-transformed by an imaging lens to cast the object image with apparent defects on a CCD camera. The wavelength of the Tungsten lamp is spread over visible light, which is from 400 nm to 700 nm. The focal length of the collimating lens and Fourier transform lens is 50cm and 30cm respectively. The inspection object is a grating which is chrome patterned on a glass substrate and is similar to a structure of LCD or PDP which have metal patterns on a glass substrate. Also the pitch of the grating is 250 um and is also similar to that of the display device that we have interest in.

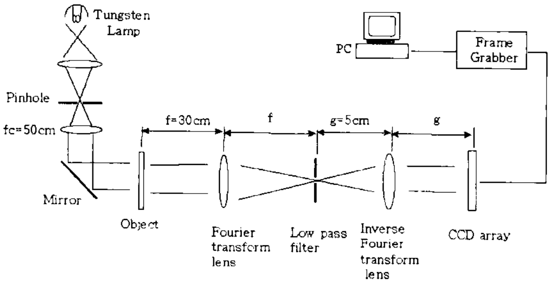


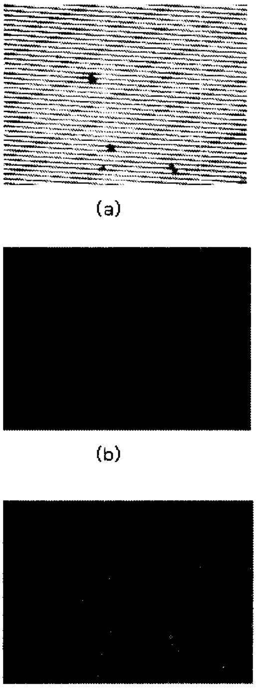
Fig. 4 Experimental setup for spatial filtering with white light source.

To use low pass filter as a spatial filter, we calculate the cut-off frequency and determine the size of circular hole size of the filter. The cut-off frequency of the system is $H \le (f\lambda_{min} / s) - (fb / 2f_c) =$ (30 mm)(400nm)/(250um)−(300mm)=(0.5mm)/(2)(500mm)=0.33mm. So the calculation shows that if we pass the signal inside the radius 0.33mm, all the periodic signal will be attenuated. But there is what we do not consider in the analysis such as lens aperture effect, component misalignment and etc. To compensate this effect, the hole radius that we use as a spatial filter is determined 0.25 mm.

6. Results and Discussion

Figure 5.a shows the grating image used in the experiment where the light passing through the grating is proceeded and figure 5.b is the result obtained with a He-Ne laser as a light source and we can see several circular band-type interference patterns in the spatially filtered image. A small speck of dust in the input plane produce scattered waves and a resulting interference pattern in the output plane and a significant level of background disturbances in captured images due to the coherent noise. Figure 5.c shows the resulting result obtained by white-

light processing technique and any coherent noise is hardly seen in the output image. From these two results, we see that the coherent noise is well suppressed with temporally incoherent white light processing.

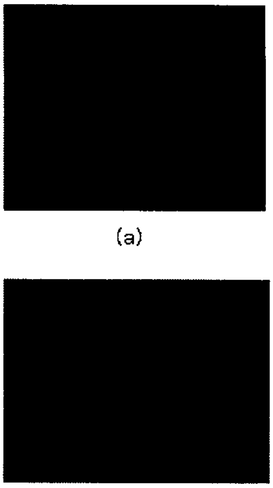

(a)

(b)

(c)

Fig. 5 Test results for a line grating; (a) grating image (b) spatially filtered image with white light source (c) with He-Ne laser.

Figure 6.a show the obtained result with a He-Ne laser where that reflected light from the grating is spatially filtered. we can see some fringe patterns due to multi reflection on the both side of the glass substrate. When the white light is used as a light source, there is no fringe at all in the output image as shown in figure 6.b and the coherent noise is well suppressed. The defect size is measured as the area deviation of a hole from its nominal value, while the intensity deviation is scaled by the absolute difference from the mean background level being normalized by the S/N(signal-to-noise) ratio of the electronics used for image frame grabbing. The test results is that this system can detect 10um thickness variation over 20 x 20 mm^2 inspection area and that is 15% tolerance from nominal pattern thickness, which is sufficiently more than the industrial requirement of 20 % tolerance.


(a)

(b)

Fig. 6 Spatial filtering result of a line grating in reflective mode; (a) with white light source b) with He-Ne laser.

7. Conclusion

A series of tests were performed using chrome-deposited patterns made on a glass substrate. Test results show that when a coherent laser beam is used for illumination, severe coherent noise appears in filtered image. Coherent noise from the object is not stationary because it appears sensitive to the thickness variation and tilt motion of the object during scanning process to inspect whole area of a display device. But when a collimated white light is used, the coherent noises are seldom seen in the image due to the temporal incoherence of the light source. Also, we investigated the effect of the spatial coherence of illumination on the system and spatial coherence is released to use efficient power of the light source until the Fourier transform components of the pattern are not overlapped at Fourier plane. Experimental results prove that this method is useful with a detection capability of 15% tolerance from nominal pattern thickness, which is sufficiently more than the industrial requirement of 20 % tolerance.

References

1. J. Goodman, *Introduction to Fourier optics,*

(McGraw-Hill, 1968)

2. P.M. Will and K. Pennington, "Filtering of defects in integrated circuits with oriental independence", Appl. Opt., 10, pp.2097-2100 (1971)
3. A. Flamholz and H. Froot, "Mask tolerance measurement and defect detection with spatial filtering", Electro-Optical System Design, March, pp. 26-30 (1973)
4. D. Cavan et al, "Patterned wafer inspection using laser holography and spatial frequency filtering", J. Vac. Sci.Technol. B, 6(6), pp. 1934-1939 (1988)
5. C. Ciamberlini et al, "Defect detection in textured materials by optical filtering with structured detectors and self-adaptable masks", Opt. Eng., 35(3), pp. 838-844(1996)
6. A. Iwamoto and H. Sekizawa, "Defect-type discriminating optical system.", Appl. Opt., Vol. 20, pp.1724-1726 (1981)
7. C. Uhrich and L. Hesselink, "Submicron defect enhancement in periodic structures by using photorefractive holography", Opt. Lett, 17, pp. 1087-1089(1992)
8. F. Yu, *Optical Information processing*, (John Wiley and Sons,1983)
9. L. Watkins, "Inspection of Integrated Circuit Photo masks with Intensity Spatial Filters", Proc. Of IEEE, Vol. 57, No. 9, pp. 1634-1639(1969)