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Deformation Invariant Optical Correlator Using Photorefractive Medium

(광굴절 매질을 이용한 공간계 불변 광상관기에 관한 연구)

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要 約

변형불변 패턴인식을 실현하기 위하여 크기와 회전변위에 대해 불변인 극-로가리즘 좌표변환을 이용하였고, 좌표변환을 수행하기 위하여 Lee 방식의 투과함수를 갖는 CGH를 CAD용 포토(UV light) 패턴 발생기에 의해 마스크로 제작하였다.

광학적으로 좌표변환된 입력패턴은 본 논문에서 제시한 광상관기에 입력되었으며, 실시간 홀로그래피에 의한 기록매질로서 $BaTiO_3$ 단결정을 정합필터로 사용하였다.

본 논문에서 제시한 광상관기를 사용하여 크기와 회전변위된 입력에 대한 자기상관값의 변화를 실험적으로 제시함으로서 변형불변 패턴인식을 증명하였다.

Abstract

Scale and rotation invariant polar-logarithmic coordinate transformation is used to achieve deformation invariant pattern recognition. The coordinate transformation is produced by a computer generated hologram (CGH). The mask fabricated by a photo (UV light) pattern generator for the $\ln r\text{-}\theta$ coordinate transformation is made of the CGH whose transmission function is derived by the use of Lee's method. The optically produced coordinate transformed input pattern is interfaced to an optical correlator. A $BaTiO_3$ single crystal is used as a real-time matched filter based on real-time holography.

Variations of autocorrelation for scaled and rotated input patterns are suggested experimentally using implemented optical correlator.

I. Introduction

The advantages of optical processing, descriptions of various operations possible, and many applications of optical processors have been described elsewhere.

Conventional correlators using a coherent optical system has great advantages of high speed

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and parallel processing, but cannot recognize scaled or rotated images of the reference object. [1]. For example, the SNR of the resultant correlation peak can be 10dB down from that of the autocorrelation for 1% scale changes of the reference object, and a 20dB loss can occur for a 1.7° rotation of the input from the reference.[2] [3] Recently, much interest has been shown in nonlinear and space variant systems because of the limited applications of linear space invariant systems.

In order to solve these problems, it is required to develop a space-variant optical processor which combines a space-invariant system with coordinate transformation (CT) for a deformation invariant correlator and pattern recognition. Coordinate transformations such as the logarithmic transformation which is scale invariant, the polar (r, θ) transformation which is rotation invariant, and the 1nr-θ coordinate transformation which is deformation invariant have been reported.[4]

In this paper, we consider the Optical implementation of deformation invariant optical pattern recognition using a CGH and a $BaTiO_3$ single crystal. By the use of a CGH with a Fourier transform lens, 1nr-θ coordinate transformation is performed. The CGH is composed of many interferometrically produced holographic optical elements (HOEs) for coordinate transformations. The design of the CGH is presented in Sec. II. A $BaTiO_3$ single crystal is used instead of a conventional optical matched filter for real-time processing.[5]

Scale and rotation invariant pattern recognition is achieved by the coordinate transformation and the optical matched filtering based on the real-time holography. Pseudo real-time scale and rotation invariant pattern recognition is verified experimentally in Sec. III.

II. CGH for 1nr-θ Coordinate Transformation

1. Coordinate transformation

The two dimensional coordinate transformation of an input distribution is achieved when a point (x,y) in plane P_0 is approximately mapped to a point(u,v) in plane P_1, with

$$\begin{bmatrix} x \\ y \end{bmatrix} \rightarrow \begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} U(x, y) \\ V(x, y) \end{bmatrix} \qquad (1)$$

$$U(x, y) = (\lambda f/2\pi)\ \partial \phi/\partial x \qquad (2a)$$

$$V(x, y) = (\lambda f/2\pi)\ \partial \phi/\partial y \qquad (2b)$$

Eq(2) defines a mappng given a CGH phase function ϕ (x,y)

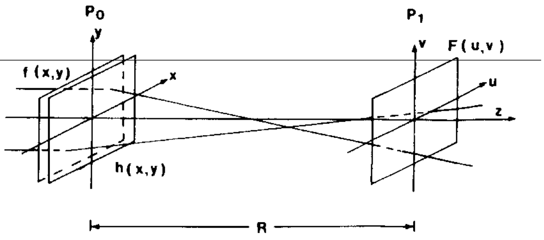

Fig.1. Optical system to perform coordinate transformations.

As shown in Fig.1, in the input plane P_0 the input f(x,y) is placed in contact with CGH of transmittance h(x,y)=exp[jϕ(x,y)], where ϕ (x,y) is a two dimensional phase transmittance function.[7] The phase function for this optical system is given by eq(3).

$$\partial\phi/\partial x = (k/R)\ (u-x)$$
$$\partial\phi/\partial y = (k/R)\ (v-y) \qquad (3)$$

where $k=2\pi/\lambda$ and R is the distance between plane P_0 and P_1. For a two dimensional phase function to exist, the condition that

$$\partial u/\partial y = \partial v/\partial x \qquad (4)$$

must apply. Under this condition the required phase function can be obtained by integration.

2. CGH design

For making a binary synthetic hologram, it is necessary to find a hologram function h(x,y) that has 0 or as 1 its values and which can produce any desired wavefront just changing its parameters[1].

Fig.2 shows the system to realize the 1nr-θ coordinate transformation.

Consider the optical system of Fig.2 with an input light amplitude distribution f(x,y) in the

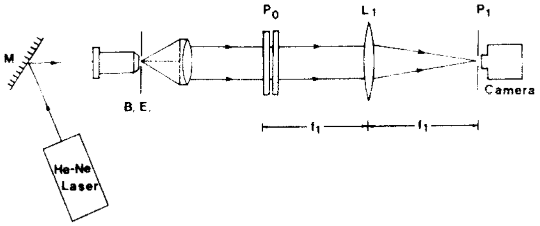

Fig.2. Schematic diagram for optical coordinate transformation system.

front focal plane P_0 of lens L_1. A CGH is also located in plane P_0 and has amplitude transmittance $\exp[j\,\phi(x,y)]$. The output light amplitude distribution F(u,v) is in the back focal plane P_1 of lens L_1. The relationship between f(x,y) and F(u,v) is given by eq(5).

$$F(u,v)=\iint_{-\infty}^{\infty} f(x,y)\,\exp[j\,\phi(x,y)]\,\exp[-j\,(2\pi/\lambda f_1)\,(xu+yu)]\,dx\,dy \qquad (5)$$

where λ is wavelength and f_1 is focal length of lens L1. From eq(2), the mapping is

$$U(x,y)=\ln(x^2+y^2)^{\frac{1}{2}}=\ln r$$
$$V(x,y)=-\tan^{-1}(y/x) \qquad (6)$$

and eq(4) is satisfied. By solving eq(3), the desired phase function is

$$\phi(x,y)=(2\pi/\lambda f_1)\,[x\ln(x^2+y^2)^{\frac{1}{2}}-y\tan^{-1}(y/x)-x] \qquad (7)$$

With the collimated coherent plane wave on P_0 plane, the lnr-θ coordinate transformation is performed by CGH and the transformed pattern appears in the focal plane P_1 of lens L_1. Since we need a continuous phase function to be recorded on the mask, we can use a binary recording technique. The interferogram is the interference pattern of $\phi(x,y)$ and a plane wave reference at an angle θ. The interference fringe pattern is formed by the points satisfying

$$2\pi\alpha x-\phi(x,y)=2\pi n \qquad (8)$$

where n is an integer which denotes different fringes and the carrier frequency $\alpha=\sin(\theta)/\lambda$ If $\phi(x,y)$ is constant, the binary synthetic hologram made by using eq.(8) is a periodic grating with period T. It is the constant T that determines the angular separation of the different waves in the reconstruction. Since the positions of the fringes are obtained by solving eq(8), the accuracy of the solutions found depends on the sampling periods along x-direction. In practice, the sampling period is selected as T/M, where M is an integer. The accuracy of the fringe position can be set by M. To solve eq(8) by a digital computer, a sampled version of it is first obtained by substituting T/Mkx for x, 2Tky for y. Residue arithmetic can be used to simplify the computation. To detect only the first order diffraction pattern at P_1, α should satisfy

$$a>\left(\frac{1.5}{\pi}\right)\max\left|\frac{\partial\phi(x,y)}{\partial x}\right| \qquad (9)$$

We used parameters T=0.025, M =10, n= 400, λ = 0.0006328mm, f_1=400mm, α=40 line pairs/mm. We solved various points (kx,ky) instead of finding (x,y) that satisfy eq(8) for making Lee type CGH.[1]

III. Experiments

1. CGH mask fabrication

The most attractive property of CGH is its ability to encode an arbitrary complex amplitude transmittance on the mask. In our experiments, the data array is compiled by the computer SUN III-160 and stored for the most efficient writing pattern for the photo (UV) pattern generator. The computer then controls the operation of the pattern generator to produce the desired mask. The pixel dimension of the written CGH is chosen to be 2μmx5μm. The size of CGH is 10mmx 10mm. Fig. 3 is the central part of our CGH pattern on the mask and Fig. 4 shows fabricated CGH mask.

The carrier frequency is 40 lines/mm in the x-direction. The light source is 5.38mW He-Ne laser and the focal length f_1 is 400mm.

2. Deformation invariant optical correlator

The CGH to perform deformation invariant optical pattern recognition in real-time is tested

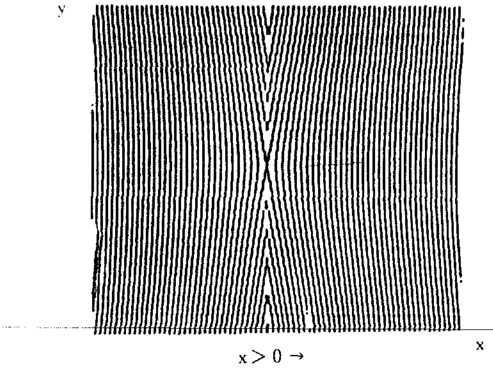

Fig.3. Central portion of CGH pattern.

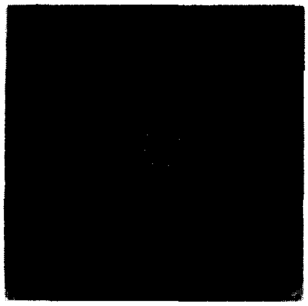

Fig.4. Fabricated CGH mask.

in the system of Fig.2 with reference patterns which are distorted by the rotation and scale changes in the P_0 input images.

Fig.5 shows the overall experimental set up.

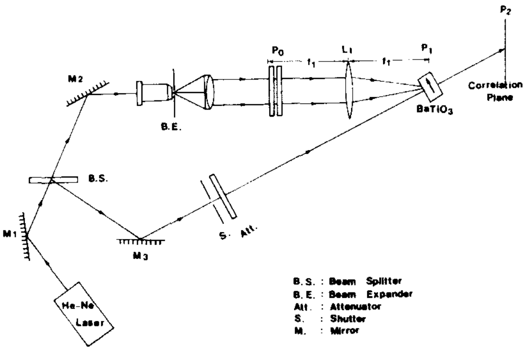

Fig.5. Experimental set up.

The coordinate transformed object to be recognized is formed at $P_1(BaTiO_3)$ with the beam balance ratio chosen to yield the optimal correlation SNR. The output correlation of P_2 is detected by a camera. The specification of $BaTiO_3$ is 7.8x5.5x5.1mm of Sanders Co. The original binary image is Fourier transformed by the lens L_1 and a hologram is formed in the $BaTiO_3$ single crystal with reference beam at angle 8°.

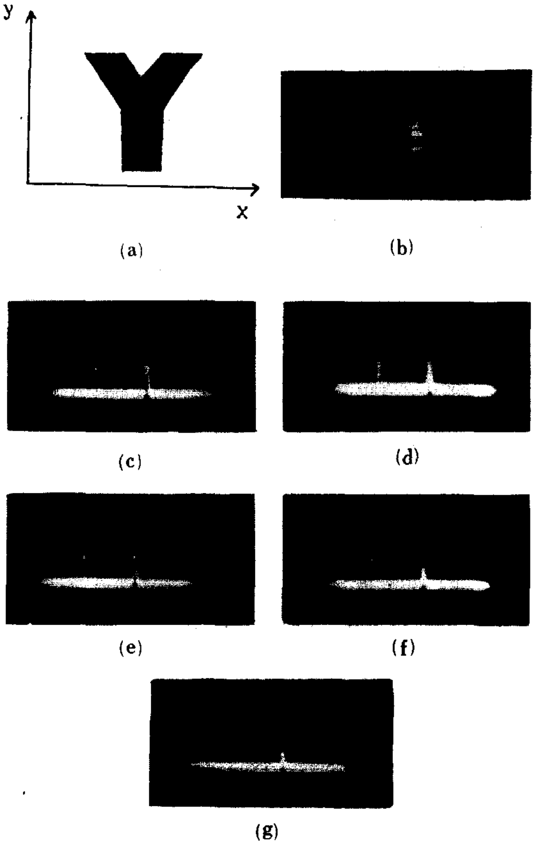

Fig.6. Experiment results.

(a) input pattern.
(b) coordinate transformed pattern.
(c) coorelation peak for original pattern.
(d) correlation peak for 70° rotated pattern.
(e) correlation peak for 90° rotated pattern.
(f) correlation peak for 50% scaled pattern.
(g) correlation peak for 50% scaled and 45° rotated pattern.

The scale and rotation invariance of the system is demonstrated in Fig.6. The coordinate transformed pattern[Fig.6(b)] of the original pattern [Fig.6(a)] and its autocorrelation [Fig.6(c)] are shown. Figures 6(d) and (e) show the correlation peak variation for 70° rotation and 90° rotation respectively. Figures 6(f) and (g) represent degradation of correlation peak for 50% scaled pattern and combination of 50% scaled and 45° rotation pattern respectively.

Comparing the conventional correlator which is very sensitive to scale or rotated images with the obtained results, we can see that the implemented correlator carries out pattern recognition successfully in the case of space-variant images.

Ⅳ. Conclusion

The scaled and rotation invariant optical pattern recognition system which is composed of CGH and lens in series with conventional optical correlator is examined in pseudo real-time processing, and we have confirmed the insensitivity of the proposed correlator to deformation inputs.

We use a $BaTiO_3$ single crystal as the recording material for the coordinate transformed pattern based on real-time holography. To improve the performance of the proposed system, more precise fabrication of CGH using Rissajous coding technique must be considered. If SLM is used for input device, the proposed system will be processed in real-time.

Reference

[1] W.H. Lee, "Binary synthetic hologram," *Appl. Opt.*, vol. 13, no. 7, pp. 1677-1682.

[2] D. Casasent and C. Szczutkowski, "Optical Mellin transform using computer generated holograms," *Opt. Comm.*, vol. 19, no. 4, pp. 217-222, 1976.

[3] D. Casasent and D. Psaltis, "New optical transforms for pattern recognition," *Proc. IEEE*, vol. 65,no. 1, pp. 77-83, 1977.

[4] Y. Saito, S. Komatsu and H. Ohzu, "Scale and rotation invariant real time optical correlator using computer generated hologram," *Opt. Comm.* 47, no. 1, pp. 11-660, 1978.

[5] A. Yariv, "Phase conjugate optics and real-time holography," *IEEE J. Quan. Elec. QE.-14*, pp. 650-660, 1978.

[6] O. Bryndahl, "Geometrical transmission in optics," *J. Opt. Soc.* Am. vol. 64, no. 8, pp. 1092-1099, 1974.

[7] W.J. Hossack, P. Mcowan, and R.E. Burge, "Computer generated optical fan-out element," *Opt. Comm.*, vol. 68, no. 2, pp. 97-102, 1988. *

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