論 文

공간광변조기용 LCTV의 성능측정 및 개선

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Performance Evaluation and Modification of LCTV for Spatial Light Modulator

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要 約 LCTV를 이차원 공간 광변조기로 사용하기 위하여 성능평가 및 특성개선을 수행하였다.

LCTV 스크린의 위상 왜곡은 홀로그램 기판과 굴절을 정합액을 사용해 보정하였고, 실제 사용시 문제시되는 전극 격자패턴의 제거를 위해 BaTiO3 결정에서의 위상공액파를 이용하는 새로운 방법을 제안하고 실험하였다.

ABSTRACT Performance evaluation of inexpensive LCTV to function as a two-dimensional spatial light modulator is performed.

Correction of the phase distortion of the device is performed using the substrate of hologram plate and index matching oil.

A new method for eliminating electrode grid pattern that incorporates phase conjugation in a BaTiO3 crystal is proposed and experimented.

I. INTRODUCTION

Real-time optical processor and optical computer are limited mainly by the capability and availability of real-time devices, such as two-dimensional spatial light modulator(SLM).

Until now, many types of SLMs have been studied and developed, including Liquid Crystal Light Valve(LCLV), MOSLM, PROM, and so on. But these devices are expensive and are still in development stage[1]. The appearance of inexpensive commercilally available liquid crystal television(LCTV) set shows promises to application it as a SLM and much studies have been carried out[2-5]. However, unless corrective measures are taken, the performance of these devices is limited by its low contrast and phase distortion. Corrective measures such as prerecorded hologram[3], optical flat[4], and

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liquid gates[4] have been employed to remove phase distortion of LCTV screen. Contrast can be enhanced by the use of external high quality polarizers instead of original polarizers, and by the use of low pass filtering to remove electrode grid pattern in the modulated signal [4].

In this paper, we remove original polarizers and separate liquid crystal display(LCD) from the driver(body) for easy use, and evaluate parameters of Radio Shack Realistic Model 16-156 LCTV for SLM, includign optical transmission characteristics, modulation index, and modulation transfer function(MTF). And using the substrate of hologram plate and index-matching oil, phase distortion of the device is corrected.

With this modified version of LCTV, electrode grid pattern in the modulated signal is removed using phase conjugation in a $BaTiO_3$ crystal.

Ⅱ. Performance Evaluation of LCTV

LCTV used in experiments is the Radio Shack Realistic Model 16-156 TV which has an external video jack for direct video input from any video sources such as a TV camera or a computer. Table 1 shows specifications of the device.

Tabel 1. Specifications of LCTV

Display	Black & white
LC mode	TN(twisted nematic)
Driving type	HDM(High duty simple multiplexing)
Screen size	71.7mm×53.7mm
Number of pixels	192um×143um
Response time	30ms(rising)
	45ms(falling)
Supplier	Radio Shack
Model	Realistic Model 16-156

Performance of SLM can be estimated in terms of resolution, contrast, dynamic range, and optical flatness of the screen. To evaluate performance of LCTV as a SLM, optical transmission characteristic, modulation index, and MTF are tested.

Operation of LCTV orginates from twisted nematic effect[3] due to the applied voltage across each individual cell. Therefore, optical transmission characteristic of the screen depends on both the value of the video waveform which drives it and the value of the brightness control voltage.

Because the voltage applied to each cell is difficult to access, optical transmission characteristic is measured for the brightness control voltage, Vref.

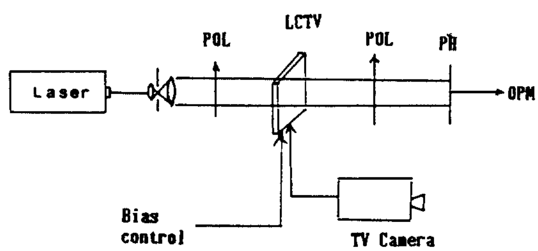


Fig. 1. Measurment setup
POL, polarizer; PH, pinhole; OPM, optical power meter

Fig.1 shows as experimental setup. Plane-polarized laser beam illuminates through LCTV which is modulated by TV camera, and polarizer and analyzer are aligned so as to have maximum transmisson. With the variation of the voltage Vref from 0 to 4.2V, transmitted optical power Pout is measurd. Optical transmittance of the screen is given by[1].

$$T = \frac{Pout}{Pin} \qquad (1)$$

Where Pin is the power behind the input polarizer.

Curve A shows optical transmittance of the screen with no video signal from the TV camera, and curve B shows optical transmittance with uniform minimum video signal.

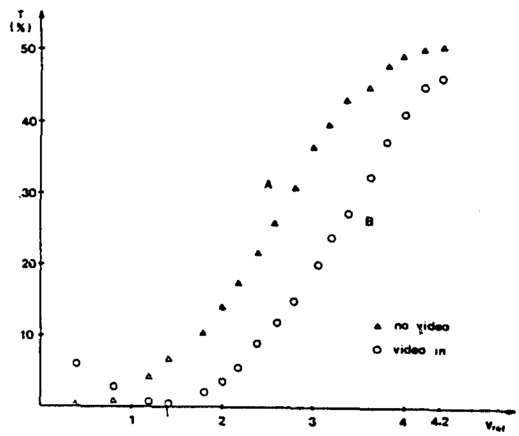


Fig. 2. Transmittance of the LCTV

Optical transmission is increased with increasing Vref, and maximum transmittance, Tmax, is 52% and minimum transmittance, Tmin, is 2.5%. Inversion of image was observed below 1.0V.

Modulation index is the measure of ouput contrast according to the applied voltage Vref. With the measured values of Tmax and Tmin for transparent and opaque target, respectively, modulation index M can be calculated by

$$M = \frac{T_{max} - T_{min}}{T_{max} + T_{min}} = \frac{\frac{P_{max}}{P_1} - \frac{P_{min}}{P_1}}{\frac{P_{max}}{P_1} + \frac{P_{min}}{P_1}} = \frac{P_{max} - P_{min}}{P_{max} + P_{min}} \qquad (2)$$

Fig.3 shows the modulatin index of the device. Maximum contrast is 60.5% when Vref is 1.4V and contrast ratio is approximately 5:1. With increasing Vref, modulation index decreases rapidly.

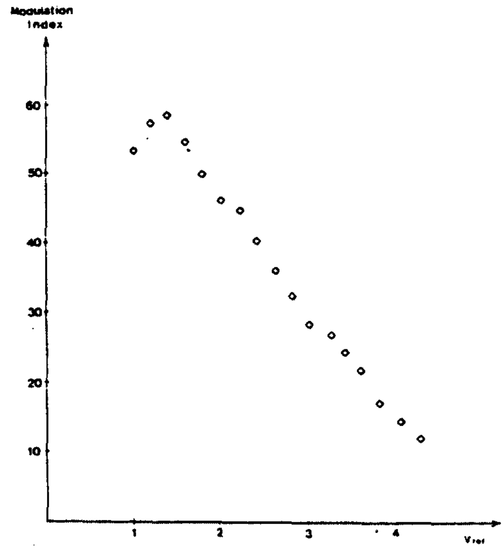


Fig. 3. Modulation index of LCTV

Modulation transfer function represents resolution of the device. We assume the pattern recorded on the LCTV to be a rectangular waveform at spatial frequency u, that is

$$t(x) = 1 + \text{rect}\ [2\pi ux] \qquad (3)$$

then MTF of the device at given spatial frequency u is given by Eq.(2)[1].

Tmax and Tmin are measured when LCTV is modulated with various spatial frequency targets, then M is calculated. Fig.4 shows MTF of LCTV.

MTF decreases with increasing spatial frequency, but it has more than 40% MTF below 1.1cycle/mm target. This means that we can use LCTV as a SLM for the moderate spatial frequency target.

Another figure of merit for SLM, that is, phase distortion of LCTV will be given in part Ⅲ.

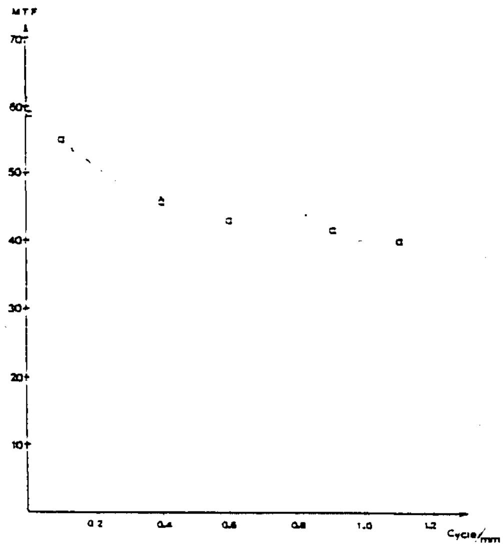


Fig. 4. MTF of LCTV

Ⅲ. Performance Enhancement of LCTV

Because phase nonuniformity and electrode grid pattern in the modulated output signalo are main limiting factors of LCTV as a SLM, some corrective measures have to be applied.

A. Phase correction of LCTV

Phase distortion due to surface nonuniformity, which causes space-variant problem in optical processor can be measured by Mach-Zender interferometer shown in Fig. 5.

Output of Mach-Zender interferometer is given by

$$I_0(x,y)=I_1(x,y)+I_2(x,y)+2\sqrt{I_1(x,y)\, I_2(x,y)}\cos[\phi(x,y)] \quad (4)$$

where $\Phi(x,y)$ is phase error of LCTV, $I_1(x,y)$ and $I_2(x,y)$ are intensity distributions of reference and signal beam, respectively.

Photo 1-(a) shows pure interferogram of Mach-Zender interferometer, that is, $\Phi(x,y)=2n\pi$, $n=0, \pm1, \pm2,$. Photo 1-(b) is the interferogram of LCTV. This shows that our LCTV has severs biconcave type surface nonuniformity and requires some phase correction. Photo 1-(c) and (d) are the interferogram for the substrate of Agfa 8E75 (d=1.5 mm) and Agfa 649F(d=3mm) hologram plate, respectively. These show that Agfa 649F has better phase uniformity than Agfa 8E75 due to the larger thickness.

Photo 1 (d) shows interferogram of optical flat-based phase corrected LCTV. LCTV is sandwithched between two optical flats(Agfa 649F plate), and phase distortion is somewhat compensated compared with Photo 1-(b). Photo 1-(e) represents the interferogram of phase corrected LCTV using two optical flats

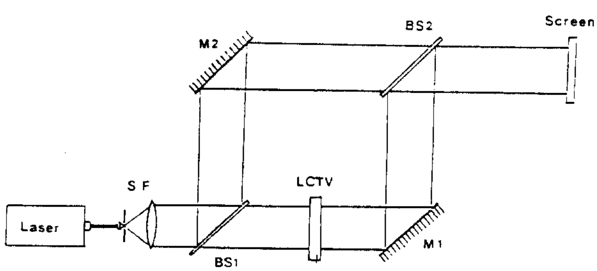
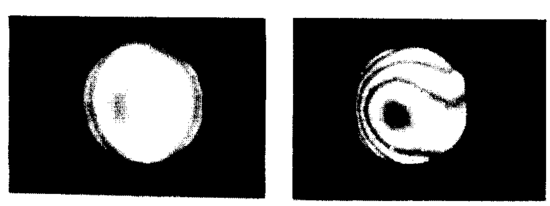


Fig. 5. Mach-Zender interferometer
SF,spatial filter; M1, M2, mirrors; BS1, BS2, beam splitters



(a) (b)

Photo 1. Interferograms

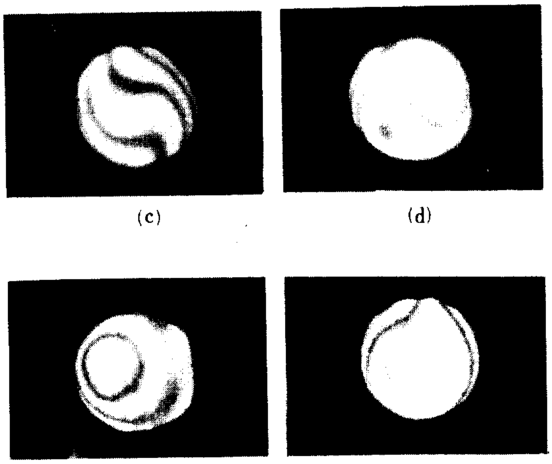


Photo 1. Interferograms (continued)
(a) Pure interferogram
(b) LCD
(c) Agfa 8E75 hologram plate
(d) Agfa 649F hologram plate
(e) LCD+two flats
(f) LCD+Oil+two flats

and index-matching oil. Cargille laser liquid 5610 ($n=1.51\pm0.0002$ at 5893 Å) index-matching oil is spread on each LCTV sides and two optical flats are attached tightly on both sides with silicon resine. Result shows that phase correction of LCTV is nearly perfect compared with Photo 1-(a).

B. Elimination of Electrode Grid Pattern

LCTV uses mesh type electrode grid, therefore modulated signal is

$$s(x,y)=f(x,y)\ g(x,y)$$

$$g(x,y)=c_1\ \mathrm{rect}(\frac{x}{a},\frac{y}{b},) \ast \mathrm{comb}\ (\frac{x}{c},\frac{y}{d}) \quad (5)$$

Where $s(x,y)$ is modulated signal, $f(x,y)$ is input signal, and $g(x,y)$ is grid pattern. And C1 is constant, a,b are the pixel image size in the x,y direction, respectively, c,d are the distances between the centers of adjacent pixel images.

The Fourier transform of Eq.(5) is given by

$$S(u,v)=F(u,v) \ast G(u,v)$$

$$G(u,v)=C_3\ \mathrm{Sinc}\ (au,\ bv)\ \mathrm{Comb}\ (cu,\ dv)$$

$$u=\frac{x}{\lambda f},\ v=\frac{y}{\lambda f} \quad (6)$$

where u,v are the spatial frequencies.

Photo 2-(a) shows the Fourier transform of the electrode grid pattern. Because this grid pattern lowers space-bandwidth product(SBP) of image, conventional low pass filtering

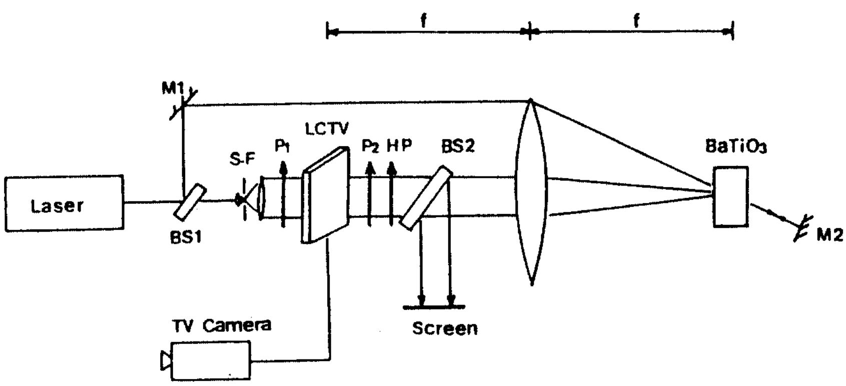


Fig. 6. Modified PCM for grid pattern elimination
SF, spatial filter; L1, lens; M1, M2, mirror; BS 1, BS2, beam splitter.

method has been adopted for eliminating higher diffraction order of grid[5]. But because LPF requires additional 4-f optical system for filtering operation, resultant system become larger, and needs laser sources of longer coherence length.

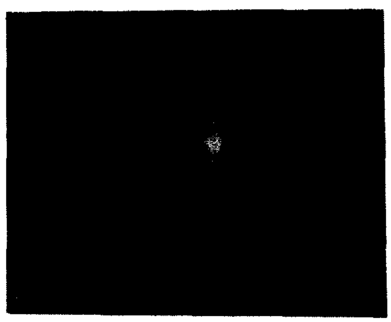
In this paper, we use a new method which incorporates phase conjugation in a $BaTiO_3$ crystal.

Fig. 6 shows modified phase conjugation mirror(PCM) which needs no external backward pumping beam with mirror M2.

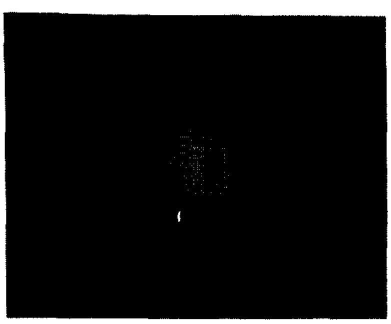
Modulated signal shown in Phloto 2-(b) is focused onto the $BaTiO_3$ by Fourier transform lens L1 and volume holographic interference pattern between signal and referecne beam is recorded in the crystal. Then retroreflective reading beam by mirror M2 and BS2 produces the phase conjugated image.

In recording step, only the lowest diffraction order is separated from the higher ones by adopting lens L1 with long focal length(f=550mm), then is recorded in the crystal. Therefore output phase conjugated beam is low pass filtered replica of input image.

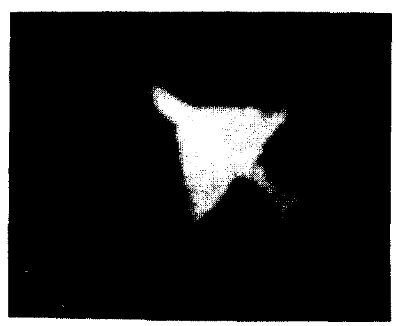
Photo 2-(c) shows the output image having relative high quality. Mechanism described above is very useful for future implementation of real-time hologram based pattern recognition system or holographic associative memory in that grid patern can be simultaneously eliminated in the recording process of holographic matched filter. This work is now under way.



(a)



(b)



(c)

Photo 2. Grid pattern elimination
(a) Fourier transform of grid
(b) Modulated signal
(c) Phase conjugate output

Ⅳ. CONCLUSIONS

Several performance of Radio Shack 16-156 LCTV as a SLM, including transmittance, modulation index, and MTF are measured. Test results are comparable with the Huges LCTV[1], and our LCTV can be easily applicable to SLM.

For full applicability of the device, correction of phase distortion is performed using optical flat(Agfa 649F hologram plate) and Cargille index-matching oil.

Then based on phase conjugation, a new method of electrode grid pattern elimination is performed.

This modified LCTV is well suitable for any optical signal processor such as optical correlator and computing system.

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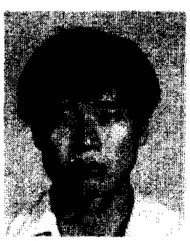

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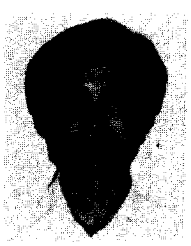

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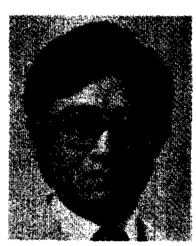

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