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ABSTRACT In this article, a type of binary joint transform correlator based on an electrically addressed spacial light modulator is described. This system primarily includes a cathode ray tube coupled liquid crystal light valve (CRT-LCLV), a CCD camera, and a COMPAQ 386 computer. On a foundation of theoretical analysis, this article gives results of computer simulations and preliminary experiments, clearly showing that the correlator has good discrimination characteristics.

KEY WORDS Joint transform correlator Spatial light modulator Pattern Recognition.

1 FORWARD

In the structures of optical pattern recognition systems, due to their being able to alter reference images at will and eliminate the manufacturing of matching wave filter devices as well as such difficulties as their precise pairing, calibration, and so on, they have, thereby, given rise to attention from numerous researchers [1-3]. At the present time, in real time joint transform correlators, option is made for the use of electrically addressed spatial light modulators with primarily liquid crystal televisions (LCTV) [4]. Patterns associated with deformable mirror devices (DMD) [5] or taken from monitoring devices are formed onto liquid crystal light valves (LCLV), thereby reaching electrically addressed objectives [6]. However, fill factors, spatial bandwidth products, and resolutions associated with liquid crystal televisions and deformable mirror devices are all relatively limited. Moreover, going through monitoring devices to form images onto liquid crystal light valves, the exterior dimensions of the system are increased yet again. Moreover, there is also loss of information and energy. On the basis of the considerations discussed above, taking high resolution cathode ray tubes and coupling them directly through optical fiber panels and liquid crystal light valves will produce a type of electrically addressed spatial light modulator which has relatively high perfomance and price--cathode ray tube coupled liquid crystal light valves. These are advantageous for the miniaturization, application to practical use, and increased performance of joint transform correlators. On the basis of theoretical analysis and computer simulations, this article makes use of autonomously developed cathode ray tube coupled liquid crystal light valves to carry out preliminary experimental research with regard to binary joint transform correlators. Results clearly show that this correlator possesses good discrimination capabilities.

2 BINARY JOINT TRANSFORM CORRELATION THEORY

Normal joint transform correlator structures require two spatial light modulators and two sets of the same kind of light paths. For the sake of compact structures, it is possible to take the two and merge them together, only making use of one spatial light modulator. Light paths using a single cathode ray tube coupled liquid crystal light valve to realize binary joint transform correlators are as shown in Fig.1. P1 plane is the input plane. It includes the reference pattern r(x+xo,y) and the unknown object pattern s(x-xo,y). On plane P1, the optical field transmission rate function can be expressed as:

$$t(x, y) = r(x + x_0, y) + s(x - x_0, y) \quad (1)$$

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Going through a Fourier lens, the optical field distribution on the back focal plane is expressed as:

$$U(\alpha, \beta) = S(\alpha, \beta) \exp [i \phi_S(\alpha, \beta)] \exp (-i x_0 \alpha) + R(\alpha, \beta) \exp [i\phi_R(\alpha, \beta)] \exp (ix_0\alpha) \quad (2)$$

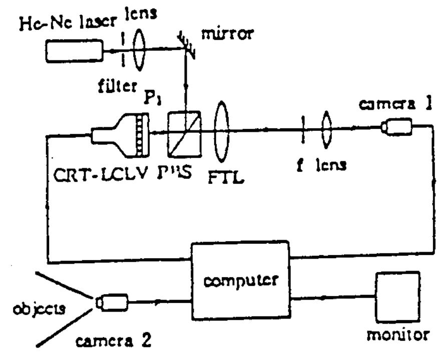


Fig. 1 Experimental setup of binary joint transform correlator

Fig.1

In the equation, (α,β) is the spatial frequency coordinate associated with Fourier transform planes. $S(\alpha,\beta)\exp[i\phi s(\alpha,\beta)]$ and $R(\alpha,\beta)\exp[i\phi R(\alpha,\beta)]$ are, respectively, the Fourier transforms associated with S(x,y) and r(x,y). It is possible to use CCD cameras (square law detector devices) to receive joint transform power spectra:

$$E(\alpha, \beta) = |U(\alpha, \beta)|^2 = S^2(\alpha, \beta) + R^2(\alpha, \beta) + 2S(\alpha, \beta)R(\alpha, \beta) \cos [2x_0\alpha + \phi_S(\alpha, \beta) - \phi_R(\alpha, \beta)] \quad (3)$$

In classical joint transform correlators, directly carrying out inverse Fourier transforms with regard to $E(\alpha,\beta)$ produces correlation signals. However, in binary joint transform correlators, joint transform power spectra $E(\alpha,\beta)$ need to go through threshold network binary nonlinear processing after which inverse Fourier transforms are carried out again. Assuming the threshold value is $VT(\alpha,\beta)$, then, binary joint transform power spectra are:

$$E_B(\alpha, \beta) = \begin{cases} +1, & E(\alpha, \beta) \geqslant V_T(\alpha, \beta) \\ -1, & E(\alpha, \beta) < V_T(\alpha, \beta) \end{cases} \quad (4)$$

Assuming that, in equation (3), $R(\alpha,\beta)$ and $S(\alpha,\beta)$ as well as $\phi R(\alpha,\beta)$ and $\phi S(\alpha,\beta)$ are smoothly changing with respect to

cos(2xoα),
then, binary joint transform power spectrum EB(α,β) can be seen as a periodicity function in direction α. The period is π/xo . In accordance with Fourier series, the expansion is

$$E_B(\alpha,\beta) = -1 + \frac{2x_0 d}{\pi} + \sum_{\nu=1}^{\infty} H_\nu[R(\alpha,\beta), S(\alpha,\beta)] \cos[2\nu x_0 \alpha + \nu\phi_S(\alpha,\beta) - \nu\phi_R(\alpha,\beta)] \quad (5)$$

$$d = d(\alpha,\beta) = \frac{1}{x_0} \cos^{-1}\left[\frac{R^2(\alpha,\beta) + S^2(\alpha,\beta) - V_T(\alpha,\beta)}{2R(\alpha,\beta)\, S(\alpha,\beta)}\right] \quad (6)$$

$$H_\nu[R(\alpha,\beta), S(\alpha,\beta)] = \frac{2}{\pi\nu} \sin\left\{\nu \cos^{-1}\left[\frac{R^2(\alpha,\beta) + S^2(\alpha,\beta) - V_T(\alpha,\beta)}{2R(\alpha,\beta)S(\alpha,\beta)}\right]\right\} \quad (7)$$

$$\left|\frac{R^2(\alpha,\beta) + S^2(\alpha,\beta) - V_T(\alpha,\beta)}{2R(\alpha,\beta)S(\alpha,\beta)}\right| \leqslant 1 \quad (8)$$

Equations (5)~(8) clearly show that binary joint transform power spectra are the sum of a series of harmonic wave components. Only if there is a first harmonic component associated with when v = 1, does it possess the correct phases and maximum amplitude, that is, the component which produces first order correlation signals:

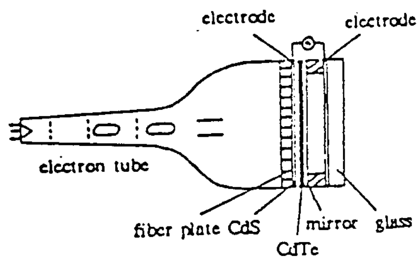
$$E_{1c}(\alpha,\beta) = 2H_{1c} \cos[2x_0\alpha + \phi_S(\alpha,\beta) - \phi_R(\alpha,\beta)] \quad (9)$$

$$H_{1c} = \frac{2}{\pi}\left\{1 - \left[\frac{R^2(\alpha,\beta) + S^2(\alpha,\beta) - V_T(\alpha,\beta)}{2R(\alpha,\beta)S(\alpha,\beta)}\right]^2\right\}^{1/2} \quad (10)$$

As far as the selection of different thresholds VT(α,β) is concerned, it alters amplitude modulation H1(unclear)(α,β) and goes a step further to change binary joint transform correlator characteristics.

3 CATHODE RAY TUBE COUPLED LIQUID CRYSTAL LIGHT VALVES

Cathode ray tube coupled liquid crystal devices are a type of electrically addressed spatial light modulator developed on the basis of alternating current reflection type optically addressed liquid crystal light valves. The structure of the instruments in question and an actual photograph of the item are as shown in Fig.2. They are on the verge of using fiber optic panels to replace the original glass screens associated with high resolution, high luminosity cathode ray tubes, and, in conjunction with that, taking coupled liquid crystal light valves and making them directly on fluorescent screens associated with cathode ray tubes, forming electrically addressed cathode ray tube coupled liquid crystal light valves. Cathode ray tube optical fiber panel diameter is ϕ55mm. Fiber optic bundle diameter is 3~5μm. Expansion coefficients required and tube glass expansion coefficients are the same. The luminosity is greater than 1000cd/m2. /1314



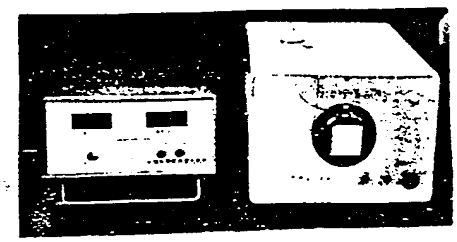


Fig.2 Structure and picture of the CRT-LCLV

Liquid crystal light valves are composed of several types of thin film layers sandwiched between high precision parabolic optical fiber panels and glass substrates. A low voltage (2-20Vrms) audio frequency power (100-20kHz) power source is connected across to transparent thin film electrodes of oxides of indium and tin on the two sides. Optical conductor and optical resistance layers are, respectively, CdS and CdTe. Dielectric mirrors use optical conductors receiving light being written in and optical isolators being read out. Liquid crystals are twisted 45° toward phased materials. During off states (there is no electrical voltage on liquid crystals), operations are done using the effects of the twisting arrangement. However, during on states (there is electrical voltage on liquid crystals), optical double refraction effects are used for operations. The resolutions associated with composite cathode ray tube coupled liquid crystal light valve devices are 35 lp/mm. Contrast gradient is 50:1. The devices in question are capable of carrying out programable operations by video frequency signals sent to computers. They are also capable of being directly driven by video frequency signals associated with cameras. In this connection, specially designed electric drive power sources and port circuits are switched in between the two types of sweep scanning and interval scanning.

4 COMPUTER SIMULATIONS AND EXPERIMENTAL SYSTEMS

Joint transform correlator test set ups are as shown in Fig.1.

Target patterns are inputed by CCD cameras into a COMPAQ 386 computer. The computer takes reference patterns and matches them with target patterns. In conjunction with this, they are sent to cathode ray tube coupled liquid crystal light valves. Then, use is made of He-Ne lasers with powers of 3-5 mW (λ=632.8nm) for beam expansion collimation of coherent optical read out. Going through Fourier lens transformations, the focal length of the Fourier transform lenses used is 380mm. On back focal planes, power spectra associated with the latter are produced. As far as these power spectra are concerned, use is made of a lens with focal length of 138mm to enlarge them into an image on the other CCD camera. This enlargement procedure is necessary with regard to guaranteeing compliance with Nikuisite (phonetic) frequency sampling. The power spectra received by cameras will be sent back to the computer to carry out binary nonlinear processing. Here, on the basis of theoretical deductions above, consideration is given to joint transform power spectra being strongly linearly superpositional. Therefore, first of all, option is made for the use of joint transform power spectra and reference pattern Fourier transform power spectra mutual reduction methods in order to weaken direct current components. With regard to reference patterns, their own Fourier transform power spectra, acting as system memory information, has already been stored beforehand in the computer. In statistical histograms after reduction of reference pattern Fourier transform power spectra, use is made of their intermediate values to act as threshold values in carrying out binary conversion. Binary joint transform power spectra after processing are then sent to cathode ray tube coupled liquid crystal light valves, with inverse Fourier transforms carried out by coherent light read outs to produce correlation results. Correlation results are still received by CCD cameras. It is possible to go through monitoring device fixed time observations. It is also possible to go through computers to carry out digital processing with respect to correlation peaks.

Fig. 3 Input of correlation (a) Input of auto-correlation, (b) Input image of cross-correlation

Fig.3

The authors made use of 128x128 point two dimensional high speed Fourier transform software to carry out simulations. The reason is that image plate resolution is 512x512 elements. When a video frequency signal frame coming from cameras is digitized on image plates, it is necessary to take 512x512 image samples to 128x128 indivdual elements in order to facilitate compatibility with two dimensional fast Fourier transform software. During the sampling process, preprocessing such as binary conversion, pattern division, and so on, are carried out with respect to images. Fig.3(a) and Fig.3(b) are, respectively, auto-correlation and cross correlation input images (tank and armored car models) printed out by image printing programs. The correlation output results make use of three dimensional graphics programs to be drawn out. As is shown in Fig.4(a) and Fig.4(b), among them, the autocorrelation strengths and direct current components in Fig.4(a) and the cross correlation strengths and direct current component strengths in Fig.4(b) have, between the four of them, the specific values 100:2.96:1.1:6.39. Fig.4(c) is preliminary autocorrelation optical test results (zero order optical faculae already filtered out). From the Fig.'s it is possible to see that binary conversion joint transform correlators possess possess quite sharp correlation peaks. Output signal to noise ratios are high. It is possible to see that they possess relatively high discrimination sensitivities.

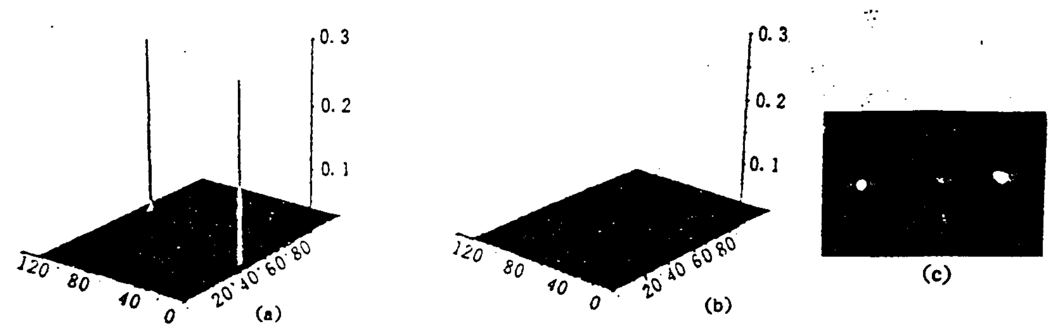


Fig. 4 Output of correlation

(a) Output of auto-correlation, (b) Output of cross-correlation, (c) Optical output of auto-correlation

Fig.4

CONCLUSIONS Making use of cathode ray tube coupled liquid crystal light valves, binary joint transform correlators were set up. Computer simulations and preliminary test results clarified that cathode ray tube coupled liquid crystal light valves possess relatively good processing capabilities associated with mixed photoelectric information, clearly showing that binary joint transform correlators possess pairing adjustment precision requirements with regard to optics which are not high, there is no need to manufacture spatial wave filter devices, output correlation peaks are sharp, and other such advantages. On the basis of improving a step further the performance associated with cathode ray tube coupled liquid crystal light valves, the correlators in question can hope to have relatively large applications in the fields of automatic target recognition and robot vision.

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