Experimental Model of a Combined Optical Processing Correlation System

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Abstract - This paper describes an experimental model of an optical correlator. Optical information processing systems became a new generation of very high speed processing units because of their natural parallelism and generally fast performance [1]. Calculation of the correlation function is one of the most important mathematical tasks in the field of signal and image processing. Special problems such as identification, detection of weak signals below noise level etc. are frequently solved by using correlation units.

The most important part of an optical processing system is a spatial modulator. Spatial modulator - a converter of an electrical signal into an optical image - can be based upon many physical principles. From them we have tested a combined setup consisting of an 18-line LCD modulator as a computer-controlled reference and an acoustooptic unit as a signal modulator. The model has been used for a real time identification of codewords up to 18 bits long in a signal flow. Finally, some parameters of the experimental system model are summarized and future expectations of improvement are outlined.

Optical Correlation

Optical processing systems are exceptionally suitable for calculating the convolution of two images. As shown in Fig.1, an optical transparency represents a set of analog point multipliers and the convolution integral can be computed simply by an integrating positive lens.

Because of the massively parallel nature of such optical calculation the convolution integral is evaluated in real time and the speed of the whole system is limited only by the maximum speed at which the transparency can be modified.

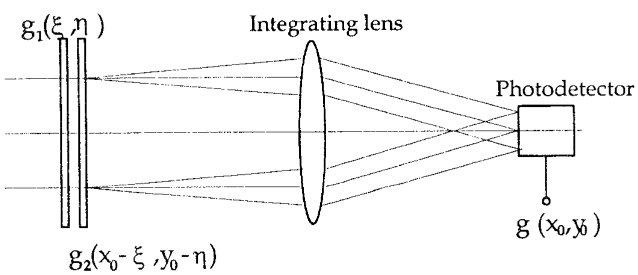

Fig.1: Optical convolution according to Equation 1

A particular transparency can be created by an ordinary photographic record or by an electronically controlled spatial optical modulator. A spatial modulator (LCD, acoustooptic etc.) creates a signal relief - an optical image of the input signal. Calculating the correlation function requires a continuous sliding of the first optical image against the second one - see Equation (1).

$$u(t) = \iint_{-\infty}^{+\infty} g_1(\xi,\eta).g_2(\xi - v.t,\eta)d\xi.d\eta \qquad \text{Eq. (1)}$$

In most spatial modulators the sliding of one image is accomplished by changing the input data quickly and shifting them in the required direction. In some cases, especially with the LCD, the spatial modulator itself is too slow compared to the time of convolution integral evaluation. The acoustooptic spatial modulator, on the other hand, exhibits the advantage of natural signal relief motion because of acoustic wave propagation. The signal image is sliding along the cell at the speed of acoustic wave and a so called sliding time window is created - see Fig.2.

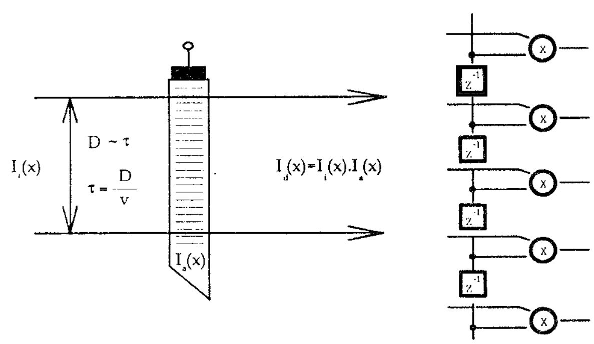

Fig. 2: Acoustooptic unit as a parallel multiplier
and its signal flow model
$I_i(x)$, $I_o(x)$ - input resp. output intensity of optical beam
$I_a(x)$ - intensity of acoustic beam

Optical correlators have been used in applications where high computational power is essential, many of them coming from the defence and military fields such as radar signal processing. Acoustooptic units are capable of handling signals even from the microwave band (with limit frequencies approx. 10 GHz) which corresponds to total resolution of several thousands of pixels.

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Several configurations of signal correlators with an acoustooptic unit are known from the early seventies [3]. From several possible arrangements we have chosen the spatially integrating architecture of the correlator. It is shown in Fig. 3.

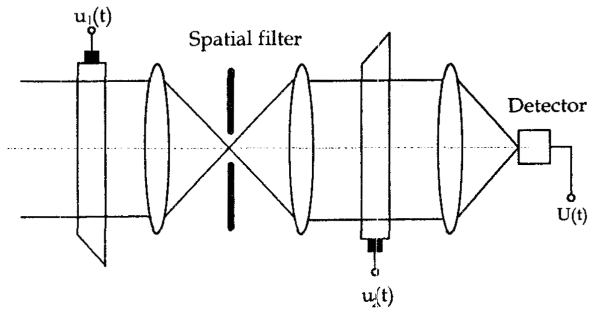

Fig.3: Spatially integrating correlator

Basic Idea of Our Model - Proposed Configuration

The basic idea of our experimental correlator model is to apply an acoustooptic spatial modulator for evaluating the correlation function along lines of an image such as finger print or eye iris with the same reference in every line - see Fig.4. In this configuration the searched image is modulated onto the LCD while the reference signal flows through the acoustooptic cell. The two profiles modulated onto the optical beam are multiplied and integrated spatially in the detector. The correlation functions for all lines are thus obtained simultaneously. An application of this mode is under testing for analysis of finger prints. It is possible by the means of correlation to compare profiles extracted from the tested finger print with a set of stored reference profiles and decide on their presence in existing database.

A significant improvement of system is expected from using a multichannel acoustooptic unit. Such extended configuration demonstrates the most significant advantage of optical systems - the possibility of a three - dimensional interconnection scheme. A multichannel acoustooptic spatial modulator will allow for searching for several reference patterns in parallel and thus to increase the computational power significantly. This concept seems to bring most effect when a larger set of reference patterns is transferred from the system memory into the processing unit and it propagates along the acoustooptic unit in the form of a signal relief. Generally, a multiline multichannel system can be modified for concurrent analyses of a number of images.

An alternative mode of operation of the suggested configuration is possible too. The sequential flow of data passes through the acoustooptic cell and a set of reference codewords is stored in the LCD. The peaks in correlation functions indicate for each reference codeword its occurrence and position in the dataflow. Such device is suitable for high-speed analysis of e.g. access codes.

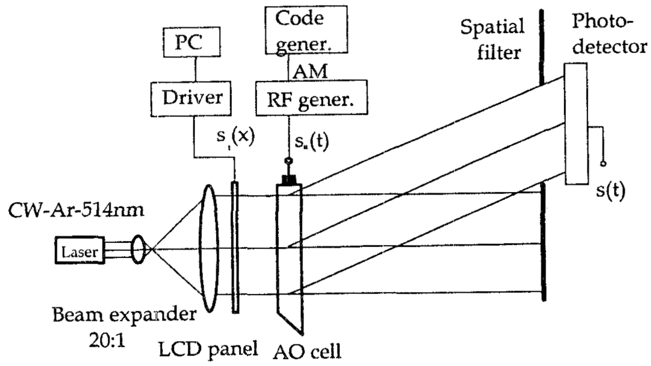

Fig.5: Optical setup of a simple correlator

Experimental Setup

To verify some fundamentals of an optical correlating system an experimental laboratory setup has been built. First, the simplest configuration shown in Fig.5 with a single acoustooptic unit and one 18-element LCD panel was tested. The acoustooptic unit is based upon a new single crystallic material - mercurous chloride - with the bandwidth

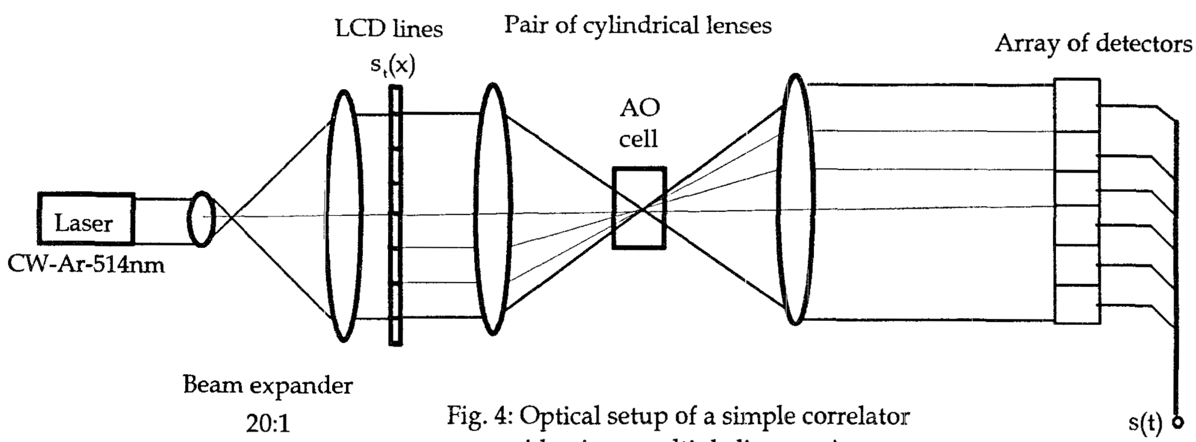

Fig. 4: Optical setup of a simple correlator - side view, multiple line version

of 30MHz and a time window of 100 μsec.. It provides a theoretical resolution power of about 3000 pixels. A photomultiplier was used as a detector. We used the LCD panel model 18D.501 manufactured by Tesla Vrchlabi.

For the purpose of evaluating the signal to noise ratio for the best matched pattern the LCD panel has been used to obtain a reference image containing a sample bit sequence with two bits set to high level. The same sequence was fed into the acoustooptic unit. This input sequence and the resulting autocorrelation function are shown in Fig.6

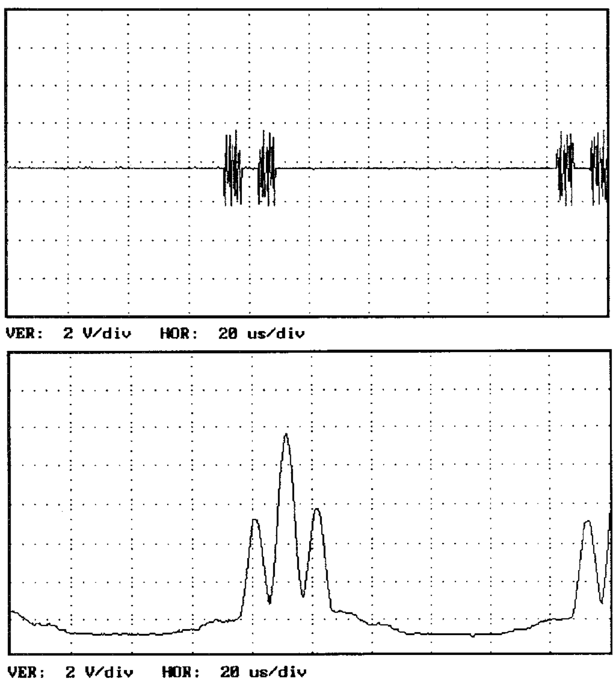

Fig.6: Autocorrelation function of the sample bit sequence. On the top is the input sequence, below is the autocorrelation function.

An acoustooptic unit is used principally as an analog modulator. Although the LCD panel is usually used as a binary spatial modulator, its analog applications have been investigated too. In Fig.7 the measured transfer function of the LCD is given. A special PC-controlled driver is used which allows for modulating the LCD transparency in 8-bit depth and thus enables all-analog operation of the setup.

Another very important parameter characterizing the performance of the device is its computational power. For this simplest possible configuration for correlation of 18-element sequences described above it reaches 25 MIPS. Such configuration, however, utilizes only a limited portion of full resolution capabilities. By simply extending the setup with another LCD panel the computational power is increased to 50 MIPS. In case a higher resolution LCD panel is used, the computational power increases dramatically. The setup equipped with a 100x100 pixel LCD (commonly available in the market) is capable of estimated performance corresponding to 2×10^5 MIPS.

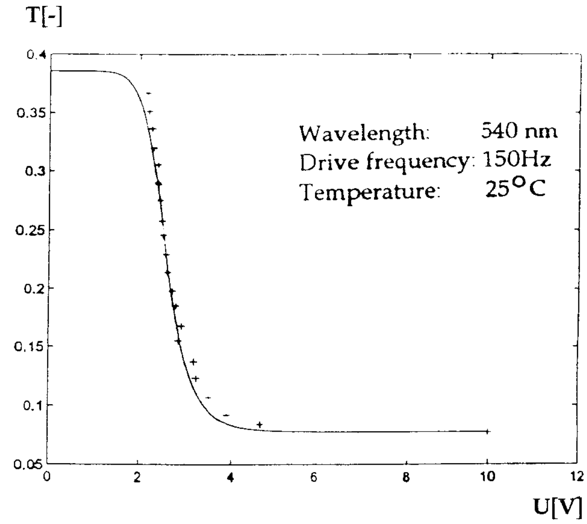

FIg. 7: Transfer function of the LCD. Transparency is plotted against amplitude of the harmonic input voltage (frequency 150 Hz).

Conclusion

In our experiment we have demonstrated a model of an efficient optical correlation system for general use. It was shown that any available spatial modulator - a slide, an acoustooptic unit or an LCD panel can be used either as the signal or reference relief which offers designers of particular systems a large flexibility.

Expected security applications are oriented esp. into two main fields. One of them is an identification of patterns in lines of an image such as finger prints, pictures of iris, signature or identity cards. The second field is a real time detection of particular signal patterns - codewords - in a serial signal flow for the purpose of identification of e.g. a computer address, priority etc. Our future effort will be focused into the field of identification of a limited number of authorized personnel as a part of an access control system.

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