Osaka University Knowledge Archive

Title	Pure Optical Parallel Array Logic System : An Optical Parallel Computing Architecture
Author(s)	Konishi, Tsuyoshi; Tanida, Jun; Ichioka, Yoshiki
Citation	IEICE Transactions on Electronics. 1994, E77-C(1), p. 30-34
Version Type	VoR
URL	https://hdl.handle.net/11094/2889
rights	copyright©1994 IEICE
Note	

Osaka University Knowledge Archive : OUKA

https://ir.library.osaka-u.ac.jp/

Osaka University

| PAPER   *Special Issue on Optical Interconnection* |

Pure Optical Parallel Array Logic System
—— An Optical Parallel Computing Architecture ——

Tsuyoshi KONISHI†, *Nonmember*, Jun TANIDA† *and* Yoshiki ICHIOKA†, *Members*

SUMMARY   We propose an optical computing architecture called pure optical parallel array logic system (P-OPALS) as an instance of sophisticated optical computing system. On the P-OPALS, high density images can be processed in parallel using the optical system with high resolving power. We point out problems on the way to develop the P-OPALS and propose logical foundation of the P-OPALS called single-input optical array logic (S-OAL) as a solution of those problems. Based on the proposed architecture, an experimental system of the P-OPALS is constructed by using three optical techniques: birefringent encoding, selectable discrete correlator, and birefringent decoding. To show processing capability of the P-OPALS, some basic parallel operations are demonstrated. The results obtained indicate that image consisting of 300×100 pixels can be processed in parallel on the experimental P-OPALS. Finally, we estimate potential capability of the P-OPALS.
key words: optical computing, optical interconnection, parallel processing, spatial light modulator, birefringence

1. Introduction

Light has excellent features as a medium of information. Parallelism, high velocity of propagation, and broad bandwidth in the information transmission and processing are important features of light and are expected to be utilized in a parallel information paradigm in future. Making good use of these features of light, a lot of methods and techniques are proposed in the field of optical interconnection and optical computing [1]-[6]. The purpose of this paper is to present an new architecture of an optical computing system called P-OPALS as an instance of sophisticated application of the above methods and techniques.

Optical parallel array logic system (OPALS) is an optical digital computing system based on optical array logic (OAL) [7]. OAL is a computing paradigm to implement logical operations on 2-D image data in parallel. The authors are engaged in investigation of OAL and the OPALS. To clarify usefulness of the OPALS, several experimental systems of OPALS's have been constructed [8]-[10]. Since they are mainly based on hybrid techniques combining with optics and electronics techniques, these systems are called hybrid OPALS's (H-OPALS).

Although the H-OPALS constructed by opto-electronic integration is considered as a reasonable one for practical application, the system cannot fully utilize the capability of the internal optical interconnection of the OPALS. To demonstrate capability of optical computing system, the authors consider a pure optical version of OPALS (P-OPALS) and construct an experimental system of P-OPALS.

In Sect.2, we propose the architecture of P-OPALS and point out problems on the way to develop the P-OPALS. In Sect.3, we describe logical foundation of the P-OPALS called single-input OAL (S-OAL). In Sect.4, we show an experimental system of P-OPALS and in Sect.5, we describe operation of the experimental system and demonstrate experimental results of basic processing. In Sect.6, we estimate potential capability of the P-OPALS.

2. P-OPALS

The OPALS is an optical digital computing system for 2-D information processing. As shown in Fig. 1, the OPALS consists of encoder, correlator, decoder, and feedback-line. The P-OPALS is a pure optical version of OPALS, in which a huge amount of image data are processed with keeping their arrangement by optical interconnection capability. Using the excellent features of light, the P-OPALS is expected to provide quite high processing capability. However, to exploit inherent capabilities of optical interconnection, several problems must be solved.

Usually, an optical system requires precise adjustment and misalignment restricts practical processing capability of the system. This is an essential problem
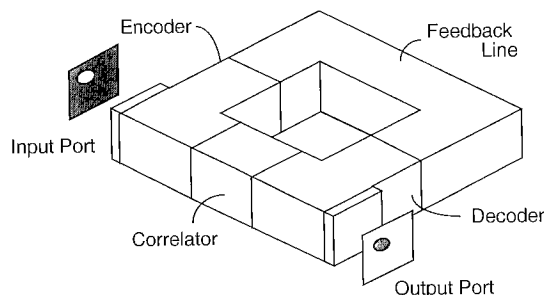
Fig. 1   OPALS.

and troubles many optical engineers. Loss of optical power is also another problem. Reflection and absorption by individual optical components reduce optical power. Decrease of optical power causes slowdown of signal detection and degradation of system performance. In addition, to accomplish one-to-many fan out, we must guarantee appropriate power for individual signal transmission lines.

These problems cause reduction of processing capability of the P-OPALS, that is, reduction of pixel number to be processed on it. Since the P-OPALS consists of many optical components, the problems are dominant in practical implementation. Therefore, the authors consider a simple architecture of P-OPALS capable of reducing the number of required optical components by introducing the concept of S-OAL.

3. S-OAL

S-OAL is a simplified version of OAL. OAL is a technique based on image encoding and 2-D discrete correlation [7]. Arbitrary logical operation for neighboring pixels can be executed in parallel with OAL. Whereas OAL has two input images and produces one output image, S-OAL treats one input image and provides one output image. In case of processing two images like OAL, the contents of the images is rearranged onto one image and processed by means of neighborhood operations on the image. Both OAL and S-OAL schemes have close relationship with array logic. S-OAL can execute the same operations as OAL at the cost of processing efficiency.

Figure 2 shows the processing procedure of S-OAL. The encoding rule and the form of operation kernel are slightly modified as compared with OAL. Other processing procedures are same as those in the OAL. Using S-OAL, we can reduce the number of optical components in the system. In addition, the coding in S-OAL does not affect data continuity along the vertical direction. This feature promise to treat the image with high density and increases data capacity processed on the system.
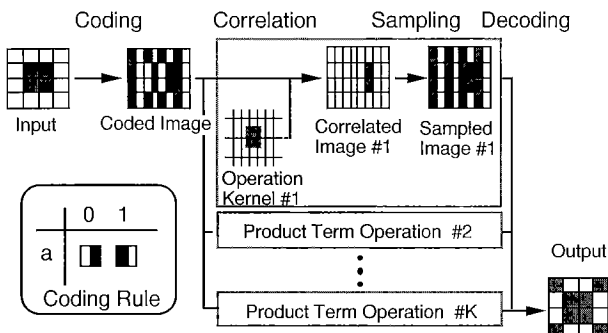
4. Experimental System of P-OPALS

To evaluate processing capability of the P-OPALS, an experimental system of P-OPALS is constructed. In the experimental system, three optical techniques are utilized: birefringent encoding [11], selectable discrete correlator [10], and birefringent decoding. On the P-OPALS, high density images can be processed with the optical system with high resolving power.

Birefringent encoding is a technique to encode the input image in parallel. Figure 3 shows the principle of the birefringent encoding for a pixel. Using polarization modulation by a spatial light modulator (SLM), either of two coding patterns in S-OAL is obtained behind the birefringent crystal. The selectable discrete correlator is based on a coherent 4-f spatial-filtering system with multiple holographic
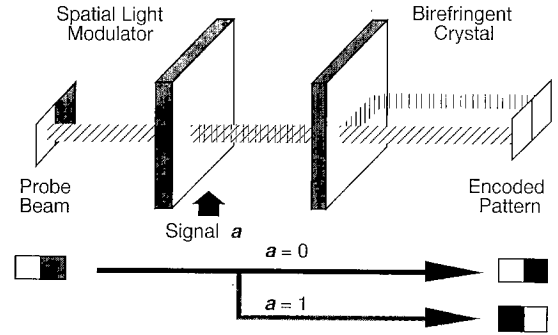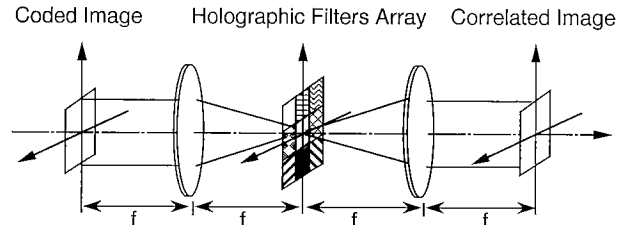

Fig. 3 Principle of birefringent encoding.

Fig. 4 Optical setup of selectable discrete correlator.

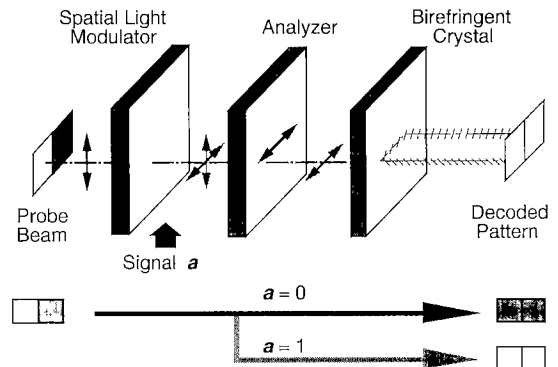Fig. 2 Processing procedure of S-OAL.

Fig. 5 Principle of birefringent decoding.

filters arranged in the array form. Impulse response of individual holographic filter is identical to pattern of operation kernel, which corresponds to switching configuration of LED's in shadow casting implementation of OAL. We can specify an operation by selecting an appropriate filter on the filter array. Figure 4 shows the optical setup. This correlator has capability to execute discrete correlation with large operation kernels. Birefringent decoding is a technique to decode information after processing effectively. Figure 5 shows the principle of the birefringent decoding for a pixel. This technique is considered as dilation of the sampled pixels in OAL. The same optical component as used in birefringent encoding can be used in birefringent decoding. As a result, we can reduce the number of optical components in the system.

Figure 6 shows the schematic diagram and the overview of the experimental system of P-OPALS. To execute procedures in S-OAL, we use an optically addressed liquid crystal SLM (LAPS-SLM, Seiko Instruments, Inc.)[12]. The available area of the LAPS-SLM is 20×20 mm^2 and the maximum resolving power of it is 200 points/mm. For the encoding and decoding, a thin calcite plate with thickness of 1 mm is used as the birefringent crystal. The effective area of

the calcite plate is 27×27 mm^2. And hence, the spatial shift of the pixel provided by the calcite plate is about 0.1 mm. To control optical path in the system, mechanical shutters are equipped in front of each SLM. A personal computer (PC-9801NS/T, NEC) and D/A converter (98DA12(4)-H, Interface, Inc.) are used as a system controller.
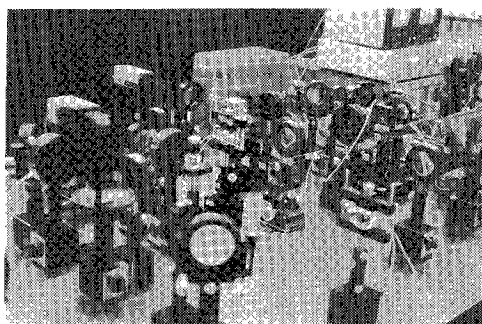
5. Operation of Experimental P-OPALS

The experimental P-OPALS executes logical operations according to the sequence shown in Fig. 7. First, the input image is recorded onto the SLM1 by the He-Ne laser (path ①). During this process, only S1 is open. A continuous image can be used as the input. Second, the image recorded is read out by discrete beams corresponding to individual pixels (path ②). The image is encoded by Calcite1. During this process, only S1 is open. Note that pixel data are continuously arranged along the vertical direction in S-OAL. Thus the input mask consisting of vertical strip patterns are used to produce the readout light. The encoded image is latched on the SLM2. Third, the encoded image is read out by plane wave (path ③). During this process, S1 is closed and S2 and S3 are open. The readout image from SLM2, which is amplified by bright readout light, is used as the input of the coherent discrete correlator. The correlated image is recorded on the SLM1 for iterative operation. This correlated image is read out with discrete beams and re-encoded for the next step of operation. During this process, only S1 is open.

As shown in Fig. 3, in S-OAL, an pixel datum can be coded by referring datum on the left half of the corresponding pixel area. Since the processing result is obtained as either dark or bright signal at the left half of the corresponding pixel area, the result can be directly used to modulate the readout light in the
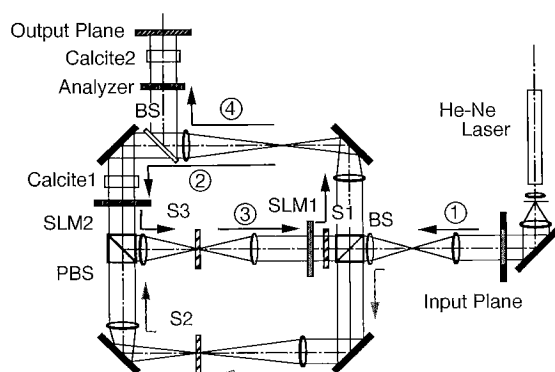
(a)

(b)

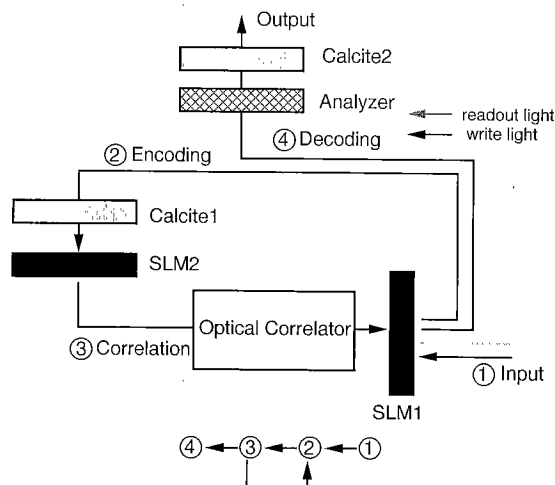**Fig. 6** Experimental P-OPALS: (a) schematic diagram and (b) overview.

Fig. 7 Operational sequence of experimental P-OPALS.

20mm

(a)   (b)   (c)
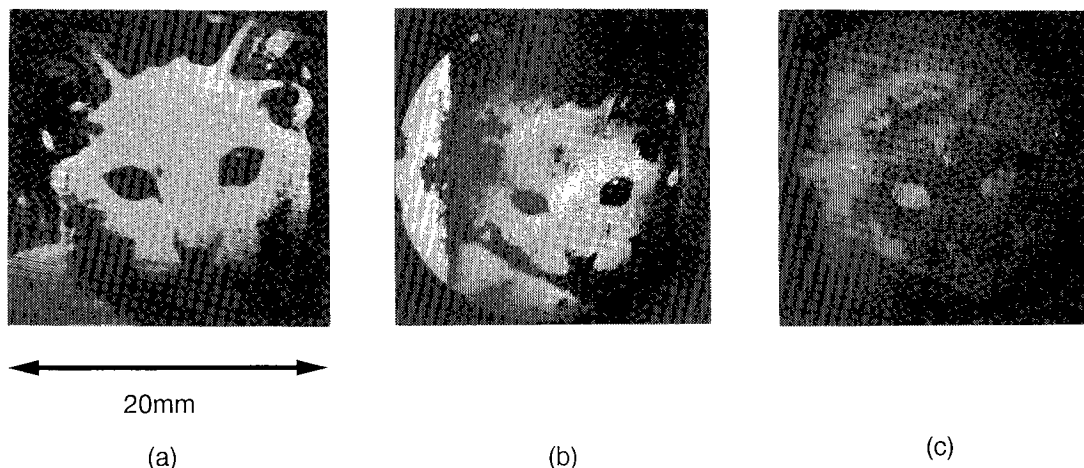
Fig. 8 Parallel logic operations executed on experimental P-OPALS:
(a) input image, (b) A, and (c) Not A operations.

coding process of the next iteration. This means that decoding process can be omitted during iterative processing. To obtain the final output, the analyzer and the calcite plate are used for decoding (path ④). Note that all procedures are executed in parallel for individual pixels.

To verify basic operations on the experimental P-OPALS, we executed A (direct through of the input) and NOT A (inversion of the input) operations for a picture. Figure 8 (a) is an input image and Figs. 8(b) and (c) are the results of A and NOT A operations, respectively. Each processing image has the extension of 20×20 mm², which contains 2000×100 pixels. As seen from Fig. 8, high density image is successfully processed by the developed system.

6. Discussion

To evaluate information capacity of the experimental P-OPALS, the test chart was set at the input plane, transferred through the SLM1 and the SLM2, and recorded on the SLM1. Figure 9 shows the image of the USAF test chart readout from the SLM1. In this case, the Calcite1 was removed to measure performance of the optical system. The result indicates that about 300×300 pixels can be processed by the system. However, since, in actual operation, a calcite plate which provides horizontal image shift with the amount of 0.1 mm is inserted behind the SLM1, the number of the horizontal pixels is limited to 100 pixels. Therefore, the number of pixels which can be processed on the experimental P-OPALS is 300×100.

In the ideal case estimated by diffraction theory, resolving power of the 4-f imaging system used in the experimental system of P-OPALS is 600 points/mm and possible pixel number to be processed is 2500×2500. To utilize full of the information capacity of the P-OPALS, we must use a material with weak birefrin-
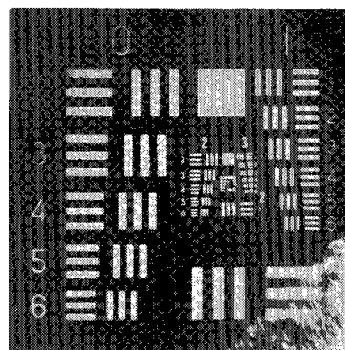

Fig. 9 Image of USAF test chart readout from the SLM1 in the optical system of experimental system of P-OPALS.

gence and develop a sophisticated technique to reduce misalignment.

7. Conclusions

We have presented an optical computing architecture called P-OPALS as an instance of sophisticated optical computing system. Based on the proposed architecture, an experimental system of the P-OPALS has been constructed and some basic parallel operations have been demonstrated. The results obtained indicate that the image consisting of 300×100 pixels can be processed in parallel on the experimental P-OPALS.

References

[1] Tanida, J. and Ichioka, Y., "Optical logic array processor using shadowgrams," *J. Opt. Soc. Am.* vol. 73, no. 6, pp. 800-809, Jun. 1983.

[2] Brenner, K.-H., Huang, A. and Streibl, N., "Digital optical computing with symbolic substitution," *Appl. Opt.*, vol. 25, no. 18, pp. 3054-3060, Sep. 1986.

[3] Huang, K.-S., Jenkins, B. K. and Sawchuk, A. A., "Image algebra representation of parallel optical binary arithme-

tic," *Appl. Opt.*, vol. 28, no. 6, pp. 1263-1278, Mar. 1989.

[4] Fukui, M. and Kitayama, K., "Image logic algebra (ILA) and its optical implementations," *Appl. Opt.*, vol. 31, no. 5, pp. 581-591, Feb. 1992.

[5] Brenner, K.-H. and Huang, A., "Optical implementations of the perfect shuffle interconnections," *Appl. Opt.*, vol. 27, no. 1, pp. 135-137, Jan. 1988.

[6] Jahns, J. and Murdocca, M. J., "Crossover networks and their optical implementation," *Appl. Opt.*, vol. 27, no. 15, pp. 3155-3160, Aug. 1988.

[7] Tanida, J. and Ichioka, Y., "A paradigm for digital optical computing based on coded pattern processing," *Intl. J. Opt. Comput.*, vol. 1, no. 2, pp. 113-128, Dec. 1993.

[8] Tanida, J., Nakagawa, J., Yagyu, E., Fukui, M. and Ichioka, Y., "Experimental verification of parallel processing on a hybrid parallel array logic system," *Appl. Opt.*, vol. 29, no. 17, pp. 2510-2521, Jun. 1990.

[9] Miyazaki, D., Tanida, J. and Ichioka, Y., "Construction of modularized OPALS using optoelectronic devices," *Jpn. J. Appl. Phys.*, vol. 29, no. 8, pp. 1550-1552, Aug. 1990.

[10] Miyazaki, D., Kakizaki, S., Konishi, T., Tanida, J. and Ichioka, Y., "Iterative processing on a hybrid optical parallel array logic system with a selectable coherent correlator," *Appl. Opt.*, vol. 32, no. 17, pp. 3053-3058, Jun. 1993.

[11] Tanida, J., Nakagawa, J. and Ichioka, Y., "Birefringent encoding and multichannel reflective correlator for optical array logic," *Appl. Opt.*, vol. 27, no. 18, pp. 3819-3823, Sep. 1988.

[12] Yamamoto, S., Sekura, R., Yamanaka, J., Ebihara, T., Kato, N. and Hoshi, H., "Optical pattern recognition with LAPS-SLM (1) / light addressed photoconductor and smectic c* liquid crystal spatial light modulator," *Proc., SPIE*, vol. 1211, pp. 273-283, Jan. 1990.

Jun Tanida received the BE, ME and DE degrees in Applied Physics from Osaka University, Osaka, Japan, in 1981, 1983 and 1986, respectively. He was associated with the Department of Applied Physics in 1986, and is an Assistant Professor there. His research interests are in the area of optical computing with emphasis on the optical parallel digital computing system. He is also interested in the application of the optical computing system, including image processing, numerical computing, and fractals. Dr. Tanida is a member of OSA, the Japanese Society of Applied Physics.

Yoshiki Ichioka received the BE, ME and DE degrees in Applied Physics from Osaka University, Osaka, Japan, in 1960, 1962 and 1966, respectively. He was associated with the Department of Applied Physics in 1962, and became a Professor there in 1985. His main research activities are in the area of digital image processing, optical information processing, optical computing, and development of digital image processing systems. His present research interest is in the area of massively parallel information processing using optical and electronic techniques. Dr. Ichioka is a fellow of OSA, a member of IEEE, the Japanese Society of Applied Physics.

Tsuyoshi Konishi received the BE and ME degrees in Applied Physics from Osaka University, Osaka, Japan, in 1991 and 1993, respectively. He is presently a Ph. D student of the Department of Applied Physics. His research interests are in the area of optical computing with emphasis on the optical parallel digital computing system. He is also interested in the application of the optical computing system and optical techniques including holography and phase-conjugate. He is a student member of the Japanese Society of Applied Physics.