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Veacheslav L. Perju, David P. Casasent, "Optical-electronic multiprocessors computer systems controlled by input images parameters," Proc. SPIE 5816, Optical Pattern Recognition XVI, (28 March 2005); doi: 10.1117/12.604312

Event: Defense and Security, 2005, Orlando, Florida, United States

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ABSTRACT

We present a new class of optical-electronic reconfigurable image processing systems, controlled by the parameters of the input image. The systems use multiprocessors and are distributed. We describe two different optical processors, each performs the Fourier transform and correlation with an adaptive filter or with a fixed set of filters.

Keywords: correlation, image, processor, optical, reconfigurable, system

1. INTRODUCTION

The new concept of a computer architecture whose data sampling is controlled by the maximum spatial frequency of the input image is proposed[1]. In Sec.2, we describe the system's architecture. We then describe the electronic units (Sec.3.) and two optical processors (Sec.4). They are reconfigurable and distributed computer systems. When the order in which the units are used is varied, the system is reconfigurable. The control module can be a specific internal control processor or an external PC. The last version of the system is more flexible and allows simpler software algorithm development. Both optical processors implement the Fourier transform (FT) on input data as well as correlations using adaptive filters (using a joint transform correlator[2]) or using a fixed set of filters, accessed with a 2-D array of laser diodes[3]. In Sect.5, we present different methods for using the units of the system, when the input image contains one or several objects. The speed of the system is summarized in Sec.6. We show that by controlling the input sampling, based on the maximum input spatial frequency, we can decrease the processing time by a factor of 1.6 to 3.7. Comparative analysis of the different systems is presented (Sec.7) taking into account the time expenditures, speed of functioning, the number of stored standards, the necessity of preliminary recording of the holographic filters, the flexibility of the systems, their dimensions, and their power consumption.

Optical Pattern Recognition XVI, edited by David P. Casasent, Tien-Hsin Chao,
Proceedings of SPIE Vol. 5816 (SPIE, Bellingham, WA, 2005)
0277-786X/05/$15 doi: 10.1117/12.604312

2. THE ARCHITECTURE OF THE BASIC IMAGE PROCESSING COMPUTER SYSTEM

The architecture of the image processing computer system (IPCS) is presented in Fig.1.The system consists of an image preprocessor (PP), a unit that performs image coordinate transformation (CT), a system that performs output correlation plane analysis (CPA), a fast memory (FM) and a multi frame slow memory (SM), and an image complexity analysis (ICA) unit. All of the above units are electronic ones. The system also contains either an optical joint transform correlator (JTC) or an optical frequency plane correlator that uses a laser diode array that addresses a fixed optical filter bank. A controller completes the set of units. Fig.2 shows a photo of the system with the electronic portion on the right (one card per unit) and with one of the optical processors shown to the left. The electronic portion of the system is 300x400x250mm including the power supplies and the optical processor portion is 600x700x250mm.

The image preprocessor (PP) reduces noise and locates separate candidate objects in the input. The coordinate transform (CT) module together with the JTC is used to produce space variant processors that produce scale and rotation – invariant features using Mellin and polar CT's [4]. It can also produce a normalized object image with scale, rotation, and shift effects removed. The optical JTC module determines the scale, rotation and location of each input object. For the present system, input images use assumed to be 256x256 pixels.

The classification of the systems depend on the type of optical processor used (JTC or laser diode array, LDA) and the type of controller used as shown in Table 1.

Table 1. Classification of IPCS

Type of controller	Built-in control computer		External control computer	
Type of optical processor	JTC	LDA	JTC	LDA
Type of IPCS	IPCS-1.1	IPCS-1.2	IPCS-2.1	IPCS-2.2

These computer systems allow one to identify one or a group of objects that can have different position, angular orientation, and scale, and can also determine all of the required parameters of the objects. The systems can realize scaling and rotation of the images, image edge detection, and calculation of the coordinates of the objects. We now more fully detail each of the units of the system.

3. UNITS IN THE ELECTRONIC PROCESSING MODULE

We now discuss the various units in the electronic processing module (upper portion of Fig.1). The preprocessor (PP) performs various 3x3 filtering on the input image, specifically median filtering (to remove salt and pepper noise) and Sobel filtering [5] to produce edge - enhanced data. Each of these operations is performed in 20ms (half of the European TV frame rate of 40 ms). This PP digital unit uses cellular logic and employs 9 separate elementary processors. It was fabricated in

Republic of Moldova.

The image coordinate transformation (ICT) processor consists of a digital and an analog module. The digital module produces log, polar and log-polar ICT versions of the image. This is done by pre calculated ICT operations using table look-up in ROM with digital processing in 20 msec. The second module performs scale, rotation and shift correction to the image. This is achieved by analog processing (using operational amplifiers and analog multiplier elements) with digital storage in 0.1μsec per pixel. The latter operation is referred to as normalization.

The correlation plane analysis (CPA) unit determines the location of the correlation peak. For a standard correlation, the location of the correlation peak indicates the location of the object. For the space variant correlation the peak location describes the scale (horizontal and vertical) or the scale and rotation of the input object [4].

The image complexity analysis (ICA) unit determines the possible input image resampling (assuming an over-sampled image). The input image is optically Fourier transformed (FT) and sampled in annular rings. An estimate f_m of the maximum input spatial frequency is made and the amount k of the total FT amplitude present at this f_m is estimated. The product kf_m is used as a measure of image complexity (IC) .

The fast memory (FM) units each consist of a fast static memory chip (model KP541RU1A*) each with 256x256x8 bits. The slower memory (SM) consists of 40 dynamic memory chips (model KP565RU5*) each with 256x256x8 bits of storage.

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For the built in control unit, the microprocessor K580VM80A* is used with all software in assembly in ROM. For different image processing functions, the ROM must be reprogrammed. Use of an external PC avoids this at an increased cost, but with more flexibility in terms of the possible operations.

If refabricated with more modern Western hardware components, speed can be greatly improved and system size can be greatly reduced.

4. OPTICAL PROCESSING MODULES

The joint transform correlator architecture is shown in Fig.3. The two patterns to be correlated are fed to a CRT (model 8LK3B*) and imaged onto the left side of an optically-addressed liquid crystal (LC) spatial light modulator (SLM) through an optical amplifier (model Obruch*) with a fiber optic front end. The input data is read out in reflection with a model LG-52* laser. The joint transform is detected on a TV camera (model PTU43*), rewritten on the SLM via the CRT, read out and Fourier transformed to produce the correlation.

* - indicates models of microchips and another elements produced in Russia

Fig.4.shows the schematic of the laser diode (LD) matrix-addressed fixed filter bank. The input image is written on an LC SLM. It is read out by a matrix of LDs (a 3x3 array is used) and correlated with one of a bank of 9 filters as proposed earlier [3]. The LD activated determines the filter accessed and the correlation that appears at the output. Thus, by activating different LDs, the input data can be correlated with up to 9 different filter patterns. Each correlation occupies the full output plane (using different reference beam angles in recording each filter). If one of the filters is replaced by a lens element, the FT of the input occurs at the output.

Fig.5 shows the LD array fabricated at the Technical University of Moldova. Al-GaAs diodes are used; they are on 2mm centers with an active area of 2x13µm, they emit 5mW at 820mm. Larger arrays can be produced. A more compact version of this processor has been designed (fig.6) that measures $250x40x20mm^3$. In fig.6, 1 is a CRT, 2 is the SLM, 3 is optics, 4 and 7 are the beam splitters, 5 is the LDs array, 6 is the output detector, 8 is the output detector array, 9 is the filter bank and 10 is a prism.

If monomials are recorded on the filter bank, then the system of figs. 5 and 7 can calculate the moment features of the input data [6].

5. OPERATION OF THE SYSTEM

The operation of the modules in the system of Fig.1 is now described for a pattern recognition problem with one of N possible objects present in the input image. The object can be present at any scale and in plane rotation and it can be anywhere in the input field of view. The input image is first fed to the preprocessor PP and stored in a fast static memory FM. It is then fed to the optical processor JTC. We also calculate the intensity of the Fourier transform FT of the input image and feed it to the image complexity analysis ICA module. Space-variant image coordinate transformation ICT processing requires that the input data be centered [4]. Since the magnitude FT is shift-invariant, we apply CT processing to the $|FT|^2$ of the input image, as suggested elsewhere [3,4].

We feed the $|FT|^2$ to the digital CT bloc, where its polar-log CT transform is formed and stored in static memory FM. The ICT of the $|FT|^2$ of the input image is then fed to the JTC, where it is correlated with the image coordinate transformed $|FT|^2$ of the N possible input objects. The reference data are input from dynamic memory SM. The correlation with the largest output denotes the class of the input object, the coordinates of the output correlation peak denote the scale and rotation of the input object as detailed elsewhere [6]. The optical output plane analysis module performs the needed correlation plane analysis.

In assembly, grasping, and ATR, the position of the input object is needed. To obtain this, we use the analog CT module to rotate and scale the input preprocessed image. This produces an input image whose scale and rotation matches that of the nominal reference one. Then we correlate this transformed input image with the reference image (not its $|FT|^2$). The location of the correlation peak indicates the position of the object in the input.

This system either requires the input object to occupy a large part of the input (so that the $|FT|^2$ data is primarily object) or it requires little background clutter (for a similar reason).

The LD matrix addressed fixed filter bank system could also be used in place of the JTC one, if filters of the N reference objects and of the ICT of these $|FT|^2$ could be pre-stored in the filter bank.

This second optical system configured to calculate the moments of the input image could also be used, But in this case, the preprocessor PP must remove essentially all input noise and only one object can be in the input field of view. This approach is detailed elsewhere [8]. Neither the CT nor the moment approach handles out-of-plane aspect view distortions.

6. SPEED OF THE SYSTEMS

Evaluation of the speed of the systems is now addressed. The results of investigations show the following. The speed of the system depend on the complexity of the images and on the optical processor used. As the number of objects in the analyzed image increases, processing time increases: in IPCS-X.1 from 0.86 to 5.73 sec and in IPCS-X.2 from 0.3 to 3.73 sec. From preliminary analyses, we can decrease the processing time in IPCS-X.1 by a factor of 1.25 to 1.9 times and in IPCS-X.2 by a factor of 2.6 to 3.7 times.

7. CONCLUSION

Analysis of the systems described shows the following.

1. By using image complexity calculations and reducing resolution, we can increase the speed of the system by a factor of 3.7.

2. The systems IPCS-1.2 and IPCS-2.2 have higher speed.

3. In the system IPCS-1.1, the number of stored references cannot exceed 40. In the system IPCS-2.1, the number of references can be in the thousands. In the systems IPCS-1.2 and IPCS-2.2, the number of references is 8 and can be increased to 100 if a larger (10x10) matrix of lasers and holograms is used.

4. In the systems IPCS-1.1 and IPCS-2.1, there is no need to prerecord holographic filters. This increases the flexibility of the JTC system.

5. In the optical processors in the systems IPCS-1.1 and IPCS-2.1, holographic amplitude-phase filters can be used. In the systems IPCS-1.2 and IPCS-2.2, amplitude-phase as well as phase filters are possible.

6. The systems IPCS-1.X using built-in control computer are smaller in size and power consumption. Systems IPCS-2.X using external control computer provide a number of additional image processing algorithms.

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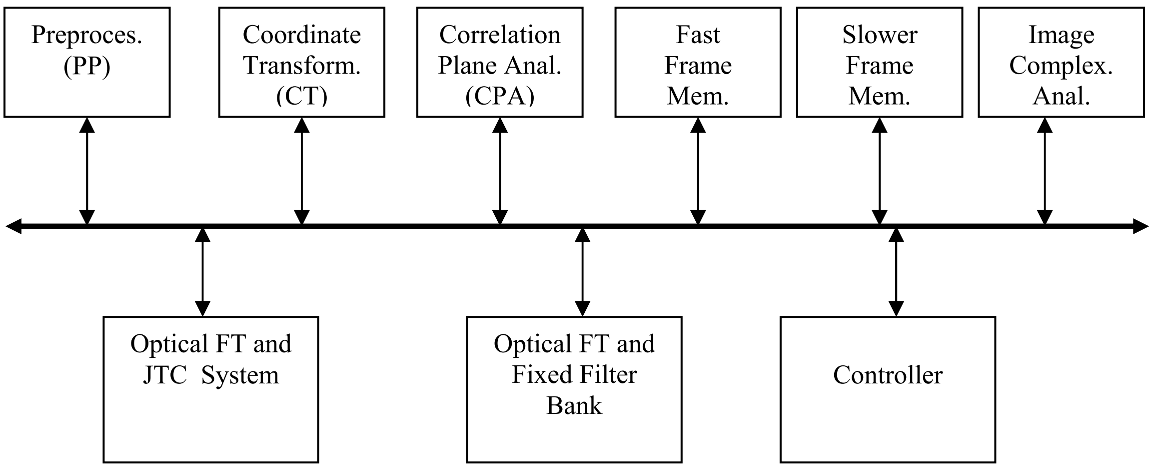

Fig.1. The structure of the optical electronic system

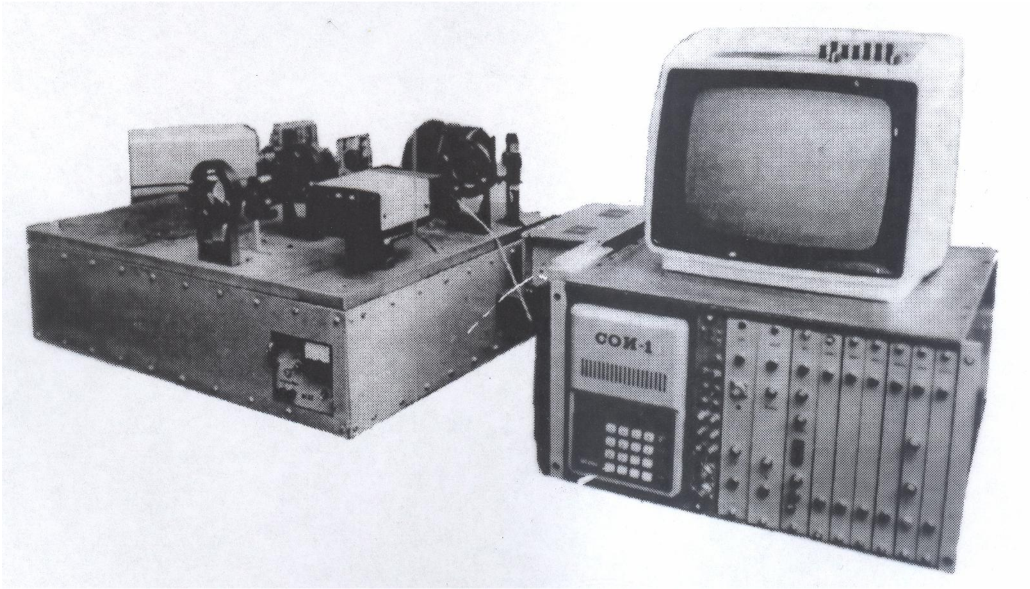

Fig.2 Multiprocessor optical-electronic computer system
on the basis of the built – in control computer

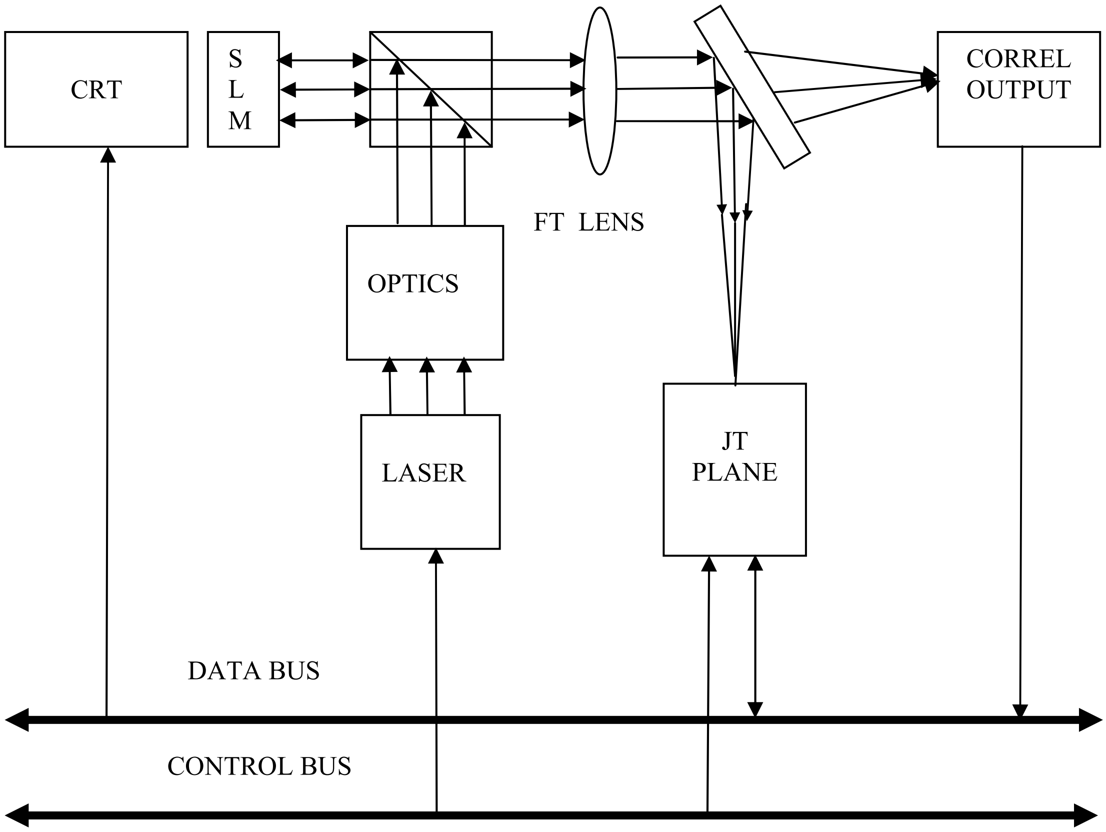

Fig.3. Optical joint transformation processor

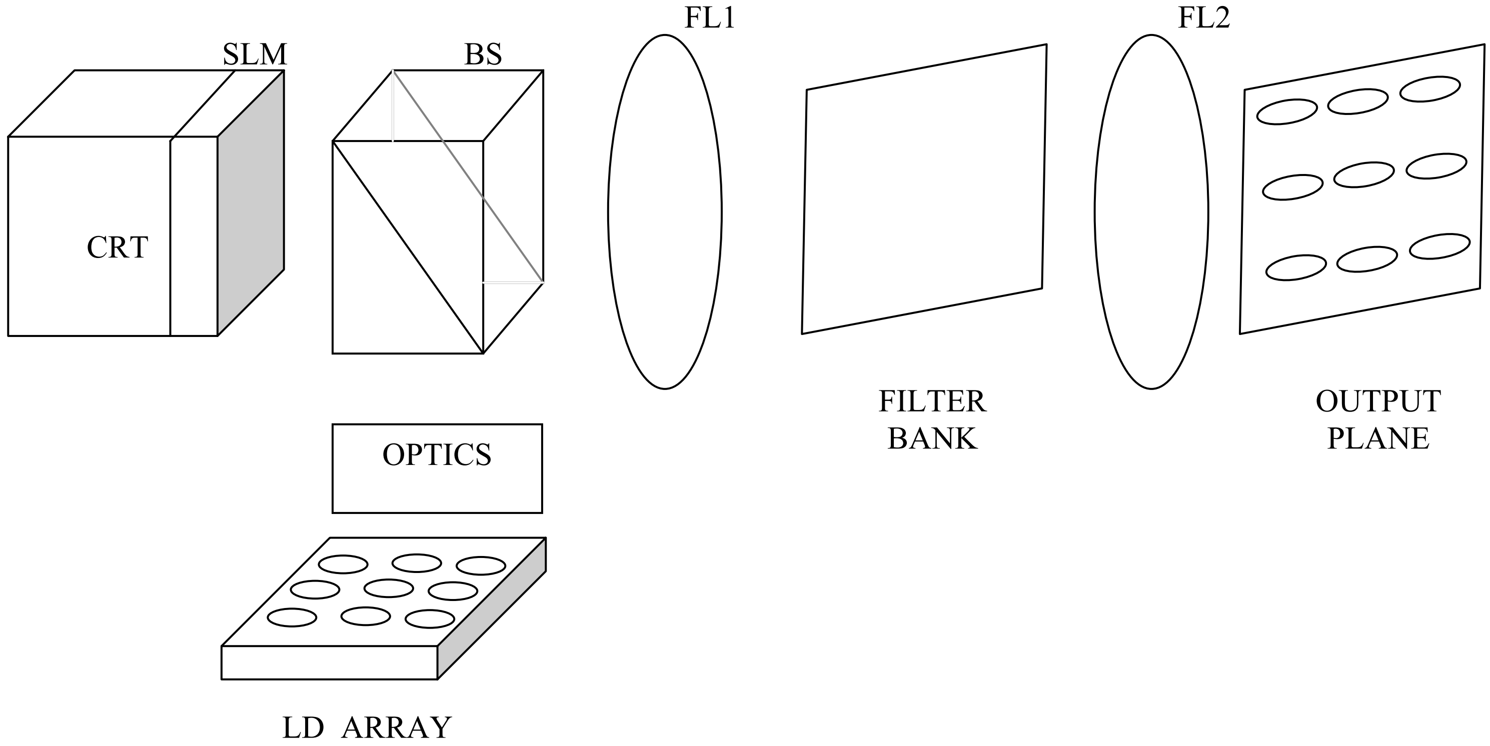

Fig.4. Optical processor using laser diode array

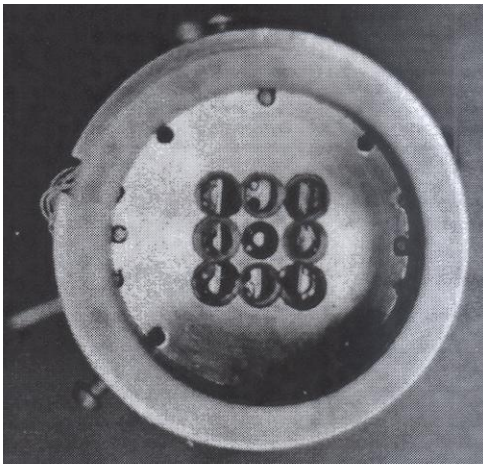

Fig.5 Laser diode array

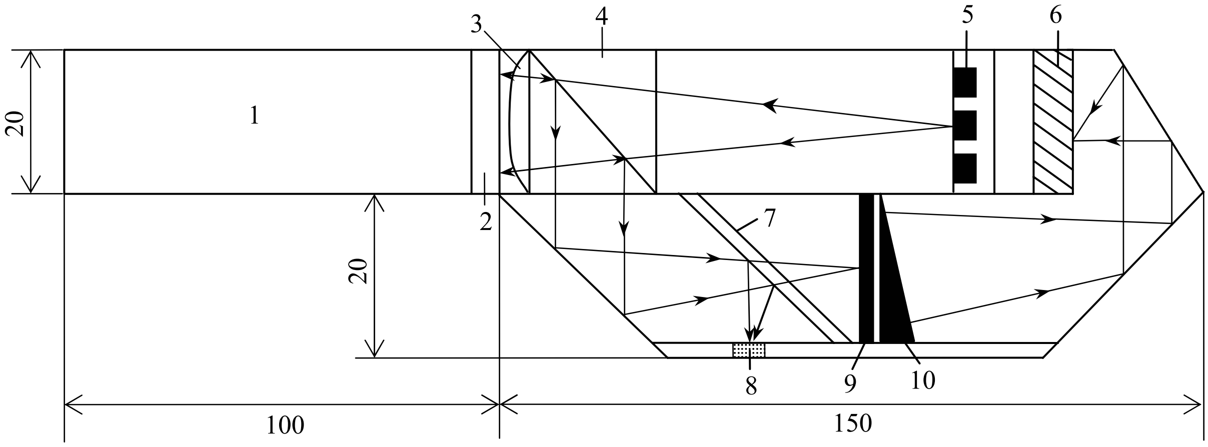

Fig. 6   Compact optical processor