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One-Piece-Type Neural-Network-Based Optoelectronic Printhead

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Abstract

An optoelectronic printhead having the configuration of optically and electrically controlled full-frame light valve was studied. The distinctive feature that sets our printhead apart from most conventional is that it is based on the neural network principles according to which massively parallel arrays of individually controlled pixels form the arrays of simple processing units. Supported digitally by soft and hard modeling of the adaptive self-learning neuron structures, such an "intellectual" light valve, allows executing of image processing operations in parallel mode until the image is ready for output.

Introduction

Usually we consider the printhead as an output portion of imaging system. The output data is assumed to be completely prepared and ready on the eve of printing that is the final stage of the image processing.

However, full-frame optoelectronic printheads operating on the principles of light valve (LV) have a great potential for solving the problems of image processing directly inside the body of optical system.

Optical systems are inherently parallel in nature and are preferred for real time applications, whereas digital systems are more flexible and suitable for nonlinear operations. In this paper we consider the model of optoelectronic printhead that combines advantages of both digital and optical systems. Each modulating element of this device, responsible for producing every separate pixel of the output image is involved in turn into the massive array of closed circuits that form a self-organizing structure.

Due to high parallelism of the architecture, the system admits executing of the massive sets of operations using relatively low-speed means for coordinative access.

In spite of analog nature of operations which are to be executed in the optical part, system possesses high accuracy due to self-learning mechanisms that work together with cost function estimators incorporated into the decision making subarea of system's architecture.

The most impressive results may be obtained in the interactive systems where the user is able to interfere into the image creating process being performed under his supervision. This gives additional contour to the decision making procedure, so that the user may decide when the image is ready to be printed.

Elementary Cell of the System

An adaptive artificial neural network (ANN) model lies in the basis of our approach to system's architecture. Regardless of the kind of recording medium (color film, paper, intermediate photoreceptor, etc) as well as the color coding and performance method (frame-sequential, multichannel, spatio-selective, or combined) each image forming element is involved into a ring neuron structure.

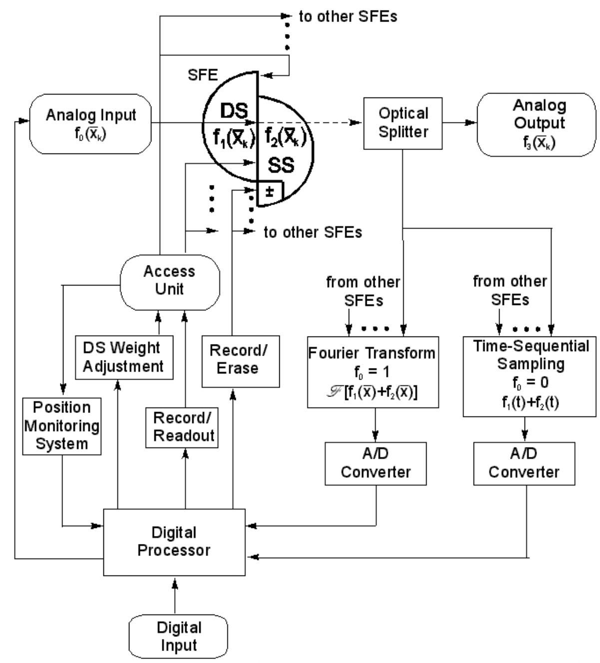

Figure 1. Sample forming element (SFE) embeded in the system structure

As shown on the Figure 1, the elementary (one-pixel) imaging system has two main components: optical and digital. In optical subsystem a sample forming element (SFE) is an elementary optical unit which contains information about intensity of the minimally distinguishable (by the system) point of output image. SFE in turn consists of two parts: storage section (SS) and driving section (DS).

The important problem in many image processing systems is the design of optimal filters for processing of raw image data. It is clear that such filters should be designed to extract information which is located both in spatial and frequency domain. DS models a synapse of neuron and serves as an element of matrix of weights in spatial domain. The weight is equal to the value of spatially sampled filtering function $f_1(\mathbf{x}_k)$ in the arbitrary point $(\mathbf{x}_k)$. All the weights are set as analog values but their levels are computed digitally.

The implementation of back-propagation technique provides stability of the system, current error compensation in spatiotemporal signals and, more importantly, executing of all necessary image processing algorithms.

There are two paths in the system structure by which digital processor derives the back-propagation data: through the Fourier transform module and time-sequential sampling module. We can obtain a spectral presentation of the entire image in its Fourier plane when homogeneous coherent input signal $f_0(\mathbf{x})=1$ is propagated via massive array of SFEs taking into account not only values $f_2(\mathbf{x}_k)$ stored in SS, but also their weights predicted by digital processor.

A common approach to the ANN design usually assumes creating several stages of information processing with multilayer neuron structure in each stage. In the system proposed we use a ring network architecture where each layer arises virtually, only during one (and each) image processing cycle. The cycle stability is supported by existence of two memories: digital (part of processor) and optical (SS). A mutual information exchange between them provides main information flow in the system, irrespective of the task to be solved.

In the absence of a separate channel for each spatial sampling point of LV, it is necessary to scan the SFEs time-sequentially. A line-by-line or lexicographic ordering is most commonly used, and the Access Unit shown in Figure 1 is an instrument that yields this action.

An attractive way to improve the system effectiveness is to unite two operations connected with the necessity of addressable access: SS data refreshment and DS weight adjustment. As an example, this can be done in practice either optically combining beams from separate laser sources of different wavelengths or by splitting a beam into two parts, separately modulating these new beams and then recombining them. Obviously, each SFE's section must interfere with its "own" beam. A special position monitoring system picks up the current coordinates of the SFE, the state of which is processed by the system at the moment.

What concerns the analog input, there is a parallel channel for it, and the SS is able to perceive all the input image points simultaneously.

Though the system meets the main requirements of the feedforward back-propagation neural networks theory, strictly speaking it can not be called a pure optical ANN. Nevertheless, supported by soft- and hardware it has quite a flexible structure, and is able to solve difficult image processing tasks, such as: image enhancement, restoration of images from partial data, filtering, color conversion and correction, color and halftone matching of the LV with arbitrary varying properties of the recording media.

The most elegant solution can be achieved when using recursive image processing algorithms. Being applied, they hold a great promise because of the multicycle ANN structure.

How it Works

Let us consider a generalized image restoration algorithm by the method of alternative orthogonal projections [1] in application to the goals discussed in this paper. This method is not new and has got its further development, but is worth discussing in this context to explain how the system works.

As it was proved[1] the reconstructing problem of some partially determined function f known *a priori* that its Fourier spectrum is bandlimited ($f \in P_b$, where P_b is a closed linear manifold (CLM) in a Hilbert space) is completely posed under certain conditions. We are given only the projection $g=P_a f$ on the known CLM P_a. The fundamental recursion

$$f^{n+1}=g+Q_a P_b f^n \; (n=1 \rightarrow \infty, f^1=g) \qquad (1)$$

leads to the proper solution. This recursion, where P_b and Q_a are orthogonal projection operators projecting onto P_b and $\perp P_a$ (orthogonal complement of P_a), respectively and n denotes the iteration number, allows constructing of the multi-step algorithm, according to which the system works.

A simplified version of the process looks as follows. The initial data $f^1=g=P_a f$ is set in the storage sections of SFE array either in parallel mode through analog input or using scanning conversion of the digital model of the image. On the next step, analog input signal is set as $f_0(x)=1$ and then being multiplied by $f_2^1(x)$ in SS, it gets Fourier-transformed. For $n \geq 1$ the signal spectrum is bandlimited to the interval $|\omega| \leq \omega_b$.

Important comment: the values of the boundary spatial frequencies are determined as the network gets trained. More complex tasks demand in turn the use of more sophisticated filtering techniques (order-statistics, morphological, stack filters, etc.).

According to (1) the resultant projection is projected subsequently onto $\perp P_a$, that is the set of all functions vanishing in known bounded interval. Furthermore, the state of all driving sections of the SFE array is set in accordance with driving coefficients computed at the previous step.

Sometimes the result obtained comes into contradiction with positivity condition of the filtering function $f_1(\mathbf{x})$. In this case either all the 2D working fields have to be normalized within the total system range or the record/erase input of the storage section has to be used.

The module assigned for time-sequential sampling controls the state of SFE at every moment of time. Its output gives us the values of the sum of two components of recursion (1), thus completing the last step of the cycle. Further system work is a repetition of the iteration steps described above.

Criterial estimations, task adjustments, consideration of color coding methods and physical limitations of the imaging device, system structural retuning during its training - all this lies within the sphere of the system software.

Physical Modeling

There were several types of "intellectual" light valves tested in the experimental setup as full-frame optoelectronic printheads. A typical experimental LV has a one-chip multilayer structure. Basically, it consists of two main parallel sections, namely: optically and electrically controlled storage section, and adjacent driving section that is controlled optically. SS is a combination of transparent electrodes, multilayer organic photoconductor and memory-type liquid crystal-polymer composite. As a DS, the differently sensibilized reversible recording media having photoinduced optical anisotropy properties were investigated.

Two linearly polarized scanning laser beams having different wavelengths λ_1=488 nm and λ_2=633 nm were focused within 6 micrometers in the DS-layer and photoconductor planes, respectively. Both beams were propagated through the same path. The difference was that the former passed the polarization rotator, and the intensity of the latter was modulated by acousto-optic modulator. Current position of the scanning beams was controlled by the 2D coordinate measuring system described in [2]. Laser beam λ_1 is assigned for the DS state setting, while λ_2 affects the storage section in three modes, namely: image capture, recording and erasing.

Ring and wedge detectors were used for Fourier transform acquisition and their zero order parts were applied for the time-sequential signal capturing. Accordingly, the higher order detector elements served for the crosstalk noise extraction and suppression. This noise appears because of a very close SFE placement in the array. LV spatially modulates both the coherent (used for the Fourier transform) and incoherent light flows (used for image output). The printhead design is determined to a considerable extent by the color coding scheme used. Use of the method of the successive color field replacement, which was tested, provides a great information capacity (more than 6000x4000 pixels in our experiment) but has a lower speed of information processing. The number of gray scale levels was determined in experimental setup by its bottleneck which was the driving section polarization decoding ability. The number achieved (several dozens) is obviously insufficient for high quality graphic arts applications. But the system showed a great level of adaptation to various classes of images and good adjustment to the different image processing tasks.

For example, being trained on the certain statistically defined class of color images, distorted by additive and context-dependent noise, system demonstrated much higher results than in case of digital image processing due to its internal heuristic mechanisms that partially use the image semantics. Self-learning mechanisms allow the system adaptation to the changes of recording media spectral sensivity, so that the raw output image feeds again, the analog system input retuning, thus, the structure in conformity with new conditions.

A new optoelectronic printhead integrated onto a single chip together with nonius type position monitoring system is now in progress. Trilevel driving section structure is assumed to increase a number of halftones up to a hundred in each color channel.

References

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Biography

Vladimir Bukatin graduated with honor from the Minsk Radioengineering Institute in 1971. In 1973 he started his research work in the field of high-performance laser displays as a Head of the Research Group at the Institute of Engineering Cybernetics , Belarus Academy of Sc. Since 1992 he has worked in the Three S , Ltd. , R&D Company specializing in digital printing instrumentation design for publishing industry and graphic arts . At present he is a Director of the Digital and Hybrid Imaging Department within the Terco Met, Ltd. Company, where he continues his studies connected with image aquisition , storage and recording . V. Bukatin is the author or co-author of over twenty papers and co-inventor of 10 patents in the field mentioned .