Neighbourhood as a speed-limiting factor in local image processing using optical interconnects

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Pixel oriented photonic parallel systems are attractive for image processing because the time complexity of their algorithms is independent of the number of pixels processed in the image. However, in the case of local image processing, where every pixel is processed as a function of the pixel values in the neighbourhood, the size of this neighbourhood determines the speed of the processing. When the size of the local neighbourhood increases the speed decreases in the same way both for parallel photonic and serial electronic implementations. In photonic systems the limited energy available for every pixel-emitter is responsible for this negative trend. In this paper we present simulation results and discuss consequences for photonic image processing.

1. Introduction

Since 1982 when the mathematical morphology was introduced a lot of effort has been made to apply it to electronic and photonic image processing [1]. Independently several other concepts based on local image processing were developed, such as *optical array logic* [2], *symbolic substitution* [3], *cellular automata* [4] and *cellular neural networks (CNN)* [5]. All these techniques can be implemented as software tools or as dedicated electronic and photonic image processors [6].

Local operations such as morphological erosion and dilation are usual parts of image processing software like *SCIL-Image* [7] provided by TNO Institute of Applied Physics in Delft, Netherlands and *Micromorph* [8] provided by the Centre for Mathematical Morphology in Paris, France. Taking into account the fast development of PC computers the software implementation of mathematical morphology is useful for real-time image processing and static image processing. However, these methods are too slow for high-speed processing necessary in industrial monitoring and large size image processing using large neighbourhoods. To fulfil the expectation of high-speed image processing the parallel processing systems have to be introduced. A few years ago, the Centre for Mathematical Morphology in Paris has designed a multiprocessor electronic chip for image analysis based on morphological operations [9]. The chip consists of 12 processors working in parallel, which enables the processing of five images with VGA resolution per second. However, ultra-fast image processing can be implemented only in parallel-cellular electronic or photonic systems, where every cell with its own processor corresponds to a single pixel.

2. Local image processor - experimental system

We previously described a dual-rail cellular morphological processor in the form of an array of differential pairs of optical thyristors (Fig. 1). It also performs a parallel thresholding of grey scale images [10-11].

Due to the specific requirements of the local image processor based on differential pairs of emitter-receiver devices we use *a dual-rail* description of local operations. In the system every pixel is represented by a pair of emitters and by a differential receiver.

We assume that when a pixel belongs to the object it takes a value "+1" ($u_{ij}^+=1, u_{ij}^-=0$) and when a pixel belongs to the background it takes a value "-1" ($u_{ij}^+=0, u_{ij}^-=1$) . The local operations using dual notation can be split into a positive and a negative part and written as

$$u_{ij}^+ = \sum_{k=-r}^{r}\sum_{l=-r}^{r} B^+_{k,l}\, x^+_{i+k,j+l} + I^+ \qquad u_{ij}^- = \sum_{k=-r}^{r}\sum_{l=-r}^{r} B^-_{k,l}\, x^-_{i+k,j+l} + I^- \tag{1}$$

$$y_{ij}^+ = \begin{cases} 1 & u_{ij}^+ - u_{ij}^- \geq 0 \\ 0 & u_{ij}^+ - u_{ij}^- < 0 \end{cases} \qquad y_{ij}^- = \begin{cases} 1 & u_{ij}^+ - u_{ij}^- < 0 \\ 0 & u_{ij}^+ - u_{ij}^- \geq 0 \end{cases}$$

where u_{ij} is the internal state of the pixel *(i,j)*, y_{ij} is the output signal of the pixel, x_{ij} is the input value of the pixel, , B is the structuring element, I is the bias value, and r is the radius of the local neighbourhood. All parameters indicated by '+' denote parameters of the left hand-side transceiver of a differential pair, that represent a logic value '1', while all parameters indicated by '–' denote parameters of the right hand-side transceiver, that represent a logic value '-1'. The value of bias signal depends on a size the structuring element. The structuring element and the bias value for nearest neighbourhood (r=1) erosion and dilation are written in the following way

$$\text{erosion: } B^+ = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix} \quad I^+ = 0 \quad B^- = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix} \quad I^- = 4 \tag{2}$$

$$\text{dilation: } B^+ = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix} \quad I^+ = 4 \quad B^- = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix} \quad I^- = 0$$

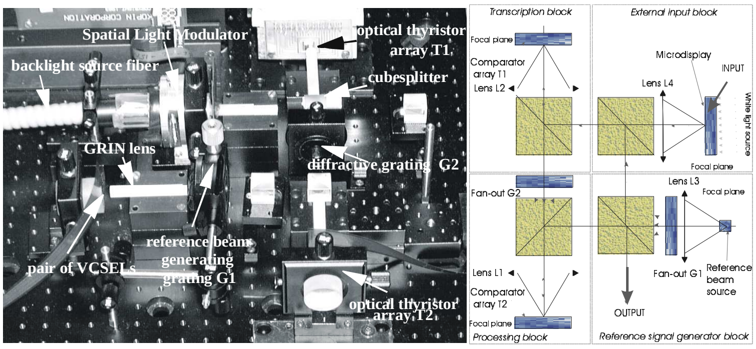

Fig. 1 Practical implementation and functional scheme of the morphological processor.

3. Speed assessment - simulation results

To show the advantages of parallel local image processing we compare speeds available in a few possible implementations of the dual-rail cellular morphological processor versus the available software.

Four versions of the proposed photonic system for morphology are as follows:

- Morph_1 - As Morph_1 we note the experimental system with the clock speed corresponding to 100 Hz, which was experimentally obtained for morphological operations [10].
- Morph_2 - As Morph_2 we note the experimental system with the clock rate of 40 kHz, which was obtained for transcription, but not for morphological operations.

The same speed can be available for morphological operations after improvement of the quality of diffractive fan-out elements.

- Morph_3 - As Morph_3 we note the future cellular photonic system with the clock rate of 50 MHz. Such a system may be realised using nowadays state of technology of optical thyristors [12] or other smart pixel systems.
- Morph_4 - As Morph_4 we note the future cellular photonic system with the clock rate of 1 GHz. Such a system could be built with smart pixels based on VCSELS and differential detectors [13]. This is an ultimate perspective for the development of cellular processors according to the present state of the art.

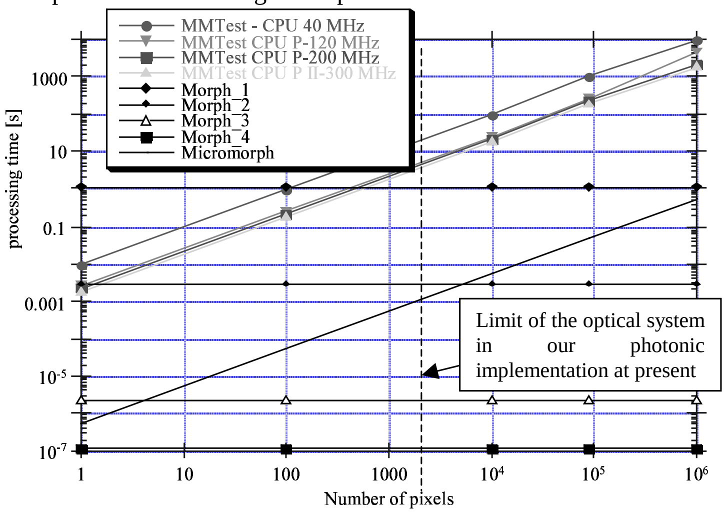

Figure 2 Processing times of dilation and erosion performed with 15x15 structuring element as a function of a number of pixels in an image.

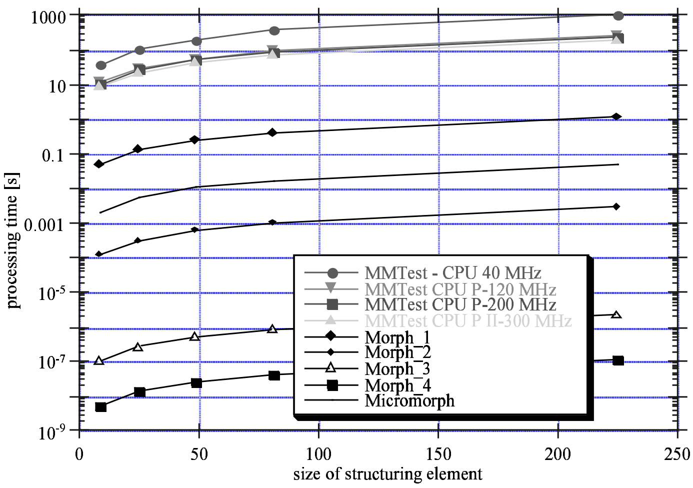

Figure 3 Processing times of dilation and erosion made on 300x300 pixels image as a function of a structuring element size.

Our program called *MMTest* estimates the time necessary to perform erosion and dilation operations using a PC computer. The program was tested on computers with four different CPUs. Data on the speed of morphological operations in the commercial software *Micromorph* are included.

Processing time necessary to calculate morphological erosion and dilation as a function of a number of processed image pixels for nine above mentioned morphology implementations and for structuring element of 15x15 is presented in Figure 2.

Figure 3 shows processing times necessary to calculate morphological erosion and dilation in an image composed of 300x300 pixels using structuring elements of various sizes from 3x3 to 15x15.

4. Conclusions

From the above we conclude that the pixel oriented parallel systems like *Morph* are attractive for image processing because their time of operation is independent of the number of processing pixels in an image. The demonstration platform we built begins to be competitive with respect to the commercial software *Micromorph* for images of more than 9000 pixels and clock rate of 40 kHz.

However it is important to noticed that the speed of the morphological operations decreases when the size of a structuring element increases both in case of photonic and software implementations (Fig. 3). In photonic systems the limited energy transfer between transcription and processing planes is responsible for this negative tendency.

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