Non-uniformity tolerance of diffractive optical interconnect elements for errorless local image processing

R. Buczynski [a], O. Morell Tormo [a], K. Bui Viet [a], M. Taghizadeh [b], T. Szoplik [c], I. Veretennicoff [a] and H. Thienpont [a]

[a] Vrije Universiteit Brussel, Dep. of Applied Physics and Photonics, Pleinlaan 2, B-1050, Brussels, Belgium, Tel: (32 2) 629 3567, Fax: (32 2) 629 3450, e-mail: rbuczyns@vub.ac.be
[b] Department of Physics, Heriot-Watt University, Edinburgh EH14-4AS, United Kingdom
[c] Warsaw University, Faculty of Physics, Pasteura 7, 02-093 Warsaw, Poland.

Local interconnects, established with diffractive optical elements (DOE), are a key function for parallel optoelectronic image processing such as mathematical morphology, rank-order filtering or cellular neural nets. In such systems, the diffractive interconnects define the neighbourhood which influences every pixel. The uniformity of DOEs has a considerable influence on the performance of these optoelectronic systems. We present results of simulations that indicate up to what extent intensity non-uniformity in fan-out elements can be tolerated for errorless local image processing. We compare it with the influence of input beam non-uniformity on local operations. Finally we show characteristics of fabricated DOEs.

1. Introduction

An important parameter, which decides upon the usefulness of photonic systems for local image processing, is its resistance to distortions of the signal. Small distortions appear in all important elements of the systems: inaccuracies of phase shifts introduced by does lead to non-uniform fan-out beams which define neighbourhoods and non-uniformities of receiver and emitter arrays which detects the input images and emit the output ones. These technological artefacts limit the performance of the processors. Photonic systems for local image processing use phase DOEs to generate local interconnects (structuring elements) [1-2]. Nowadays technology allows production of phase DOEs with a uniformity of 97-99 %. Therefore, it is important to check the photonic system resistance to small errors caused by DOEs and receiver/emitter arrays inaccuracies.

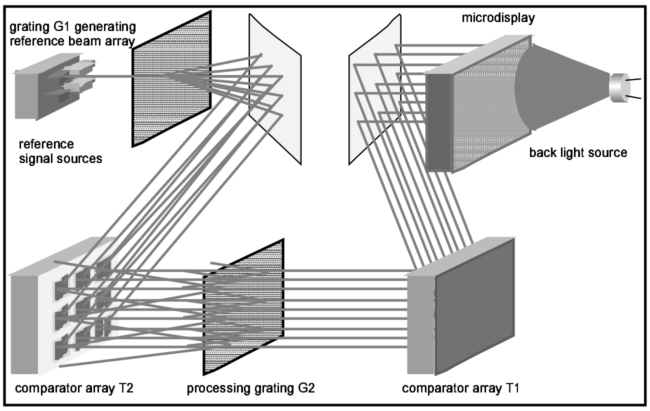

Figure 1 The functionality scheme of a photonic local image processor.

2. Photonic local image processor

In Fig. 1 we show where are the possible sources of errors which result from technological inaccuracies of passive and active devices used in a photonic processor. Non-uniformities of their detector matrix sensitivity and their emitter matrix output power influence performances of comparator arrays T1 and T2. Phase DOE G2 produces fun-out beams with unwanted non-uniform intensities.

3. A study of non-uniformity tolerance - a simulation

In this paper optical interconnects in the processor are analysed to assess the system resistance to signal distortions. In the fist step, we simulate the influence of non-uniformities of DOEs G2, which control local processing on output images. Non-uniformities have random values and localisations, therefore can be simulated by random noise. A noise with Gaussian distribution of intensity is randomly added to all special elements of the signal. A series of 100 000 simulations for every tested set of parameters is performed. Then results of output signals with and without noise are compared. Every difference between the output image values obtained with or without adding noise is consider an error. The simulations are realised for all possible neighbourhood patterns in proportion to their probability of appearance.

Figure 2 presents the influence of the fan-out beams (structuring element) non-uniformities on the output signal. Results are obtained for different sizes of structuring elements with 3, 5 and 9 neighbours. The *x-axis* represents the input error given in terms of standard deviation values, which are expressed as a percentage of the errorless intensity of input signal value, while the *y-axis* represents the number of erroneous pixels at the output image in percents.

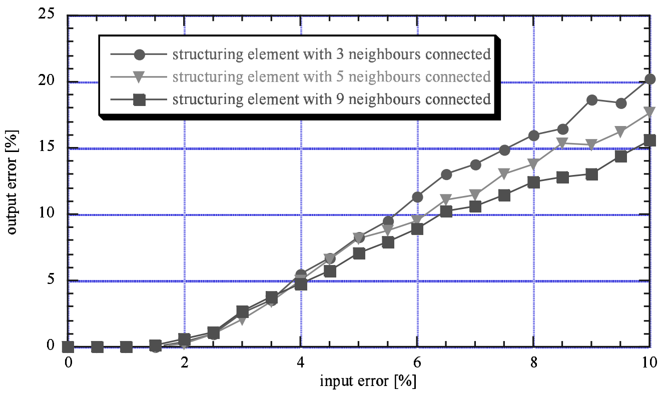

Figure 2 The influence of structuring element non-uniformities with 3, 5 and 9 connected neighbours on the output signal..

In the second step, we simulate the influence of non-uniformities of processing arrays T1 and T2 on output images. Similarly as above, non-uniformities have random values and localisations and can be simulated by random noise. Again a noise with Gaussian distribution of intensity is randomly added to all special elements of the signal. A series of 100 000 simulations for every tested set of parameters is performed. Then results of output signals with and without noise are compared.

Figure 3 presents the influence of the processing arrays T1 and T2 non-uniformities on the output signal. Results are obtained for different sizes of structuring elements with 3, 5 and 9 neighbours. The *x* and *y* axes in Fig. 3 have the same meaning as in the previous one.

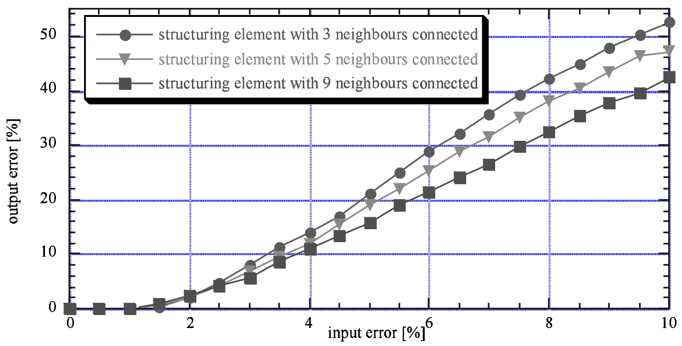

Figure 3 The influence of input image non-uniformities on the output signal in the presence of structuring elements with 3, 5 and 9 connected neighbours

4. Measurement of fan-out beams non-uniformity

To explain our interest in consequences of technological non-uniformities in DOEs we show the measurements of intensity distribution in fan-out beams for the 1:81 example (see Fig. 4). The analysed DOE was used in our local image processor [2]. The intensity values measured in diffracted beams and expressed in the average intensity value are shown in Table 1.

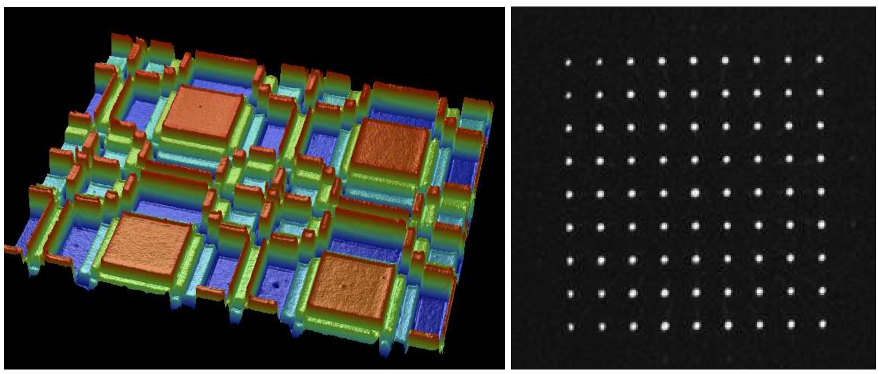

Figure 4 3D profiles of DOE with a 1x81fan-out (on the left) and its output intensity distribution.

	-4	-3	-2	-1	0	+1	+2	+3	+4
+4	0,72	0,76	0,64	1,04	0,72	1,01	0,68	0,64	0,75
+3	0,74	0,57	0,87	0,80	0,86	0,81	0,86	0,56	0,88
+2	0,64	0,85	0,85	0,67	0,86	0,65	0,74	0,85	0,72
+1	1,03	0,76	0,68	0,63	0,82	0,65	0,60	0,81	0,87
0	0,70	0,87	0,87	0,81	1,84	0,62	0,82	0,75	0,81
-1	0,99	0,79	0,63	0,62	0,61	0,62	0,56	0,85	0,83
-2	0,67	0,86	0,75	0,60	0,85	0,58	0,66	0,87	0,73
-3	0,63	0,57	0,86	0,85	0,75	0,87	0,85	0,55	0,49
-4	0,74	0,61	0,70	0,89	0,79	0,85	0,72	0,48	0,77

	-4	-3	-2	-1	0	+1	+2	+3	+4
+4	0,70	0,74	0,62	1,01	0,70	0,98	0,66	0,62	0,73
+3	0,72	0,56	0,84	0,77	0,83	0,78	0,83	0,55	0,86
+2	0,62	0,82	0,82	0,65	0,84	0,63	0,72	0,82	0,70
+1	1,00	0,74	0,66	0,61	0,79	0,63	0,58	0,79	0,85
0	0,68	0,84	0,84	0,79	1,78	0,60	0,79	0,73	0,78
-1	0,96	0,77	0,61	0,60	0,59	0,60	0,55	0,82	0,80
-2	0,65	0,83	0,73	0,58	0,82	0,57	0,64	0,84	0,71
-3	0,61	0,55	0,84	0,82	0,73	0,84	0,82	0,53	0,48
-4	0,72	0,59	0,68	0,87	0,76	0,82	0,70	0,47	0,75

Table 1. Experimental diffraction efficiency in percentage (on the left) and power distribution normalized to average value (on the right) for DOE with a 1x81 fan-out.

5. Conclusions

We find that the most important error sources in photonic local image processing are the non-uniform output intensity of processing arrays and then the non-uniformity of light distribution introduced by the diffractive elements.

From the simulations we know that the influence on the output image of the same error located in the input image and the structuring element is different. In the case of a structuring element formed by a DOE, the same error causes a lower number of errors in the output image than in the case of processing arrays T1 and T2. It is because in the processing arrays both *zeros* and *ones* are represented by distorted values of light intensity in the dual rail logic, while in the structuring elements they represent only distorted *positive* values of interconnection with 3, 5 and 9 neighbours.

Another interesting conclusion is that when the size of the neighbourhood increases the importance of the same error located in the input image or in the structuring element decreases. It results from averaging of a higher number of distorted signals in a larger neighbourhood.

In local processing, structuring element distortions up to 2% of its size, have practically no influence on the output signal. The input signal intensity distortions less than 1.5%, introduced by the processing arrays T1 and T2, does not influence the system performance.

References

[1] R. Buczynski *et al.*, “Realization of mathematical morphology operations with an optoelectronic demonstrator system for early image processing”, *Proc. of the OSA Technical Digest*, Aspen, Colo., USA, 1999, pp. 78-82.

[2] R. Buczynski *et al.*, “Fast optical thresholding with an array of optoelectronic transceiver elements”, *IEEE Phot. Techn. Lett.,* vol.11, no.3, 1999,. pp. 367-369.