# Optimal Thresholds Selection for Adaptive Image Interpolation

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*Abstract* - **An analysis of local characteristics of images in 2x2 areas is presented. On this base the optimal selection of thresholds for dividing into homogeneous and contour blocks is made and interpolation order is changed with zero or bi-linear. Experimental results suggest that the effective use of local information contribute to decreasing of the mean-square error.**

*Keywords* - **digital signal processing, 2D image interpolation, local adaptation, image processing.**

## I. Introduction

The basic methods for 2D interpolation of halftone images are divided into adaptive and non-adaptive [1], [2], [3]. Sharpness of edges and freedom from artifacts are two critical factors in the perceived quality of the interpolated images. Ease of computation is also an important factor. It has recently been recognized that improved image quality may be obtained by taking edge information into account [4], [5], [6]. In these works, edge information is used to modify the interpolation scheme so that smoothing is not performed across an edge, but at the expense of high calculation complexity.

In this paper analysis of local characteristics of the images in small regions is accomplished using distribution of differences of adjacent elements in vertical and horizontal directions. On this base the optimal selection of thresholds for dividing into homogeneous and contour blocks is made and interpolation order is changed with zero or bi-linear for the developed adaptive 2D interpolation filter [7], [8]. The analysis of mean-square errors and signal to noise ratios for some test images show that the effective use of local information contributes to decreasing of interpolation errors.

## II. Mathematical Description

The input m-level halftone image of size *M* x *N* and the output interpolated image of size *pM* x *qN* can be represented by the matrices:

$$\mathbf{A}_{MxN} = \{\mathbf{a}(\mathrm{i,j}) \;/\; \mathrm{i} = \overline{0, M-1};\; \mathrm{j} = \overline{0, N-1}\},$$
$$\mathbf{A}^{*}_{pMxqN} = \{\mathbf{a}^{*}(\mathrm{k,l}) \;/\; \mathrm{k} = \overline{0, pM-1};\; \mathrm{l} = \overline{0, qN-1}\}, \qquad (1)$$

where *p* and *q* are the interpolation coefficients in horizontal and vertical direction respectively [7], [8].

The differences between each neighborhood pixels are given by the equations:

$$\Delta_{2m+1} = \left|a(i+m, j) - a(i+m, j+1)\right|, \text{ for } m = 0,1;$$
$$\Delta_{2n+2} = \left|a(i, j+n) - a(i+1, j+n)\right|, \text{ for } n = 0,1. \qquad (2)$$

The logical variables $f_1$, $f_2$, $f_3$ and $f_4$ depend from the differences by the thresholds in horizontal ($\theta_m$) and vertical ($\theta_n$) directions and are shown in Eq. (3).

$$f_{2m+1} = \begin{cases} 1,\ if: \Delta_{2m+1} \geq \theta_m \\ 0,\ if: \Delta_{2m+1} < \theta_m \end{cases};\quad f_{2n+2} = \begin{cases} 1,\ if: \Delta_{2n+1} \geq \theta_n \\ 0,\ if: \Delta_{2n+1} < \theta_n \end{cases}. \qquad (3)$$

Then each interpolated pixel can be presented as linear convolution of 4 basic neighborhood elements:

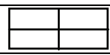
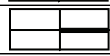
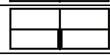
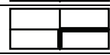
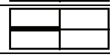
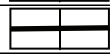
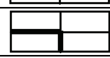
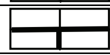
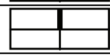
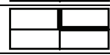
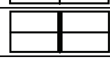
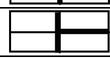
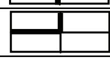
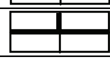
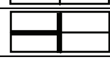
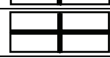
$$a^{*}(k,l) = \sum_{m=0}^{1}\sum_{n=0}^{1} w_{m,n}(r,t)\,a(i+m, j+n), \qquad (4)$$

for $r = \overline{0,p}$ ; $t = \overline{0,q}$ . Interpolation coefficients:

$$w_{m,n}(r,t) = F.Zr_{m,n}(r,t) + \overline{F}.Bl_{m,n}(r,t), \qquad (5)$$

are dependent from the logical function F, which gives the type of the interpolation (zero or bi-linear): $F = f_1 f_3 \cup f_2 f_4$. The zero or bilinear interpolation coefficients are defined by the equations, given in works [7] and [8]. The dependence of functions F from the coefficients $f_1$ - $f_4$ is shown on Table I.

Table I

| No. | $f_1$ | $f_2$ | $f_3$ | $f_4$ | F | Transitions |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |  |
| 1 | 0 | 0 | 0 | 1 | 0 |  |
| 2 | 0 | 0 | 1 | 0 | 0 |  |
| 3 | 0 | 0 | 1 | 1 | 0 |  |
| 4 | 0 | 1 | 0 | 0 | 0 |  |
| 5 | 0 | 1 | 0 | 1 | 1 |  |
| 6 | 0 | 1 | 1 | 0 | 0 |  |
| 7 | 0 | 1 | 1 | 1 | 1 |  |
| 8 | 1 | 0 | 0 | 0 | 0 |  |
| 9 | 1 | 0 | 0 | 1 | 0 |  |
| A | 1 | 0 | 1 | 0 | 1 |  |
| B | 1 | 0 | 1 | 1 | 1 |  |
| C | 1 | 1 | 0 | 0 | 0 |  |
| D | 1 | 1 | 0 | 1 | 1 |  |
| E | 1 | 1 | 1 | 0 | 1 |  |
| F | 1 | 1 | 1 | 1 | 1 |  |

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The analysis of the local characteristics of neighborhood image elements is accomplished for small image regions with size 2x2 on the base of distribution of difference in vertical and horizontal directions. On Fig.1 the distribution of differences in vertical and horizontal directions for the test image Lenna.bmp are shown.

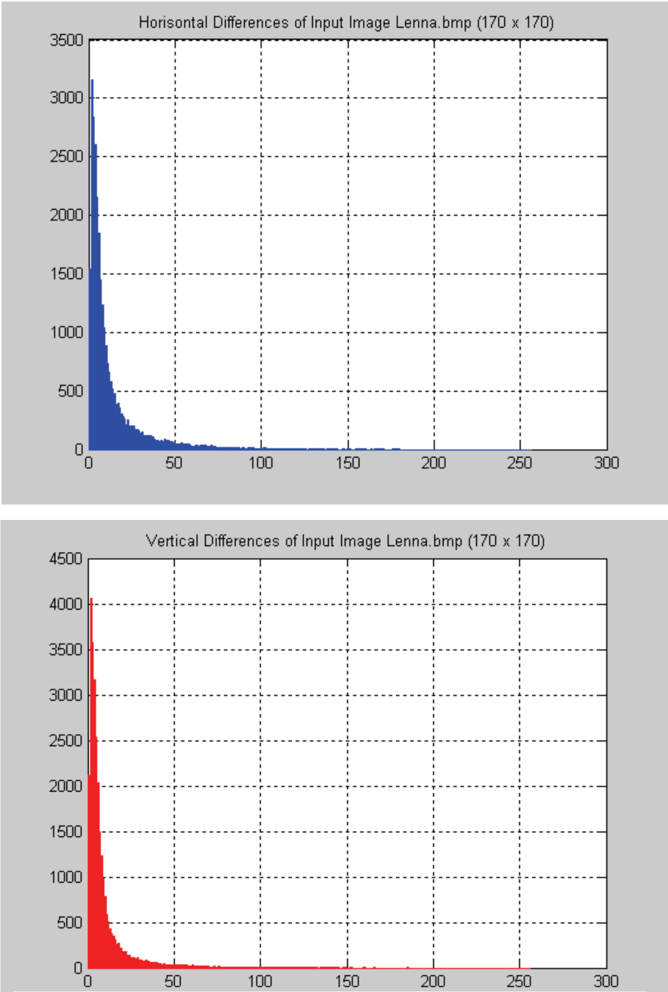


Fig.1. Difference histograms

The choice of thresholds ($\theta_m$) and ($\theta_n$) are proceed on level 0.2% from the maximum of histogram functions. This is shown on Fig. 2, where the histogram is amplified and with red line this level is denoted.

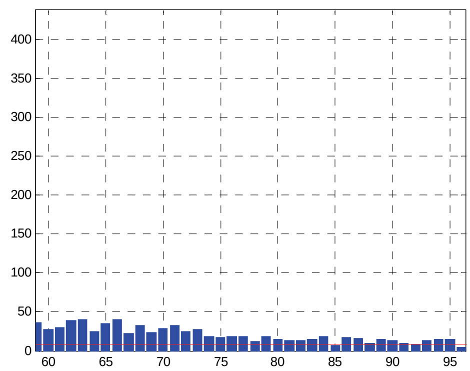


Fig.2. Choice of thresholds

This level is calculated experimentally and indicates the linear sector of histogram. The choice of optimal threshold is proceed in the beginning of the linearity sector. From the Fig.2 this are the levels 78 to 81.

## III. Experimental Results

For the analyses of interpolation distortions the mean-square error (MSE), normalized mean-square error (NMSE in %), signal to noise ratio (SNR in dB) and peak signal to noise ratio (PSNR in dB) can be used as a criterion. On Fig.3 are shown 5 test standardized images: „Lenna", "Baboon", "Cameraman", "Peppers", "Boat", with the size 512x512 and 256 gray levels.

Fig.3. Test images „Lenna", "Baboon", "Cameraman", "Peppers", "Boat" with size 512x512, 256 gray levels

The analyses of quality of the interpolated images are made by simulation with MATLAB 6.5 mathematical package. The obtained results for each test image is summarized on Tabl.2, including calculated threshold value, number of homogenous and contour blocks, MSE, NMSE, SNR and PSNR for interpolation with coefficient of amplification 3. On Fig. 4 distributions of PSNR in dB for each test images are given.

## IV. Conclusion

On the base of performed experiments for 2D adaptive interpolation on halftone images the following conclusions can be made:

- the use of optimal thresholds for selection of homogenous and contour blocks lead to decreasing of

TABLE II

| Image | Lenna | Babboon | Cameraman | Peppers | Boat |
|---|---|---|---|---|---|
| $\theta_{m=}\theta_n$ | 81 | 33 | 96 | 7 | 141 |
| Homogenous blocks | 28361 | 23697 | 28012 | 17748 | 28554 |
| Contour blocks | 200 | 4864 | 549 | 10813 | 7 |
| MSE | 47.72229 | 9.74984 | 58.82865 | 31.04577 | 56.84090 |
| NMSE | 6.19091e-006 | 1.19110e-006 | 8.20160e-006 | 4.21125e-006 | 5.95112e-006 |
| SNR | 52.08245 | 59.24053 | 50.86101 | 53.75589 | 52.25401 |
| PSNR | 31.37759 | 38.27483 | 30.46891 | 33.24478 | 30.61819 |

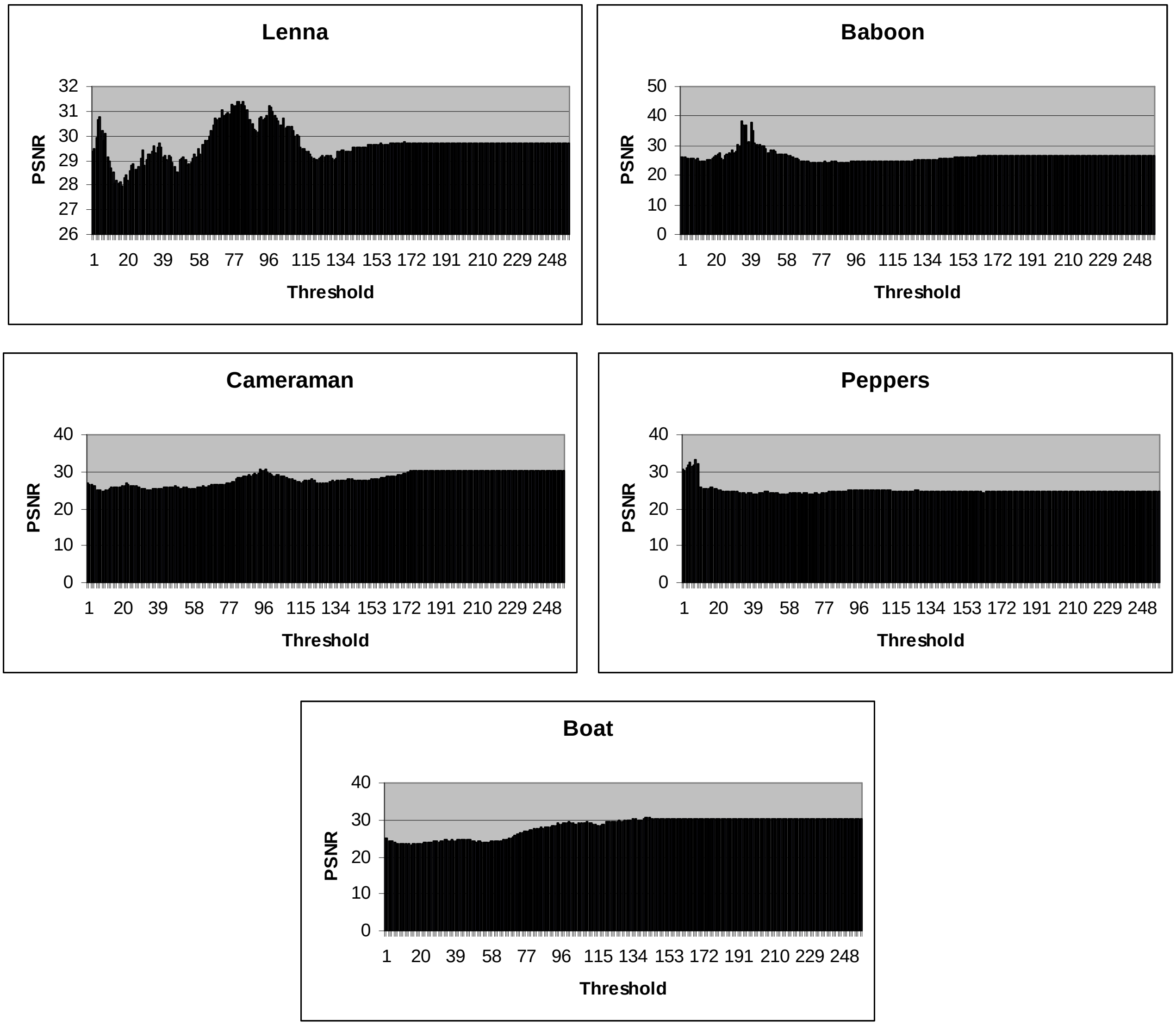


Fig.4. Distribution of PSNR for images „Lenna", "Baboon", "Cameraman", "Peppers" and "Boat"

mean-square error, normalized mean-square error and increasing of signal to noise ratio and peak signal to noise ratio with about 7-10%;

- the complexity of adaptive interpolation is higher than zero and bilinear but is lower than other high-level interpolations;
- using smaller area for analysis and choice of optimal thresholds for image separation lead to decrease of calculation speed;
- the maximal effective interpolation for the local characteristic of images can be achieved by using coefficients p,q=2-4.

The received results for quality of interpolated images show that the proposed method for adaptive interpolation can change the high-level interpolations, which are slower in systems, using digital image processing and visualization as: digital photography, videoconference systems, security systems and etc.


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## REFERENCES


[1] P. Stucki. *Advances in Digital Image Processing*. N. J. Plenum Press, 1979.

[2] R. Crochiere, L. Rabiner. Interpolation and Decimation of Digital Signals - A Tutorial Review", *Proc. of IEEE*, Vol. 69, No. 3, March 1981.

[3] T. C. Chen, R. P de Figueiredo. "Image Decimation and Interpolation Techniques Based on Frequency Domain Analysis", *IEEE Trans. on Communications*, vol. COM-32, No.4, April, 1984.

[4] Y. Wong, S. K. Mitra. "Edge Preserved Image Zooming", *Signal Processing IV:Theories and Applications*, EURASIP, 1988.

[5] S. Carrato, G. Ramponi, St. Marsi. “A Simple Edge-Sensitive Image Interpolation Filter”, *Proc. ICIP’96*, 1996.

[6] J. Allebach, P. W. Wong. “Edge-Directed Interpolation”, *Proc. ICIP’96*, 1996.

[7] R. Kountchev, R. Mironov. “Analysis of Distortions for Adaptive 2D Interpolation of Halftone Images", *XXV Science Session "Day of Radio'90"*, Sofia, Bulgaria, 7-8 may, 1990.

[8] R. Mironov. “Error Estimation of Adaptive 2D Interpolation of Images”, *XL International Scientific Conference on Information, Communication and Energy Systems and Technologies*, ICEST 2005, Niš, Serbia and Montenegro, June 29 –Jily 1, 2005