Communications to SIMAI Congress,
ISSN 1827-9015, Vol. 1 (2006)
DOI: 10.1685/CSC06136

ENO/WENO Interpolation methods for the ZOOMING of digital images

R. M. PIDATELLA, F. STANCO, C. SANTAERA
Dipartimento di Matematica ed Informatica - Università di Catania
Viale A. Doria 6 - 95125 Catania, Italy

INTRODUCTION

In this paper we address the problem of producing an enlarged picture from a given digital image (zooming). This problem arises frequently whenever an user wishes to zoom in to get a better view of a given picture. There are several issues to take into account about zooming: unavoidable smoothing effects, reconstruction of high frequencies details without the introduction of artifacts and computational efficiency both in time and in memory requirements.

As input, a generic zooming algorithm takes a RGB picture and, as output, provides a picture of double size preserving as much as possible the information content of the original image. For a large class of zooming techniques, this is achieved by mean of some kind of interpolation: replication, bilinear and bicubic are the most popular choices and they are routinely implemented in commercial digital image processing software.

In this paper, we use interpolation methods like ENO [1] and WENO [1, 2, 3, 4, 5] techniques, generally used to solve hyperbolic PDEs, for the zooming process of digital images. The key idea lies at the approximation level, where a nonlinear adaptive procedure is used to automatically choose the locally smoothest stencil, hence avoiding crossing discontinuities in the interpolation procedure as much as possible. The algorithms work on monochromatic images, but they are easily adapted to zoom RGB color pictures.

Our experiments show that the proposed methods beat in quality pixel replication, bilinear and bicubic interpolation, and LAZA (Locally Adaptive Zooming Algorithm) [6]. Moreover our algorithm is competitive both for quality and efficiency with the other traditional techniques of zooming.

1. THE BASIC ALGORITHM

In this section, we give a description of proposed algorithm in the case of gray scale picture.
The first step expands the source $n \times n$ pixels image into a regular grid of size $(2n - 1) \times (2n - 1)$ (see Fig. 1). More precisely, if $S(i,j)$ denotes the pixel in the i-th row and j-th column of the source image,

and *Z(l,k)* denotes the pixel in the l-th row and k-th column in the zoomed picture, the expansion is described as a mapping $E:S \rightarrow Z$ according to the equation:

$$E(S(i,j))=Z(2i-1,2j-1)$$

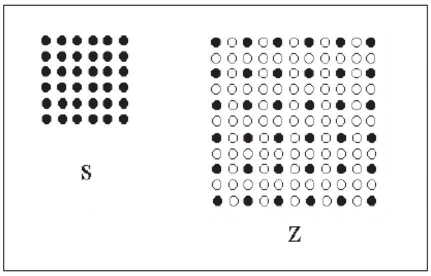


Fig 1: *The first step of zooming (expansion)*

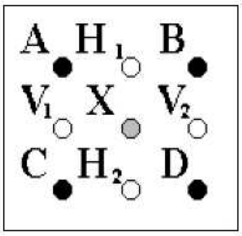


Fig. 2: Pixels' Labels

Fig. 3: *Description of the algorithm*

The mapping E leaves undefined the value of all the pixels in Z with at least one even coordinate (white dots in Fig. 1).

In the second step, we apply the selected ENO or WENO technique, to the rows of odd index in Z, to compute the value of all pixels (i.e. $\boldsymbol{H}_1$ and $\boldsymbol{H}_2$ in Fig. 2).

Then we apply the same technique, to all the columns in Z, to compute the value of all pixels (i.e. $\boldsymbol{V}_1$, $\boldsymbol{X}$ and $\boldsymbol{V}_2$ in Fig. 2).

2. ZOOMING COLOR PICTURES

The basic algorithm described above for gray scale pictures can be easily generalized to the case of RGB color images. In this case, we take advantage of the higher sensitivity of human visual system to luminance variations in comparison with the sensitivity to crominance values. Hence, we allocate higher computational resources to zoom luminance values, while crominance values may be processed with a simpler and more economical approach. Accordingly, we propose to operate as follows:

- Translate the original RGB picture I into the YUV color model.
- Zoom the luminance values Y according with the basic algorithm described in section 1.
- Zoom the U and V values using just a simple pixel replication algorithm.
- Back translate the zoomed picture into a RGB image.

The results obtained with this basic approach are qualitatively comparable with the results obtained using bicubic interpolation over the three color channels.

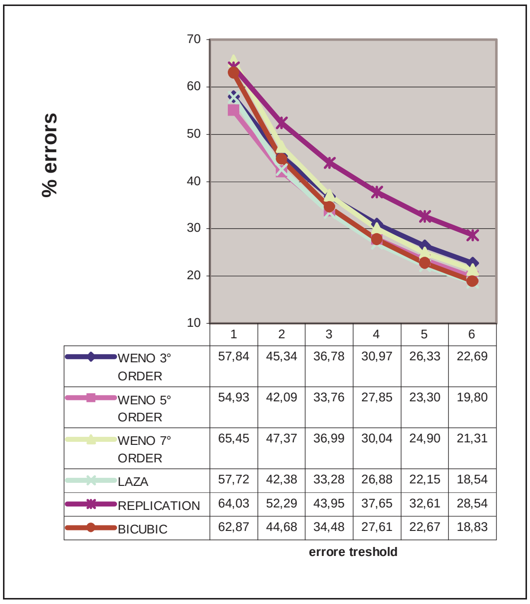
3. EXPERIMENTAL RESULTS

In our experimental context, we have first collected a test pool of 100 gray scale pictures. For each image *I* in this set we have performed the following operations:

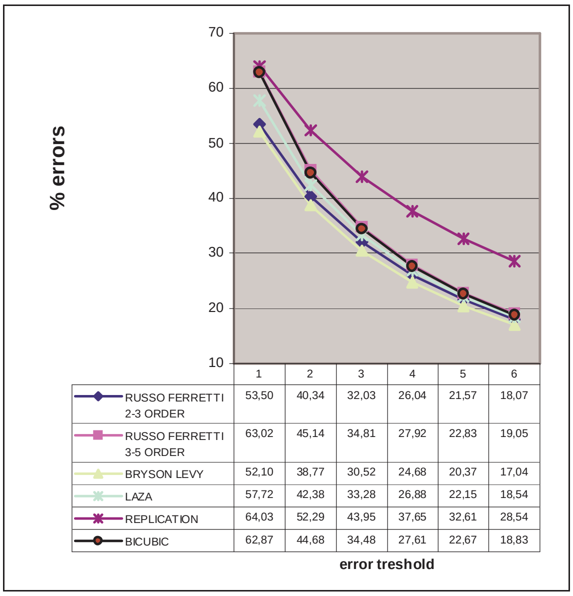
- reduction by decimation: a new picture I_d of half size of *I* is obtained taking only the pixels with both odd coordinates of the original picture;
- starting from I_d, we have obtained the zoomed image;
- calculation of the following quantitative measurements between the original picture and the reconstructed picture: PSNR, cross correlation coefficient and error threshold;
- calculation of the cpu-time;
- qualitative evaluation of the zoomed image.

	CPU-TIME	CROSS-CORRELATION COEFFICIENT	PSNR
ENO 2° ORDER	**5,23**	**0,9858**	**29,42**
ENO 3° ORDER	**15,72**	**0,9847**	**29,06**
ENO 4° ORDER	**34,38**	**0,9826**	**28,44**
ENO 5° ORDER	**71,58**	**0,9852**	**23,35**
ENO3-INCROCI	**15,18**	**0,9898**	**30,83**
LAZA	**12,75**	**0,9946**	**33,58**
REPLICATION	**0,07**	**0,9854**	**29,32**
SPLINE	**0,93**	**0,9952**	**34,27**
BILINEAR	**0,43**	**0,9950**	**33,95**
BICUBIC	**1,05**	**0,9953**	**34,36**

	CROSS-CORRELATION COEFFICIENT	CPU-TIME	PSNR
WENO 3° ORDER	**0,9902**	**1,08**	**30,94**
WENO 5° ORDER	**0,9924**	**1,50**	**32,11**
WENO 7° ORDER	**0,9936**	**1,86**	**32,73**
WENO7-2D	**0,9946**	**2,10**	**33,47**
OWENO1-2D	**0,9947**	**2,14**	**33,58**
RUSSO FERRETTI 2°-3° ORDER	**0,9953**	**1,56**	**34,06**
RUSSO FERRETTI 3°-5° ORDER	**0,9957**	**1,95**	**34,34**
BRYSON LEVY	**0,9956**	**1,46**	**34,33**
LAZA	**0,9950**	**12,99**	**33,58**
REPLICATION	**0,9871**	**0,05**	**29,32**
SPLINE	**0,9955**	**0,75**	**34,27**
BILINEAR	**0,9953**	**0,42**	**33,95**
BICUBIC	**0,9957**	**1,01**	**34,36**



	1	2	3	4	5	6
WENO 3° ORDER	57,84	45,34	36,78	30,97	26,33	22,69
WENO 5° ORDER	54,93	42,09	33,76	27,85	23,30	19,80
WENO 7° ORDER	65,45	47,37	36,99	30,04	24,90	21,31
LAZA	57,72	42,38	33,28	26,88	22,15	18,54
REPLICATION	64,03	52,29	43,95	37,65	32,61	28,54
BICUBIC	62,87	44,68	34,48	27,61	22,67	18,83



	1	2	3	4	5	6
RUSSO FERRETTI 2-3 ORDER	53,50	40,34	32,03	26,04	21,57	18,07
RUSSO FERRETTI 3-5 ORDER	63,02	45,14	34,81	27,92	22,83	19,05
BRYSON LEVY	52,10	38,77	30,52	24,68	20,37	17,04
LAZA	57,72	42,38	33,28	26,88	22,15	18,54
REPLICATION	64,03	52,29	43,95	37,65	32,61	28,54
BICUBIC	62,87	44,68	34,48	27,61	22,67	18,83

(a) (b) (c)

Fig. 4: *Examples of zoomed pictures with the Bryson-Levy (b) and Russo-Ferretti (c) based methods.*

4. CONCLUSIONS

In this paper a new technique for zooming a digital picture has been proposed. It is based on the ENO and WENO interpolation techniques. We have obtained competitive results using the RUSSO-FERRETTI [4] and BRYSON-LEVY [3] version of them.

REFERENCES

[1] Chi-Wang Shu, *Essentially Non-Oscillatory and Weighted Essentially Non-Oscillatory Schemes for Hyperbolic Conservation Laws*, in *Advanced Numerical Approximation of Nonlinear Hyperbolic Equations*, edited by B. Cockburn, C. Johnson, C.-W. Shu, and E. Tadmor, Lect. Notes in Math. (Springer-Verlag, Berlin/New York, 1998), Vol. 1697, p. 325.

[2] Z. J. Wang, R. F. Chen, *OWENO Schemes for Linear Waves with Discontinuity* , Journal of Computational Physics 174 (2001), pp. 381–404.

[3] Steve Bryson, Doron Levy, *High-Order Central Weno Schemes for multidimensional Hamilton-Jacobi equations*, SIAM J. NUMER. ANAL. Vol. 41, No. 4 (2003), pp. 1339–1369.

[4] E. Carlini, R. Ferretti, G. Russo, *A Weighted Essentially Non-oscillatory, large time-step schem for Hamilton–Jacobi Equations*, SISC, Vol. 27 Issue 3 (2005), pp. 1071-1091.

[5] Andrew K. Henrick, Tariq D. Aslam, Joseph M. Powers, *Mapped weighted essentially non-oscillatory schemes*: *Achieving optimal order*, Journal of Computational Physics 207 (2005), pp. 542–567.

[6] S. Battiato, G. Gallo, F. Stanco, *A locally adaptive zooming algorithm for digital images*, Image and Vision Computing 20 (2002), pp. 805–812.