POCS BASED ADAPTIVE IMAGE MAGNIFICATION

Krishna Ratakonda and Narendra Ahuja *

Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801
{ratakond,n-ahuja}@uiuc.edu

Abstract

In this paper we tackle the problem of magnifying an image without incurring blurring, ringing or other artifacts common to classical schemes. The proposed iterative scheme starts with an initial magnified image generated by a process of selective interpolation. By placing suitable constraints on the final magnified image, which are convex in nature, we show that magnification can be posed as a problem of finding a solution which lies at the intersection of convex sets. By avoiding explicit high frequency enhancing assumptions in the iterative process, we avoid edge enhancement artifacts in the magnified image.

1 Introduction

Resolution enhancement involves the problem of magnifying a small image to several times its size while avoiding blurring, ringing or other artifacts. Classical methods include bilinear, bi-cubic or FIR interpolation schemes followed by a sharpening method like unsharp masking [1]. Such interpolation schemes tend to blur the images when applied indiscriminately. Unsharp masking, which involves subtracting a properly scaled Laplacian of the image from itself, produces artifacts and increases noise.

More sophisticated schemes involving wavelet or fractal based techniques have also been proposed [2, 3, 4]. Such methods perform extrapolation of the signal in either the wavelet or fractal domain, which lead to objectionable artifacts when the assumptions behind such extrapolation are violated. It may also be noted that such extrapolatory assumptions predict and actively enhance the high frequency content within the image thus increasing any noise present in the unmagnified image. Methods which selectively interpolate accross edges have been previously proposed in [5, 6]. Such methods might promote false edges, especially at high magnifications, since the positions of the edges in the magnified image are imprecise and the algorithms make one-step decisions as to the course of action in edge-areas of the image. The proposed method starts with an initial magnified image obtained through selective interpolation in edge areas followed by an iterative procedure which aims to avoid edge related artifacts while retaining and enhancing sharpness.

The initial image in the iterative process is a composite image formed from a base interpolation scheme[1] in the smooth areas of the image and from a selective interpolation mechanism in the non-smooth (or edge) areas. The proposed iterative algorithm aims to find a magnified image satisfying two constraints: one of the constraints is derived from sampling theory while the other constraint reflects the confidence that we place on the initial iterate. Both the constraints are convex sets; thus we seek a solution which is at the intersection of these two convex sets and

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[1] we use bilinear interpolation as the base interpolation scheme in this paper.

can be obtained using the Projection on Convex Sets (POCS) method. Starting with the initial iterate, we project alternately on the two constraints. Convergence is guaranteed since we operate within the POCS formalism.

2 Magnification Scheme

Our magnification scheme consists of three steps: (a) obtain the edge locations, (b) obtain the initial image and (c) use an iterative algorithm to construct the magnified image.

2.1 Finding edges

Edge locations are found using a multi-scale segmentation algorithm reported in [7]; the segmentation scheme results in a partition of the image into connected regions whose grey level homogeniety is controlled by the scale at which the segmentation is performed. Thus each pixel in the image is a part of a unique region at a given scale; the edge pixels are the pixels at the edges of each region. Note that we have access only to the unmagnified image but need the location of the edges in the magnified image. [5] first finds the edges in the unmagnified image and then finds their approximate location in the magnified image by interpolating the edge positions. It is to be noted that in the process of interpolating edge locations there is no involvement of the intensity profile accross the edge. This process infact results in significant staircase artifacts. We found that interpolating the image (using bilinear interpolation) first and then finding the edge locations in the magnified image yields lesser artifacts in general. In the results presented in this paper we use the latter approach.

It is also possible to combine the above two approaches to finding edge locations in an iterative scheme by selecting a suitable cost function to be minimized. However, the process of optimization is inherently non-linear and the amount of gain is doubtful.

2.2 Initial image

As explained in the previous section, the initial image is obtained using the bilinear interpolation scheme in the smooth (or non-edge) areas of the image and a selective interpolation mechanism in the non-smooth (or edge) areas. Since the algorithm in [7], used for finding the edge locations, gives connected regions as its output, we know which neighbors of a given edge pixel belong to the same region as itself. The image value at each edge location is found by averaging over the nearest 8-pixel neighborhood with appropriate weighting corresponding to distance (a weight of $1/\sqrt{2}$ is assigned to pixels along the diagonal and a weight of 1 is assigned to other pixels). A weight of zero is given to pixels which do not belong to the same region as the edge pixel.

We note that the initial image could have been obtained from a more sophisticated interpolation algorithm rather than bilinear interpolation. For example, Sheppard's method yields slight improvement in sharpness at the expense of stipple artifacts.

2.3 Iterative Algorithm

The reconstruction algorithm is based on the POCS formalism [8]. The solution (reconstructed image) lies at the intersection of the following convex sets:

1. Sampling theory suggests that the unmagnified image can be viewed as being obtained from the magnified image by sub-sampling without aliasing. In other words, the DFT of the unmagnified image will be the same as the low frequency portion of the DFT of the magnified image[2]. Thus the first constraint is: low frequency coefficients of the DFT of the magnified image are constrained to be the same as those obtained by taking the DFT of the unmagnified image.

2. The values in the non-edge locations are constrained to vary within limits $(+\delta_1,-\delta_1)$ from their initial value and the values in the edge locations are constrained to vary within limits $(+\delta_2,-\delta_2)$ from their inital value. The parameters δ_1 and δ_2 are chosen to be constant for the entire image and represent the amount of confidence that we place in the

[2] For 4X magnification the DFT of the unmagnified image gives us $(1/16)th$ of the DFT coefficients of the magnified image.

different interpolation mechanisms used in forming the initial image.

Both the convex sets, as defined above, have particularly simple projection operators which can be found in literature [8]. The choice of the parameters δ_1 and δ_2 plays a crucial role in determining the behaviour of the algorithm and are discussed in the next section.

3 Implementation Issues

In the implementation described above, the edge pixels were taken to be those pixels in each region which have pixels from other regions as immediate neighbors (a one pixel wide border). Therefore pixels belonging to relatively thin strips around the edges are classified as edge pixels. However, it is reasonable to assume that at high magnification factors classifying a larger number of pixels as edge pixels would be advantageous. It was found that a two pixel wide border yields better results at 8X magnification. For the results presented in this paper, which required 4X magnification, we used a one pixel wide border.

The implementation of the iterative algorithm requires the choice of the parameters δ_1, δ_2. They control the amount by which the pixels at edge/non-edge locations can vary from their initial values. Sharpness can be improved, possibly at the expense of some amount of artifacts, by choosing a small value for δ_2 and a relatively large δ_1. For the images shown in this paper, which are 8 bits/pixel greyscale images, $\delta_1 = 5$ and $\delta_2 = 2$ were used.

The algorithm, as described above, is applicable to greyscale images and the luma (Y) component of color images. In order to extend this algorithm to color images we need to define suitable interpolation mechanisms for the U and V components. A naive approach might be to use the same algorithm for U and V components also. Experimental evidence suggests that we can use a simple bilinear interpolation scheme on the U and V components with out loss in perceptual quality. This is a direct consequence of the fact that the human visual system is much more insensitive to the chroma components as compared to the luma component.

Computational complexity of the proposed algorithm depends mainly on the number of POCS iterations that are needed for convergence. We found that the algorithm converges to the final image in 2-3 iterations. In the results shown in the next section the algorithm has been stopped after 3 iterations.

4 Results

To test the efficacy of our algorithm, we initially did experiments with an unmagnified image obtained by subsampling "Lenna" by a factor of 4 (so that we can compare with the ground truth). We used two different scales of segmentation[3]. At both scales of segmentation we get more than 1.5 dB improvement in PSNR over the baseline interpolation scheme (bilinear interpolation) relative to the ground truth (the original, unsub-sampled version of "Lenna"). Figure 2 shows the corresponding images. Images obtained our method are visibly sharper and yet contain little or no magnification artifacts.

Another set of results are shown in figure 1. The unmagnified image used for these experiments is a block from the image Gold hill (obtained without subsampling). Figure 1 (a)-(b) show the result of different interpolation schemes applied to this image. Note the improvement in the texture on the wall and the crisper bars on the windows. We note that the laser printer has imposed its own filter on the images shown in figures 2 and 1. Better quality images, as well as experiments with color images will be presented in the conference and can be obtained by contacting the authors.

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[3]The scale parameter controls the grey level homogeniety of the regions and hence the number of regions into which the image is partitioned

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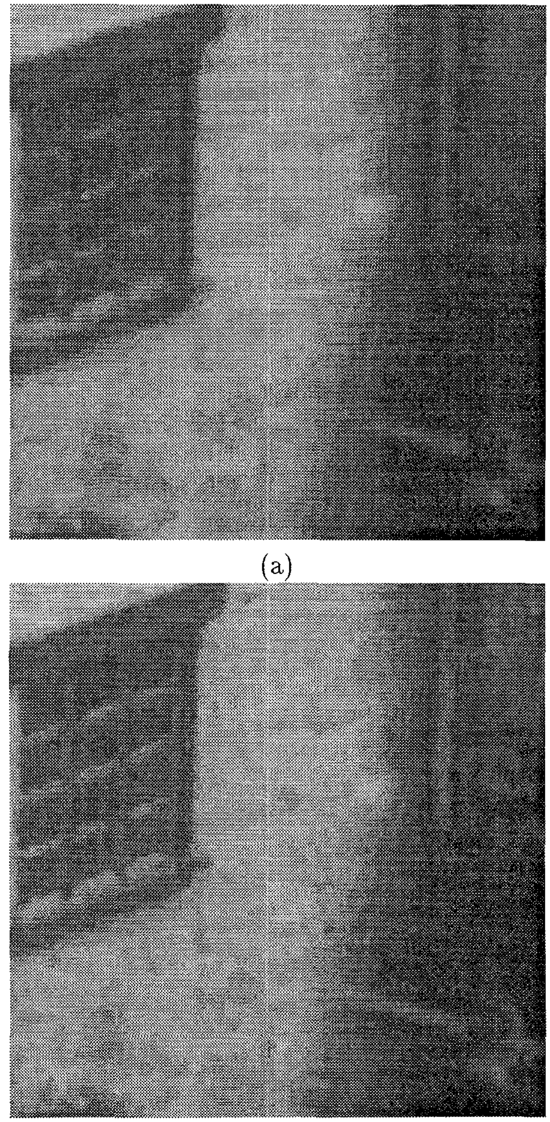

(a)

(b)

Figure 1: Resolution Enhancement Results (4X Magnification): (a) Bilinear Interpolation and (b) Proposed scheme. The unmagnified image is a 64x64 block from the image Goldhill. Note the improved texture on the wall and the crisper bars on the windows.

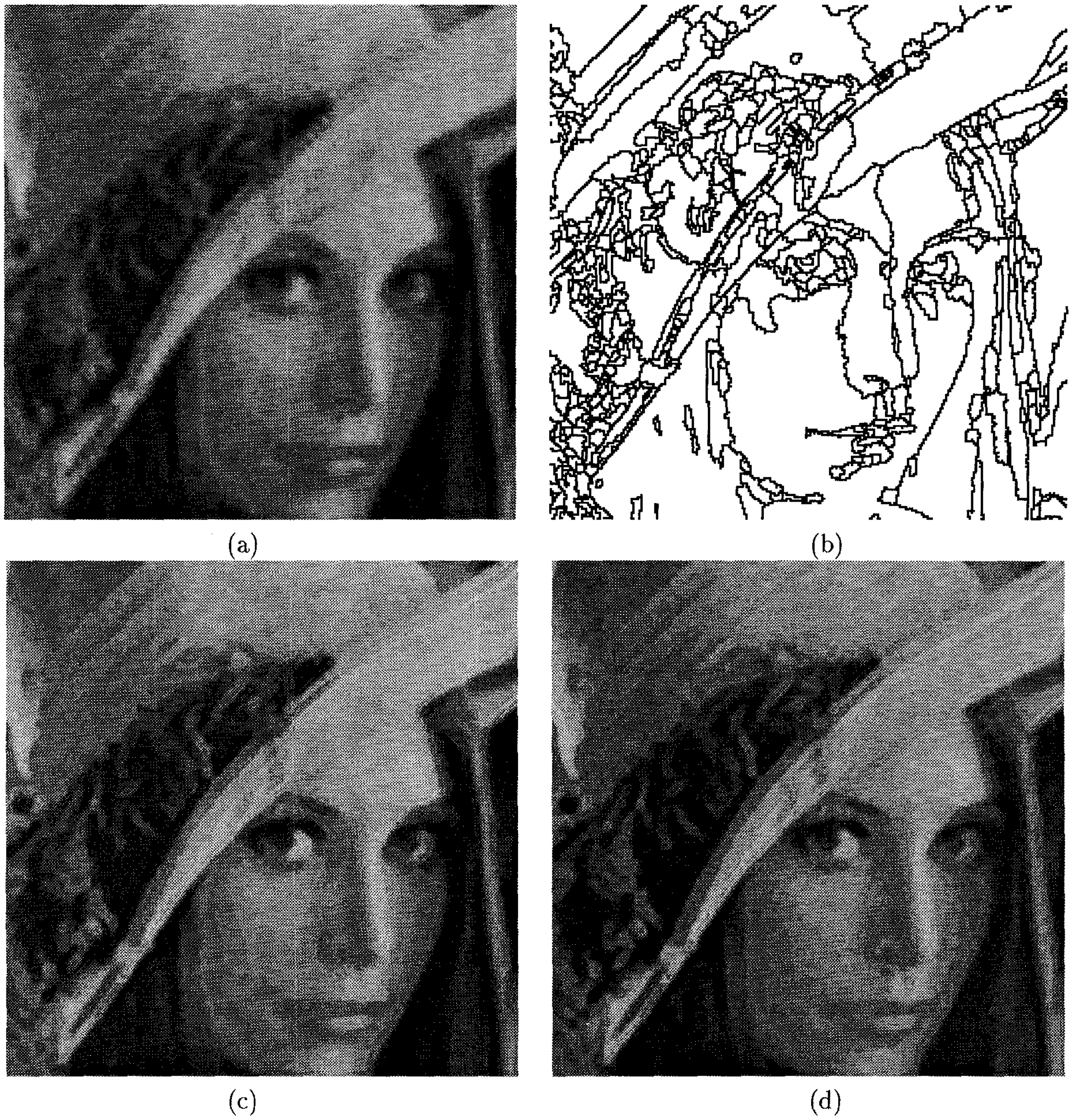

Figure 2: Resolution Enhancement results (4X magnification): (a) Bi-linear Interpolation (c) Proposed scheme at a coarse scale of segmentation and (d) Proposed scheme at a fine scale of segmentation. Both (c) and (d) have more than 1.5 dB improvement in PSNR over (a) when compared with original Lena image (the ground truth). The images obtained using our method are found to be visibly sharper. (b) shows the result of applying the segmentation algorithm on the baseline interpolated version of (a) (only the fine scale is shown).