MVA2005 IAPR Conference on Machine VIsion Applications, May 16-18, 2005 Tsukuba Science City, Japan
3-1

A Hyper-Resolution Scheme for Enhancement on a Down-Sampled Image

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Abstract

The quality of an image can be evaluated on its spatial and spatial-frequency resolutions. Image interpolation and super-resolution are perhaps the way to respectively produce high spatial and spatial-frequency resolutions of an image, especially for a down-sampled image. In this paper, we first address an approach to interpolating an image with noise removal by exploiting the probability filter coupled with a pyramidal decomposition. Then, the high spatial-frequency spectrum of any interpolated image can be reconstructed using the improved Poisson maximum *a posteriori* (MAP) super-resolution algorithm. This hybrid scheme called "hyper-resolution" here is proposed for enhancing the spatial and spatial-frequency resolutions of down-sampled images. Utilizing the hyper-resolution scheme, this research has studied resolution enhancement of gray-level and color images. Simulation results demonstrate that this hyper-resolution scheme substantially improves the quality of down-sampled images.

1 Introduction

As known, the process of decimation or down-sampling is an effective way aid often used to reduce image sizes; thus, reducing the amount of information transmitted through the communication channels and the local storage requirements, while trying to preserve as much as possible the image quality. Conversely, the reverse procedure of this, referred to as interpolation or up-sampling, is useful in restoring the original high resolution image from its decimated version or for resizing or zooming a digital image. Decimation and interpolation are used for several purposes in many practical applications, such as progressive image transmission systems, image zooming, photographic enlarging, image reconstruction, optical scanners, high resolution printer, and in multi-media applications which require browsing or retrieval of images from the internet or image and video databases. These problems are further aggravated in the case of color images which usually require larger storage capacity and processing time.

A number of conventional interpolation techniques have been proposed in the literature to increase the spatial resolution of an image [1-3]. These techniques degrade quality of the magnified image due to various artifacts, which are quite sensitive to human eyes such as blocking artifact and excessive smoothing. Those degradations become worse as the magnification ratio increases and there also exists trade off between reducing blocking artifact and excessive smoothness [4].
Basically, the quality of an image can be evaluated on its spatial and spatial-frequency resolutions. Image interpolation and super-resolution are perhaps the way to respectively produce high spatial and spatial-frequency resolutions of an image especially for a down-sampled image. For convenience, the term "hyper-resolution" used here represents the approach to enhancing the spatial and the spatial-frequency resolutions of an image. This paper will consider hyper-resolution for gray-level and color images. This paper first addresses an approach for simultaneous image interpolation and smoothing by exploiting the probability filter [5] coupled with a pyramidal decomposition, thereby extending the conventional applications of the probability filter originally designed for noise removal. Then, the improved Poisson MAP super-resolution [6] is performed to reconstruct the high spatial-frequency spectrum of the interpolated image. To illustrate the performance of the proposed scheme, this research has studied the resolution enhancement on gray-level and color images.

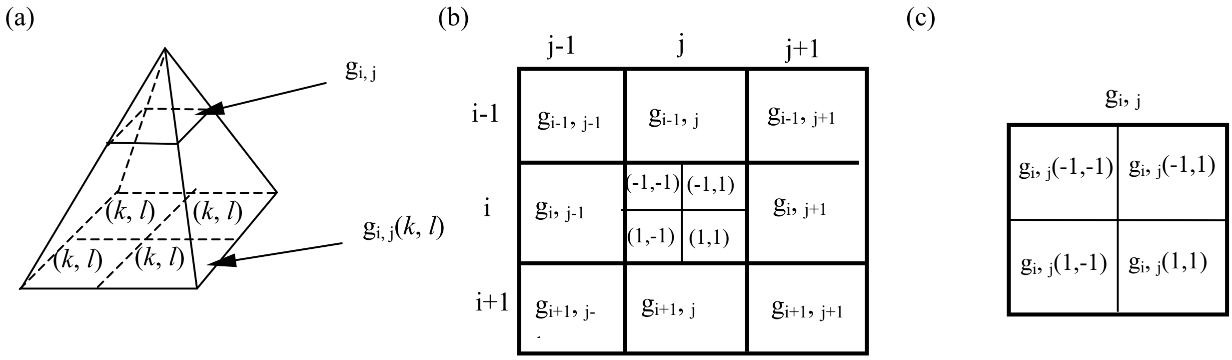

Figure 1: The pyramidal decomposition for interpolation. (a) Diagram of pyramidal decomposition, (b) The notation and relation of interpolated and original pixels, (c) $g_{i,j}$ decomposed into $g_{i,j}(-1,-1)$, $g_{i,j}(-1,1)$, $g_{i,j}(1,-1)$, $g_{i,j}(1,1)$.

Following the above introduction, this paper is organized as follows: Section 2 details the hyper-resolution scheme proposed here for down-sampled images. Experimental results and evaluations are shown in Sec. 3 and finally some conclusions are drawn in Sec. 4.

2 Proposed Hyper-resolution Scheme

A hyper-resolution scheme proposed here is a hybrid approach, including a novel probability-filtering based interpolator and the improved Poisson MAP super-resolution algorithm for enhancing the spatial resolution and the spatial-frequency resolution, respectively.

2.1 Interpolation based on the probability filter

For the purpose of image interpolation with noise removal, this probability filter [5] is modified as follows. According the pyramidal decomposition as Fig. 1, the new interpolated pixel, $g_{i,j}(k, l)$, yielded from the original pixel, $g_{i,j}$, can be defined as below:

$$g_{i,j}(k,l) = (p_{i,j}\, g_{i,j} + p_{i+k,j}\, g_{i+k,j} + p_{i,j+l}\, g_{i,j+l} + p_{i+k,j+l}\, g_{i+k,j+l})/\mathrm{Norm} \tag{1}$$

where

$$p_{i,j} = w.\exp(-(g_{i,j} - \bar{g})^2 / 2T^2) \tag{2}$$

$$p_{i+k,j} = \exp(-(g_{i+k,j} - \bar{g})^2 / 2T^2) \tag{3}$$

$$p_{i,j+l} = \exp(-(g_{i,j+l} - \bar{g})^2 / 2T^2) \tag{4}$$

$$p_{i+k,j+l} = \exp(-(g_{i+k,j+l} - \bar{g})^2 / 2T^2) \tag{5}$$

$$\mathrm{Norm} = (p_{i,j} + p_{i+k,j} + p_{i,j+l} + p_{i+k,j+l}) / 4 \tag{6}$$

$$\bar{g} = (g_{i,j} + g_{i+k,j} + g_{i,j+l} + g_{i+k,j+l}) / 4 \tag{7}$$

$$T = (|g_{i,j} - \bar{g}| + |g_{i+k,j} - \bar{g}| + |g_{i,j+l} - \bar{g}| + |g_{i+k,j+l} - \bar{g}|) / 4 \tag{8}$$

and w, a weight number, is chosen to be 1.5 here and (k, l) = (-1,-1), (-1,1), (1,-1), (1,1) shown as Fig. 1. The modified definition, (1)~(8), employs the characteristics of interpolating an image with noise removal.

2.2 Improved Poisson MAP super-resolution algorithm

Mathematically, it is shown as below:

$$(\hat{f}_{n+1})' = (\hat{f}_n)' \;\; exp[(\frac{(g \otimes h)'}{(\hat{f}_n)' \otimes (h \otimes h)} - 1) * (h \otimes h)] \tag{9}$$

Thus, the final hyper-resolved image $\hat{f}$ can be obtained by integrating $(\hat{f}_{n+1})'$. The whole process of this improved Poisson MAP includes re-blurring, differentiation, restoration, integration, and then correction for a DC offset. More details about this algorithm can be found in the author's previous work [6].

3 Experimental Results and Evaluations

To assess the performance of our proposed hyper-resolution scheme, the resolution enhancement of gray-level and color images is considered. In illustrated examples, a gray-level image of clown with the size of 200x320 pixels and a color image of lotus with the size of 100x100 pixels were rectangular decimated with a factor of $1/2^{2k}$.

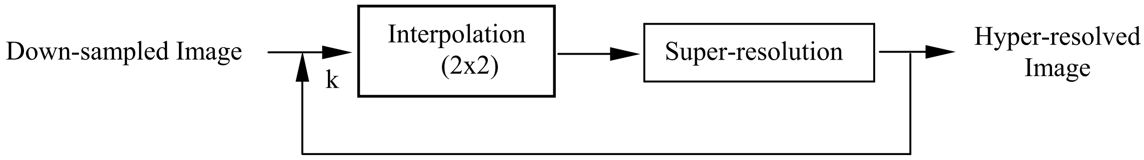

Figure 2: The mechanism of hyper-resolution loop.

Therefore, the interpolation was done with a factor of 2^2 for each cycle; then, the super-resolution procedure of the proposed hyper-resolution scheme, shown as Fig. 2, adopted 25 iterations and the PSF with a standard deviation of 1 pixel because of the pyramidal decomposition used here, conversely, four neighboring pixels in the interpolated image mainly contributing to one pixel in its own decimated image. Thus, the proposed hyper-resolution scheme can magnify the size of an image by any factor that is a power of two along each dimension where this resizing scheme consists of two steps: the first step is to interpolate the down-sampled image using bilinear, cubic spline or the novel proposed probability-filtering based interpolation and the second step is to super-resolve the interpolated image. The implementations of bilinear and cubic spline interpolation are taken from MATLAB 5.3. In the following, it can be seen that hyper-resolved images derived from the conventional interpolators still have blocky, jagged lines, and are blurred whereas the proposed method appears to suppress these artifacts, preserve the edges, and retain the image details better.

3.1 Resolution enhancement of gray-level images

This case applied the proposed hyper-resolution scheme to a down-sampled image shown as Fig. 4(a). It can be seen that a highly down-sampled image shows serious blocking artifacts. To solve this problem, this down-sampled image was hyper-resolved using our proposed scheme where hyper-resolution was performed three times for comparison; these three hyper-resolved images are shown in Figs. 3 (b), (c), and (d), respectively. Obviously, blocking artifacts are further reduced, especially for the case of which interpolation with the factor 2^3x2^3, shown as Fig. 3(d) in which pupils of the clown are clearly identified.

3.2 Resolution enhancement of color images

The results presented here show good performance using the simple approach of applying the hyper-resolution scheme to the red, green, and blue planes independently and then combining the results into a single color image.

As the case of Fig. 4, this down-sampled color image with serious blocking artifacts, Fig. 4(a), was hyper-resolved three times using our proposed method; thus, three hyper-resolved images are shown in Figs. 4(b), (c), and (d), respectively. Apparently, the proposed algorithm generates hyper-resolved images with a higher visual quality, especially for the case of 2^3x2^3 hyper-resolution shown as Fig. 4(d).

Acknowledgements

This work is substantially supported by a grant from the National Science Council in Taiwan, R.O.C. (Project No. NSC 92-2213-E-236-004).

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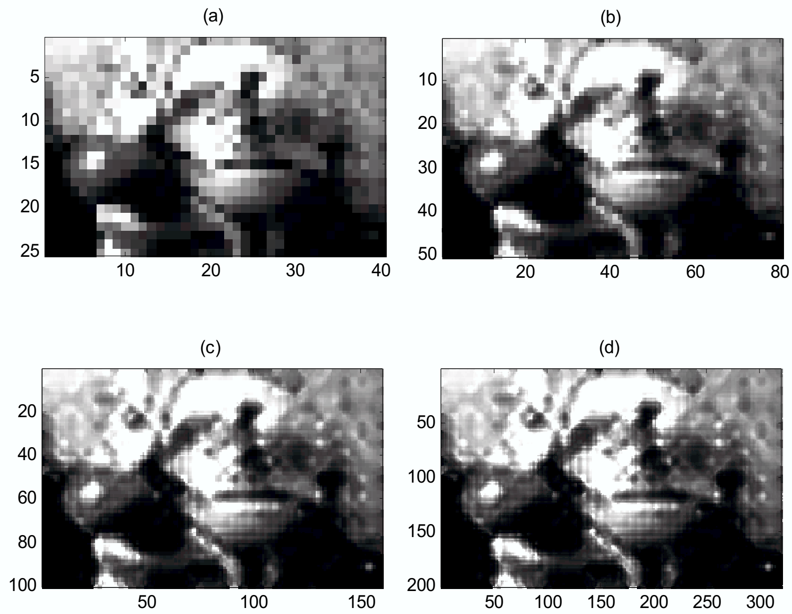

Figure 3: Demonstration of hyper-resolution for a down-sampled gray-level image. (a) Down-sampled image, (b) Hyper-resolved image with a factor 2x2, (c) Hyper-resolved image with a factor 2^2x2^2, (d) Hyper-resolved image with a factor 2^3x2^3.

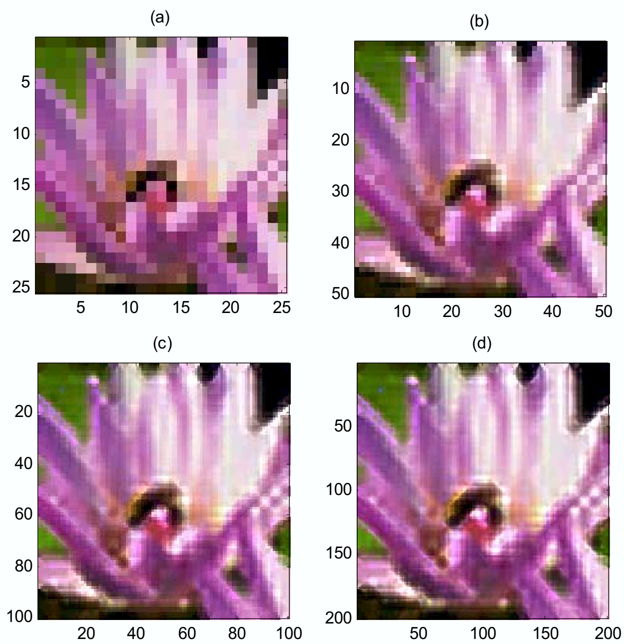

Figure 4: Demonstration of hyper-resolution for a down-sampled color image. (a) Down-sampled image, (b) Hyper-resolved image with a factor 2x2, (c) Hyper-resolved image with a factor 2^2x2^2, (d) Hyper-resolved image with a factor 2^3x2^3.