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Two-channel spatial interpolation of images

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Abstract

Proposed is a new method for the spatial image interpolation. The proposed method interpolates the low- and high-pass filtered images in separate channels so that it can not only recreate the stationary region naturally but also preserve the edges clearly. It can be used for the image format conversion. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Two-channel interpolation; Image format conversion

1. Background

Image interpolation has many applications. Changing the size of a digital image is a typical one where the spatial interpolation is used to make the enlarged image smoother and visually more pleasant. Image coding is another, where, from the coded pixels, the interpolator recreates some others discarded for bit rate reduction.

Basically, interpolation is an inverse problem that is to reconstruct an analog signal $f_c(x, y)$ with a two-dimensional sequence $f(n_1, n_2)$ assuming that the latter is obtained by sampling the former. However, it is impossible or impractical to perfectly reconstruct the original image, because the analog signal $f_c(x, y)$ cannot be truly band-limited and the ideal low-pass filter required for interpolation cannot be implemented with a finite-extent [1].

One practical approach is to use a low-pass filter that is spatially limited. The low-pass filter can be constructed by repeated convolution of a rectangular windowing function [3]. As the number of repetitions increases, the resulting low-pass filter has a smoother shape in the impulse response but a sharper transition in the transfer function [3].

Another method is *polynomial interpolation*. In this method, a local spatial region of $f_c(x, y)$ is approximated by a polynomial. Polynomial interpolation has an advantage that some noise smoothing is accomplished by fitting a polynomial with fewer coefficients than the number of pixels in the region [1].

The most significant disadvantage of the two types of methods discussed up to now is that the edges in the interpolated image are blurred. Blurring seriously degrades the image, especially when the given sampling is sparse compared with the size of the image.

To overcome the blurring artifact, knowledge of human visual system has been exploited to design more sophisticated methods. One of them is

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directional interpolation, in which the local gradients (or contrasts) of the image along three or five directions are determined and then the pixels are interpolated along the direction of the minimum gradient (or contrast) [2,4]. It guarantees that if the pixels are on an edge then they will be interpolated along the edge. Because the human eye is indifferent to the noise along the edges, a very short-extent low-pass filter is sufficient for the directional interpolation. Nevertheless, this method sometimes generates salt-and-pepper noise in the texture region due to the malfunction of the edge detection, which is very annoying to the human eye. Another defect of directional interpolation is that it sometimes yields unnatural images in the constant or slowly varying regions because the interpolation filter has only a short support region.

In this paper, we propose two-channel interpolation method in order to preserve the sharpness of the edges on the one hand, and to recreate more natural stationary region on the other.

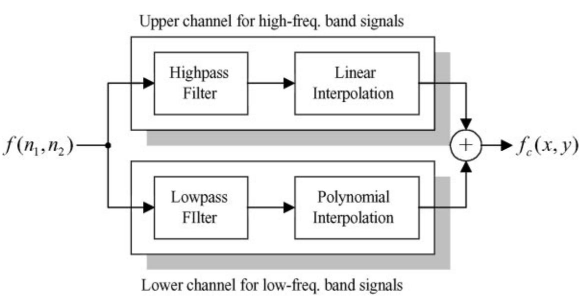

Fig. 1. The block diagram of the proposed two-channel spatial interpolator.

2. Interpolation algorithm

Fig. 1 shows the proposed algorithm. The input sequence is processed in two channels: the lower channel consists of a low-pass filter and a polynomial interpolation, while the upper consists of a high-pass filter and a short-extent linear interpolation.

The lower channel interpolates the local means of the image that are considered to be slowly varying. Polynomial interpolation in the slowly varying region yields better performance than any other convolution method. The reason for the best performance is that the extent of polynomial interpolation is generally much larger than that of the practical convolution method and therefore can reproduce images more faithfully.

In the upper channel, the edges are intensified by the high-pass filter and then linearly interpolated. To interpolate the edges as sharply as possible, one may consider zero-order interpolation. But zero-order interpolation often produces jerky or staircase-like contours, which is very annoying to the human eye. So we use linear interpolation instead. Linear interpolation has the shortest-extent except zero-order interpolation so that it is expected to yield the least blurring artifact.

Table 1
The pSNR performances of the interpolation algorithms (in dB)

Image \ Algorithm	Two-channel (Proposed)	Conventional single-channel algorithms: Linear	Polynomial	Directional [2]	Simonethi [4]
Lena	37.60	37.58	33.67	35.85	35.15
Bridge	27.89	27.88	25.83	26.82	26.83
Crowd	33.25	33.14	30.78	32.10	31.59
F16	35.66	35.50	32.79	33.96	33.38
Bank	29.91	29.71	27.58	29.65	28.10
Jaguar	29.89	29.17	27.82	29.32	28.45
Lake	31.59	31.43	29.75	31.45	30.54
Peppers	35.32	34.60	33.18	34.88	34.56
Average	32.64	32.38	30.18	31.75	31.08

3. Simulation results

We applied the proposed algorithm to enlarging a digital image vertically by 2. This circumstance is often encountered in the interlaced to progressive scanning conversion.

In the lower channel in Fig. 1, each local region of the low-pass filtered image containing 3×3 pixels is approximated as a polynomial with six coefficients whose basis functions are $\phi_i(x, y) = 1, x, y, x^2, y^2, xy$. With the estimated polynomial, the inner 1×2 up-sampling grids are approximated. Therefore, the interpolation processes can be performed with as many pixels as possible.

Basically, the performance of the algorithm can be measured only subjectively, which results from the fact that interpolation is used to construct an enlarged but new image from a small-sized one and its goal is only to make the resulting image smoother and visually more pleasant. But we use a quantitative measure called the pseudo signal-to-noise ratio (pSNR), which copies the subjective

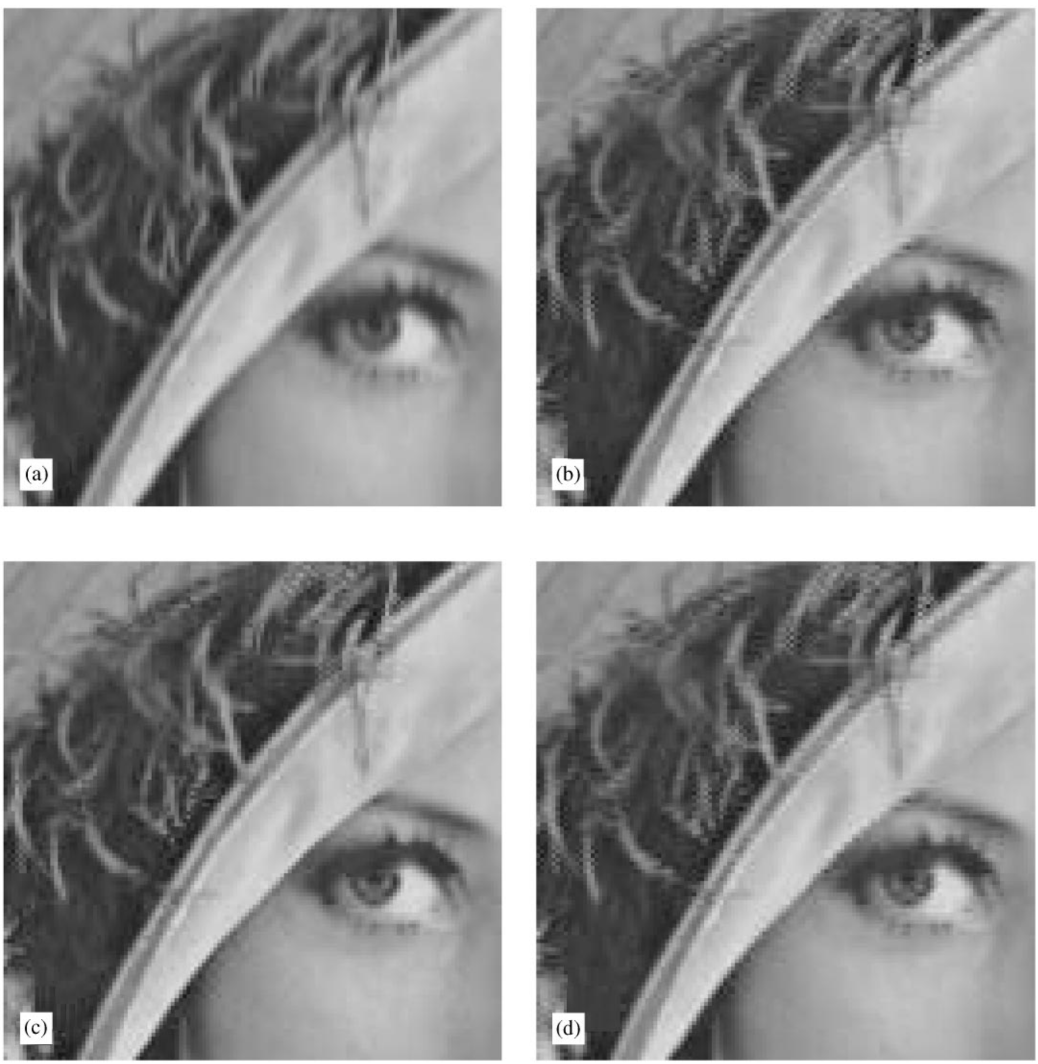

Fig. 2. Lena images interpolated by the algorithms: (a) proposed method, (b) linear interpolation, (c) directional interpolation [2] and (d) Simonethi's algorithm [4].

performance well not de jure but de facto. The pSNR is computed with the mean squared differences between the original image and the interpolated one as follows:

$$\mathrm{pSNR} = 10\log_{10}\left(\frac{255^2}{E[f(n_1,n_2)-\hat{f}(n_1,n_2)]^2}\right), \quad (1)$$

where $f(n_1, n_2)$ is the original image and its subsampled image decimated vertically by 2 is processed to yield the interpolated image $\hat{f}(n_1, n_2)$ which has the same size as the original image.

Simulation is performed with eight USC images of 512×512 pixels named *Lena, Bridge, Crowd, F16, Bank, Jaguar, Lake* and *Peppers*. Table 1 shows the pSNR performance of the proposed algorithm in comparison with those of the conventional single-channel interpolation algorithms such as the linear, polynomial [3], directional [2] and Simonethi's algorithm [4]. Simonethi's algorithm

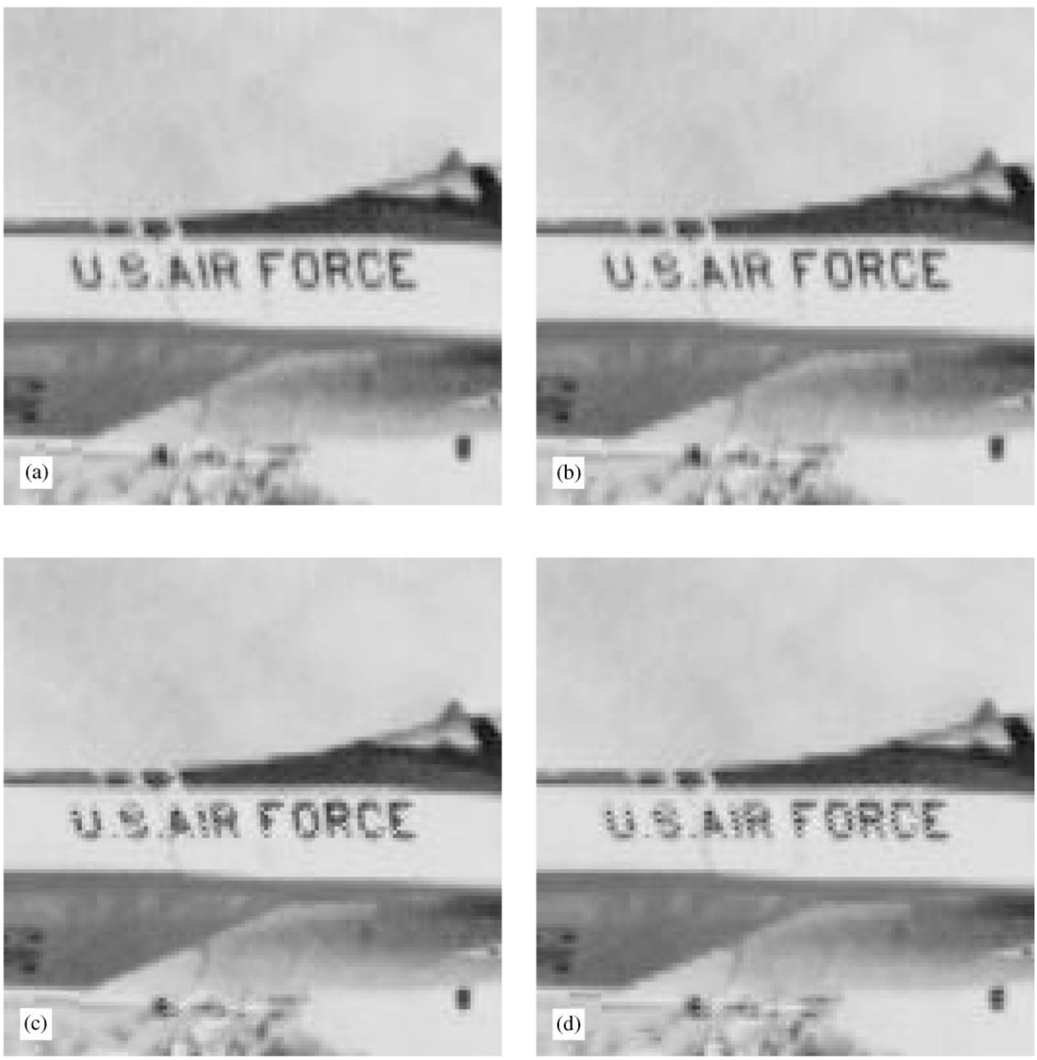

Fig. 3. F16 images interpolated by the algorithms: (a) proposed method, (b) linear interpolation, (c) directional interpolation [2] and (d) Simonethi's algorithm [4].

performs median filtering of the directional averages. The simulation results show that the proposed method could reconstruct an image most faithfully if it existed. It is also noticeable that the single-channel polynomial interpolator reveals the worst performance among them.

Figs. 2 and 3 show parts of the interpolated *Lena* and *F16* images. From the figures, we can first notice that the proposed method preserves the contours or the edges as clearly as the directional interpolation methods. Also, obviously it recreates very natural stationary region. We can also notice that the proposed method does not breed any salt-and-pepper noise that can be seen distinctly in the case of the directional interpolation [2] and Simonethi's algorithm [4].

4. Concluding remarks

This paper asserts that two-channel processing is adequate to interpolate a high-resolution image from a low-resolution one because it preserves the edges unblurred and recreates the stationary region naturally. The proposed interpolation method can be used in the post-processing of digital television signals for the quality improvement or multimedia applications.

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