GENERIC METHOD FOR 2D IMAGE RESIZING WITH NON-SEPARABLE FILTERS*

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ABSTRACT

2D image resizing is an important issue for pixel oriented displays with variable input formats. Low-resolution pictures look bad on high-resolution screens, especially when only simple up-conversion methods like pixel and line repetition or bi-linear interpolation are used. Even when applying separable polyphase up-conversion filters, the problem of jagged lines (staircases) remains. The approach investigated for high-quality resizing by rational factors is based on pixel and line repetition with suitable post-filtering. The novel resizing method uses very simple, non-separable filters, and is suitable for all kinds of image and video material such as analog sources (PAL, NTSC), digital sources (JPEG, MPEG), low-resolution up to high-resolution images, and noisy pictures. Jagged lines can be smoothened perfectly.

1. INTRODUCTION

The number of graphics and video formats increased over the past years, and differ widely depending on the application. This holds for standard analog video up to high definition, in the PC domain and increasingly for mobile devices. Since displays are becoming more and more pixel orientated, there is a strong need for high quality, but low-cost scalers for various formats. Scalers perform the interpolation/decimation between the input and the output format.

Pixel or line repetition by natural factors is an easy up-scaling method, but the rectangular pixel structure will be magnified by the up-scaling factor. State-of-the-art up-scaling methods with separable polyphase filters aim at a broad bandwidth up to the Nyquist frequency of the input image signal to preserve the resolution. They suppress all frequencies above the Nyquist frequency to eliminate the appearance of the original pixel block structure [1-2].

These filters are relatively computationally complex and of high order, since the requirements are very high. Independent of their complexity, they can only approximate their ideal characteristics. High-order filters have the additional disadvantage of introducing ringing along single lines or edges. A remaining problem of spatial scaling is the appearance of jagged lines (staircases). They usually appear after applying up-conversion techniques with separable filters, including commonly used bi-cubic interpolation. As a first step in spatial up-scaling, jagged edges should be avoided. We describe a novel method to do resizing on progressive images with simple filters, without suppressing original image content. Signal components in the repetition spectra therefore have to be accepted. Still, output images should be of very high quality, without the original pixel structure and with smooth diagonal edges.

The resizing method should be suitable for de-interlaced analog (PAL, NTSC) and digital (JPEG, MPEG) video material, as well as for low-resolution up to high-quality images. The resizing method should also allow for non-linear post-processing like "resolution enhancement".

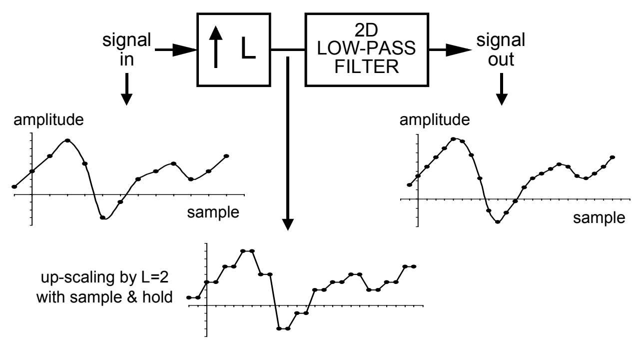

Fig. 1. Basic approach for up-scaling by natural factors. The graphs show an example for an up-scaling factor of 2. They include the input signal for one dimension, the up-sampled signal by L = 2 with S&H, and the low-pass filtered output signal.

2. SPATIAL UP-SCALING BY NATURAL FACTORS

The straight-forward approach for image up-scaling by natural factors is shown in figure 1. The up-sampling by a natural factor L includes the insertion of zeros between the

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original samples, and a low-pass filter to smooth the output signal. Alternatively, the up-sampling can be done by inserting the original sample values, which is known as sample & hold (S&H). Still, a low-pass filter is required to smooth the output image.

The theoretically ideal approach for an interpolation by 2 is illustrated in figure 2 [3]. All frequencies up to the Nyquist frequency pass without amplitude reduction, while all other frequencies are perfectly suppressed. Unfortunately, the impulse response has an infinite length which cannot be realized in praxis. The typical compromises are either to suppress signal frequencies (blurring) or to allow aliasing.

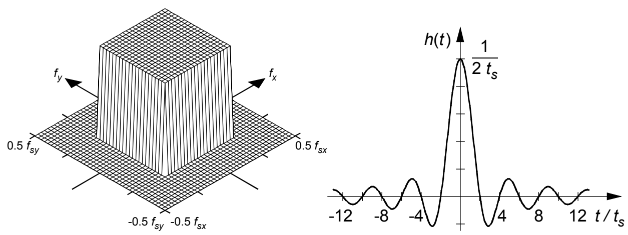

Fig. 2. Frequency response of an ideal interpolation filter for up-scaling by a factor of 2.

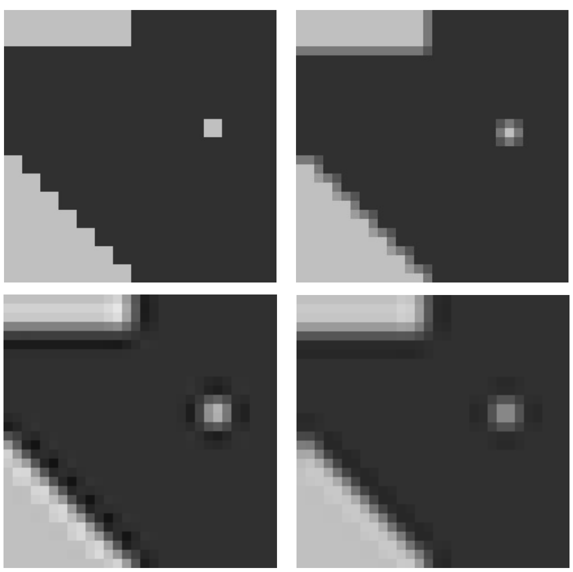

Fig. 3. Test image (original input image 15x15 pixels): spatial up-scaling by a factor of 2 with pixel and line repetition (top left), with bi-linear interpolation (top right), with bi-cubic interpolation (Jasc PaintShopPro8.0) (bottom left) and with S&H in series with 7-tap polyphase filter (bottom right).

2.1 Up-scaling by a factor of 2 with bi-linear interpolation and polyphase filters

Figure 3 shows an up-scaled test image after post-processing with different filters. Especially the S&H and the bi-linear interpolation do not remove the original pixel structure leaving a strong staircase structure at diagonal edges. The polyphase filter behaves better. Still, diagonal pixel values alter, and overshoots become visible on both sides of an edge. These typical artifacts will remain even when using separable polyphase filter of high order.

2.2 Generic approach for up-scaling with diamond shaped filters

The novel non-separable filters are found to be a solution for creating smooth edges on up-scaled S&H images. Suitable, non-separable filters must have specific characteristics:

- The previously created staircase structure of diagonal lines is smoothed, at best completely eliminated.
- The general block structure created by up-scaling is removed, at best completely eliminated.
- The basic horizontal and vertical image resolution has not been reduced, in order to preserve the image quality.

The novel 2D low-pass filter uses the equivalent S&H coefficients, but in a diamond structure (rotation by 45 degrees). Examples for up-scaling by factors of 2, 3 and 4 are shown in figure 4. Other natural up-scaling factors follow the same rule.

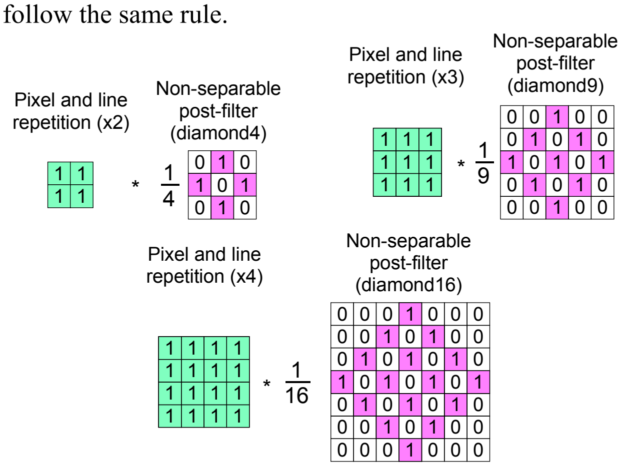

Fig. 4. Up-scaling by a factors of 2, 3 and 4. The non-separable filters at the right are referred to as diamond filters.

The diamond shaped filters are not separable and have alternating zero coefficients in both spatial dimensions. Figures 5 and 6 show the frequency responses after S&H up-scaling and diamond postfilters. The frequency responses are far from ideal compared to figure 2. The frequency response of the S&H function has an amplitude decrease of 3.9 dB at the horizontal and vertical Nyquist frequency, while the diamond shaped post-filters decrease the amplitude for the factors 2 to 4 by 5.1 dB till 7.2 dB. These moderate values can further been lowered by peaking filters without introducing the blocking structure again. Still, the stop-bands contain significant amplitudes which theoretically should be suppressed.

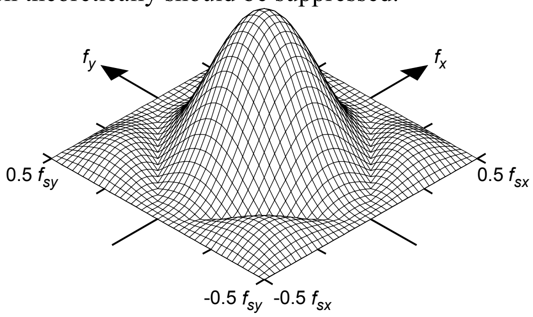

Fig. 5. Frequency response of a non-separable 'diamond4' filter for up-scaling by a factor of 2.

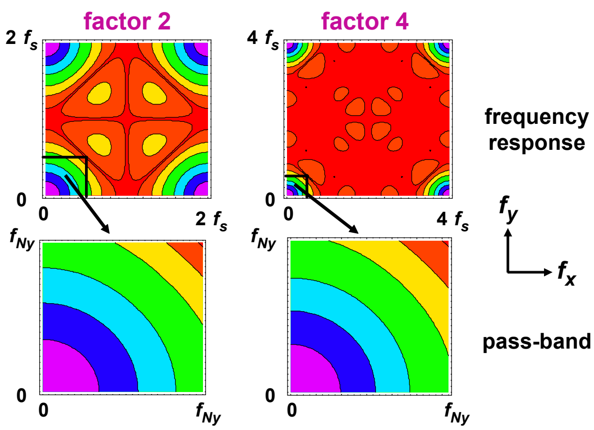

Fig. 6. Pass-bands and stop-bands of S&H plus diamond shaped filters for different up-scaling factors.

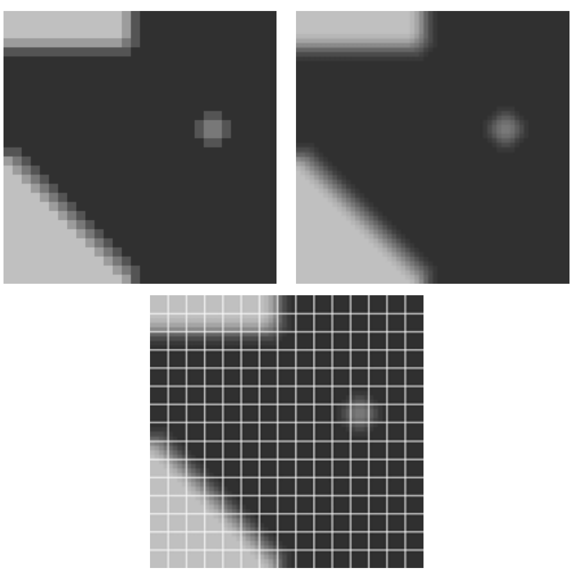

Fig. 7. Test image after pixel and line repetition: up-scaling factor 2 and 'diamond4' filter (left), up-scaling factor 4 and 'diamond16' filter (right), and marked borders of original pixels (bottom).

Beside the theoretically non-ideal characteristics, this up-scaling method guarantees optimally smooth diagonal edges, constant pixel values along the center line of a diagonal edge, and very high quality for edges in other directions (Figure 7). It can be seen that smoothing takes place only over the originally neighbored pixels of an edge.

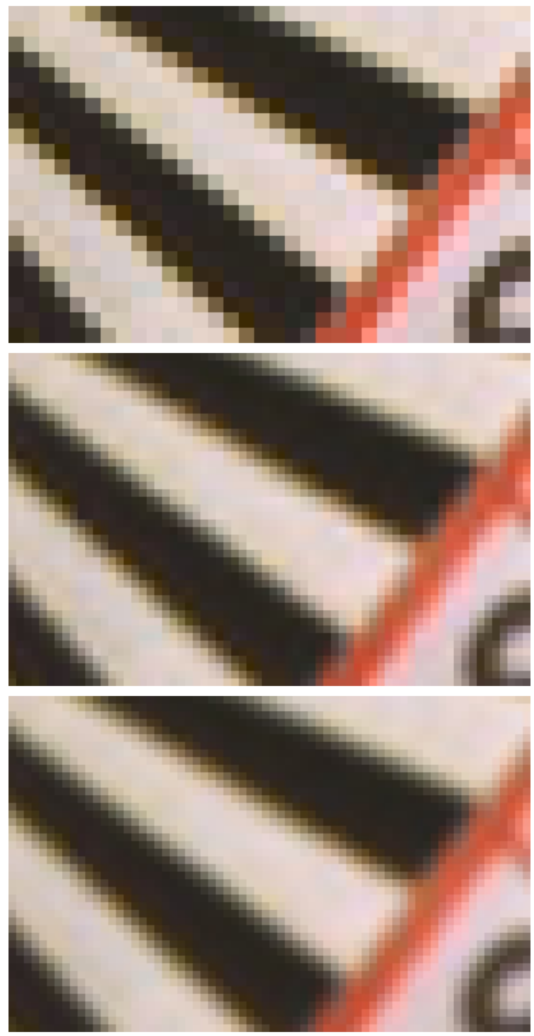

Fig. 8. Part of 'bicycle' test image after pixel and line repetition by a factor of 2 (top), bi-linear interpolation (middle), and proposed 2D, non-separable diamond4 filter (bottom).

The results for up-scaling by a factor of 2 are shown in figure 8 for a part of the 'bicycle' sequence. The illustrated edges have angles between 25º and 50º. Other material with different properties in quality and distortion (noise and coding artifacts) has also been tested. The processing was done in the RGB domain. The bi-linear interpolation does not eliminate the original pixel structure and shows staircase-like structures at diagonal edges. Also other, separable poly-phase filters were tested with up to 25 coefficients in each dimension. None of them could eliminate the staircase structure introduced by S&H up-scaling. The diamond shaped low-pass filter behaves much better: it completely eliminates the original pixel structure and provides very smooth edges for any angles. Peaking filters can be applied without introducing the blocking structure again.

3. GENERIC APPROACH FOR UP- AND DOWN-SCALING WITH RATIONAL FACTORS

The novel approach for up-scaling can be complemented by down-scaling as shown in figure 9 to realize rational scaling factors. The largest of the factors L and M defines the most suitable, diamond shaped low-pass filter.

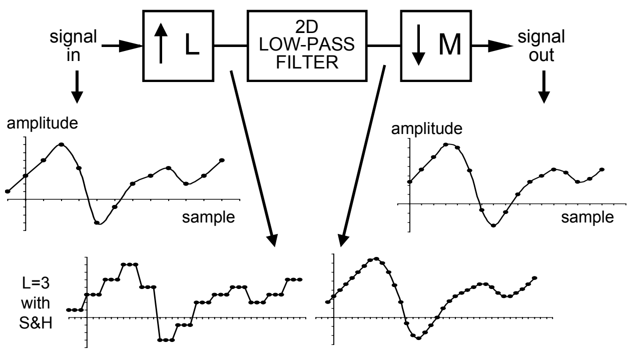

Fig. 9. Basic structure of image resizing by rational factors. The graphs show an example for a resizing factor of 1.5. They include the input signal for one dimension, the up-sampled signal by a factor of 3 with S&H, the low-pass filtered signal, and the down-sampled output signal by a factor of 2.

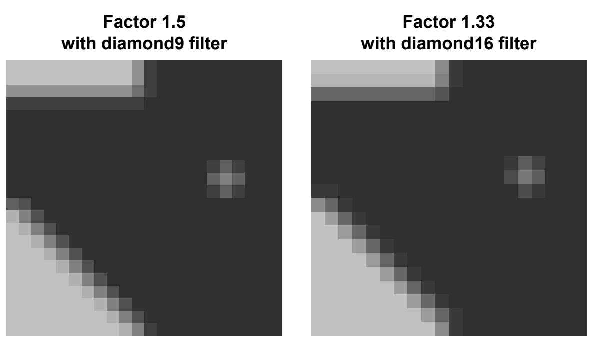

Fig. 10. Test image after up-scaling with rational factors 1.5 and 1.33 using S&H and diamond shaped filters.

We successfully tested several rational factors for L = 1…4 and M = 1…4. Results are shown in Figure 10. All pixels along the diagonal lines have the same value. There is no limitation for other factors that could be used. Also scaling factors near or smaller than one are possible.

4. IMPLEMENTATION OF DIAMOND SHAPED FILTERS FOR SPATIAL SCALING

An important question concerns the implementation of this novel scaling method. Figure 11 shows an example of the involved pixels for an up-scaling factor of 4. The big squares (3x3) mark the boarders of the pixels with equal values after S&H. The black center pixel depicts the output sample position. The shown three output sample calculations are sufficient for all possible output samples, which have similar involved neighbored pixels. Here, the maximum number of involved neighboring pixels is 5. This scheme has been evaluated for any rational up-scaling factor. The result is that a maximum number of 7 neighboring original pixels are necessary to calculate an output pixel at any phase. Even a simple 3x3 filter uses already 9 neighbored pixel, not to talk about higher order filters. Thus it becomes clear that transitions will not be soften over several pixels in any direction when using these diamond shaped filters for resizing. This is a distinct advantage for scaling factors close to one. In addition, possible border processing artifacts are limited to one original pixel in any direction.

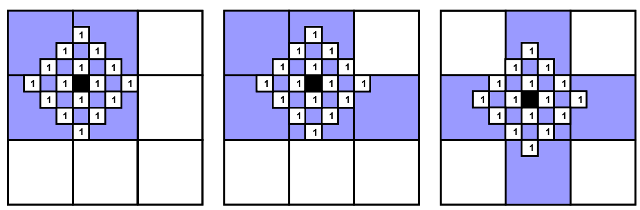

Fig. 11. Involved original pixels for spatial up-scaling by a factor of 4 with 'diamond16' filter.

5. CONCLUSION

Scaling is a known and used technique for various purposes. The proposed method uses simple, non-separable filters, and has been compared with other methods that use separable filters.

The non-separable filter provides superior performance. It is suitable for all kinds of compressed or otherwise affected images, and ranges from low-resolution up to high-resolution high-quality images. The jagged edges or "staircases" can be effectively removed, while distortions will not be enhanced.

Non-linear processing can be applied for further image quality improvement. For resolution enhancement, the correct detection of all kinds of edges is of utmost importance. This edge detection can benefit from the proposed method.

6. REFERENCES

[1] A. V. Oppenheim, R. W. Schafer, "Digital signal processing", *Prentice-Hall*, Englewood Cliffs, 1975.

[2] R. B. Crochière, L. R. Rabiner, "Interpolation and decimation of digital signals – A tutorial review," *Proc. of the IEEE*, Vol. 69, No. 3, pp. 300-321, 1981.

[3] C. E. Shannon, "A mathematical theory of communication", *The Bell System Technical Journal* 27, pp. 379-423, 623-656, 1948.