AN EFFICIENT DIRECTIONAL IMAGE INTERPOLATION METHOD

Xiqun Lu

Zhejiang University
School of Computer Science
Hangzhou, 310027 P. R. China
xqlu@zju.edu.cn

Paul S. Hong and Mark J. T. Smith

Center for Signal and Image Processing
Georgia Institute of Technology
Atlanta, Georgia 30332-0250 U.S.A.
phong@ece.gatech.edu, mjts@ece.gatech.edu

ABSTRACT

This paper introduces a new method for interpolation in which the angular orientation of image features is exploited to enhance subjective quality. This involves, as a first step, extracting the low frequency information and expanding its size in a parallel channel. The mid to high frequency information is decomposed directionally into angular subbands. The subbands are then interpolated to enhance edge definition and then recombined. Experimental results show that the subjective quality of the interpolation is improved relative to conventional methods. Moreover, the interpolation method when combined with JPEG compression enables significantly higher coding performance to be achieved at low bit-rates—bit-rates at which JPEG typically breaks down.

1. INTRODUCTION

Expanding the size of an image is a common practice. The textbook approach for 2-D signal enlargement is upsampling followed by filtering, which is classical interpolation. Quite often, interpolation (more specifically, bilinear interpolation) is employed in commercial software packages when the need for enlargement occurs. This approach is generally effective but results in the appearance of blurred edges and image features.

Other software packages may take a simpler route, employing pixel replication. From a textbook perspective, this operation is equivalent to upsampling with a 2-D zero-order hold. The degradation observed can be described as blocking distortion and is typically called *pixelation*.

Recently, edge-directed interpolation methods have been prposed that emphasize the geometric features in edge areas to create smoother subpixel approximations of image edges [1–5]. Edge-directed interpolation techniques such as [1–3] employ an estimated high-resolution edge map to modify the linear interpolation result so as to spatially adapt the interpolation coefficients to better match the local structures around the edges.

Like the approaches taken in [1–5], the method introduced in this paper attempts to preserve the geometric features of the image. Toward this end, a new directional image decomposition is employed. Processing is then performed on the directional outputs. Because the directional features have been isolated, the former 2-D interpolation task now more closely resembles 1-D interpolation where preservation of geometric features can be approached differently.

2. METHOD AND BACKGROUND

A diagram of the system set-up is shown in Figure 1. The lowpass/highpass separation serves to extract the DC and low frequency information from the directional interpolation path. The low frequency channel undergoes conventional interpolation. Any reasonable interpolation will preserve the information accuracy associated with the low frequency content. The challenge is handling the high frequency components where edge information resides. This is the domain in which the perceptual distortions are manifested.

As shown in the block diagram, the high frequency channel is split into directional subbands prior to interpolation. This provides independent control over the angularly-oriented edge features, which offers the freedom in theory for perceptual tuning. Research has shown that the human visual system (HVS) has inherent orientation sensitivity [6, 7]. In fact, the cortical channel model describes the HVS as a contiguous directionally-oriented filter bank.

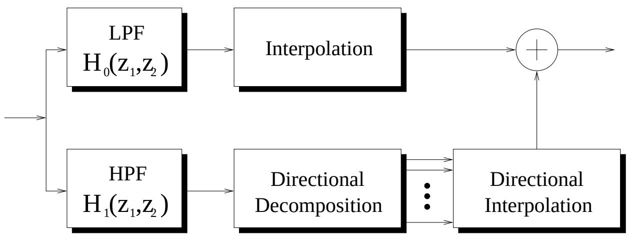

Fig. 1. A flowchart of the proposed method.

The decomposition used in this paper is the directional filter bank (DFB) presented in [8]. The general structure of the DFB involves a tree hierarchy of two-band splits, where each split increases the angular resolution by a factor of 2. The polyphase form of the two-band split may be seen in Figure 2 as well as the equivalent channels in the general form, indicated by the dotted lines and the diamond filters. The first structure (denoted by $\mathbf{R}_n$) is either a modulation with respect to either n_1 or n_2 or a unitary matrix resampling. If it is a modulation, the input is shifted by π in the frequency domain, necessary only in the first two stages of the DFB. The resamplings, used in the latter stages, correspond to warping of the input in both the frequency domain and the spatial domain. An example of both modulation and resampling are shown in the figure. With respect to the polyphase form, the input to the lower channel is spatially shifted by a coset vector $\underline{c}$ of the quincunx matrix $\mathbf{Q}_k$ is used. The filters $P_0(\underline{\omega})$ and $P_1(\underline{\omega})$ are both separable and may be linear or non-linear phase, IIR or FIR. Two examples are shown in the figure, one using modulation, the other using resampling, with both sets of outputs. By using this structure, an arbitrary number of directional subbands of a 2-D signal can be generated. An alternative structure to the polyphase form involves the use of ladder filters. These allow for separable filtering as well.

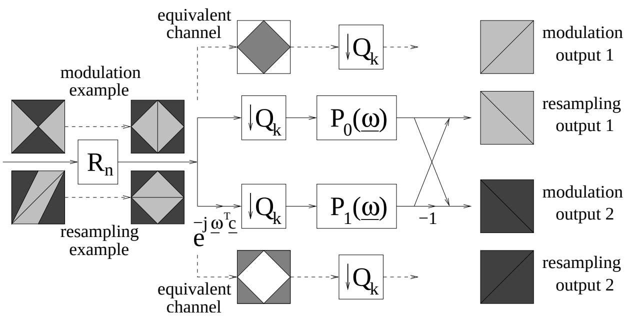

Fig. 2. The general form of a two-band split for the DFB.

The decomposition is performed as described above. An eight-band decomposition is shown in Figure 3. Within the decimated domain, efficient processing can be performed to emphasize features of interest if so desired. However, care must be exercised because aliasing components [9] are embedded in the decimated subbands. The interpolation process is built on reconstructing the subbands through the synthesis filter bank as shown in Figure 4.

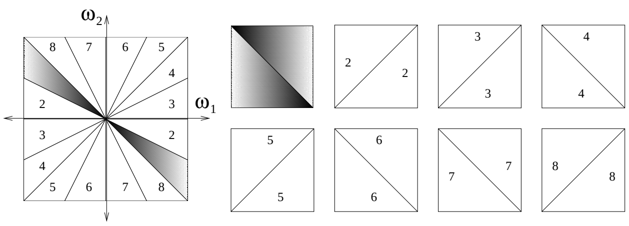

Fig. 3. The directional decomposition and its subbands in the decimated domain. A single subband is highlighted for emphasis.

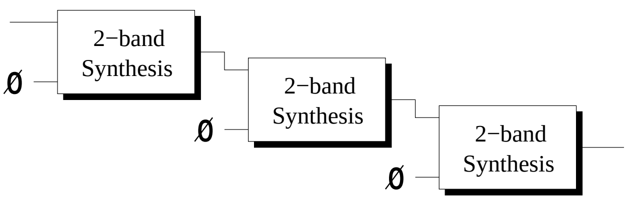

Fig. 4. The synthesis filter bank of a single subband.

3. DIRECTIONAL BAND INTERPOLATION

The directional representation captures the geometric features of the image in the form of striations. The amplitude variation and width of these striations are related to the edge definition and sharpness of the interpolated image.

Thus, interpolation may be performed by following strategies that preserve or reduce the width of the striations in the directional subbands. Since the features corresponding to edge definition are all in one specific direction within any given subband, 1-D enhancements may be applied along the direction associated with that particular subband, as depicted in Figure 5. This effectively allows interpolated features to be smoothed along their expanse and not across their transition. Perpendicular to the direction of the subband, selective processing can be performed. This can include applying pixel replication when the adjacent row indicates a sharp edge transition and applying low-pass filtering when adjacent rows show small average differences. The result of interpolating a directional subband in this fashion may be seen in Figure 6. The striations discussed earlier are illustrated in Figure 6(c).

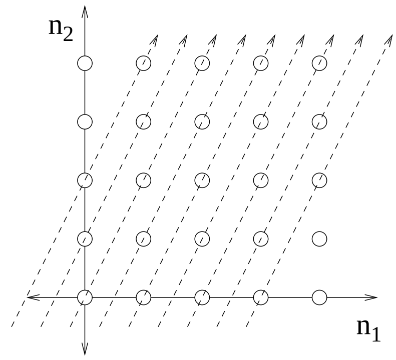

Fig. 5. The concept of applying one-dimensional interpolation techniques to an image in a particular direction.

4. EVALUATION

The directional interpolation system developed in this paper is defined by several parameters. First, the low frequency and high frequency components are separated at the beginning. Hence the cut-off frequency associated with this partitioning is a defining parameter. In our experiments, we chose that cut-off to be $\pi/16$ radians in both frequency variables, ω_1 and ω_2. Second, the number of directional bands employed is a design variable. To ensure reasonably good angular resolution, at least eight bands is suggested, which is what was used in our experiments. Finally, it is helpful to use filters with good frequency characterisitics in conjunction with symmetric extension.

The subjective quality of the new interpolation is noticeably better than the replication and bilinear methods mentioned in the introduction. The examples shown in Figures 7 and 8 illustrate the improvement.

The original 256×256 *Lenna* image is shown in Figure 7(a). The input to the other methods was the decimated version of this original. The staircase effect can be seen in the replication image

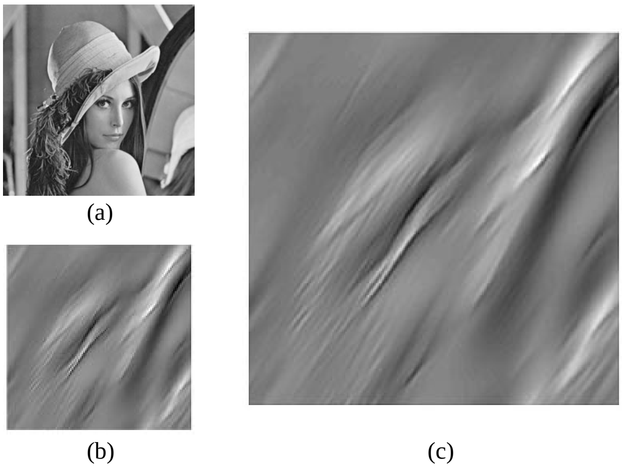

Fig. 6. (a) The original *Lenna* image, (b) a single directional subband of the *Lenna* image, and (c) the corresponding interpolated subband.

in Figure 7(b), as well as in selected parts of the bilinearly interpolated image in Figure 7(c), which also exhibits some particularly blurry areas around the eye on the left. In general, the proposed method produces a sharper image with features closest to that of the original.

The *Cameraman* image is another example and may be seen in Figure 8. The staircase effect may be seen along the edges of the camera handle in Figure 8(a), as expected from simple pixel replication. A similar effect may be seen in Figure 8(b), using bilinear interpolation, along the center of the handle. The proposed method provides a good interpolation of the handle in particular, as the center is relatively uniform from end to end, yet the edges remain crisp, but not jagged.

5. APPLICATION AND CONCLUSION

Given the subjective quality obtained, interpolation of this kind could be employed in a number of situations. One in particular is in connection with the JPEG coding algorithm. It is well known that the JPEG algorithm suffers a steep roll off in subjective quality when the bit-rate falls below a certain level. This level varies from image to image, but for 512×512 *Lenna*, for instance, at rates below 0.2 bpp, the quality is very poor.

Directional interpolation can be used in conjunction with JPEG to extend JPEG's effectiveness at rates well below its normal operating limit. This procedure is illustrated in Figure 9.

To compress an $N \times N$ image below the JPEG bit-rate range, the image is first decimated or downsampled to $\frac{N}{2} \times \frac{N}{2}$. If the target bit-rate is R bpp, then the $\frac{N}{2} \times \frac{N}{2}$ image is compressed using JPEG at a rate of $4R$ bpp. This result is then interpolated back to $N \times N$ using the directional interpolation method to produce the end result.

An example of the effectiveness of this approach is shown in Figure 10, where we considered compressing 512×512 *Lenna* at a target rate of 0.125 bpp. Applying JPEG directly, one obtains the image shown in Figure 10(a). Clearly this rate is below the range of acceptable operation for JPEG. However, by employing

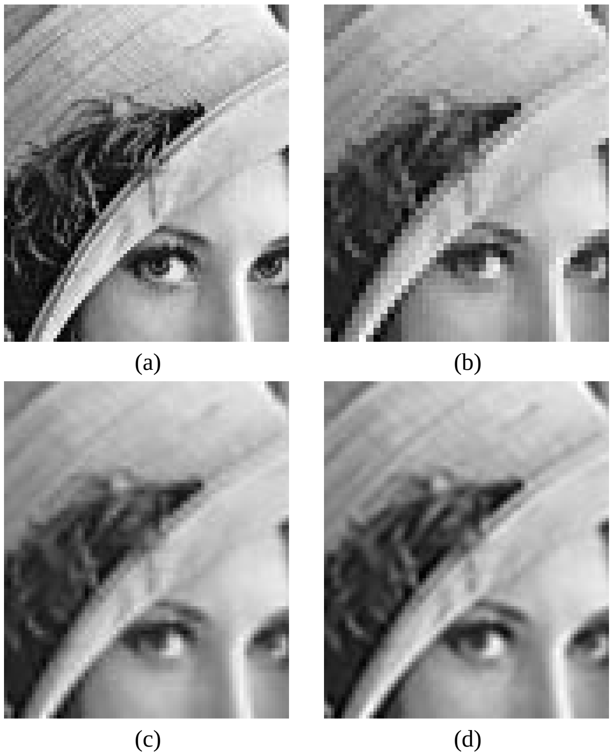

Fig. 7. A cropped version of (a) the original 256×256 *Lenna* image and versions interpolated from 128×128 using (b) pixel replication [23.20 dB PSNR], (b) bilinear interpolation [27.25 dB PSNR], and (c) the proposed method [27.38 dB PSNR].

the directional interpolation method described above, we obtain the image shown in Figure 10(b). Both are using JPEG for compression and both have been compressed to the same bit-rate. But the DFB augmentation has allowed the useful range of the JPEG algorithm to be extended.

A variety of options exist for processing the DFB subbands to enhance the quality of interpolation. The examples presented in this paper highlight a couple of these possibilities, along with an example application to low bit-rate JPEG compression.

6. REFERENCES

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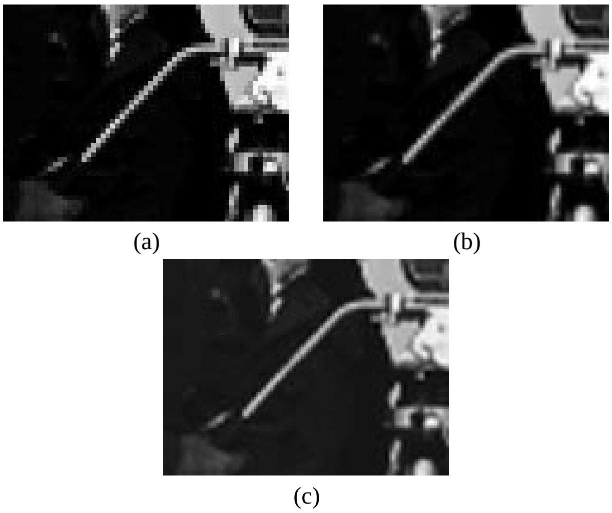

Fig. 8. A cropped, interpolated version of the 256×256 *Cameraman* image using (a) pixel replication, (b) bilinear interpolation, and (c) the proposed method.

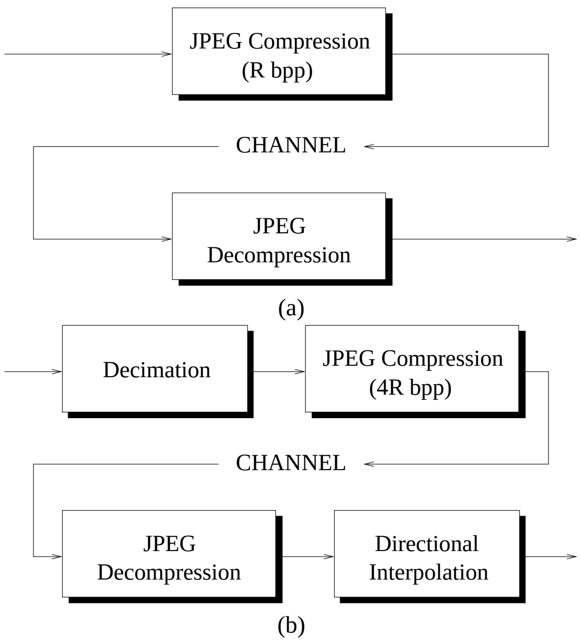

Fig. 9. (a) The original JPEG coding method and (b) the DFB-augmented JPEG coding method.

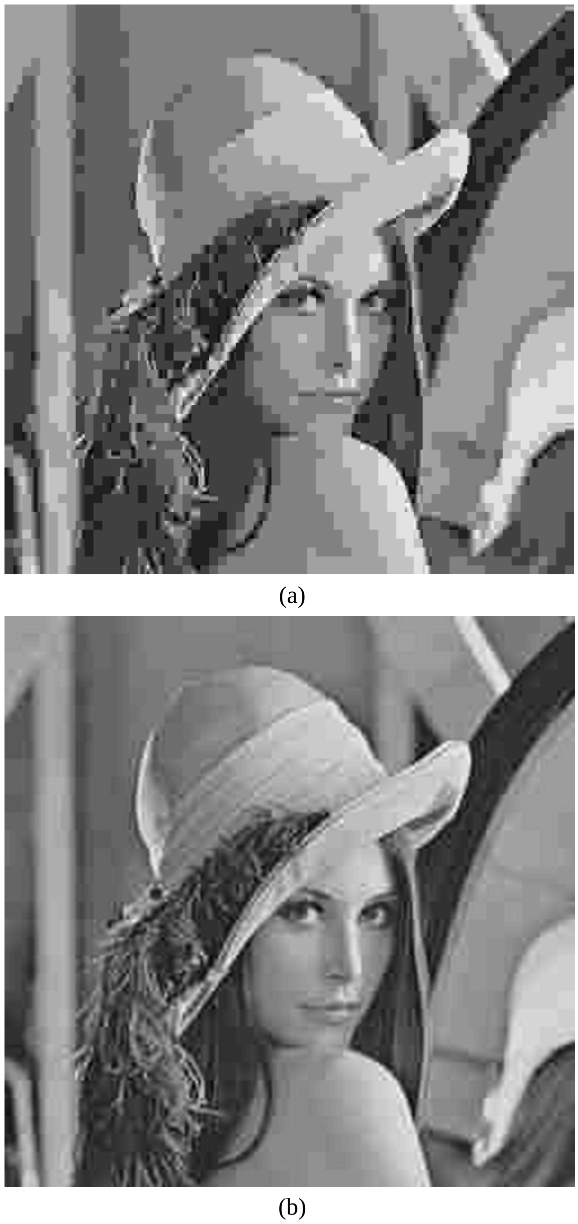

Fig. 10. A comparison between (a) a 512×512 image of *Lenna* coded at 0.1335 bpp using JPEG and (b) DFB-augmented JPEG where a 256×256 image of *Lenna* is JPEG encoded at 0.4917 bpp and then interpolated using the DFB.

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