LINEAR FILTERING TECHNIQUES FOR REDUCTION OF BLOCKINESS

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ABSTRACT: A computationally easy linear filter, namely the odd harmonic suppression filter, has been suggested to reduce blockiness in images. A simpler mapping from 1-D to 2-D has been shown to be more effective for this filter. For a vector quantizer, a new scheme of prefiltered codebook has been proposed to further improve quality. It is easy to construct the inverse filter for such a scheme. Simulation results are provided to support the improvement.

I. ODD HARMONIC SUPPRESSION FILTERING:

Block image coders, such as vector quantizer, orthogonal transform coder, block truncation coder, etc., are known to produce a kind of annoying coding error, namely blockiness, in the decoded image, specially at low bit rates. Because of the mismatch between the luminance values of two spatially adjacent blocks, discontinuity is developed at the block boundaries and a staircase effect shows up at the edges. In this paper simple linear filtering is suggested to enhance a decoded image with blockiness.

For a block of size $m \times m$, the blockiness error is mostly located at a regular interval of m pixels in both horizontal and vertical directions. Therefore, the error spectrum is expected to have amplitude peaks at $(\omega_h, \omega_v) = \left(0, \pm\frac{(2i+1)\pi}{m}\right)$ and $\left(\pm\frac{(2i+1)\pi}{m}, 0\right)$ in the two-dimensional frequency plane, where subscripted frequencies are along horizontal and vertical direction in the 2-D plane, and i is a non-negative integer not exceeding $\frac{m-1}{2}$. A filter suppressing these spectral components may be referred as an *odd harmonic suppression* (OHS) filter. Due to computational difficulties in designing such a 2-D filter using iterative optimization algorithms, mapping techniques from 1-D to 2-D may be used. Due to phase sensitivity of images, linear phase is required. Placing just one zero for each frequency component to be suppressed, $\theta_i = \pm\frac{(2i+1)\pi}{m}$, $0 \geq i \geq \frac{m-1}{2}$, such a 1-D linear-phase OHS filter with smallest length $l = 4\lceil\frac{m}{2}\rceil + 1$ will have a transfer function:

$$\mathbf{H}_d(z) = \prod_i \Big[(1 - 2r_i \cos\theta_i z^{-1} + r_i^2 z^{-2}) \\ (1 - 2r_i^{-1} \cos\theta_i z^{-1} + r_i^{-2} z^{-2})\Big]. \qquad (1)$$

Since linear filters used on images have typically very little attenuation in the stop band, this small length is feasible. The value of r_i depends on the attenuation required. Magnitude response of such a filter is shown in Figure 4, labelled 'Decoder filter', for $m = 8$.

Due to difficulties in directly designing a 2-D OHS filter, as explained in [1, pp. 58–60], our first choice is a separable 2-D linear phase filter of length l^2 achieved by taking the product of $\mathbf{H}_d(z)$ with itself. Due to the square shape of the bands, this filter is henceforth referred to as the *rectangular* filter. The generalized transfer function of an OHS rectangular filter is

$$\begin{aligned}\mathbf{H}_r(z_h, z_v) = \prod_i \Big[\Big\{&1 - 2r_i \cos\theta_i (z_h^{-1} + z_v^{-1}) + r_i^2 (z_h^{-2} \\ &+ z_v^{-2}) + 4r_i^2 \cos^2\theta_i z_h^{-1} z_v^{-1} \\ &- 2r_i^3 \cos\theta_i (z_h^{-1} z_v^{-2} + z_h^{-2} z_v^{-1}) \\ &+ r_i^4 z_h^{-2} z_v^{-2}\Big\} \cdot \Big\{1 - 2r_i^{-1} \cos\theta_i (z_h^{-1} \\ &+ z_v^{-1}) + r_i^{-2} (z_h^{-2} + z_v^{-2}) \\ &+ 4r_i^{-2} \cos^2\theta_i z_h^{-1} z_v^{-1} \\ &- 2r_i^{-3} \cos\theta_i (z_h^{-1} z_v^{-2} + z_h^{-2} z_v^{-1}) \\ &+ r_i^{-4} z_h^{-2} z_v^{-2}\Big\}\Big].\end{aligned} \qquad (2)$$

Secondly, using the *McClellan trnasformation* [2] a 2-D non-separable *circular* (since the contour 'ω = constant' runs approximately circularly around the origin) linear phase filter of length l^2 is designed. This OHS filter has a transfer

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function as follows:

$$\begin{aligned}\mathbf{H}_c(z_h, z_v) = \textstyle\prod_i \Big[& \tfrac{1}{16}(1 + z_h^{-4} + z_v^{-4} + z_h^{-4}z_v^{-4}) + \tfrac{1}{4}(z_h^{-1} \\ & + z_v^{-1} + z_h^{-3} + z_v^{-3} + z_h^{-1}z_v^{-4} \\ & + z_h^{-4}z_v^{-1} + z_h^{-3}z_v^{-4} + z_h^{-4}z_v^{-3}) \\ & - \tfrac{1}{2}(r_i + \tfrac{1}{r_i})\cos\theta_i(z_h^{-1}z_v^{-1} + z_h^{-1}z_v^{-3} \\ & + z_h^{-3}z_v^{-1} + z_h^{-3}z_v^{-3}) + \tfrac{3}{8}(z_h^{-2} + z_v^{-2} \\ & + z_h^{-2}z_v^{-4} + z_h^{-4}z_v^{-2}) - \big(\tfrac{1}{2} + (r_i \\ & + \tfrac{1}{r_i})\cos\theta_i\big) \cdot (z_h^{-1}z_v^{-2} + z_h^{-2}z_v^{-1} \\ & + z_h^{-2}z_v^{-3} + z_h^{-3}z_v^{-2}) + \big(\tfrac{1}{4} + r_i^2 + \tfrac{1}{r_i^2} \\ & + 4\cos^2\theta_i + 2(r_i \\ & + \tfrac{1}{r_i})\cos\theta_i\big) z_h^{-2}z_v^{-2}\Big].\end{aligned} \tag{3}$$

The McClellan mapping of frequency from one to two dimensions, even in the generalized form [3, eq. (3)], is quite restricted. For the OHS filter, this restriction may be avoided. We propose a simple frequency mapping for this special case, $\omega = \omega_h + \omega_v$. The 2-D filter resulting from this mapping is called a *striped* (since the contour 'ω = constant' is a straight line with slope -1) filter. This filter is nonseparable in general. Using $\mathbf{H}_d(z)$, the 2-D linear phase striped filter of length l^2 has the transfer function

$$\begin{aligned}\mathbf{H}_s(z_h, z_v) = \textstyle\prod_i \Big[& (1 - 2r_i\cos\theta_i z_h^{-1}z_v^{-1} + r_i^2 z_h^{-2}z_v^{-2}) \\ & (1 - 2r_i^{-1}\cos\theta_i z_h^{-1}z_v^{-1} + r_i^{-2}z_h^{-2}z_v^{-2})\Big].\end{aligned} \tag{4}$$

All the three filters have same attenuation characteristics along the two axes, but the responses differ from one another in between the axes. The magnitude response of these filters is shown in Figure 1 for $m = 8$.

These three 2-D filters with similar parameters have been applied on block coded (in this case, vector quantized with $m = 8$) images to compare their performance. The resulting images are very similar in terms of reduction of blockiness. The circular filter is found to be marginally better. However, a problem is faced in this type of linear filtering. The sharp edges in the picture are affected by filtering, and the filtered image shows mild shadows (ringing) around them. While the horizontal and vertical edges are most affected by the rectangular filter, edges of all orientations are affected by the circular filter. The striped filter affects only the edges with a slope of -1. Therefore, the striped filter is preferred on this account.

While the rectangular and circular filters have l^2 nonzero coefficients in general, the striped filter has only l nonzero coefficients. Therefore direct implementation (using 2-D convolution) of the former two types requires order of l^2 operations per output point as opposed to order of l operations for the striped filter. However, realization of the rectangular filter as two cascaded 1-D filters, while exploiting the symmetry of the transfer function, requires $(l+1)$ multiplications and $(2l-2)$ additions. Similarly, the circular filter may be realized using the direct transformed implementation, which requires $(5l-4)$ multiplications and $(10l-10)$ additions [4, eq. (15) and (16)]. Even though these are only order of l operations, the exact number of operations is always more than that needed for the striped filter.

Figures 2 and 3 show the filtering results with the striped OHS filter. While figure 2 is the decoded image from a low rate vector quantization coder without any processing (conventional method), figure 3 is the OHS filtered version (from here on referred as method-I). The blockiness in the second image is visibly less.

II. PREFILTERED CODEBOOK FOR A VECTOR QUANTIZATION CODER:

The disadvantage of a linear filtering (method-I) is that it always affects the original image (such as sharp edges), which may be compensated by prefiltering at the encoder. The source image is prefiltered by the encoder filter, $\mathbf{H}_e(z)$, having the inverse response of the decoder filter, $\mathbf{H}_d(z)$, and then encoded. The decoded image is then postfiltered by the decoder filter (say, method-II). It is expected that in absence of any coding error, the postfiltered image would be nearly identical to the original image. In this scheme each frame needs to be filtered twice.

For the particular case of a vector quantization coder [5], the prefiltering computation can be avoided. The vector quantization encoder finds out from the codebook, which is a library of a few typical blocks, a block most resembling the input block to be transmitted. An identifier to this typical block is then sent to the decoder. The decoder also has the codebook, so it simply regenerates the chosen typical block from the identifier. We suggest that the decoder codebook be a prefiltered version of the encoder codebook, and the reconstructed image from this codebook be postfiltered at the decoder (referred as method-III). This'll result in an effect similar to prefiltering, but needs no extra computation at the encoder. If the block length is much more than the filter length, then a prefiltered codebook is nearly as good as prefiltering. However, in practice it is just the opposite, but blocks with sharp edges could be prefiltered in such a way that they are not much affected by the postfiltering process. The decoder codebook in this scheme will no longer be the same as the encoder codebook.

Now we look into the design of the 1-D encoder filter. Given the $\mathbf{H}_d(z)$ to be FIR, ideally $\mathbf{H}_e(z)$ should satisfy

$$|\mathbf{H}_e(e^{j\omega})\mathbf{H}_d(e^{j\omega})| = 1, \tag{5}$$

or $\mathbf{H}_e(z) = 1/\mathbf{H}_d(z)$. Since $\mathbf{H}_d(z)$ is linear phase and not minimum phase, the IIR encoder filter will be unstable. Also from the implementation point of view it is desirable that $\mathbf{H}_e(z)$ is also FIR. From (5), the magnitude response of this filter, $|\mathbf{H}_e(e^{j\omega})|$, should be equal (or, almost equal) to $1/|\mathbf{H}_d(e^{j\omega})|$. For the OHS filter with little attenuation (appropriate for image), $|\mathbf{H}_d(e^{j\omega})| = 1 - \epsilon(\omega)$, where $\epsilon(\omega)$ is always small compared to unity. Therefore, (5) can be approximated as

$$|\mathbf{H}_e(e^{j\omega})| \approx 2 - |\mathbf{H}_d(e^{j\omega})|. \tag{6}$$

But $\mathbf{H}_d(e^{j\omega}) = e^{-j((l-1)/2)\omega}|\mathbf{H}_d(e^{j\omega})|$ (linear phase), and same is true for $\mathbf{H}_e(z)$ of equal length. Thus, (5) may be approximated as

$$\mathbf{H}_e(z) + \mathbf{H}_d(z) \approx 2z^{-\frac{l-1}{2}}, \tag{7}$$

which is used to design $\mathbf{H}_e(z)$. Figure 4 shows the magnitude response of the linear phase decoder filter, the ideal IIR encoder filter, and the linear phase FIR encoder filter obtained using (7) for $m = 8$.

If the decoder filter is not linear phase, slight modification of the above strategy allows us to approximate (5) as a different condition,

$$\mathbf{H}_e(z)\mathbf{H}_e(z^{-1}) + \mathbf{H}_d(z)\mathbf{H}_d(z^{-1}) \approx 2, \tag{8}$$

which may now be used to design $\mathbf{H}_e(z)$. Once $\mathbf{H}_e(z)\mathbf{H}_e(z^{-1})$ is found, the zeros of this sequence are to be computed. Only the zeros inside (and, on) the unit circle are then taken to form the minimum phase encoder filter, $\mathbf{H}_e(z)$. The results are quite similar to that of figure 4.

Simulation results on monochrome images show that both the 'method-II' and the 'method-III' results in improved image quality when compared to 'method-I' images of section I. The edges are notably better represented. The 'method-III' coder, which uses the prefiltered codebook, offers more subjective improvement and better suppression of blockiness over the 'method-II' coder using the normal codebook. Thus, use of prefiltered codebook followed by postfiltering in a coder produces the best subjective quality. Figure 5 shows the result of using a prefiltered codebook. While figure 3 is the 'method-I' image (from a normal codebook), figure 5 is the 'method-III' image (fron the prefiltered codebook). The filter used here is a 2-D linear phase striped OHS filter.

III. CONCLUSION & ACKNOWLEDGEMENT:

Some computationally simple linear filtering techniques have been proposed in order to reduce blockiness in the decoded image of a block coder. Using a simple mapping of frequency from one to two dimensions, a linear phase striped OHS filter has been designed which produces the same or better improvement than rectangular or circular filter but requires less computation. Also, use of prefiltered codebook instead of prefiltering the input image has been suggested in context of vector quantization coder, and is shown to be not only computationally easy but also subjectively superior.

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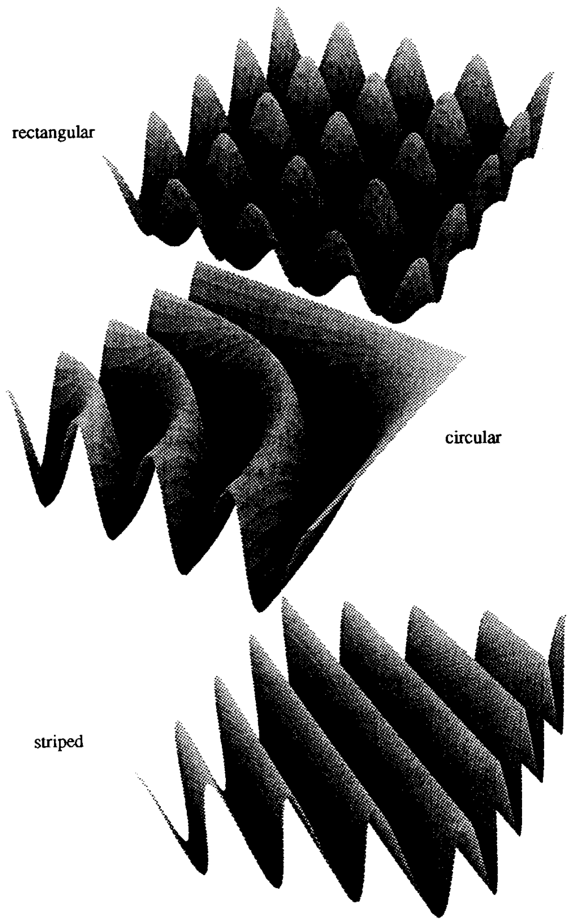

Figure 1: Magnitude Response of 2-D OHS Filters

Figure 2: Decoded Image Before Filtering (Conventional)

Figure 3: Decoded Image After Striped OHS Filtering ('Method-I')

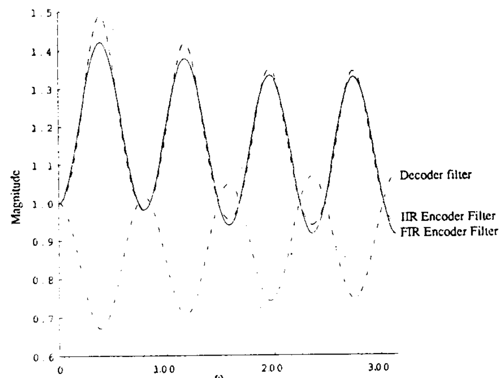

Figure 4: Magnitude Response of 1-D Linear Phase Decoder and Encoder Filters

Figure 5: Decoded Image Using Prefiltered Codebook After Striped OHS Filtering ('Method-III')