

Boundary Artefact Reduction Using Odd Tile Length and the Low Pass First Convention (OTLPF)

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ABSTRACT

It is well known that tile boundary artefacts occur in lossy wavelet-based image coding [1, 2, 3, 4, 5]. The base model of the JPEG2000 standard (ie JPEG2000 Part I) suffers from these artefacts, being a wavelet-based coding system. This paper analyses the tile boundary problems of JPEG2000 Part I and presents a novel method for reducing these tile boundary artefacts. This method has recently been adopted as part of the JPEG 2000 Verification Model 9.0 and as an addition to Part II of the JPEG2000 standard.

Keywords: wavelet transform, tile boundary artefacts, JPEG2000, OTLPF convention

1. INTRODUCTION

It has been shown [6] that tile boundary artefacts are an intrinsic feature associated with the common method used to choose the tile size and the type of symmetric extension employed in wavelet-based image decomposition. It has also been shown that a significant reduction in boundary artefacts can be achieved by choosing an odd tile size given by $2^N + 1$ and by down-sampling using the low-pass first convention rather than using the traditional even tile size given by 2^N .

2. TILE BOUNDARY PROBLEMS IN JPEG2000 PART I

Figure 1 shows the mean square errors (MSE) for each row and column of the reconstructed image of Lena compressed at a bit rate of 0.5 bit/bpp using JPEG2000 Part I [7] technology, verification model (VM) 8.0. Tile sizes of 64x64 were used and the tiles are distinguished by alternating light and dark sections in the plots. In the down-sampling process, low-pass coefficients were kept in the far-left column and top row of each tile. Since the tile lengths are even, high-pass coefficients populate the far-right column and bottom row of each tile. The large MSE spikes at the tile boundary can be clearly seen in both plots. These spikes are associated with the right and bottom sides of each tile, indicating that there are large errors in each tile's far right and bottom sides where the high-pass coefficients occurred at the tile boundary.

Next we change the order of the low-pass and high-pass coefficients retained in the down-sampling to locate high-pass coefficients at the far-left column and top row of each tile. Hence low-pass coefficients will populate the right-hand column and bottom row of each tile. Shown in Figure 2 is a plot of the same Lena image compressed at 0.5 bpp but now with high-pass coefficients located in the far-left column and top row of each tile. It is now clear that the large MSE spikes associated with the tile boundaries have flipped from the right-hand side to the left-hand side and from the bottom to the top of each tile.

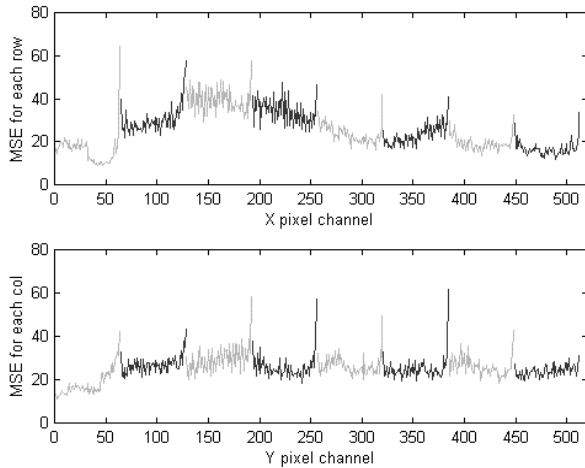


Figure 1: Average MSE for each row and column of "Lena" with a tile size of 64x64, starting with low-pass coefficients and ending with high-pass coefficients in each tile.

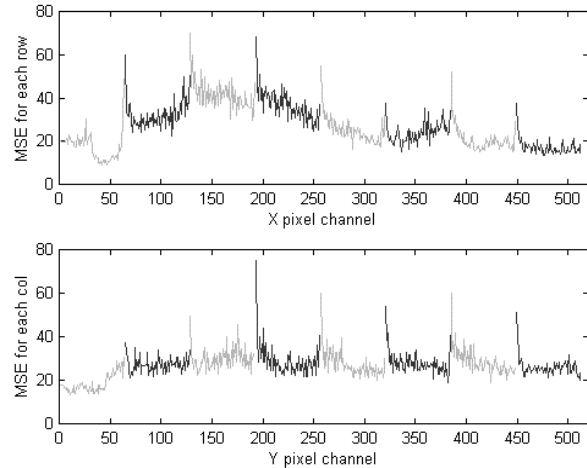


Figure 2: Average MSE for each row and column of "Lena" with a tile size of 64x64, starting with high-pass coefficients and ending with low-pass coefficients in each tile.

It can be concluded that if even tile sizes are used there are always large errors in two of the four sides of the tile boundary. The errors can be flipped from left to right and from top to bottom but large errors cannot be eliminated from all four sides of the tile boundary.

One way to avoid the large errors in the tile boundary associated with high-pass coefficients is to locate low-pass coefficients along all four sides of the tile boundary. To achieve this odd sized tiles are required, such as 65x65.

Figure 3 shows a plot of the MSE for the same Lena image compressed at 0.5 bpp but with a tile size of 65x65. Now, instead of a MSE spike associated with one side of a tile boundary, in the two plots for the rows and columns, there are now large MSE spikes along two sides of every second tile in both plots. The result of this effect is a "good tile", e.g. the first tile, where the boundary MSE is about the same magnitude as the interior of the tile. Following the "good tile" however is a "bad tile" such as the second tile from the plots, where there are large MSE spikes associated with both sides of the tile boundary.

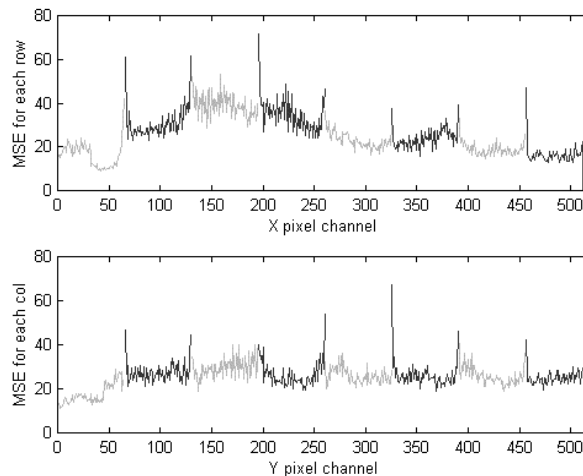


Figure 3: Average MSE for each row and column of "Lena" with a tile size of 65x65.

As defined in the JPEG2000 standard, low-pass coefficients must be located on even canvas coordinates and high-pass coefficients on odd canvas coordinates regardless of the tile and image position in the canvas coordinate system. Thus, if the first column of the first tile is located on even coordinates the last column will end on even coordinate as well, due to the odd tile length. Therefore, as defined, this tile will start and end with low-pass coefficients. As we know this will reconstruct a good tile without a large MSE at the tile boundary. The second tile, having its first and last columns located on odd coordinates will therefore have high-pass coefficients located at both left and right sides of the tile boundary. Hence there will be a large MSE on both left and right sides at the tile boundary (e.g the second tile).

3. ODD TILE SIZE LOW PASS FIRST CONVENTION (OTLPPF)

Let us consider the low-pass (L) and high-pass (H) coefficients used for the decomposition and reconstruction of an image. For tiles with even size (e.g. 64x64) we have:

LHLHLH...LHLH
 or
 HLHLHL...HLHL

Since there is always a high-pass coefficient at one side of the *even* tile boundary there will be large MSEs in either the right or left side of the tile boundary.

For tiles with odd size e.g. 65x65 we have:

LHLHLH...LHLHL for "good" tiles
 and
 HLHLH...LHLHLH for "bad" tiles.

For good tiles, because there are low-pass coefficients L at both ends of the tiles, there are no large errors in the tile boundary. For bad tiles, because there are high-pass coefficients H at both ends of the tiles, there are large errors in both sides of the tile boundary.

Hence to avoid a large MSE at the tile boundary the following criteria should be met:

1. Odd Tile-sizes
2. Low Pass coefficients at the start of every tile

The technique proposed to meet these criteria is called the Odd Tile Low Pass First (OTLPPF) convention and is currently being adopted by and defined in the JPEG2000 VM9.0. It will be shown that this simple convention reduces the tile boundary artefacts significantly. Figure 4 shows a plot of the MSE for the Lena image reconstructed using the OTLPPF convention with tile sizes of 65x65. The bit rate is 0.5 bpp as in the plots shown in previous figures.

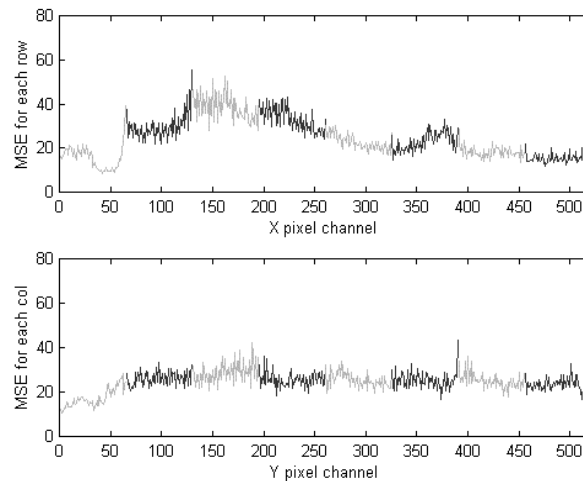


Figure 4: Average MSE for each row and column of "Lena" with a tile size of 65x65 and OTLPPF convention.

We can see that all the large MSE spikes in the plot have been eliminated. In other words, the tile boundary artefacts have been significantly reduced by simply choosing an odd tile size and always having the low-pass coefficients first in every tile.

This method is very simple and involves no new algorithm. This method not only reduces the tile boundary artefacts but also reduces the bit rate for a given PSNR in a compressed image. Shown in table 1 is the PSNR for all above processes and the one discussed in the next section. It can be seen that over all there is a 0.1 to 0.3 dB improvement for this technique compared to not using OTLPF convention. It should be pointed out that this is a comparison of the PSNR for the entire image when this technique only reduces errors for the samples at the tile boundary which is small compared with the total number of samples in a tile.

Rate (bpp)		0.1	0.25	0.5	1.0	1.5
PSNR	Part I tile size 64x64	24.2	30.0	33.9	37.3	39.5
	Part I tile size 65x65	24.5	30.1	33.8	37.3	39.4
	OTLPF tile size 65x65	24.8	30.3	34.0	37.4	39.5
	OTLPF/overlap tile size 65x65	24.7	30.3	34.0	37.3	39.5

Table 1: PSNR vs bits/pixel.

The benefits of the OTLPF convention are not dependent on the choice of image, tile size or compression factor; using the traditional convention high errors always occur at tile boundaries regardless of the tile size and compression factor being chosen.

Results for the "Lena" image coded at 0.25 bpp are shown in Figures 5 and 6, with results for 1.0 bpp shown in Figures 7 and 8. It shows clearly that, in both high and low bit rate cases, using the OTLPF convention has significantly less error at the tile boundary compared to the traditional coding convention of even tile sizes.

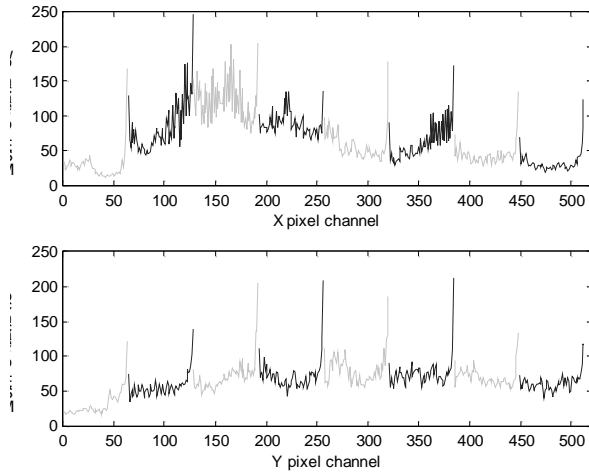


Figure 5: Average MSE for each row and column of "Lena" with 0.25 bpp, a tile size of 64x64.

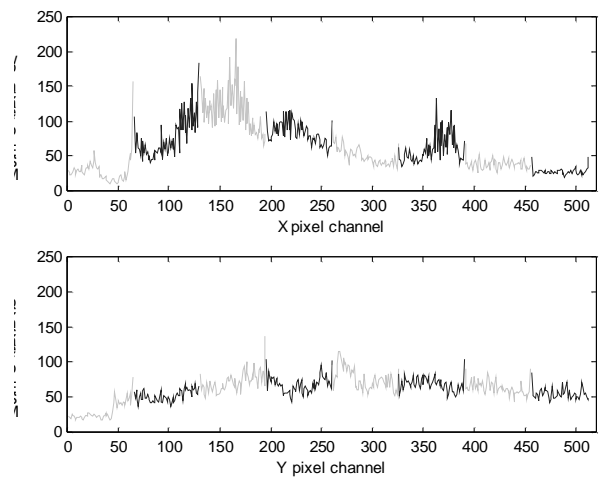


Figure 6: Average MSE for each row and column of "Lena" with 0.25 bpp, a tile size of 65x65 and OTLPF convention.

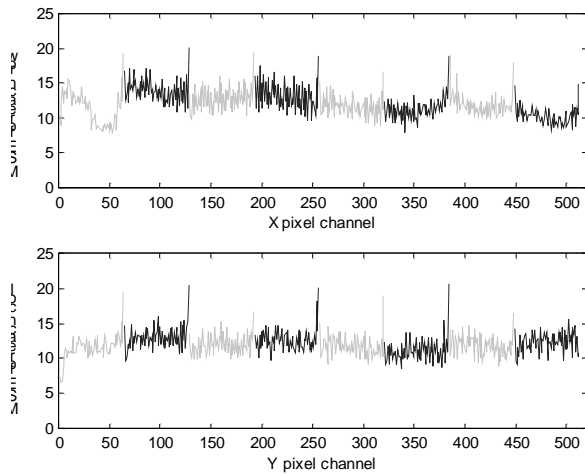


Figure 7: Average MSE for each row and column of "Lena" with 1.0 bpp, a tile size of 64x64.

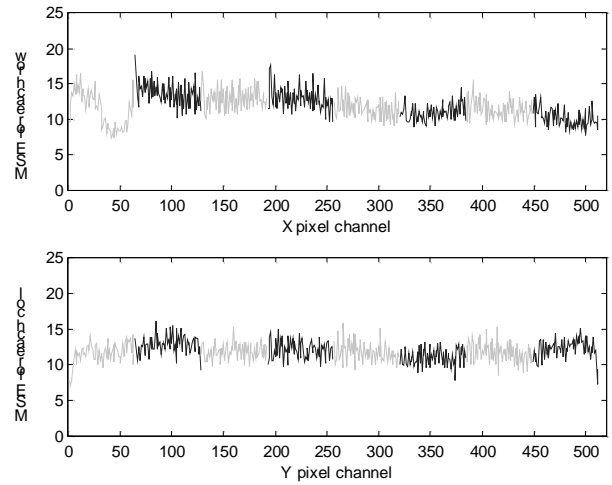


Figure 8: Average MSE for each row and column of "Lena" with 1.0 bpp, a tile size of 65x65 and OTLPF convention.

Figures 9 to 12 show plots of the MSE of the "Café" image coded at 0.5 bpp but with different tile sizes. Results for traditional coding convention using even sized tiles are shown in figures 9 and 11. Although tile sizes are quite different (64x64 and 256x256) there is no difference in the large MSE spikes at the tile boundaries. Results using the OTLPF convention with tile sizes 65x65 and 257x257 are shown in figures 10 and 12. The improvement in the MSE for tile boundary samples in both cases is obvious.

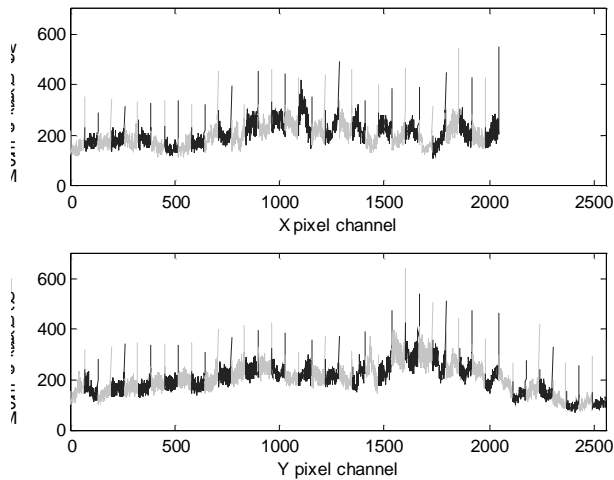


Figure 9: Average MSE for each row and column of "Café" with 0.5 bpp, a tile size of 64x64.

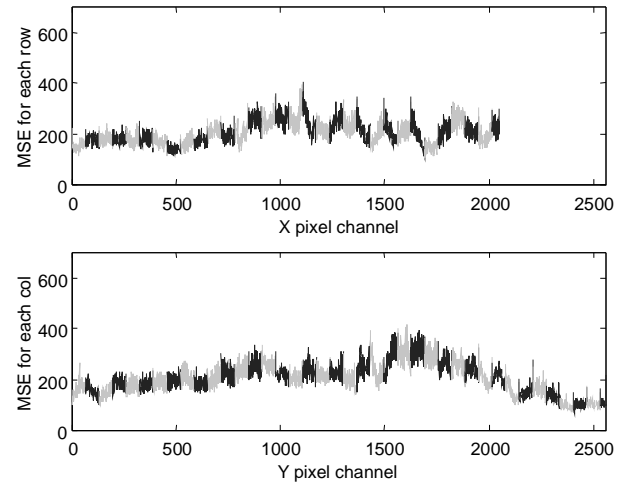


Figure 10: Average MSE for each row and column of "Café" with 0.5 bpp, a tile size of 65x65 and OTLPF convention.

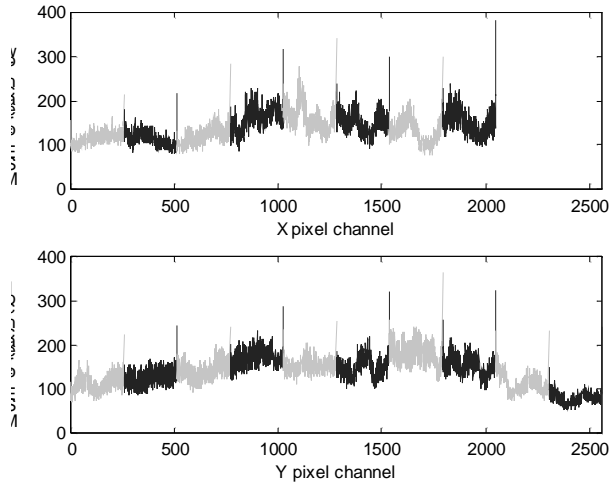


Figure 11: Average MSE for each row and column of "Café" with 0.5 bpp, a tile size of 256x256.

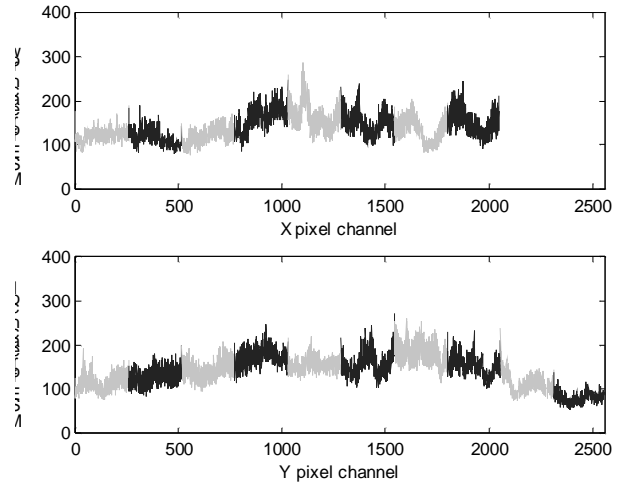


Figure 12: Average MSE for each row and column of "Café" with 0.5 bpp, a tile size of 257x257 and OTLPF convention.

4. OTLPF WITHIN THE JPEG2000 STANDARD

As discussed above the JPEG2000 standard dictates that low-pass coefficients must be located on even canvas coordinates and high-pass coefficients on odd canvas coordinates, regardless of the tile and image position in the canvas coordinate system. To use the OTLPF convention and also meet this requirement an overlap method is employed. Tiles are now overlapped with neighbour tiles by one sample. Because of this overlap we can have odd tile sizes with the top left sample of every tile located at an even-even coordinate in the canvas system. Figure 13 shows the row and column MSE results for the OTLPF convention when using this overlap technique.

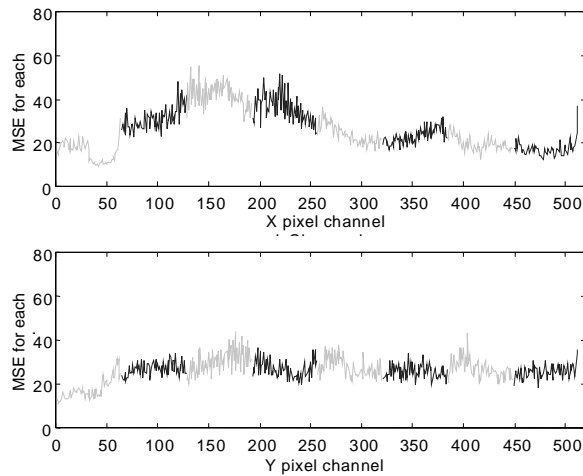


Figure 13: Average MSE for each row and column of "Lena" with a tile size of 65x65 using OTLPF and tiles overlapped by one sample.

5 SUBJECTIVE RESULTS

Boundary artefacts often form a significant proportion of the degradation occurring due to image compression. It has been demonstrated above that implementation of the OTLPF convention can greatly reduce the MSE associated with samples at tile boundaries. The difference in subjective quality is illustrated in Figures 14 and 15, showing reconstructed "Lena" image compressed at 0.25 bpp using JPEG2000 VM 9.0 with and without the OTLPF convention.



Figure 14: Decoded "Lena" image with a tile size of 64x64 at 0.25 bpp.



Figure 15: Decoded "Lena" image with a tile size of 65x65 at 0.25 bpp using OTLPF convention.

6 CONCLUSIONS

It has been demonstrated that the OTLPF convention is simple and reduces tile boundary artefacts significantly in wavelet-based image compression. This reduction can be observed in subjective results and in the MSE regardless of the size of the tiles and the compression factor.

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