CHAPTER 4: VISUAL SIGNAL CONTENT BASED IMAGE COMPRESSION

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4.1 INTRODUCTION

The conventional image compression methods are JPEG & JPEG 2000. These methods have a superior compression performance to their credit along with multiple resolution representation of the image. However, as a consequence of this flexibility, JPEG 2000 requires complex and computationally demanding coders.

4.1.1 Limitations in JPEG & JPEG 2000 Standards

As stated by Bruckstein et al. [48] and Usevitch and Wallace [49-51], “JPEG’s good middle & high rate compression performance and low computational and memory complexity make it an attractive method for natural image compression.” Nevertheless, as we go to low bit rates, these compression algorithms introduce disturbing artifacts.

At low bit rate coding, i.e., when the compression ratio is increased, the bits allocated per pixel decrease resulting in heavy deterioration in the coded picture quality. Under such conditions, the insufficient bit representation achieved by these standard schemes introduces severe coding artifacts.

Quoting Yuen and Wu [52], “JPEG 2000 produces ringing artifacts, manifested as blur and rings near edges in the image, while JPEG produces ringing as well as blocking artifacts due to its 8x8 blocks”.

These effects are highly undesirable.
4.2 DOWNSAMPLING

Since most images contain areas of high spatial correlation, and subsequently are highly redundant, the necessary information to retrieve an image can be got from sparse pixel data (after eliminating redundant information). Hence, it follows that some of the pixels can be neglected or in other words, the image can be down sampled prior to compression and the image can be restored from the remaining pixel data through interpolation. In fact, research [48,53,54] has already proved that down sampling before performing compression and coding and up sampling after decoding definitely improves the coded image quality at low bit rates.

4.2.1 Visual Content Significance in an image

In order to exploit the high spatial correlation existing in most images, the visual content of the signal can be a powerful parameter. As demonstrated by Lin and Dong [27] via their adaptive algorithm, “based on the local visual significance of the signal, the appropriate down sampling ratio, direction of down sampling and the optimum quantization step can be decided”.

Since the emphasis is on the spatial visual content of the image, the effect of the direction of spatial variations is of primary importance. The significance of this parameter is based on the psycho visual aspects of the human visual system and as Ran & Farvardin [55] have stated, “the objective is to extract and discriminate different properties of image signals that are of significance to our perception”. They have emphasized that “the collection of the individual pixel intensity values, without any interaction between them, is not what produces the visual perception. It is the edge information of the image signal that stimulates our visual perception”.

Based on these observations, Ran & Farvardin [55] have proposed “a three-component image model comprising of i) strong edges, ii) areas of smooth variation, and iii) textures”. They claim that “the three components play different roles in the formation of perception. Therefore, the edge information in an image is basically responsible for our perception. While stronger edges are of higher importance to our perception, the smooth areas influence our perception together with the edge information”.

4.2.2 Down Sampling based on the visual content
Low spatial variation in a direction in a particular area of the image suggests very low visual significance in that direction at the given location. Hence, down sampling in that particular direction will yield less coding distortions & high compression rate. Conversely, high spatial variation in a given direction implies the existence of perceptually important visual details such as edges etc., whose information has to be preserved. Hence, down sampling will result in loss of information and significant distortions in the decompressed image. Therefore, in such situations, down sampling must be avoided.

4.2.3 Limitations of the existing schemes
In the existing schemes [48,53,54], the following limitations exist:

i) the down sampling ratio is fixed by the user

ii) the critical bit rate is low and image dependent, and

iii) the encoding process has to switch between a down sampling scheme and a traditional scheme to give a good coding quality for different images.
4.3 The Proposed Scheme

The proposed scheme aims at taking these decisions adaptively. Further, the critical bit rate as well as the coding quality will be superior. In addition to this, the coding scheme will be image-independent. Hence, the limitations of the existing schemes will be overcome.

In low bit rate coding, the decision regarding the appropriateness of down sampling and, if it is decided that down sampling is advantageous, then, the decision regarding the level of down sampling should be determined by the key factor, the *local visual signal content*. This decision will ensure that minimum bits can be used to obtain optimum coding quality.

4.3.1 Down Sampling Process

Let \( I \) = Full resolution Original image

\[ I^{h,v} = \text{Down sampled sub-image of } I \]

\[ I^{h,v} = \text{Discarded portion of } I \text{ after down sampling} = I - I^{h,v} \]

where \( h \) = down sampling factor in horizontal direction

\( v \) = down sampling factor in vertical direction

and \( h,v = 0,1 \)

In the present study, the values of \( h, v \) are restricted to two values only – 0 and 1. Hence, the following cases of down sampling are possible. They are

1. \( h=0, v=1; 1/2 \) down sampling in vertical direction only (2 cases)
2. \( h=1, v=0; 1/2 \) downsampling in horizontal direction only (2 cases)
3. \( h=v=1; 1/2 \) down sampling in both directions : total down sample ratio is \( 1/4 \)

(4 cases)
4.3.2 Physical Effects of Down Sampling

**Increase in Spatial Frequencies:**

There is a reduction in the geographical distance between sampled pixels. Hence, the spatial frequencies can be expected to increase in a down sampled image.

**Coding distortions:**

Down sampling results in a smaller coding distortion because more bits are now available for coding $I_{h,v}$ alone.

Also, considering the fact that the coding distortion and the estimation distortion are dependent on the spatial visual content in an image, it follows that, for the down sampling scheme to be successful, down sampling must be avoided in directions having more spatial variations or high visual significance. When the visual significance is low along one direction in the original image, it means that spatial variation is low along that direction and hence, down sampling will result in small coding distortion.

**Reduction in the number of non-zero coefficients used:**

As down sampling reduces redundancies, the number of non-zero coefficients used reduces drastically leading to significantly higher compression ratios.

4.3.3 Strategy for the decision regarding the MMD sampling and quantization

In order to achieve the proposed adaptive algorithm, it is required that two parameters are chosen properly for each block in the image. They are
- The appropriate down sampling mode
- The appropriate quantization step

Since, the current implementation is only on two values of the down sampling factors, it follows that the down sampling ratios used in this work range from \( \frac{1}{4} \) to \( \frac{1}{2} \) only.

Therefore, the possible options for down sampling are as listed in Table 4.1.

It is to be noted that the down sampling mode \( M_0(\text{h}=0,\text{v}=0) \) performs no down sampling and therefore, is not used here. The proposed scheme aims at finding a down sampling mode \((M_{1-3})\) and a quantization step \((QS)\) to achieve a superior coding performance for a given bit-rate.

<table>
<thead>
<tr>
<th>Down Sampling Mode</th>
<th>Down Sampling Factors</th>
<th>Down Sampling Ratio</th>
<th>Cases Per Mode</th>
<th>Down Sampled Blocks</th>
<th>Down Sample Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_1 )</td>
<td>0 1</td>
<td>( \frac{1}{2} )</td>
<td>2</td>
<td>Two ( 8 \times 8 ) blocks in horizontal direction</td>
<td>1-D Down Sampling (reduced in vertical direction)</td>
</tr>
<tr>
<td>( M_2 )</td>
<td>1 0</td>
<td>( \frac{1}{2} )</td>
<td>2</td>
<td>Two ( 8 \times 8 ) blocks in vertical direction</td>
<td>1-D Down Sampling (reduced in horizontal direction)</td>
</tr>
<tr>
<td>( M_3 )</td>
<td>1 1</td>
<td>( \frac{1}{4} )</td>
<td>4</td>
<td>One ( 8 \times 8 ) block</td>
<td>2-D Down Sampling</td>
</tr>
</tbody>
</table>

The quantization steps being used are listed in Table 4.2.

<table>
<thead>
<tr>
<th>QS</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
</tr>
</thead>
</table>

Table 4.1: Possible Down Sampling Mode Details

Table 4.2: Quantization Steps
4.3.4 Algorithm for the proposed multi-modal down sampling decision

- Input Image File
- Enter Block Size
- Enter the Standard Quantization Matrix
- Obtain Adaptive DCT Compression

> For each block, Apply the Eight Down Sampling Mode options on the image

➢ For each down sampled block
  - Perform DCT using different Quantization Steps
  - Perform IDCT and Resize using three interpolation methods
  - Evaluate the coding distortion using the MSE for each output
  - Identify the combination of the Down Sampling Mode and the QS which gives the minimum MSE
  - Index the corresponding down sampled block (compressed block with least MSE)

➢ Repeat for all blocks

- Obtain JPEG Compression
- Calculate PSNR, CR and Number of down sampled blocks for both the adaptive DCT and JPEG methods

4.3.5 Predicted advantages of the proposed Adaptive Down Sampling scheme

- Automatic switching of the coder between the standard and the adaptive modes.
- Capable of outperforming the standard coders in terms of coding quality.
- Significant increase in the critical bit rate.
- Image-independent compression scheme.
4.3.6 Flow chart representation of the proposed scheme

![Flow chart representation of the proposed scheme](image)

Fig. 4.1: Flowchart Representation of the Proposed Algorithm for ADCT
### 4.4 RESULTS

The algorithm proposed in Section 4.3.4 has been implemented on the standard images of Lena, Peppers and Wheel and also on an own image named as Twin Towers and the PSNR & CR values of the Proposed Algorithm for ADCT are tabulated as in Table 4.3.

Table 4.3: PSNR (in dB) & CR Performance of the Proposed Algorithm for ADCT

<table>
<thead>
<tr>
<th></th>
<th>Q P</th>
<th>0.20</th>
<th>0.40</th>
<th>0.60</th>
<th>0.80</th>
<th>1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LENA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSNR</td>
<td>JPEG</td>
<td>40.85</td>
<td>38.55</td>
<td>37.33</td>
<td>36.46</td>
<td>35.80</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>34.55</td>
<td>33.93</td>
<td>33.42</td>
<td>33.03</td>
<td>32.69</td>
</tr>
<tr>
<td>CR</td>
<td>JPEG</td>
<td>7.24</td>
<td>11.02</td>
<td>14.07</td>
<td>16.91</td>
<td>19.34</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>14.89</td>
<td>22.02</td>
<td>27.74</td>
<td>33.44</td>
<td>37.87</td>
</tr>
<tr>
<td><strong>PEPPERS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSNR</td>
<td>JPEG</td>
<td>45.95</td>
<td>43.21</td>
<td>41.72</td>
<td>40.61</td>
<td>39.74</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>38.95</td>
<td>38.08</td>
<td>37.37</td>
<td>36.83</td>
<td>36.38</td>
</tr>
<tr>
<td>CR</td>
<td>JPEG</td>
<td>10.82</td>
<td>16.27</td>
<td>20.63</td>
<td>25.08</td>
<td>28.70</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>20.32</td>
<td>29.68</td>
<td>37.23</td>
<td>44.32</td>
<td>50.03</td>
</tr>
<tr>
<td><strong>TWIN TOWERS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSNR</td>
<td>JPEG</td>
<td>41.66</td>
<td>37.78</td>
<td>35.82</td>
<td>34.51</td>
<td>33.58</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>31.26</td>
<td>30.79</td>
<td>30.31</td>
<td>29.93</td>
<td>29.57</td>
</tr>
<tr>
<td>CR</td>
<td>JPEG</td>
<td>7.31</td>
<td>9.51</td>
<td>11.40</td>
<td>13.20</td>
<td>14.75</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>14.16</td>
<td>18.66</td>
<td>22.42</td>
<td>26.04</td>
<td>29.48</td>
</tr>
<tr>
<td><strong>WHEEL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSNR</td>
<td>JPEG</td>
<td>42.40</td>
<td>38.15</td>
<td>35.83</td>
<td>34.19</td>
<td>33.10</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>28.36</td>
<td>28.04</td>
<td>27.72</td>
<td>27.37</td>
<td>27.05</td>
</tr>
<tr>
<td>CR</td>
<td>JPEG</td>
<td>7.09</td>
<td>8.51</td>
<td>9.76</td>
<td>10.89</td>
<td>11.98</td>
</tr>
<tr>
<td></td>
<td>ADCT</td>
<td>14.68</td>
<td>17.68</td>
<td>19.97</td>
<td>22.10</td>
<td>23.87</td>
</tr>
</tbody>
</table>

The graphs for PSNR and CR performance for all the images are presented below in fig. 4.2 and fig.4.3. The following observations are evident from Table 4.3 as well as the graphs in figures 4.2 and 4.3:

- The standard JPEG Algorithm has outperformed the proposed algorithm using Adaptive DCT compression in terms of PSNR values.
However, the compression achieved is much higher in case of the proposed adaptive algorithm.

The significance of better compression performance of the proposed algorithm can be viewed in the perspective of the visual signal content of the images.

The compressed-decompressed images presented in Figs.4.4-4.7 show that though the PSNR values are lower for the adaptive approach, the visual quality of the images is well preserved.

Fig.4.2: PSNR (in dB) and CR Comparisons for LENA and PEPPERS for ADCT
Fig.4.3: PSNR (in dB) and CR Comparisons for TWIN TOWERS and WHEELS for ADCT
Fig. 4.4: LENA Images using JPEG and Adaptive DCT based Compression
Fig. 4.5: PEPPERS Images using JPEG and Adaptive DCT based Compression
Fig. 4.6: TWIN TOWERS Images using JPEG and Adaptive DCT based Compression
Fig. 4.7: WHEEL Images using JPEG and Adaptive DCT based Compression
4.5 CONCLUSIONS

The results and inferences presented in the previous section support the proposed adaptive DCT based compression algorithm in its claim of achieving better Compression Ratios while preserving the visually significant details in the image.

However, the inherent disadvantages of DCT (discussed in section 3.2.3) introduce some undesirable artifacts in the images which account for the lower PSNR values. This setback can be overcome by employing the Wavelet Transforms which are free of these inherent disadvantages. The following chapter introduces the use of the wavelet transform in place of the DCT.
REFERENCES:


