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Parallel Image Compression and Analysis with Wavelets

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***Abstract*—**This paper presents image compression with wavelet based method. The wavelet transformation divides image to low- and high pass filtered parts. The traditional JPEG compression technique requires lower computation power with feasible losses, when only compression is needed. However, there is obvious need for wavelet based methods in certain circumstances. The methods are intended to the applications in which the image analyzing is done parallel with compression. Furthermore, high frequency bands can be used to detect changes or edges. Wavelets enable hierarchical analysis for low pass filtered sub-images. The first analysis can be done for a small image, and only if any interesting is found, the whole image is processed or reconstructed.

***Keywords*—**image compression, jpeg, wavelet, vlc

I. Introduction

In recent years the interest in image compression techniques has been steadily grown. The trend is firstly to store and transmit images and video clips digitally and secondly to add multimedia properties to wireless mobile devices. The capacity of the long distance wireless networks is limited, which causes need for more efficient multimedia compression methods. The problem is to achieve sufficient compression ratio with acceptable degradation in low cost embedded consumer devices.

The basic JPEG standard for still image compression is the most commonly used intra-image compression method at the moment, but wavelet based methods have promising features for the future needs. JPEG is based on the discrete cosine transformation (DCT) of the 8x8 blocks (see. Figure 1). JPEG2000, which is a recent compression standard, utilises wavelet transformations. Wavelets normally require more computation power than DCT. The benefit is that they also retain spatial domain characteristics, which can be utilised for other purposes easier than DCT results.

This publication bases to a wavelet codec which was created at VTT for testing the feasibility of the methods to practical applications. The name of the codec is wavecodec. Wavecodec is software which is flexible for various image processing applications. The wavelet based codec is suitable when high compression ratios are needed [1]. Filtering is done in sequences of horizontal and vertical low- and high pass transformations.

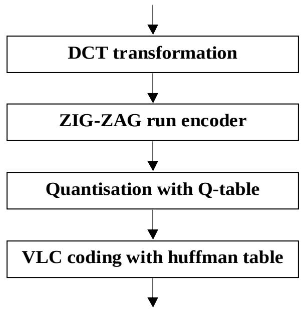

FIGURE 1: SIMPLE DESCRIPTION OF THE BASIC JPEG ENCODING PROCEDURE

II. Wavelet Transformation

The purpose of the transformations in image compression is to pack the significant information through sub-band coding. Then information can be carried with fewer bits. Irrelevant information on low entropy sub-bands can be totally removed.

Wavelets produce separate low and high frequency sub-bands (see. Figure 2) [3]. The interesting issue is that those bands can be investigated in spatial domain.

FIGURE 2: ABOVE, THE ORIGINAL IMAGE AND BELOW, THE WAVELET TRANSFORMED IMAGE SHOWN IN SPATIAL DOMAIN. THE DISTURBANCES IN THE TOP LEFT CORNER ARE A NOT CONSEQUENCE FROM WAVELET TRANSFORMATION. THEY ARE CAUSED BY IMAGE PRINTING TECHNIQUE TO USER INTERFACE.

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The low pass filtered image is similar to original image, but edges are blurred and image size is smaller due to the narrowed sub-band width. From the high pass filtered bands, sharp edges and defects can be found.

III. Variable Length Coding

Wavelet is a transformation which compresses significant information from the original image to narrower energy sub-bands. The transformation does not reduce image size. On the contrary, after transformation more bits are needed to preserve information. For actual compression, variable length coding (vlc) is needed after the transformation [4].

The purpose of the transformation is to reduce the number of gray levels which are needed in image reconstruction. The number of the quantisation levels has a direct effect onto the image quality and compression ratio. Decreasing the number of quantisation levels causes higher quality loss, but produces smaller images.

High frequencies do not need as many quantisation levels as lower bands because their amplitude typically is much lower than the amplitudes of the lower frequency bands. Furthermore, the high frequency sub-bands contains detail information of the image. The low frequencies store most of the information and are more important for the image quality.

IV. Compression Algorithm in Wavecodec

The presented compression algorithm begins by executing a wavelet transformation (see. Figure 3). The wavelet transformation is done in four nested loops. In the first round the whole image is filtered. In the second round only the low-pass filtered portion is processed, which covers 1/4 of the image. In the third round, 1/16 and in the last round, 1/64 of the whole image size is filtered. 1-dimensional banks are convolved horizontally and vertical pixel rows sequentially.

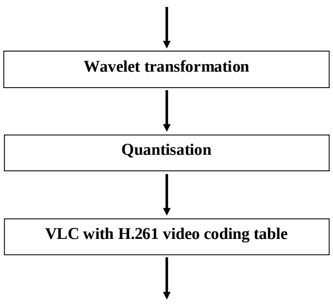

Figure 3. Description of the wavecodec application

8-tap Daubechies filters are used in wavecodec (see. Figure 4). It is not computationally efficient. Better coding efficiency would be achieved with shorter filters but the compression ratio would be worse. LeGall 5/3 and Daubechies 9/7 filters are implemented in JPEG2000. Nevertheless, the used filter is sufficient for testing purposes. In wavecodec horizontal and vertical filters are executed sequentially, starting with horizontal one.

Huffman coding is done at same time with run length encoding (RLE). This reduces computation power requirements. The used coding method corresponds to the H.261 video standard. Typical pixel values are fetched from a Huffman table. The length of the zero runs is appended in the Huffman code word. Values not found in the table are presented with 24-bit ESCAPE codes.

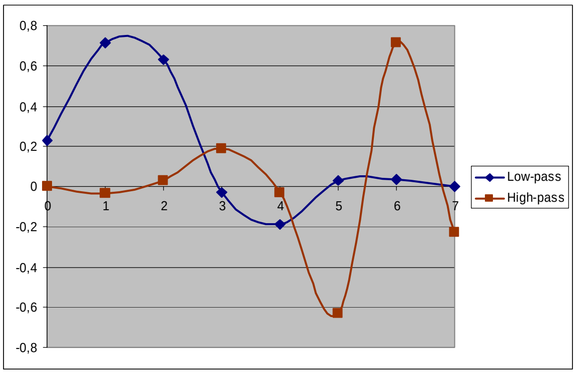

Figure 4. 8-tap Daubechies filters, which are implemented in the wavecodec algorithm.

Wavecodec is developed for efficient CPU units. The intended compression ratio was 1:10 or even better. The wavelet was chosen as the transformation method because there were interests to use small images in the pre-processing stage. Furthermore, the opportunity to execute image processing parallel with compression was an attractive feature.

V. Test Methods and Tools

The developed compression algorithm is compared with JPEG codec in the same testing environment. JPEG was implemented to the same application as wavecodec. Both compression methods were built with Borland C++ Builder 6 compiler (Figure 5). The utilised JPEG algorithm was an internal component of the compiler. The testing program runs on Microsoft Windows XP operating system. The hardware of the test platform was a laptop with Intel PIII 1,13 GHz Mobile CPU. The size of the main memory was 320 MB.

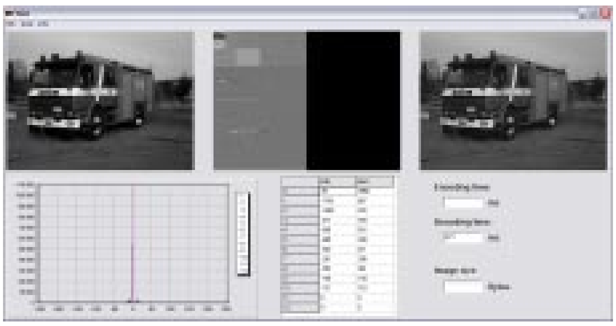

Figure 5. Program which is built for testing purpose

The Nyquist pattern (Figure 6) was used as a test image for the compression tests. The pattern contains both low and high frequencies. However, in most practical applications only low frequencies are significant. Therefore, the pattern is a kind of an extreme test for the high frequency retaining properties of a method. For this reason the fire truck images are also studied in the experimental section.

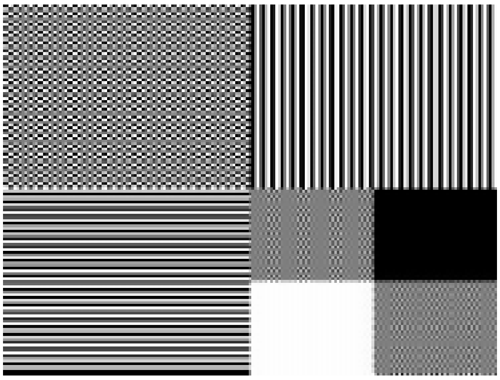

FIGURE 6. NYQUIST PATTERN

VI. EXPERIMENTAL RESULTS

As mentioned above, the most attractive feature of the wavelet-based method is the possibility to simultaneously perform other image processing functions, in addition to compression. After the wavelet transformation, horizontal and vertical filtered images are available. Figure 7 and Figure 8 show examples how to utilize high pass filters. From those images, direction related information can be extracted.

FIGURE 7. HORIZONTAL HIGH-PASS FILTERED IMAGE PARTITION

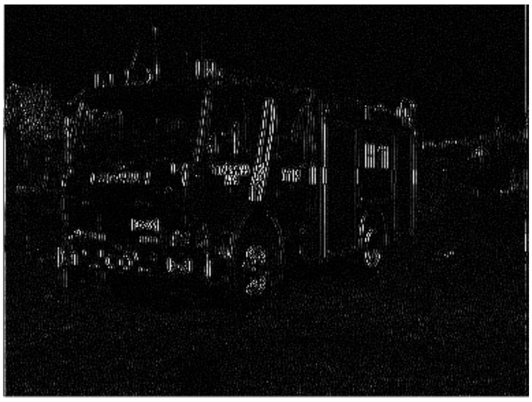

FIGURE 8. VERTICALLY HIGH-PASS FILTERED IMAGE PARTITION

After the wavelet transformation the energy of the image is mainly concentrated around the zero point, see Figure 9. The higher compression rate follows from the narrow energy band. Fewer levels are needed for maintaining image quality in the quantisation stage. The energy distribution of the fire truck image is like Gaussian and concentrated in the lower frequency bands.

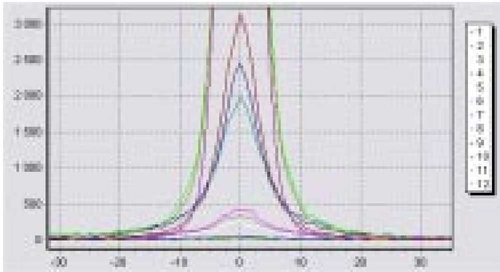

FIGURE 9. ENERGY DISTRIBUTION OF THE FIRE TRUCK AFTER THE WAVELET TRANSFORMATION

The following images show minimum and maximum values of each sub-band before and after the variable length coding. The highest frequency sub-bands are totally lost in VLC coding, because the quantisation threshold for those was high. This explains some loss of sharpness of the image in the coding stage.

	MIN	MAX
0	-337	4449
1	-1900	899
2	-1134	1009
3	-422	399
4	-592	523
5	-417	411
6	-346	212
7	-280	323
8	-358	366
9	-176	202
10	-160	180
11	-201	227
12	-105	106

	MIN	MAX
0	-57	3956
1	-1742	667
2	-1095	976
3	-417	384
4	-586	516
5	-405	389
6	-342	211
7	-281	388
8	-352	361
9	-166	194
10	-131	153
11	0	0
12	0	0

FIGURE 10. MINIMUM AND MAXIMUM VALUES AFTER WAVELET TRANSFORMATION (LEFT) AND AFTER VLC CODING (RIGHT)

Figure 11 and Figure 12 show differences between the original Nyquist pattern and the image after decompression. Practical tests indicate that wavecodec causes more losses than JPEG with a compression ratio 1:10. Peak quantisation signal-to-noise ratio for the wavelet based method is 25,9 dB and for the JPEG image 29,3 dB. This is mainly due to the coarse quantisation in the higher frequencies in wavecodec, as can be seen from the difference images.

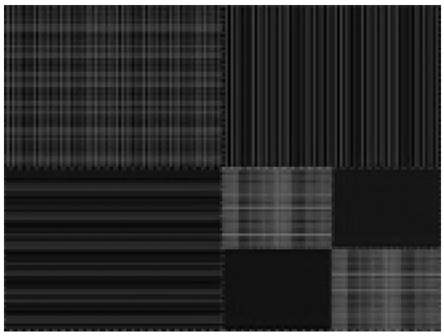

FIGURE 11. DIFFERENCE IMAGE BETWEEN WAVECODEC AND ORIGINAL NYQUIST PATTERN. PSNR RATIO IS 25,9 DB

FIGURE 12. DIFFERENCE IMAGE BETWEEN NYQUIST PATTERN AND JPEG COMPRESSED IMAGE. PSNR RATIO IS 29,3 DB

The encoding time of the wavecodec method was 311 ms for the Nyquist pattern (see. Table 1). Decoding is as fast. The wavelet transformation consumes 280 ms (see Table 2) from total coding time. The inverse transformation requires 290 ms. In other words, wavelet calculation is the bottleneck of the current implementation. However, the results are not surprising because of the iterative nature of wavelet filtering, and the rather long filter kernel used. The algorithm of the wavecodec is less complicated than that for JPEG, but because of the iterations it requires more computation power.

TABLE 1. COMPARISON OF THE JPEG AND WAVELET BASED METHODS

Method	Time	Size of the result image
JPEG	151 ms	45 KB
wavecodec	311 ms	47 KB

TABLE 2. PERFORMANCES OF THE WAVELET AND VLC ROUTINES

	Time
Wavelet transformation	280 ms
VLC encoding	31 ms

VII. CONCLUSIONS

Without any optimisation work the coding time with Borland's JPEG codec is faster than that for the implemented wavelet-based codec. The source code was not thoroughly optimised, so the performance can be increased with code analysers and processor optimised compilers. The easiest way to increase performance is to calculate the wavelet transformation with a less iterative method. Optimisation work of the algorithm is active at the moment. Thus the computation time in the final application will be lower than presented in this paper. Anyway, it is clear that the JPEG compression and decoding methods still are faster than wavelet, as reference [2] proposes. Of course, we have to keep in mind that present CPU's typically have dedicated addressing modes for DCT-type computation.

The wavelet transformation has two clear benefits compared to the conventional DCT- based compression methods. Firstly, low and high pass filtered parts are done separately, which enables frequency analysis during compression. Secondly, the small sub-images can be used in image processing (see Figure 13), which results from the nested transformations. This enables hierarchical image analysis whereas only partly reconstructing the image. If something abnormal is found, often only then the whole image needs to be decoded and analysed.

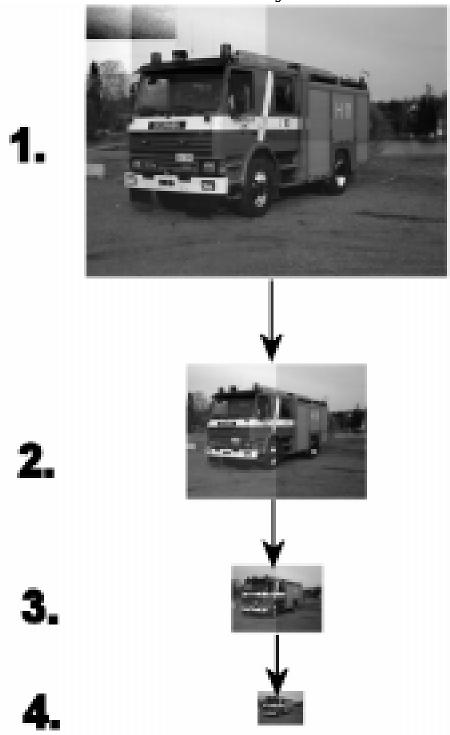

FIGURE 13. TREE OF THE LOW PASS FILTERED IMAGES

Despite the high losses, the result of wavecodec is adequate for many practical applications. One example could be detection of defects of flat surfaces and transmission of the data via a LAN link. In this case the frequency analysis in spatial domain gives the CPU efficient way to execute image processing parallel with compression.

Another example for the wavelet based method is mobile devices or wireless telecommunication. If the sub-bands are coded separately, then the quality of the image can be selected according to the transmission speed. It means that only the low-pass filtered parts of the image are transmitted which guarantees sufficient frame rate for video clips. This could solve the data overload problems of the wireless surveillance cameras.

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