FINDING A SUITABLE WAVELET FOR IMAGE COMPRESSION APPLICATIONS

Shahid Masud *Student Member IEEE* and John V. Mc Canny *Senior Member IEEE*

DSiP Laboratories, School of Electrical Engineering and Computer Science,
The Queen's University of Belfast, Stranmillis Road, BT9 5AH, N. Ireland.

ABSTRACT

In this paper we assess the relative merits of various types of wavelet functions for use in a wide range of image compression scenarios. We have delineated different algorithmic criteria that can be used for wavelet evaluation. The assessment undertaken includes both algorithmic aspects (fidelity, perceptual quality) as well as suitability for real-time implementation in hardware. The results obtained indicate that of the wavelets studied the biorthogonal 9&7 taps wavelet is the most suitable from a compression perspective and that the Daubechies 8 taps gives best performance when assessed solely in terms of statistical measures.

1 INTRODUCTION

Wavelet transforms have established their viability in image compression applications. This is mainly due to the lapped nature of this transform and the computational simplicity which comes in the form of filter bank implementation. The work in this paper attempts to answer the basic question - which wavelet is most suitable for designing an image compression system? In particular, we present a qualitative measure of image quality after being analysed and synthesised by a wavelet based image coder. The paper first explains the use of wavelets in image coding and the criteria that has been used for wavelet evaluation. The choice of wavelets and images is then listed followed by the experiments and results obtained from their evaluation.

2 WAVELETS IN IMAGE CODING

Many different kinds of wavelets exist in literature. The choice of a suitable wavelet functions for image coding is still an open question. Many interesting image coding schemes based on wavelets have recently been presented in many applications. They are based on a particular wavelet, quantization scheme and more importantly they are targeted towards a specific class of images.

The quantization and entropy coder part of an image coding system have drawn considerable attention in recent years due to JPEG, MPEG-1 and MPEG-2 standards. The transform part comprising wavelet analysis and synthesis filters has become the subject of research only in last few years. There has been at least one standard defined for wavelet based finger print compression by FBI [1]. This standard allows the use of any wavelet filter up to a length of 32 taps. Obviously a good choice of wavelet significantly improves coding performance, fidelity and image perceptual quality [20].

A variety of parameters have been reported for wavelet evaluation. Buschgens and Hartenstein [6] have extended the evaluation criteria to include the number of vanishing moments, step response error, linear phase and time frequency resolution. In the process they indicate that linear phase and shift variance are not a very helpful criteria for such an evaluation. Rioul in [7] has stressed the use of regularity as a criterion for better control over stop-band attenuation and this makes Daubechies filters a better choice for compression. DeVore et al [8] have used the L^P norm as the evaluation criteria and concluded that the L^1 norm is the closest to human visual system. Coding gain, defined as the ratio of variances of the original image and the sub-bands has been used as an evaluation criterion by Andrew et al [9, 11], Phillipe et al [10], Calvagno et al [12] and Buschgens [6]. Villasenor et al [13, 14] have adopted a more analytical evaluation criterion based on impulse and step response of a linear shift variant system. Another interesting measure of coder quality is 'picture quality scale PQS' introduced by Lu and Estes [17]. This measure maps various distortion factors to a single quality scale and the picture is rated in terms of perceived distortion. In addition to these criteria, the normalised mean square error ratio (NMSE) and peak signal to noise ratio (PSNR) are universally used for the measurement of image quality. Another useful measure of wavelet effectiveness is its ability to represent the signal in as few non-zero coefficients as possible. This has been defined as 'sparsity' [19]. The compression performance resulting from a wavelet decomposition is measured in terms of the number of zero coefficients [8], [15], [16].

In this paper, we report the result of wavelet analysis and synthesis on a range of images representing different classes. Word length constraints were put on transformed coefficients and various parameters of reconstructed images were measured.

3 CHOOSING WAVELETS AND IMAGES

3.1 Choice of Wavelets

The range of wavelets which can be utilised to evaluate performance can be an impractically large number. For example, Villasenor et al in [13] and [14] have used over 4300 candidate filter banks from the biorthogonal family but only six filter banks give acceptable result in terms of image compression applications. Balasingham et al [18] have evaluated 1160 filters out of a total of over 70,000 odd and even length filter banks using the 'Lena' and 'Barbara' images and could not reach at a definitive conclusion. We have adopted an approach similar to that of Andrew et al [9] in selecting wavelets for evaluation experiments. We have focused our choice of wavelets on the following options:

1. Wavelets which have been applied and tested in image compression applications, and
2. Wavelets which are potentially attractive from the point of view of real time implementation and practical realisation. We have also avoided longer filters because of the 'ringing at the boundary' effect [20].

The second criteria seeks to minimise the number of real number multipliers required for hardware implementation. For a single level image decomposition six filters are required [20]. The usual requirement of three levels necessitates eighteen filters and a large buffer memory to store the intermediate results. From a practical technology point of view it was decided to reduce the choice of wavelet to one with ten taps or less and to consider their use in conventional video or HDTV applications. The wavelets investigated were as follows:

1) 'Biorthogonal with 9 and 7 taps' (bior9&7); these have been approved by the FBI as part of their finger print compression standard [1], [16].

2) 'Daubechies 4 taps ' (daub2); multiplier-less and integer implementations exist [2].

3) 'Daubechies 8 taps' (daub4); this contains a high number of vanishing moments, possesses regularity and it is suitable for dealing with details in images [11].

4) 'Biorthogonal with 9 and 3 taps' (bior9&3); this is symmetric and suitable for integer implementation [3].

5) 'Short Kernel' (shortkern); this was proposed for fast implementation of sub-band coding [4].

6) 'Bath 6 taps' (baluncer); this is based on the minimisation of the diagonal of a Heisenberg uncertainty rectangle and maximises the psychovisual quality [5].

3.2 Choice of Images

The following 256 level grey scale (8 bits) images, of size 256 x 256, were chosen for the experiments undertaken. Each of these is a representative of typical classes encountered in image compression applications:

1) The image '**airport**' for aerial and satellite photography.

2) The image '**circuit**' for PCBs, lithographic data.

3) The image '**fingerp**' for finger prints.

4) The image '**compgen**' is typical of computer generated 'lego' blocks with regular and well defined boundaries.

5) The image '**lena**', representative of the human face.

6) The image '**medical**' typical of MRI scan pictures.

7) The image '**microorg**' typical of microscope photographs obtained from pathological objects.

8) The image '**scene**'; this is a natural harbour scene.

3.3 Choice of Evaluation Criteria

In order to reach a quantitative conclusion based on experimentation the following measures were investigated:

1. Signal to Noise Ratio (SNR),
2. Compression score percentage,
3. Recovery of pixels,
4. Picture Quality Scale (PQS) i.e. psychovisual tests,
5. Implementation efficiency.

The evaluation experiments were carried out at successively increasing quantization levels (also defined as bin-width). The step size was chosen as $2^{(level-1)}$ starting from 'rounding to the nearest integer' (level 1) to 32 (level 6) This also produces improvements in different aspects of coding, such as reduction in the memory required to store the results and reductions in the length of code books. From evaluation perspective, this enabled us to determine the degree of 'sparsity' of each wavelet i.e. the better wavelet would have more energy compaction so setting the smaller coefficients to zero has a lesser effect on image quality. All experiments were performed with a zero padding extension to deal with the boundary effects of finite length signals [20].

4 RESULTS AND DISCUSSION

4.1 Signal to Noise Ratio

The signal to noise ratio values obtained vary from one image to another. It was observed that at all quantization levels, images with greater detail (e.g. fingerp, airport) generally produce a better SNR in comparison to other images. The best SNR was obtained using Daubechies 8 taps wavelet followed by the 'baluncer' and 'bior9&7' wavelets. The worst performer was the Short Kernel filter which shows a difference of about 6 dBs at all threshold values. The SNR for 'circuit' at different quantization levels is plotted in figure 1. The trend illustrated for this image is similar to the other images except that in images containing less detail, SNR values are typically 3 to 8 dBs lower.

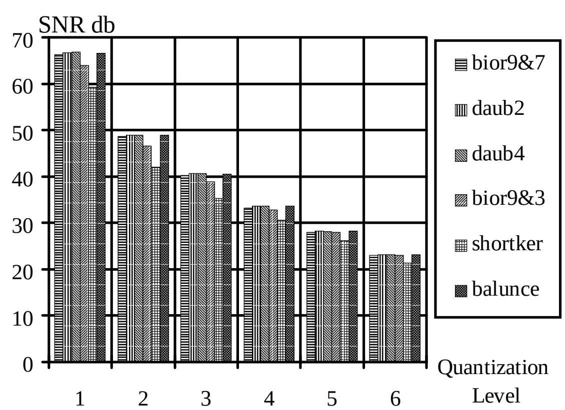

Fig 1: Variation of SNR for image 'circuit'

4.2 Compression Score Percentage

The compression performance was evaluated by determining the percentage of zeros in the transformed coefficients at different quantization bin widths. At quantization levels 1 and 2, the 'bior9&3' wavelet produced the best compression performance (11% and 25% for 'fingerp' respectively). This was followed by 'bior9&7' with about 2% lesser zeros (10% and 23% respectively). Other filters typically produced values which are 3% less. For the worst case scenario (i.e. the highest quantization level), the performance of 'bior9&7' was marginally better than 'bior9&3' followed by other wavelets.

Similar patterns in the compression score were observed in all images. The results for ‘fingerp’ are shown in figure 2.

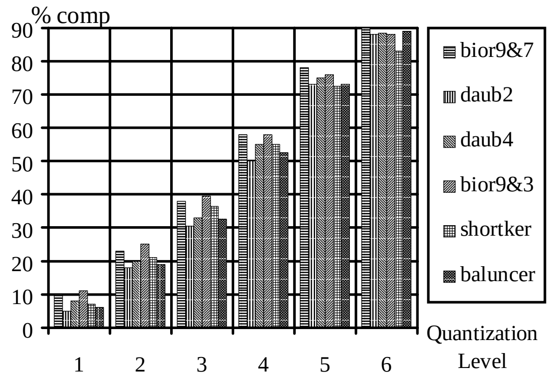

Fig 2: Compression increase for image ‘fingerp’

4.3 Recovery of Pixels

The purpose of an image coding system is to reduce the number of bits required to store or transmit an image. In doing so, the system should be able to recover information not only is a statistical sense (NMSE) but also in terms of exact values. This is a very stringent requirement in any coding system. For example, the FBI finger print compression standard calls for over 99% recovery of exact pixel values. The pixel values obtained after reconstruction were truncated and compared to original pixels. It was found that all wavelets, after analysis and synthesis at lowest quantization level (rounding to nearest integer), offered 100% exact reconstruction of pixel values. This shows that using integer or fixed point representation for transformed coefficients does not affect system performance. As the quantization bin-width increases this value decreases as illustrated in figure 3.

The performance of each wavelet can then be established on the basis of the percentage of exactly recovered pixels. At quantization levels of 2^1 and 2^2, it was found that the Daubechies 8 taps and 4 taps wavelets offer highest recovery values respectively. The performance of ‘daub2’ and ‘baluncer’ was better, at quantization level 2^3, than other wavelets for all but ‘compgen’ and ‘medical’ images. For these two images the biorthogonal filters (both 9&7 and 9&3 taps) gave a better pixel recovery than other wavelets. At the two highest quantization levels, the exact recovery of pixels in all wavelets was not more than 15% except for the ‘compgen’ and ‘medical’ images. These produced values of over 20% recovery with some wavelets. This observation can be attributed to the presence of large smooth surfaces in these images. Moreover, these images are computer generated and, as such, possess regular boundaries and have minimal noise characteristics. The coefficient recovery pattern for the ‘lena’ image is shown in figure 3.

4.4 Psychovisual Evaluation

Due to the ‘non-block’ based nature of sub-band coding, the image quality degrades gracefully. In this experiment the images were transformed, quantized and synthesized. The reconstructed images were tested for subjective quality by zooming and panning in order to compare them with original images. The subjective quality obtained from all wavelets was comparable until a threshold level of 4. The variation in image quality became discernible at threshold levels of 8 and above. The observations reported below are therefore for higher quantization levels only. The ‘shortkernel’ filters proved inferior in all cases because of a pronounced checkerboard effect in all images. Ringing at the boundary was observed with the ‘baluncer’ and ‘daub4’ wavelets when used with the ‘lena’ and ‘microorg’ images. The image ‘airport’ showed blockiness along features such as buildings and runways for all wavelets examined. The performance of ‘daub2’ proved the best in this image. The biorthogonal filters did not show any ringing or checkerboard effects in any of the images investigated. In the ‘fingerp’, ‘airport’ and ‘microorg’ images artefacts (mainly region growing and merging, loss of details) became objectionable at threshold level 8. In all other images, the loss of details in images became objectionable at threshold level 16 and above.

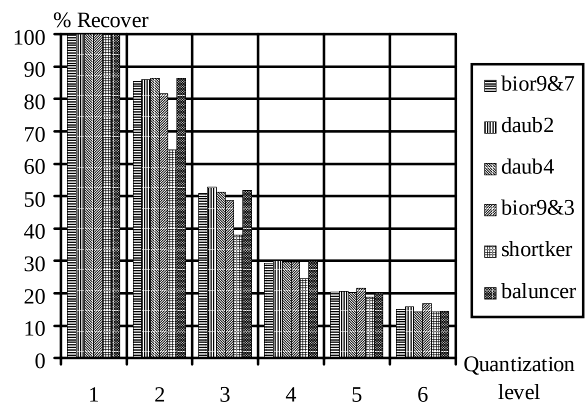

Fig 3: Recovered pixels for ‘lena’

4.5 Implementation Efficiency

An important criteria in considering the real time implementation in silicon of any DSP function is the number of multipliers involved. This ultimately determines the silicon area required, performance and power consumption. The number of multipliers required for each wavelet type for a single analysis block comprising lowpass and highpass filters is summarised in table 2. Where it is possible to reduce this number, for example, through exploitation of symmetry, this is also listed.

The main difference between the orthonormal and biorthogonal filters, from an implementation perspective is the symmetry/anti-symmetry exhibited by the latter. This reduces the number of multipliers by half. From an implementation point of view short kernel filters are attractive because they involve coefficients values which are powers of two. This means that multipliers can be implemented using simply shift operations. The biorthogonal 9 and 3 taps wavelet is attractive because only integer arithmetic is required. Moreover, after simplification, the number of multipliers reduces to just seven. The implementation of Daubechies 4 taps filter without multipliers described by Lewis and Knowles [2] is attractive but cannot be generalised. The least attractive wavelets, from an implementation point of view are the Daubechies 8 taps and balanced uncertainty for which no simplification exists.

Type of Filter	Number of multipliers	Reduced number	Remarks
Biorthogonal 9 & 7	9+7 = 16	5+4 = 9	Real coefficients
Daubechies 4 taps	4+4 = 8	8	Iplementation without multipliers is reported
Daubechies 8 taps	8+8 = 16	16	Real multiplications
Biorthogonal 9 &3	9+3 = 12	5+2 = 7	Integer coefficients
Short Kernel	4+4 = 8	8	Integer/powers of 2 coefficients
Balanced Uncertain	8+8 = 16	16	Real coefficients

Table 1: Multipliers required for implementation

5 CONCLUSION

Through a series of different tests we have quantitatively evaluated the suitability of different wavelets for use in image compression systems. The results indicate that the compression performance of biorthogonal filters is better than the rest. However, in terms of statistical measures, the Daubechies filters perform better. The decision to use a particular family of wavelets then depends on implementation complexity. Good choices are the bior9&3 and daub2 wavelets because they can both be implemented using integer arithmetic. If a real number implementation is possible then the ‘bior9&7’ and ‘daub4’ wavelets are good choices although the former should be preferred because of its symmetric impulse response. This leads to a reduction in the number of multipliers required. The discussion in this paper also leads to another conclusion on the suitability of wavelets for image compression. Since each wavelet filter gives a different performance for different evaluation measures and different images, it is appropriate to tailor the choice of wavelet to a target application area and available bit budget. Based on compression efficiency, visual results and implementation efficiency we conclude that the biorthogonal 9&7 wavelet filters appear to be well suited to the real-time image compression systems.

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