WAVELET IMAGE CODING BY DILATION-RUN ALGORITHM

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ABSTRACT

This paper presents a novel wavelet image coder, dilation-run algorithm, which provides an embedded coder based on bit-plane coding technique. At each bit-plane, morphological dilation is used to extract and encode the clustering significant wavelet coefficients, and a run-length coding method is used to encode the positional information of each cluster. The experiment results show that our coder outperforms the zerotree coder SPIHT and is competitive with the morphology coders MRWD and SLCCA. For wavelet images with strong clustering feature, the new coder outperforms both the morphology coders above.

1. INTRODUCTION

Recently, image compression using the wavelet transform has attracted great attention [1]-[4]. The four well known wavelet image coders are Shapiro's EZW (Embedded Zerotree Wavelet) [1], Said and Pearlman's SPIHT (Set Partitioning in Hierarchical Trees) [2], Servetto *et al.*'s MRWD (Morphological Representation of Wavelet Data) [3] and Chai *et al.*'s SLCCA (Significance-Linked Connected Component Analysis) [4]. Both EZW and SPIHT are zerotree based coders and exploit the cross-subband dependency of insignificant wavelet coefficients, while MRWD and SLCCA are based on morphology representation, and mainly make use of the within-subband clustering feature of significant wavelet coefficients.

The main drawback of zerotree based coders is that it may be expensive to represent the arbitrarily shaped zero (i.e. insignificant coefficient) regions by the union of a highly constrained set of tree-structured regions. Different from the zerotree based coders, the morphology based ones directly form the irregular shaped non-zero regions, i.e., the clusters of significant coefficients, through morphological dilation operation [3], [4].

In this paper, we introduce a novel algorithm based on morphology representation for wavelet image coding. The key feature of our algorithm is that an efficient run-length coding method is designed to encode the positional information of the seed for each cluster, i.e., the pixel from which a cluster is originated. The algorithm, which we refer to as "dilation-run," mainly involves discrete wavelet transform, bit-plane coding, morphological dilation of significant coefficient cluster within subbands, coefficient's significance predicting across subbands, run-length coding of the insignificant coefficients before each seed, and adaptive arithmetic coding.

The paper is organized as follows. The background of wavelet image coder based on morphology representation is reviewed and the motivation for the development of our algorithm is addressed in section 2. The algorithm is presented in section 3. Experimental results and discussions are given in section 4. Finally, the conclusion is made in section 5.

2. BACKGROUND

A coefficient is called insignificant if its magnitude is below a predefined threshold; otherwise, it is deemed significant. Significant wavelet coefficients indicating the occurrence of edges or textures tend to cluster in highpass subbands. If a given coefficient is known to be significant, then its neighboring ones, with high probability, will be significant too. Morphological dilation operation gives one way to encode the clustering significant coefficients. If the seed for a cluster is known, then dilation operation can intuitively seek and encode the whole cluster. The positional information of the seeds needs to be encoded.

A fully embedded bitstream is desirable in image coding, which is valuable for rate scalability and progressive transmission. Bit-plane coder can generate such a bitstream. When morphological operation is combined with bit-plane coder, significant coefficients with respect to a set of octavely decreasing thresholds are progressively sought through morphological dilation and the positional information of the seeds for the newly emerging clusters with respect to each threshold needs to be encoded.

In MRWD, all coefficients are scanned in raster order and coded regardless of their significance. The seed of

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each cluster is specified by transmitting a special symbol. This scheme can be easily used in a bit-plane coder, but it is complex to code the significance of the coefficients one by one. In SLCCA, connected component analysis of significant coefficients is first performed and extremely small clusters are eliminated before encoding. As a result, the number of the seeds is reduced. This scheme with preprocessing is not feasible for embedded coding. Different from above coders, the proposed dilation-run algorithm, as a bit-plane coder, uses an efficient run-length coding method to encode the positional information of the seeds. Thus one-by-one zero coding is avoided and the bit budget for the positional information of the seeds is also greatly reduced. The description of dilation-run algorithm will be given in section 3.

3. DILATION-RUN ALGORITHM

In this section, the dilation-run algorithm is presented. The main points of the algorithm are described at first. Then the whole algorithm is given.

3.1. Morphological Dilation

Firstly, the morphological dilation operation is reviewed [3], [4]. Consider a set S to which the dilation operation will be applied, and let B represent some structuring element. Let $\oplus$ denote the morphological dilation operator. Then dilated set $S \oplus B$ is defined to be the union of all points falling under the support of the structuring element B, when B is centered at each point in S. Intuitively, dilation operation produces an enlarged set containing the original S, plus a few nearby elements. Clusters of significant coefficients can be progressively constructed by using dilation. Some typical structuring elements are shown in Fig. 1.

3.2. Run-Length Coding of the Seeds

The seed for a cluster is the pixel from which the dilation operation is originated. When coefficients are scanned for new significant clusters, only a fraction of the coefficients are seeds because a rather large portion of the DWT coefficients is usually insignificant and most of the significant ones are detected through dilation operation. Encoding the lengths of insignificant coefficient runs before each seed can not only locate the position of the seeds, but also reduce the storage requirements.

In our algorithm, seeds are sought by raster scan within each subband. When a seed is encountered, the number of the unencoded insignificant coefficients before this seed and its sign are encoded and output. Then the dilation operation is applied to the seed. Once the process terminates, raster scanning resumes on those unencoded

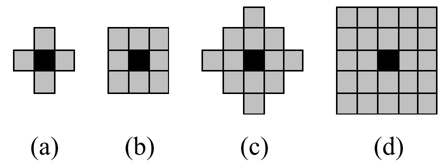

Fig.1. Structuring elements used in dilation.

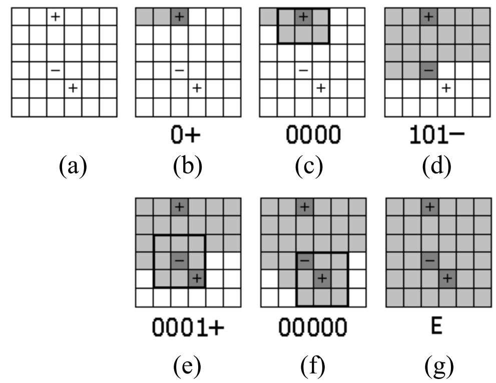

Fig.2. Illustration of run-length coding of positional information of the seeds and dilation operation applied on each significant coefficient.

coefficients. A similar run-length coding idea is also presented in stack-run algorithm [5], where the number of the unencoded insignificant coefficients before each significant one is encoded.

A symbol set consisting of "0", "1", "+", "-" and "E" is used in run-length coding, where "0" and "1" are used for the binary code of the run-length, "+" and "-" are for the signs, as well as indicate the end of the code of the run-lengths, and "E" is used to signify that no seed appears in the remaining coefficients in the subband scanned. We take advantage of the fact that all nonzero binary numbers begin with 1, and therefore encode the binary representation of the run-length from the least significant bit to the second most significant one. For all runs of length $2^k - 1$, where k is an integer, it is necessary to retain the most significant bit (MSB) because problems will occur in representation of a run of length one which would not be representable if all MSB "1" symbols are eliminated.

Fig. 2 shows an example on run-length coding of the positional information of the seeds and progressive cluster detection by dilation operation. Suppose the coefficients in Fig. 2(a) are to be encoded and the coefficients marked with signs are the significant ones. Fig. 2(b)-(g) show the encoding steps. The symbols below each figure correspond to those actually encoded at that step. Fig. 2(b) and (d) are run-length coding steps, in which the run-lengths of the unencoded insignificant coefficients and the signs of the seeds are presented by "0", "1", "+" and "-" according to the rules described above. Fig. 2(c), (e) and (f) show how the dilation operation is applied to each significant coefficient with the structuring element in Fig. 1(b). In these steps, the significance of the newly sought ones is represented by "0" or "1" symbols. When a new significant coefficient is detected, its sign "+" or "-" is also encoded. Finally, in Fig. 2(g), an "E" symbol is output to show the end of run-length coding.

3.3. Significance Predicting across Subbands

Relative to a given wavelet coefficient, the four coefficients at the next finer scale which correspond to the same spatial location are referred to as its children; accordingly, the given coefficient is called their parent. We predict the existence of clusters at finer scales according to the dependency between the magnitudes of parent and children. However, this dependency is not very strong, so significance predicting is performed in a subordinate encoding pass at each bit-plane.

3.4. Entropy Coding

Adaptive arithmetic coder [6] is used to encode the symbols. For run-length coding, there are 5 symbols and a probability model is used. For significance coding of coefficients in dilation operation, 10 conditional probability models are adopted, which are determined by the contexts similar to those defined in JPEG2000 [7]. However, significance of parent is also considered in our contexts. Signs are encoded in the same way as JPEG2000. For magnitude refinement bits, only the second most significant bits are entropy encoded and one model is used, while other bits are output directly.

3.5. Dilation-Run Algorithm

For each bit-plane of the wavelet coefficients, the coding proceeds in four distinct passes. The whole dilation-run algorithm can be briefly described as follows.

Dilation-run algorithm:

1) Output the maximum value n of the MSBs, which means that at least one wavelet coefficient's magnitude is not below 2^n for the whole image.
2) Apply dilation operation to the clusters of the significant coefficients found at former bit-planes in each subband. (**Within-Subband Significance Propagation Pass**)
3) Scan each subband in raster order and output the significance of each unencoded coefficient with a significant parent. If a seed (i.e. significant coefficient) is identified, then apply dilation operation on it. (**Across-Subband Significance Propagation Pass**)
4) Output the nth most significant bit of all the significant coefficients identified at former bit-planes. (**Magnitude Refinement Pass**)
5) Apply run-length coding to the unencoded coefficients in each subband and apply dilation operation to the seeds. (**Seed Search Pass**)
6) Decrement n by one, and go to Step 2).

Image	Rate (bpp)	0.125	0.25	0.5	1
Barbara	SPIHT	24.86	27.58	31.39	36.41
	MRWD1 [4]	25.27	27.86	31.44	36.24
	SLCCA [4]	25.36	28.18	31.89	36.69
	Dilation-Run	**25.45**	**28.47**	**32.18**	**37.27**
Goldhill	SPIHT	28.48	30.56	33.13	36.55
	MRWD1 [3]	28.47	30.53	33.15	36.56
	MRWD2 [3]	28.31	30.61	32.92	35.96
	SLCCA [4]	-	30.60	33.26	36.66
	Dilation-Run	**28.61**	**30.67**	**33.43**	**36.84**
baboon	SPIHT	21.72	23.27	25.64	29.17
	MRWD1 [4]	-	23.26	25.74	29.35
	SLCCA [4]	-	**23.44**	**25.86**	**29.36**
	Dilation-Run	**21.86**	23.29	25.78	29.26

Table 1. Comparison of the rate/distortion performance of the proposed algorithm with other high performance coders found in the literature.

4. EXPERIMENTAL RESULTS

Dilation-run algorithm is evaluated on three standard 512×512 grayscale images, i.e., Barbara, Goldhill and baboon. The performance is compared with three wavelet coders SPIHT, MRWD and SLCCA. In our algorithm, each original image is decomposed into a five-scale subband pyramid using the 9/7 biorthogonal filters. In the two significance propagation passes, the structuring element in Fig. 1(b) is used for dilation. In the seed search pass, the structuring element in Fig. 1(d) is used. The bit rates are calculated from the actual file sizes. The image quality is measured by the peak signal to noise ratio (PSNR), which is computed from actually decoded images. The original Barbara image, and the reconstructed images at 0.5bpp and 0.25 bpp are shown in Fig. 3(a)-(c).

The comparison between SPIHT, MRWD, SLCCA and dilation-run algorithm on the test images is shown in Table 1. The MRWD1 is a single rate coder, while MRWD2 is an embedded one. As shown in the Table 1, our algorithm outperforms SPIHT and is competitive with the morphology coders MRWD and SLCCA. For the images with strong clustering feature after wavelet transform, for example Barbara, our algorithm outperforms both the morphology coders. For Barbara image, dilation-run algorithm separately outperforms

(a) (b) (c)

Fig. 3. Coding Results for 512×512 Barbara image. (a) Original, reconstructed images (b) at 0.5bpp, PSNR = 32.18dB, and (c) at 0.25bpp, PSNR = 28.47dB.

SPIHT, MRWD1 and SLCCA by 0.78dB, 0.64dB and 0.31dB on average. As an embedded coder, the dilation-run algorithm also provides the useful functionality such as progressive fidelity transmission and precise rate control.

5. CONCLUSION

This paper has proposed a new wavelet image coding algorithm, the objective of which is to provide a high performance embedded image coder based on morphology representation. The key encoding methods that we employ are morphological dilation and run-length coding of the positional information of the seeds. Experiment results show that dilation-run algorithm is among the state-of-the-art image coding algorithms reported in the literatures.

6. ACKNOWLEDGEMENTS

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