A new class of filter banks for seismic data compression

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Summary

Reducing the volume of seismic data would substantially improve the system management for both transmission and storage purposes.

We propose in this paper a new class of filter banks (GenLOTs) for seismic data compression. GenLOT is a generalization of local transforms with overlapping windows. The transforms are used in an embedded coding scheme, incorporating control quality features and allowing exact bit rate compression.

Comparing GenLOTs with wavelet in seismic compression, the simulation verifies that GenLOTs offer better performance than wavelets at a constant distorsion rate, achieving much higher compression ratios. Furthermore, coherent noise is reduced significantly in GenLOTs-based coder, and allowed compression of stack sections by compression ratio of 150 : 1 without visible loss.

Introduction

Modern seismic surveys generate Terabytes of data and seismic data compression is often used to limit the signal band-width in transmission (such as in satellite communication). Compression also can reduce storage costs, at the expense of small accuracy loss in the data. Classical compression methods (known as *transforms methods*) capture the redundancy in the data using transform-domain coefficients. These coefficients are then quantized and encoded. Among these methods are the *wavelet transform*, as used in (Donoho et al., 1998), and more generally subband compression (Røsten et al., 1997). Another example is the local cosine transform, whose overlapping windows are well suited to capture the band-limited oscillary nature of seismic signals (Vermeer et al., 1996).

In this paper, we propose to use GenLOTs (Generalized Lapped Orthogonal Transforms) with overlapping window in the transform-based coder. They provide a more regular frequency partition than wavelets, and may be designed to match the signal properties. They are implemented as a block transform, in a new encoding scheme, where both quantization and encoding are embedded. This feature allows:

- exact bit rate compression, to match a fixed bandwidth transmission exactly;
- progressive transmission, providing straight-forward quality checks (QC) and fast data visualization, without decompressing the whole compressed set.

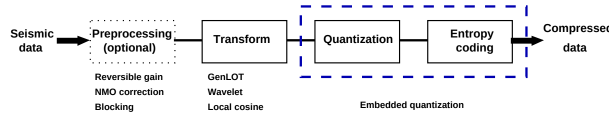

Fig. 1: Implementation of a transform based coder.

We compare the performance of the GenLOT-based coder with the wavelet-based coder on several data sets, both in raw form and in processed form. Both coders use the same progressive encoding scheme for a fair comparison. For the same distortion level, GenLOT-based coder has higher compression ratio. Further tests on synthetic data to show the impact of compression noise on seismic processing conclude that GenLOT has better performance than wavelet, both subjectively and objectively. They introduce less coherent noise, and offer better performance for several error measures, such as higher signal/noise ratios (SNR).

Methods and techniques

The performance of a transform coder depends on its abitility to concentrate most of the signal information in a small set of coefficients. It also depends on the choice of the frequency partition, and optimization procedures, as demonstrated below.

Another important issue is the encoding scheme of the transform coefficients. They are usually quantized and then encoded with techniques such as Huffman or arithmetic coding. We introduce in this paper a new encoding scheme (Fig. 1) where the QC feature can be easily implemented.

Filter banks, GenLOT and transform design

Subband coding is widely used in seismic data compression where wavelets is used in both compression and as a part of the acquisition process (Donoho et al., 1995). Local cosine transform (Vermeer et al., 1996) is also used as alternative transform in several studies. We refer to (Strang and Nguyen, 1996) for a comprehensive survey on wavelets and filter banks.

De Queiroz *et al.* developped GenLOT (de Queiroz et al., 1996), to overcome blocking artifacts in DCT-based image compression. This problem with seismic data has been addressed in (Donoho et al., 1998). GenLOT is a M-channel linear phase paraunitary filter bank where linear-phase filter is often critical in many seismic applications. GenLOT has regular frequency partition (uniform-band

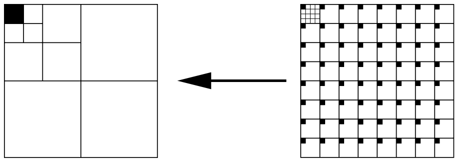

Fig. 2: Dyadic wavelet (left) and regular GenLOT (right) frequency partition.

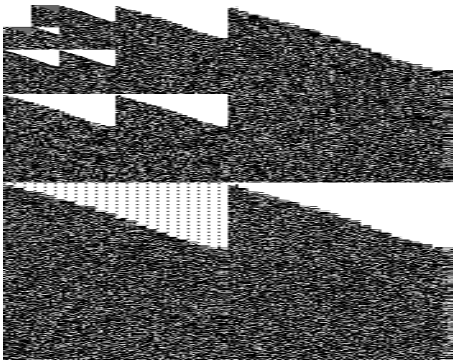

Fig. 3: Frequency decomposition of a seismic shot.

decomposition), whereas wavelets is dyadic as seen in Fig. 2. GenLOT filter length is assumed to be a multiple of M (KM). The discrete cosine transform (DCT) and Malvar's Lapped Orthogonal Tranforms (LOT) are special cases of GenLOT, with $K = 1$ and 2, respectively.

Recent works in image processing have shown than GenLOTs with proper design outperform wavelet compression for conventional images (Tran and Nguyen, 1997). Several criteria are used for transformation optimization: for instance, *Coding gain* (CG) optimization usually correlates with higher SNRs (objective measure). Other objective measure includes *DC leakage* (DC), though not essential, often improve the visual quality of the reconstructed data (subjective measure). The article (Tran and Nguyen, 1997) discusses issues on filter bank optimization, and comparison to wavelet coders.

Seismic data are often modelled using separable processes in the horizontal and vertical direction. This assumption is particularly true for raw data, such as common shot or common CDP gathers, but also for stack section, as demonstrated in (Røsten et al., 1997). Hence, separable filter banks are used in this study and its details are in the example section.

Embedded coding and progressive compression

Earlier coders performed quantization and encoding independently from block to block and its major drawback includes blocking artifacts where the correlation between the subbands is not fully exploited. The dyadic scheme of the wavelet transform allows the reduction of the subband redundancy. In a similar way, GenLOT coefficients can be reorganized to fit the dyadic wavelet structure. A 2^M-channel block transform is analogous to a L-level wavelet decomposition. As an example, we can see some similarities between the subbands in Fig. 3, which shows the transformed image of shot gather. Exploiting them will enhance the embedded coding performance.

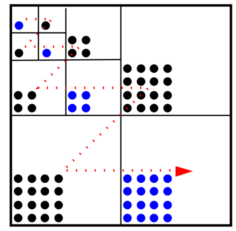

Fig. 4: Scan order in the embedded coding scheme.

Shapiro first introduced in (Shapiro, 1993) the embedded coding scheme. We will use the following encoding scheme:

1. the largest coefficients are transmitted first, according to their decreasing value;
2. their values are progressively refined;
3. spatial correlation between subbands are exploited in a tree shaped structure, from the lowest to the highest frequencies.

The scan order in the trees is shown in Fig. 4. Relationships bewteen the root and the leaves of the trees are then coded using adaptive arithmetic coding. Quantization is performed *via* the refining process. We refer to (Said and Pearlman, 1996) for practical implementation.

As a result, there is no redundancy in the transmission, and compressed data can be decoded on the fly, only with the first transmitted bits. They give the coarse approximation of the data, which are progressively refined by the additional transmitted bits. This method provides two interesting features: first, the compression process can stop anytime, for instance when the desired compression ratio is reached. The most important features are kept. Another consequence is that the bitstream for the $100 : 1$ compressed data is appeared at the beginning of the bitstream for the $20 : 1$ compressed data, which offers an easy way to implement QC. Suppose that one would like to transmit $20 : 1$ compressed data, while ensuring that the data looks satisfactory. One can send the first $1/20$ of the $20 : 1$ compressed data, which is equivalent to a $100 : 1$ compression. If the QC is satisfactory, the remaining 95% of the compressed file can be sent in order to recover the $20 : 1$ compressed data. There is no need to send the same coefficients twice. It can also be applied to fast vizualisation of the data.

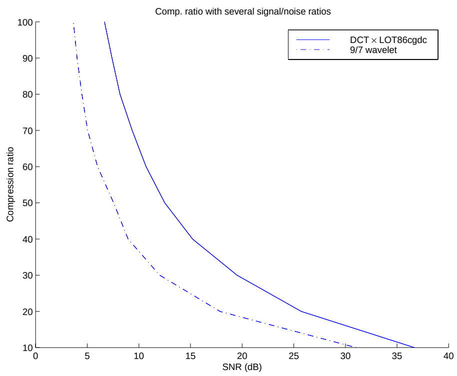

Fig. 5: Compression ratio with fixed SNR.

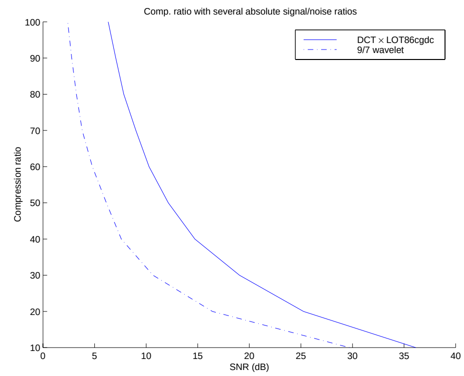

Fig. 6: Compression ratio with fixed ASNR.

Examples

Compression of raw data

Several sets of 2-D seismic data are used in the simulation, with several error measures. Similarly as in (Vassiliou and Wickerhauser, 1997), we compute two types of signal/noise ratios, the conventional SNR and the absolute SNR (ASNR):

$$\begin{aligned} \text{SNR} &= 10\,log_{10}\left(\textstyle\sum_n s_n^2 / \sum_n \Delta s_n^2\right) \\ \text{ASNR} &= 20\,log_{10}\left(\textstyle\sum_n |s_n| / \sum_n |\Delta s_n|\right) \end{aligned}$$

This study uses several choises of GenLOTs. We obtain the best results with longer overlapping bases in the vertical direction (Table 1). For common shot gathers, we use the DCT in the horizontal direction because of the limited data size and less correlated information. Fig. 5 and 6 show compression ratios versus SNR and ASNR respectively. Suppose that the maximum distorsion rate is fixed at 15 dB for the raw data, GenLOT reaches around 41 : 1 compression, while the wavelet coder (with the 9/7 filters used in (Vassiliou and Wickerhauser, 1997) reaches only 25 : 1 compression. GenLOT performs better at most distortion rates between 5 and 35 dB. Results with other data sets can be found in (Duval et al., 1999).

Filter	Channels	Overlap	Optimization
DCT	8	1	none
LOT85cg	8	5	CG
LOT86cgdc	8	6	CG/DC

Influence on seismic processing

We compress the data set at 20 : 1 with GenLOT and wavelet, and apply the same processing as on the original data. Fig. 7 shows objective distorsion measure before and after processing. Fig. 8 and 9 show the error on a portion of the stack sections. GenLOT both performs better with objective (7 dB gain on raw data, (8 dB after processing) and subjective measures. While Fig. 8 (GenLOT) exhibits mostly uncoherent noise, seismic information appears in Fig. 9 (wavelet). Although not harmful to interpretation in this case (difference merely visible on the stacks), more seismic features would disappear at higher bit rate.

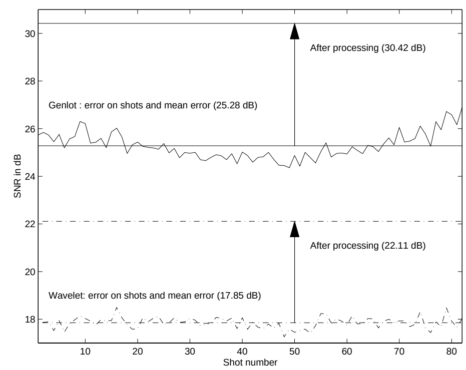

Fig. 7: Results of 20 : 1 compression: SNR at each shot point, average SNR and SNR after processing for GenLOT (top) and wavelet (bottom).

Conclusions

We have proposed a compression algorithm based on GenLOT, a new class of filter banks well suited to seismic data. GenLOTs are implemented with a progressive coding scheme, which embeds the quantization et encoding stages. The resulting features include simple QC procedure, as well as fast database visualization abilities. The use of well suited filter banks with a regular frequency partition leads to improvements over

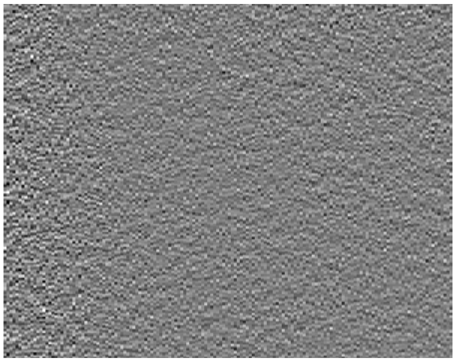

Fig. 8: Difference stack from 20 : 1 compression with GenLOT.

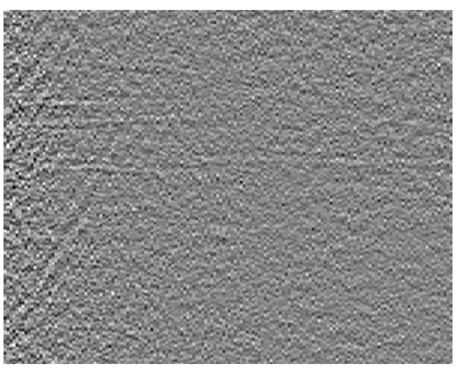

Fig. 9: Difference stack from 20 : 1 compression with wavelet.

wavelet filter banks (between 3 and 8 dB). The block transform implementation also allows parallel processing. GenLOT make a flexible and useful tool for seismic data compression, both for transmission or for storage.

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