Efficient Representation of Chrominance for Very Low Bitrate Coding

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Abstract. The paper describes an original method to represent chrominance in color images and video. This method can be combined with an arbitrary technique of luminance representation or compression. The two chrominance components are represented by one scalar signal obtained using vector quantization. The luminance is encoded entirely independently from chrominance. The scalar representation of chrominance exhibits high redundancy and high correlation with luminance. They both are strongly reduced using differential coding with adaptive prediction that exploits the information about edges extracted from decoded luminance component.

1 Introduction

Low-cost multimedia, visual services over narrow-band networks and content-based browsing of visual databases are examples of the application areas where efficient highly-compressed representation of digital image and video data are of vital importance. The sophisticated algorithms need to exploit any possible source of redundancy, among them better compression of color information.

Standard video and still image coders allocate most bits to luminance and very small number of bits is available for chrominance if the compression ratio is high. Small numbers of allocated bits result in numerous artifacts, e.g. discontinuities between neighboring blocks in block-based schemes. These distortions, when occurring in chrominance, are perceived as false colors. In many cases, especially in the image regions representing human skin, this effect causes strong negative impressions, since the human visual system in some contexts exhibits high sensitivity to color inaccuracy.

The objective of the paper is to propose a general technique to represent chrominance in still images and video. This chrominance representation can be combined with any kind of luminance data, e.g. obtained using block-based DCT-based techniques, subband/wavelet coding, object-based or region-based methods. A technique that is fully independent of the type of luminance compression is proposed for coding of color information in video sequences compressed at very low bitrates. The original idea is to convert the two components of the chrominance vector (C_b, C_r) into one scalar chrominance using vector quantization with properly ordered and relatively small codebook, and then to encode the scalar chrominance using edges extracted from decoded luminance signal (cf Fig. 1).

The technique is based on chrominance vector quantization scheme reported and investigated previously together with lossy coding of the scalar chrominance signal (Bartkowiak and Domański 1997a, 1997b). The new proposal consists in application of adaptive lossless compression of the scalar chrominance. The original and interesting issue of this approach is that while the compression ratio is still quite high, the reconstructed color is of good quality, what is hardly achievable using traditional video compression techniques.

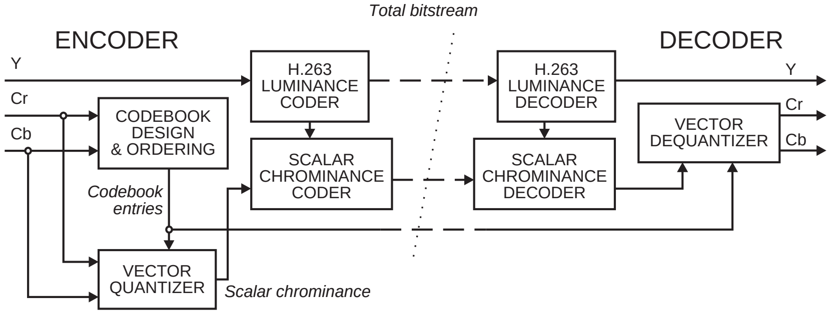

Fig. 1. General structure of the compression scheme based on chrominance vector quantization

2 Chrominance Vector Quantization

The assumption is to encode the luminance entirely independently from chrominance components. The basic idea is to convert the two chrominance components (C_b, C_r) into one scalar chrominance using vector quantization. The latter consists of two steps. At first, some set of chrominance pairs called codebook is chosen. Then, each chrominance from the input picture is substituted by its nearest neighbor from the codebook. Euclidean norm in chrominance plane is applied as a distance measure.

The codebook is automatically designed for a frame. The obtained codebook is a set of chrominance pairs. A unique number labels each pair, and an order in the codebook entries is defined in this way. A stream of these labels constitutes the scalar chrominance.

In order to achieve high coding efficiency and make the codebook ordering easy, its size should be as small as possible. On the other hand, a desired level of quality requires some minimum number of codebook entries, depending on the design algorithm and assumed error criteria.

Experimental results show that the chrominance of a typical video frame can be quantized to very few representatives which can produce lots of colors in combination with individual luminance values. Therefore, especially for low-resolution QCIF images of natural scenes (cf. Fig. 2) small sets with even 15-30 chrominance pairs are still applicable as codebooks for vector quantization and usually do not lead to significant degradation of picture quality (Bartkowiak and Domański 1996, 1997a).

Numerous algorithms have been proposed to design codebooks in color spaces. In order to keep the computational complexity of the coder low, a fast suboptimum algorithm, similar to the binary split algorithm described by Orchard and Bouman (1991), is used. This heuristic algorithm, based on hierarchical data clustering, at each step minimizes quantization error in one data cluster selected for further partitioning. Various criteria of error minimization can be applied. For example, Fig. 3 shows the design process using maximum squared error and mean squared error criteria. Resulting quantized frames which can be viewed at the WWW site `http://www.et.put.poznan.pl/~mbartkow/ecmast98.html` exhibit subtle, but acceptable discrepancies, mostly in details of scarce and highly saturated colors, which is a natural consequence of the compromise between quality, compression ratio and computational complexity.

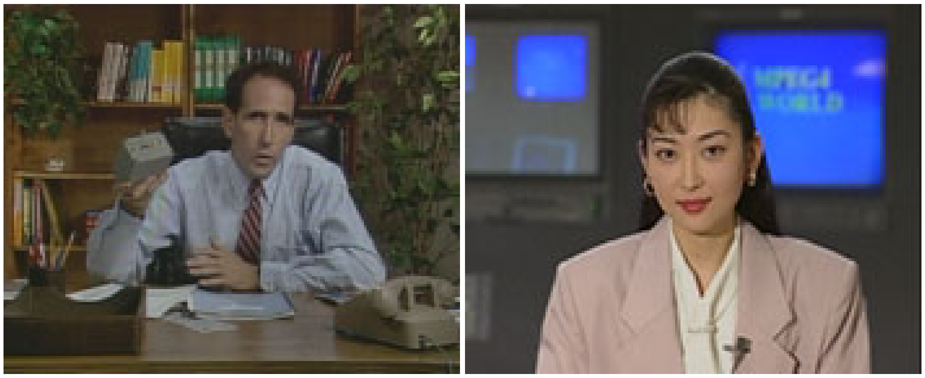

Fig. 2. Single frames from the original test sequences SALESMAN (left) and AKIYO (right)

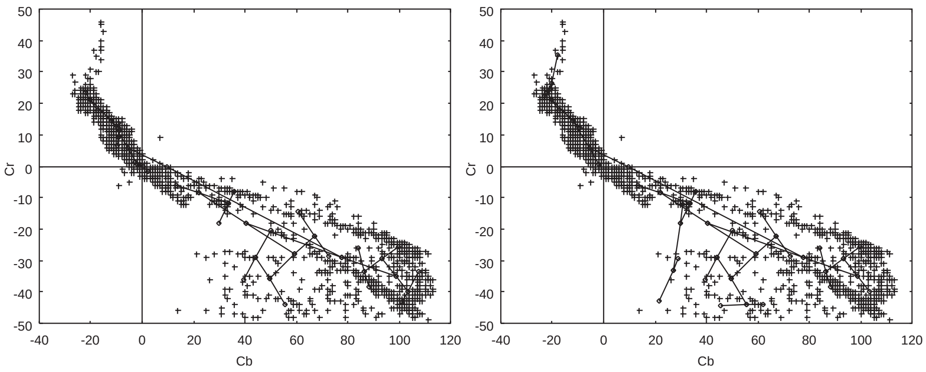

Fig. 3. Tree structured codebook design process shown on the background of chrominance data of a frame from the test video sequence AKIYO. Left: application of mean squared error criterion, right: application of the maximum squared error criterion.

3 Properties of the Scalar Chrominance Signal

The statistical and spectral properties of the scalar chrominance signal are deeply affected by codebook size and order its entries are sorted and labeled in. The results obtained are similar to those reported by Zaccarin and Liu (1991) which show that the indices of images with vector quantized color are highly correlated with the adjacent indices, if the codebook is appropriately arranged, i.e. if consecutive indices are assigned to visually similar colors and distant indices represent colors that are visually different. In such case, possibly few high frequency artifacts is introduced into the scalar image within areas where its color counterpart is visually smooth (see Fig. 4 and 6). Therefore a simple but efficient ordering algorithm has been proposed. The algorithm combines codebook design process with simultaneous ordering. The resulting order of codebook entries is illustrated in Fig. 5.

As shown in Fig. 4, proper ordering of the codebook entries leads to much smoother the image of scalar chrominance as compared to a randomly ordered codebook. The bandwidth is also narrower. Nevertheless the spectral properties of the scalar chrominance signal, even with properly ordered codebook, are different than typical properties of the chrominance components. In particular, wider bandwidth makes the signal hard to compress efficiently using traditional lossy schemes. In fact, the scalar chrominance signal contains numerous "flat" areas of constant value with sharp discontinuities between them (cf. Fig. 4 and 6). This implies that the scalar chrominance signal exhibits high statistical redundancy that can be easily exploited by predictive coding.

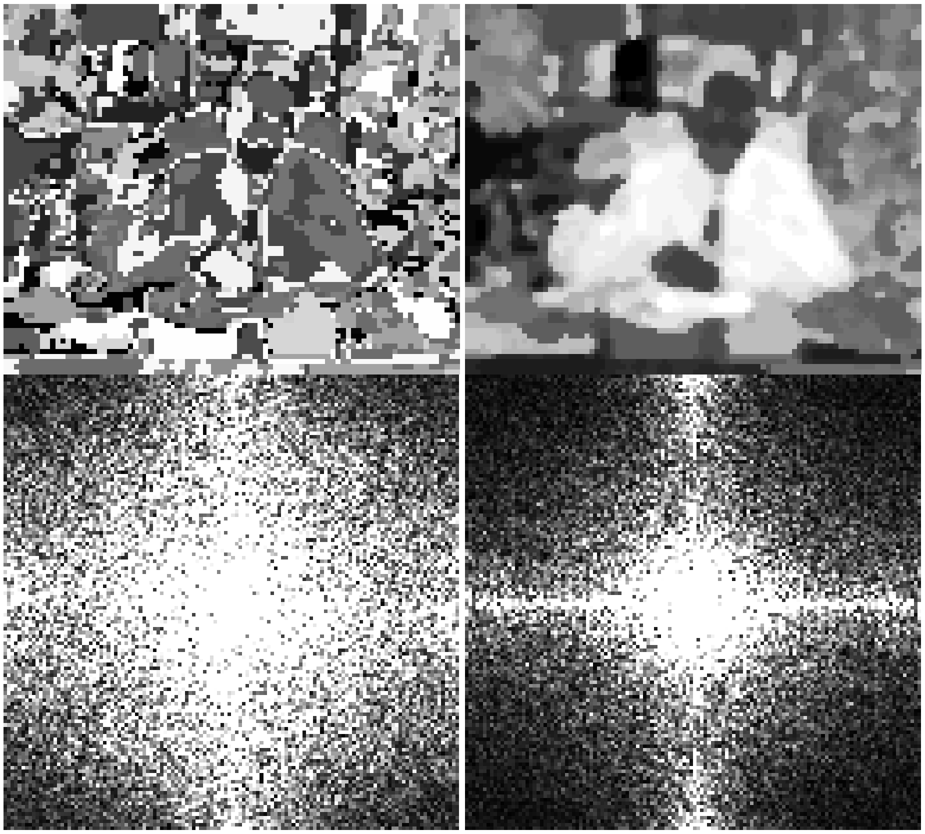

Fig. 4. Scalar chrominance signal obtained with a codebook of size 30 for a frame from the test video sequence SALESMAN (upper row) and its power spectra (below). Left column: codebook ordered randomly. Right column: codebook ordered using proposed algorithm.

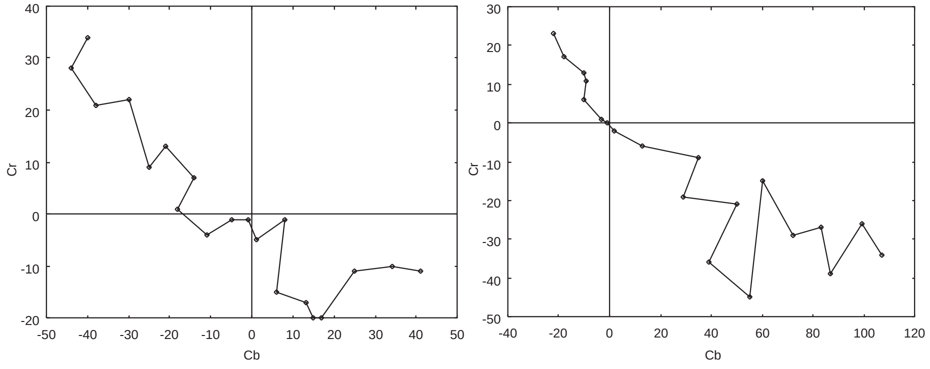

Fig. 5. Chrominance codebooks designed and simultaneously ordered for single frames from the test video sequences CLAIRE (left plot) and AKIYO (right plot).

Fig. 6. The original frame from the test video sequence CLAIRE (left image) and its scalar chrominance image (right).

4 Scalar Chrominance Compression by Adaptive Differential Coding

The previously discussed specific morphological properties of the scalar chrominance signal make it well suitable to differential coding, where at each point the actual signal value is estimated on the basis of its already transmitted neighbors and only the difference between the estimate and the actual value is transmitted. In case of an image with flat areas of a constant value the probability of zero valued difference is very high (cf. Fig. 9). Therefore variable length code applied here benefits from this nonuniform distribution of transmitted values.

Experiments show that for natural scene images, the significant changes in chrominance and luminance are highly correlated (Maragos et al. 1984, Abel et al. 1992). Similarly, in images with vector quantized chrominance, the location of borders between constant valued chrominance regions usually corresponds to edges and object borders in the luminance component (cf Fig. 6). In the proposed technique the chrominance coder and decoder use the reconstructed luminance in order to exploit these mutual dependencies (Fig. 7).

Edge detectors are used as the luminance activity estimators in order to identify locations, where significant luminance changes are encountered. The activity map is determined on the basis of the reconstructed luminance image and does not need to be transmitted. Separate estimation of vertical and horizontal luminance activity allows to select the best prediction direction, i.e. the direction in which previous chrominance label has most likely identical value.

The image is analyzed line by line. Apart from the border pixels, the actual value of the scalar chrominance $C_{x,y}$ is estimated by one of the neighboring points $C_{x-1,y}$ and $C_{x,y-1}$. The direction is chosen on the basis of previously calculated luminance activity L_x and L_y. The values L_x and L_y express the discrete estimate of the horizontal and vertical gradient in reconstructed luminance.

$$\text{if } L_x > L_y \Rightarrow \widehat{C}_{x,y} = C_{x,y-1}$$
$$\text{if } L_x < L_y \Rightarrow \widehat{C}_{x,y} = C_{x-1,y}$$

In case of identical values of L_x and L_y the chosen direction depends on the comparison of previously transmitted neighboring scalar chrominance values, $C_{x-1,y-1}$, $C_{x-1,y}$ and $C_{x,y-1}$:

$$\text{if } |C_{x,y-1} - C_{x-1,y-1}| > |C_{x-1,y} - C_{x-1,y-1}| \Rightarrow \widehat{C}_{x,y} = C_{x,y-1}$$
$$\text{if } |C_{x,y-1} - C_{x-1,y-1}| \leq |C_{x-1,y} - C_{x-1,y-1}| \Rightarrow \widehat{C}_{x,y} = C_{x-1,y}$$

The prediction error $\Delta C_{x,y} = \widehat{C}_{x,y} - C_{x,y}$ is compressed using Huffman codes and transmitted to the decoder. Additional information must be transmitted in case of $L_x = L_y = 0$ and $\Delta C_{x,y} \neq 0$. The latter corresponds to a situation where the scalar chrominance change is not associated with a change of luminance that is significant enough to be detected by the activity estimators. Nothing is transmitted if $L_x = L_y = 0$ and $\Delta C_{x,y} = 0$. Therefore, unnecessary transmission of zero valued $\Delta C_{x,y}$ is avoided.

The codebook entries are losslessly encoded and transmitted as a side information with neglible number of bits (mostly under 100).

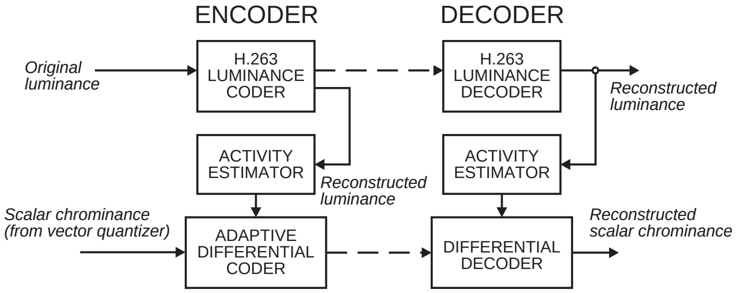

Fig. 7. The proposed compression scheme using differential coding of scalar chrominance and exploiting the mutual correlation between scalar chrominance and luminance.

5 Experimental Results

Experiments show, that the number of locations with non-zero prediction error heavily depends on the image complexity. Moreover, it is very important to set properly the threshold level in the luminance activity estimator, in order to minimize the number of locations, where $L_x = L_y = 0$, and, on the other hand, to minimize unnecessary transmission of zero-valued prediction errors. The statistical properties of the prediction error $\Delta C_{x,y} = \widehat{C}_{x,y} - C_{x,y}$ allow to encode it very efficiently using appropriately designed Huffman codes (cf. Fig. 9 and Table 1).

Operation of the standard H.263 codec results in artifacts that are more concentrated spatially, while the artefacts of the method presented here exhibit more random distribution. Therefore, PSNR ratings presented in Table 2 do not necessarily give a relevant comparison. The color examples can be viewed at the WWW site `http://www.et.put.poznan.pl/~mbartkow/ecmast98.html`.

Table 1. Exemplary statistics obtained for typical video sequences.

Sequence name	CLAIRE	AKIYO	AKIYO
Number of codebook entries (number of different scalar chrominances)	30	30	20
Number of zero-valued prediction errors	1002	1607	1809
Number of non-zero valued prediction errors	914	1160	480
Number of locations, where chrominance changes, but no luminance change has been detected	438	663	185

Table 2. Experimental comparison of the proposed scheme (denoted as CVQ) with standard H.263 codec operating in intraframe mode.

Sequence name	CLAIRE	CLAIRE	AKIYO	AKIYO
Compression method	H.263	CVQ	H.263	CVQ
Total number of bits for chrominance in one frame	3107	about 4500	4038	about 5500
PSNR for C_b [dB]	37.2	38.4	37.4	35.0
PSNR for C_r [dB]	39.9	43.3	39.5	40.3

6 Conclusions

The application of chrominance vector quantization and carefully designed adaptive predictors together with efficient entropy coding results in a technique which

Fig. 8. Experimental results for a frame from video sequence AKIYO (20 codebook entries). Upper row: scalar chrominance image (left), magnitude of the prediction error $\Delta C_{x,y}$ (right). Lower row: Luminance activity map (left) and locations of non-zero values of $\Delta C_{x,y}$ while luminance activity has not been detected (right).

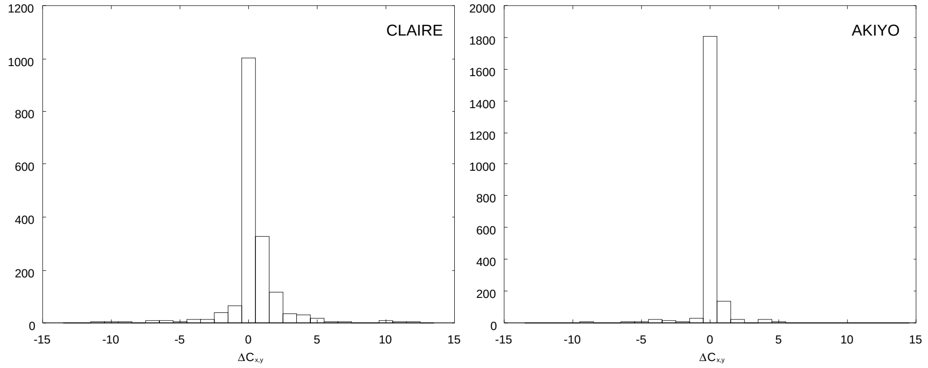

Fig. 9. The histograms of the transmitted prediction errors $\Delta C_{x,y}$ for video sequences CLAIRE (left plot) and AKIYO (right plot).

challenges the H.263 intraframe codec, i.e. the proposed technique gives better subjective quality at similar compression. While the first step of this approach is lossy and the amount of loss can be controlled mostly by the size of the chrominance codebook, the second step is completely lossless. The technique is intended mostly for applications in still image coding and intraframe coding of video but applications for intraframe video coding are currently investigated. The technique is also suitable for object-based analysis-synthesis video coding.

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