BAYER PATTERN COMPRESSION BY PREDICTION ERRORS VECTOR QUANTIZATION

Antonio Buemi, Arcangelo Bruna, Filippo Vella, Alessandro Capra
Advanced System Technology
STMicroelectronics
Stradale Primosole 50, 95121 Catania
ITALY

Keywords: Bayer Pattern, Color Filter Array (CFA), Vector Quantization (VQ), Differential Pulse Code Modulation (DPCM), Image Compression.

Abstract: Most digital cameras acquire data through a Bayer Colour Filter Array (CFA) placed on sensors where each pixel element records intensity information of only one colour component. The colour image is then produced through a pipeline of image processing algorithms which restores the subsampled components. In the last few years the wide diffusion of Digital Still Cameras (DSC) and mobile imaging devices disposes to develop new coding techniques able to save resources needed to store and to transmit Bayer pattern data. This paper introduces an innovative coding method that allows achieving compression by Vector Quantization (VQ) applied to prediction errors, among adjacent pixel of Bayer Pattern source, computed by a Differential Pulse Code Modulation (DPCM)-like algorithm. The proposed method allows a visually lossless compression of Bayer data and it requires less memory and transmission bandwidth than classic "Bayer-oriented" compression methods.

1 INTRODUCTION

Bayer pattern data (Bayer, 1976) are acquired by camera's sensor used in digital cameras, phone cameras and in many kind of low-cost integrated image acquisition devices. It allows acquiring one colour component for each pixel. The acquired colours are Green, Red and Blue. Then a colour interpolation technique recovers the missed colours. Due to the increasing of the sensor's resolution and to the developing of applications based on the transmission of images, compression of the Bayer pattern has become a strategic feature to reduce the amount of data to store and to transmit.
It's important to point out that any manipulation of the Bayer pattern should preserve the integrity (i.e. the information content) of the data, because every image generation pipeline uses it as input to create the final full colour image. So, ideally, compression of these data should be obtained using lossless techniques, reducing only the inter-pixel and coding redundancies. On the other side, lossless techniques allow low compression rates and preserve psychovisual redundant information.
Lossy compression methods, instead, yield high compression ratios and ideally they should discard only visually not-relevant information.
The problem of the Bayer data compression is quite recent and although traditional coding techniques offer good performances on full colour images, most of them do not offer the same performances with images captured by Colour Filter Array (CFA) digital sensors.
The most trivial, inexpensive solution (both in terms of computational complexity and hardware resources) is to split the Bayer image colour channels and compress them independently using an efficient compression algorithm, i.e. DPCM (Gonzales et alii 1993, Hynix). A more sophisticated compression method for images in Bayer pattern format (Acharya et alii, 2000) is based on Wavelet transform. This approach consists on two steps.

Buemi A., Bruna A., Vella F. and Capra A. (2004).
BAYER PATTERN COMPRESSION BY PREDICTION ERRORS VECTOR QUANTIZATION.
In *Proceedings of the First International Conference on E-Business and Telecommunication Networks*, pages 325-330
DOI: 10.5220/0001392503250330

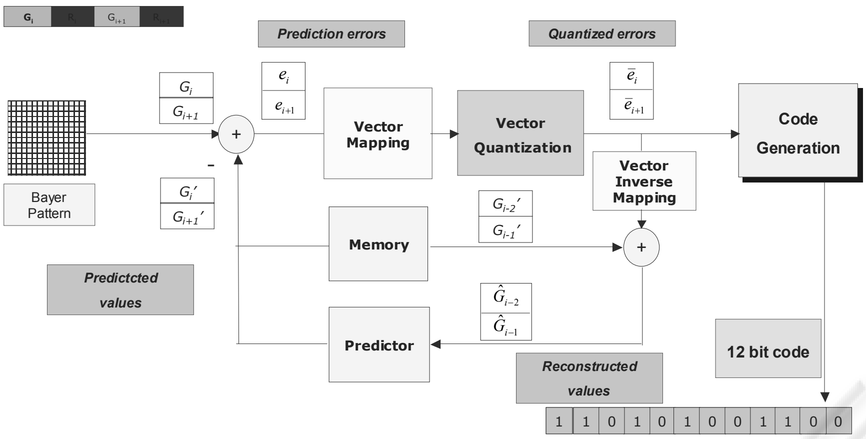


Figure 1: Proposed coding scheme

First, a 2-dimensional Discrete Wavelet Transform (DWT) is applied and then the DWT coefficients are quantized. DWT is used because it allows to describe abrupt changes better than Fourier transform.
The result is a lossy compression that is perceived as visually lossless by the Human Visual System (HVS). Several sub-band coding compression methods have been introduced by Toi (Toi et alii, 1999) and Le Gall (Le Gall et alii, 1988).
An algorithm (Lee et alii, 2001) for Bayer image compression based on JPEG (Wallace, 1991) has been recently proposed. This method, encodes the image using the JPEG standard. The image is pre-processed to convert from Bayer to YCbCr format with 4:2:2 or 4:2:0 sub-sampling. After this transformation, Y data presents blank pixels, so JPEG compression cannot be directly applied. Therefore a simply 45^o rotation of Y data is performed. After the rotation, Y data is localized in the centre of the image in a rhombus shape by removing rows and columns containing blank pixel. The blocks located on the boundaries Y image data are filled by using a mirroring method before encoding with JPEG.
All these approaches require appreciable amount of memory and bandwidth. An efficient compression technique based on Vector Quantization (VQ) techniques coupled with consideration on Human Visual System (HVS) has been proposed recently (Battiato et alii, 2003). Bayer pattern values are gathered in groups of two pixels accordingly to their colour channel and then the generated couple is quantized with a function considering effects of “Edge Masking” and “Luma Masking”.
This paper presents an efficient Bayer Pattern lossy compression technique devised specifically to reduce the data acquired by the sensor of 40% with a final low bit rate (about 2:1) and low distortion (about 50 dB of PSNR).
The paper is organized as follows: Section 2 describes the proposed method. Section 3 presents the results of the experiments, while conclusions and final remarks are discussed in Section 4.

2 BAYER PATTERN COMPRESSION

The proposed algorithm scheme is described in Figure 1. First, the DPCM algorithm is applied to compute the difference between the actual and the predicted pixel values gathered in vectors of two consecutive elements of the same colour channel. Prediction is performed assuming the adjacent samples of the same colour components having similar brightness values.
The error between the current value and the prediction is then processed by the “Vector Mapping” block in order to reduce the symmetry and lossy compressed through the “Vector Quantization” block. The vector quantizer has been designed to discard information not perceivable, accordingly to psychovisual considerations based on HVS properties. The quantized values are then taken as input by the “Code Generation” block that will yield a 12 bit code. The encoded data is decoded in order to retrieve the prediction for the next values. This allows avoiding propagation errors during the encoding process.
This scheme assumes to process 10-bpp images, so each couple of 10 bit pixels generates a 12-bit code with a compression of 12/20 (60%). The same process can be easily extended to 8 bpp-images.

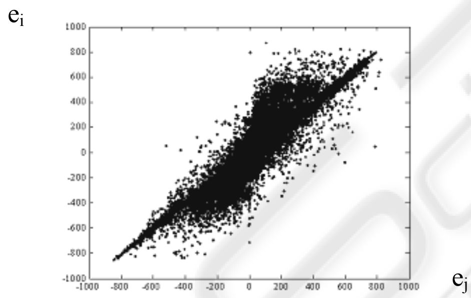
Next subsections describe with more detail each step of the co/decoding procedures.

2.1 Step 1: Prediction and Differential Block

The DPCM step is based on the idea of reducing the entropy of the source by coding the difference between the current value and a prediction of the value itself. In our approach the prediction function is performed with 2-dimensional vectors obtained applying VQ. In particular, let (V_i, V_j) be the vector to be coded. The second value of the previous vector (V_{i-1}, V_{j-1}) is used to build a vector of two identical components (V_{j-1}, V_{j-1}) which is the predictor for (V_i, V_j). This strategy has been chosen because V_{j-1} is spatially closer to (V_i,V_j) than V_{i-1} and usually closer samples are statistically more correlated. The error vectors (e_i, e_j) are computed as the difference between the vector to be coded and the prediction vector:

$$(e_i, e_j) = (V_i, V_j) - (V_{j-1}, V_{j-1}) = (V_i - V_{j-1}, V_j - V_{j-1}).$$

A typical error distribution for this kind of prediction scheme is showed in Figure 1.



Observe that a very high percentage of values falls near the origin, so the used vector quantizer has been modelled optimizing this distribution.
Note that the prediction function uses, as input, the restored values that are used as input for the predictor block in the decompressor. In this way no errors propagation is present in the compression-decompression system (Figure 1 and Figure 7).

2.2 Step 2: Vector Mapping

In the prediction error distribution described above is evident an odd symmetry. It can be exploited to reduce the size of the table used for the VQ. In fact the vectors falling in the third and in the fourth quadrant can be mapped in the first and in the second one, so just the two upper quadrants are to be quantized.
This task is performed by the "Vector Mapping" block: it checks whether the input vector falls in the upper part of the diagram or not. In the first case no changes occur, while, in the other case, the sign of the values is changed as shown in the Figure 3.
One bit is used in the compressed code in order to take into account such mapping (see Paragraph 2.4 for details).

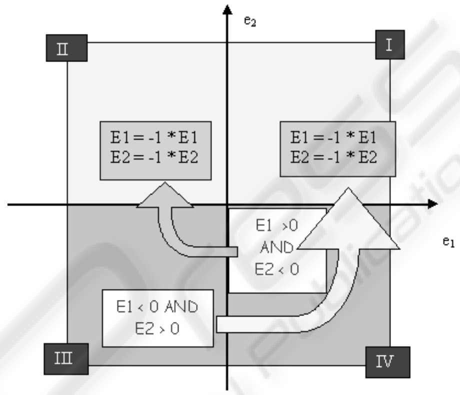


Figure 3: Vector Mapping.

2.3 Step 3: Vector Quantization

Given a vector (X_1,...,X_n) of size N, basic concept of Vector Quantization (Gray et alii, 1998) can be described geometrically. The associated binary representation can be seen as a set of N coordinates locating a unique point in the N-dimensional space. The quantization is performed partitioning the space with N-dimensional cells (e.g. hyperspheres or hypercubes) with no gaps and no overlaps. As the point defined by the input vector falls in one of these cells, the quantization process returns a single vector associated with the selected cell. Finally, such vector is mapped to a unique binary representation, which is the actual output of the vector quantizer. This binary representation (code) can have fixed or variable length.
A vector quantizer is said to be "uniform" if the same quantization step is applied to each vector element, so that the N-dimensional space is divided into regular cells. If the space is partitioned into regions of different size, corresponding to different quantization step, the quantizer is called "not-uniform". The "target" vector is called "codevector" and the set of all codevectors is the "codebook". A grayscale 10 bit image is described by 2-dimensional vectors of brightness values falling into the range [0, 1023]. In the proposed model, each codevector

represents a 2-dimensional input vector. Moreover, the proposed algorithm uses a not uniform quantization according with the properties of HVS. In particular, two considerations should be taken into account: the quantization errors are less visible along the edges and the HVS discriminates better the details at low luminance levels. Thus, in the areas near the origin (where the prediction error is low) a fine quantization is performed and most information is preserved. On the contrary, in the area far from the origin, a coarse quantization is applied due to the presence of boundaries and more information is loss. Furthermore, since DPCM drifts the values towards zero, a very high percentile of input samples will fall in the area around zero.

Figure 4: Outer Quantization Regions.

In the testing database used in experiments reported in this paper containing 130 images, the 65% of prediction errors are less than 20 and the 80% of values are less than 38. This information has been exploited partitioning the two upper quadrants of the 2-dimensional space into regions shaped and distributed to minimize the quantization error. Each region has different size and position in the quantization board and it has been divided into 64 “sub-regions”. Such regions have been obtained dividing the horizontal and vertical dimension by a constant number. In this way, bigger regions cover bigger areas and the quantization is stronger (more loss of information), while in smaller areas a lighter quantization is applied and most information is preserved (Figure 4). The Figure 5 shows an enlarged image of the quantized region near the origin.

We assumed that the regions are 32 and that each region is fragmented into 64 sub-regions (Figure 6).

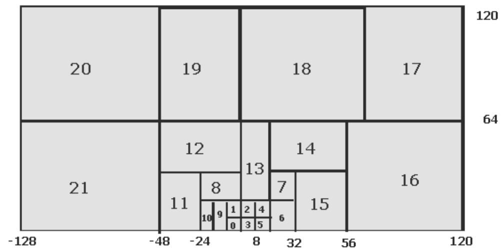


Figure 5: Inner Quantization Region.

Each vector (e_1, e_2) to be quantized is approximated with the nearest couple in the corresponding sub-region. The quantization step in the horizontal direction *X_step* is given by:

$$X\_Step = \frac{RegionWidth}{HorizontalQuantizationStep}$$

In the same way, the quantization step in the vertical direction *Y_step* is given by:

$$Y\_Step = \frac{Region\_Height}{VerticalQuantizationStep}$$

Where *RegionWidth* and *RegionHeight* are the width and the height of each region, while *HorizontalQuantizationStep* and *VerticalQuantizationStep* are the number of partitions in each direction.

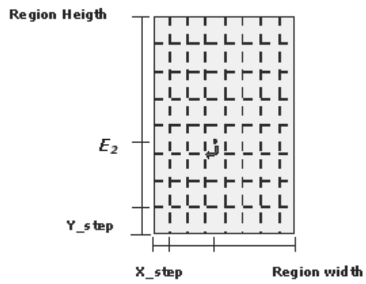


Figure 6: Sub-region partitioning.

The Horizontal and Vertical Quantization Step are set accordingly to the length of the code and the allowed distortion in quantization (Figure 6).

2.4 Step 4: Code Generation

The code representing the vector quantized samples is a fixed length code. It summarizes information about the vector mapping, the region where the point falls and the quantization steps applied in each region. The first bit is the "Vector Mapping" bit, indicating if the swap between upper and bottom quadrants has happen or not (section 2.2). Next bits following indicate the index of the region in the quantization table. The length of this part of the code depends on the number of regions in the quantization table. The remaining bits give information on the number of steps, in both vertical and horizontal direction inside the region.

In this discussion we assumed that a 12-bits code should be generated, in order to represent samples falling in a space partitioned into 32 regions and 64 "sub-regions". Thus, the code reserves five bits to index 32 regions and 6 bits to index one of the 64 sub-regions. Different code structure could be defined if the space partitioning or the target bitrate change.

2.5 BP Decoding

Decoding procedure consists on three main steps. The first one is the code evaluation allowing the extraction of the compressed values. The second one is the "Inverse Vector Mapping". It assigns the right sign to values depending on the inversion flag. Then the retrieving of the original values is obtained adding the decoded prediction error to the previously restored vector. Since the predictor is equal both in the encoder and the decoder, the predicted values are equal in the two part of the processes, so there is no propagation of error during the decoding process. The decoder block diagram is shown in Figure 7.

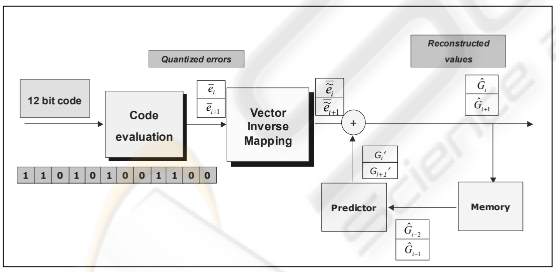


Figure 7: Bayer Pattern Decompressor scheme for a pair of green pels

3 RESULTS

The algorithm has been tested on two sets of images acquired in different light conditions. A first set, named "Wide Range Image set", contains images acquired by a CMOS-VGA sensor and with a histogram distributed in almost all the intensity range for each channel. In the second set the images have a very narrow histogram. The proposed method had very good performance with a PSNR of about 56 dB in the first set (Figure 8).

Lower, but still high (about 50 dB) PSNR has been achieved when the images with a wider range have been processed (Figure 9). In both cases compression didn't introduce perceptible artefacts in the output images. The algorithm has been compared with another VQ-based compression method introduced by S.Battiato et alii in 2003. Both the approaches yield a fixed-length coding providing a compression from 10 to 6 bpp.

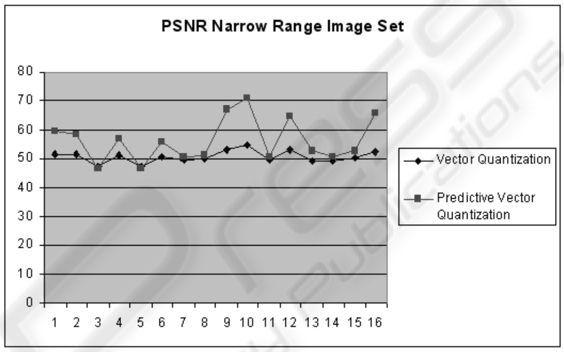


Figure 8: PSNR comparison between the proposed method and a classic algorithm on narrow range image set

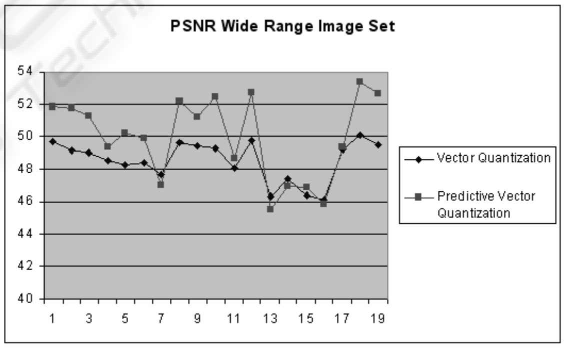


Figure 9: Figure 10: PSNR comparison between the proposed method and a classic algorithm on wide range images.

4 CONCLUSIONS

A new algorithm to compress images acquired by sensors is presented. The algorithm is oriented to the compression of the Bayer pattern, the most used pattern in image acquisition devices.

The technique is based on a predictive schema where the prediction error is encoded. Each input

vector is composed by two adjacent pixels of the same colour component.
The proposed method allows achieving a compression of 40% of the input data using a fixed-length 12-bits code assigned to each couple of 10-bits input pixel. Moreover, experimental results showed that compression doesn't involve a perceptible loss of quality in the output. As a result, the bit rate is low and the distortion introduced by compression is very limited (about 50 dB PSNR).

REFERENCES

R.M. Gray, D.L. Neuhoff, 1998, Quantization, *IEEE Trans. on Information Theory*, vol. 44, n. 6.

R.C. Gonzales, R.E. Woods, 1993, Digital Image Processing, Addison Wesley, pp.358-374.

B.E. Bayer, 1976, Color Imaging Array, U.S. Patent 3,971,065.

Hynix CMOS Image Sensor Application Note 2002, *Endpoints SE401 Demokit Information*, http://www.hynix.com/datasheet/pdf/system_ic/sp/SE401_Demokit.pdf

T. Acharya, L.J. Karam, F. Marino, 2000 Compression of Color Images Based on a 2-Dimensional Discrete Wavelet Transform Yielding a Perceptually Lossless Image, U.S.Patent 6,154,493.

T.Toi, M.Ohita, 1999, A Subband Coding Technique for Image Compression in Single CCD Cameras with Bayer Color Filter Arrays, *IEEE Transaction on Consumer Electronics*, Vol.45, N.1, pp.176-180.

Sang-Yong Lee, A. Ortega, 2001, A Novel Approach of Image Compression in Digital Cameras With a Bayer Color Filter Array, *In Proceedings of ICIP 2001* – International Conference on Image Processing – Vol. III 482-485 - Thessaloniki, Greece.

G. K. Wallace, 1991, The JPEG still picture compression standard, Communications of the ACM 34(4), pp. 30-44.

Le Gall, A. Tabatabai, 1988, Subband Coding of Digital ImagesUsing Symmetric Shor Kernel Filters and Arithmetic Coding Techniques, in *Proceedings of the ICASSP 88 Conference, (New York)*, pp. 761-764.

S. Battiato, A. Buemi, L. Della Torre, A. Vitali, 2003, “Fast Vector Quantization Engine for CFA Data Compression”, *In Proceedings of IEEE-EURASIP Workshop on Nonlinear Signal and Image Processing,* NSIP, Grado, Italy.