A Fast Vector Quantization Engine for CFA Data Compression

Sebastiano Battiato[1], Antonio Buemi[1], Luigi Della Torre[2], Andrea Vitali[2]

Abstract - This paper presents an efficient algorithm to compress digital images in CFA (Color Filter Array) format. The proposed technique is mainly based on a vector quantization (VQ) engine followed by an entropy encoder (e.g. DPCM). The VQ strategy adopted exploits both chromatic correlation and psychovisual/perceptive characteristics. Experiments show effectiveness in terms of overhead computation and compression performance.

Index Terms -Vector Quantization, Differential Pulse Code Modulation (DPCM), Bayer Color Filter Array, Compression.

I. INTRODUCTION

The wide diffusion of digital still and video image capturing devices pointed out new challenges mainly focused in quality improvement and reduction of the processing time [1]. Increasing of digital pictures quality is achieved by reducing noise introduced by the sensor during the acquisition of the data [2],[3], while increasing the resolution of the sensor allows improving compression performances for a more efficient manipulation and storage of images [4][5].

Most digital cameras place color filters on monochrome sensors and use image processing schemes in order to produce good quality RGB images. A simplified scheme of the conventional Image Generation Pipeline (IGP) is shown in Figure 1. Data are acquired by the sensor through the Bayer Color Filter Array (CFA) [6], so there is just one color component for each pixel. Intensity values corresponding to the other two color components for a given pixel have to be interpolated using neighboring pixel information. A visually lossless image compression algorithm is then applied before storing the image (usually JPEG [7]).

Performing compression directly on the Bayer pattern image, of course, is a desirable feature because it reduces the amount of data to transmit and it makes the hardware architecture less expensive. It's important to point out that any manipulation of Bayer data should preserve the integrity of the data themselves, because most algorithms used in each stages of IGP to improve the image quality take these data as input. Thus a lossless or visually lossless compression is required, at cost of higher bit-rate. Common approaches consist on separate the sensor output into three data records, one for each color channel, treating them independently, as three different grey-levels pictures.

"Bayer-oriented" compression algorithms usually apply also an image transform from the linear space metric of the digitized data to some more perceptually uniform metric, in order to take properly into account the non-linearity of the human visual system [8],[9].

This paper describes a compression method suitable addressed for Bayer data compression. The proposed approach consists of two independent stages. The input images, acquired by the sensor in CFA format, is first compressed using a non-uniform vector quantizer [10],[11]. Such quantizer has been specifically obtained after an exaustive experimental phase considering large databases of CFA images acquired with different CCD/CMOS sensors at different resolution. Using statistical information about chromatic spatial correlation together with a serie of HVS heuristics [12],[13],[14],[15] it has been possible to describe each pair of CFA pels in the input images with a suitable code. Such a code could be used as input for a light view-finder engine. The resulting codestream is then further compressed applying a lossless entropy engine (DPCM algorithm [16]).

The rest of the paper is organized as follows. Section 2 presents basic concepts about vector quantization together with a detailed descritpion of the proposed algorithm Experimental results are presented in Section 3. Final remarks and future works are discussed in the last section.

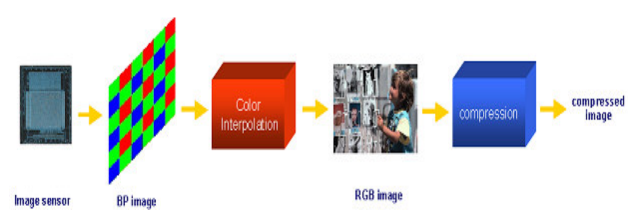


Figure 1 - Image Generation Pipeline basic scheme.

II. BAYER DATA COMPRESSION BY VECTOR QUANTIZATION

A uniform vector quantizer [10] processes the input vector ($X_1, \ldots, X_n$) appling the same quantization step Q to each sample X_i (with $1 \leq i \leq n$) according to the following formula:

$$VQ(X_i)=floor(X_i/Q)*Q, \forall\ i = 1,2,\ldots, n.$$

[1] STMicroelectronics, Advanced System Technology, Digital Still Camera and Multimedia Group, Catania Lab, Italy;
[2] STMicroelectronics, Advanced System Technology, Agrate Brianza, Italy.

Resulting quantizer vector $(Y_1,\dots,Y_n)$ contains the reconstruction points for all samples of the n-dimensional space that fall in the range $Y_i \le X_i \le Y_i+Q,\ \forall\ i = 1, 2, \dots, n$. Given a 2-D image, it is described by a 2-dimensional vector of luminance values falling into the range [0, 255]; each pair of adjacent pixel could be mapped into a 2-D histogram, which could be partitioned in regular cells, corresponding to the fixed quantization step.

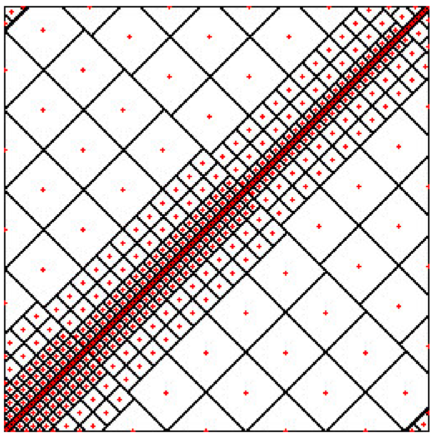


Figure 2 - Non-uniform partitioning of the 2-D histogram using the proposed adaptive quantizer.

However, since points along the diagonal of the histogram correspond to pels of similar luminance values (homogeneous regions), while points that fall far from the diagonal were generated by pair of pels of different luminance values (edge regions), exploiting simple properties of the Human Visual System (HVS), a more sophisticated, non-uniform quantizer has been defined. Vector quantization can also be used to reduce the perceptual irrelevancy by quantizing more roughly where the quantization error is less visible. The visibility of the error depends on two masking effects. In particular, since quantization errors are less visible along edges, a finer quantizazion has been performed near the diagonal of the histogram using bigger cells. Furthermore, high intensity luminance could be quantized more roughly, so finer quantization has been performed near the bottom left corner of the histogram, as showed in Figure 2. A Bayer pattern image of size NxN contains $N^2/2$ green pels, $N^2/4$ red pels and $N^2/4$ blue pels, so a scheme to build pairs of pels of the same component should be chosen. The proposed scheme, that maintains the Bayer pattern structure, is showed in Figure 3.

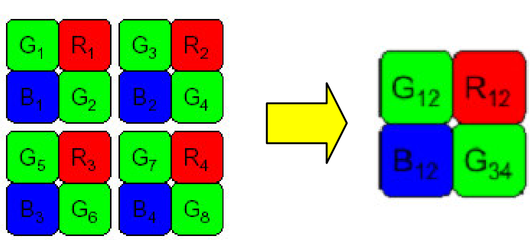


Figure 3 – Pixel pairs construction scheme.

Moreover, a code is assigned to each reconstruction point corresponding to a pair $<C_i,C_j>$ of pels in a color component, applying an appropriate function f:

$$C_{ij} = f(<C_i, C_j>) \qquad (1)$$

The proposed vector quantizer is defined by 512 reconstruction points, so a 9-bits code is assigned to each pair of pels in the original image and a bit rate of 4,5 bpp is achieved. Defining f such that codes assignment is related to the distribution of reconstruction points in the 2-D space. Residual redundancy has been eliminated by iterated compression performed applying a lossless DPCM [16] algorithm to the "codes-image".

III. Experimental Results

Since Bayer pattern data are the basic input for IGP algorithms, the compression step should be performed in a way that doesn't compromise their integrity. Thus, a "Bayer-oriented" compression algorithm must primary guarantee a near-lossless compression, even if at the cost of a high bit-rate. For "real-time" applications, an appropriate average target is obtained considering a compression factor 2:1, with no quality loss. Performances of the proposed method were evaluated using PSNR (Peak Signal to Noise Ratio) as measurement of quality of the compressed image with respect to the original one. Also a comparison with standard JPEG compression [7] has been realized. Three different CFA image databases at different resolutions (356x292, 644x484, 800x1000) were processed. All images have been acquired using CCD/CMOS sensors available in our lab. Results are summarized in Table 1.

Resolution	**356x292**		
Algorithm	**VQ**	**VQ+DPCM**	**JPEG**
Bit Rate (bpp)	4.5	3.02	3.02
PSNR (dB)	42.38	42.38	41.58
Resolution	**644x484**		
Algorithm	**VQ**	**VQ+DPCM**	**JPEG**
Bit Rate (bpp)	4.5	2.97	2.97
PSNR (dB)	41.12	41.12	40.13
Resolution	**800x1008**		
Algorithm	**VQ**	**VQ+DPCM**	**JPEG**
Bit Rate (bpp)	4.5	2.21	2.21
PSNR (dB)	44.83	44.83	38.14

Table 1 - Performances comparison between the proposed method and standard JPEG.

Using the adaptive vector quantizer defined in the previous section a compression factor of 1.78:1 is obtained. The further compression obtained applying DPCM allows to overcome, on the average, the target bit-rate of 4 bpp. As expected, performances grow with resolution, because a higher resolution corresponds to a stronger correlation among adjacent pels, thus a better compression is obtained.

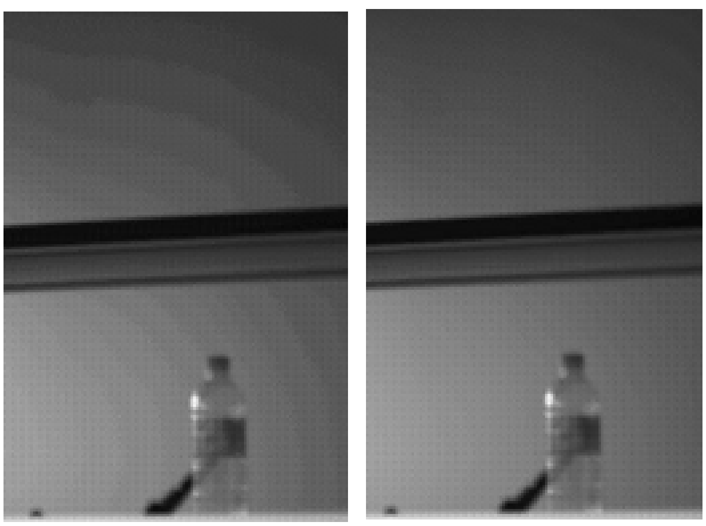
For comparison the input images are also compressed using JPEG compression, (of course fixing the same bit-rate) but the final quality gives worst results in terms of PSNR. Even if a more fair comparison could be obtained applying JPEG to each color component of the Bayer pattern, the proposed approach has a lower complexity, because it processes the image line by line, while JPEG needs more memory resources because it works partitioning the image into 8x8 blocks.

Figure 4 shows a comparison between the compressed images obtained using a uniform vector quantizer (a) and the proposed vector-quantizer (b).

In Figure 5 the effects of compression over a CIF Bayer image is showed. No quality loss is perceptible in the coded image (b), respect to the original one (a). Some kind of blurring effect is visible after color interpolation process, as showed in Figure 6, while no losses in terms of quality are visible in the case of VGA images (Figures 7 and 8).

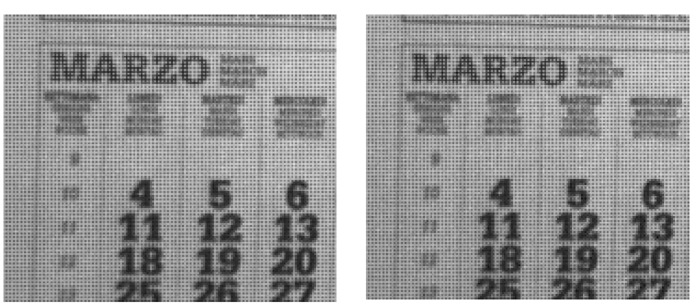
IV. Conclusions

An efficient compression algorithm for Bayer pattern images has been presented. The proposed approach, based on joined application of a not-uniform vector quantizer and lossless DPCM, provides a compression of at least 50% with no visually loss in the output image quality.



(a) (b)

Figure 4 - Comparison between uniform (a) and adaptive Vector Quantizers (b).

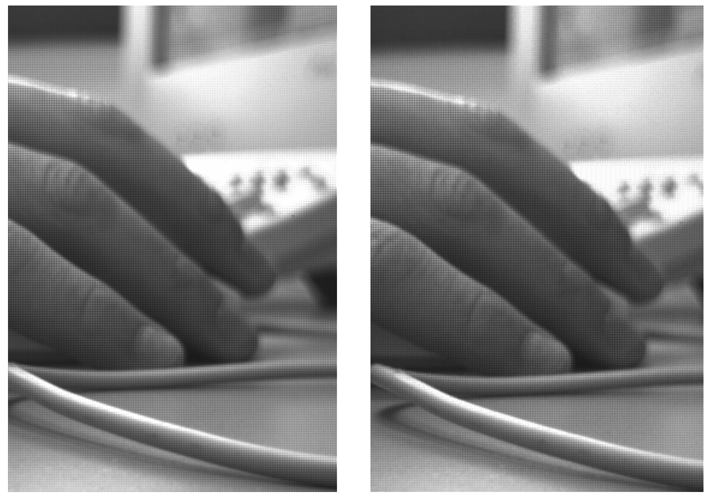


(a) (b)

Figure 5 - Example of VQ-based compression over a CIF Bayer image. (a) Original image; (b) Co-decoded image.

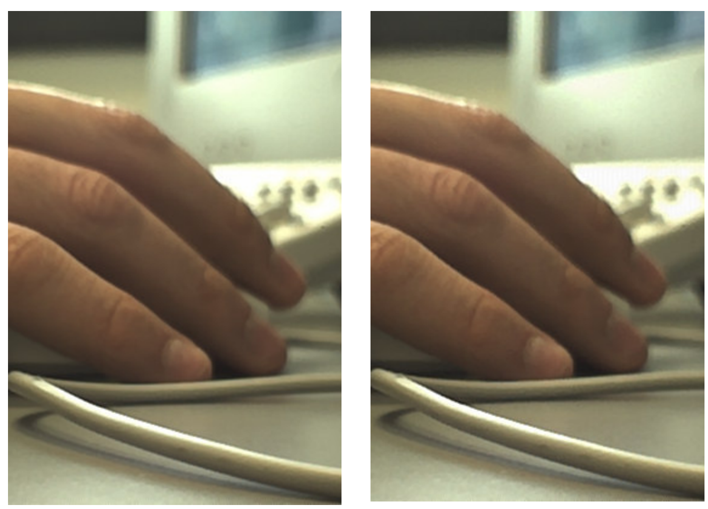
(a) (b)

Figure 6 - RGB images reconstructed by typical IGP**,** applied on Bayer images showed in Figure 5.



(a) (b)

Figure 7 - Example of VQ-based compression over a VGA Bayer image. (a) Original image; (b) Co-decoded image. No perceptive difference is noticeable.



(a) (b)

Figure 8 - RGB images reconstructed by typical IGP**,** applied on Bayer images showed in Figure 7. No perceptive difference is noticeable.

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