



pipeline group together different computations that can be executed as a single step and avoid redundant processing (e.g. benefits coming from an anti-aliasing algorithm would be negligible for such low resolution final images). The main proposed improvements could be summarized in the following list:

- White Balancing (WB) gains are not evaluated for each frame. The relative statistics collected are estimated sub-sampling the input data;
- Join together Scaling and Color Interpolation;
- Join together, in a single step, Color Matrixing and White Balancing;
- Gamma correction is done with a Look-up-table;
- The classical artifacts introduced by hard quantization are avoided using a smart anti-contouring technique.

The overall pipeline is schematically described in Figure 1. When the sensor acquires a scene, the White Balancing block processes the raw data. Considering that, between consecutive frames, light condition does not change significantly, the WB gain estimation is performed every  $K$  frames (8, for instance). The raw data are then scaled and interpolated in a single step, deciding only the scaling factor (we have assumed as possible factors 3, 4 and 5). The colors of the scaled image are then corrected, adapting the spectrum to the human sensitivity, with a matrixing operation. Both Matrixing and White Balancing are linear algebraic operators, thus it is possible to combine them in a single step. At this point, a gamma operation is performed to adapt the colors to the display response, and finally a quantization with anti-contouring reduces the color planes.

### 2.1. White Balancing Gains computation

White Balancing algorithms take into account color casting in scenes taken under non-white illumination. The algorithm divides the Bayer pattern in 4-pixels blocks (each of them containing 1 R, 1 B and 2 G pixels) and considers for computation purpose one pixel for each channel. As displayed in Figure 2 this means that the G pixel ( $\times$ ) will not be considered. White Balancing is achieved forcing the chromatic channel energy values to equal the maximum energy. In order to avoid excessive saturation of original colors, while computing the energy for a channel, values are weighted with the minimum value in the 4-pixel block and furthermore near saturation values are discarded. In detail three channel energies are computed using the following:

$$ce_i = \sum_{j=0}^B c_{ij} \cdot \min(c_{rj}, c_{gj}, c_{bj}) \cdot \alpha(T, c_{rj}, c_{gj}, c_{bj}) \quad (1)$$



Figure 2 – Pattern for WB gain computation.

where  $c_{ij}$  is the value of the  $i$ -channel of block  $j$ ,  $B$  is the number of total 4-pixels blocks, and  $\alpha$  is a 4-ary operator whose value is 0 if all channels are greater than an user fixed threshold  $T$ , 1 otherwise. Adopting both spatial and temporal sampling a considerable amount of computations are avoided [2], [4]. In fact, since illumination is usually uniformly distributed across the image, the aforementioned elaboration is done sub-sampling the 4-pixel blocks across vertical and horizontal directions (see Figure 3). Due to the data pattern the sampling step in terms of pixels must be in the form  $2N$ . Furthermore in video sequences illumination conditions are expected to vary smoothly from frame to frame and channel gains update can be done only every  $K$  frames.

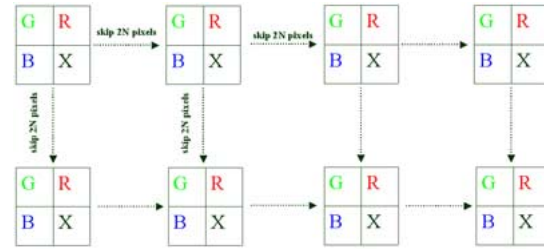


Figure 3 – Sub-sampling in WB gain estimation.

For a sequence composed by  $M$  frames of dimension  $H \times V$ , combining the two speeding techniques the number of considered blocks  $B$  is only:

$$B = \frac{M}{K} \times \frac{H \times V}{16 \times N^2} \quad (2)$$

### 2.2. Scaling and Color Interpolation

Starting from the sensor raw data (i.e. in CFA format) this step builds a full color image, at a given scaled resolution. Conventional scaling techniques do not perform any type of color interpolation. Such classical techniques are usually applied on full RGB color images. Averaging or decimation techniques, that throw away original pixels in the scaled image, are not a good choice if applied directly to CFA images. We propose to realize scaling and color interpolation in a simultaneous step. In order to manage different display resolutions, several scaling factors have been considered. Changing the scaling factor, the kernel dimension for the interpolation operator must be changed, according to the Shannon's theorem. Considering the

Bayer structure shown in Figure 4, in the case of a scaling x3 (using 3x3 kernel), from each quadrant  $Q_i, i = 1, \dots, 4$  a triplet of values (RGB) will be calculated by the following formulas:

$$\begin{aligned} \text{For Q1} \quad & \text{Red1} = B2 \\ & \text{Green1} = (B1 + A2 + C2 + B3)/4 \\ & \text{Blue1} = (A1 + C1 + A3 + C3)/4 \end{aligned} \quad (3)$$

$$\begin{aligned} \text{For Q2} \quad & \text{Red2} = (D2 + F2)/2 \\ & \text{Green2} = (D1 + F1 + D3 + F3)/4 \\ & \text{Blue2} = (E1 + E3)/2 \end{aligned} \quad (4)$$

$$\begin{aligned} \text{For Q3} \quad & \text{Red3} = (B4 + B6)/2 \\ & \text{Green3} = (A1 + C1 + A6 + C6)/4 \\ & \text{Blue3} = (A5 + C5)/2 \end{aligned} \quad (5)$$

$$\begin{aligned} \text{For Q4} \quad & \text{Red4} = (D4 + F4 + D6 + F6)/4 \\ & \text{Green4} = (E4 + D5 + F5 + E6)/4 \\ & \text{Blue4} = E5 \end{aligned} \quad (6)$$

For each of this four cases the result is an usual RGB pixel.

The previous example could be used, for instance, to obtain a QCIF preview from a VGA sensor (with a scaling by 3). Scaling by 4 (from VGA to 160x120) and by 5 (from VGA to 128x96) are analogous. In the last case a 5x5 kernel is used (see figure 5). Similarly to the previous case, the corresponding formulas to obtain the missing data can be easily derived. It is important to note how in both cases, 3x3 and 5x5 kernel, the formulas implicitly implements suitable low pass filters for the image subsampling, taking into account for each channel, only the real data.

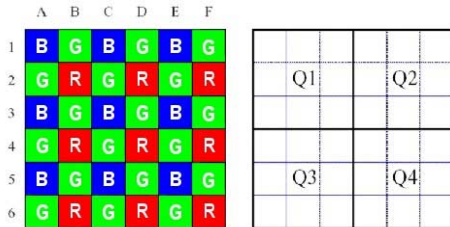


Figure 4 – Bayer scaling in the x3 case.

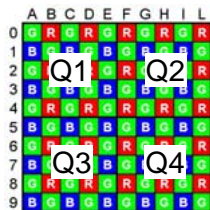


Figure 5 – Bayer scaling in the x5 case.

### 2.3. Matrixing and White-balancing

Color Matrixing is aimed to improve the color rendition and saturation of the image. In particular it corrects the

spectral sensitivities of the image sensor accordingly to the chromaticities of the display and the characteristics of the human eye. This enhancement is achieved manipulating the color matrix table coefficients to be applied to each R-G-B color pixel. On computational side, Matrixing is a matrix product between the input color channels and a correction matrix, whose coefficients are fixed referring to the specific display characteristics. White Balancing correction and Matrixing have been coupled together, and thus performed as a single step by multiplying the Matrixing matrix by a diagonal one. Elements of the diagonal matrix are the White Balancing channel gains computed as described in the previous paragraph. Formulas (7) and (8) show how a single White Balancing/Matrixing matrix is derived and applied.

$$\begin{vmatrix} c_{1,1} & c_{1,2} & c_{1,3} \\ c_{2,1} & c_{2,2} & c_{2,3} \\ c_{3,1} & c_{3,2} & c_{3,3} \end{vmatrix} = \begin{vmatrix} G_r & 0 & 0 \\ 0 & G_g & 0 \\ 0 & 0 & G_b \end{vmatrix} \bullet \begin{vmatrix} m_{1,1} & m_{1,2} & m_{1,3} \\ m_{2,1} & m_{2,2} & m_{2,3} \\ m_{3,1} & m_{3,2} & m_{3,3} \end{vmatrix} \quad (7)$$

$$\begin{vmatrix} R_b & G_b & B_b \end{vmatrix} = \begin{vmatrix} R & G & B \end{vmatrix} \bullet \begin{vmatrix} c_{1,1} & c_{1,2} & c_{1,3} \\ c_{2,1} & c_{2,2} & c_{2,3} \\ c_{3,1} & c_{3,2} & c_{3,3} \end{vmatrix} \quad (8)$$

Ideally values coming from White Balancing processing should be clipped in the output range before Matrixing. Avoiding the clipping phase between these two corrections, out of range values could be processed by Matrixing step creating false color effects in the final image. Actually this problem affects the less significant bits of pixels and this piece of information will anyway be cut by the quantization thus avoiding unpleasant effects in the final displayed image.

### 2.4. Gamma Correction

The luminance generated by a physical device is generally not a linear function of the applied signal. This non-linearity must be compensated in order to achieve correct reproduction of luminance. The Gamma correction is a nonlinear transformation applied to each pixel. To apply this function with a low computational cost a look-up-table is used where the  $i$ -th element is generated considering the relation:

$$GC(i) = 255 \times \left( \frac{i}{255} \right)^{\frac{1}{\gamma}} \quad (9)$$

with a device-specific  $\gamma$ .

### 2.5. Improved Gray Scale Quantization

A simple quantization of a channel from 8 to 4 bit, or less, produces a series of noticeable artifacts in the final image. A suitable algorithm able to avoid a brutal truncation of

preventing the creation of artifacts in the image is needed. To each pixel value is added a pseudo-random noise before truncation. In this way spatially near pixels with same values can have slightly different values in the output image breaking false contours due to the loss of the smooth degradation. The pseudo-random noise to be added is given by the less significative bits of the sum between the pixel value and the previously evaluated noise. The result of the improved quantization is an image where false contours are highly reduced. See also [6], [7] for more details.

### 3. EXPERIMENTAL RESULTS

In order to validate the proposed pipeline plenty of tests have been made on a real time acquisition system. In particular the overall scheme was implemented in a real-time framework, using a CMOS-VGA sensor on the "STV6500 - E01" Evaluation Kit equipped with a "502 VGA sensor" [9]. Besides considering the complexity of a typical IGP for High End Digital still cameras in term of simple operations such as: shift, add, mac, compare, multiply, it is correct to consider that about 300ops/pixel are needed, from the acquisition to the final RGB image (before the compression). Thus, for a VGA image about 90 Mops. are needed. Using our pipeline we have obtained (for a VGA image) in the case of x3 scaling about 310Kops., for x4 scaling about 950Kops. and for x5 scaling about 620Kops. The achieved performances allow embedding the overall processing in a real-time system. A snapshot of the system is shown in Figure 6 where the application was implemented using a C-code interface to the sensor. The final quality of the image is not affected by color artifacts due to the lighter computation implemented while the relative frame-rate is sensibly improved.

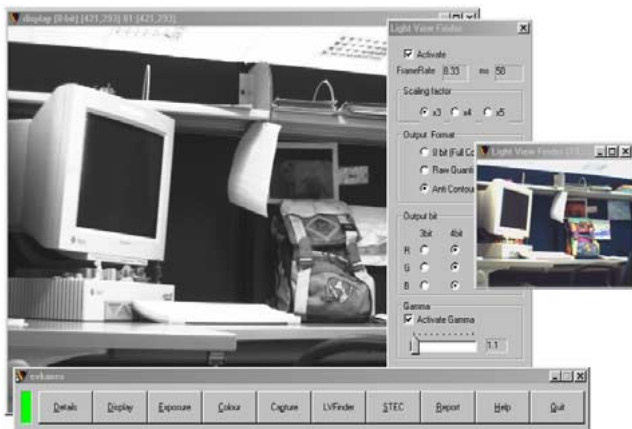


Figure 6 - Snapshot of the Viewfinder implementation.

### 4. CONCLUSIONS

The proposed pipeline processes image from a sensor with Bayer CFA and swiftly creates, with a low computational cost a preview of the image. It can be used in any device to pre-view real time image sequences acquired by a sensor and it is suited to mobile device for its low power consumption. The view-finder has been achieved avoiding all redundant processing. The overall system is also optimized (e.g. White Balancing gains estimation are spatially and temporally subsampled). Some typical IGP steps are coupled and melted in a single block (e.g. Scaling and Color Interpolation are carried out together and the WB is applied during the Color Matrixing elaboration). Experiments have confirmed the effectiveness of the proposed pipeline.

Future works will include objective tests based on *no-reference metrics* to evaluate the quality loss with respect to a full IGP + Scaling.

### 5. REFERENCES

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