

# Image Reconstruction Based On Bayer And Implementation On FPGA

Sun Chen<sup>1, a</sup>, Duan Xiaofeng<sup>2, b</sup> and Wu Qijing<sup>3, c</sup>

<sup>1</sup> Xi'an Institute of Optics and Precision Mechanics, CAS., Xian 710119, China;

<sup>2</sup> Xi'an Institute of Optics and Precision Mechanics, CAS., Xian 710119, China;

<sup>3</sup> Xi'an Institute of Optics and Precision Mechanics, CAS., Xian 710119, China.

<sup>a</sup>sunchen2009@126.com, <sup>b</sup>duanxiaofeng@opt.ac.cn, <sup>c</sup>wuqijing@126.com,

**Keywords:** bayer image, gradient, color reconstruction, FPGA.

**Abstract.** This paper mainly introduces color images interpolation algorithm which based on bayer template. In order to estimate the missing two components in one pixel accurately, this algorithm selects gradient correlation between pixels to calculate them. The bayer image, whose resolution ratio is 5120\*3840, captured by CMOS, is output by DVI interface. Experimental results shows that this algorithm both ensure the quality of reconstruction images and the real-time processing on FPGA.

## Introduction

With the development of information technology, quality of people's life has improved. More and more people use digital cameras replace film cameras. The sensor of digital cameras is a light-sensitive Charge-Coupled Device or Complementary Metal Oxide Semiconductor. The image which is captured by sensor is a gray scale image; digital cameras need a series of image processing to enhance image quality. For example, the color image reconstruction based on bayer template, white balance, automatic integration algorithm and so on. The one important image processing is color image reconstruction based on bayer template, it is known as demosaicing.

In order to capture a full-color image, theoretically require three photosensitive arrays in digital cameras, each of these arrays to capture one of red, green and blue colors. This way of capturing a color image requires a large storage space, high cost and high difficulty device deployment. Most digital cameras put a color filter array CFA on single photosensitive array to achieve primary separation, so that the adjacent photosensitive array can capture different colors of light (red, green or blue). Each pixel lost the other two color components needs an image interpolation algorithm to rebuild full-color image. this algorithm has been implemented on Xilinx FPGA spartan6 platform. Whole system can be divided into three parts, the first part is to write data into SDRAM; the second part is to read data out from SDRAM and calculate these data by interpolation algorithm and restored in SDRAM; the third part is to read data out from SDRAM, output through DVI interface and bus.

R <sub>1,1</sub>	G <sub>1,2</sub>	R <sub>1,3</sub>	G <sub>1,4</sub>	R <sub>1,5</sub>
G <sub>2,1</sub>	B <sub>2,2</sub>	G <sub>2,3</sub>	B <sub>2,4</sub>	G <sub>2,5</sub>
R <sub>3,1</sub>	G <sub>3,2</sub>	R <sub>3,3</sub>	G <sub>3,4</sub>	R <sub>3,5</sub>
G <sub>4,1</sub>	B <sub>4,2</sub>	G <sub>4,3</sub>	B <sub>4,4</sub>	G <sub>4,5</sub>
R <sub>5,1</sub>	G <sub>5,2</sub>	R <sub>5,3</sub>	G <sub>5,4</sub>	R <sub>5,5</sub>

Fig. 1 Bayer template

## Common demosaicing methods

**Bilinear interpolation.** Bilinear interpolation algorithm is one of the widely used interpolation algorithm. When we calculate R and B at G values in Figure 1 based on this algorithm, We can estimate G and B at R values and R and G at B values by same method. Bilinear algorithm has low complexity. It is easy to implement on FPGA and works well in smooth area. But at the edge area, pixel values has direction, we cannot easily calculate pixel values by the average of surrounding

pixels. So, this algorithm will have zigzag on the edge of the area, it is called zipper effect.

**Constant color difference.** There are a lot of divisions in the formula of Aberration interpolation, if a pixel value is 0, this pixel will not be calculated by the above formula. This is a limitation of Aberration interpolation. In order to overcome this limitation of Aberration interpolation, there is a proposed algorithm based on Mondrian model, it is called Aberration interpolation, it use subtraction instead of division.

**Gradient direction interpolation algorithms.** Gradient information is an important factor affecting visuals; it is not only can transfer most of image information, but can also sketch out the basic outline of objects in an image. We can get useful structure information from edge detection so that we can reduce the processed data and improve efficiency. Gradient direction interpolation algorithm is an adaptive interpolation algorithm; each pixel can get a more appropriate interpolation direction. This interpolation has been widely used, you can change the size of region to get a better interpolation results.

**3\*3 regions:** Every pixel has three components, the relationship between three components are very close in the research of algorithm. This algorithm is first-order edge detection proposed by Hibbard.

**5\*5 regions:** Second order differential interpolation algorithm is proposed by Laroche edge detected algorithm, in this algorithm, edge detection is a linear shift invariant second order differential operator, it is called Laplace operator. For calculating interpolation direction at G based on Laroche edge detected algorithm, we remain comparing horizontal direction and vertical direction. The difference is that we calculate a pixel's gradient interpolation direction by itself instead of G gradient interpolation direction.

**High quality linear interpolation algorithm.** Several interpolation algorithms described above do not take into account the correlation between the various color components. The experiments show that variation of different color components are very slowly in local region. If we add information of the other two components, we will estimate the other two components accurately. Luminance information is much more important than chrominance information, so we will not discard red values at  $R_{3,3}$  when we calculate G values at  $R_{3,3}$ , R values is useful information. Malvar proposed a new type of high quality interpolation algorithm on 2004. The whole idea of this algorithm is average and correction. This algorithm chooses a 5\*5 filter for calculating and makes full use of correlation between three channels. The filters are shown as following:

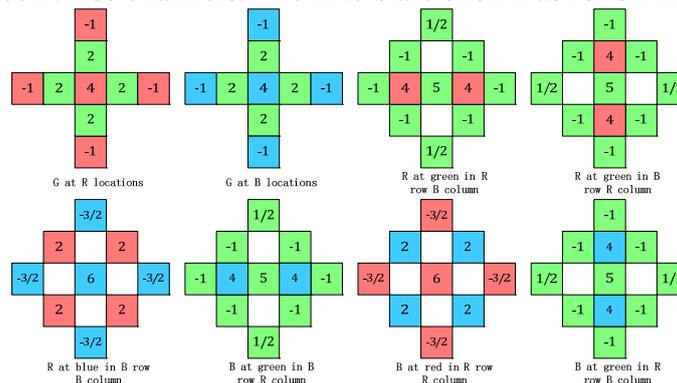


Fig.2 Filters

These linear filters make full use of correlation between three channels, they come up with appropriate values of  $\{\alpha, \beta, \gamma\}$ , is  $\alpha = 1/2$ ,  $\beta = 5/8$ ,  $\gamma = 3/4$ , the quality of this algorithm is much higher than bilinear.

**Wavelet transform Interpolation algorithm.** The purpose of wavelet transform is to distinguish high frequency signal from low frequency signal. The signal has been converted into wavelet domain by Scaling and translation transformation. For many problems which cannot be solved by Fourier transform, Wavelet transform works very well and very effective. S.mallat reference Burt and Adelson pyramid image decomposition and reconstruction algorithms, lead the field of computer vision into wavelet domain, put forward a fast algorithm for wavelet transform called mallat.

Interpolation algorithm based on wavelet transform has a good effect in color image reconstruction, but the high complexity and a large amount of computation limit the algorithm application. It cannot be complement on FPGA.

**Proposed linear interpolation algorithm.** Bilinear is easy to lead zipper effect in high frequency region, color constant will have a good interpolation results in smooth areas, but many error values in sudden changes region. Gradient interpolation algorithm works well in high frequency region, subtle changes will be processed as image edge, so this algorithm keeps edge information as well as brings in random noises. The color characteristic is very important information in image and the high frequency region is also an important part of an image. Therefore, the design of proposed algorithm is based on gradient information. First order and second order edge detection algorithm is easier to implement on FPGA. In order to find a more appropriate real-time processing and high quality image reconstruction, I put forward a proposed algorithm based on gradient algorithm. This algorithm ensures quality of image reconstruction; achieve real-time and low resource consumption.

For the missing G at R<sub>3,3</sub>:

a. We define vertical direction  $T_v$ , horizontal direction  $T_h$ , 45°direction  $T_{hd}$  and 135°  $T_{vd}$  direction, formulas are shown as following:

$$T_h = |2 * R_{3,3} - R_{3,1} - R_{3,5}| \quad (1)$$

$$T_v = |2 * R_{3,3} - R_{1,3} - R_{5,3}| \quad (2)$$

$$T_{hd} = |2 * R_{3,3} - R_{1,5} - R_{5,1}| \quad (3)$$

$$T_{vd} = |2 * R_{3,3} - R_{1,1} - R_{5,5}| \quad (4)$$

b. Comparing  $T_h$  and  $T_v$  to determine interpolation direction, formulas are shown as following:

$$\hat{g}_{3,3} = |(G_{3,2} + G_{3,4}) / 2 + \alpha * T_h| \quad T_h < T_v \quad (5)$$

$$\hat{g}_{3,3} = |(G_{2,3} + G_{4,3}) / 2 + \alpha * T_v| \quad T_h > T_v \quad (6)$$

$$\hat{g}_{3,3} = |(G_{3,2} + G_{2,3} + G_{4,3} + G_{3,4}) / 4 + \alpha * (T_v + T_h)| \quad T_h = T_v \quad (7)$$

c. Comparing  $T_{hd}$  and  $T_{vd}$  to determine interpolation direction, formulas are shown as following:

$$\hat{b}_{3,3} = |(B_{2,2} + B_{4,4}) / 2 + \alpha * T_{hd}| \quad T_{hd} > T_{vd} \quad (8)$$

$$\hat{b}_{3,3} = |(B_{2,4} + B_{4,2}) / 2 + \alpha * T_{vd}| \quad T_{hd} < T_{vd} \quad (9)$$

$$\hat{b}_{3,3} = |(B_{2,2} + B_{4,4} + B_{2,4} + B_{4,2}) / 4 + \alpha * (T_{hd} + T_{vd}) / 2| \quad T_{hd} = T_{vd} \quad (10)$$

**Implement on FPGA:** The whole system consists of three parts: first, sensor captures Bayer image; second, demosaicing; third, output module. The whole system is shown as following:

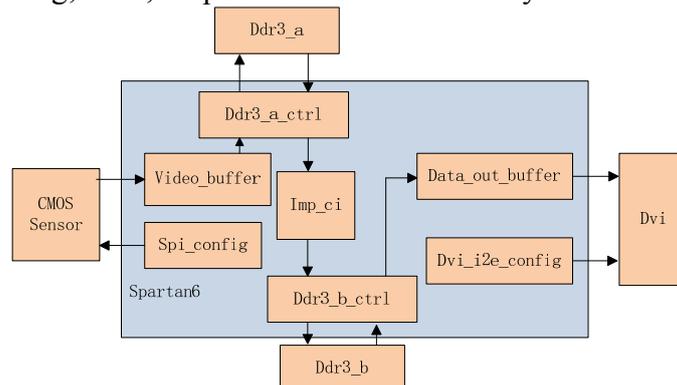


Fig 3. System

**Video\_buffer module:** This module mainly consists of data storage module and storage control module. The data captured by sensor are wrote in SDRAM, then, FPGA write these data in Video\_buffer which is SDRAM, and then read these data in Ddr3\_ain order, Ddr3\_a consists of four blocks, control module transferred eight pixels every time in parallel to Imp\_ci which is demosaic module.

**Demosaic module:** Demosaic module devide into two parts: interpolation processing and control module. Control module load data into interpolation module by address signal. Each pixel in bayer image captured by sensor is 10bits, in order to meet the requirements of clock synchronization; we convert each pixel into 16bits. This algorithm includes simple addition or subtraction and comparison operation. There are 5120\*3840 pixels in one frame image.

**DVI output module:** This module includes buffer part and control part, too. Control module convert the processed data into image standard data, and then save these image data into Ddr3\_b. before getting out image data, control module transferred these data into data\_out\_buffer and then displayed by DVI interface. The frame can reach 25 frame per second.

**Performance:** I choose different algorithms to process same image, the results shows as following:



Fig 4.Lena

Details:

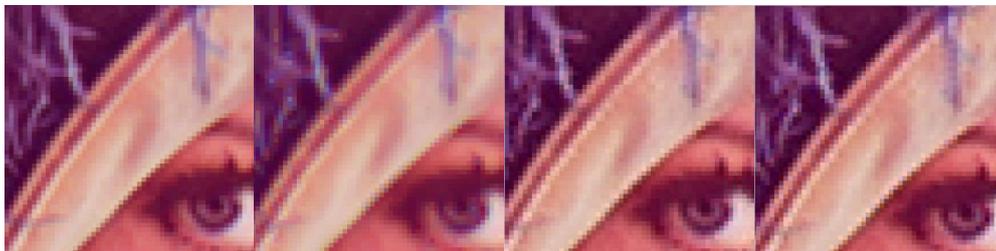


Fig 5. From left to right; original, ,5\*5regions gradient, high-quality linear, proposed method.

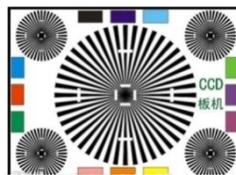


Fig 6. CCD prototype

Details:

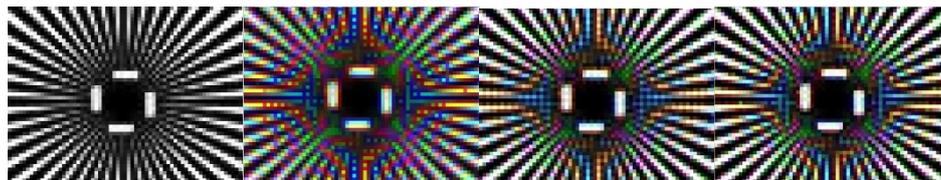


Fig 7. From left to right; original, 5\*5regions gradient, high-quality linear, proposed method.

Table 1 PSNR, for the 4 images, A)Bilinear; B)5\*5 regions gradient; C)high-quality linear; D) proposed method

Numble	ch	A	B	C	D
1	R	25.25	28.55	29.12	29.81
	G	26.55	26.61	27.15	27.65
	B	25.21	25.54	25.84	27.52
2	R	22.50	25.31	25.51	26.22
	G	27.32	24.22	25.12	26.35
	B	23.01	23.18	23.25	24.20
3	R	31.84	31.78	31.97	32.87
	G	33.55	32.55	33.68	34.51
	B	30.27	32.41	32.86	34.63
4	R	32.20	32.12	33.52	34.28
	G	33.16	33.54	33.42	34.59
	B	34.61	36.21	36.35	37.21
Average	R	28.02	29.44	28.53	30.78
	G	30.18	29.23	29.84	30.79
	B	28.70	29.34	29.58	30.89

## Summary

This paper proposed an efficient image reconstruction algorithm, this algorithm estimate value of pixel based on gradient correlation between pixels. This method is verified on FPGA, it can provide a high-speed, high-quality reconstruct image. This whole system has been applied to industrial successfully with low-cost, high-quality.

## References

- [1] HUANG W T, CHEN C H, TSAI Z H, et al. High-quality and high-speed demosaicking algorithm design[J]. Taipei University Technol., 2007,40(2):13-25.
- [2] Nai-Xiang Lian, Lanlan Chang, Yap-Peng, et al. Adaptive Filtering for Color Filter Array Demosaicking. IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL.16,NO.10,OCTOBER 2007.
- [3]Zhang Qigui, Zhao Lijuan, Implementation of Bayer Image Interpolation based on FPGA. Taiyuan University of Technology, 2010
- [4]Ning Yang. Processing system of video image based on FPGA. Dalian Maritime University.2008.
- [5]Malvar H S, HE L W, Cutler R. High quality linear interpolation for demosaicing of bayer-patterned color images[C]// Processing of the IEEE International Conference on Speech, Acoustics, and Signal Processing, Montreal, Canada; IEEE,2004.
- [6] Jung, T.-Y., Yang, S., Lee, J., and Jeong, J., “Enhanced Directionally Weighted Demosaicing for Digital Cameras,” IEEE International Conference on Signal Image Technology and Internet Based Systems 2008, 518-522 (2008).