Color Filter Array Design Based on Multi-Edge Constant Hue Algorithm

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***Abstract*—In this paper, we propose color filter array design based on multi-edge constant hue algorithm. The reconstructed image quality can be improved with lower computational complexity. The algorithm performs edge judgment and interpolation reduction on the green image plane. The result shows that multi-angle judgment can improve color accuracy and image quality.**

***Index Terms*—Color Filter Array (CFA), constant hue, digital camera, multi-edge**

I. Introduction

Digital Still Camera (DSC) was used three-primary image sensor for landscape capture. Consumer DSC and camera module of smart phone used Color Filter Array (CFA) for landscape capture in order to reduce hardware cost and system architecture complexity recently. CFA uses most commonly Bayer Pattern which catches one color on every pixel in the image. After capturing single channel image, CFA adjusts image and performs Color Interpolation (CI) to recover image.

The most commonly used color filter array arrangement is the Bayer Pattern [1], [2]. Many related CFA interpolation algorithms have been proposed in the Literature [3]-[6].

The main algorithm is divided into two types, one is the algorithm to deal with the faster spatial domain algorithm, and the other is frequency algorithm for the high-quality image.

We can further divide the spatial domain algorithm into two types, mainly based on whether to classify for edge processing.

The first is a generalized spatial domain algorithm [7]-[9]. This algorithm is non-adaptive algorithm, mainly for the whole image to do the integration calculation, and will not take into account the variables in the process of calculation.

The other is the edge-oriented spatial domain algorithm [10]-[17]. Such an algorithm adds edge detection conditions to the calculation process and needs additional judgments and calculations. The effect of the restored image is better than the generalized interpolation, and the relative computational complexity is also higher.

In addition, the frequency domain interpolation algorithm has also been proposed [18]-[24]. The processing steps of the image restoration algorithm using the frequency domain algorithm are quite complex and difficult. So it is also difficult and costly to design and implement the hardware.

In this paper, we propose a new spatial domain algorithms "multi-edge constant hue interpolation" for color filter array application. The proposed scheme can improve image quality using lower calculation complexity. At first, this approach executes three times edge detect and interpolation. Second, it runs red and blue plan interpolation. We use Kodak's standard pictures for simulation in this paper which uses subjective view, PSNR and operation complexity to compare with different algorithms. Therefore, multi-edge detection can enhance edge color accuracy and provide well image quality.

II. Proposed Method

We propose color filter array design based on multi-edge constant hue algorithm in this paper. The algorithm is based on edge-directed interpolation algorithm and constant-hue interpolation algorithm.

For the part of the edge detection algorithm, we provide a multi-angle judgment method for calculation, which includes horizontal and vertical adaptive color plane interpolation and multi-edge directed interpolation.

In addition, plane prediction interpolation algorithm is added before the edge interpolation algorithm is processed. This method is used to estimate whether the smoothing surface is smooth, so as to reduce the subsequent edge judgment and speed up the processing of the entire algorithm.

According to the Bayer pattern of color filter array, the green pixels are accounted for half of the area, blue and red pixels are accounted for a quarter of the area.

Taking into account the arrangement of the Bayer color filter array to the highest green sample, so in several of the better spatial domain algorithms will give high priority to the green plane. When obtaining a complete green plane, then the scheme uses the green plane information to calculate the lower sampling rate of red and blue planes. Because of the improved image quality of the green plane, the quality of red and blue planes are indirectly improved and reduced the aliasing distortion of the reduction calculation.

Our algorithm has done the following steps for image interpolation restoration. In the first step, the method

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performs smooth judgment in the green plane and detects vertical and horizontal edges for interpolation calculation. In the second step, a 45-degree bevel detection and interpolation correction is performed in the green plane. In the third step, a 22.5-degree interpolation correction and compensation is achieved in the green plane. In the final step, a modified constant hue color interpolation is used to interpolate the blue plane and the red plane.

The main difference between the proposed algorithm in this paper and other algorithms in the spatial domain is the use of 7×7 array to do more angle interpolation. Therefore, the scheme can get finer edge quality

Another feature is the plane to do interpolation interpolation at first. The main reason is that most of the images have a large area of smooth surface. Using plane prediction and interpolation reduces the number of times of vertical and horizontal edges judgement. Therefore, a simpler space operation can be used to improve the operation speed of image interpolation.

III. Experimental Results

In this section, we will describe and explain the experimental results in detail. We will explain the experimental results, visual effects and image quality. Finally, we will compare the computational complexity of various methods. We use the Eastman Kodak Company test images. Each picture size is 768×512 or 512×768. We use several spatial-domain algorithms to make subjective visual comparisons. The comparison algorithm is included Bilinear Interpolation (BI), Constant-Hue Interpolation (CHI), Edge-Directed Interpolation (EDI), Adaptive Color Plane Interpolation (ACPI), Effective Color Interpolation (ECI), color plane Alternating Projection interpolation (AP) and proposed method (multi-edge constant hue interpolation).

Table I lists the comparison results of all the algorithms. It can be seen that the proposed algorithm is superior to the other spatial-domain algorithms. The main reason is that the algorithm we proposed has more precise processing and calculation at the edges. Of course, the computational complexity will certainly be more than other spatial algorithms.

Fig. 1 uses a painted room image and the image has a lot of edge components. Bilinear interpolation and constant-hue interpolation produce a lot of wrong color and zipper effect at the edges. Edge-directed interpolation algorithm performs better on the edge but does not completely solve the wrong color problem of the edge. The adaptive color plane interpolation and proposed method are very good at edge processing. Almost unnatural colors can not be seen. In particular, the algorithm we proposed is better at the edge of the corner and the outline is clearer.

Fig. 2 is a test image of wall and window. For the part of the window, bilinear interpolation and constant-hue interpolation have obvious wrong color. The location of the white curtains also have obvious unnatural colors. Edge-directed interpolation uses the most basic edge detection algorithm. Although the windows are edge-processed, there is a noticeable red erroneous color at several junctions, which should be an imprecise red sampling error. Adaptive color plane interpolation and proposed method have a very good edge processing of window in Fig. 2(e) and 2(f).

TABLE I. PSNR Comparison

Image	Bilinear	Constant hue	Edge directed	ACPI	ECI	AP [24]	Proposed
IMG01	25.51	28.53	29.14	33.87	33.21	37.17	36.41
	29.77	30.82	30.16	37.27	35.65	40.02	38.07
	24.71	30.12	29.88	32.84	33.38	36.96	36.62
IMG02	32.06	38.33	38.54	38.53	36.85	38.29	38.73
	36.42	40.56	40.61	42.27	41.28	40.20	43.61
	31.58	39.07	40.39	37.31	39.35	38.73	41.71
IMG03	33.61	31.96	30.08	40.78	40.51	41.29	41.87
	37.33	37.56	37.02	42.67	43.11	43.23	45.05
	32.91	36.02	35.64	37.65	40.07	39.82	40.92
IMG04	32.75	39.91	39.86	39.84	36.88	37.70	37.73
	36.64	40.87	40.82	41.99	42.16	42.15	43.67
	31.56	40.06	40.76	37.56	40.77	41.29	42.63
IMG05	25.93	29.12	28.69	34.72	35.04	37.70	37.22
	39.48	30.09	30.54	35.45	36.84	39.42	39.09
	24.71	29.97	29.83	33.59	34.74	35.53	36.25
IMG06	26.84	31.04	30.99	35.03	34.65	38.34	38.13
	31.20	32.10	31.82	38.51	36.98	41.21	39.43
	26.44	30.67	30.91	33.86	34.12	37.07	36.99
IMG07	32.76	36.24	36.45	40.96	40.31	41.85	42.17
	36.66	37.26	37.99	42.40	42.16	43.32	44.72
	31.10	36.26	35.75	37.89	39.69	39.54	41.39
IMG08	22.69	26.90	28.29	31.83	30.16	35.36	34.74
	27.56	28.21	29.52	36.24	33.09	37.99	36.93
	21.51	26.80	28.56	31.09	29.87	34.26	34.69
IMG09	31.69	35.84	36.63	40.27	38.66	41.37	41.47
	35.82	36.66	37.48	43.00	41.37	44.00	44.50
	30.19	35.62	36.49	37.51	39.32	40.81	43.05
IMG10	31.99	35.58	36.63	40.04	39.37	41.44	41.05
	35.48	36.31	37.48	41.77	42.07	44.30	44.33
	30.27	35.63	36.49	37.24	39.43	40.60	41.61

(a) Original Image (b) Bilinear Interpolation

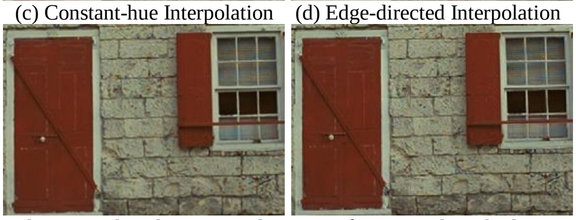
(c) Constant-hue Interpolation (d) Edge-directed Interpolation

(e) Adaptive Color Plane Interpolation (f) Proposed Method

Figure 1. Example of a ONE-COLUMN figure caption.

(a) Original Image (b) Bilinear Interpolation

(c) Constant-hue Interpolation (d) Edge-directed Interpolation



(e) Adaptive Color Plane Interpolation (f) Proposed Method

Figure 2. Example of a ONE-COLUMN figure caption.

Table II describes the computational complexity of several more representative algorithms. It is clear that the amount of computation for spatial algorithms is much smaller than for frequency domain algorithms. Our proposed method is far less computationally intensive than color plane alternating projection interpolation. We can obviously see that the spatial algorithm basically does not need to use multipliers. So the hardware architecture will be relatively simple. The efficiency will be much better.

TABLE II. COMPUTING COMPLEXITY COMPARISON

Method	Computational Operations				
	Addition	Bit-shift	Comparison	Absolute	Multi-plication
Edge-direction	4 T	2 T	0.5 T	1 T	None
Constant-Hue	4T	6T	None	None	2T
ECI	10 T	4 T	None	None	None
Adaptive color plane	13 T	5 T	1 T	4 T	None
AP	391.5 T	3.5 T	0.5 T	2 T	384 T
Proposed	15 T	3.5 T	5T	12 T	None

IV. CONCLUSION

The proposed method is an extension of the edge detection algorithm in the spatial domain. The main method is to do a more refined angle calculation based on the edge judgment. When we judge the more refined, the result will be closer to the original image. Another important point of the algorithm is to add edge judgment to the red and blue image planes. The proposed method provides well image quality and solution of the related problems.

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