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Research Article

LAGRANGE BASED COLOR IMAGE DEMOSAICING USING ITERATIVE RESIDUAL INTERPOLATION

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ABSTRACT

Interpolation technique in color image demosaicing is a big challenge to obtain RGB channels as perceived by humans. The existing demosaicing methods adopt iterative residual interpolation (IRI) technique, which performs iterations on the residuals. These methods are unable to reconstruct G channel efficiently with fewer iterations. Hence a new demosaicing method is proposed, which performs less iterative interpolations on the residuals using Residual Interpolation (RI) and Minimum Laplacian Residual Interpolation (MLRI) methods. Initially, Lagrange interpolation technique is used to estimate RGB channels independently. The G channel is reconstructed based on the estimated values of RGB channels with minimal iterations. R and B channels are reconstructed from RI method using reconstructed G as a guide. Experimental results demonstrate that, this algorithm performance is better in most cases, compared with the existing demosaicing methods both on subjective and objective evaluations.

INTRODUCTION

Many digital cameras use single image sensor technology overlaid with a Color Filter Array (CFA) [3]. A color image captured using this technology is called a mosaiced image. The mosaiced image contains only one of the three primary color components (i.e. R, G or B) at each pixel. The arrangement of the color components of the mosaiced image is determined by the selected CFA. The most widely used CFA pattern is the Bayer CFA pattern, as shown in fig. 1 [2]. Bayer filter has alternating green and red filters in odd rows and alternating blue and green filters in even rows. Each 2x2 cell has two green, one red and one blue filter.

Demosaicing is the reverse process of mosaicing. It is the process of reconstructing the full-color image from the captured CFA. In this process, the missing color components at each pixel are interpolated [1]. Most methods first interpolate the green channel and then use this estimate to interpolate the red and blue channels. This is due to the higher sampling rate of the green component, which permits an easier reconstruction of the main geometry and texture than the red and blue ones. Seemingly, the quality of the reconstructed green channel is critical to the overall demosaicing performance, as any error in the green channel will be unavoidably propagated to the red and blue channels in the succeeding steps.

Among the many existing demosaicing methods, the popular method is the residual interpolation (RI) [4]. In residual interpolation, instead of using color difference as in

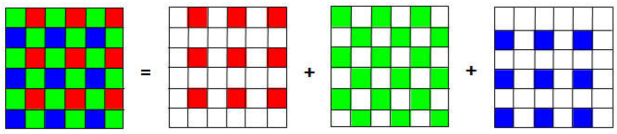

Fig. 1 Bayer CFA Pattern

Color-component Difference Interpolation (CDI), tentative estimates of R and B images are generated and residuals are calculated. Residual is the difference between the observed and the estimated R and B pixel values. These residual fields are interpolated in the RI based methods. However, the algorithm as described in [4] fail to fully exploit the RI strategy for all the three channels. Only the R and B channels are restored using the RI process, whereas the G channel reconstruction depends on a CDI-based approach, called the Gradient Based Threshold-Free (GBTF) demosaicing [8]. Moreover, these approaches are non-iterative and thus does not provide an opportunity to conduct refinement for the initially-restored values.

Recently, a new demosaicing approach is proposed, called the Iterative Residual Interpolation (IRI) [1]. The iterative residual interpolation process aims to reconstruct an accurate G channel compared with that of GBTF [8] as practiced in [4]. The obtained G channel is used in the reconstruction of the R and B

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channels, using RI based structure. Linear interpolation is used in this method. IRI method applies the RI process to all the three channels in a systematic manner and iteratively for refining their estimated values. IRI process will be conducted twice, one along the horizontal direction and the other along the vertical direction. The two restored G channels will then be combined to arrive at the final demosaiced G channel.

This paper proposes a Lagrange based iterative residual interpolation demosaicing algorithm. Initially, R, G and B channels are obtained separately which are independent, using Lagrange interpolation technique. To estimate complete G channel, separate horizontal and vertical tentative estimates are generated from initially obtained RGB channels, using RI and MLRI methods. Residuals are obtained by subtracting the estimated G values from the initially interpolated values. These residuals are interpolated horizontally and vertically by performing linear interpolation. Previously generated tentative estimates are added to these interpolated residuals to obtain G channel effectively. This G channel is used as a guiding image in the guided filter. This process is repeated till G channel is reconstructed efficiently. R channel is estimated by considering the reconstructed G channel as a guide. Residuals of R channel is obtained using bicubic interpolation technique. Effective R channel is reconstructed by adding estimated R image with its residuals. Similar procedure is used for reconstruction of B channel.

Lagrange Interpolation

Lagrange Interpolation is one of the best interpolation technique for interpolating rough and curved surfaces, for equal and unequal intervals. This paper uses Lagrange interpolation technique to interpolate the missing color components in a mosaiced image.

In a mosaiced image, each pixel consists of one of the 3 primary color components. The other two color components have to be estimated for reconstructing the full-color image from the mosaiced image. In the proposed method, the initial R, G and B channels are obtained separately using Lagrange interpolation. In Fig. 2, (a) represents the mosaiced images which are Lagrange interpolated to obtain the estimated image (b). Lagrange interpolation is given in equation (1).

$$f_n(x) = \sum_{i=0}^{n} L_i(x) f(x_i) \qquad (1)$$

where $f(x_i) = y_i$ and $L_i(x)$ is given by equation (2)

$$L_i(x) = \prod_{j=0, j\neq i}^{n} \frac{x \quad x_j}{x_i \quad x_j} \qquad (2)$$

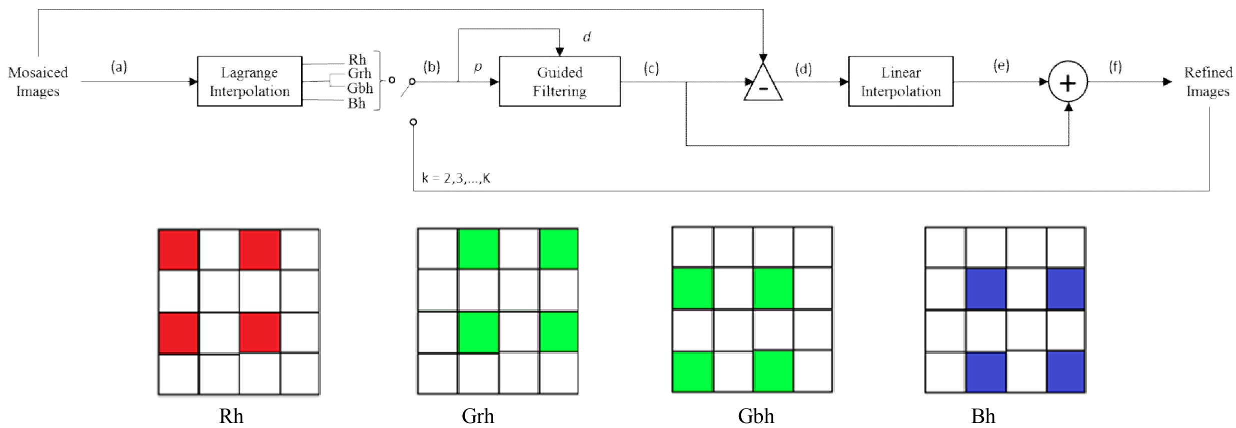

Fig. 2 The proposed Lagrange based IRI process conducted along the horizontal direction only; likewise for vertical direction (not shown).

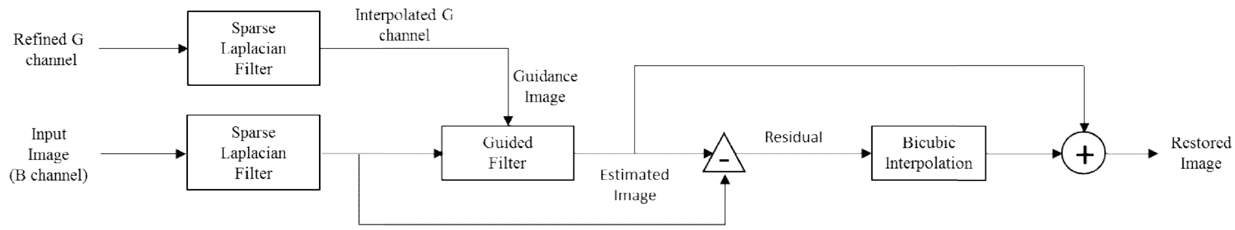

Fig. 3 RI-based reconstruction scheme for the B channel and R channel (not shown).

Lagrange Based Iterative Residual Interpolation

In a 2x2 Bayer pattern, G has the highest sampling rate. Hence for better reconstruction of G channel, Lagrange based iterative residual interpolation technique as shown in Fig. 2 is used. The other two channels are obtained by using residual interpolation technique as shown in Fig. 3 by taking G as a reference.

The interpolation polynomial is a linear system of equations, the basis polynomials depend on the position of the pixel and also on the intensity levels of its neighbourhood.

In Fig. 2, (b) takes the values Rh, Grh, Gbh and Bh, 'h' represents horizontal direction. Where interpolated pixels obtained from Lagrange interpolation technique in red channel are taken as Rh. Similarly, Grh are the interpolated pixels of G channel in red positions, Gbh are the interpolated pixels of G channel in blue positions and interpolated pixels obtained from Lagrange interpolation technique in the blue channel are taken as Rb.

Residual Interpolation (RI) and Minimized-Laplacian Residual Interpolation (MLRI)

The RI and MLRI methods are used to refine each interpolated channel image (as the input image, p) under the guidance of another interpolated channel image (as the guidance image, d) using guided filter [6]. The guided filter as shown in Fig. 2 takes two inputs and it generates the output (c) (i.e. the estimated value) by considering the contents of guidance image. The guided filter performs an edge-preserving, smoothing operation and has better behavior near the edges [7]. In this paper, horizontal and vertical tentative estimates are generated by using RI and MLRI methods. RI method performs interpolations on the residuals (d), obtained by subtracting the observed values (a) from the estimated values (c) [4]. The obtained residuals (d) are linear interpolated and the output (e) is added to the estimated values (c) to obtain refined images (f). Refined images are given as input to the guided filter in the succeeding iteration. In MLRI method [5], the tentative pixel values are estimated by minimizing the Laplacian energies of the residuals. This residual image transformation allows an easier interpolation than the standard color difference transformation. The obtained horizontal and vertical tentative estimates are combined to arrive at the refined G channel [1]. The above explained RI and MLRI based refinement process will be repeated iteratively for further improving the estimation of the refined G channel. This paper has limited the number of iterations to 3, as G channel can be effectively reconstructed in 3 iterations with high PSNR, CPSNR, and SSIM.

Reconstruction of R and B channels

Under the guidance of reconstructed G channel from the above procedure, the R and B channels can be separately reconstructed using the RI and MLRI based reconstruction schemes [4], [5].

During the reconstruction of B channel as shown in Fig. 3, the tentative estimate of B channel is generated by using guided filter. Refined G channel and input image (B channel) are interpolated separately using sparse Laplacian filter. Interpolated G channel is taken as the guidance image and the filtered B channel as the input image for the guided filter. The B channel residual is calculated by subtracting the tentative estimate of B channel from the original B channel. These residuals are interpolated by using bicubic interpolation technique. Bicubic interpolation produces smoother images compared to bilinear interpolation because bicubic interpolation takes 16 pixels (4x4) whereas bilinear interpolation considers only 4 pixels (2x2). The B channel is reconstructed by adding these interpolated residuals to the tentative estimates of B channel. Similar procedure is used in the reconstruction of R channel.

EXPERIMENTAL RESULTS AND DISCUSSION

The proposed demosaicing method has been evaluated using a standard research database.

Objective Evaluation

For quantitative evaluation of the objective performance of the demosaicing process, the difference between the original and the demosaiced image is measured. These measurements are based on the two commonly used image fidelity metrics - i.e. the peak signal to noise ratio (PSNR) and the structural similarity (SSIM) [9]. PSNR has been measured separately for each channel and also jointly for all the three channels. Color peak signal to noise ratio (CPSNR) is used for the combined measurement of the PSNR.]. CPSNR is defined as

$$CPSNR = 10\,log\frac{255^2}{\frac{1}{3HW}\sum_i^H\sum_j^W \| I_0(i,j) \quad I_d(i,j) \|_2^2}, \qquad (3)$$

where integers H and W denote the height and width of the image, respectively $I_0(i,j)$ and $I_d(i,j)$ are vectors, representing the RGB values at pixel (i,j) on the original image and the demosaiced image, respectively [1]. The measured PSNR, CPSNR and SSIM are shown in the Table I. The existing method provides CPSNR of 37.06 but our proposed method gives 39.39, which is a better result compared to the existing one.

Table I PSNR, CPSNR and SSIM results on the standard research database

IMAGES	PSNR (in dB)			CPSNR	SSIM
	R	*G*	*B*		
1	39.08	43.16	36.07	38.55	0.9899
2	40.52	43.50	37.22	39.68	0.9731
3	37.61	41.34	37.69	38.57	0.9769
4	36.67	42.08	36.87	37.93	0.9645
5	38.93	42.79	37.89	39.42	0.9730
6	39.59	41.96	39.05	40.03	0.9730
7	40.71	42.63	37.76	39.89	0.9670
8	42.87	45.49	38.09	41.06	0.9554
9	39.82	43.42	36.89	39.28	0.9585
10	37.75	42.96	39.31	39.52	0.9602
Average	**39.36**	**42.93**	**37.68**	**39.39**	**0.9692**

(a)

(b)

Fig. 4 (a) Mosaiced Image (b) Demosaiced Image

Subjective Evaluation

The proposed method shows clear advantages on the aspect of subjective quality evaluation. The mosaiced images are shown in Fig. 4(a) are demosaiced using the proposed method, and the demosaiced images are shown in Fig. 4(b). The demosaiced image using the proposed method gives a better result than the existing methods.

CONCLUSION

In this paper, a new demosaicing method called Lagrange based iterative residual interpolation technique is proposed. Lagrange interpolation is used for the initial estimation of RGB channels, therefore a better guidance image is achieved. This helps in the effective reconstruction of G channel using the proposed IRI algorithm, compared to the existing methods. For enhanced reconstruction of R and B channels, bicubic interpolation is used. Simulation results on the standard research datasets have shown that the proposed method produces better-demosaiced images in terms of both objective and subjective evaluation. Future work is to reconstruct R and B channels effectively, to provide high PSNR, CPSNR and SSIM.

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