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Development of HDR Images by Estimating Missing Color Components in Generalized Assorted Pixel Mosaic Camera Images

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Abstract- The concept of demosaicing is the process which is used to estimate & restore the missing pixels. The generalized assorted pixel (GAP) camera enables the user to capture a single image of a scene and can control the trade-off between spatial resolution, dynamic range and spectral detail. The GAP camera uses a complex array (or mosaic) of color filters. A major drawback is that the captured image is severely under-sampled. This leads the reconstructed images with strong aliasing. Thus, the demosaicing concept is used in Generalized Assorted Pixel camera. It can be possible to generate the variety of images such as High Exposure Monochrome image, Low Exposure Monochrome image, High Exposure RGB image, Low Exposure RGB image, HDR Monochrome image and HDR RGB image which consists of low exposure and high exposure color components. The proposed experimental method proves not only the less computational time, but also produces the higher quality image than previous method.

***Keywords — Color filter array, Demosaicing, Generalized Assorted Pixel camera, HDR Imaging,* Mosaic image,**

I. INTRODUCTION

Demosaicing is a digital image process used to reconstruct a full color image from the incomplete color samples output from an image sensor overlaid with the color filter array (CFA). It is also known as CFA interpolation or color reconstruction. The aim of demosaicing algorithm is to reconstruct a full color image from the spatially under sampled color channels output from the CFA. Most modern digital cameras acquire images using a single image sensor overlaid with a CFA, so demosaicing is a part of the processing to make these images into a viewable format.

Most color image sensors use a color mosaic which is an assortment of different spectral filters. A color mosaic usually consists of three primary colors Red, Green and Blue. Recently, new image sensing technologies have emerged that use novel pixel assortments to enhance image sensing capabilities. For high dynamic range (HDR) imaging, a mosaic of neutral density filters with different transmittances have been used. A new approach for high sensitivity imaging builds upon the standard Bayer mosaic by using panchromatic pixels that collect a significantly larger proportion of incident radiation. High Dynamic Range imaging is a set of methods used in imaging & photography, to allow a greater dynamic range between the lightest and darkest areas of an image than current standard digital imaging methods or photographic methods.

The notion of a generalized assorted pixel (GAP) camera is introduced, that uses a mosaic with a richer assortment of filters and enables a user to produce a variety of image types from a single captured image. Color mosaic for GAP filters are shown in fig.1.

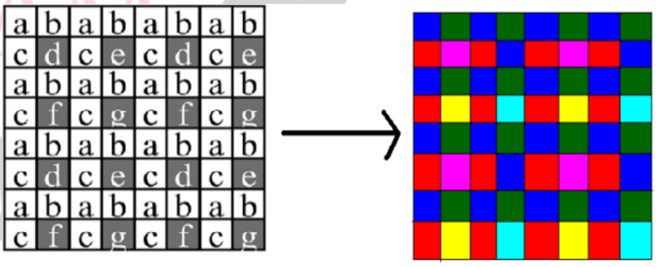

Fig.1: Color mosaic for GAP filters

Each filter type in an assortment can serve to enhance a specific attribute of image quality. Examples of attributes are color reproduction, dynamic range, spectral resolution and sensitivity.

Generalized Assorted Pixel camera enables the user to capture the single image of a scene after the fact and control the trade-off between spatial resolution, dynamic range, and spectral detail [1]. The Generalized Assorted Pixel (GAP) camera uses the complex array or complex mosaic of color filters. Unlike the simple patterns, the Gap mosaic consists of plurality of primary color filters and the secondary color filters. The main disadvantage

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of using the complex arrays in the GAP mosaic is that (i) The captured image is severely under sampled. (ii) The reconstructed image will be strongly aliased. (iii) The GAP cameras are quite expensive.

Images with small – scale detail near the resolution limit of the digital sensor can sometimes trick the demosaicing algorithm producing an unrealistic look known as artifacts. The artifacts depend on both type of texture and the software used to create the raw file.

Interpolation is the technique or method which is used for constructing the new data points within the range of discrete set of known data points. A unique color interpolation approach for digital still cameras is introduced and described in terms of color vectors [2]. New methods uses sub-image sub-band correlation to enable a good initial interpolation and accurate edge detection [3]. Another demosaicking method consists of heuristic approaches [4].

The images used in the GAP mosaic consists of different exposure. Exposure compensation can correct for metering errors or can help bring out the last shadow or high light detail. Generalized Assorted Cameras are well-suited for a wide range of imaging tasks.

The image is said to be high exposure if the image has a loss of highlight detail and the important bright parts are washed out or effectively all white. In digital cameras the high exposure image is measured in Exposure Value (EV). The high exposure has positive exposure [1]. An image is said to be low exposure if it has a loss of shadow detail, that is, when important dark areas are muddy or indistinguishable from black. The dark exposure image will have negative exposures. The zero exposure images are the images with correct exposure.

The spatial resolution of the image is used to describe the quality of the image. The spatial resolution is a term that refers to the number of pixels utilized in the construction of digital image [8]. The images with low spatial resolution will have lower number of pixels.

1.1 High Dynamic Range Imaging

High Dynamic Range Imaging [5] (MDR or HDRI) is the set of methods used in imaging and photography to capture the greater dynamic range between the lightest and darkest areas of an image than the current standard digital imaging methods or photographic methods. The dynamic range of an image refers to the range of light to the dark captured by the camera before becoming completely black or completely white. HDR images can represent more accurately the range of intensity levels found in real scene, from direct sunlight to faint sunlight and is often captured by way of plurality of differently exposed pictures of the same subject matter. HDR methods provide higher dynamic range from the imaging process. Images resulting from merging the low dynamic range and standard dynamic range photographs to obtain HDR RGB image and HDR monochrome image.

II. EXISTING APPROACH

An immense number of demosaicking methods have been proposed in the literature [3]. The existing approach for Generalized assorted pixel is to use demosaicing technique with the help of Frequency Impulse Resonance filter. Fumihito Yasuma, Tomoo Mitsunaga, Daisuke Iso, and Shree K. Nayar [1] are presenting a comprehensive optimization method to arrive at the spatial and spectral layout of the color filter array of a GAP camera, developing an algorithm for reconstructing the under-sampled channels of the image while minimizing aliasing artifacts, demonstrating how the user can capture a single image and then control the tradeoff of spatial resolution to generate a variety of images, including monochrome, high dynamic range (HDR) monochrome, RGB, HDR RGB and finally, the performance of the GAP camera has been verified using extensive simulations that use multispectral images of real world scenes.

III. PROPOSED APPROACH

At each pixel of the GAP mosaic there is only one primary color measurement which means the other primary colors must be estimated from neighboring pixels in order to produce interpolated output image. The proposed technique is used to estimate the missing primary colors. Initially the high exposure image is estimated and is refined., refining the high exposure image with, then interpolating the CMY image with strong inter channel correlation, then complimenting the CMY image for the Low exposure image and we are finding the monochrome image for the high exposure image and the low exposure image. The HDR images for high exposure and low exposure images are done by merging technique. The block diagram for the proposed approach is shown in fig.2.

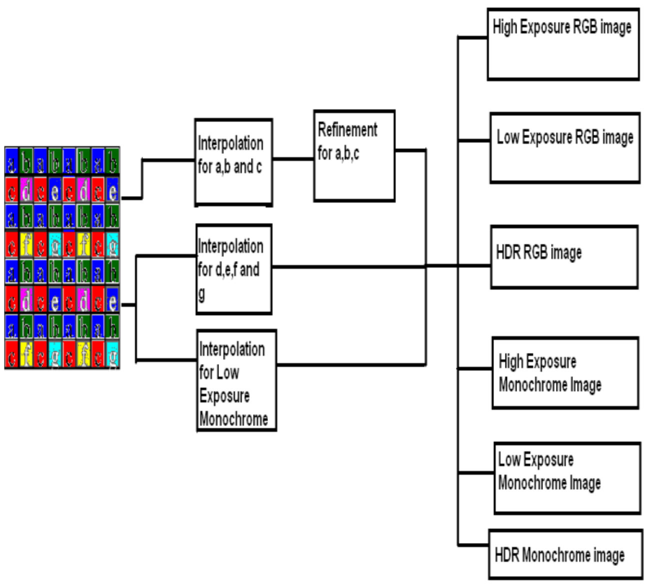

Fig.2: Block diagram of the proposed algorithm

Fig.3: Sample Images

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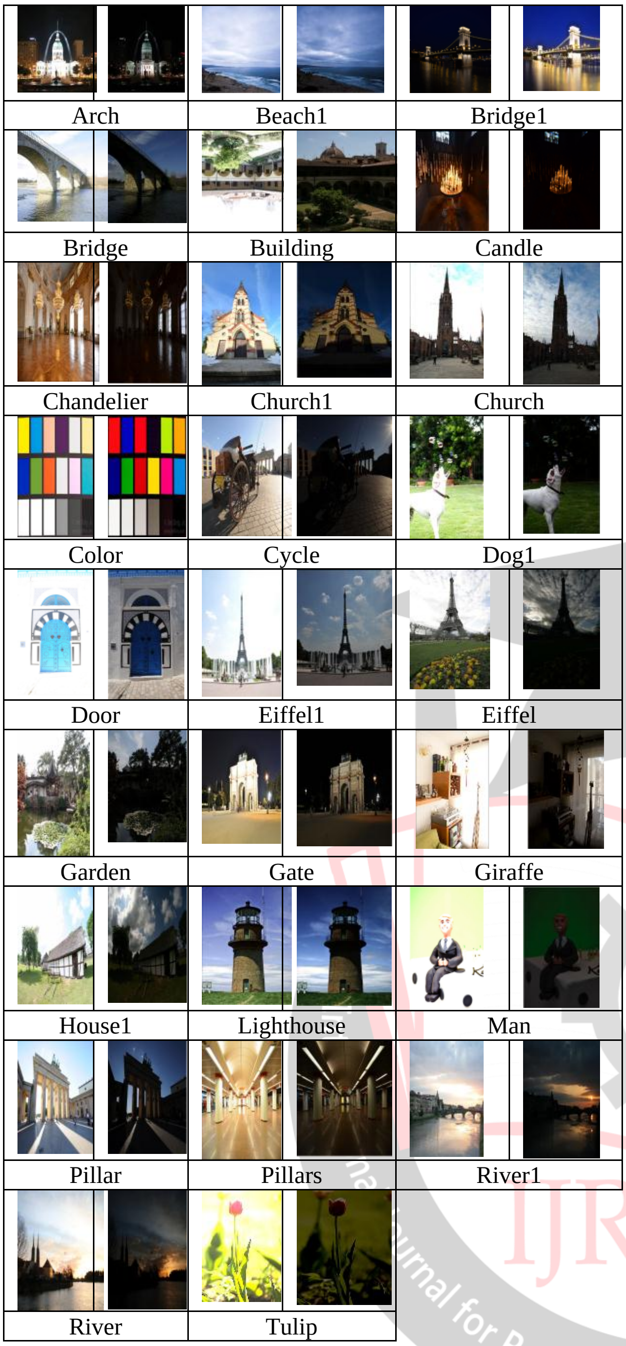

3.1 Mosaic Image

The mosaic image consists of three primary color filters and four secondary color filters. Color filters are needed because the typical photo sensors detect light intensity with little or no wavelength specificity, and therefore cannot separate color information. The raw image data captured by the image sensor is then converted to a full-color image by a demosaicing algorithm which is tailored for each type of color filter.

3.2 Demosaicing the high exposure image

A photograph may be described as *overexposed* or high exposure when it has a loss of highlight detail, that is, when important bright parts of an image are "washed out" or effectively all white, known as "blown-out highlights" or "clipped whites" [15].

3.2.1 Green plane interpolation

Interpolate the green channels row wise and column wise. Interpolate the Green channel as

$$\hat{G}(i,j) = (G(i,j-1) + G(i,j+1))/2 \qquad (1)$$

if $\hat{G}(i,j)$ is horizontal

and

$$\hat{G}(i,j) = (G(i-1,j) + G(i+1,j))/2 \qquad (2)$$

if $\hat{G}(i,j)$ is vertical

3.2.2 Red and blue plane interpolation

Red and blue plane interpolation can be done by interpolating the red and the blue channel using the bilinear interpolation technique.

Let Q (a, b) be either red or blue samples

$$S(a,b) = \hat{G}(a,b) - Q(a,b) \qquad (3)$$

The expression for Q Plane interpolations

$$\hat{Q}(i,j) = \hat{G}(i,j) - S(i-1,j) + S(i+1,j))/2 \qquad (4)$$

$$\hat{Q}(i,j) = \hat{G}(i-1,j+1) - (S(i-1,j) + S(i-1,j+2))/2 \qquad (5)$$

After the above interpolations, interpolate

$$\hat{Q}(i,j+1) = \hat{G}(i,j+1) - (S(i-1,j) + S(i-1,j+2) + S(i+1,j) + S(i+1,j+2))/4 \qquad (6)$$

3.2.3 Green plane refinement

After all the three planes have been interpolated, we have to refine the interpolated values. The interpolation and refinement of *R* and *B* channels are simply performing the bilinear interpolation on the color differences, *G –R* and *G – B*.[7].

As for the *G* channel refinement, a modified median filter is proposed. At first, refine the green values. The proposed method refines a missing *G* sample according to the sample being in red or blue location (i.e. where the sensor acquired the red or blue values).

The proposed *G* plane refinement is expressed by

$$\hat{G}(i,j) = \{R(i,j) + median(G - R)\} \qquad (7)$$

if (i, j) is a red location

$$\{B(i,j) + median(G - B)\}$$

if (i, j) is a blue location

In the above expression, *median*(•) represents a median filter operator, which outputs the median value of the pixel values in the 3x3 neighborhood of (*i,j*) location.

3.2.4 Red and Blue plane refinements

The final step of the proposed method is to refine the interpolated red and blue values. The equations for doing such refinements are the same as those used for red and blue plane interpolations. The only one thing to note is that the green values used in this step are those obtained from the green plane refinement not from the green plane interpolation.

3.3 Demosaicing the d, e, f, g images

Interpolated secondary filter images $\hat{X}_d, \hat{X}_e, \hat{X}_f, \hat{X}_g$ can be computed using only the d,e,f and g pixels. However this results in severe aliasing. In demosaicing, Color filter array interpolation which is an assumption of strong positive

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inter-channel correlation is commonly used so as to suppress aliasing of the sparsely sampled channels (R,B) by estimating the amount of aliasing from the high frequency information of a densely sampled channel. However this assumption often results in artifacts because the differences in the spectral responses of the RGB filters cause the inter-channel correlation of RGB to be not always strongly positive. In order to reduce the aliasing, aliasing reduction method can exploit the inherent inter-channel correlations within GAP Mosaic.

3.3.1 Interpolation of under Exposure Image (Blue)

In this method one primary filter color can be chosen for each secondary filter color in terms of similarity of the spectral response, with high expectation of strong positive inter-channel correlation due to strong overlap between the spectral responses of the chosen primary and secondary channels [10]. For example channel "a" is chosen as a strongly correlated channel with channel "e". So, we first sample the interpolated full resolution "a" filter image at $\hat{X}_a$ all "e" locations to estimate the aliasing of "e" filter image. These samples are then used to compute the full resolution image for the "e" filter

$$\Omega * \{ W_z(i,j)\, \hat{X}_a(i,j) \} \tag{7}$$

where $W_z(i,j) = \{1$ if $(i,j) \in \hat{X}_z$

0 otherwise

and $Z \in \{a,b,c,d,e,f,g\}$

and Ω is the low pass filter with the values [3/4, 1/2 , 1/4 ; 1/4 , 1/2 , 1/4] , and W_e is the sampling.

Aliasing can be inferred by subtracting the original $\hat{X}_a$ value from this interpolated one. To get the final estimate of aliasing in the "e" channel "λ_e" , we used assumption that the color ratios within an object in an image is constant. The color ratio α_{ae} within an object is "a" channel and "e" channel image is used for the interpolation of the "e" channel.

The color ratio

$$\alpha_{ae}(i,j) = ((\Omega * \{W_e(i,j)\}) / (\Omega * \{ X_a(i,j)\})) + 1 \tag{8}$$

The estimated aliasing () is the "e" channel is given by

$$\lambda_e(i,j) = \alpha_{ae}(i,j).[\Omega * \{W_e(i,j).\ \hat{X}_a(i,j)\} - \hat{X}_a(i,j)] \tag{9}$$

The image $\hat{X}_e$ with reduced aliasing is obtained as

$$\hat{X}_e(i,j) = \{ W_e(i,j)\, y(i,j)\} - \lambda_e(i,j) \tag{10}$$

where $y(i,j) = \Sigma_{Z \in (a,b,c,d,e,f,g)} W_z(i,j).\ X_z(i,j)$

and $\hat{X}_z$ is the Z^{th} channel full resolution image.

The proposed aliasing estimation technique also assumes positive inter-channel correlation. It is not effective in the case of negative inter-channel. Here we select the channel pairs for aliasing reduction such that they have the highest positive correlation between them.

3.3.2 Interpolation for the CMY image (d,e,f,g)

The other secondary filters $\hat{X}_d, \hat{X}_e, \hat{X}_f, X_g$ can be similarly computed. We select the color filter pairs of $\hat{X}_b$ with $\hat{X}_f$, $\hat{X}_b$ with $\hat{X}_g$ and $\hat{X}_c$ with $\hat{X}_d$, because that inter-channel correlation becomes stronger positive due to maximizing the spectral overlap.

IMG NO	IMAGE NAME	HIGH EXPOSURE IMAGE BEFORE REFINEMENT					
		MSE R	MSE G	MSE B	PSNR R	PSNR G	PSNR B
1	Arch	14.3498	14.7233	14.0929	36.5623	36.4508	36.6408
2	Beach1	7.9495	7.9384	9.506	39.1274	39.1335	38.3508
3	Bridge1	14.9789	19.2066	18.9772	36.376	35.2963	35.3485
4	Bridge	7.4846	6.1596	6.8104	39.3891	40.2352	39.7991
5	Building	16.5634	19.324	17.5781	35.9393	35.2698	35.6811
6	Candle	12.8441	10.298	7.5774	37.0438	38.0033	39.3356
7	Chandelier	18.2309	18.6174	17.2344	35.5227	35.4316	35.7668
8	Church1	7.1404	9.694	8.6193	39.5936	38.2658	38.7761
9	Church	15.2351	17.3153	20.3104	36.3024	35.7465	35.0536
10	Color	9.802	6.2682	6.959	38.2177	40.1594	39.7053
11	Cycle	21.2597	21.5991	20.7349	34.8552	34.7864	34.9619
12	Dog1	16.5141	12.7341	21.4715	35.9523	37.0811	34.8122
13	Door	15.8158	13.4684	12.2077	36.1399	36.8376	37.2645
14	Eiffel1	12.9281	16.0634	14.6485	37.0154	36.0724	36.4729
15	Eiffel	11.4106	11.9393	11.486	37.5577	37.361	37.5291
16	Garden	23.76	29.432	26.2446	34.3723	33.4426	33.9404
17	Gate	13.3172	12.8598	13.5087	36.8867	37.0385	36.8247
18	Giraffe	16.9669	15.8899	15.2596	35.8348	36.1196	36.2594
19	House1	14.8792	18.2919	17.0348	36.405	35.5082	35.8174
20	Lighthouse	15.7348	16.9438	18.0749	36.1622	35.8407	35.56
21	Man	6.1482	5.8554	6.2559	40.2433	40.4562	40.1679
22	Pillar	14.3123	15.2163	17.0618	36.5737	36.3077	35.8105
23	Pillars	19.2284	16.3641	15.5303	35.2914	35.9919	36.219
24	River1	7.4398	8.8762	9.0244	39.4152	38.6485	38.5766
25	River	5.8428	7.5501	7.9599	40.4646	39.3513	39.1217
26	Tulip	12.0928	10.2577	16.5835	37.3055	38.0203	35.934
AVERAGE		13.5472	13.9571	14.2597	37.0980	37.0329	36.9126

Table.1: High Exposure image before refinement

3.4 Low exposure image

A photograph may be described as underexposed or low exposure image when it has a loss of shadow detail, that is, when important dark areas are "muddy" or indistinguishable from black [11], known as "blocked-up shadows" (or sometimes "crushed shadows", "crushed blacks", or "clipped blacks", especially in video [12][13][14]. The low exposure image can be obtained by using the complement of the image.

3.5 Demosaicing the low exposure monochrome image

In order to compute an HDR Monochrome image, compute a low exposure monochrome image. Computation of low exposure monochrome image will be done by using only the four secondary filters which have lower exposure and also collectively cover the entire visible spectrum. In the proposed method it was specified that four different secondary pixels are arranged diagonally about each "a" pixel. Therefore, the monochrome value at

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each "a" pixel can be computed as the average of the measurements at the four neighboring secondary pixels.

$$L(i,j) = W_a(i,j)\{Q_{diag} * y(i,j)\} \qquad (11)$$

where Q_{diag} = [1/4 , 0 , 1/4 ; 0 , 0 , 0 ; 1/4 , 0 , 1/4]

The vertical pixels can be calculated as

$$L(i,j) = Q_V * L(i,j) \qquad (12)$$

where Q_V^T = [0.5 , 0 , 0.5]

The horizontal pixels can be calculated as

$$L(i,j) = Q_H * L(i,j) \qquad (13)$$

where Q_H = [0.5 , 0 , 0.5]

3.6 High exposure monochrome image

Monochrome describes the drawings, the paintings, and the photographs or design in one single color or values of one color. A monochromatic object or image reflects colors in shades of limited hues or colors. Images using only shades of grey (with or without black or white) are called gray scale or black – and - white. However, scientifically speaking, monochromatic light refers to visible light of a narrow band of wavelengths. The high exposure monochrome image can be computed using rgb2gray ( ) function.

3.7 HDR RGB image

The Dynamic Range of real-world scenes can be quite high -- ratios of 100,000:1 are common in the natural world. An HDR (High Dynamic Range) image stores pixel values that span the whole tonal range of real-world scenes. Therefore, an HDR image is encoded in a format that allows the largest range of values, e.g. floating-point values stored with 32 bits per color channel. Another characteristic of an HDR image is that it stores linear values. This means that the value of a pixel from an HDR image is proportional to the amount of light measured by the camera. In this sense, HDR images are scene-referred, representing the original light values captured for the scene. The HDR RGB image can be obtained by merging high exposure RGB image and the low exposure RGB image.

3.8 HDR monochrome image

The HDR monochrome image can be obtained by merging the high exposure monochrome image and the low exposure Monochrome image.

IMG NO	IMAGE NAME	HIGH EXPOSURE IMAGE AFTER REFINEMENT					
		MSE R	MSE G	MSE B	PSNR R	PSNR G	PSNR B
1	Arch	13.264	11.746	11.9849	36.904	37.4319	37.3445
2	Beach1	6.9754	5.6017	8.5297	39.6951	40.6476	39.7991
3	Bridge1	13.1694	13.4727	14.701	36.9351	36.8363	36.4573
4	Bridge	7.563	4.8768	5.7675	39.3439	41.2494	40.521
5	Building	13.5426	12.8322	12.9692	36.8138	37.0478	35.6811
6	Candle	15.208	8.6621	7.8465	36.3101	38.7546	39.184
7	Chandelier	18.6634	13.895	16.2686	35.4209	36.7022	36.0713
8	Church1	5.9222	6.0446	6.5696	40.406	40.3171	39.9554
9	Church	16.1546	13.9199	18.5898	36.0478	36.6944	35.4381
10	Color	11.6878	5.5493	6.6643	37.4535	40.6884	39.8932
11	Cycle	19.9113	16.3118	17.3622	35.1398	36.0058	35.7348
12	Dog1	16.7333	12.7829	20.2423	35.895	37.0645	35.0682
13	Door	15.7231	10.4002	12.328	36.1654	37.9604	37.2219
14	Eiffel1	11.1025	10.8533	11.7233	37.6766	37.7752	37.4403
15	Eiffel	10.8878	9.1754	10.2709	37.7614	38.5046	38.0147
16	Garden	20.0579	19.5734	19.7495	35.1099	35.2142	35.1752
17	Gate	13.0084	9.6715	11.5653	36.9886	38.2759	37.4992
18	Giraffe	17.2726	11.6605	14.1335	35.7572	37.4636	36.6283
19	House1	11.5425	11.8908	12.4584	37.5078	37.3787	37.1762
20	Lighthouse	13.1168	13.4151	15.7821	36.9525	36.8549	36.1492
21	Man	5.7912	4.1173	4.8358	40.5032	41.9847	41.2861
22	Pillar	13.5503	10.7389	14.9647	36.8113	37.8212	36.3854
23	Pillars	20.1789	13.9129	15.9995	35.0818	36.6966	36.0897
24	River1	6.414	6.5714	7.0464	40.0595	39.9542	39.6511
25	River	5.253	5.3308	6.3737	40.9267	40.8628	40.0869
26	Tulip	13.1945	10.7272	17.197	36.9269	37.8259	35.7763
Average		12.9187	10.5282	12.3816	37.3305	38.2312	37.5280

Table.2: High Exposure image after Refinement

Images	Existing		Proposed		Performance %	
	PSNR	MSE	PSNR	MSE	PSNR	MSE
Low Exposure Image	32.9	26.7	34.7	20.63	5.47	-22.73
High Exposure Image	35.6	13.8	37.1	11.1	4.21	-19.57
CMY Image	30.5	45.3	31.2	38.8	2.30	-14.35
HDR RGB Image	30.7	32.8	38.1	7.3	24.10	-77.74
Low Exposure Monochrome Image	22.1	71.4	28.7	29.1	29.86	-59.24
High Exposure Monochrome Image	29	51	36	7.3	24.14	-85.69
HDR Monochrome Image	29.1	50.4	38.9	5.1	33.68	-89.88
Average					17.68	-52.74

Table.3: Comparative analysis of existing & proposed method

IV. RESULTS & DISCUSSIONS

The experiment is carried out under windows environment by using Matlab software. The sample high exposure and low exposure images used in this experiment is shown in fig.3. The quality metrics Peak Signal to Noise Ratio (PSNR) and Mean Squared Error (MSE) of the reconstructed images are calculated according to eqns. (14) and (15) respectively.

$$PSNR = 10 \log_{10}(255^2/MSE) \qquad (14)$$

where MSE is the Mean Squared Error

$$MSE = 1/HW \sum_{y=1}^{H} \sum_{x=1}^{W} (Io(x,y) - Ir(x,y))2 \qquad (15)$$

where I_0 and I_r represents the original image and reconstructed images of size H xW each.

The tables (1) and (2) shows the calculated PSNR values and the MSE values for the sample pictures.

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The comparison chart of PSNR and MSE values between the proposed method and the existing method for High Exposure images is shown in fig. (4). The mean square error and peak signal to noise ratio for the high exposure image were calculated. PSNR and MSE were calculated for low exposure image, CMY exposure image, high exposure monochrome image, low exposure monochrome image, HDR RGB image and HDR monochrome image after refining the high exposure image. The results of PSNR and MSE values show that the reconstructed images are in better quality than the existing method.

The comparative analysis of the existing system and the proposed system is calculated and shown in Table.3. The quality of reconstructed Low Exposure image is improved by 5% in PSNR and MSE is reduced to 22%. The reconstructed High Exposure image is improved by 4% in PSNR and MSE is reduced by 19%. The reconstructed CMY image is improved by 2% in PSNR and MSE is reduced to 14%. The reconstructed HDR RGB image is improved by 24% in PSNR and MSE is reduced by 77%. The Low Exposure Monochrome image is improved by 29% in PSNR and MSE is reduced by 59%. The High Exposure Monochrome image is improved by 24% in PSNR and MSE is reduced by 85%. The HDR Monochrome image is improved by 33% in PSNR and MSE is reduced by 89%.

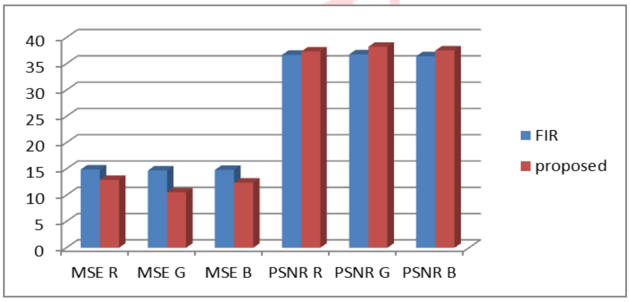

Fig.4: High Exposure image

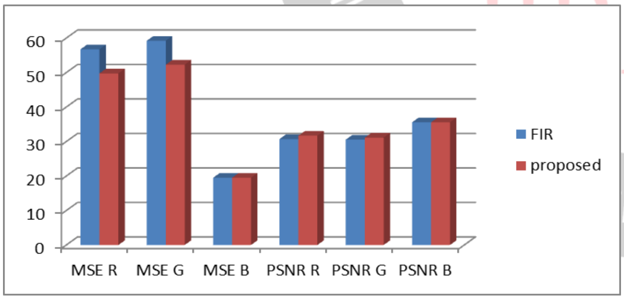

Fig. 5: CMY image

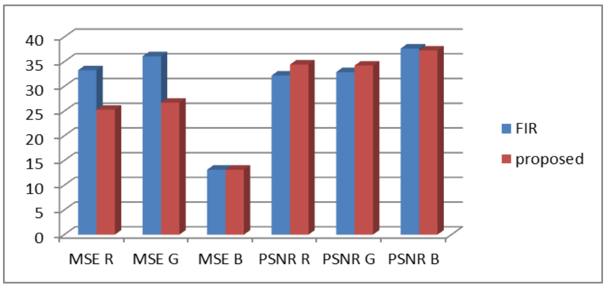

Fig.6: Low Exposure image

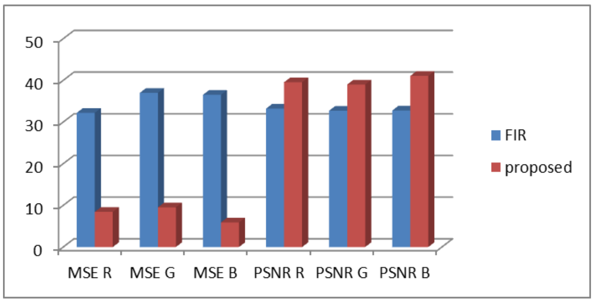

Fig. 7: HDR RGB image

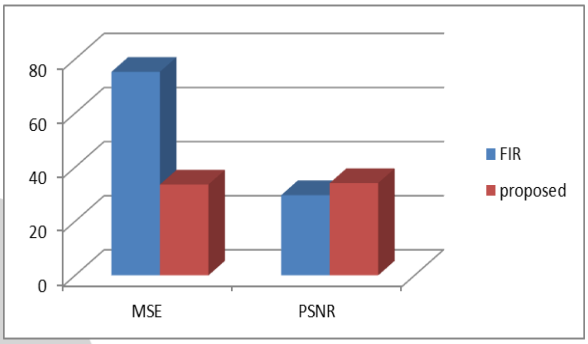

Fig.8: Low Exposure monochrome image

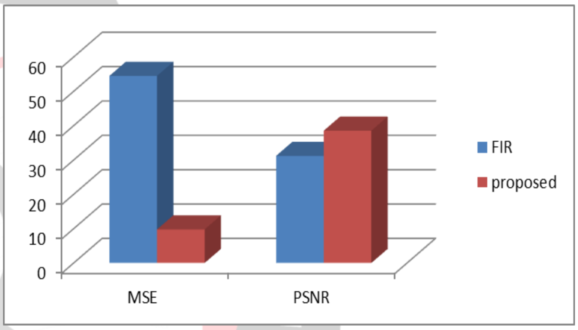

Fig.9: High Exposure monochrome image

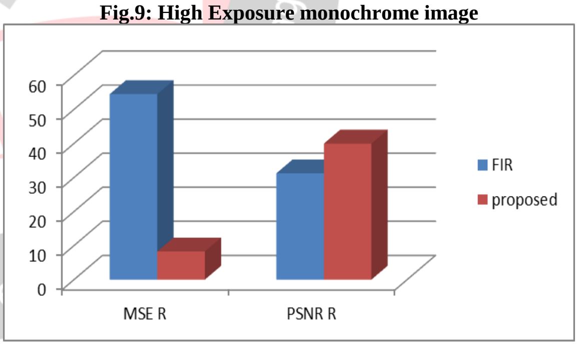

Fig.10: HDR monochrome image

V. Conclusion

The proposed demosaicing method used in Generalized Assorted Pixel camera generates reconstructed Low Exposure image, High Exposure image, CMY image, HDR RGB image, Low Exposure Monochrome image, High Exposure Monochrome image and HDR Monochrome image from the low exposure and high exposure color components. It also gives better results over the existing method. The overall quality of the reconstructed images is improved by 17% in PSNR and MSE is reduced to 52%.

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