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NEW DEMOSAICING ALGORITHM ESPECIALLY FOR MEASUREMENT OF GEOMETRIES BY IMAGE PROCESSING

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Abstract – Most cost-effective colour cameras have single image sensors with a fixed repeating pattern of colour filters with transmission spectra analogous to the human eye. To reconstruct a full colour image a process often referred to as “demosaicing” is necessary. Almost every past method for demosaicing had the intention to create the most pleasant image for the human observer. For dimensional measurement the priority is to create images without geometric errors, while the aesthetics of an image should only be the second priority. From a metrological point of view, the most important issue with this type of raw image data is that the three channels all have different pixel-grid positions and two different resolutions. This paper presents a new demosaicing method that is especially designed for applications of dimensional measurement and compares its application to common demosaicing methods.

Keywords: demosaicing, colour images, geometric measurement

1. INTRODUCTION

In most dimensional measurement applications by image processing systems monochromatic (greyscale) images are being used. The reason is that most objects of interest have features that can be measured by intensity contrast only when a suitable spectrum is used for illumination. Despite common practise there are good reasons for the use of multi-channel (i.e. colour) imaging systems: There are objects which require more than one image channel to achieve a sufficient contrast for dimensional measurement. Many tasks in quality assurance require additional image processing like colour measurement, object recognition or scene analysis and it is not economically worthwhile to use separate imaging systems. In addition, humans have a trichromatic visual perception, and therefore, the operator of a machine is likely to feel more comfortable with a coloured live image.

2. PROPOSED METHOD

The central idea for the new method is that the reconstruction influences the data only in the way a real world optical system would alter information on its way from object plane to image sensor. The contour position of geometries and the characteristics of an edge image by refractive optics [1] are not to be altered. The desired result is a digital image in which subsequent edge probing algorithms can expect to have no artefacts caused by the demosaicing algorithm, since this could lead to coarse errors.

Fig. 1: Bayer-pattern CFA

For one-chip cameras, the most common colour filter array (CFA) arrangement is the one proposed by Bayer [2]. It is shown in Fig. 1. For every pixel position only one of the three colour values is known. Simply filling the gaps poses a problem: Low-pass filtering would only be applied for 2/3 of the image information. This leads to requirements for the new method: If a missing value is calculated from information of a bigger area, the known values need to be adapted to represent the same size of their surrounding area and all three channels need to be treated the same way.

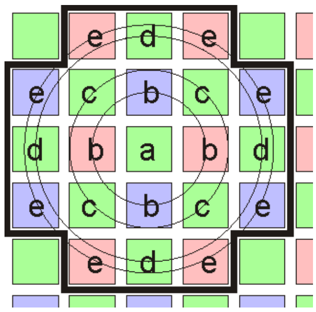

Fig. 2: mask for demosaicing process

Most imaging optics have radial symatric characteristics. Therefore, the second requirement is that the area used for approximating missing data should closly resemble to the shape of a circle. To keep computational complexity and low-pass filtering moderate, the decision was made to use a mask of a 5 pixel diameter as shown in Fig. 2. Fixed pattern positions lead to fixed centre pixel distances (a, b, c, d, e) and therefore 5 weights w(r) at the positions as shown in Fig. 2. As a consequence of the arrangement of the Bayer-Pattern-CFA, relations between weights are (1), (2) and (3).

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$$w(c) = \frac{1}{4} \quad (1)$$

$$2 * w(b) + 4 * w(e) = 1 \quad (2)$$

$$w(a) + 4 * w(d) = 1 \quad (3)$$

To solve the system of equations and determine the weights, two more relations were needed that are specified by an energetic consideration: By which rules would the energy that fell on a single pixel in the image plane distribute to a larger area of pixels? A suitable approximation for a spread function of an image of an incoherently lit object is a two-dimensional Gaussian-function (fig. 3) (4). Relations between w(a)/w(d) and w(b)/w(e) can now be calculated by the ratio of the integral values of the two-dimensional Gaussian density function over the respective areas (5).

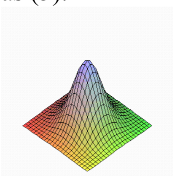

Fig. 3: 2d Gauss-function

$$f(\sigma, x.y) = \frac{1}{2\pi\sigma^2} e^{\frac{-(x^2+y^2)}{2\sigma^2}} \quad (4)$$

leads to:

$$\frac{w(a)}{w(d)} = \frac{w(b)}{w(e)} = 13{,}0564 \quad (5)$$

and:

Table 1: radius dependent weights

	r	w(r)
a	0	0,765483
b	1	0,4335828
c	$\sqrt{2}$	0,25
d	2	0,05862925
e	$\sqrt{5}$	0.0332086

Due to the doubled resolution of the green channel, half weight values are used for those pixels.

2.1. Comparison to other methods

To decide whether or not the new approach is suitable for its purpose, a full resolution colour image was artificially reduced to an image a camera with CFA would create. The following results of the demosaicing were compared to the original image, as well as those of other established methods:

- The adaptive homogeneity direction method (AHD) [4] with its implementation in DCraw [5], which is especially designed for photography purposes. In this comparison it is the representative for this type of adaptive demosaicing.
- Bilinear interpolation and bicubic interpolation which are often used in signal processing
- Simple weight based approximation [3] where mathematics is similar to the new method but rules for the choice of the weights were less strict

2.2. Subjective visual inspection

Fig. 4 shows strongly magnified crops of the original and the according reconstructed images. Compared to (F), the original full resolution image, (A) manages to restore more details than the other methods. This is not surprising since it is especially designed for photography purposes where image detail is of importance. The results of (B) and (C) look almost identical, both displaying a mediocre restoration of detail but a “zippering” effect [4] at sharp edges is visible. Both constant weight methods, (D) and (E) restore less detail in comparison to other methods, where (D) does create slightly better results. In images restored by (E) the low-pass filtering is strongest among all demosaicing methods compared.

Subjective qualities of the image are important for inspection purposes and user-friendly appearance, but the main application for the new method is dimensional measurement.

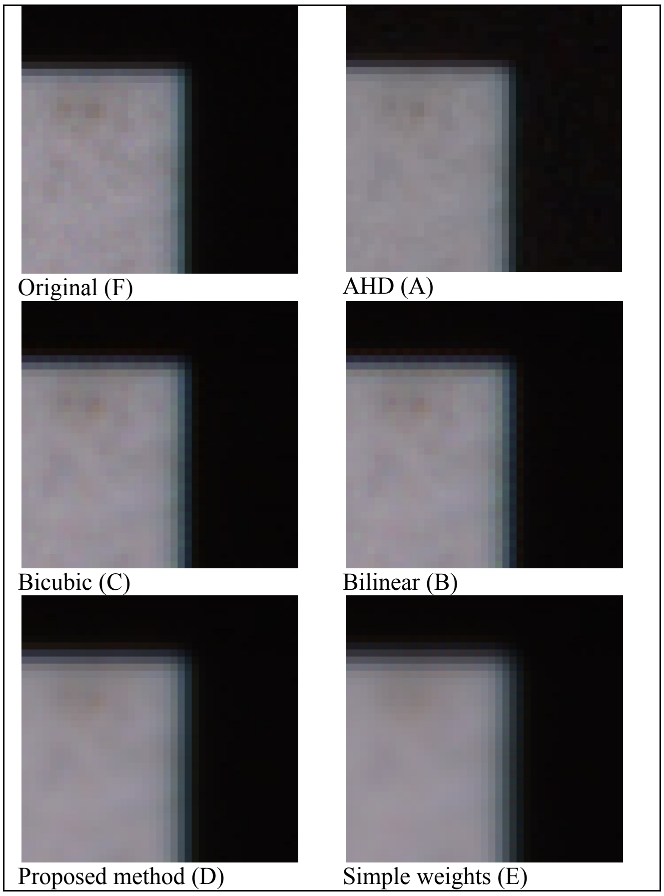

Fig. 4: reconstruction in detail

2.3. Measurement of geometries

Along with subjective visual inspection of the image quality, it is also critical to determine if measurement of geometric features of an object can be done in images reconstructed by the method. Since the chain of measurement with image processing systems has a lot of components (hard- and software) a comparison to real object metrics is not applicable. Measurement results of the reconstructed images were compared to the results in the original image. The test target used has a diffuse reflecting background with an almost constant reflectivity over VIS-spectrum. There are high precision structures that are diffuse reflecting with very low reflectivity (basically a black-white contrast). The lack of a test target with high precision colour contrast objects means that the results will not reveal problems created when an algorithm treats the different channels differently. But it is possible to examine whether a single channel displays coarse errors compared to the original image. Geometries measured were circles and straight lines. Subpixel precision edge probing was done by algorithms of the QID-Library [6]. Edge probing works by a line search based approach. In one series of tests all parameters for the edge probing were fixed so that the only variation was the method used for demosaicing. All values are in units of pixels. There are no direct comparisons to the object size, only relative comparisons between images of the objects features.

Table 2: deviations in geometry measurement

	channel G diameter circle	channel G y-position straight line (horizontal)	channel R diameter circle	channel R y-position straight line (horizontal)
(F)	155,6134	510,1743	155,5557	510,2876
(A)	-0,1877	-0,1968	-0,2254	-0,2174
(B)	-0,0016	+0,0036	+0,0002	+0,0029
(C)	+0,0026	+0,0052	+0,0067	-0,0002
(D)	+0,0080	+0,0006	+0,0109	-0,0035
(E)	+0,0168	-0,0015	+0,0183	-0,0001

	RGB diameter circle	RGB y-position straight line (horizontal)
(F)	155,5083	509,1324
(A)	-0,2074	-0,1920
(B)	-0,0090	+0,0017
(C)	-0,0119	-0,0042
(D)	-0,0009	+0,0089
(E)	+0,0056	+0,01171

By the parameters of the test series (number of search-lines, single line precision) the variation of the geometric feature should be below ±0,02 pixels. According to the example results shown in Table 2, all methods except for (A) are suitable in situations where geometric primitives are measured in images with a large number of search-lines. The strongly detail oriented (A) creates edge position shifts towards brighter areas by 0,2 pixels. This does not necessarily mean that adaptive algorithms in general are not applicable for dimensional measurement, but it is more likely that they will create errors. The zippering effect of (B) and (C) does not seem to cause deviations when a large number of contour points is used for a geometric element calculation.

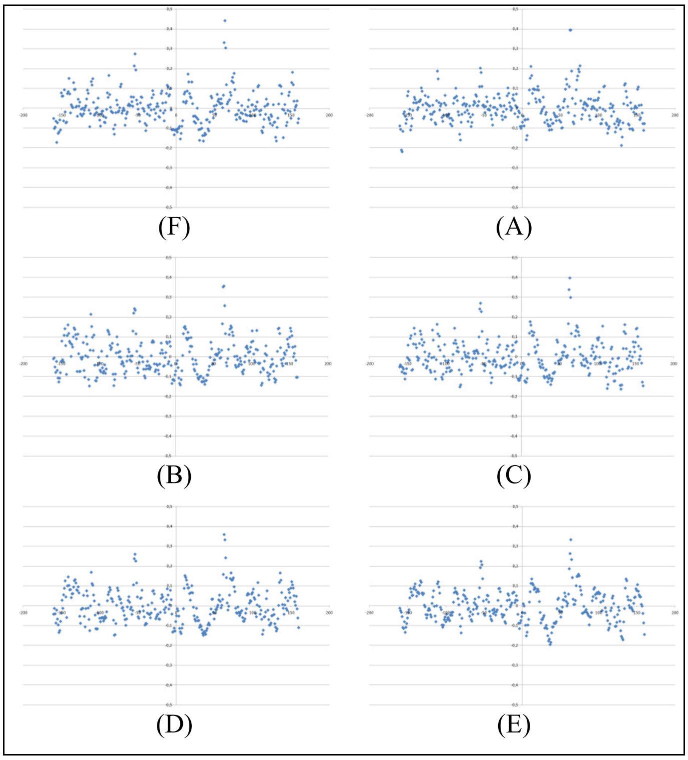

Fig. 5 distribution of contour points for a line object

Results of geometries calculated from a large number of points can only indicate systematic errors like offsets. For problems concerning the single search line, a look at the distribution of the points for a geometric feature is of interest. Fig. 5 shows point distributions for an almost horizontal straight line probed along pixel columns in the red channel.

All demosaicing methods lead to similar distribution patterns as (F). The zippering effect of (B) and (C) at edges visible in Fig.4 does not seem to have an influence in the test series conducted. The deviation of the position determined for a single contour point is about ±0,02 pixels and almost identical in original and reconstructed images, which is a good result considering 2/3 of the image information was lost in the artificial CFA process. The low-pass filtering does not lead to loss of edge information, with the specific edge probing applied here.

2.4. Edge position in synthetic images

After the initial results that did not show a significant advantage for the proposed method over bilinear demosaicing, further test series where conducted to determine differences between these two. The bilinear algorithm is of high interest because it is the algorithm that needs the least computational power and in addition it is the most common demosaicing method used in industrial image processing.

The test consists of a series of images with a synthetic edge image. This edge image was created by using a Gaussian-function with a scattering parameter of one pixel as a point spread function. In nine images the edge was then shifted by ¼th of a pixel in a range from 0 to 2 pixels. The same procedure as in the preceding trial was applied: Artificial mosaicing followed by the different demosaicing methods for reconstruction of the images, followed by subpixel precision edge probing.

Differences in the resulting edge position are shown in figures 6 and 7.

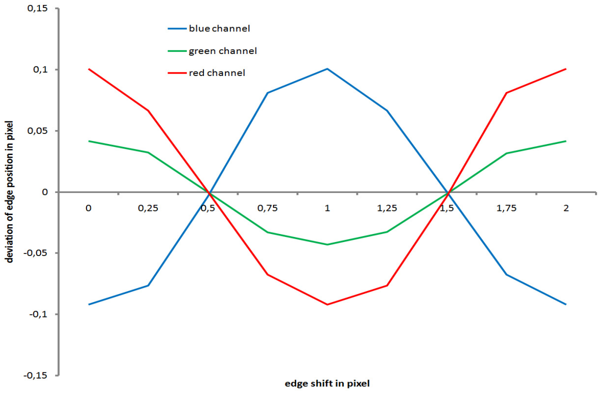

Fig. 6 bilinear demosaicing: edge position deviation

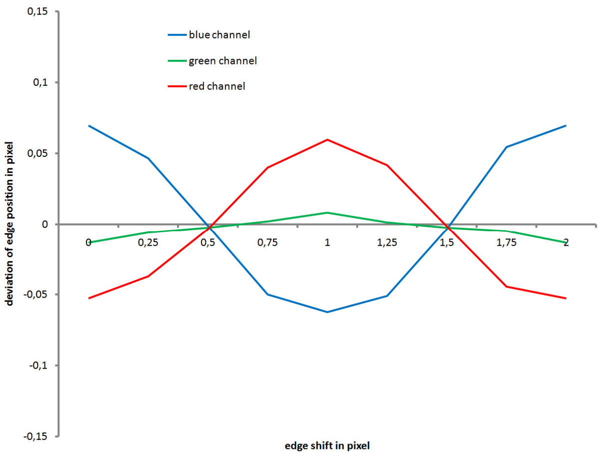

Fig. 7 proposed method: edge position deviation

One observation is, that there is symmetry for the deviation of the edge position in all three channels in both methods. It is most likely a two-pixel-periodicity. This was expected as it is in the nature of the Bayer-Pattern. Another result of the CFA characteristic is the effect that the green channel has approximately half the edge position error of the red and blue channel; due to its two times higher resolution.

Additionally, it is noteworthy that in the two methods the deviations in the channels are complementary in sign. The explanation of this effect is the expected signal characteristics of the interpolation / approximation algorithms. The bilinear method a signal that is not linear between two sampling points leads to typical higher or lower values. Neither common edge spread functions of optical systems, nor the ESF used in the synthetic images, are linear. Therefore the same effect is visible with the proposed method: Signal characteristics that differ from those expected lead to typical deviations, in this case in opposite direction as with linear interpolation.

The result of this experiment is, that the images reconstructed with the proposed method have about half the deviation of edge position of images reconstructed by bilinear interpolation. This difference might vary with the actual PSF of an optical system, but the PSF used for the synthetic images is closer to real world functions [1] than any linear characteristic.

3. CONCLUSION

In the test series conducted with real world images there were only little differences in the result of the non-adaptive demosaicing for measurement of geometric quantities. In the synthetic test, differences were detectable. From the point of view that even the smallest deviations impair measurement uncertainty, the proposed method (D) has an advantage over the most common demosaicing method (B). However, it comes with a cost in computation time.

From an image quality point of view (restoration of detail), the results with the proposed method are smoother but exhibit less demosaicing artefacts, i.e. zippering effect, than (B).

It seems that adaptive algorithms (A) are not suited for applications with subsequent subpixel precision edge probing algorithms, but they might be a good choice for subjective inspections of the recorded scene, since they reconstruct more details (i.e. texture) in the images.

In conclusion, the proposed method is a very good choice when precision of edge probing is of highest interest, and computation time and image detail are of secondary concern only.

REFERENCES

[1] M. Young, *Optik, Laser, Wellenleiter,* Berlin; Heidelberg 1997

[2] B. E. Bayer, *Color imaging array*, U.S. Patent 3 971 065, 1976

[3] J. Schnee, *Untersuchungen von Algorithmen zu Kantenortsbestimmungen für die hochauflösende Messung mit Farbkameras,* Ilmenau 2007

[4] K. Hirakawa, T.W. Parks, *Adaptive homogeneity-directed demosaicing algorithm, Ieee transactions on image processing, vol. 14, no. 3, march 2005*

[5] D. Coffin, *Raw photo decoder "dcraw" v8.88,* http://www.cybercom.net/~dcoffin/dcraw/ 2008

[6] STZ Ilmenau GmbH, *Quick Image Development Software Library 7.01,* Ilmenau, 2008