Survey on PCA based Image denoising for Single-Sensor Digital Cameras

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***Abstract*— This paper presents digital camera image compression solutions suitable for the use in single-sensor consumer electronic devices equipped with the Bayer color filter array (CFA). The proposed solutions code camera images available either in the CFA format or as the full-color demosaicked data, thus offering different design characteristics, performance and computational efficiency. MOST existing digital color cameras use a single sensor with a color filter array (CFA) to capture visual scenes in color. Since each sensor cell can record only one color value, the other two missing color components at each position need to be interpolated. The color interpolation process is usually called color demosaicking (CDM). The quality of demosaicked images is degraded due to the sensor noise introduced during the image acquisition process. The conventional solution of combating CFA sensor noise is demosaicking first, followed by a separate denoising processing. This strategy will generate many noise-caused color artifacts in the demosaicking process, which are hard to remove in the denoising process. Many advanced denoising algorithms, which are designed for monochromatic (or full color) images, are not directly applicable to CFA images due to the underlying mosaic structure of CFAs. A well-designed "denoising first and demosaicking later" scheme can have advantages such as less noise-caused color artifacts and cost-effective implementation. In this paper, a single channel ICA based image denoising algorithm is proposed by constructing a noise image to as another observation signal for single channel noise reduction based on independent component analysis, thereby noise and original image can be separated through independent component analysis. Simulation result shows that much better denoising effect and signal-noise ratio can be obtained by using this algorithm.**

***Index Terms*— Color filter array (CFA), demosaicking, transform domain, Principal component analysis (PCA).**

I. INTRODUCTION (HEADING 1)

Single-sensor digital color cameras use a process called color demosaicking to produce full color images from the data captured by a color filter array (CFA). Since each sensor cell can record only one color value, the other two missing color components at each position need to be interpolated from the available CFA sensor readings to reconstruct the full-color image. The color interpolation process is usually called color demosaicking (CDM). Many CDM algorithms proposed in the past are based on the unrealistic assumption of noise-free CFA data. The presence of noise in CFA data not only deteriorates the visual quality of captured images, but also often causes serious demosaicking artifacts which can be extremely difficult to remove using a subsequent Denoising principle component analysis (PCA)-based denoising scheme which directly operates on the CFA domain of captured images. Single-sensor digital color cameras use a process called color Denoising principle component analysis (PCA)-based denoising scheme which directly operates on the CFA domain of captured images. Single-sensor digital color cameras use a process called color demosaicking to produce full color images from the data captured by a color filter array (CFA). The quality of demosaicked images is degraded due to the sensor noise introduced during the image acquisition process. The conventional solution to combating CFA sensor noise is demosaicking first, followed by a separate denoising processing. This strategy will generate many noise-caused color artifacts in the demosaicking process, which are hard to remove in the denoising process. Few denoising schemes that work directly on the CFA images have been presented because of the difficulties arisen from the red, green and blue interlaced mosaic pattern, yet a well-designed "denoising first and demosaicking later" scheme can have advantages such as less noise-caused color artifacts and cost-effective implementation. An approach called principle component analysis (PCA) based spatially-adaptive denoising algorithm, works directly on the CFA data using a supporting window to analyze the local image statistics, but when noise level is high, accurate estimation of the PCA basis is not possible and the image denoising performance is decreased [1].

Many advanced denoising algorithms which are designed for monochromatic (or full color) images, are not directly applicable to CFA images due to the underlying mosaic structure of CFAs .All these traditional methods consider the signal and noise as the same status but not consider the independence of signal and noise, so they may tend to affect the denoising effect, while Principal component analysis (PCA) renders the images as statistically independent as possible by evaluating higher-order statistics of observation images, so it performs well in noise removal and it preserves edge sharpness. Principal component analysis is a statistical procedure that uses an orthogonal property to transform to convert a set of observations of possibly correlated variables into a set of values of uncorrelated variables. The denoising phenomenon goal is to remove the noise while retaining the maximum possible the important signal or image features. To achieve a good performance in this respect, a denoising algorithm has to adapt to image discontinuities. Generally the quality of image can be measured by the peak signal-to noise ratio (PSNR). Many algorithm are based on the PCA based denoising like CFA- PCA, two stage denoising PCA through LPG and Bayesian PCA [8] and so on. They consider the group of pixels through the filter based algorithm for finding the pixel values.

This paper presents a comparative study based on noise estimation and noise removal through principal component analysis. Estimating the noise level from a single image seems like an impossible task: we need to recognize whether local image variations are due to color, texture, or lighting variations from the image itself, or due to the noise.

Demosaicking methods rely on color models to complete the interpolation process. Popular schemes such as the smooth hue transition (SHT) interpolation scheme [8], the Kimmel's algorithm (KA) [9], and the saturation based adaptive interpolation (SAI) scheme [10] employ the color-ratio model [8],[11]. Note that other camera image processing steps such as CFA image zooming [12] and demosaicked image postprocessing [13] employed in the digital camera pipeline can use the color-ratio model as well. The color-ratio model utilizes both the spectral and spatial characteristics of the RGB image and is used to interpolate the missing color components using the neighboring color vectors and the available color component positioned at an interpolation location.

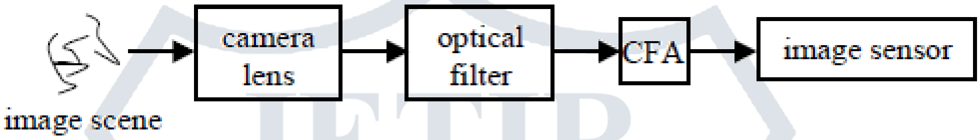


Fig. 1. A single-sensor imaging device.

II. PCA (PRINCIPAL COMPONENT ANALYSIS)

Principal component analysis is appropriate when you have obtained measures on a number of observed variables and wish to develop a smaller number of artificial variables that will account for most of the variance in the observed variables. In this case, redundancy means that some of the variables are correlated with one another, possibly because they are measuring the same construct. Because of this redundancy, you believe that it should be possible to reduce the observed variables into a smaller number of principal components (artificial variables) that will account for most of the variance in the observed variables. Technically, a principal component can be defined as a linear combination of optimally-weighted observed variables. For example, in figure 2[6], suppose that the triangles represent a two variable data set which we have measured in the X-Y coordinate system. The principal direction in which the data varies is shown by the U axis and the second most important direction is the V axis orthogonal to it. If we place the U V axis system at the mean of the data it gives us a compact representation. If we transform each (X;Y) coordinate into its corresponding (U;V)value, the data is de-correlated, meaning that the co-variance between the U and V variables is zero. For a given set of data, principal component analysis finds the axis system defined by the principal directions of variance . The directions U and V are called the principal components . Consider two variables that are nearly related linearly as shown in figure 3. As in figure 1 the principal direction in which the data varies is shown by the U axis, and the secondary direction by the V axis. However in this case all the V coordinates are all very close to zero. We may assume, for example, that they are only non zero because of experimental noise. Thus in the U,V axis system we can represent the data set by one variable U and discard V. Thus we have reduced the dimensionality of the problem.

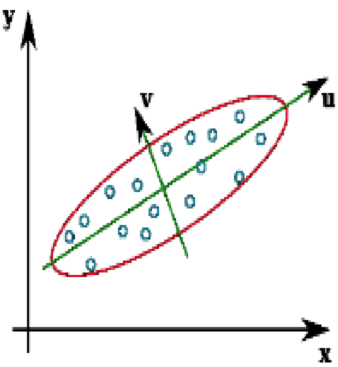


Figure 2: PCA for Data Representation

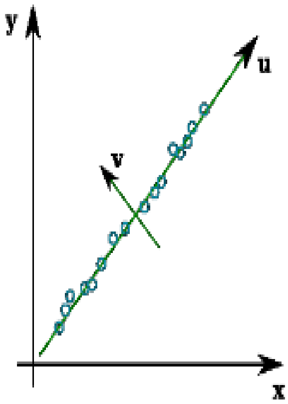


Figure 3: PCA for Dimension Reduction

III. Image denoising algorithm based on PCA

A large number of different noise reduction methods have been proposed so far. Traditional denoising methods can be generalized into two main groups: spatial domain filtering and transform domain filtering. Spatial domain filtering methods have long been the mainstay of signal denoising and manipulate the noisy signal in a direct fashion. Conventional linear spatial filters like Gaussian filters try to suppress noise by smoothing the signal. While this works well in the situations where signal variation is low, such spatial filters result in undesirable blurring of the signal in situations where signal variation is high[9].

3.1 Patch Based PCA for image denoising

Deledalle and salmon [7] are introduce three patch based denoising algorithms which perform hard thresholding on the coefficients of the patches in image-specific orthogonal dictionaries. The algorithms consider three methods: local PCA, hierarchical PCA and global PCA. It consists of the following two steps: a) an orthogonal basis from the noisy image by performing a Principal Component Analysis (PCA), b) Obtain the denoised patch by zeroing all the small coefficients in the representation of the noisy patch in the learned basis.

3.1.1 Patch based Global PCA (PGPCA):

we create an orthogonal basis adapted to the target image by performing a PCA on the whole collection of patches extracted from the noisy image.

3.1.2 Patch based Hierarchical PCA (PHPCA):

we use quadtrees with iterative partitions, i.e. we recursively divide the image into four rectangles and proceed to the PCA to the level k of partitioning. At each step a few (usually one) axes are added to the bases and the remaining patches are projected onto the orthogonal supplement of the current orthogonal sub-basis.

3.1.3 Patch based Local PCA (PLPCA):

we use dynamic localization to build the axes. This strategy relies on a sliding window of size WS * WS in which the patches are selected to proceed to a local PCA.

3.2 Two Stage Image Denoising By Principal Component Analysis

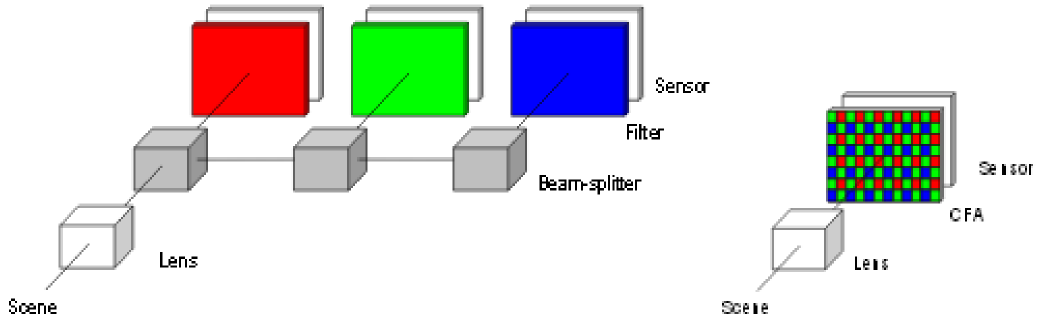
Zhang [3] presents an efficient image denoising scheme by using principal component analysis (PCA) with local pixel grouping (LPG). The algorithm divides in to two stages. The first stage evaluates an initial estimation of the image by removing most of the noise and the second stage will further refine the output of the first stage. The two stages have the same procedures except for the parameter of noise level. Number of PC is equal or less than the original values. Then passed to inverse PCA transform and denoised output is taken as a result. A new algorithm called BM3D is developed, where block matching is done and matched blocks from frames are grouped together on the basis of similarity.Fig.2 details the stages of image denoising by PCA with LPG. Average weight of all overlapping block is anticipated. Pro of this paper is it preserves local image structures while denoising,Con is due to low peak signal to noise ratio the quality of image is low.

3.3 PCA-Based Spatially Adaptive Denoising of CFA images

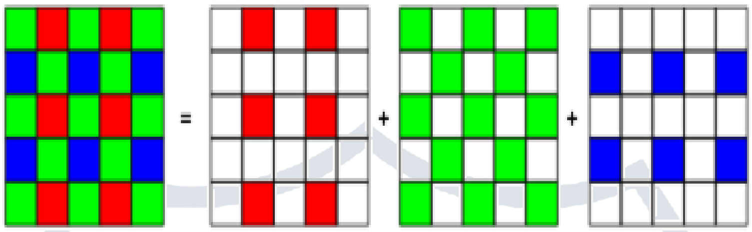
Zhang [5] presented a principal component analysis based denoising algorithm which works on directly on th color filleting array(CFA) images. This algorithm can effectively suppress noise while preserving color edges and details. The technique of principle component analysis (PCA) is employed to analyze the local structure of each CFA variable block, which contains color components from different channels. The proposed spatially adaptive PCA denoising scheme works directly on the CFA image and it can effectively exploit the spatial and spectral correlation simultaneously.

IV. Colour filter array and Bayerpattern

The digital cameras uses a very precious part i.e., single senser with a colour filter array (CFA) or capturing the visual scene in color form as shown in fig.1. A color filter array (CFA), is a mosaic of tiny color filters placed over the pixel sensors of an image sensor to capture color information. Color filters are needed because As we have discussed in the last section the sensor cell can record only one color value. There are two missing color components at each position need to be interpolated from the available CFA sensor readings to reconstruct the full color image. The color interpolation process is usually called color demosaicing (CDM). There are many patterns out of which a CFA can have any pattern. The most commonly used CFA pattern is Bayer pattern shown in fig. 2.A Bayer filter mosaic is a color filter array (CFA) for arranging RGB color filters on a square grid of photo sensors. Its particular arrangement of color filters is used in most single-chip digital image sensors used in digital cameras, camcorders, and scanners to create a color image. The filter pattern is 50% green, 25% red and 25% blue, hence is also called RGBG, GRGB, or RGGB. The Bayer array measures the G image on a quincunx grid an the R & B images on rectangular grids. The G image is measured at higher sampling rate because sensitivity of human eyelid in medium wavelengths, corresponding to the G portion of the spectrum[4].



Demonstration of optical path digital camera



Bayer pattern used in single-chip digital cameras

V. CONCLUSION:

Performance of noise estimation and removal algorithms is measured using quantitative performance measures such as peak signal-to-noise ratio (PSNR), signal-to-noise ratio (SNR) as well as in terms of visual quality of the images. Many of the current techniques assume the noise model to be Gaussian. Principal component analysis is used for both noise estimation and noise removal. Principal component analysis is used with different methods like LPG and CFA for denoising. This paper focused on the use of prinicipal component analysis for noise estimation and noise removal though different types of algorithms. It is clearly given that principle component analysis gives best PSNR value among other denoising methods. In this paper we focused on use of PCA for image processing like noise estimation and removal. It is expected that the future research will focus on building robust statistical models of Principal component analysis based on their features.

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