AN EFFICIENT METHOD FOR DEMOSAICING

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ABSTRACT

We propose an efficient method for reconstructing a full-color image from its partially sampled version. The suggested algorithm is based on the properties of the human visual system. We tested our algorithm on several problematic images and found it to be often superior than many state-of-the-art algorithms, without consuming high computational power.

1. INTRODUCTION

The problem of demosaicing is that of reconstructing a multi-color image from a single array image, which is a subsampled version of the original image. The most popular single array pattern is the Bayer Color Filter Array (CFA), which is shown in Figure 1, and will be the pattern considered here. In this pattern, 50% of the pixels are green, 25% are red,

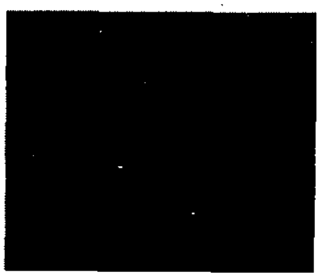

Fig. 1. The Bayer array pattern.

and 25% are blue.

Many algorithms have been proposed over the last decade for the demosaicing problem see, e.g. [1], [2], [3], [4], [5] to mention a few. The algorithms can be broadly divided into three categories. In the first category, standard interpolation techniques, such as nearest neighbor, bilinear, or cubic interpolation are used to interpolate the missing pixels. Such methods are computationally efficient, but result in severe color artifacts. The algorithms belonging to this category completely ignore the color attributes of the image in the interpolation process, explaining their degraded visual quality.

The second category of algorithms takes into account the cross-correlation among the three color channels. Common use of this correlation is to assume that the hue changes smoothly between neighboring pixels, and therefore interpolation is performed on the color ratios instead of on the channels themselves. Examples of algorithms belonging to this category are [4], [1]. These algorithms lead to higher quality images than the algorithms in the first category, demonstrating that combining knowledge of the human visual system can improve the quality of the reconstructed image. Nevertheless, most of the above mentioned algorithms still yield poor results in certain problematic regions of the image. Those which succeed in preventing some of the color artifacts, do so in a very complex way, for example solving partial differential equations [1].

In the third category of algorithms we include all the algorithms whose visual results are considered the best. Common to all of them is that they start with an initial estimation of the original image (such as bilinear interpolation), after which a correction procedure is applied. This procedure is intended to eliminate most of the color artifacts caused by the initial interpolation scheme. Examples of such algorithms are [2], [3], [6]. These algorithms are usually computational demanding, and still do not overcome all of the visual artifacts.

What is lacking, therefore, is a demosaicing method, which is not too complex (both conceptually and computationally), but at the same time can reduce most of the common problems arising from the subsampling of the color channels. In this paper we present an algorithm which takes into account the properties of color images, and is also computationally efficient. It starts with an initial estimation of the color image, and then applies a correction method to deal with the visual artifacts. The main difference, however, in comparison with existing algorithms is that the initial interpolation of the color is much better than the existing methods and gives rise to much less artifacts. In order to enhance the visual quality of the resulting image, a novel

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approach for handling specific kinds of visual artifacts, introduced by the initial estimation, is also considered. As a consequence, the visual quality of the final image outperforms that of the state-of-art algorithms, without substantially increasing the computational complexity.

In Section 2 we discuss the main idea of our algorithm, while in Section 3 we describe it in detail. Finally, we compare our algorithm with other algorithms, using benchmark images in Section 4.

2. THE MAIN IDEA OF THE ALGORITHM

As noted in the introduction, the demosaicing problem can be regarded as an interpolation problem. It is obvious, that if the consumer of the image is a person, then a subjectively good solution should rely on the interaction between color and the human visual system. The structure of the algorithm we propose consists of two main stages: an adaptive initial interpolation of the color image from the partially sampled one, followed by a method which corrects the visual artifacts that remain in the image. The initial estimation procedure first interpolates the green channel by using a classification of the missing pixels into regions. The classification allows us to apply different interpolation schemes according to the nature of the neighborhood of each missing pixels. In particular, it allows us to locate the highly problematic regions in the image, caused by aliasing of the green channel itself. These regions are further classified into horizontal and vertical regions, creating two versions of the green channel. An horizontal version in which all the aliased regions are interpolated in the horizontal direction, and a vertical version, which has the corresponding regions in the vertical direction. It turns out that such a separation between horizontal and vertical direction is a key to eliminating most of the color artifacts in an efficient way, as the positions of these regions are saved and their right direction is determined in the correction stage. It is also worth noting that adaptation schemes were suggested in [5], using a template matching technique, and a horizontal and vertical gradient method was previously proposed in [7]. We will further develop these techniques to achieve higher quality images.

After the green channel is interpolated, the red and blue channels are interpolated exploiting the inter-channel correlation, that is using the estimate of the green channel to determine the values of the red and blue pixels. Since we have two green estimates, horizontal and vertical, we must interpolate the red and blue channel twice, once for each direction. A similar idea to that in [4] is used to interpolate the red and blue channels on the basis of the green channel. The resulting two color images are passed through the correction stage, in which color artifacts are reduced. The goal of this step is to determine the right direction of pixels for which we could not deduce any information from their neighborhood due to the aliasing effect. Recall that we know the exact location of these pixels, thanks to the classification we performed in the green estimation stage. The main key for detecting color artifacts relies on the relative smoothness of the chrominance component of each region, and therefore requires a transformation to the YIQ space. Assuming slow varying chrominance changes, each problematic region (which was originally classified in the green estimation stage) is determined to be either horizontal or vertical, depending on its relative smoothness in the chrominance (I and Q) components. The resulting color image has a smooth chrominance components, which is in accordance with the low sensitivity of the human eye to rapid color changes. Note that separating luminance and chrominance has already been suggested in several algorithms, but as mentioned in the introduction, this separation typically relies on a poor estimate of the original color image. In [2], for example, the I and Q components are low-passed filtered, while most of the computational resource is spent on the estimation of the Y component. Such a method is justified by the assumption that the eye is more sensitive to high frequencies in the luminance than in the chrominance.

Our correction technique relies on the I and Q components, and succeeds in correcting most of the color errors. The success depends on our ability to estimate the red, green and blue channels before the transformation to the YIQ space is performed. A YIQ image, whose corresponding RGB image is poorly estimated, will not yield the desired results, as can be seen in many state-of-the-art algorithms. The YIQ space is just an error correction stage, not the main estimation stage, as will soon become clear. In fact, we use the YIQ space to correct very specific kinds of color artifacts, caused by aliasing in the green channel itself.

3. ALGORITHM DESCRIPTION

A block diagram of our algorithm is shown in Figure 2. This section provides an overview of each of the boxes in the synopsis. The following are the basic steps of the algorithm:

3.1. Green Estimation

The input to this stage is the subsampled version of the green channel. In order to "fill in" the missing pixels, an adaptive interpolation scheme is performed on the input. Adaptation is achieved by classifying the regions to which each missing pixel belongs to, where with each class, we associate a different interpolation method. In our development, we consider only three possible classes, which are schematically depicted in Figure 3. The classification criterion is the degree of smoothness of the missing pixel's

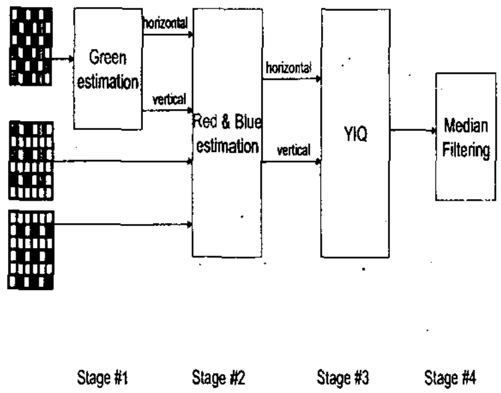


Fig. 2. A block diagram of the algorithm.

neighborhood.

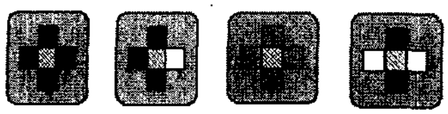


Fig. 3. The three classes used in the classification process.

A "smooth" neighborhood of a missing pixel results in averaging the values of its neighbors. Pixels with "smooth" neighborhood are said to be class A pixels.

In a "less smooth" neighborhood the missing pixel is interpolated using a larger neighborhood. The enlarged environment consists of the neighbors of the missing pixel in addition to pixels from the other two channels, which are spatially close to it. Note that it is here, where we exploit the inter-channel correlation for the first time. Pixels whose neighborhood is "less smooth" constitute class B.

Class C is characterized by the property, that neither the neighboring pixels, nor these of the other channels, can help in estimating the value of the desired pixel. Such a situation is the result of the aliasing created in the subsampling of the green channel itself. Needless to say, that an even more destructive aliasing occurs in the red and blue channels. We are therefore led to a situation, where the inter-channel correlation can no longer be exploited in the interpolation process. This is why we treat pixels whose neighborhood is neither smooth nor "less smooth" as a special class. For reasons of simplicity, we consider only horizontal and vertical frequencies that were aliased. Practically, this means that pixels in class C will either be an average of their left and right neighbors, or the average of their upper and lower ones. Since no useful information exists at this stage as to the real orientation of the pixels in class C, we postpone their interpolation to a later stage. In the meantime, we allow the pixels of this class to take on two values. One value corresponds to the average of the horizontal neighbors of the missing pixel, while the other one to the average of the vertical ones. As a consequence, we end up with two versions of the reconstructed green. One, called the horizontal image, has all its aliased regions interpolated in the horizontal direction. The second image, the vertical one, has them all vertically interpolated. The pixels belonging to the other two classes remain the same in both images.

3.2. Red and Blue Estimation

The input to this stage are the two green channel images from last stage, and two subsampled versions of the red and blue components. Using the cross correlation among the channels, the differences between the red and green are interpolated, after which they are added to the partially sampled red channel to yield its estimate. A similar procedure is carried out for the blue channel. The whole process is performed twice for each channel, resulting in two color images, where one image has all its aliased regions interpolated horizontality, while the other has them all in the vertical direction.

3.3. YIQ transformation

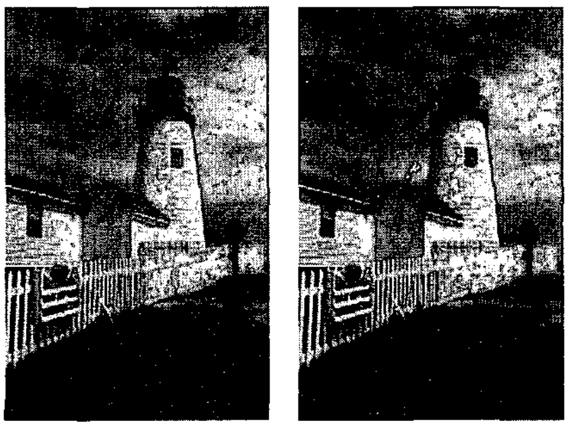
We now use the YIQ transformation to combine the two color images from the previous stage. It is obvious that only aliased regions constitute a problem, since the aliased-free regions are already determined. Since the location of the aliased regions is known from the first stage, all that is left is to select for each region, which interpolation scheme, i.e horizontal or vertical averaging, result in a smoother chrominance component. Testing the chrominance smoothness is easily accomplished in the YIQ space, due to the separation between luminance and chrominance, as opposed to the RGB space. Considering an aliased region in the I component, we compare the relative smoothness of its horizontal and vertical versions, and finally select the smoother one. By selecting, we mean replacing the corresponding triplet of Y, I and Q components (horizontal or vertical) in the final output. Thus, the final image is a combination of the two input images. In the aliasing-free regions any of this images gives a good visual result, while in the aliased ones the region whose corresponding I component is smoother relative to its environment is selected. The reason for comparing only the I component stems from the fact that, empirically, the Q component was found to be less helpful in the determination of the smoothness.

3.4. Median Filtering

The resulting image from last stage may still contain splotches, that are very annoying to the human eye. To eliminate these false color points, we median filter the image.

4. EXAMPLES

To evaluate our algorithm, we tested it on several benchmark images and compared it to state-of-the-art algorithms. Here, we compare our result with one of the state-of-the-art algorithms [1] on the Lighthouse image, which is considered to be a highly difficult image to demosaic [1].



(a) (b)

Fig. 4. (a) An interpolation using color gradients methods (third category) (b) Our interpolation method.

Note that in the aliased regions, such as the fence and house our algorithm manages to eliminate all color artifacts. In contrast, these artifacts can be seen in the algorithm of [1], which is much more complex than ours.

As another example, Figure 5 shows the an enlarged part of the Window image, in which we can see that the stem of the flower in the algorithm exhibits false colors. In contrast, our algorithm is free from such artifacts.

We tested our algorithm on other images, and compared it with other state-of-the-art algorithms. Similar results were demonstrated.

[1]The images are best viewed on a monitor. On-line versions are available in http://www.ee.technion.ac.il/Sites/People/YoninaEldar/ under Conferences Publications

(a) (b)

Fig. 5. (a) An interpolation using color gradients methods (third category) (b) Our interpolation method.

5. ACKNOWLEDGMENT

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