

A Contrast Enhancement Method Based on Analysis of Local Color Information

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Abstract

A new contrast enhancement method for color images is presented. The method is based on local color analysis even though the actual contrast adjustment phase is spatially global. The adjustment parameters, however, vary depending on the location in the color space. The color gamut is divided into fragments, which are analyzed and adjusted separately. Color variables used for color space division are different from those used for image adjustment.

The new contrast enhancement method proved to be a useful color adjustment tool. It can well be used together with traditional global color image enhancement methods. In most cases it is capable of enhancing contrast even when other color adjustments have already been made.

The method was tested with a special preprocessed image set where all images had good gray balance and contrast, right overall lightness level and RGB histograms covering the full tonal range. Analysis of this test image set showed that despite the extraordinary starting point, additional contrast enhancement was possible. Most photographic color images had at least some potential to benefit from this method. In practice, the utilization of this potential led to significant improvement of visually assessed image quality in more than half of the cases.

Introduction

The step often preceding global contrast enhancement is the analysis of statistical image properties (e.g. color histograms). If enhancement is automated, quite versatile analysis is required[1,2] but even when colors are adjusted interactively, knowing some basic statistical image properties can be very helpful. The actual image adjustment is commonly carried out by means of one or a few rendering curves changing the values of the global color components. Sometimes this kind of global enhancement is insufficient and it may be desirable to enhance contrast locally in certain image areas. In theory, adjusting all visually important areas separately might give good results. In practice, however, this would require a lot of time and tedious "handwork". Image segmentation algorithms and other image processing methods could be used to partially automate this work. The requirements for the selected methods would, however, be very high and some user interaction would probably still be needed.

It is possible to get results which are, at least to some extent, similar to spatially local contrast enhancement even with global color adjustment. This can be attained by assigning image segments to different areas of the available color space. This implies separate color analysis of each segment. The color fragments corresponding to one or a few image segments are then adjusted separately. If the image segments differed in color from all other segments needing different adjustment, the method could give the same result as spatially local adjustment. It cannot be presumed, however, that this is true, except for special cases. Thus, how this method works as compared with spatially local color adjustment, depends on image content. Visual tests proved that the results are often comparable and, more importantly, even if they are not, image quality can usually be improved. In practice the method has turned out to be a useful general tool for enhancement of photographic color images.

Description of the Algorithm

The principal phases of the contrast enhancement method based on analysis of local color information are illustrated in Figure 1.

It is worth noticing that image segmentation and color analysis of the segments are not imperative steps of this procedure. Color space can be divided into color fragments without image segmentation. In principle, even predefined division could be used. In practice, however, this would be unsatisfactory for many reasons. Contrast enhancement may need to be different for every color space fragment and notable differences even between adjacent fragments must be allowed. At the same time it is important that visually uniform image areas are adjusted substantially in the same manner. Otherwise unwanted visual artifacts may easily appear. This is what happens if predefined color gamut division is used, unless significant enhancement changes between color fragments are prohibited. This in turn would jeopardize most of the assets the method has as compared to traditional global contrast enhancement.

If spatial image segments could reliably be detected and assigned to separate areas of the color gamut, the starting point for contrast enhancement would be ideal. Different color fragments could be adjusted independently of each other without fear of disturbing artifacts. In practice, however, different parts of an image cannot be enhanced very differently even if this might reveal many details that would remain invisible otherwise. The reason is that in order to keep the naturalness distinctive to photographic images, even an enhanced image must, to some extent, remain faithful to the original. Thus, the contrast enhancement potential revealed by local color analysis can seldom be utilized to its full extent in all color areas. Some limits must be set to control the strength of the enhancement. In practice, however, even a partial utilization of the enhancement potential may result in a significant increase of overall visual contrast.

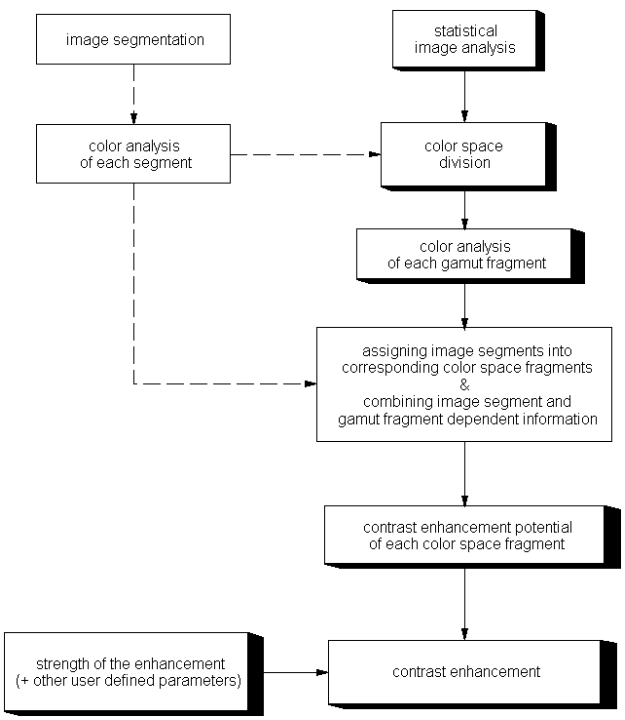

Figure 1. Contrast enhancement based on analysis of local color information

Unlike predefined color space division, diversified statistical image analysis can successfully be used as a substitute for image segmentation in the procedure illustrated in Figure 1. Statistical color properties of an image can be analyzed as a function of color variables (such as hue) which are used for color gamut division (but not for color adjustment). This kind of data can be used in much the same way as corresponding image segment dependent information. If an image segment is assigned to a certain color area, the same level of enhancement is applied to this color fragment. Analogously, if statistical image analysis shows that a considerable number of pixels are concentrated in a certain color area, this part of the color gamut is enhanced using the same, or at least nearly the same, adjustment parameters. In areas where the number of pixels is low, the adjustment parameters may change a lot since this does not cause any drastic visual effects. Moreover, this makes it possible to apply clearly different levels of enhancement to different color areas. In this way image segmentation can be substituted and removed from the analysis phase of the process. This can be motivated by the fact that at the moment no segmentation method works flawlessly. If, for example, areas that visually belong together are divided into separate parts, consequences may be visually quite disturbing. If, however, statistical analysis combined a few spatially separate image segments, this wouldn't necessarily much affect the result of the contrast enhancement. All in all, as the contrast adjustment itself is not spatially local, the advantages of using segmentation in the image analysis phase are limited. Besides, practical segmentation methods can be based on the same kind of analysis of image colors and color differences that can be used directly for color space division. In a special case an image might be successfully segmented solely on the basis of color data. Furthermore, the possible extra enhancement potential resulting from the spatial part of the image analysis may easily be wasted because of the limitations set to the adjustment phase.

The functionality of the contrast enhancement method does not drastically depend on whether image segmentation is used or not. If, however, segmentation is replaced by statistical image analysis it becomes unclear whether it still can be said that the method is "based on analysis of local color information". In this paper the word local has two meanings: spatially local and local within the color space (i.e. color fragment dependent). Often color fragments may correspond to certain spatial image areas quite well. But of course, without spatial analysis we cannot know this for sure. Fortunately, the empirical tests of the method showed that usually we do not even need to know.

A simple example of how contrast enhancement can be realized on the basis of local color information is given here. Variables used to divide the color space into fragments are hue angle and saturation. The actual adjustment is carried out by means of three simple linear RGB (red, green and blue) rendering curves. These curves are the same for the RGB components but vary between different color areas. Even though both color space division and color adjustment can be carried out in many other ways as well, it should be kept in mind that it is not advisable to use the same color variables for both purposes. Hue and saturation are calculated from RGB values with simple formulae. The definition of hue is the same as in the HSV color model. This color model and the algorithm used to calculate hue are described e.g. in references [3] and [4]. The calculation of saturation s is likewise simple (1) but differs somewhat from the HSV model. The main reason for this is that in this application the HSV color model would overemphasize the saturation of dark tones.

$$s = c\,\frac{max(R,G,B) - min(R,G,B)}{max(R,G,B)} + (1-c)(max(R,G,B) - min(R,G,B)) \qquad (1),$$

where the constant c and the tonal values R, G and B are scaled from 0.0 to 1.0. (The value used for c was 0.6).

The color gamut is divided into fragments as a function of hue. Obviously neutral colors cannot be used when this is done (since their hue cannot be determined). There are also other limitations and requirements which affect both image analysis and adjustment. Only pixels exceeding the predefined saturation limit (which is considerably higher than zero) are fully taken into account. Color fragments are classified according to their pixel intensity, and hue angle limits are set to (hue) values which correspond to low pixel intensity values. After the color fragment borders are set, fragment dependent RGB histograms are calculated. The basic principle of the adjustment is to calculate the minimum and maximum tonal values and enhance contrast linearly in the tonal area defined by these two values. The initial values are derived from histogram data but they are changed according to predefined parameters that limit the strength of the enhancement. These limits are set separately for low and high tonal values. In addition, the (min. and max.) tonal values are filtered before images are adjusted. This procedure is illustrated in Figures 2 and 3.

The adjustment of contrast may sometimes result in change of overall lightness. Should this happen, the lightness change is partially compensated for with a very straightforward procedure. After contrast enhancement the image is adjusted with a simple (relative) gamma function. This function can be selected so that the sum of the RGB tonal values retains its original value. This procedure is not recommended for general use but in this application it seems to work at least as well as some other more scientific approaches such as minimizing colorimetrically defined average color differences.

Experiments and Results

The algorithm was tested with 200 photographic RGB images selected from various sources. The only aim was to evaluate how the new algorithm enhances contrast. Therefore the test image set was gathered in a selective manner and some preprocessing was used in order to eliminate all excess factors affecting the result of visual tests. For many high quality originals, no adjustments were necessary. However, if needed, gray balance, contrast and overall lightness level were adjusted using RGB curves.

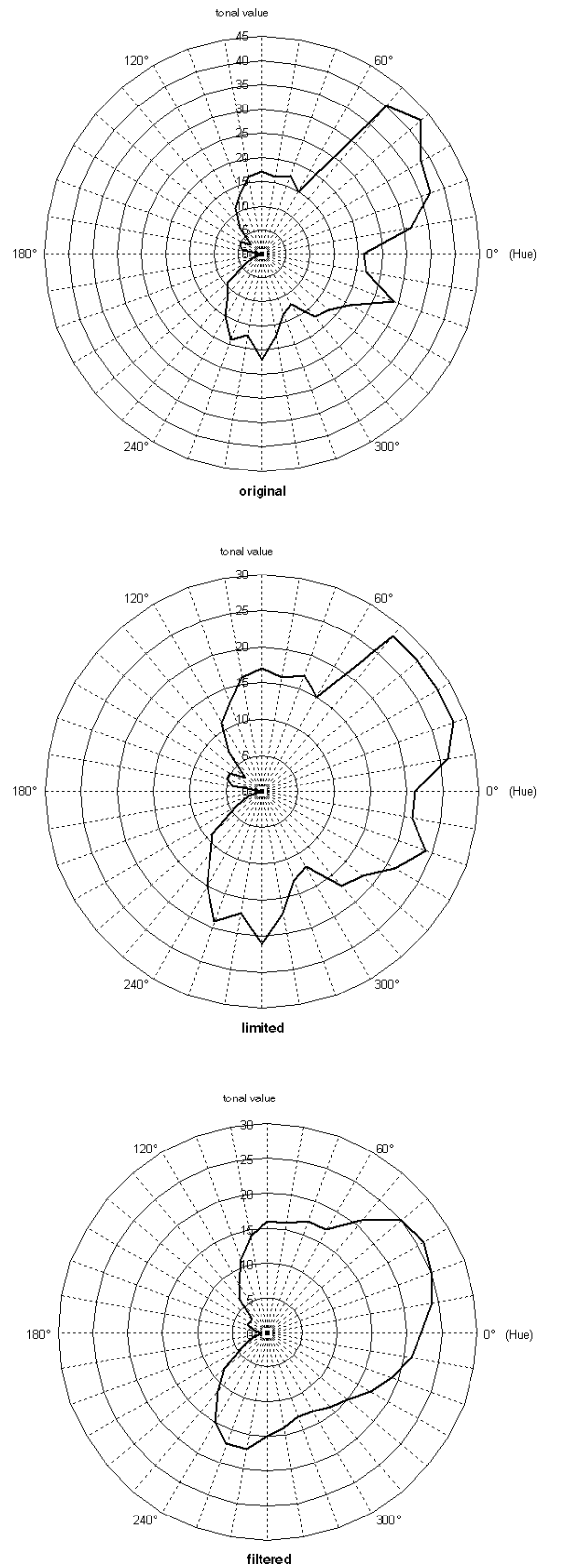

Figure 2. An example of setting the limits for low tonal values

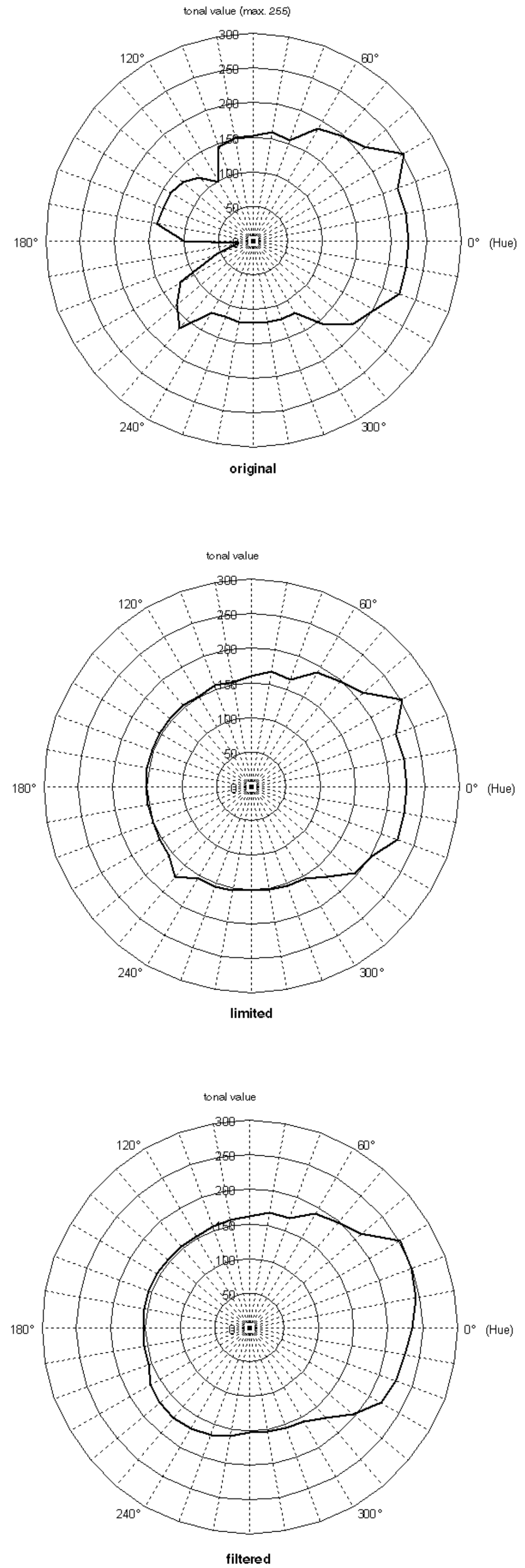

Figure 3. An example of setting the limits for high tonal values

If, however, it turned out to be difficult to get visually good results for an image with such simple adjustments, the image was rejected. (This preprocessing as well as the actual visual tests were made using a CRT monitor, which was calibrated according to the sRGB standard.) As a result, all images used for this test had RGB-histograms covering full tonal range for all three color components. Moreover, visual evaluation was used in order to ensure that all qualified test images had good contrast, color balance and right lightness level.

There were several reasons to use this kind of special test image set. One goal was to eliminate all accidental image improvements. More importantly, the aim was to study how this new method works with simple traditional global adjustments and whether it can improve image quality further even when other color adjustments have already been made.

Analysis of this test image set showed that despite the extraordinary and demanding starting point, majority of the tested photographic color images had at least some potential to benefit from this method. In practice, the contrast enhancement led to significant improvement of visually assessed image quality in slightly more than half of the cases.

Conclusion

The new contrast enhancement method based on analysis of local color information has proved to be a useful color adjustment tool. It can be used together with traditional global color image enhancement methods since in most cases further enhancement is possible even when other adjustments have already been made. This study showed that the method is applicable in interactive color image adjustment. In future it is also intended to utilize it as part of the automatic image enhancement algorithms[1,2] developed at the Helsinki University of Technology.

References

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Biography

Pekka Laihanen received his Ph.D. in Graphic Arts and Image Science from the Helsinki University of Technology (HUT) at Espoo in 1995. He has worked in the Laborarory of Media Technology (at HUT). He has also done research work for the Hewlett Packard Barcelona Division. His work has primarily focused on different aspects of color image manipulation and enhancement.