

A Fast Method for Contrast Correction of Color Images

Jaana Parkkinen, Petri Nenonen; NOKIA Technology Platforms, P.O. Box 1000, FIN-33721 Tampere, Finland
Radu Bilcu; NOKIA Research Center, P.O. Box 1000, FIN-33721 Tampere, Finland

Abstract

In this paper we propose a fast contrast optimization procedure that is suitable for mobile implementations. The proposed method is based on a new way to analyze the histogram of the image, and then computing a global mapping function optimizing the contrast of the captured images. The analysis and the mapping function computation of the proposed method are designed to optimize the vast variety of the contrast characteristics in the captured images and simultaneously to retain the natural appearance of the images. The complexity and processing power requirements of the method are designed to be very suitable for limited amount of memory and processing power in mobile implementations. The method is described in details in this paper. We also present experiments showing the performances of our approach on real images captured with a camera phone.

Introduction

Nowadays it is a common fact that mobile devices, such as mobile phones and PDA's, are equipped with miniature digital cameras. This gives users an opportunity to capture digital images and video sequences. The quality of images captured with mobile imaging devices is increasing constantly. However, the captured images may still contain distortions that are decreasing the image quality. A limited contrast is one of the most significant among such distortions. This distortion appears when the real scenes have a much wider dynamic range than the dynamic range of the imaging sensors. This usually happens in the miniature camera modules, and quite often also in the high end digital cameras.

During the last years, many solutions that address the problem of contrast correction have been proposed in the open literature [1-9]. The approaches published so far can be divided into categories of hardware solutions and image processing solutions. The target of the hardware solutions is to reduce the limitations due to the camera module hardware properties. The image processing solutions are targeting on algorithms and software for optimizing the contrast of the captured images.

The hardware methods have the advantage of real time operation since the image is corrected at the sensor level using electronic circuitry. However, the hardware approaches have the disadvantage of needing specific integrated circuit designs and therefore being more expensive than the basic camera modules. The mobile devices have increased, although still limited, amount of processing power that is available also for image processing use. A cost and quality optimized solution can be achieved using algorithms requiring low processing power. The software solution also provides freedom to use the algorithm as a part of image processing chains, such as described in [10], and dynamically select the processing order of different algorithms.

The image processing approaches can also be categorized into single frame and multi-frame processing algorithms. In the first case, one image is captured and the dynamic range of that image is

optimized. In the second case multiple images with different exposures are captured, which makes possible to cover very wide dynamic range, i.e. high dynamic range (HDR) imaging. Ultimately, the HDR images, obtained by means of fusing multiple differently exposed images, must be shown on a display. Usually the displays have a smaller limited dynamic range, for instance bit depth 8, such that the dynamic range of an HDR image must be properly scaled. This can be done by means of tone mapping methods that reduce the dynamic range of an HDR image to the available range of the display [11]. Tone mapping methods designed for displaying HDR images on low dynamic range displays must ensure that the most important details of the scene are preserved hence, they must properly redistribute the pixel values into the new dynamic range. However, multiframe imaging necessitates more complex processing.

In this paper we introduce a computationally effective solution to the problem of contrast optimization of digital images by using image processing means. The developed algorithm can be fully implemented on mobile devices by software. Our proposed method is based on single frame processing. We provide detailed description of the algorithm and practical experimental results.

The contrast optimization problem

The contrast in the image means amount of difference in two intensity levels of interest [12, 13]. For example the intensity level of a detail of interest vs. background intensity. The greater the difference is the higher is the contrast and visibility. In contrast optimization problem the target is to maximize the contrast of all details, but retaining the natural appearance at the same time.

The main reason for a suboptimal contrast in captured images is the wide dynamic range in captured scenes, when compared to the available dynamic range of the imaging sensor and captured image bit depth. The scenes also often contain dark and bright areas of the interest simultaneously. How the scene brightness levels are mapped into the image levels is dependent on the exposure and digital gain settings during the capture. With long exposure time, or high gain, the contrast and details of the dark areas are captured well, but the bright areas are saturated to the maximum value of the captured image dynamic range. With short exposure time, or low gain, the scene dynamic range is mapped to the available dynamic range of the captured image, but the dynamic range, and therefore also the contrast, is reduced. The visibility of details is not optimal, and may be lost due to the quantization into the available bit depth.

The intensity level histogram of the image gives information about the contrast. The contrast optimization problem is presented with histograms in the figure 1. In the top drawing a histogram of the original scene is shown. The available dynamic range of the captured image is depicted in the two other drawings. The middle drawing shows the scene captured with long exposure time. The dark area is seen well, but the information in the bright area is lost. The bottom drawing shows the scene captured with a short

exposure time. The dynamic range is compressed, which reduces contrast and visibility of details. The problem is visible especially in the dark areas in this illustrative case.

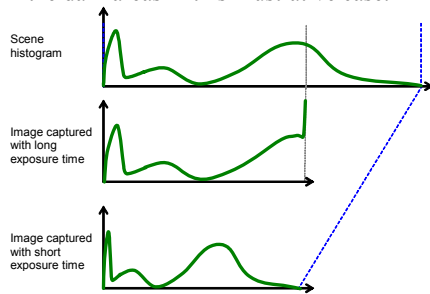


Figure 1. Contrast optimization problem

There is vast variety of contrast characteristics in the captured scenes. The scene may contain only bright areas, only dark areas or both. Also scenes with only middle brightness areas can be captured. All combinations of these also exist in all possible proportions. The corresponding histogram characteristics of the different contrast types are shown in the figure 2.

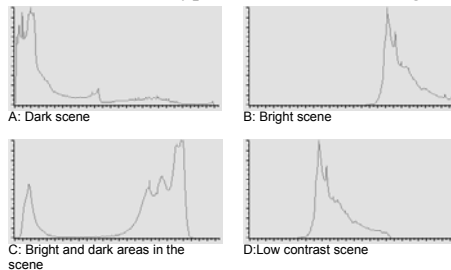


Figure 2. Different histogram types

In the contrast optimization problem the target is to optimize the use of the available dynamic range so that the visibility of details is optimal both in dark and bright areas of the image, as well as in the middle area of the dynamic range.

Existing approached

In this chapter an overview to existing contrast correction and optimization methods is given. We limit into the scope of single exposure based methods.

A simple approach for contrast correction is a contrast stretch described in [12]. Automatic selection of stretching parameters is possible as described, for example, in [14]. The method is simple but cannot correct all images. For example, it is clear that images of types A and B in the figure 2 cannot be corrected with the linear stretch. One solution is a piecewise stretch, described in the same reference. However, in order to make the correction automatic the computation of the knee points have to be added. This problem is solved by our proposed method.

The concept of using an image content adaptive gamma correction is described in [15]. Dark and bright images can be corrected with the nonlinear gamma correction, but it is not solving the problem of images containing both dark and bright areas.

One of the simplest methods that is capable of correcting visibility of details in all brightness ranges simultaneously is the histogram equalization [12, 13, 16]. While histogram equalization is a fast method its main disadvantage is due to the fact that there is no parameter controlling the amount of correction. The histogram equalization tends also to maximize the contrast in the information extraction sense [17]. There are multiple modifications of the histogram equalization aiming at overcoming these properties [1, 2, 3]. However the simplicity of the methods and the accuracy of the strength control as well as also the capability of retaining the natural appearance are the key features that are improved in our proposed method.

One improvement on the simple methods can be achieved by processing the dark and bright areas of the images differently. This requires classification of the image data into bright and dark areas, or into greater number of sub ranges. The classification have to be able to work smoothly in order to avoid extra contours, but also at the same time not to produce ringing type artefacts around the sharp edges in the image. However, the complexities of good quality classification and segmentation methods are still beyond the limits of the computational processing power targeted in this research.

Methods based on Fuzzy Logic [4], Wavelet domain processing [5] and modeling the image degradation [6] have also been proposed. However many of the methods, although their excellent performance, suffer from high computational complexity and memory load.

The proposed method

The core of the proposed method is to use the piecewise linear stretching with 2 knee points computed from the image histogram. Only single image is used and no multiframe processing is needed. There are no methods capable of correcting saturated areas, but when using the contrast optimization the exposure can be set short enough for avoiding saturation and the image can then be corrected by post-processing. The method can operate either on brightness or RGB components separately. The method can be implemented as LUT after the stretching function has been calculated and therefore the method does not require a lot of processing power.

The method starts by measuring the image histograms (R, G and B or Y) and computing the mean value M of all the image pixel values. The low mean LM (the mean of all pixel values less than previously calculated mean) and the high mean HM (the mean of all pixel values greater than previously calculated mean) are also calculated. The absolute nonzero maximum and minimum values from the tails of the histograms and the predetermined amount of nonzero pixel values P_d and P_w from both tails of the histograms are found. These min and max results are compared and it is determined whether the min and max values are actual image data or dark and bright pixel outliers. False min and max can be either random noise or other minor spots in the image. If the difference d between the absolute min value and the P_d , or the difference between the absolute max value and the P_w , are greater than some predetermined limit value L , the min and max values are probably due to outliers. In this case the ends of the histogram are considered to be P_d and P_w .

The values to be stretched to the full dynamic range are based on the results found i.e. P_w and P_d , or absolute min and max values.

The overall stretching gain is computed and limited to an acceptable value, which retains the natural appearance of images. If the stretching gain is set too high, the stretch points are moved towards the ends of the dynamic range in such amount that the gain is within the acceptable limit. The effect is shown with solid and dashed lines on the mapping function in the figure 3.

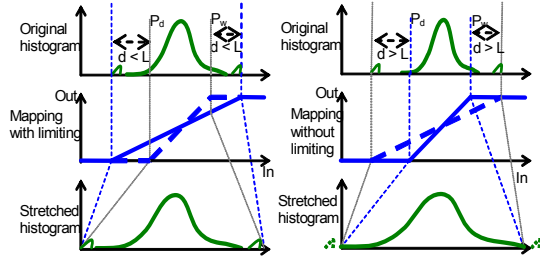


Figure 3. Global stretching with and without limiting

The overall stretching function $y=ax+b$. The measured mean points LM, M and HM are corrected as those would be stretched by the overall stretching to SLM (stretched low mean), SM (stretched mean) and SHM (stretched high mean) as shown in figure 4.

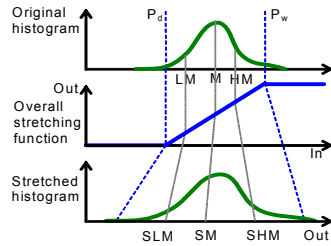


Figure 4. Stretched mean values

Next the used knee points are defined. The CSM (corrected and stretched mean point) is moved towards the middle value of the dynamic range. The amount of correction G (gain) is predetermined. This CSM is used as the basis for the calculation of knee points in the piece-wise linear stretching function. The CSHM (corrected stretched high-mean) and CSLM (corrected stretched low-mean) target points are also computed based on the CSM. The target points are at points defining predetermined ratios GL (low gain) for low-mean and GH (high gain) for high-mean between the CSM and the ends of the dynamic range. This is shown in figure 5.

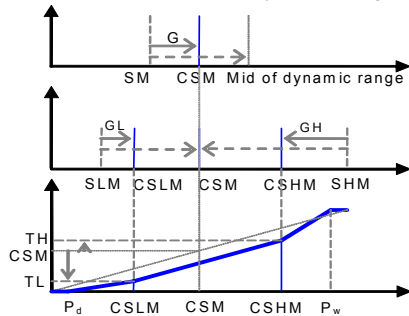


Figure 5. Correcting the stretched mean values

The SHM and SLM values are corrected to CSLM (corrected stretched low mean) and CSHM (corrected stretched high mean) by moving them slightly with a predetermined amount towards the CSM, so that the final stretching function is extended over the SLM and SHM (CSLM and CSHM knee points are between SLM and SM, and between SM and SHM).

At final stage of the stretching function calculation, the gains of each part of the stretching function are computed, and limited to values retaining the natural appearance of images. The stretching function is reshaped so that the gain of each part is between predetermined min and max limits (individual for each part, MinLow, MaxLow, MinMid, MaxMid, MinHigh and MaxHigh in figure 6) to prevent too flat or negative slope for middle contrast values (and therefore causing too much compression of middle brightness values). This is shown in figure 6.

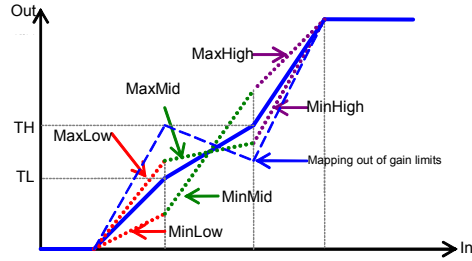


Figure 6. Mapping with gain limits

The mapping function is implemented by creating the corresponding stretching. When operating with YUV image, the stretched component is the luminance Y . The saturation of image should be unchanged and U and V components are corrected accordingly [15], by using gains computed with equations:

$$\text{Gain} = 0.7 * \text{StretchedY} / Y \quad (1)$$

$$U = 128 + \text{Gain} * (U - 128) \quad (2)$$

$$V = 128 + \text{Gain} * (V - 128) \quad (3)$$

The saturation correction gain for each original Y value is also implemented as saturation correction gain LUT.

At the final stage of our contrast optimization method, the image pixels are processed with the computed LUTs.

Experiments and results

Quality evaluations

A typical example on the performance of the proposed method is shown in the figure 7. The left hand side is the original scene with fairly dark contents, but still having important information also in the mid brightness and bright areas. The right hand side shows the processed image. The visibility of details in the dark area is clearly increased. The mid part of the dynamic range is used more effectively. Information and natural appearance of the image is retained in all areas. The figure shows also the brightness histograms of the images.

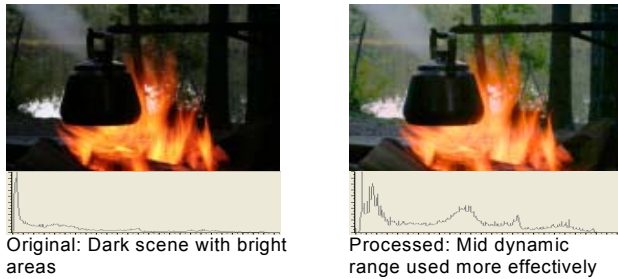


Figure 7. Typical experimental results

Complexity evaluations

The proposed method was implemented with C++ programming language on NokiaS60 platform. The computational complexity was analyzed by measuring the processor clock cycles used for processing the image. The complexity is about 50 cycles per pixel. The implementation could be further optimized by using assembly code.

Conclusions

In this paper we have introduced a tone mapping method for contrast correction of digital images. The experiments, done on real images captured with camera phones, shown that the proposed method is both simple and effective and can be used to improve the overall contrast of digital images. Our method has a low computational complexity which makes it very suitable for mobile implementations.

Although, the proposed method was primarily designed to maintain the dynamic range of the processed image equal to the dynamic range of the input image, we believe that it can be adapted also for mapping high dynamic range images to the low dynamic range of a display. In such application the tone mapping will not only redistribute the pixel values inside the image dynamic range but will also reduce the bit depth of the image to fit into display's dynamic range.

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Author Biography

Jaana Parkkinen received her M.Sc. in Electrical Engineering from the Tampere University of Technology (2000). Since then she has worked first in the NOKIA Research Center and then NOKIA Technology Platforms in Tampere, Finland. Her work has focused on the development of image enhancement algorithms.

Petri Nenonen received his M.Sc. in Information Engineering from the Tampere University of Technology (1996). Since 1995 he has worked first in the NOKIA Research Center and then NOKIA Technology Platforms in Tampere, Finland. His work has focused on the development of image processing methods for mobile imaging applications.

Radu Bilcu received his M.Sc. in Electronics from the Technical University of Cluj-Napoca, Romania (1996) and his Dr.Tech in Signal Processing from Tampere University of Technology, Finland. Since then he has worked in the NOKIA Research Center in Tampere, Finland. His work has focused on the development of image processing algorithms.