Optik 157 (2018) 467–483

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Less-visible contrast enhancement based on the human visual perception

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ARTICLE INFO

Article history:
Received 23 December 2016
Received in revised form
30 September 2017
Accepted 15 November 2017

Keywords:
Image contrast enhancement
Human perception
Adaptive non-linear scaling function
Pyramid-based blending

ABSTRACT

Typically, conventional image-enhancement methods have a common problem concerning the over-enhancement in an image which contains both less-visible and nicely-visible areas. To solve such problem, we propose a new contrast enhancement method based on the singular value decomposition (SVD), an adaptive non-linear scaling function, and a pyramid-based blending method. The SVD is used to decompose an image and to identify image noise if the image contains high noise level. Then, the less-visible areas of the noise-removal image is strengthened by using the proposed adaptive non-linear scaling function based on the human perception. Finally, the proposed pyramid-based blending scheme is deployed in order to recover nicely-visible area of the image. This recovery process is mandatory because enhancing images in the previous step might cause the over-enhancement. Objective and subjective evaluations were conducted, and experimental results show that our proposed method can successfully improve the less-visible contrast without amplifying noise. It also preserves the tone and texture of original images and produces satisfying results in terms of human preference.

1. Introduction

Over the last few years, one of the challenging problems in digital image processing is to enhance an image which contains both less-visible and nicely-visible areas. In this case, only the former are needed to be enhanced, whereas the latter areas should be preserved. Note that, in this work, we call an image that is correctly exposed a nicely-visible one. In general, a good enhancement method should produce a resulting image in which information in less-visible areas can be easily perceived by our visual system. Also image tone, texture, and other characteristics, e.g. the naturalness, should be similar to those of the original image. Moreover, a good enhancement process should avoid unwanted side effects, such as noise amplification or the halo effect [1].

During the early years, the power-law transformation, the logarithmic transformation, and the histogram equalization (HE) are ones of famous techniques for enhancing images [2]. The power-law and the logarithmic transformations deploy non-linear functions to expand input image ranges, i.e. a smaller input value is amplified with a greater factor. Therefore,

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https://doi.org/10.1016/j.ijleo.2017.11.096
0030-4026/

the less-visible areas could be enhanced. However, both introduce a side effect, i.e. hidden noise in the less-visible areas is amplified, and nicely-visible areas are unnecessarily amplified as well. Consequently, they cause the noisy and over-exposed image. The HE enhances an input image by expanding its histogram range. However, performance of this method strongly depends on characteristics of the histogram. These three methods are classified as the global enhancement, and they all share the common problems of noise amplification and over-enhancement.

Later, several local enhancement methods have been proposed. These methods include the histogram-based [3,4], the just-noticeable-different-based (JND-based) [5], the retinex-based [6–8], and the singular-value-decomposition-based (SVD-based) methods [9,10]. For example, the adaptive histogram equalization (AHE) and the contrast limit adaptive histogram equalization (CLAHE) [3] are histogram-based and widely used to improve local contents. However, this approach still suffers from unnecessarily amplifying, and it suppresses values in some regions in the case that distribution of intensity is narrow and intensity values are too high or too low. Recently, Fu et al. try to solve these problems by implementing an enhancement method based on the multi exposure fusion with a sigmoid function and adoptive histogram equalization [11]. In this paper, we abbreviate the name of this method as MEF. According to this method, the under-exposed images, well-exposed images, and over-exposed images are blended together to generate the resulting image. This method can solve those two problems. However, in some cases, it still amplifies the hidden noise. An example of this case is to be shown in Section 3.1.

The JND-based approach employs the Weber's law, which is based on the human visual perception, to create a non-linear function [5]. The advantage of this approach is that an enhanced image looks clearly visible because the average local contrast is increased. Although the less-visible areas can be seen clearly, the contrast in the nicely-visible areas is also strengthened. Hence, in some cases, the resulting image looks different from the original one.

The retinex-based methods, such as the single-scale retinex (SSR) [6], the multi-scale retinex (MSR) [7], and the multi-scale retinex with color restoration (MSRCR) [8], originate from a theory proposed by Land et al. [12]. Functions used in these methods are based on the human visual perception. These methods enhance less-visible areas by using logarithmic transformation and the Gaussian surround function. These methods have a critical problem concerning the value of standard deviation of the Gaussian function. That is, if the standard deviation is too small, the nicely-visible parts of an enhanced image will be degraded and look unnatural. Even though the MSR and the MSRCR have tried to solve the problem by using several different standard deviations, the problem still persists, especially when the biggest standard deviation used by the algorithm is smaller than an object size displayed on the image. The multi-scale retinex with chromaticity perservation (MSRCP), which is an improved MSRCR, was proposed by Petro et al. [13] to solve such problem. Instead of performing the algorithm to each RGB channels, MSRCP performs only on the luminance channel. Then, it computes the scaling factor to restore true color. In most of the cases, resulting images enhanced by the MSRCP are excellent. However, in some cases, this algorithm produces an image which is too colorful, hence an unnatural-looking image. The Frankle and McCann algorithm is another retinex, and this method uses a single pixel to estimate a new value by computing long-distance interactions between pixels and progressively move to short-distance interactions [14]. The benefit of this method is that it can reduce a computational-complexity time. However, it cannot tolerate hidden noise. Another method similar to the retinex-based is fast center surround modification [1]. The algorithm employed concept of the shunting centre-surround cells of the human visual system to modify the under and over-expose regions [1]. To our knowledge, this method produce the best resulting images in terms of tone preservation, detail preservation, and human preference. However, in some cases, it still amplifies the hidden noise. An example of this case is to be shown in Section 3.1.

The SVD-based methods enhance an input image by amplifying all singular values of the matrix representing the image [9,10]. The performance of these methods depends on characteristics of the input image. That is, the algorithm works well only when most pixel of the input image have low intensity values; otherwise, the problem of over-enhancement occurs.

The hybrid method, which combines SVD and a non-linear scaling function, is proposed in order to select a suitable range to be enhanced without amplifying image noise [15]. This method can perform well in an image containing both less-visible and nicely-visible areas. However, it has a problem concerning the foggy effect due to selecting some SVD layers for the enhancement.

From this survey, it can be seen that enhancing an image only the less-visible areas without amplifying hidden noise and without modifying the original tone, texture, key-lighting, etc., has been a difficult task. To enhance only the less-visible areas, we first analyze a hidden noise level of an image. If the level of hidden is greater than a predefined value, an SVD-based technique will be used to remove the noise. Then, we use that image to create the result. We believe that a function used to enhance a pixel value should depend not only the pixel value but also on its neighbors. Also, this enhancement function should be based on a human perception model.

This paper proposes a new less-visible enhancement method based on the human visual perception using an adaptive none-linear scaling function. The proposed method aims to satisfy the following properties.

- The less-visible areas are enhanced to be visible without amplifying noise.
- The tone, texture, and key-lighting of the enhanced image should be similar to those of the original one.
- The enhancement method should not cause unwanted side effects, such as the halo effect, over-enhancement, etc.
- The enhancement method should create the resulting image that is preferred by participants in a preference test.

Therefore, compared with the existing methods in literature, this work has three contributions as follows. First, it proposes a new noise-reduction technique, which is the preprocessing of the proposed method. Second, we introduce a new