Fuzzy Rule-based Image Exposure Level Estimation and Adaptive Gamma Correction for Contrast Enhancement in Dark Images

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Abstract—Image enhancement of badly illuminated dark images is always a challenging as well as an important task in image processing. A technique which is often used to increase the contrast of dark images is gamma correction. However, the value of gamma suitable for appropriate enhancement of a given image remains a question. In this paper, we propose to first estimate the level of exposure in the input image using fuzzy reasoning that is based on a set of fuzzy rules. Following this, we derive the gamma value as a function of the exposure level. Also, we propose to apply the gamma correction on the negative of the input image since it produces a better contrast compared to the conventional gamma correction. The proposed method was applied to several badly illuminated images, both gray and color, and the results obtained were compared to that obtained using histogram equalization.

Keywords—image enhancement; exposure level; fuzzy inference system; adaptive gamma correction; image histogram.

I. INTRODUCTION

Image enhancement is an important issue in image processing applications such as digital photography, medical image analysis, remote sensing and scientific visualization. It is the process by which the appearance of an image is improved such that the resultant image is suitable for visual perception of human beings or for machine analysis. It is useful not only from aesthetic point of view but also helps in image segmentation, analysis, feature recognition, etc. Often, image captured using general purpose camera has a low contrast and many of its features are difficult to see. This may be due to lack of dynamic range in the imaging device, poor illumination and/or wrong setting of lens aperture. A variety of imaging devices respond according to a power-law that tend to produce images that are darker than in actual. Also, in low-light environment, the lacking in ambient light leads to poor and lowly contrasted images. Inappropriate opening of camera aperture during image acquisition also produces badly exposed images. So, it is of utmost importance to apply necessary corrections on the image captured before it can be used by the user, whatever the purpose may be. Image enhancement accomplishes this task by remapping the values of the original image so that the output image has better contrast and clarity.

Several image enhancement techniques are available in the literature [1]. Image enhancement methods are mainly categorized as either spatial domain methods or frequency domain methods among which spatial domain methods are more popular due to their easy implementation. Spatial domain methods use basic point processing operations that directly manipulate the gray-values of pixels in an image aiming mainly to increase the dynamic range of the image. Techniques in this category are generally based on transforming the pixel intensity at every point in the image either by using some standard gray-value transformation functions or via histogram processing. The most common histogram processing approach is histogram equalization while gamma correction is the most frequently used transformation function.

Spatial domain image enhancement techniques are mostly developed with the aim to improve the contrast by changing the luminance of the images and hence are generally suitable for enhancing gray images. Nonetheless, several image enhancement techniques and their variants are also extended for application to color image enhancement. A proper color model is chosen for the purpose that decouples the achromatic and chromatic information while maintaining the color distribution of the original image. One traditionally used color model in image processing is the HSV model in which hue (H) quantifies the color content, saturation (S) is used to measure the amount of dilution in the color content and V represents the intensity of the color content. By preserving H and S while changing only V, it is possible to enhance color images.

As said above, histogram equalization is one simple and widely used method that is based on histogram processing. In this method, the transform function is created from the cumulative density function of the pixels in the input image in such a way that the transform function stretches or compresses the pixel gray-values to result in a more or less uniform distribution after processing. The disadvantage of this method is that it is not a suitable property in applications where brightness preservation is necessary to avoid annoying artifacts. For preserving the input brightness of the image, many different variants of histogram equalization have been proposed in the literature such as the bi-histogram equalization (BBHE) [2], quadrant dynamic histogram equalization (QDHE) [3], modified histogram equalization due to Arici et al [4] and so on.

Another technique which is often used to increase the contrast of dark images is gamma processing. In gamma correction
method the value of gamma modifies the pixel intensity to appropriately enhance the image. The method is based on power-law transformation and hence proves to be a suitable technique to compensate for the low contrast caused due to the imaging device. However, it is often difficult to select suitable gamma values without the prior knowledge about the imaging device. Moreover, inadequate exposure due to lack of ambient light and/or inappropriate opening of camera aperture also contributes to the cause of low contrast. So, the value of gamma is to be chosen in such a way that all these factors are taken into consideration and the image is corrected to an appropriate level. Wrong choice of gamma may lead to loss of texture details in the image because of over or under correction. Moreover, the varieties of images greatly challenge the performance of the traditional Gamma correction.

In this paper, we propose to use gamma correction technique for contrast enhancement in images that are affected by inadequate exposure during acquisition. For this, we first estimate the level of exposure of the input image using fuzzy reasoning that is based on a set of fuzzy rules. Following this, we determine a suitable gamma value as a function of the exposure level. Thus, our proposed gamma correction-based image enhancement technique is capable of adapting to the input image. Further, we observe that better contrast image is obtained if gamma correction is applied to the negative of the input dark image. Accordingly, we propose to first invert the input image, apply gamma correction to it, and then re-invert the processed negative image. A detailed description of our proposed method is given in Section II. Experimental results in support of our proposed technique are given in Section III. Finally, we draw our conclusion in Section IV.

II. PROPOSED ADAPTIVE GAMMA CORRECTION

In the context of image enhancement, people have to deal with many ambiguous situations. Fuzzy set theory is a useful tool to handle such ambiguous and uncertain things. The linguistic variables or hedges like ‘poor contrast’, ‘good exposure’, etc., can be perceived qualitatively by the human reasoning but are not formally definable. Fuzzy logic tools empower a machine to mimic human reasoning. Accordingly, fuzzy set theory has been employed in recent years to develop new techniques for contrast improvement.

A local gamma correction method with three level thresholding is proposed in [5] by Shi and Cai. Three level thresholding is used to segment the image into three gray levels on the basis of maximum fuzzy entropy. Local gamma correction is then applied to these three levels, respectively. In [6], Pal and King proposed an image enhancement algorithm based on fuzzy sets that finds good applications in pattern recognition and medical image processing. Another fuzzy-based enhancement technique is given in [7] by Russo and Ramponi. A generalized iterative fuzzy enhancement algorithm was proposed by Dong-liang and An-ke in [8]. The method presented in [9] divides an input image into fuzzy regions on the basis of fuzzy entropy and every region is enhanced by optimization. Fuzzy logic-based image enhancement method is also presented in [10] by fuzzifying the color intensity property of the image using Gaussian membership function for under-exposed images. Enhancement of the fuzzified image is carried out using a general intensification operator of sigmoid type.

In this paper, we propose to use fuzzy theory for estimating the exposure level of the input image. In our proposed approach, we first assess the level of exposure in the input image using several fuzzy rules. A fuzzy inference system that uses these fuzzy rules gives a measure of the level of exposure which is subsequently used to determine an appropriate gamma value adapted to the level of exposure in the input image.

A. Fuzzy rule-based image exposure level estimation

In our proposed method for enhancement of dark images, we first assess the level of exposure so that appropriate correction can be applied. For this, we propose to use some “IF ... THEN ...” fuzzy rules and estimate the exposure level using a fuzzy rule-based inference mechanism. A fuzzy rule typically includes a group of ‘antecedent clauses’ which define conditions and a ‘consequent clause’ which defines the corresponding output action and/or conclusion. These fuzzy rules give directives much similar to human-like reasoning. Such a rule, which is expressed in a plain linguistic form, can be translated into the more formal structure of a fuzzy operator.

It is observed that in a badly illuminated dark image the components of histogram are concentrated on the lower side of the gray-scale. Similarly, the gray-levels of an over-exposed image are clustered on the higher side of the gray-scale. An image with low contrast has a histogram that is narrow while in a well contrasted image, the gray-levels are well spread over much of the range. Therefore, in under-exposed image mean pixel intensity \( \mu \) as well as variance of pixel intensity level \( \sigma^2 \) are very small. On the other hand, over exposed image contains high mean pixel intensity but low variance. Based on this knowledge, image exposure may be calculated using deductive fuzzy inference system based on a set of four fuzzy rules, as stated below.

- Rule 1: IF mean is low AND variance is low THEN exposure level low (under-exposed image).
- Rule 2: IF mean is high AND variance is low THEN exposure level high (over-exposed image).
- Rule 3: IF variance is high THEN exposure level medium (adequately exposed image).
- Rule 4: IF mean is medium THEN exposure level medium (adequately exposed image).

Thus, our fuzzy system is a two-input and one-output system — two input variables are the mean pixel intensity \( \mu \) and their variance \( \sigma^2 \); the resultant output variable is the level of exposure \( \lambda \). The first two THEN-rules include two conditions (antecedent clauses) about the input variables and specifies a
consequent clause related to the output variable. Antecedent clauses are linked by fuzzy AND operators. Each of the last two THEN-rules includes only one antecedent clause. Each clause is completely defined by the shape and position of a fuzzy set, which maps the corresponding variable to the real interval $[0, 1]$. Five fuzzy sets for the antecedents and three fuzzy sets for the consequent are used, as represented in Figs. 1–3. Fuzzy sets for the antecedents are labeled as ‘low mean’, ‘medium mean’, ‘high mean’, ‘low variance’, and ‘high variance’. Fuzzy sets for the consequents are ‘low exposure’, ‘medium exposure’ and ‘high exposure’.

The ‘exposure level’ $\lambda$ is calculated on the basis of the mean and variance of the pixel intensities in the input image by combining the above stated fuzzy rules using Mamdani’s max-min inference method followed by centroid-based defuzzification. A detailed description of the inference mechanism can be found in [11] which otherwise is beyond the scope of this paper. Thus, our fuzzy system maps the input variables mean pixel intensity $\mu$ and the variance $\sigma^2$ in the image to the output variable $\lambda$ that gives a measure of the level of exposure $-1$ to $+1$; negative value of $\lambda$ means under-exposed image and positive valued $\lambda$ implies over-exposed image. Accordingly, our image enhancement strategy is targeted to improve the exposure level such that the value of $\lambda$ in the processed image is close to zero.

B. Determining appropriate value for gamma

Gamma correction method for image enhancement is a power-law transformation approach generally used to counter the power-law effect of the imaging device. The basic form of the gamma transformation is given as

$$V_{\text{out}} = cV_{\text{in}}^\gamma$$

(1)

where $V_{\text{in}}$ is the intensity (normalized) at one pixel location in the input image, $V_{\text{out}}$ is the transformed pixel intensity (normalized), $c$ and $\gamma$ are positive constants. For simplicity, $c$ is often taken to be unity. The transform with fractional values of $\gamma$ expands values of dark pixels and compresses values of bright pixels in the input image. Therefore, for contrast enhancement in dark images, we need to choose gamma in the range 0 to 1. At the same time, we target zero ‘exposure level’ in the resultant image upon enhancement. This suggests that an appropriate value of $\gamma$ in the interval $(0, 1)$ is to be determined in accordance to the level of exposure $\lambda$ in the input image, as estimated using the method above. Accordingly, for dark images with exposure level $\lambda$ in the range $-1$ to 0, the required gamma is calculated as

$$\gamma = k^\lambda$$

(2)

Here $k$ is a positive constant greater than 1, determined via some optimization technique such that the ‘exposure level’ in the output transformed image is equal to zero. It may also be noted that in case of medium exposed image, the $\lambda$ value is zero and so $\gamma = 1$. Consequently, the gamma transformation reduces to the identity transformation conforming to our desired result in case of adequately exposed good images.

C. Proposed modification to gamma correction

A close look into the transform function in (1) reveals that for fractional value of $\gamma$ (as it is in our case of enhancing dark...
images) the slope of the curve is very high at input gray-values near to zero; the slope being infinite for $V_n = 0$. Consequently, the gamma correction curves with fractional values of $\gamma$ map a very narrow range of dark gray-values into a broader range in the gray-scale. Although this is desired to some extent, it may result in mapping of very dark pixels (almost zero but not zero gray-values) to some reasonably high gray-values, particularly when the gamma value is quite small and the slope of the curve is extremely high. This results in an image having 'washed out' appearance with the histogram shifted from the lower side of the gray-scale to the higher side but without much spread along the gray-scale, as seen in the examples given in Fig.4.

However, for gamma values greater than one, as used in case of over-exposed images, the effect is not exactly the opposite. Here the slope of the gamma correction curves varies gradually from 0 to $\gamma$ (which in general is finite) as the input $V_n$ varies from 0 to 1. So, in this case, very bright pixels do not map to very dark gray-values. For example, a dark pixel with normalized value 0.1 is mapped to a value 0.56 for $\gamma = 0.25$, while its negative (with normalized gray-value 0.9) is mapped down to 0.66 only for $\gamma = 4$ (inverse of the gamma value above). Negative of the transformed bright pixel gives gray-value equal to 0.34. Hence, the problem encountered in the above case is not that prominent in this case. In view of this, we propose to modify the conventional gamma correction method by first inverting the dark image and then applying the gamma correction on the negative of the input image. Finally, the enhanced image is re-inverted to obtain the required output image. That is,

$$V_{out} = 1 - (1 - V_n)^\frac{1}{\gamma} \quad (3)$$

where the value of $\gamma$ is as calculated in (2) above.

D. Steps of the algorithm

- RGB to HSV conversion of the input image (in case of colored image) and normalization of pixel intensities.
- Calculation of mean pixel intensity and variance of the input image.
- Application of fuzzy rules stated earlier to calculate image exposure level.
- Determination of an appropriate value of gamma using (2).
- Application of image transformation given by (3) so as to achieve desired enhancement of the input image.

III. EXPERIMENTAL RESULTS

In our experiments, we applied our proposed modified gamma correction method for image enhancement to several badly illuminated dark images, both gray and color, that show very low contrast. We compare the performance of our proposed method with the traditional histogram equalization method and a recently proposed bacterial foraging-based method [12]. Fig. 5 and Fig. 6 show the resultant enhanced images along with their histograms. It is observed that images obtained in our proposed method have a better visual appearance than those obtained using histogram equalization and bacterial foraging-based method. Comparing the histograms obtained using these three methods we see that the image texture is preserved better in our method thereby eliminating the problem of unnatural intensity saturation artifacts observed in case of the other two methods.

In order to check the quality of the output images after enhancement, we also evaluate the exposure level of the enhanced images using our proposed fuzzy rule-based method. The results obtained are tabulated in Table I. The value of the parameter $k$ adopted in our method for each case is also indicated within parenthesis. We observe that histogram equalization and bacterial foraging-based method may not always achieve exposure level $\lambda = 0$, as desired, while it is possible to achieve the desired result using our proposed method.

<table>
<thead>
<tr>
<th>Test Images</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Img 1</td>
<td>Original</td>
</tr>
<tr>
<td>Img 2</td>
<td>-0.663</td>
</tr>
<tr>
<td>Img 3</td>
<td>-0.656</td>
</tr>
<tr>
<td>Img 4</td>
<td>-0.665</td>
</tr>
<tr>
<td>Img 5</td>
<td>-0.662</td>
</tr>
<tr>
<td>Img 6</td>
<td>-0.47</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

Gamma correction method for image enhancement is a power-law transformation approach which is often used to increase the contrast of dark images. However, the problem with this method is that the value of gamma appropriate for enhancing a given image is generally not known. In view of this, we propose a method to estimate the exposure level of the input image using fuzzy reasoning based on a set of fuzzy rules. The measure of the exposure level so obtained is now utilized to determine an appropriate gamma value. Thus, in this paper, we propose a modified gamma correction method for image enhancement that is capable of adapting to the nature (level of exposure and contrast) of the input image. The proposed method is simple in implementation, computationally less complex, and gives good results without using too many parameters.
Fig. 5. Results of image enhancement in case of gray images with histograms of the images given below each of the respective images.

Fig. 6. Results of image enhancement in case of color images with histograms of the images given below each of the respective images.

REFERENCES


