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Fuzzy Logic Supported Coloured Image Information Enhancement

Annamária R. Várkonyi-Kóczy, András Rövid

Dept. of Measurement and Information Systems, Budapest University of Technology and Economics
Integrated Intelligent Systems Japanese-Hungarian Laboratory
e-mail: koczy@mit.bme.hu

Abstract: High dynamic range of illumination may cause serious distortions and information loss in the viewing and further processing of digital images. On the other hand, digital processing can often improve the visual quality of real-world photographs or views. Recently, HDR imaging techniques have come into the focus of research because of their high theoretical and practical importance. In this paper, a new fuzzy supported colour tone reproduction algorithm is introduced which may help in developing hardly or non-viewable features and content of colour images. It results in high quality colour HDR images containing the maximum level of details and colour information.

Keywords: high dynamic range images, colour image reproduction, fuzzy tone reproduction, information enhancement, multiple exposure time image synthesization

1 Introduction

High dynamic range of illumination may cause serious distortions and information loss in the viewing and further processing of digital images. On the other hand, digital processing can often improve the visual quality of real-world photographs, even if they have been taken with the best cameras by professional photographers in carefully controlled lighting conditions. This is because visual quality is not the same as accurate scene reproduction. In image processing most of the recently used methods apply a pre-processing procedure to obtain images which guarantees – from the point of view of the concrete method – better conditions for the processing. A typical example is noise elimination from the images which yields much better results as else.

There are many kinds of image properties to which certain methods are more or less sensitive [1], [2]. The different image regions usually have different features. The parameters of the processing methods in many of the cases are functions of these image features.

An organism needs to know about meaningful world properties, such as colour, size, shape, etc. for the interpretation of the view. These properties are not explicitly available in the retinal image and must be extracted by visual processing.

In this paper, we deal with the reproduction of colour images when the high dynamic range of the lightness causes distortions in the appearance and contrast of the image in certain regions e.g. because a part of the image is highly illuminated looking plain white or another is in darkness. This may result in the loss of both detail and colour information.

The dynamic range in photography describes the ratio between the maximum and minimum measurable light intensities. High dynamic range (HDR) imaging covers a set of techniques that allow a far greater dynamic range of exposures than normal digital imaging techniques [3]. HDR images enable to record a wider range of tonal detail than the cameras could capture in a single photo.

Recently HDR imaging techniques have come into the focus of research because of their high theoretical and practical importance. The application of HDR capable sensors in cars may get an important role in traffic safety, because in many of the cases the environment around the car has high dynamic range (dark and bright) illumination. (Just consider the case when a car leaves a tunnel and enters the bright sunshine.) An HDR sensor, in contrast to a linear sensor, can detect details that bright environment washes out and it misses fewer details in dark environment [3].

Another example can be the application of HDR techniques in the pre-processing phase of images, by which the performance of different image processing algorithms, like corner and edge detectors, scene reconstruction, object recognition, and categorization algorithms can be improved. Especially in the latter cases, the colour information may have a primary role. In case of complex searching and image understanding tasks, the application of grey scale images is usually not enough effective. The primary aim is to keep and/or enhance the colour information, as well because it is useful for categorizing the detected object(s) more precisely, thus the colour information may significantly improve the reliability of the decisions.

Several HDR methods can be found in the literature addressing the basic problem. Each of them tries to compress the high dynamic range of luminance values to a displayable range keeping as much amount of information as possible, however they usually process grey scale images. Just to mention some characteristic approaches, Rubinstein and Brooks' method in [4] is based on fusion in the Laplacian pyramid domain. The core of the algorithm is a simple maximization process in the Laplacian domain. Wide dynamic range CMOS image sensors play also very important role in HDR imaging (see e.g. Kawahito's work in [5]). The sensor introduced in [5] uses multiple time signals and such a way extends the image sensor's dynamic range. Reinhards in [6] applies a so-called zone system.

The authors of this paper also have introduced new fuzzy based tone reproduction algorithms in [7], [8], and [9].

In this paper, a new fuzzy tone reproduction algorithm is introduced which may help in developing hardly or non-viewable features and content of colour images. The method applies former results of the authors including the synthesization of multiple exposure time images from which the dense part, i.e. regions having the maximum level of detail are included in the output image [9]. The proposed new technique addresses colour images and the Red, Green, and Blue colour components of the pixels are handled separately. The modification of the components is supported by a fuzzy decision making system. In the output, the corresponding (modified) colour components are blended. As a result, a high quality colour HDR image is obtained, which contains both all of the detail and the colour information. Using HDR colour images, the performance of information enhancement, object and pattern recognition, scene reconstruction, etc. algorithms can significantly be improved.

The paper is organized as follows: In Section 2 the basic concept of the proposed new gradient based multiple exposure time fuzzy synthesization algorithm is presented. Section 3 details how we can measure the level of detail in an image region. Section 4 is devoted to the fuzzy image synthesization, while in Section 5 an example is shown for illustrating the effectivity of algorithm.

2 The Gradient Based Multiple Exposure Time Fuzzy Synthesization Algorithm

When the dynamic range of the scene is high, taking just one photo by using a normal camera is not enough for producing a high quality image containing all the information. In such cases several pictures are needed to capture all the scene details. These images should be merged together in such a way, that all the involved information should be preserved.

If the scene contains regions with high luminance values, then in that highly illuminated region it is necessary to take a picture with low exposure time for the visualization of the details. On the other hand, if the scene contains very dark areas, then the exposure time should be possibly much higher. Approaching from the opposite site, if we have images with different exposures we have to decide somehow which exposure contains the maximum level of information in case of a certain region.

The basic concept of the proposed gradient based multiple exposure time fuzzy synthesization algorithm is as follows: We have N colour images of a static scene obtained at different exposures by using a stationary camera. The introduced method combines the images into a single one in which each of the input image information is included without producing noise.

The images are segmented into small local regions, each having the same size. The shapes of these regions are rectangular. The introduced method deals with the Red, Green, and Blue (RGB) colour information of the regions separately. The first step of the algorithm is to measure the level of detail for each colour component. Afterwards, the most informative image region is selected for each local image region. This is defined as the maximum of the sum of the level of detail of the three (RGB) region components. As result, the corresponding, most informative image segment is included into the output scene.

In this part of the processing, the main task is to identify the image that contains the highest information density within a local region. There are existing methods, which use statistical elements for selecting the most informative image region while others apply the histogram of the luminance values of the processed region. According to our experiments, the level of the details in a region can be measured based on the sum of gradient magnitudes of luminance in that region. This can be solved easily by handling and measuring the RGB components of the region separately and at the end by summing up the component results. The complexity of this approach is lower than that of the other ones, thus the processing time can also be reduced. As detailed is the information as higher the sum of the gradient values is in that region.

After finding the segments with the highest sum of RGB gradient values for each local region, we can merge these segments and as the output of this task we get an image, which contains the maximum amount of information in each region however with a burden of usually having big intensity changes (sharp lines) at the segment transitions. Thus, we have to apply some kind of smoothing to be able to eliminate the sharp transitions, which arise at the borders of the regions.

During the smoothing, the Red, Green, and Blue colour components of the pixels are modified separately according to a fuzzy algorithm which attaches fuzzy sets to the image regions. The 2D fuzzy sets represent the ‘centralness’ of the pixels in the regions. The RGB values of the pixels of a certain region are modified according to the membership values of the corresponding fuzzy set attached to this image region. This is followed by the blending of the corresponding colour components. As result, a high quality colour HDR image is obtained which contains the detail and colour information, as well and does not have any discontinuities along the image regions.

In the next sections we will detail the two main steps of the new method, i.e. how can we measure the level of the detail in an image region and how is the HDR fuzzy image synthesization performed.

3 Measuring the Level of the Colour Detail in an Image Region

For extracting all of the details involved in a set of images of the same scene made with different exposures, it is required to introduce a factor for characterizing the level of the detail in an image region. We propose the sum of the gradients of the R, G, and B intensity functions corresponding to the processed image and a linear mapping function, which is applied for setting up the sensitivity of the measurement of the detail level. In the followings the description of the estimation of the mentioned factor is introduced.

Let $I^R(x,y)$, $I^G(x,y)$, and $I^B(x,y)$ be the R, G, and B intensity components of the pixel at location $[x, y]$ in the image to be processed. Let us consider the group of neighboring pixels which belong to a 3x3 window centered on $[x, y]$. For calculating the gradients of the intensity functions in horizontal $\Delta I^{\cdot}_x$ and vertical $\Delta I^{\cdot}_y$ directions at position $[x, y]$, the intensity differences of the RGB components between the neighboring pixels are considered. For simplicity, we show the expressions for only one (let's say the R) component (the same has to be evaluated in case of the other two, G and B components):

$$\Delta I_x^R = \left| I^R(x+1, y) - I^R(x,y) \right|$$
$$\Delta I_y^R = \left| I^R(x, y-1) - I^R(x,y) \right|. \tag{1}$$

For the further processing the maximum of the estimated gradient values should be chosen, which solves as the input of the normalized linear mapping function P defined as $P(v) = v / I_{\max}$, where I_{max} stands for the maximum intensity value. (For 8 bit RGB scales it equals 255.)

Let **R** be a rectangular image region of width *rw* and height *rh*, with upper left corner at position $[x_r, y_r]$. The R component level of the detail inside of region **R** is defined as

$$M_D^R(\mathbf{R}) = \sum_{i=0}^{rw} \sum_{j=0}^{rh} P\left(\max\left(\Delta I_x^R(x_r + i, y_r + j), \Delta I_y^R(x_r + i, y_r + j)\right)\right) \tag{2}$$

The sum of the three, R, G, and B component levels of detail gives the level of detail in region **R**

$$M_D(\mathbf{R}) = M_D^R(\mathbf{R}) + M_D^G(\mathbf{R}) + M_D^B(\mathbf{R}) \tag{3}$$

As higher is the calculated M_D value as detailed the analyzed region is. In the followings we will use this parameter for characterizing the measure of the image detail.

4 HDR Fuzzy Image Synthetization

Let I^R_k, I^G_k, I^B_k denote the RGB intensity functions of the input image with index k, where $k = 1, \dots, N$ and N stands for the number of images to be processed, each of them taken with different exposures. Each image contains regions, which are more detailed than the corresponding regions in the other N-1 images. Our goal is to produce an image, which is the combination of the N input images and contains all details involved in all of the images without producing noise. Using such detailed image, the most of the feature detection, image understanding, object and pattern recognition, and scene reconstruction methods can be improved and can effectively be used even if the lighting conditions are not ideal.

The first step of the processing is to divide the pictures into n rows and m columns, which yields nxm rectangular image regions. The regions in the images are of the same size with height rh and width rw. Let $\mathbf{R}_{ijk}$ denote the region in the ith row and jth column of the image with index k. Let rx_{ij}, ry_{ij} denote the horizontal and vertical coordinates of the center of the region in the ith row and jth column. $I^R_k(x,y)$, $I^G_k(x,y)$, $I^B_k(x,y)$ stand for the RGB intensity values of the pixel at position (x,y) in the image with index k.

For each image, the level of the detail has to be estimated inside every region $\mathbf{R}_{ijk}$ (see Section 3). This information helps us to select the most detailed regions among the corresponding image parts (indexed by the same i and j values).

Let **D** denote the matrix of regions with the highest level of detail. Let d_{ij} be the element in the ith row and jth column of **D**, which stands for the index of the image, which has the most detailed region in the ith row and jth column, i.e.

$$M_D\left(R_{ijl}\right) > M_D\left(R_{ijk}\right) \mid k = 1\dots, l-1, l+1, \dots, N; l = d_{ij}\,. \tag{4}$$

The next step is to merge the most detailed ($\mathbf{R}_{ijl}$) R, G, and B regions together, where l=d_{ij} i=1..n, and j=1..m. Merging the selected regions together results in three images (a red, a green, and a blue) which contain every detail involved in the N input images. Unfortunately, the resulted images usually contain sharp transitions along the borders of the regions. These sharp transitions should be eliminated. For this purpose a smooth fuzzy blending can be applied advantageously where the applied fuzzy sets represent the 'centralness' of the pixels in the corresponding image regions. We have chosen cut, Gaussian shape like fuzzy sets in the universe of image space. The membership values of the fuzzy sets are exceeding zero only within a predefined ε environment of the center of the corresponding regions, outside this environment they are cut to zero.

The fuzzy sets take the form of

$$F_{ij}(x,y)=\frac{e^{-\left(\frac{(x-rx_{ij})^2}{2\sigma_x^2}+\frac{(y-ry_{ij})^2}{2\sigma_y^2}\right)}}{\sum_{p=1}^{m}\sum_{q=1}^{n}e^{-\left(\frac{(x-rx_{pq})^2}{2\sigma_x^2}+\frac{(y-ry_{pq})^2}{2\sigma_y^2}\right)}}U(x,y), \tag{5}$$

$$U(x,y)=\begin{cases}1 & (x,y)\in\mathbf{R}_{rs} \quad \Big| \quad |rx_{rs}-rx_{ij}|\wedge|ry_{rs}-ry_{ij}|\le\varepsilon\\ 0 & \text{else}\end{cases}. \tag{6}$$

Here i and j stands for the row and column indices of the region over which fuzzy set is centered (see Figure 1), m denotes the total number of columns and n the total number of rows in the input images. σ_x and σ_y stand for the standard deviation of the 2D Gaussian function of the fuzzy set. The values rx_{pq} and ry_{pq} represent the coordinates of the center of the region in the pth column and qth row, $1\le r\le n$, $1\le s\le m$. Function U is used for cutting the Gaussian function, i.e. for eliminating the influence of those segments, who’s center points fall outside a predefined ε environment of the actually processed pixel.

Using the fuzzy sets of (6) as blending functions, the output image can be evaluated according to

$$\begin{aligned}
I_{out}(x,y)&=\langle I_{out}^{R}(x,y),I_{out}^{G}(x,y),I_{out}^{B}(x,y)\rangle,\\
I_{out}^{R}(x,y)&=\sum_{i=1}^{n}\sum_{j=1}^{m}F_{ij}(x,y)I_{d_{ij}}^{R}(x,y),\\
I_{out}^{G}(x,y)&=\sum_{i=1}^{n}\sum_{j=1}^{m}F_{ij}(x,y)I_{d_{ij}}^{G}(x,y),\\
I_{out}^{B}(x,y)&=\sum_{i=1}^{n}\sum_{j=1}^{m}F_{ij}(x,y)I_{d_{ij}}^{B}(x,y).
\end{aligned} \tag{7}$$

The output colour and intensity can be influenced by changing the size of the regions and the characteristics of the fuzzy sets. E.g., when applying Gaussian shape fuzzy sets, as smaller is the standard deviation of the Gaussian function as higher influence the regions with low detail level onto the result have.

In Figure 1 in case of exposure 1 the region in the 2nd row and 2nd column has the maximum level of detail compared to the other images, in case of exposure 2 the region in the 2nd row and 1st column while in case of exposure k the region in the 3rd row and 3rd column is the most detailed. The fuzzy sets are centered at (rx_{ij}, ry_{ij}) of the maximum level regions.

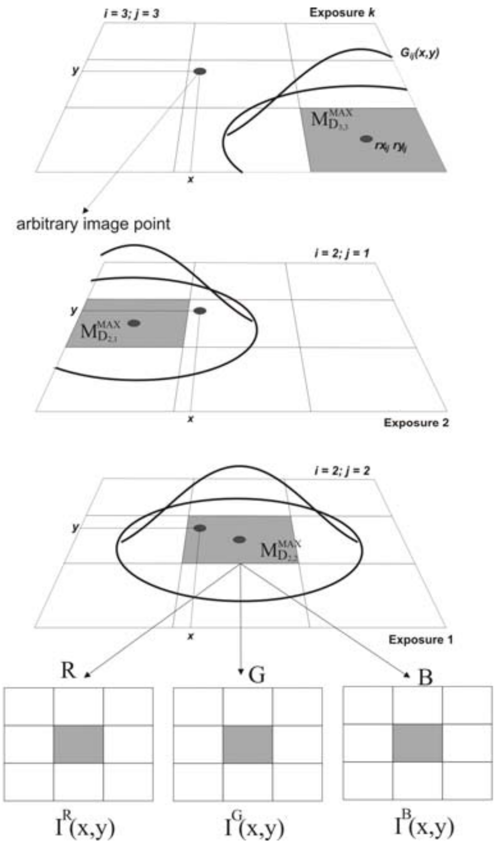

Figure 1
Illustration of the Gaussian shape fuzzy sets over the maximum level of detail regions used in the blending of the three (RGB) output component images

5 Illustrative Example

The effectivity of the proposed algorithm is illustrated by an example. The photos of the example are taken by Lou Haskell [10]. As input, three different exposure time colour images are used (Figure 2). The width and height of the regions are chosen to 10 x 10 pixels. Deviations σ_x and σ_y equal to 60. For increasing the speed of the processing, during the merging we formulated groups of the adjacent regions originally belonging to the same exposure time image. A single Gaussian shape fuzzy set is applied over each of the groups for the blending, with center point falling into the center of gravity of the group. The cutting function U is defined in such a way that the membership functions of the fuzzy sets exceed zero over the whole image domain.

Figure 2
Input images of a scene taken by different exposures, photo: Lou Haskell [10]

Figure 3
Picture processed by the gradient based multiple exposure time fuzzy synthesization algorithm

Figure 4
Picture processed by easyHDR [10]

Figure 3 shows the result got by the proposed new method. For comparison, the picture processed with easyHDR [10] can be seen in Figure 4.

Conclusions

In this paper a new gradient based fuzzy colour image synthesization approach is introduced for extracting image details. The method uses multiple exposure colour images of the same scene as input data. During the processing, the images are divided into regions, the RGB region components are handled separately, and always the most detailed region is chosen from the different exposure versions for the output image. When merging the highest information dense regions, the RGB colour components of the pixels are modified separately according to the fuzzy sets attached to the image region. As result the technique makes possible to produce a good quality colour HDR image from a set of low quality photos taken by a range of exposures.

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