Paper:

Fuzzy Based Brightness Compensation for High Dynamic Range Images

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High dynamic range of illumination may cause serious distortions and other problems in viewing and further processing of digital images. In this paper a new fuzzy based tone reproduction pre-processing algorithm is introduced which may help in developing hardly or nonviewable features and content of the images making easier the further processing of it.

Keywords: image reproduction, high dynamic range images, tone reproduction, image processing, fuzzy techniques

1. Introduction

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 thing as accurate scene reproduction. In image processing most of the recently used methods apply a so called preprocessing procedure to obtain images which guarantees – from the point of view of the concrete method – better conditions for the processing. Eliminating noise from the images for example, yields much better results as else. There are many kinds of image properties to which the certain methods are more or less sensitive [1, 2]. Certain image regions have different features. The parameters of the processing methods in many cases are functions of the image features. The light intensity at a point in the image is the product of the reflectance at the corresponding object point and the intensity of illumination at that point.

The amount of light projected to the eyes (luminance) is determined by factors such as: the illumination that strikes visible surfaces, the proportion of light reflected from the surface and the amount of light absorbed, reflected or deflected by the prevailing atmospheric conditions such as haze or other partially transparent media [3]. Only one of these factors, the proportion of light reflected (lightness), is associated with an intrinsic property of surfaces and hence is of special interest to the visual system. If a visual system only made a single measurement of luminance, acting as a photometer, then there would be no way to distinguish a white surface in dim light from a black surface in bright light. Yet humans can usually do so, and this skill is known as lightness constancy [4]. The constancies are central to perception. An organism needs to know about meaningful world properties, such as color, size, shape, etc. These properties are not explicitly available in the retinal image and must be extracted by visual processing. A gray patch appears brighter when viewed against a dark background, and darker when viewed against a bright background. This effect, known as “simultaneous contrast,” is one of many brightness effects that are commonly attributed to simple visual processes, such as the lateral inhibition that occurs in the retina, whereby cells in one region inhibit cells in adjacent regions. In this paper we will deal with the reproduction of the image 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. Using such an algorithm in preprocessing phase of the images, we improve the performance of different image processing algorithms, e.g. corner and edge detectors.

The paper is organized as follows: Section 2 deals with the so called anchoring theory, Section 3 shows how to segment an image into local frameworks. In Section 4 an alternative for the estimation of the anchor is introduced. Section 5 discusses how to merge the frameworks. In Section 6 an example is shown and Section 7 reports conclusions.

2. Anchoring Theory

Although the ambiguous relationship between the luminance of a surface and its perceived lightness is widely understood, there has been little appreciation of the fact that the relative luminance is scarcely less ambiguous than absolute luminance values [5]. Consider a pair of adjacent regions in the retinal image whose luminance values stand in a 5 to 1 ratio. That informs the visual system only about the relative lightness of the 2 surfaces, not their specific or absolute lightness. It provides information only about the distance between the 2 gray shades on the phenomenal gray scale, not about their specific location on that scale. An infinite family of pairs of gray shades is consistent with the 5 to 1 ratio. For example, if the 5 represents white then the 1 represents middle gray. But the 5 might represent middle gray as well, in which case the 1 will represent black. Indeed, it is even possible that the 1 represents white and the 5 represents an adjacent self-luminous region. So the solution is not even restricted to the scale of the gray surface. To derive specific shades of gray from relative luminance in the image, one needs an anchoring rule. An anchoring rule defines at least one point of contact between luminance values in the image and gray scale values along our phenomenal black to white scale. Lightness values cannot be tied to absolute luminance values because no systematic relationship exists between absolute luminance and surface reflectance, as noted earlier. Rather, lightness values must be tied to some measure of relative luminance. The relative lightness of two regions in an image may remain fully consistent with the luminance ratio between them, even though their absolute lightness levels depend on how the luminance is anchored [5].

Highest luminance rule: The value of white is assigned to the highest luminance in the display and serves as the standard for darker surfaces [6].

Average luminance rule: The average luminance rule is derived from adaptation level theory and states that the average luminance in the visual feld is perceived as middle gray. Relative luminance should thus be anchored by its average to middle gray [5].

The highest luminance tends to appear white and the largest area tends also to appear white [4]. Therefore the highest luminance rule was redefined based on this experimental evidence. As long as there is no conflict, i.e. the highest luminance covers the largest area, the highest luminance becomes a stable anchor. If the darker area becomes larger, the highest luminance starts to be perceived as self-luminous. The anchor becomes a weighted average of the luminance proportionally to the occupying area.

3. Segmentation of the Image into Frameworks

The anchoring rule, described in the previous section, cannot be applied directly or obviously to complex images. The main concept is based on decomposition of the image into frameworks or segments, to which the anchoring rule can be applied directly.

By the segmentation we have to find the so called centroids using the K-means clustering algorithm [7]. We initialize the K-means algorithm with values ranging from the minimum to maximum luminance in the image with a luminance step equal to 1 order of magnitude and we execute the iterations until the algorithm converges. We

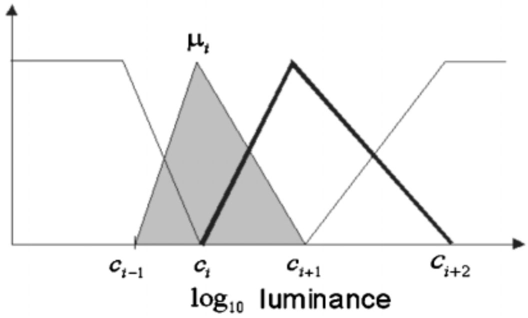

Fig. 1. Membership functions μ_i.

operate on a histogram in the log10 of luminance. After the K-means algorithm has finished, the centroids we have got are merged by the following criteria: when the difference between 2 centroids is below a certain threshold, e.g. 1 then these centroids must be merged. This is done iteratively. In each iteration step the 2 closest centroids are merged together and the new centroid value is calculated as the weighted average of the 2 merged centroids proportional to their area:

$$c_{ij} = \frac{c_i a_i + c_j a_j}{a_i + a_j} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where c_i and c_j correspond to centroids with indices i and j. a_i and a_j stand for the number of pixels in the ith and jth frameworks, i.e. they represent the number of pixels corresponding to the ith and jth centroids.

It is not ambiguous to assign a concrete border to the certain frameworks. We can get better results if we look at the frameworks as fuzzy sets, which means that to each pixel a fuzzy membership value is assigned to define the membership of the pixels belonging to the certain frameworks. Starting from this reasoning we estimate the membership functions corresponding to the certain frameworks using centroids determined in the previous step by the K-means clustering algorithm.

Let μ_i be the membership function corresponding to the ith centroid (framework) defined as follows (see **Fig.1**):

$$\mu_i(x,y) = \frac{I(x,y) - c_{i-1}}{c_i - c_{i-1}}, \quad I(x,y) < c_i \quad \ldots \quad (2)$$

$$\mu_i(x,y) = \frac{c_{i+1} - I(x,y)}{c_{i+1} - c_i}, \quad I(x,y) \geq c_i \quad \ldots \quad (3)$$

where $\mu_i(x,y)$ is the membership function corresponding to the ith framework. The c_i values are the centroids estimated by the K-means clustering algorithm and $I(x,y)$ stands for the luminance value in the log10 space of the pixel at position $[x;y]$. The membership depends also on the articulation of the certain frameworks [8], i.e., frameworks with low variance have less influence on the global lightness.

As next step we have to determine an articulation factor for each framework independently. Frameworks with wider intensity range will have a greater weighting factor in the determination of the final luminance value of