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Visibility Enhancement Technology for Cameras

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Abstract

This paper introduces an algorithm and its implementation of the image visibility enhancement technology which is suitable for a variety of applications such as vehicle-mounted cameras. The important things in visibility enhancement are to maintain information in original signal from image sensor, and to reflect the information into the processed image in a visible way for human beings. The proposed algorithm adopts tone redistribution to the input image depending on local luminance distribution, followed by extraction and correction of illumination and reflectance, and histogram equalization. The luminance contrast of dark area was expanded about 4 times and that of bright area was expanded 1 to 1.5 times compared with original image, and this enables obtaining clear picture even in hard shooting condition such as backlight and spotlight. Also, this technology was implemented as a software application and as an FPGA-based camera system and it was confirmed that the proposed algorithm is applicable for handling 30-frames-per-second movies in real-time.

1. Introduction

Camera signal processing such as noise reduction or edge enhancement have been studied to obtain clear images from image sensor outputs. As a result, cameras have become a convenient device for acquiring images easily, and have become widespread in industrial equipments as represented by vehicle-mounted cameras. The largest requirement for these cameras is to provide images in which every object is clearly recognizable with the human eye. However, for example, vehicle-mounted cameras are required to provide clear images under circumstances that the brightness of the surroundings varies spatially and temporally. For providing "visible" images even under hard shooting conditions, visibility enhancement is regarded as a key technology.

As a technology to improve visibility of images taken by a camera, image visibility enhancement methods based on the modeling the human visual characteristics have been studied extensively, and a number of algorithms ([2]-[10]) are proposed. Some of the methods are based on psychophysical model[6] and some are based on the adaptation model of the human eye[7].

It is said that human visual system eliminates the influence of the illumination and perceives object with its reflectance. Recently, various methods ([2]-[5], [8]-[10]) derived from Land's Retinex theory[1] are being studied actively. The basic idea of Retinex theory is to estimate and equalize the illumination and to enhance the reflectance for visibility improvement. However, many of these algorithms require large amount of calculation and result in less adoption in commercial equipments or industrial cameras because of its difficulty in real-time processing.

This paper presents a signal processing algorithm which provides visibility enhancement with low amount of calculation by introducing the basic idea of illumination correction of the Retinex theory, combining it with the region-based tone redistribution and histogram equalization. This paper also presents results of implementation of the proposed algorithm as a software application and as an FPGA-based system which are capable to perform video processing such as backlight correction in real-time.

2. Algorithm overview

The outline of the proposed algorithm is described in Figure 1. This algorithm consists of three processes; tone redistribution, illumination and reflectance correction, and histogram equalization. Tone redistribution suppresses the loss of information in the original signal. Illumination and reflectance are extracted from input image and corrected with Retinex-based method. Then, the contrast of the image is expanded by histogram equalization. These processes provide highly visible pictures for human eye. Each process is explained below.

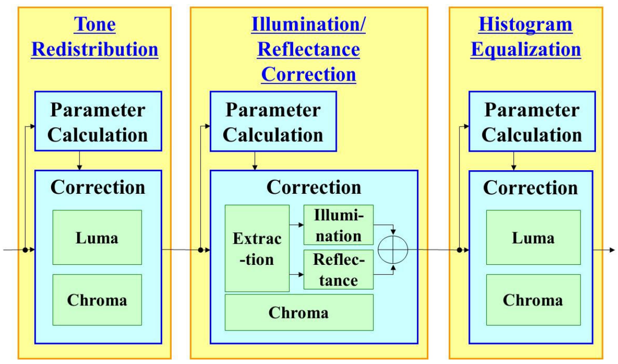

Figure 1. Block diagram of the proposed algorithm.

2.1. Tone Redistribution

Most image sensor available today has 10- or 12-bit digital signal output. Nevertheless, it is quite common that the signal is rounded to 8-bit for the purpose of image compression such as JPEG, MPEG, H.264 etc. when recording or transmitting the digital image. Rounding causes loss of information in the original image signal and decrease in dynamic range. For example, consider input signal in Figure 2. There are two regions which have low signal level (A) and high signal level (B), and each region has a subtle signal fluctuation. If the signal is simply rounded down to lower bit resolution, the fluctuation is rounded off and consequently the information in original signal is lost. In this case, it is possible to maintain the information in original signal by enhancing the signal difference for the positive direction in area A, the negative direction in area B before rounding down to lower bit resolution. This is the basic idea of tone redistribution.

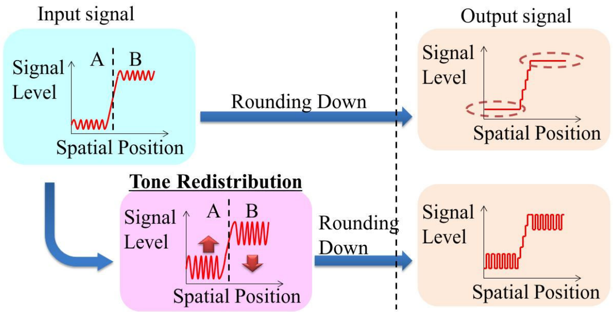

Figure 2. Basic idea of tone redistribution.

This idea was applied to image signals. The outline of the process is shown in Figure 3. First, the input image was separated into some small regions, and luminance histograms were calculated for each region. The histograms show the luminance distribution per region. Next, enhancement for input image signal was performed. The enhancement process can be described as

$$F(x,y) = A \cdot f(x,y) - B \tag{1}$$

where $F(x,y) = C \cdot f(x,y)$ if $F(x,y) < C \cdot f(x,y)$, $F(x,y) = D \cdot \{f(x,y) - 1\} + 1$ if $F(x,y) > D \cdot \{f(x,y) - 1\} + 1$, $f(x,y)$ is a luminance at position (x,y) in the input image, $F(x,y)$ is a luminance at position (x, y) in the enhanced image and $f(x,y)$ is normalized so as to take a value in range [0,1]. A, B, C and D are parameters which take positive values and adjusted so that $A > C$, $A > D$.

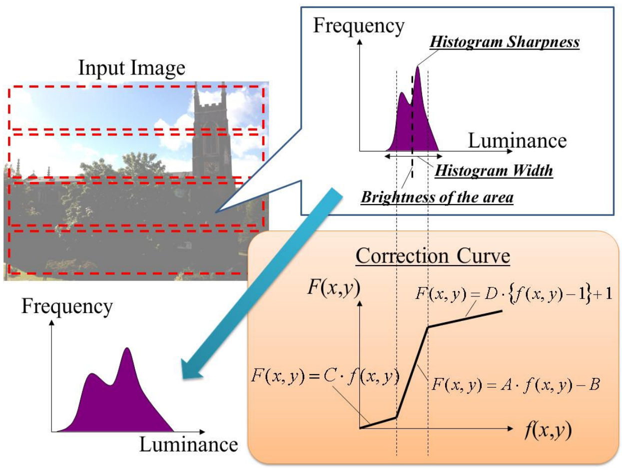

Figure 3. Tone redistribution for input image.

The parameters are adjusted for every pixel in the input image depending on the regional luminance distribution measured at first step of this process. A is a parameter relative to the width of the luminance distribution and adjusted to take large value if the luminance distributes in narrow range. B is a parameter relative to the local brightness of the area and adjusted to take large value if the area is bright. C and D are parameters relative to the sharpness of the luminance distribution and adjusted to take large value if the distribution is broad. Thus, tone distribution is executed so that it matches the areal luminance distribution of the input image.

2.2. Illumination/Reflectance Correction

It is known that the vision system of a human being perceive luminance of a certain point in a visual field depending on the contrast between the brightness of the point and the surrounding area rather than the absolute brightness of the point. This characteristic forms the basis of Retinex theory and other derived visibility enhancement methods. These methods can enhance the visibility of the objects in the underexposed and overexposed area by estimating the illumination from the input image and equalizing it. However, it is difficult to estimate illumination from the image precisely, and most of the method require wide-tap Gaussian filter to extract illumination from the image and large amount of calculation for correction. Moreover, illumination equalization sometimes produces unnatural low-contrast image or degrade visibility of the part where the objects can already be seen clearly.

The outline of the illumination and reflectance correction of our method is shown in Figure 4. Tone redistribution described above is applied to the input image of this process, and the inequality of illumination is already reduced to some extent. When combined with tone redistribution, small-tap and simple filter which requires small amount of calculation can be adopted without significant performance degrades. The proposed algorithm introduces a 15-tap average filter instead of the wide-tap Gaussian filter to extract illumination from the input image.

Additional approach to reduce amount of calculation and to avoid unexpected harmful effect caused by the correction is pre-defined illumination correction. Some typical scenes in which the objects cannot be seen clearly (backlight, very high contrast etc.) are picked up in advance and the desirable input/output characteristics of the illumination correction for each scene are also pre-defined. Then, the correlation between the luminance distribution of the input image and that of the pre-defined scene is calculated to decide the correction characteristics. By this method, the correction is applied for only specified scene and therefore degradation of visibility is suppressed.

Reflectance is amplified according to the difference of luminance before and after correction described above. The gain of the reflectance can be described as

$$G = \begin{cases} F(x,y)/f(x,y) & \text{if } F(x,y) \geq f(x,y) \\ f(x,y)/F(x,y) & \text{if } F(x,y) < f(x,y) \end{cases} \tag{2}$$

where $f(x,y)$ is a illumination at position (x,y) in the input image, $F(x,y)$ is a illumination at position (x,y) in the corrected image. The objects in the image become “visible” by illumination correction, and details of the objects become clear by reflectance correction.

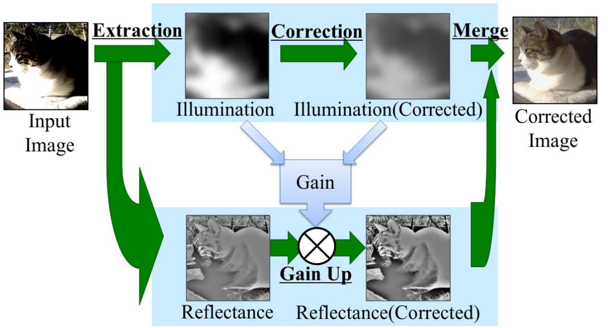

Figure 4. Illumination and reflectance correction.

2.3. Histogram Equalization

Histogram equalization is performed after illumination/reflectance correction considering that there are scenes not corrected substantially because of low correlation with the pre-defined scenes at the previous process. The correction curve is decided according to the shape of cumulative histogram as described in figure 5. The slope at the steepest point in the curve is calculated and the correction curve is redefined so as not to apply excessive enhancement to the input picture.

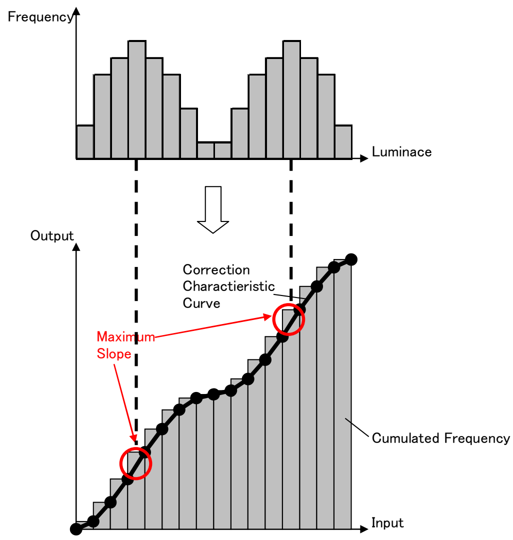

Figure 5. Correction curve determination at adaptive histogram equalization process.

3. Implementation

3.1. Full-software implementation

A PC-based evaluation environment was constructed for performance measurement and algorithm development. Our evaluation environment is a PC with a Core i7-3770K (12 cores) processor, an 8GB physical memory and a GeForce GTX680 (2GB video memory). A camera is connected to the environment and raw camera signals are captured. Raw signals are converted into luminance and chrominance, and the proposed algorithm is applied after noise reduction. The entire image processing including visibility enhancement with the proposed algorithm is implemented as a software application on this environment. Some processes such as RAW-to-YUV conversion and noise reduction are accelerated by multi-threading using OpenMP or GPU computation. Correction parameter calculation algorithm is written in plain C language, considering reuse of the same source code to FPGA-based system described below. Real-time (30 frames per second) processing is capable for VGA size images on this evaluation environment.

3.2. Implementation as an FPGA-based system

The proposed algorithm was also implemented as an FPGA-based system. Raw camera data to luminance/chrominance conversion, noise reduction, visibility enhancement were implemented similarly with the full-software environment. Additional embedded processor was attached for system management and correction parameter calculation using the same algorithm as the software environment. We confirmed that this FPGA-based system is capable to handle Full HD movies in real-time. The logic size of the visibility enhancement hardware block (processor excluded) was about 400,000 logic gates, which can be adopted for industrial equipments without special efforts.

4. Experiments

Examples of correction result with the proposed algorithm are shown below. For a high-contrast scene (Figure 6), visibility of indoor is drastically enhanced while that of outdoor is being maintained. For backlight scene (Figure 7), the area of spotlight remains unchanged and objects in underexposed area can be seen clearly after correction. Moreover, for the spotlight scene (Figure 8), the objects in the darkness get clear after correction. As an indicator of the performance, contrast enhancement ratio (CER) was calculated. CER is defined as

$$\mathrm{CER} = W_{out} / W_{in} \qquad (3)$$

where W_{in} and W_{out} are width of the luminance histogram of input and output images, respectively. It was measured that the average CER of the dark area is about 4, and that of the bright area is 1 to 1.5 depend on the scene.

5. Conclusion and future works

A visibility enhancement algorithm suitable for embedded system such as vehicle-mounted camera etc. was proposed. This algorithm is capable to provide highly visible picture even under poor shooting condition like backlight and spotlight scene. Also, this algorithm was implemented as a software application and hardware-based embedded system. It was confirmed that real-time processing for movies are possible on both environments.

The future work includes enhancement of the proposed algorithm and the development of new enhancement algorithm suitable for object recognition.


Figure 6. Example of visibility enhancement at high-contrast scene (left: before correction, right: after correction).

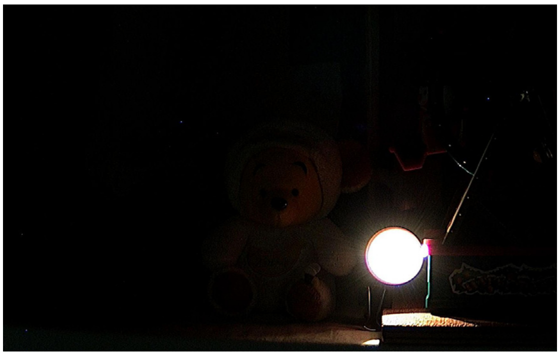


Figure 7. Example of visibility enhancement at backlight scene (left: before correction, right: after correction).


Figure 8. Example of visibility enhancement at spotlight scene (left: before correction, right: after correction).

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