Denighting: Enhancement of Nighttime Images for a Surveillance Camera

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(a) Nighttime image. (b) Denighted image.

Figure 1. Denighting a nighttime image.

Abstract

Nighttime images of a scene from a surveillance camera have lower contrast and higher noise than their corresponding daytime images of the same scene due to low illumination. Denighting is an image enhancement method for improving nighttime images, so that they are closer to those that would have been taken during daytime. The method exploits the fact that background images of the same scene have been captured all day long with a much higher quality. We present several results of the enhancement of low quality nighttime images using denighting.

1 Introduction

Nighttime images of a scene from a static surveillance cameras are difficult to understand because they have a lower contrast and higher noise than daytime images of the same scene due to low and uneven illumination. Improving the quality of nighttime images is an important issue.

In this paper, we propose a *denighting* method that enhances nighttime images so that they are closer in quality to images taken during the daytime. Figure 1(a) shows a nighttime image of a car entering a gate. Figure 1(b) shows the same image denighted. In the nighttime image as shown in Figure 1(a), it is difficult to understand where this images was taken, what the objects that appear in the image are, or what the situation in the lower left and upper right regions of the image. On the other hand, in the denighted image it can be clearly be understood that there are trees in the lower left region of the image, and we can see their shape. Also, there is a road in the upper right region of the image, and we can see a street gutter on the left side.

Our denighting method is based on an observation. It exploits the simple fact that the static camera captures the same scene all day long, obtaining a large quantity of data about the scene. In particular, to enhance the nighttime image, we decompose the image into an illuminance layer L, and a reflectance layer R that is assumed to be the textures. We enhance the nighttime image by improving the illuminance of nighttime so that it is closer to the illuminance of daytime by using day and nighttime background illuminances that have already been computed.

2 Related work

Under dark illumination scene, such as nighttime scenes, high contrast images are taken using infrared cameras. In many cases, infrared cameras can capture an image that can be used to identify a person, but the image do not include color information. Some methods have been proposed that combine the color images taken by CCD cameras, with the grayscale images taken by infrared cameras [1, 6]. These methods require spe-

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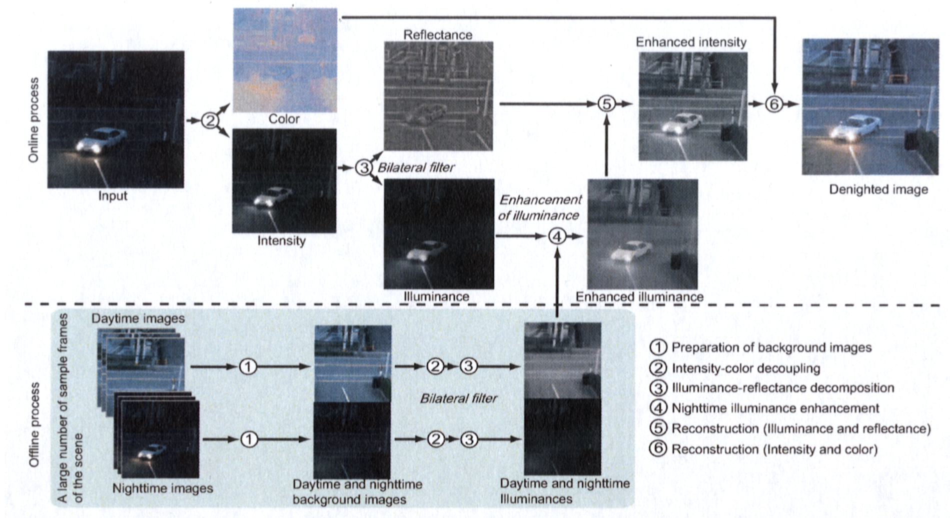


Figure 2. Flow of denighting.

cial devices or cameras to obtain the color and infrared images at the same time.

Raskar et al. [5] proposed the enhancement method that combine images taken at different times by using image fusion techniques. They can decrease artifacts such as aliasing and ghosting by computing in a gradient domain. Cai et al.[2] have proposed other fusion method based on the image segmentation and the object extraction technique. If the segmentation is correct, these enhancement methods using image segmentation and object extraction are powerful. But if errors occur in their process, unnatural mixture images may be generated in the result image.

Our proposal method can produce natural-appearing enhanced nighttime images that do not appear to be fake, by decomposing the image into illuminance and reflectance and only modifying the illuminance of the images.

3 Denighting

Figure 2 shows the flow of our denighting method. The lower area shows the preprocessing while offline and the upper area shows the online processes that are performed for each input nighttime image.

The day and nighttime background images are created using data obtained in advance from the static camera (in Figure 2①), and then their illuminances are computed (in Figure 2②· ③). The processes listed above are executed offline.

The following processes are performed online in the input image. First, we decouple the input image into an intensity and a color (in Figure 2②). Next, the intensity image is decomposed into two layers; an illuminance L, and a reflectance R (in Figure 2③). We then enhance the illuminance of the input nighttime image by using the day and nighttime background illuminances (in Figure 2④). Finally, a denighted image is reconstructed from the enhanced illuminance and the reflectance and color of the input nighttime image (in Figure 2⑤, ⑥).

(a) (b) (c)

Figure 3. Denighting a nighttime illuminance. (a) Nighttime illuminance L_N. (b) Daytime background illuminance L_{DB}. (c) Denighted illuminance $L_{Denight}$.

3.1 Illuminance-reflectance decomposition

We first decouple an input color image into an intensity I, and a color layer C (in Figure 2②). The color layer $C \triangleq (r, g, b)$ is given by dividing the input pixel values by the intensity I (such as $r \triangleq Red/I$).

We use the Retinex theory [4] to decompose an image into the illuminance layer L and the reflectance layer R. Using this theory, an image I is represented by the product of the illuminance L and the reflectance R:

$$I \triangleq R \times L \tag{1}$$

The illuminance L is assumed to be the low frequency component of an image I, and is estimated by using a low-pass filter such as a Gaussian filter. The reflectance R is estimated as the ratio of the image I and the illuminance L.

We use a bilateral filter [7] as a low-pass filter to estimate the illuminance, which is similar to the approaches of Durand et al [3].

The bilateral filter is an edge-preserving smoothing filter that was developed by Tomasi and Manduchi. The output of the bilateral filter of an input image I at pixel$\boldsymbol{s}$, with the Gaussian function $g(x;\sigma) = exp(-x^2/\sigma^2)$, is defined by:

$$BF(I(\boldsymbol{s})) = \frac{1}{k(\boldsymbol{s})}\sum_{\boldsymbol{p}} g(\|\boldsymbol{p}-\boldsymbol{s}\|;\sigma_s)g(|I(\boldsymbol{p})-I(\boldsymbol{s})|;\sigma_r)I(\boldsymbol{p}) \tag{2}$$

$$k(\boldsymbol{s}) = \sum_{\boldsymbol{p}} g(\|\boldsymbol{p}-\boldsymbol{s}\|;\sigma_s)g(|I(\boldsymbol{p})-I(\boldsymbol{s})|;\sigma_r) \tag{3}$$

where σ_s and σ_r are parameters of the Gaussian function in the spatial domain and the range of intensity difference, respectively.

The output of the bilateral filter from the intensity image I provides the illuminance layer L:

$$L \triangleq BF(I) \tag{4}$$

The reflectance layer R is calculated from the ratio of the intensity image and the illuminance layer from equation (4).

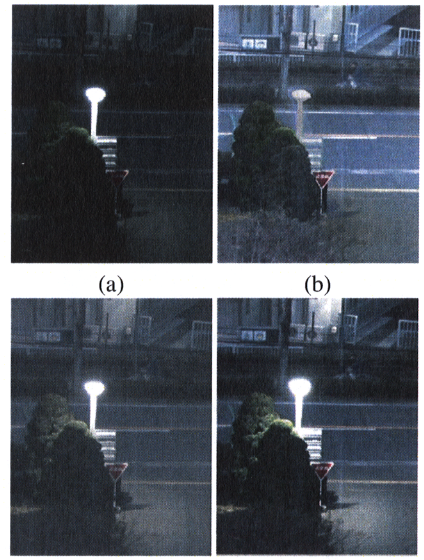
Using the above processes, the illuminance and the reflectance of the nighttime image are obtained while online. In the offline process, the day and nighttime background illuminances are computed (in Figure 2).

3.2 Nighttime illuminance enhancement

The illuminance of a nighttime image (Figure 3(a)) has a darker and lower contrast than its daytime illuminance (Figure 3(b)). We enhance the nighttime illuminance so that it is closer to its daytime illuminance.

The denighting method defines the ratio of the enhanced illuminance $L_{Denight}$ and its input nighttime image illuminance L_N according to the ratio of day and nighttime background illuminances L_{DB}, L_{NB}.

$$\frac{L_{Denight}}{L_N} = \frac{L_{DB}}{L_{NB}} \tag{5}$$



(a) (b)

(c) (d)

Figure 4. Comparison of nighttime image enhancement methods. (a) Input nighttime image. (b) Denighted image. (c) Gamma correction (γ = 2.0)). (d) Histogram stretched image.

Figure 3(c) shows the enhanced illuminance from the above processes. When comparing the results with the input nighttime illuminance L_N (Figure 3(a)), we see that the enhanced illuminance $L_{Denight}$ is closer to the daytime background illuminance L_{DB} (Figure 3(b))

3.3 Reconstruction

Finally, we reconstruct the image. The intensity image $I_{Denight}$ is obtained by multiplying the enhanced illuminance $L_{Denight}$ calculated in the previous section by the input nighttime reflectance R (Figure 2⑤). The denighted color image is created by combining this intensity image and the color from the input nighttime image C_N (Figure 2⑥). We use the color and the reflectance of the nighttime image to preserve the nighttime details and color.

Figure 1(b) shows the denighted image, which is an enhanced nighttime image (Figure 1(a)).

4 Results and discussion

We demonstrate our denigiting method on several images. Figures 1(a)-(b), 4(a)-(b) and 5(a)-(b) show a

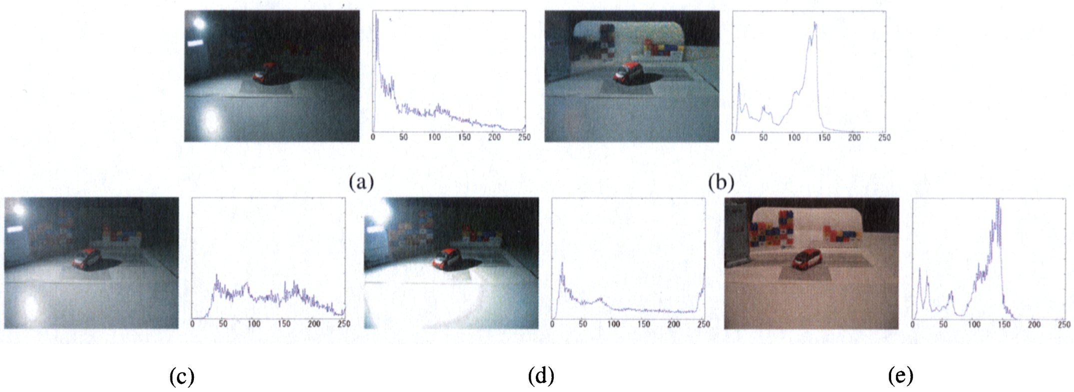


Figure 5. Comparison of nighttime image enhancement methods and their histograms. (a) Input nighttime image. (b) Denighted image. (c) Gamma correction (γ = 2.0)). (d) Histogram stretched image. (e) Daytime image.

pair of input nighttime and denighted images. The result images are enhanced more than the input nighttime images. For example, the nighttime image as shown in Figure 4(a) is difficult to understand that there is a person on the bike. On the other hand, the denighted image is easier to understand (Figure 4(b)).

Figures 4(c)-(d) and 5(c)-(d) show a comparison of our results with the results from other general methods of image enhancement, such as gamma correction and histogram stretching.

When we inspect image histograms, we can understand the meaning of denighting. Figure 5 shows comparison of the histograms of an input nighttime image, a daytime image taken at same situation and each enhancement method. The histogram of the denighted image (Figure 5(b)) is more similar to the daytime histogram (Figure 5(e)) than with the histograms of gamma correction (Figure 5(c)) and histogram stretching (Figure 5(d)). For this reason, the denighted image is enhanced so that it is closer to those that would have been taken at daytime.

The computation time of our denighting method is about 1.5 seconds on a desktop PC (Intel Xenon at 3.20GHz) for a 640x480 image. Improving the processing speed is one of the important issues for our future work, and it is necessary for our method to be able to be applied to surveillance in real time.

5 Conclusions

We have presented a denighting method that improves nighttime images taken by surveillance cameras, such that they look closer to those that would have been taken during the daytime. It exploits the fact that the same camera captures a large number of images of the same scene all day long to create day and nighttime background images. In addition, our denighting method requires just a normal static camera. Therefore, this method can be applied for various purposes. For example, if a surveillance camera system has our denighting function, observer's stress will be considerably reduced.

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