HOMOMORPHIC PROCESSING TECHNIQUES FOR NEAR-INFRARED IMAGES

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ABSTRACT

The images of objects in total darkness can be captured using a relatively low cost camcorder with the NightShot® function. However, the resulting images exhibit non-uniformity due to irregular illumination. In this paper, we investigate the characteristics of and propose an image formation model for near-infrared images. A homomorphic processing technique built upon the image model is then developed to reduce the artifact of the captured images. We discuss how the parameters of the homomorphic filter should be selected and demonstrate the effectiveness of the proposed image processing technique with experimental results.

1. INTRODUCTION

Capturing images under dim light or in total darkness used to be a rather expensive procedure, requiring equipments such as thermal infrared cameras and related accessories. The high cost of data acquisition has limited the applications of night vision to critical missions such as medical or defense purposes [1]. With the introduction of CCD sensors capable of recording images in the near-infrared band[1], however, the data acquisition component becomes quite affordable and has thus opened up new opportunities for practical applications of night vision. For example, a surveillance system equipped with near-infrared camera can detect the presence of foreign objects regardless of the lighting condition. An autonomous robot can navigate through various types of environments with the aid of cameras with the NightShot® function. A face recognition system would continue to function no matter whether the surrounding light is on or off.

While the cost of image acquisition has brought down by using near-infrared instead of mid- or far-infrared (thermal radiation) images, the artifact created by the image formation process of such low cost systems needs to be identified and eliminated. Basically, a "0 Lux" operateable camcorder works by emitting invisible near-infrared (NIR) lights toward the direction of target objects and collecting the reflected light to form the image.

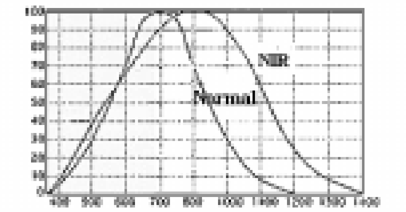


Figure 1: Sensitivity levels of CCD sensor with NightShot®.

Therefore, the strength of the reflected energy, or equivalently, the intensity of the image, becomes a function of the distance between the camera and the target object. It is also observed that response decays as we move away from the center of the image, as shown below.

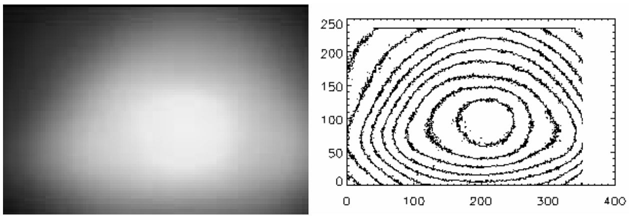


Figure 2: Image of a wall in total darkness and its contour plot.

Fig. 2 depicts the image of a white wall obtained using Sony's TRV16 camcorder with NightShot® turned on. The distance between the camera and the wall is approximately 3 meters. The undesirable over-exposure phenomenon near the center of the image can be clearly observed. In order for the subsequent image analysis procedure to work effectively, it is necessary to account for the non-uniformity introduced at the image formation stage and make corresponding adjustments. Fig. 3 shows an image of a human subject taken under similar conditions. The intensity of the pixels near the center of the image is much larger than that of the surround pixels. Consequently, the captured image is not only visually unpleasant, but can also hinder the feature extraction process [2]. These significant issues must be properly addressed to ensure successful applications of near-infrared imaging devices.

The rest of this paper is organized as follows: Section 2 discusses the characteristics of near-infrared images and motivates the Gaussian illumination model; Section 3 explains the proposed homomorphic filtering technique

[1] Between 0.8 nm and 1.4 nm, refer to Fig.1 for details.

[3], giving details of the models and algorithm used; Section 4 shows experimental results and comments on how the filter parameters should be selected; and Section 5 ends with a brief conclusion and an outlook on how the proposed method can be applied to face recognition.

Figure 3: Image of a human subject recorded in total darkness.

2. CHARACTERISTICS OF NIR IMAGES

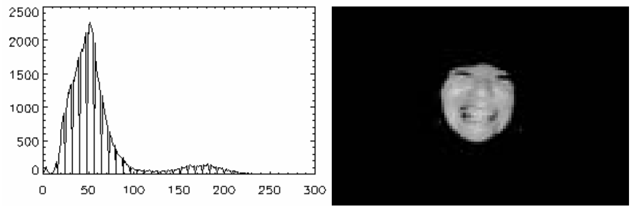
The term "night vision" refers to the ability to see things in reduced illumination (moonlight) or total darkness. Infrared thermal imaging devices are capable of measuring heat radiation from the object surface, thereby generating images of any object whose temperature is above 0K. The presence of external illumination or light source is not of concern. Even though thermal cameras have found numerous applications, wide adoption of these devices is obstructed by their high costs. Another option that enables us to possess night vision capability is through the use of near-infrared CCD cameras. In this section, we describe the image formation process of such devices, discuss the characteristics of the acquired NIR image, and present an illumination model based on the basic principles of the image formation process.

2.1. NIR Image Formation

Many camcorders (analog or digital) currently in the market claim the support of '0 Lux' recording function. For example, most Sony© camcorders have a NightShot® mode, which is used to record scenes in dim light or total darkness. Switching to the NightShot® mode physically displaces the camcorder's internal glass filter called "IR Cut Filter". As a result, much more near-infrared light can reach the CCD. Since the NightShot® camcorders have a relatively high sensitivity level in the NIR band, the resulting image can exhibit amazing details, even in a low or no light condition. On the other hand, signals within the visible spectrum have been intentionally blocked off to emphasize the response in the NIR range. Therefore, the acquired NightShot® images lack color information. They usually appear greenish or black-and-white. It is possible to attach specialized filters to further enhance the strength of NIR signals, extending the potential applications of NIR imaging to areas such as camouflage detection, document inspection, pollution monitoring… etc.

2.2. NIR Image Characteristics

As discussed previously, NIR images often display a bright, sometimes seemingly over-exposed, region around the center. The brightness decreases gradually as we move farther and farther away from the center. It is desirable to reduce, or totally eliminate such artifact using image processing techniques. At first glance, it is tempting to employ histogram processing method to adjust the contrast/range of the image to make it appear "normal". However, if we examine the histogram of a typical NIR image, we will discover that the curve resembles a bimodal distribution. The portion that falls in the high-intensity interval of the histogram is directly associated with the "super-bright" area in the image, as depicted in Figs. 4(a) and 4(b). Simple linear transform or histogram processing are not adequate to resolve the problem we have encountered. Evidently, a more sophisticated approach needs to be developed to correct the non-uniformity of NIR images.



(a) (b)

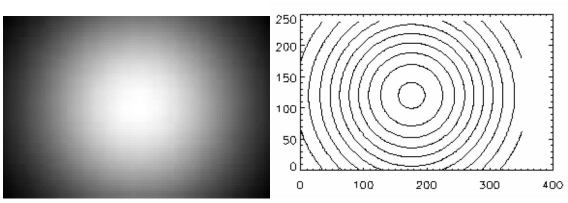
Figure 4(a): Histogram of Figure 3. (b): Pixels corresponding to the high intensity interval (150-255) of the histogram.

2.3. Gaussian Illumination Model

To exploit a theoretically sound approach for correcting NIR images, we will regard an NIR image $f(x,y)$ as the product of a reflectance component $r(x,y)$ and an illumination component $i(x,y)$. When the background is uniform, i.e., $r(x,y)$ is constant, the acquired image is proportional to the illumination component. The image intensity is largest near the center, and decays outwards gradually. The rate of decay appears to be circularly symmetric, depending only on the distance from the center. Therefore, it becomes reasonable to model the illumination component, $i(x,y)$, as a Gaussian function. Specifically,

$$i(x,y)=\alpha\exp[-(\frac{(x-M/2)^2}{2\sigma_x^2}+\frac{(y-N/2)^2}{2\sigma_y^2})] \qquad (1)$$

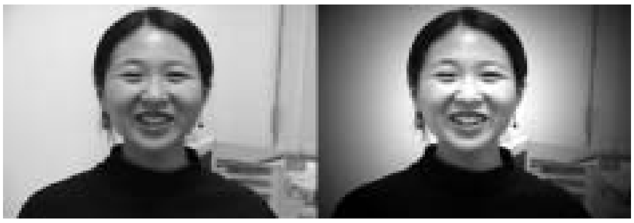
where α is a normalizing factor, MxN is the image size, and σ_x and σ_y are parameters which control the rate of decay in x and y directions. Fig. 5(a) depicts a simulated Gaussian illumination model with $\sigma_x = \sigma_y = 105$, and Fig. 5(b) depicts the contour plot.



(a) (b)

Figure 5 (a): Gaussian illumination model and (b) contour plot.

If we take an image acquired under "normal" condition and multiply it with the Gaussian illumination source, we can simulate the effect of NIR images, as shown in Fig. 6.



(a) (b)

Figure 6 (a): Original image (b) with Gaussian illumination. .

3. HOMOMORPHIC FILTERING TECHNIQUES

This section starts by comparing the reflectance and illumination components of a simulated NIR image. We then proceed to justify the utilization of homomorphic filtering techniques and elucidate the construction of a homomorphic filtering function to suit our purposes [4].

3.1. Separating the Illumination Component

The Fourier transform is commonly used to study the frequency domain characteristics of an image. When a signal is expressed as a product of two functions, however, the Fourier transform can operate directly one each of the term, i.e.,

$$\Im\{f(x,y)\} \neq \Im\{i(x,y)\} \cdot \Im\{r(x,y)\} \quad (2)$$

But if we define

$$z(x,y) = \ln f(x,y) = \ln i(x,y) + \ln r(x,y) = i'(x,y) + r'(x,y) \quad (3)$$

Then

$$\Im\{z(x,y)\} = \Im\{i'(x,y)\} + \Im\{r'(x,y)\} = F_{i'}(u,v) + F_{r'}(u,v) \quad (4)$$

Suppose that *a priori* information about the illumination source is provided, then the properties of $F_{i'}(u,v)$ can be estimated, and the adverse effects caused by $i(x,y)$ can be eliminated by means of an properly designed filter function.

To investigate the frequency domain features of the illumination component, let's consider the Gaussian illumination model discussed in the previous section with minor modification to dispose of the dependency on image size:

$$i(x,y) = \alpha \cdot \exp[-(\frac{(x-0.5)^2}{2\sigma_x^2} + \frac{(y-0.5)^2}{2\sigma_y^2})] \quad (5)$$

Taking the logarithm of $i(x,y)$, we obtain:

$$i'(x,y) = \ln i(x,y) = -[\frac{(x-0.5)^2}{2\sigma_x^2} + \frac{(y-0.5)^2}{2\sigma_y^2}] + \ln\alpha \quad (6)$$

The Fourier transform $F_{i'}(u,v)$ can be calculated once the parameters σ_x , σ_y and α have been specified. Using the example shown in Section 2, we can compute the Fourier transform of the log-illumination and log-reflectance components individually. Denote t_1 as the magnitude of the Fourier transform of the log-reflectance function, i.e.,

$$t_1 = \| F_{r'}(u,v) \| \quad (7)$$

Similarly, define t_2 as

$$t_2 = \| F_{i'}(u,v) \| \quad (8)$$

We now define a quantity r to measure the relative magnitude of these two terms:

$$r(u,v) = \ln(\frac{|t_1 - t_2|}{t_1}) \quad (9)$$

Fig. 7 displays the computed $r(u,v)$ of the simulated image shown in Fig. 6. It is evident from the result that t_1, the log-reflectance response, is much greater than the log-illumination counterpart t_2 in the mid and high frequency range since $r(u,v)$ approaches 0 for large u and v. The contribution made by the log-illumination falls mostly within the low frequency interval.

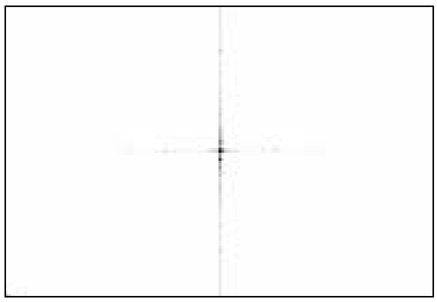


Figure 7: *r(u,v)* of a simulated NIR image.

3.2. Homomorphic Filtering

To effectively reduce the artifact of non-uniform illumination, we process the $Z(u,v)$, the frequency response of the log-image, with a filter function $H(u,v)$. The result, denoted by $S(u,v)$, is then expressed as:

$$S(u,v) = Z(u,v)H(u,v) = F_{i'}(u,v)H(u,v) + F_{r'}(u,v)H(u,v) \quad (10)$$

Taking the inverse Fourier transform, we get:

$$\begin{aligned} s(x,y) &= \Im^{-1}\{S(u,v)\} \\ &= \Im^{-1}\{F_{i'}(u,v)H(u,v)\} + \Im^{-1}\{F_{r'}(u,v)H(u,v)\} \quad (11) \\ &= i''(x,y) + r''(x,y) \end{aligned}$$

The desired enhanced image *g(x,y)* can then be obtained by:

$$g(x,y) = e^{s(x,y)} \quad (12)$$

A modified Gaussian high-pass filter of the following form:

$$H(u,v) = (r_H - r_L) \cdot (1 - \exp[-(\frac{u^2}{2D_u^2} + \frac{v^2}{2D_v^2})]) + r_L \quad (13)$$

can be used to control the low- and high-frequency components of *Z(u,v)* in different ways. If the parameters r_L and r_H in Eq. (13) are chosen so that $r_L < 1$ and $r_H > 1$, then the resulting filter *H(u,v)* will decrease the contribution of the low frequencies (illumination) and amplify the contribution of mid- and high frequencies (reflectance). Fig. 8 depicts the cross section of such a filter function.

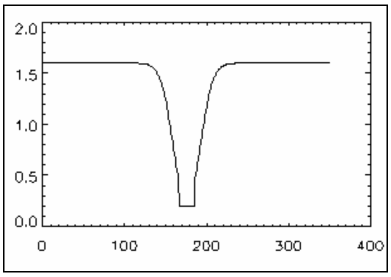


Figure 8: A modified Gaussian high-pass filter.

4. EXPERIMENTAL RESULTS

In this section, we present experimental results of applying the proposed homomorphic filtering scheme to images taken with Sony NightShot® camcorders. We also consider how the filter parameters should be selected to arrive at satisfactory results. Since our main interest is to study the feasibility of using NIR images for face recognition, all the images included in this paper contain only human subjects.

To start with, we process with the NIR image shown in Fig. 3 with $r_H=1.6$, $r_L=0.4$, and $D_u=D_v=0.2$. The enhanced image and its histogram are shown in Fig. 9.

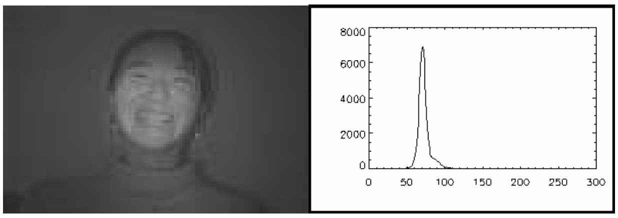


Figure 9: Homomorphic filtered image and its histogram.

The bright region of the original NIR image has become less apparent. The histogram of the filtered image becomes a uni-modal distribution, and is subject to further enhancements via histogram processing. More results of the homomorphic filtering are illustrated in Figs. 10-11.

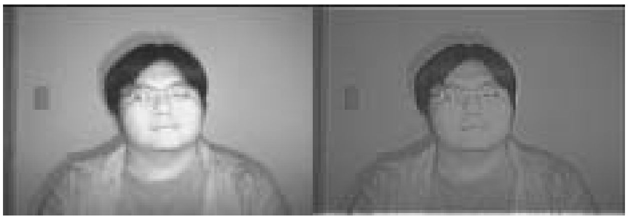


Figure 10: Filtering with $r_H=1.6$, $r_L=0.7$, and $D_u=D_v=0.22$.

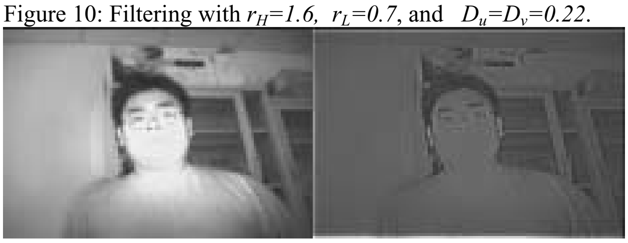


Figure 11: Filtering with $r_H=1.6$, $r_L=0.4$, and $D_u=D_v=0.2$.

To address this issue of filter parameter selection, we need to estimate the intensity contrast of the central and peripheral regions. If there exist big differences between these two areas, r_L has to be chosen small in order to further attenuate the low-frequency component. On the other hand, the parameters D_u and D_v that control the slope of the filter function are related to rates of decay of the illumination source. The basic guideline is to set D_u and D_v in accordance with the rates of decay, i.e., for an NIR image with sharp transition (small σ_x and σ_y), choose small values for D_u and D_v.

5. CONCLUSIONS

In this paper, we presented an effective approach to correct NIR images with highly non-uniform brightness. Following the homomorphic filtering strategy, the low-frequency component that is closely associated with the illumination source is identified. A modified Gaussian high-pass filter is then applied to amplify the contribution made by high frequencies (reflectance). The combined effect is simultaneous dynamic range compression and contrast adjustment. The experimental results demonstrate noticeable improvements of the processed NIR images. It is speculated that with appropriate pre-processing, a face recognition system using NIR images can perform with great accuracy under various lighting conditions.

6. REFERENCES

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