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Image Contrast Enhancement by Analysis on Embedded Surfaces of Images

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Abstract

Image contrast enhancement plays an important role in many machine vision applications. In this study, we propose a new method for edge enhancement based on analysis on embedded surfaces of images. The proposed method gives an insight into the relationship between the image intensities (also the gradients) and image contrast. In our method, scaled surface area and the surface volume are used to reconstruct the image for edge enhancement, and then the contrast of the reconstructed image is adjusted by a 'strengthen-weaken' process. Although, current method for edge enhancement such as curvelet transform can enhance the edge part, it does not provide good tonal rendition or color constancy sometimes. The experimental results show that our method can give good performance not only in edge enhancement, but also in tonal rendition and color constancy.

1 Introduction

Machine vision has many important applications in digital images capturing in low contrast conditions. These images often encounter serious problems in recognition systems. How to enhance the contrast is a vital factor in image recognition problem, and many methods for improving the image quality in contrast have been proposed. Histogram equalization [1] is one of the most well-known methods for contrast enhancement in images with poor intensity distribution. Retinex [5] is an important model of human vision system and many methods based on it have been developed. The single scale retinex method (SSR) [4] and the multiscale retinex (MSR) [3] are the most useful two. MSR can provide better tonal rendition [6] than SSR. Edge enhancement is also important in contrast enhancement. Multiscale edge enhancement using the wavelet transform [9] is a way to enhance the contrast by enhancing the edges in scale space since edges play a fundamental role in image understanding. Because the curvelet transformation is also well-adapted to represent images containing edges, it works well for edge enhancement [8]. Curvelet coefficients can be modified in order to enhance edges in an image. It can preserve edges better than wavelet transformation.

On the other hand, embedding intensity images as 2D surfaces in 3D space is not new. It is also well known as a scale space or geometric diffusion. Sochen et al. [7] first introduce a general framework for low level vision by treating images as embedded surfaces in 3D space and show some applications to image reconstruction. Many features from the embedded surface such as line element and the Beltrami flow are applied directly on the surface.

In this study, we propose a new method based on features of embedded surfaces to enhance edges. We first propose a new feature on the embedded surfaces named scaled surface area, and give a new metric to compute the volume under embedded surface. In our method, images are first reconstructed from the ratio of surface volume to scaled surface area, which the edge enhancement can be obtained by specifying the scale weight. Then the contrast of the reconstructed image is adjusted by a 'strengthen-weaken' process. We compare our method with curvelet method in low contrast images in the experiment. The experimental results show that our method gives good results in edge enhancement and image quality, i.e. tonal rendition or color constancy, is improved much than curvelet method.

Our work makes four new contributions to image contrast enhancement in scale space. First, we propose the scaled surface area and use it for image enhancement; Second, we introduce a new method for computing the volume under surface. Third, image reconstruction is obtained by analysis on the scaled surface area and volume; Finally, the 'strengthen-weaken' process provides a simple, yet powerful enhancement method for contrast adjustment.

The remainder of this paper is organized as follows. First, we discuss the scaled surface area and volume of embedded surfaces in detail in Section 2; Section 3 is about the whole procedure of the new image enhancement method; Section 4 presents some experimental results using the proposed method and comparisons with curvelet method. Conclusions and future work are given in the last section.

2 Surface area and volume

Let I(x, y) be an image defined as $I : R^2 \rightarrow [0, 1]$, and the embedding of it described as a graph in IR^3 is:

$$X : (\alpha \ \ , \alpha^2) \rightarrow (x = \alpha^1, y = \alpha^2, z = I(\alpha^1, \alpha^2)) \quad (1)$$

where (x, y, z) are Cartesian coordinates in 3D space and we let $x \equiv \alpha^1$, $y \equiv \alpha^2$. Now we can study the surface area on the embedded surfaces. Generally, if z = f(x, y) is defined over a region R, the surface area S corresponding to R can be written as:

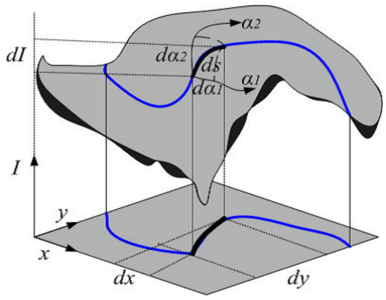


Figure 1. Embedded surface of image.

$$S = \iint_R \sqrt{(\frac{\partial z}{\partial x})^2 + (\frac{\partial z}{\partial y})^2 + 1} dA \quad (2)$$

where the integral is taken over the region R. In our method, a scaled weight β(β ∈ [0,∞]) is multiplied to the partial derivative parts in Eq. 2, that we get the scaled surface area

$$S' = \iint_R \sqrt{\beta(\frac{\partial z}{\partial x})^2 + (\frac{\partial z}{\partial y})^2 + 1} dA\,. \quad (3)$$

Considering Eq. 1, the scaled surface area also can be written as

$$S' = \iint_R \sqrt{\beta((I_x)^2 + (I_y)^2) + 1} dxdy\,, \quad (4)$$

And *scaled area element* is

$$da = \sqrt{\beta((I_x)^2 + (I_y)^2) + 1}\,. \quad (5)$$

Before discussing the volume of embedded surfaces, we will introduce the *line element* in advance. Simply, we can write *line element* as

$$ds = \sqrt{dx^2 + dy^2 + dI^2}. \quad (6)$$

For more details, please refer to [7]. An illustration of embedded image and line element is shown in Figure 1.

Normally, the volume V in a space G as can be defined as

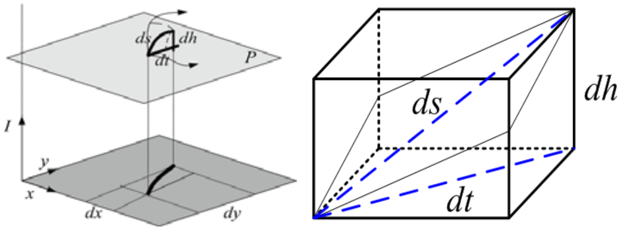
$$V = \iiint_G dvdg \quad (7)$$

where dv is *volume element*. We define the volume in a different way and give an approximation for numeric implementation in this study. If we let the volume under an *area element* be dv_r and call it as *area volume element*, the volume under the surface over region R can be computed as

$$V = \iint_R dv_r dr \quad (8)$$

as double integral form in Eqn. 2. Here, we divide the volume under an area volume element into two parts: the regular part v1 under the plane P and the irregular part above the plane P as shown in Figure 2(a). v1 can be easily obtained as Idxdy, and v2 is approximated by a model as shown in Figure 2(b):

$$v_2 = \frac{\sqrt{ds^2 - dt^2}\, dxdy}{2} \quad (9)$$



(a) (b)

Figure 2. Volume model. (a) Two parts of the volume. (b) Model for the irregular part.

where *dt* is an arbitrary parameter and we use

$$dt^2 = dx^2 + dy^2 \quad (10)$$

in our study. Submitting Eqn. 6 and Eqn. 10 to Eqn. 9, we get

$$v_2 = \frac{dIdxdy}{2}. \quad (11)$$

Then, dv_r can be written as

$$dv_r = v_1 + v_2 = (I + \frac{dI}{2})dxdy. \quad (12)$$

3 Image enhancement method

For an image *I(x, y)*, we first embed it as a surface in 3D space and compute the area element *da* and area volume element *dvr*, respectively. In this study, intensities are supposed to be in range [0, 1] in all discussions. Then, the ratio is computed as

$$r = \frac{dv_r}{da} = \frac{(2I + dI)}{2\sqrt{\beta((I_x)^2 + (I_y)^2) + 1}}, \quad (13)$$

and r is normalized as the outputs of the reconstructed images. Observing Eqn. 13, we can find that the scaled weight parameter β gives flexibility for image enhancement: if β is very small, in an extreme case, is equal to 0, the outputs r(x, y) becomes

$$r = \frac{2I + dI}{2}, \quad (14)$$

and it is similar to the enhancement method by adding the original image its Laplacian [8]; Otherwise, if β is very large, the gradient in Eqn. 13 is scaled, and the edge in outputs can be enhanced much.

Although the edge can be enhanced by the above process, we find that the intensity contrast of the edge enhancement is still low in some cases. Therefore, we propose a simple but useful process to adjust the intensity contrast named 'strengthen-weaken' process. First, the 'strengthen' process is achieved by the simple log transformation defined as

$$t = c\log(1 + 255r), \quad (15)$$

(a) (b) (c) (d)

Figure3. Contrast enhancement. (a) Original image. (b) Edge enhanced image. (c) Contrast strengthened image. (d) Contrast weakened image.

where c is a constant. The log function has the important characteristic that it compresses the dynamic range of images with large variations in pixel values. Although, the contrast can be enhanced by the log transformation, the log transformed images are always too bright and the tonal rendition and color constancy are also expected to be improved. Hence, we modify the normalized log transformed images by a 'weaken' process as follow:

$$g = t^{(\frac{1}{p})} \tag{16}$$

where p is a parameter determining the degree of nonlinearity in the nonlinear rescaling of contrast, and it is in range [0, 1]. The final result of g should also be normalized.

Figure 3 shows an example of the whole enhancement process. Figure 3(a) is the original image and Figure 3(b) is the edge enhanced image. We can observe that edges in Figure 3(b) have been enhanced; however, the intensity contrast of it is still low. Figure 3(c) shows the contrast strengthened image by log transformation and it turns to be too bright. The final result is shown in Figure 3(d), and it gives more details and the tonal rendition and color constancy are improved.

4 Experiment

In this section, we will discuss the performance of our method for edge enhancement problem. Image enhancement quality is difficult to assess. Although PSNR (peak signal to noise ratio) is a commonly used criterion, it does not evaluate the results in the way that the human vision system does, especially in edge enhancement. So, we simply evaluate the results by human eyes in this study.

The test images are from the [2] and Figure 4(a) shows the original images including ophthalmic image, Saturn image and satellite image of Marseilles. The enhanced images by curvelet are shown in Figure 4(b) and those by our method are shown in Figure 4(c). Some parameters used here are: $\beta=1$, $c=2$, $p=0.5$. In both curvelet method and our method, edges are enhanced; however, our method provides better results in tonal rendition and color constancy than curvelet method. Or we may say that the enhanced results by our method are 'closer' to the original images with edge enhancement. For example, in Saturn image, the mountain is more easily to be observed in enhanced image by our method than curvelet method, and in the satellite image, details of the port are easier to be observed by our method.

Generally, our method can provide better tonal rendition and color constancy. Moreover, by simply specifying the value of β, edges can be enhanced for different requirements.

5 Conclusions and future work

This study presents a new method for image edge enhancement based on the analysis on embedded surfaces of images. Compared to the curvelet method, our method shows its superiorities in improving tonal rendition and color constancy. Future work will aim at extending to color images and we are also considering explore a more appropriate way to evaluate the enhancement results.

Acknowledgement

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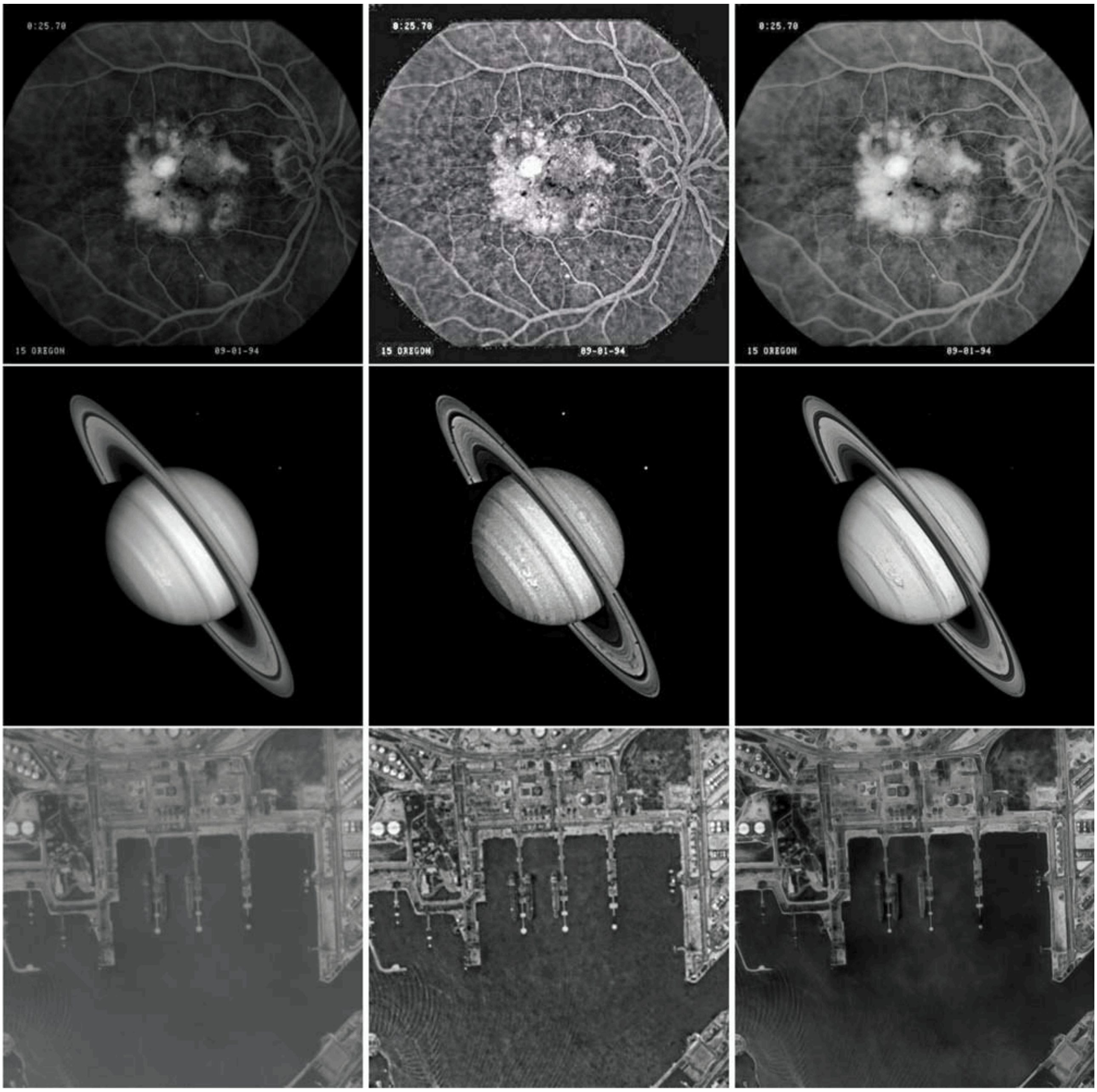

(a) (b) (c)

Figure 4. Experimental results. (a) Original images. (b) Enhanced images by curvelet. (c) Enhanced images by our method.