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Digital Medical Image Enhanced by wavelet Illumination-Reflection Model

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Abstract

When a digital medical image is enhanced, the useful details of the image should be strengthened, but the details cannot be strengthened by these algorithms based on traditional illumination-reflection model. According to the imaging principle and medical requirement, wavelet illumination-reflection model and a new algorithm based on the model are proposed. The image is decomposed into illumination and reflection by wavelet illumination-reflection model. The details of the reflection are strengthened. The dynamic range of the illumination is reduced in order to enhance the image. Experiments and analysis show that the method is obviously better than Histogram Equalization, Homomorphic Filtering and multi-scales Retinex.

Keywords*: digital medical image, illumination-reflection model, stationary wavelet transform, homomorphic filtering, multi-scales Retinex*

1. Introduction

The The images with poor contrast and low brightness bring great obstacles to doctor' diagnosis. For such images, document [1] has considered that three main methods are Histogram Equalization, Homomorphic Filtering and multi-scales Retinex, which are used to enhance these images. Homomorphic Filtering and multi-scales Retinex are based on traditional illumination-reflection model. Because of the limitations of Homomorphic Filtering and multi-scales Retinex based on the imaging principle, the details of the images can't be strengthened by them. Therefore, we should propose an effective digital medical image enhancement method. These images enhanced by the method have suitable contrast, brightness and dynamic range. Besides, the details of these images enhanced by the method can be strengthened.

In this regard, according to the digital medical image features and the shortcomings of traditional illumination-reflection model, a digital medical image enhancement method based on wavelet illumination-reflection model is proposed. In the method, the images are explained by wavelet illumination-reflection model, the images are decomposed into illumination and reflection by stationary wavelet transform, the details of reflection are strengthened and the dynamic range of illumination is compressed.

2. Image Enhancement Method based on Traditional Illumination-reflection Model

Explaining Physical though: When an image $f(x,y)$ is generated, its values is proportional to the radiation energy of the physical sources and the radiation energy must be non-zero and limitation. It is explained by Eq(1).

$$f(x,y) = i_0(x,y) \times r_0(x,y) \tag{1}$$

Where : $i_0(x,y)$---illumination decide by the physical sources and $0 < i_0(x,y) < \infty$.
$r_0(x,y)$---reflection decide by the imaged objects and $0 < r_0(x,y) < 1$.

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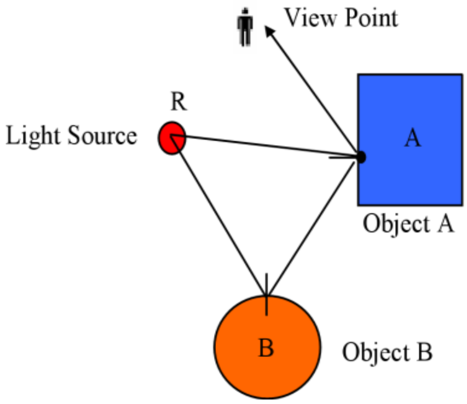

Figure 1. Traditional illumination-reflection model

Traditional illumination-reflection model thinks: The values of illumination change slowly in the spatial domain. On the contrary, dramatic changes of the image values are decided by reflection, especially the edges of objects in the image. In the meantime, the low frequency of image has something to do with illumination and the high frequency has something to do with reflection in frequency domain. The reflection is decided by the reflectivity of the objects surfaces in scene. The details are decided by the reflection. The illumination is decided by ambient light. The dynamic range is decided by the illumination.

Homomorphic Filtering is a method which enhances images in frequency domain. (Figure 2)

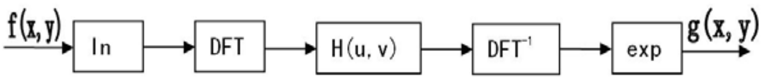

Figure2 Homomorphic Filtering

The key of Homomorphic Filtering is that the multiplication between the illumination and the reflection of images is become into the addition between them.

$$z(x,y)=\ln f(x,y)=\ln(i_o(x,y)\times r_o(x,y))=\ln i_o(x,y)+\ln r_o(x,y) \quad (2)$$

It thinks that the high dynamic range of images is caused by illumination $i_o(x,y)$. The images are filtered by high-pass frequency filter $H(u,v)$ in order to enhance these images.

Eq (2) is transformed by FFT2.

$$F(z(x,y))=F(\ln i_o(x,y))+F(\ln r_o(x,y)) \quad (3)$$

$$Z(u,v)=F_{i_o}(u,v)+F_{r_o}(u,v) \quad (4)$$

$$S(u,v)=H(u,v)\times Z(u,v)=H(u,v)\times F_{i_o}(u,v)+H(u,v)\times F_{r_o}(u,v) \quad (5)$$

The impact of $F_{i_o}(x,y)$ is eliminated in Eq (5).

$S(u,v)$ is inverse transformed by IFFT2.

$$s(x,y)=F^{-1}(S(u,v)) \\ =F^{-1}(H(u,v)\times F_{i_o}(u,v))+F^{-1}(H(u,v)\times F_{r_o}(u,v)) \quad (6)$$

Suppose:

$$i^{'}(x,y)=F^{-1}(H(u,v)\times F_{i_o}(u,v))$$

$$r^{'}(x,y)=F^{-1}(H(u,v)\times F_{r_o}(u,v))$$

We can get

$$s(x,y)=i^{'}(x,y)+r^{'}(x,y) \quad (7)$$

$$g(x,y)=e^{s(x,y)}=e^{i^{'}(x,y)}\times e^{r^{'}(x,y)}=i_o^{'}(x,y)\times r_o^{'}(x,y) \quad (8)$$

In document [2], images are decomposed into illumination and reflection by Homomorphic Filtering. Experiments show that: If the cut-off frequency of $H(u,v)$ is higher, the dynamic range compression and the details loss are higher. If the cut-off frequency of $H(u,v)$ is lower, the dynamic range compression and the details loss are lower. The details of images enhanced by Homomorphic Filtering are damaged.

Retinex is based on illumination-reflection model, too. It [3] thinks that: All details in scene are include in reflection $r_o(x,y)$. Illumination $i_o(x,y)$ consists of all light sources in scene. The high dynamic range of images is decided by illumination.If illumination is separated from images, the influence of illumination can effectively be eliminated and the images dynamic range can be compressed.

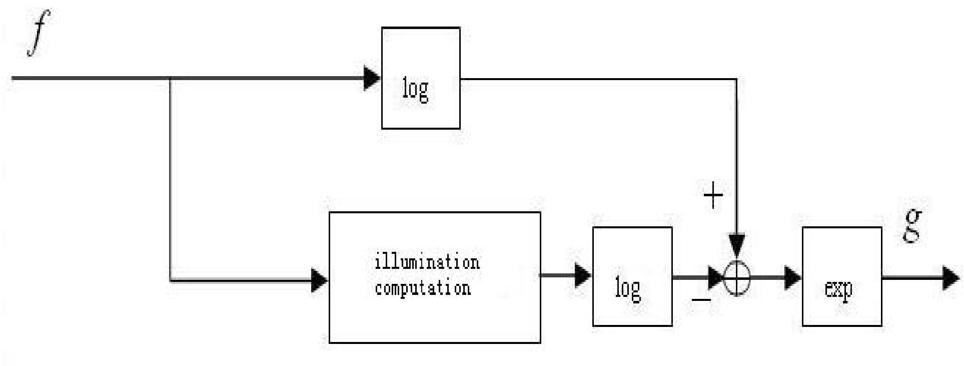

Figure 3 Retinex

$$g(x,y)=\exp(\sum_{k=1}^{K}W_k\times(\log f(x,y)-\log(F_k(x,y)\times f(x,y))) \quad (9)$$

Where: k ---scale,

$F_k(x,y)$ ---the surround function in scale k ,

W_k ---the weighting coefficients correspond to $F_k(x,y)$.

In Eq (9), it is difficult that illumination $i_o(x,y)$ and reflection $r_o(x,y)$ are separated in $f(x,y)$.

In document [4], digital medical images are enhanced by multi-scales Retinex. It thinks that: The illumination $i_0(x,y)$ is equivalent to X-ray intensity through the human body to the imaging device and decides the images dynamic range. The reflection $r_0(x,y)$ is equivalent to the change of X-ray intensity absorbed by the human body and represents the details of the imaging of the human body.

3. Digital Medical Image Enhancement based on Wavelet Illumination-reflection Model

3.1. Wavelet Illumination-reflection Model

The key disadvantage of traditional illumination-reflection model is that the illumination and the reflection of the image can not be effectively separated. Because of the disadvantage, the details of images enhanced must be lost when images are enhanced by the model. For this reason, wavelet illumination-reflection model is proposed. In the new model, images are decomposed into high frequency part and low frequency part. In other words, the illumination is replaced by the low frequency part and the reflection is replaced by the high frequency part.

An image $f(x,y)$ is decomposed by 2D multi-scale decomposition.

$$f(x,y)=V_j(x,y)\oplus W_j(x,y)\oplus W_{j-1}(x,y)\oplus\cdots\oplus W_2(x,y)\oplus W_1(x,y) \quad (10)$$

$$V_j(x,y)=V_{j+1}(x,y)\oplus W_{j+1}(x,y) \quad (11)$$

$$W_{j+1}(x,y)=\frac{V_j(x,y)}{V_{j+1}(x,y)} \quad (12)$$

$$\begin{aligned} V_{j-1}(x,y) &= (V_{j+1}(x,y)\oplus W_{j+1}(x,y))\oplus W_j(x,y) \\ &= V_{j+1}(x,y)\oplus W_{j+1}(x,y)\oplus W_j(x,y) \end{aligned} \quad (13)$$

suppose:

$$W(x,y)=W_j(x,y)\oplus W_{j-1}(x,y)\oplus\cdots\oplus W_1(x,y) \quad (14)$$

We can get

$$f(x,y)=V_j(x,y)\oplus W(x,y) \quad (15)$$

Because $V_j(x,y)$ is the low frequency part of $f(x,y), V_j(x,y)\approx i_0(x,y)$.

Because $W(x,y)$ is the high frequency part of $f(x,y), W(x,y)\approx r_0(x,y)$.

Figure 4 is an example that the illumination and reflection of a gray image are separated by wavelet illumination-reflection model.

In summary, traditional illumination-reflection model can be replaced by wavelet illumination-reflection model.

Figure4.a

Figure 4.b

Figure 4.c

Figure 4. a is an original image. Figure 4.b is the illumination of Figure 4.a. figure 4.c is the reflection of Figure 4.a. We can get the facts: it is easy that illumination and reflection are separated by wavelet illumination-reflection model.

3.2. Digital Medical Image Enhanced by Wavelet Illumination-reflection Model

The advantage of wavelet illumination-reflection model is that the illumination and the reflection of images can be effectively separated. The dynamic range of images is decided by the illumination which is the low frequency part of images decomposed by wavelet transform. The details of images are decided by the reflection which is the high frequency part of images decomposed by wavelet transform. For this reason, wavelet illumination-reflection model can synchronously do both the compression of the high dynamic range decided by the illumination and the strengthening of the useful details decided by the reflection. It is beneficial to the requirement that the useful details should be strengthened in digital medical image enhancement.

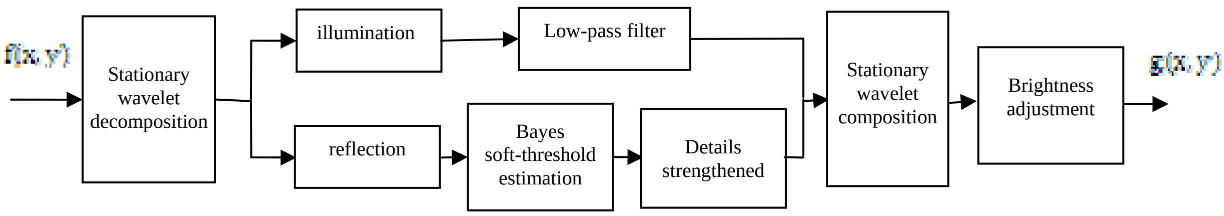

Figure 5. Images enhanced by wavelet illumination-reflection model

When a signal is decomposed by stationary wavelet transform, the signal length is not changed. It is beneficial to the decomposition and composition of images. Wavelet illumination-reflection model can be easily expressed by stationary wavelet transform. The wavelet scales and function are determined in accordance with the experiment and the actual situation. In this paper, the wavelet scales is three and the wavelet function is 'sym4'.

3.3. Low-pass Filter

Document [5] thinks that the high dynamic range of images is decided by the energy in every frequency band of the illumination. We can attenuate the energy in every frequency band of the illumination in order to compress the high dynamic range of images. First, the illumination is transformed by FFT2. Second, the illumination transformed is filtered by Gaussian low-pass filter. At last, the illumination is restructured by IFFT2. See Eq(16, 17 ,18).

$$H(u,v) = rH \times e^{-c\left(D^2(u,v) / D_0^2\right)} \tag{16}$$

$$D(u,v)=\sqrt{(u-M/2)^2+(v-N/2)^2} \quad (17)$$

Where M , N is the size of image, C is a constant which determines the inclined plane of filter, D_0 is cut-off frequency, rH is ratio coefficient and $rH = 0.7$ in this paper.

$$D_0 = 0.5 \times median(median(D(u,v))) \quad (18)$$

3.4. Bayes Soft-threshold Estimation and Details Strengthening

Images contain noise or unwanted details in varying degrees. The corresponding thresholds should be set for the reflection. The details above the corresponding thresholds are strengthened. The details under the corresponding thresholds are attenuated. Because the wavelet coefficients in reflection obey general Gaussian distribution, the thresholds are determined by Bayes soft-threshold[8]. See Eq(19 ,20,21).

$$Thr = r \times \sigma_n^2 / \sigma_x \quad (19)$$

Where :

Thr --- the corresponding threshold;

r ---coefficient, $r = \sqrt{2}$;

σ_n ---noise standard deviation;

σ_x ---signal standard deviation.

$$\sigma_n = \hat{\sigma}_n = median(|y(i,j)|)/0.6745 \quad (20)$$

Where:

$y(i,j)$ is the wavelet coefficient of the reflection.

$$\sigma_x = \sqrt{\mathrm{var}(y) - \sigma_n^2} \quad (21)$$

Where:

$\mathrm{var}(y)$ ---wavelet coefficients matrix variance.

According to the corresponding threshold, the wavelet coefficients of the reflection are strengthened or attenuated. See Eq (22).

$$\hat{y}(i,j) = \begin{cases} y(i,j) \times 2, y(i,j) \geq Thr \\ y(i,j)/2, y(i,j) < Thr \end{cases} \quad (22)$$

Where $\hat{y}(i,j)$ is the wavelet coefficient of reflection strengthened or attenuated.

3.5. Brightness Adjustment

Because the energy of the illumination is attenuated by low-pass filter for the high dynamic range compressed, the images restructured by stationary wavelet transform are darker than before. The images brightness should be adjusted by Gamma adjustment in order to the human eyes comfortable observe these images.

$$g(x,y) = g'(x,y)^t \tag{23}$$

Where $g'(x,y)$ is the image restructured by stationary wavelet transform, t is the Gamma coefficient, $t = 0.7$ in this paper.

3.6. Experiments 、Subjective and Objective Evaluation

The comparative experiment is that a digital medical image is enhanced by Histogram Equalization in Photoshop, Homomorphic Filtering, multi-scales Retinex and the method proposed in this paper.

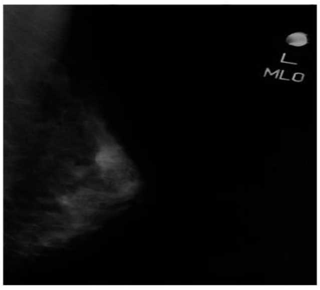

Figure 6.a

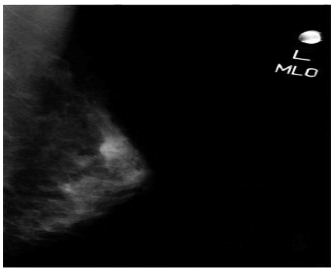

Figure 6.b

Figure 6.c

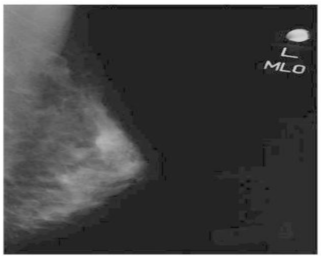

Figure 6.d

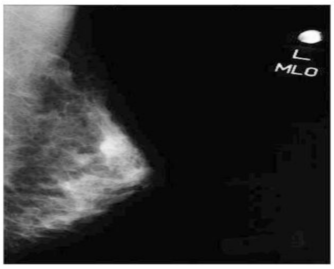

Figure 6.e

Figure 6.a is an original image, Figure 6.b is enhanced by Histogram Equalization in Photoshop, Figure 6.c is enhanced by Homomorphic Filtering, Figure 6.d is enhanced by multi-scales Retinex (The scales are 80,150,250.) and Figure 6.e is enhanced by the method proposed in this paper.

According to the subjective judgment, the effect of Histogram equalization enhancement is the worst. The image contrast of multi-scales Retinex enhancement is the best, but the loss of the image details is more and many of details can not be observed by human eyes. The image which is enhanced by Homomorphic Filtering and the method proposed in this paper contains the most details. The most abundant details can be observed by human eyes. The image contrast enhanced by the method proposed in this paper is much better than Homomorphic Filtering. Lesion of tumors and hyperplasia can be easily observed in the image enhanced by the method proposed in this paper. From human eyes observing, the effect of the method proposed in this paper is the best.

The changes in image brightness and contrast are analyzed by the method in document [6] and Eq (24, 25).

$$C = \frac{Var(g) - Var(f)}{Var(f)} \tag{24}$$

$$L = \frac{Mean(g) - Mean(f)}{Mean(f)} \tag{25}$$

Where C is the rate of contrast change, L is the rate of brightness change.
The information entropies of Figure 6 are analyzed by the method in document [7].

$$E = \sum_{i}^{n} p_i \times \lg \frac{1}{p_i} \tag{26}$$

Where E is the image information entropy, p_i is the number of the image pixels when gray value is i, n is the image gray level.

Table1 Performance Parameter

	Figure6.a	Figure6.b	Figure6.c	Figure6.d	Figure6.e
Brightness(L)	0	0.7489	7.7680	6.2934	4.2593
Contrast(C)	0	0.7341	3.3802	1.2883	2.6276
Entropy (E)	3.3914	3.7435	2.5110	3.4987	4.8268

As we can see from the Table 1, the information entropy of the image enhanced by the method in this paper is maximum and the contrast of Figure 6.e is better than figure 6.d. Figure 6.e brightness is moderate and suitable observed by human eyes. According to the evaluation method in document [5], we invited ten doctors to evaluate from Figure 6.a to Figure 6.e. They all considered that the details, the contrast, the brightness of figure 6.e is the best. We can get the conclusion that the quality of image enhanced by the method proposed in this paper is the best in these methods.

4. Conclusion

Wavelet illumination-reflection model has an intuitive physical meaning and the strict mathematical sense. It can effectively separate the illumination and reflection. This is beneficial to enhance digital medical images which the high dynamic range of the images should be compressed and the details of the images should be strengthened. Experiments and analysis show that the model is obviously better than traditional illumination-reflection model. However, the details of images enhanced by Wavelet illumination-reflection model have a certain relationship with the wavelet function used in it. From now on, we should research the type of wavelet function. Moreover, the wavelet transform theory is constantly evolving. Wavelet illumination-reflection model using curvelet transform instead of wavelet transform may have better results.

Acknowledgements

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