WIRELESS CAPSULE ENDOSCOPY IMAGES ENHANCEMENT USING CONTRAST DRIVEN FORWARD AND BACKWARD ANISOTROPIC DIFFUSION

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ABSTRACT

The wireless capsule endoscopy (WCE) has been widely used to detect the diseases in gastrointestinal tract. However, the contrast of many images it produced is rather dark due to some reasons, which casuses some difficulties to diagnosis and computer aided diagnosis. To overcome this shortcoming, we propose a forward and backward anisotropic diffusion method based on the contrast space to enhance the capsule endoscopy images. Experimental results show that this new method can provide a better visualization of the wireless capsule endoscopy images than the forward and backward Beltrami flow and the contrast-limited adaptive histogram equalization so as to assist the inspection of WCE images.

Keywords: Wireless capsule endoscopy, contrast, diffusion

1. INTRODUCTION

Colorectal diseases are now great threats to human's health. It has been reported that colorectal cancer has been the second leading cause of cancer-related deaths in U.S.A. [1]. Different diseases in gastrointestinal tract can be prevented and cured through early detection. The traditional detection methods such as endoscopy, X-ray, and CT scan have different drawbacks such as invasiveness, unclearness, and so on. The wireless capsule endoscopy, invented by Given Imaging Ltd. in Israel, can view the entire small intestine without pain, sedation, or air insufflation, so it has been widely used in hospitals to detect the status of the gastrointestinal tract. After an overnight fast of 8-12 hours, the patient ingests the WCE with a small amount of water, and then this small device propelled by peristalsis begins to work and record images while moving forward along the gastrointestinal tract. At the same time, the images are sent out wirelessly to a recorder attached to the waist. And the whole process costs about 8 hours on average. Then all the images are downloaded into a computer, and physicians could review the images and analyze the status of the gastrointestinal tract. It must be noticed that the diagnosis process is very time-consuming because of the large amount of video data, so the diagnosis is not a real-time process in fact, and this situation paves a potential way for off-line post processing and computer aided diagnosis. The wireless capsule endoscopy received its approval from the U.S. Food and Drug Administration (FDA) in 2001, and more than 200,000 patients have enjoyed the benefits of this new technology. A simple review of the wireless capsule endoscopy can be found in [2].

However, many images produced by the wireless capsule endoscopy are rather dark because of rather limited illumination of LEDs in the WCE and complex circumstances in the gastrointestinal tract. To mitigate this situation, it is necessary to enhance these images. With respect to image enhancement, methods such as homomorphic filtering [3], intensity pair distribution [4] have been used to improve the quality of the image for further analysis. Despite their strengths in different domains, these methods, however, could not preserve or even enhance edges or local details, which are important to diagnosis. Anisotropic diffusion proposed in [5], on the other hand, can preserve the details efficiently while smoothing noise, and it had been applied successfully to medical images processing such as ultrasound images [6] and MRI images [7]. In this paper, we propose a new forward and backward anisotropic diffusion in contrast space to enhance the wireless capsule endoscopy images.

2. FORWARD AND BACKWARD ANISOTROPIC DIFFUSION

Witkin [8] firstly found that the convolution of a signal with Gaussians at different scales was equivalent to solving a heat diffusion equation with the signal as an initial value. With regard to an image I, this process can be described as the following partial differential equation:

$$\frac{\partial I}{\partial t} = c\Delta I(x,t) \tag{1}$$

where c is the diffusion conductance constant, and Δ is the Laplacian operator. Because the edges at low scales will be distorted, Perona and Malik [5] proposed a great improvement to this model:

$$\frac{\partial I}{\partial t} = div[c(x,y,t)\nabla I] \tag{2}$$

where ∇ is the gradient operator. A desirable characteristic of the conductance function is that it will encourage intra-region smoothing, while inhibit inter-region smoothing. One of such functions with the above behavior is:

$$c(x,y,t)=\exp\left[-\left(\frac{\|\nabla I\|}{k}\right)\right]^2 \tag{3}$$

where k is the conductance parameter that affect the diffusion process. The original diffusion proposed by Perona and Malik is a diffusion process which selectively smoothes regions that do not contain large gradients, that is, the diffusion will smooth considerably the content of the image within edges while preserve or even enhance the edge. This seminal work triggered a lot of extensions [6-10].

To achieve the goal of enhancement for the wireless capsule endoscopy images, we firstly resort to backward diffusion. However, it's known that backward diffusion is an unstable process unless some additional approaches are taken. One method to avoid instability is to reduce the value of the backward diffusion at high gradients, so it does not continue to affect the process any more when singularity exceeds a certain gradient threshold. Another means is to use forward and backward forces to control the diffusion simultaneously [9]. These two forces can be integrated into a coupled forward and backward diffusion with a conductance function possessing both positive and negative values. In this paper, we propose a simple and effective conduction function so as to do diffusion as below:

$$C_{FAB}(x)=2[\cosh(k_1x)]^{-2}-[\cosh(k_2x)]^{-2} \tag{4}$$

where k_1 and k_2 are two parameters that control the forward and backward diffusion. To assure a good performance, the condition $k_1>k_2$ must be satisfied. Fig.1 is the plot of the conductance function when $k_1=2, k_2=0.5$ respectively.

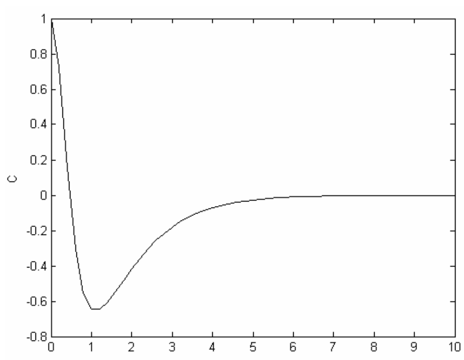

Fig.1 One forward and backward conductance function

3. DIFFUSION IN CONTRAST SPACE

From the diffusion model (2), we can see that the accurate estimation of the gradients is significant to successful diffusion. But in wireless capsule endoscopy images, gradients are often difficult to estimate directly due to the image's complicated background. In order to solve this problem, we devise a new space called contrast space. To get the contrast description of one point in the wireless capsule endoscopy image, we exploit the Hessian matrix of one point in the image. Supposing that I denotes a gray image, the Hessian matrix of one point in the image under a given scale σ is:

$$H_\sigma=\begin{bmatrix} I_{xx} & I_{xy} \\ I_{xy} & I_{yy} \end{bmatrix} \tag{5}$$

We assume that the Hessian matrix of one point has two eigenvalues: λ_1 and λ_2. Considering the fact that the intensity variation in the background of wireless capsule images is very weak, we may draw a conclusion that the differential values of those regions are small, which result into rather small eigenvalues. On the other hand, in those regions where there are rather apparent intensity variations, we could draw an opposite conclusion. Based on the above assumptions, we establish a new concept of contrast as follows:

$$f(x,y)|_\sigma=\sqrt{\lambda_1(x,y)^2+\lambda_2(x,y)^2}\,|_\sigma \tag{6}$$

Using formula (6), we can get the image's corresponding contrast space. We then do forward and backward diffusion in this new space with the diffusion model (2) changed into:

$$\frac{\partial f(x,y,t)}{\partial t}=div[C_{FAB}(|\nabla f(x,y,t)|)\nabla f(x,y,t)] \tag{7}$$

The contrast driven diffusion for wireless capsule endoscopy image is more efficient due to the following two reasons. Firstly, the second-order derivative of Hessian is more accurate than the first order derivative because the second-order derivative is more apt to extract the intensity variations under the low contrast circumstances in the WCE images. Secondly, it takes into account concrete factors such as contrast analysis about the region.

4. EXPERIMENTAL RESULTS

We do experiments by comparing the proposed algorithm with forward and backward Beltrami flow [9] and contrast limited adaptive histogram equalization (CLAHE) [11], which is one of the classical methods to do image enhancement.

The size of these images is 256*256, and the scale σ we used in all our experiments is $\sigma=1$, the parameters k_1 and k_2 are empirically set as $k_1=0.2\max f$, $k_2=0.1\max f$ respectively. It should be firstly pointed out that the wireless capsule endoscopy image is color image, so we extend the proposed algorithm into color space similar to the method in [10]. It must also be admitted that quantitative measurement of color image enhancement is very difficult, so we only do visual comparisons. However, the validation of the enhancement results will be discussed in the next section. Here, we present only three sets of the results to show the performance of the proposed method, more results can be found in our report [12].

Fig.2 illustrates one comparison experiment, Fig2.(a) is the original capsule endoscopy image, it can be seen that this image's contrast is very low, which brings many troubles to diagnosis. Fig.2 (b) is the result of algorithm [9], which is obtained experimentally with $\alpha_2 = 0.2$ $\alpha_1 = \alpha_1(s)$ $[k_f, k_b, w, \alpha]=[10, 400, 200, 0.5]$, and 20 iterations (the number of iterations was also chosen by experiments). Fig.2(c) is the result of the CLAHE, Fig.2 (d) is the result of the proposed algorithm after 20 iterations. We can see that the proposed algorithm provides a better visualization of the image than the other two methods.

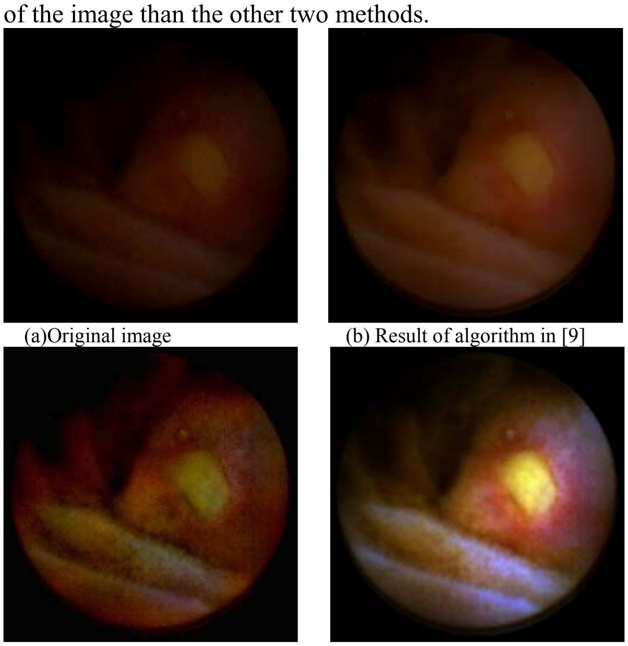
(a)Original image (b) Result of algorithm in [9]
(c)Result of CLAHE (d) Result of the proposed method

Fig.2 One image enhanced by three different algorithms

Fig.3 and Fig.4 show the other two sets of comparison experiments. The parameters are chosen the same as those of Fig.2. It can be also observed that the results of the proposed algorithm are clearer than the other two algorithms.

From the above illustrated examples, we can see that forward and backward Beltrami flow mainly contribute to image smoothing and edge enhancement, and CLAHE method mainly contribute to the image contrast enhancement while ignoring noise suppression, the proposed algorithm can improve the contrast of the image while suppressing the noise at the same time.

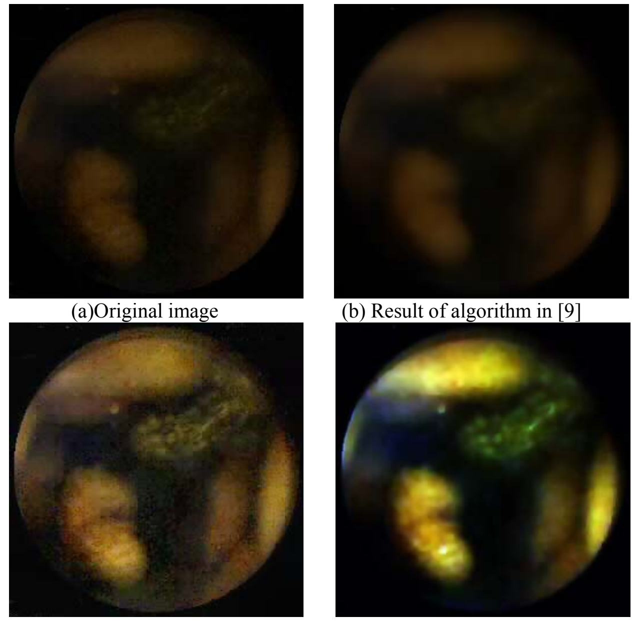
(a)Original image (b) Result of algorithm in [9]
(c)Result of CLAHE (d) Result of the proposed method

Fig.3 Enhanced results of different algorithms

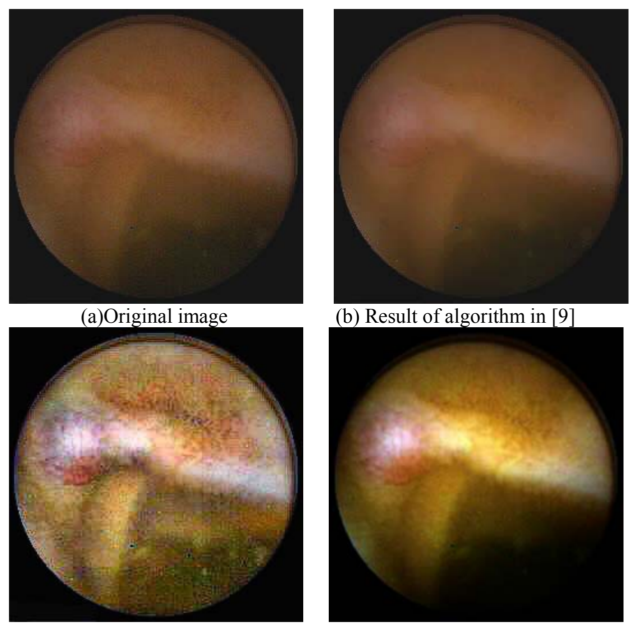
(a)Original image (b) Result of algorithm in [9]
(c)Result of CLAHE (d) Result of the proposed method

Fig.4 Enhanced results of different algorithms

5. VALIDATION OF THE RESULTS

For real clinic applications, the performance of the proposed method was evaluated by means of receiver operating characteristic (ROC) analysis. ROC analysis is a statistical technique that assesses the performance in classification. This curve denotes the relation between the true positive fraction (TPF) versus false positive fraction (FPF), and the area under the ROC curve is a measure of the classification performance. In our experiment, 146 capsule endoscopy images are selected for this investigation by a gastrointestinal expert. Fifty-eight cases among the 146 images contain abnormal regions that are hard to detect or identify.

To evaluate the detection performance of the physicians on these images, three experienced physicians inspect the four different data sets, i.e. the original image(I1), the enhanced results using forward and backward Beltrami flow [9] method(I2), the enhanced results using the CLAHE[11](I3), and the enhanced results using the proposed algorithm(I4). The fitted ROC curves of the average performance of the three physicians for the four data sets are shown in Fig.5. I4 denotes the ROC curve of the enhanced images with the proposed algorithm, I3 represents the ROC curve of the results using the CLAHE, I2 depicts the ROC curve of the results after the forward and backward Beltrami flow, and I1 is the ROC curve of the original image. And table I shows the area under each physician's ROC curve for each image set, which was fitted by the JROCFIT developed by John Eng [13].

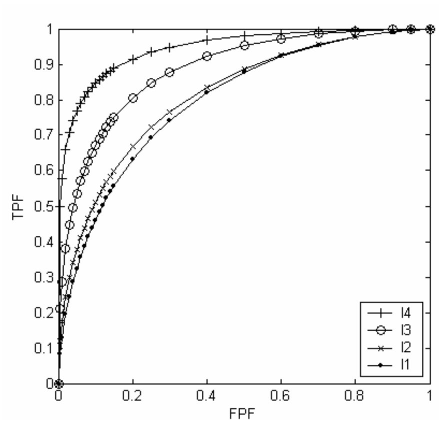

Fig.5 ROC curves of the average performance for the four sets of data

Table I Area under the fitted ROC curves

Physician	I1	I2	I3	I4
1	0.778	0.802	0.868	0.932
2	0.796	0.813	0.886	0.945
3	0.802	0.816	0.892	0.954

And the average area under the four ROC curves are respectively 0.792, 0.810, 0.882, 0.944.This demonstrates that the proposed algorithm is promising in improving the diagnostic performance of the physicians for the WCE images.

6. CONCLUSIONS

Based on the contrast space, we have presented a new forward and backward anisotropic diffusion method to enhance the wireless capsule endoscopy images. The proposed algorithm can improve the contrast of the image while suppressing noise at the same time. Experimental results demonstrate that the proposed method can lead into a better visualization of the wireless capsule endoscopy images compared to the forward and backward Beltrami flow algorithm and the contrast limited adaptive histogram equalization. The performance of the proposed algorithm was also evaluated by means of ROC analysis for the detection of abnormalities in the wireless capsule endoscopy images. The results of the ROC analysis have shown that the proposed method is effective to assist in identifying the lesions. One little problem with this new method is that some parameters need to be set beforehand, which is a part of our future work. Furthermore, motivated by these promising results, we will also focus on automatic abnormal regions detection based on the enhanced images.

7. REFERENCES

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