# FUNDUS OPTIC DISC LOCALIZATION AND SEGMENTATION METHOD BASED ON PHASE CONGRUENCY

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## ABSTRACT

It has been demonstrated that shape, area and depth of optic disc are important indexes of diabetic retinopathy. In this paper, a new fundus optic disc localization and segmentation method based on Phase Congruency (PC) is presented. Firstly, in order to highlight optic disc, channel images with the strongest contrast between optic disc and background are selected in LAB, YUV, YIQ and HSV spaces respectively. Secondly, based on PC, features of four selected channel images are extracted. Multiplication operation is used to enhance PC detection results. Thirdly, window scanning and gray accumulating are utilized to locate optic disc. Finally, iterative OTSU automatic thresholding segmentation and Hough transform are performed on location images, and so the final optic disc segmentation result is obtained. The experimental results showed that the proposed method achieved great effectiveness.

***Index Terms*—**Fundus image, Phase Congruency (PC), Optic disc localization, Optic disc segmentation, Diabetic retinopathy

## 1. INTRODUCTION

DR (diabetic retinopathy) is one of the most serious complications of DM (diabetes mellitus). Optic disc is an important object in fundus image, and its characteristics (such as brightness, position, shape and size) are important references in clinical diagnosis. Individual differences, diseases and other factors will influence characteristics of optic disc. Based on morphological structure of optic disc, many scholars proposed methods for its location and segmentation.

The existing fundus optic disc location methods can be divided into two categories. The first kind is approaches based on characteristics of optic disc itself. Lalonde relied on the combination of a Hausdorff-based template matching technique and a pyramidal decomposition for large scale object tracking [1]; Walter realized optic disc location by using the Watershed Transformation [2]. This kind of methods bases on circular structure and higher luminance of optic disc. However, it is not robust to fundus image which contains an optic disc-like disease. The second kind is approaches based on structural relation between optic disc and fundus blood vessels. Tobin used characteristics of vascular structure to extract statistical features related to vascular density, orientation and thickness to locate optic disc [3]; Foracchia detected optic disc in retinal images by means of a parabolic model of vessel structure [4]; Hoover used a novel algorithm named fuzzy convergence to determine origination of blood vessel, and got results of optic disc location [5]; Li realized automatic localization of optic disc in fundus images based on cross-network of 'blood vessels-like' [6]. Optic disc is located in the convergent area of blood vessel network. This kind of methods needs to detect of fundus blood vessels in advance, and as a result, this class of algorithms has very high computational complexity.

As far as fundus optic disc segmentation, many studies have been done. Osareh removed the blood vessels in optic disc first using morphological preprocessing, and then extracted optic disc adopting active contour model[7,8]. Lupascu located optic disc first according to texture feature, and then recognized the edge of optic disc using an improved iterative method [9]. Li eliminated blood vessels first used adaptive LAB color space morphology method, and then got the edge of optic disc adopting aided geometric active contour model according to the positioning results [10]. Among the optic disc segmentation methods above, there are two main problems. First, morphological transformation is nonlinear and irreversibility. The edge character of optic disc will be changed when using global unified and fixed structural element. Second, parameter active contour model needs an accurately original edge and unsuitable original edge will lead to a poor accuracy of edge detection.

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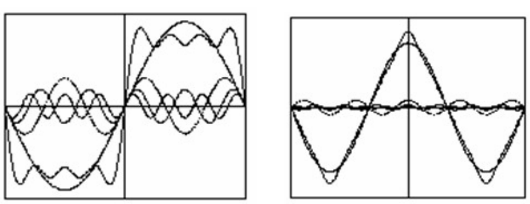
There are many factors which can affect location and segmentation result, such as low contrast between target and background, non-uniform illumination, difference in size of targets. These factors may cause wrong segmenting or even target losing. For fundus images with complex background, traditional image processing methods can not achieve satisfied results in image enhancement, segmentation, focus extraction, analysis and evaluation. Phase information, which is invariant to contrast and brightness, has good anti-noise capability and is consistent with human visual system. In this paper, a new fundus optic disc localization and segmentation method based on phase congruency is presented.

## 2. FEATURE DETECTION USING PHASE CONGRUENCY

Phase consistency research was initiated by Morrone [11]. Feature detection method based on phase congruency assumes the point at which phases of Fourier components are most consistent as feature point, rather than obtaining feature point based on gray information of image.

First of all, let us give the concept of phase consistency. Fig. 1(a) and 1(b) show the Fourier series expansions of square wave and triangle wave respectively, in which dot lines represent harmonic components. In Fig. 1(a), phase values of all harmonic components are consistent at the step point and the degree of phase congruency is the highest at this position. While phase values are different at other points and the degree of phase congruency is relatively low. As shown in Fig. 1(b), the phase congruency can reach to the highest value at the vertex of triangle wave. The most important aspect is that when using phase congruency to mark the interest feature point, it needs no assumption to waveform and only requires finding feature points according to phase congruency in Fourier transform domain.



(a) (b)

***Fig. 1.*** *Fourier series expansions of square wave and triangle wave(only several first terms are plotted)*

The phase congruency function is defined by Morrone and Owens [12]:

$$PC(x) = \max_{\bar{\phi}(x)\in[0,2\pi]} \frac{\sum_n A_n \cos(\phi_n(x) - \bar{\phi}(x))}{\sum_n A_n} \qquad (1)$$

The value of $\bar{\phi}(x)$ that maximizes value of Equation (1) is the weighted mean of local phases of all Fourier terms at the point. Thus finding where phase congruency is a maximum is approximately equivalent to finding where the weighted variance of local phases, relative to the weighted average local phase, is minimum.

Venkatesh and Owens [13] pointed out that the points of maximum phase congruency can be calculated by searching for peaks in local energy function. For a one-dimensional signal $F(x)$, the local energy can be calculated by convolving the signal with a pair of filters. This pair of filters contains an even filter $M_{even}$ and an odd filter $M_{odd}$. For signal $I(x)$, local energy can be calculated by:

$$\begin{aligned} LE &= \| E(x) \| = \sqrt{F^2 + H^2} \\ &= \sqrt{(I(x) * M_{even})^2 + (I(x) * M_{odd})^2} \end{aligned} \qquad (2)$$

where $H(x)$ is Hilbert transform of $F(x)$.

First differential or quadratic differential of Gaussian filter, Gabor wavelet function filter and their Hilbert transform are always used to calculate local energy. Gabor function is a sine and a cosine function modulated by Gaussian function, and it constitutes an even wavelet and an odd wavelet accordingly. On the linear frequency scale, transfer function of Log-Gabor function gets the form below:

$$g(\omega) = e^{\frac{-(\log(\omega/\omega_0))^2}{2(\log(\beta/\omega_0))^2}} \qquad (3)$$

where $\omega_0$ is the center frequency of the filter. To obtain the filter with constant shape, the value of $\beta/\omega_0$ must keep identical for different $\omega_0$.

## 3. FUNDUS OPTIC DISC LOCALIZATION AND SEGMENTATION METHOD BASED ON PHASE CONGRUENCY

Firstly, feature detection is performed using PC model on four channel images with good contrast between optic disc and background respectively. Secondly, to obtain distinguishing optic disc features, multiplication operation is applied on the four PC feature detection results. Thirdly, window scanning and gray accumulating are operated to locate optic disc. Finally, iterative OTSU automatic thresholding segmentation and Hough transform are performed on the location images, and so the final optic disc segmentation result is obtained.

### 3.1. Color spaces and channels selection

Due to the existence of blood vessels and diseases in fundus image, it is unsatisfactory to use PC model directly. Considering that the fundus image brightness has no effect

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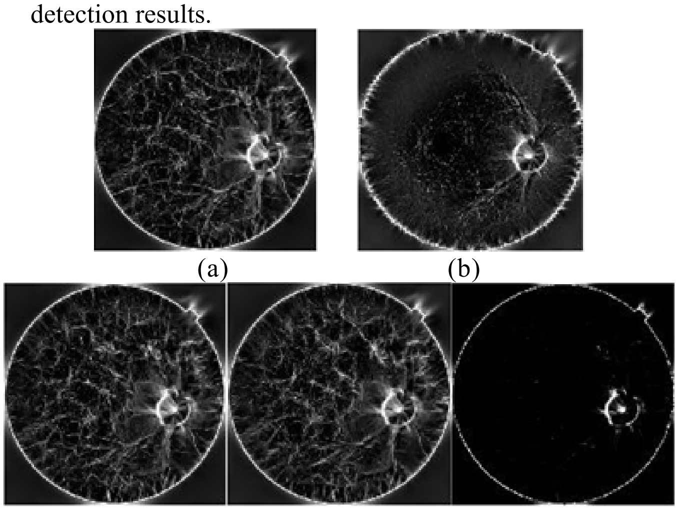
on phase information, chromatic aberration components of chromatic images are selected in LAB, YUV and YIQ spaces respectively. The HSV model is suitable for image processing algorithm which perceives color characteristics through human visual system. The S channel of HSV color space represents image saturation, and it is closely connected with people's sensing way of color. Through experiments, we select ‘A’ channel in LAB color space, ‘V’ channel in YUV color space, ‘I’ channel in YIQ color space and ‘S’ channel in HSV color space.The optic disc is obviously distinguishing in contrast to the background in above channels, which is conducive to locate optic disc in fundus images.

### 3.2. Fundus image feature detection using Phase Congruency

The implementation steps are as following and the results are shown in Fig. 2.

(1) Get feature detection results of above four channel fundus images through PC.

(2) To obtain distinguishing optic disc features, multiplication operation is applied on the four PC feature detection results.



(a) (b)

(c) (d) (e)

***Fig. 2.*** *PC detection results and multiplication result (a), (b), (c) and (d) are PC detection results of image of A, V, I and S channels respectively; (e) is the feature image by multiplication of (a), (b) (c) and (d).*

### 3.3. Fundus optic disc localization

Optic disc appears in color fundus images as a bright yellowish or white region. On the basis of this characteristic, further process is carried on multiplication result. The final location of optic disc is obtained by two steps as following:

(1) Preliminary localization: Window scan is operated to find the general position of optic disc in fundus image. Firstly, a sliding window is defined in fundus image, which requires a size equivalent to the bounding rectangle of optic disc. According to the proportion of optic disc in fundus image and consideration of optic disc deformation caused by diseases, the sliding window is set to $80\times80$ pixels. Then, the feature image of multiplication is scanned and the mean values of the image in each sliding window are calculated. Because white pixels mainly accumulate around the optic disc, the scan region with the biggest pixel mean value is considered as the position of optic disc. In a word, the algorithm finds the scan region with the biggest pixel mean value, and locates optic disc by mass center coordinate of sliding window.

(2) Precise localization: The accumulated gray values of the general located window are calculated along $X$, $Y$ direction and the maximums of which are recorded as $X_{max}$ and $Y_{max}$ respectively. To locate optic disc precisely, the accumulated gray values are compared with two thresholds. The partial image in the general located window, whose accumulated gray values along $X$, $Y$ direction are exceeds $0.5{*}X_{max}$ and $0.5{*}Y_{max}$ respectively, will be reserved. The precise localization of optic disc is obtained by the center coordinate of the reserved part in the general located window.

### 3.4. Fundus optic disc segmentation

The optic disc is segmented based on the location result. In order to highlight the optic disc and reduce the effects from secretions, blood vessels and noise, a 100×100 rectangular region larger than sliding window which contains optic disc is cut out from the original fundus image according to the localization result.

The iterative OTSU automatic threshold segmentation mainly includes three steps. Firstly, the original image is divided into background region and original target region using OTSU method. Secondly, a new threshold is conformed using OTSU method again in the original target area. Thirdly, original image is segmented based on the new threshold.

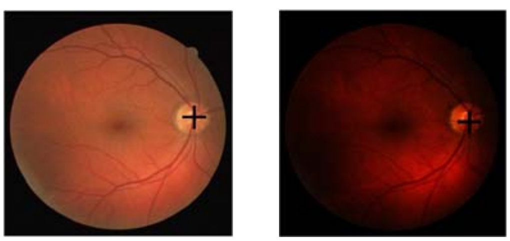
Hough transform is used to detect the edge of optic disc based on the binarization result. In general, optic disc in fundus image approximates a circle, but the radius of this circle is not fixed because of the influence of individual differences, diseases and other factors. When using Hough transform, the X-Y image plane is transformed into the a-b-r three-dimensional parameter space. Every point in X-Y plane corresponds to a cone in a-b-r three-dimensional space. Find out the peak point in the parameter space, the circle center and radius in image plane can be obtained, and then the circular contour of optic disc can be segmented.

## 4. EXPERIMENT RESULTS AND ANALYSIS

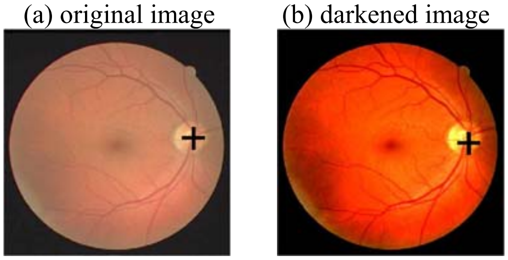
Fundus images in clinic and in STARE [14], DRIVE [15] and MESSIDOR [16] image databases are tested in our experiments over different image qualities. In all experiments, PC model with four scales and six orientations is adopted, and $\omega_0$ =0.2, $\beta / \omega_0$ =0.55 in Log-Gabor function. Parameters involved in iterative OTSU automatic thresholding segmentation and Hough transform are selected automatically.

### 4.1. Optic disc location experiment

In order to verify the stability of our algorithm for different brightness and contrast, darkened, brightened and gray-stretched fundus images are tested respectively. The optic disc location results are shown in Fig. 3.



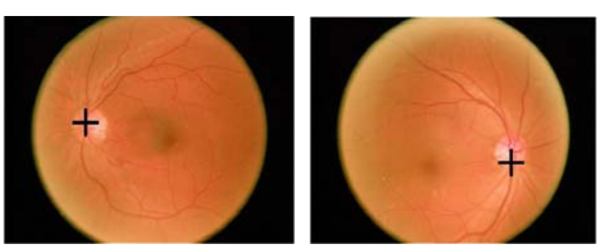
(a) original image (b) darkened image



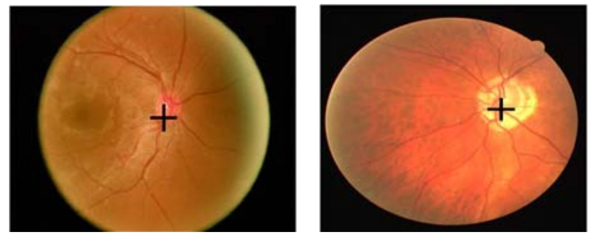
(c) brightened image (b) gray-stretched image

***Fig. 3.*** *Stability test of optic disc location algorithm*

Several clinic images are tested by the proposed method. The optic disc location results of clinic fundus images are shown in Fig. 4.



(a) (b)



(c) (d)

***Fig. 4.*** *The optic disc location results of clinic fundus images*

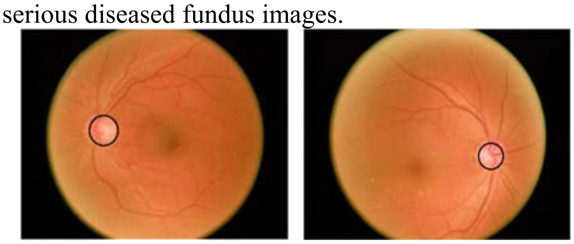
Figs. 4(a), 4(b), 4(c), 4(d) shows the optic disc location results of normal fundus image, mild fundus image, moderate fundus image and serious fundus image respectively.

The experimental results show that the proposed method achieved great effectiveness in normal, mild, moderate and serious diseased fundus images.

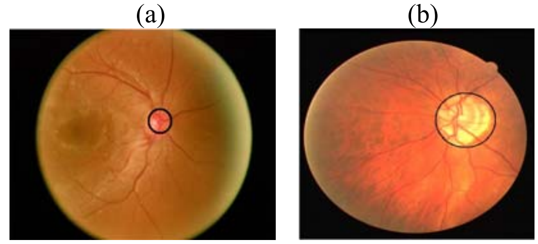
To demonstrate the performance of the proposed method further, we test it with images in STARE and DRIVE fundus image databases. The correct location rate of our method achieves 100%. Our method has better robustness compared with the methods in Ref. [3] and [5].

### 4.2. Optic disc segmentation experiment

Several clinic images are tested, including normal and pathological fundus images, which are shown in Fig. 5. The experimental results show that the proposed method can give good segmentation results for normal, mild, moderate and serious diseased fundus images.



(a) (b)



(c) (d)

***Fig. 5.*** *The optic disc segmentation results of clinic fundus images*

To demonstrate the performance of the proposed method further, images in DRIVE fundus database are

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tested and the overlap ratio $S$ is calculated to evaluate the performance of each optic disc segmentation algorithm.

$$S = \frac{Area\left(GT \cap C\right)}{Area\left(GT \cup C\right)} \tag{4}$$

where $GT$ is the real optic disc region and $C$ is the result by image segmentation method. According to overlap ratio $S$, segmentation results from excellent to bad are evaluated by rand E(excellent) when $S \geq 0.7$ , rand G(good) when $0.5 \leq S < 0.7$ , rand F(fair) when $S < 0.5$ and rand B(bad) when optic disc could not be located.

For example, the optic disc segmentation results of number 24, 39, 40 training pictures are shown in Fig. 6. The first column shows the original images; the second column gives the results by Lupascu's method; the third column gives the segmentation results by our proposed method. The optic disc segmentation level of our method and Lupascu's method are shown in Tab. 2.

Compared with Lupascu's method, segmentation level of our method has obvious improvement. Level E and G in our method account 95% in all the segmentation result, which increase 25% compared to Lupascu's method. Meanwhile, level F reduces to 5% and level B is eliminated. The results show that our method is more accurate and more robust.

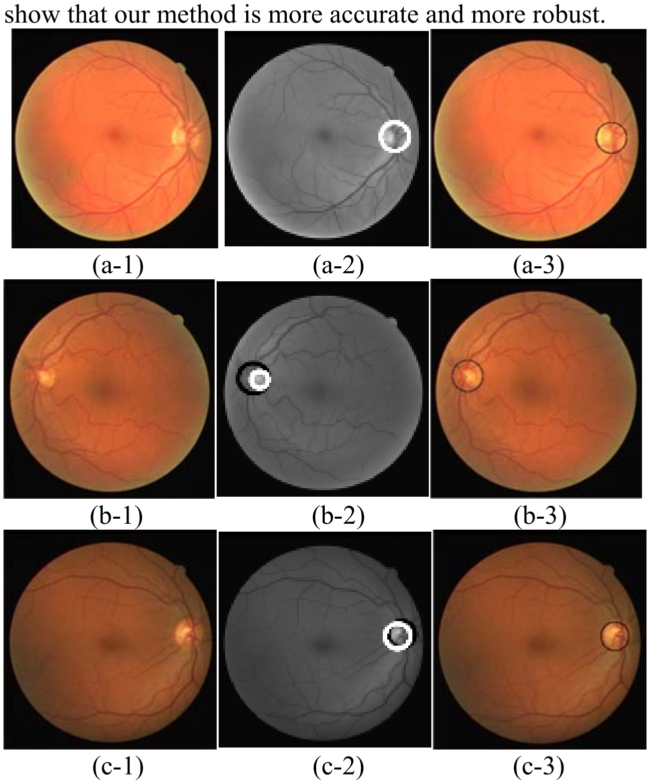


***Fig. 6.*** *The optic disc segmentation results of our method and Lupascu's method*

***Tab. 2.*** *The segmentation level of our method and Lupascu method*

| | E | G | F | B |
|---|---|---|---|---|
| Lupascu's method | 62.5% | 7.5% | 25% | 5% |
| Our method | 70% | 25% | 5% | 0% |

## 5. CONCLUSION

This paper proposes a new fundus optic disc localization and segmentation method based on Phase Congruency (PC). Firstly, in order to highlight optic disc, original images are transformed into LAB, YUV, YIQ and HSV color spaces. Secondly, four channel images with good contrast between optic disc and background are processed based on PC. Thirdly, window scanning and gray accumulating are operated to locate the optic disc. Finally, iterative OTSU automatic thresholding segmentation and Hough transform are performed on location images, and so the final optic disc segmentation result is obtained. We test our method with many kinds of images, including clinic images and images in STARE, DRIVE and MESSIDOR fundus image databases. The experimental results show that optic disc can be located and segmented accurately in all normal images in the test set.

## 6. ACKNOWLEDGMENT

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