



# DETECTING THE OPTIC DISC BOUNDARY AND MACULA REGION IN DIGITAL FUNDUS IMAGES USING BIT-PLANE SLICING, EDGE DIRECTION, AND WAVELET TRANSFORM TECHNIQUES

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## ABSTRACT

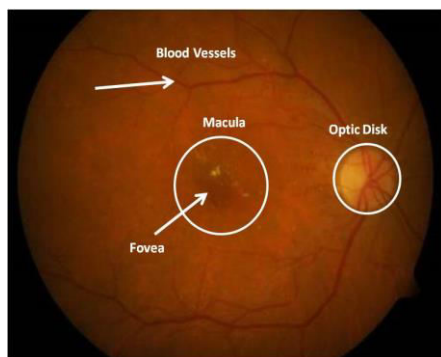
Early diagnosis of vision abnormalities is key focus for medical experts in order to start treatment earlier, particularly for Diabetic Retinopathy (DR) treatment. In this paper, we have presented a simple, novel algorithm to find the optic disc (OD) and macula in color retinal images which is a fundamental step in DR analysis. The proposed segmentation algorithm involves various image processing techniques such as bit-plane slicing, edge direction detection, HSI color space conversion and block searching using wavelet transformation matrix.

**Keywords:** diabetic retinopathy, optic disc, macula, bit-plane slicing, edge direction, wavelet transform.

## 1. INTRODUCTION

Automatic diagnosis of eye diseases from the retinal fundus images is the active research area from very long time in medical image processing. In particular analysis and segmentation of OD is the key step in all type of retinal anatomical structure analysis.

Figure-1 shows an example of fundus image with various anatomical structures of retina. Retina is the interior surface of the eye and basically it acts as film for the eye. When the light rays enter into eye, this retina converts this light energy into electrical signals and conducts these signals to the brain via optical nerve system.



**Figure-1.** Retinal fundus image with main anatomical structures.

Generally, OD is the bright spot in the retina through which optical nerve and blood vessels enter into eye. Macula is responsible for our central and colour vision.

Fovea is in center of the Macula and it is responsible for our highest visual acuity. A bunch of

vessels called vascular network supply oxygen, nutrients and blood to the retina.

Accurate and efficient segmentation of this OD is the important prerequisite task in the automated retinal analysis systems. There are many reasons for the analysis and segmentation of this OD. Some of them are discussed here.

In order to find the abnormal structures of the retina, it is often required to eliminate normal anatomical structures from the retinal image. For example, removal of OD is very important when hard exudates detection is in progress. Because, the attributes for both OD and hard exudates are similar that means the bright lesions. So, in order to avoid, false positive, removal of OD is necessary in the objective.

Diabetic retinopathy and glaucoma analysis require OD identification as the main step. Presence of glaucoma is sometimes observed based on the cup disc ratio (CDR). The cup is the inner portion of OD and always small in size. The relative size of OD and cup is calculated (CDR) and its ranges from 0.1 to 0.5. This value is an important indicator for glaucoma.

For blood vessel detection, OD can be used as reference object since all the vessels are originated from OD. Similarly, OD can be used as reference object for Macula and fovea detection also.

In this work, we have proposed a novel segmentation algorithm for the detection of OD and Macula. The proposed algorithm uses bit-plane slicing method for initial identification region of interest (ROI) of OD. Then, block by block searching for unwanted pixels removal has been implemented for further cleaning of OD ROI. An edge direction method is used for final detection of OD ROI. Then, wavelet based radial block matching algorithm on the intensity image of colour fundus image has been implemented for final detection of OD. The



Macula is localized finally in relation with position of segmented OD.

## 2. RELATED WORK

Many authors have published their works related to the optic disk segmentation (OD). In this section, some of their works have been discussed. According to ShijianLu [1], a circular transformation was designed to capture both the circular shape of the OD and the image variation across the OD boundary simultaneously. This method evaluates the image variations along multiple evenly oriented radial line segments of the specific length. The pixels with maximum variation along all line segments are determined which can be further exploited to locate both optic disc center and its boundary. Kumara, M.R.S.P *et al* [2] proposed an active contour-based segmentation algorithm for OD segmentation. Their proposed work consists of two steps: approximation of optic disk by means of edge detection, morphological operations and circular Hough transformation and exact boundary detection using an active contour model.

Attanassov intuitionistic fuzzy histon (A-IFSH) based segmentation was proposed by Muthu Rama Krishnan, M *et al* [3]. Optic disc pixel intensity and column wise neighbourhood operation was employed to locate and isolate the optic disc in their algorithm. Joshi *et al* [4] presented a novel algorithm for cup boundary detection. In their method, a relative motion model from the set of related images is estimated. The information encoded by this method was used for approximation of cup boundary and final is identified with of best fitting circles.

A new, fast, reliable and fully automatic OD segmentation algorithm was proposed by Yu, H [5] in 2012. In this novel method, first, a template matching is applied for OD localization. Then, OD location is identified based on vessel patterns. Finally, a fast hybrid level set method is applied with pre-determined OD center and approximate radius for the accurate segmentation of OD. Mahfouz, A.E and Fahmy, A.S [6] proposed a high speed OD segmentation algorithm using image features. According to them, speed up OD segmentation is achieved by computing a one dimensional projection vector for image features that encode x and y co-ordinates of OD initially. Then, the resulting projection vector is undergone for searching to determine location of OD which avoids processing of image in two dimensional spaces, hence enhancing the computation time.

Abdel-RazikYoussif *et al* [7] presented their research for OD segmentation using vessel's direction matched filter in 2008. In their method, OD localization is achieved by finding the direction of the vessels which are in the vicinity of the OD. A simple 2D Gaussian matched filter is used to determine the direction of the vessels and the center of OD and its boundary are estimated by applying morphological operations on the resulting image. Recently, Salazar-Gonzalez *et al* [8] developed a novel

algorithm for vessels and OD segmentation based on hybrid methods. In this method, retina vascular structures are extracted using graph-cut method as the first step.

Then, this blood vessel information used to find the location of the optic disk. Finally, OD is segmented using two alternative ways: 1) using Markov random field image reconstruction and 2) compensation factor method. An automatic algorithm for the segmentation of OD cup and rim in spectral 3-D OCT volumes was proposed by Kyungmoo Lee [9]. According to their work, a fast multi-scale 3D graph searching algorithm is used to segment four intra-retinal surfaces as first. After surface segmentation, the retina in each 3-D OCT scan was flattened to ensure a consistent optic nerve head shape. Then, a set of features are derived from the segmented intra-retinal surfaces and volume intensities and a classifier is trained to classify background, cup and rim. Finally, a convex hull-based approach is used to locate OD based on the prior knowledge of its shape and size.

A region growing based approach for OD segmentation was presented by Singh *et al* [10]. In their approach, the center of the OD is identified with double windowing method and this OD center is considered as seed point for region growing algorithm for intensity based OD segmentation. Jun Cheng *et al* [11] presented a new technique for OD segmentation called peripapillary atrophy elimination. In this technique, the elimination is done through edge filtering, constraint elliptical Hough transform and peripapillary atrophy detection. With the elimination, edges that are likely from non-disc structures especially peripapillary atrophy are excluded to make the segmentation more accurate. A super pixel classification based method is proposed for the initialization of deformable model based optic disc segmentation by Jun Cheng *et al* [12]. In their work, histogram of super pixels is used as feature for training and classification. They achieved good performance on OD segmentation based on this work. Mohammad *et al* [13] presented texture based approach OD segmentation. In their method, two texture measurements are used: 1) Binary Robust Independent Elementary Features (BRIF) and 2) a rotation invariant BRIEF (OBRIEF) as features for classification. A simple mathematical morphology based idea on OD segmentation was given by Oakar Phyo and Aung Soe Khaing in 2014 [14]. Mathematical morphology methods such as closing, filling, morphological reconstruction and Otsu algorithm are used for the localization and segmentation of OD. Sandra Morales *et al* [15] discussed stochastic watershed based segmentation approach. In their idea, the fundus image is pre-processed with principal component analysis and morphological operations. Then, stochastic watershed algorithm is applied in order segment OD.

The rest of the paper is arranged as follows. Section 3 details the proposed OD and Macula segmentation approach, while section 4 reports some experimental results. Finally, in section 5 conclusions are



drawn and possible future development of the system is discussed.

### 3. PROPOSED WORK

Our proposed optic disk segmentation followed by Macula identification algorithm involves sequence of image processing techniques. These methods include: (1) Bit plane analysis for ROI segmentation. (2) Block based filtering for unwanted pixels removal in ROI. (3) Edge direction identification for further removal of unwanted objects from ROI (4) HSI color space conversion (5) Optic Disk Localization using wavelet transformation matrix and (6) Macula region identification. All these methods are discussed in detail as follows.

#### 3.1 Bit plane analysis for ROI segmentation

As the retinal image has very small variation in intensity throughout the image with little bit contrast around the optic disk region, it is not an easy task to segment the optic disk using simple threshold techniques. So, accurate segmentation of OD requires multi-level of segmentation process. As the first step, the region of interest is segmented from the input fundus image using bit plane slicing method. Any gray scale image can be split into equivalent binary planes called bit planes. Bit-plane slicing is the process of extracting the specific bit plane that contributes to the region of interest in which optic disk presents. Separating a digital image into its bits planes is useful analyzing the relative importance played by each bit of the image, a process that aids in determining the adequacy of number of bits used to quantize each pixel (Gonzalez and Woods, [16]). Suppose, if a digital image is considered as composition of eight 1-bit planes, ranging from 0 for least significant bit to plane 7 for most significant bit. In terms of 8-bit bytes, plane 0 contains all the lowest order bits in the bytes comprising the pixel in the image and plane 7 contains all the higher order bits. Figure-2 illustrates these ideas. Note that higher order bits (especially top few planes) contains the majority of visually significant data whereas the other bit planes contribute to more subtle details in the image.

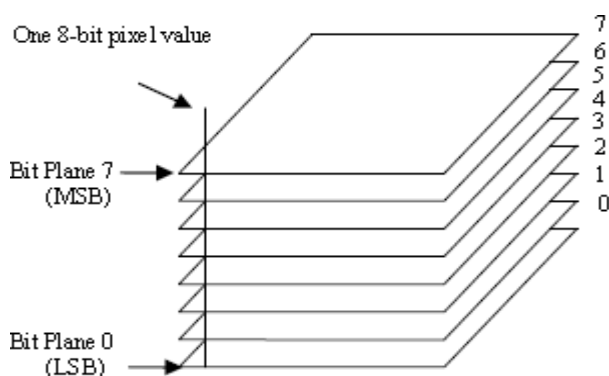


Figure-2. Bit-plane slicing.

In our proposed work, it is observed that both bit planes 7 and 8 contribute most of ROI. However, out of these two high order bit-planes, either plane 7 or plane 8 shall be selected as final ROI by finding the minimum of total number of pixels that contribute in each plane. Figure-3 shows the original retinal image and initial ROI image found using this method.

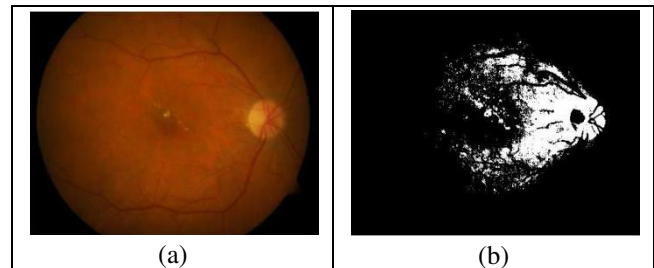


Figure-3. a) Original Fundus image b) Initial ROI image segmented using Bit-plane slicing.

#### 3.2 Block based filtering for unwanted pixels removal in ROI

The result of bit-plane analysis is a binary image which may contains large number of connected components with varying sizes. In order to make ROI to be suitable for further process, unwanted small size isolated objects must be eliminated, so that the resulting image will have smooth ROI. To do this, the bit-plane image is split further into number of small blocks. Then, total number of non-zero pixels is calculated for each block. The blocks for which non-zero pixels count greater than or equal to a predefined threshold  $T$  are retained for further process, while other blocks left unconsidered or made to zero. The reason behind this block based unwanted pixels removal is more important. Instead of removing isolated small objects based on its size in the whole image, this method will keep small objects left unaffected which has significant contribution to the ROI.

#### 3.3 Edge direction method for ROI finalization

The final ROI is refined in this step. As the vessels which are originated from center of the OD are vertical in direction than the other vessels, finding the vertical edges will be useful for finalizing ROI of the disk region. After the removal of isolated small objects in previous block based searching method, Sobel edge detection method is applied on the resulting image to segment vertical edges only. Typically, the Sobel operator is used to find the approximate absolute gradient magnitude at each point in an input gray scale image. This Sobel edge detection operator uses a pair of 3x3 convolution mask, one finding the edges horizontally, and another is used to find the edges vertically. The vertical and horizontal sobel masks are shown in Figure-4.



-1	0	+1
-2	0	+2
-1	0	+1

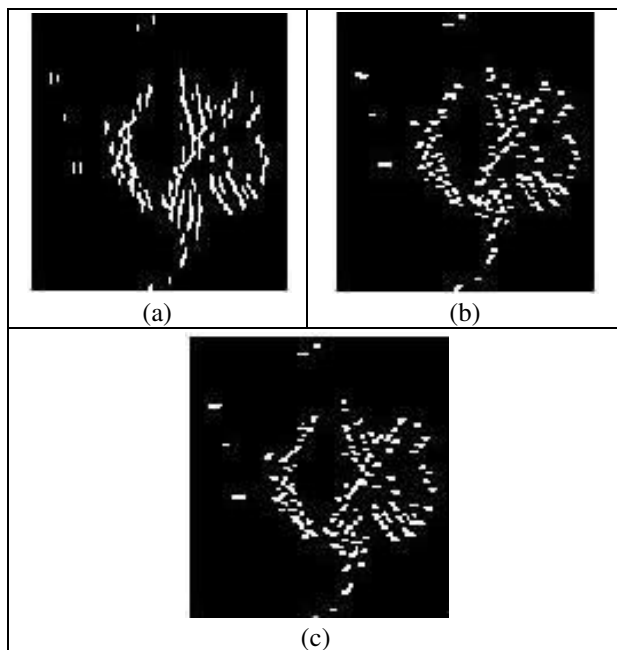
(a)

-1	-2	-1
0	0	0
+1	+2	+1

(b)

**Figure-4.** a) Sobel edge operator - vertical b) Sobel edge operator - horizontal.

Since, we are interested on vessel direction detection only which is vertical within the optic disk region, the vertical convolution mask only used for the detection of sobel edges. Then, gradients of the sobel edge image are computed and direction and magnitudes of the gradient images are estimated finally. The object which has maximum number of vertical edges within the direction range  $-90^\circ$  to  $90^\circ$ , is chosen as the final ROI and other objects are discarded for further analysis. Figure-5 shows the results of edge direction method.



**Figure-5.** a) Horizontal gradient b) Vertical gradient c) result of edge direction method.

### 3.4 Optic disk localization

Locating exact optic disk from the ROI image involves two steps: 1) RGB to HSI color space conversion and 2) Wavelet based block matching. These methods are discussed as follows.

### Converting colors from RGB to HSI

Analyzing intensity value of an image is sometimes more important rather than analyzing gray scale value because of its nature of distinguishing the various regions of an image. Since, the intensity of an optic disk is more than the other elements of the retinal image; it is easy to segment OD when the intensity based analysis is applied. Among the many colour spaces, Hue, Saturation and Intensity (HSI) colour space domain gives intensity information of an image. In our method, the original RGB retinal image is converted into HSI color space using the following equations 3.1 to 3.3.

H component of each RGB pixel is obtained using the following equation [3.1].

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases} \quad (3.1)$$

Where,

$$\theta = \cos^{-1} \left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}} \right\} \quad (3.2)$$

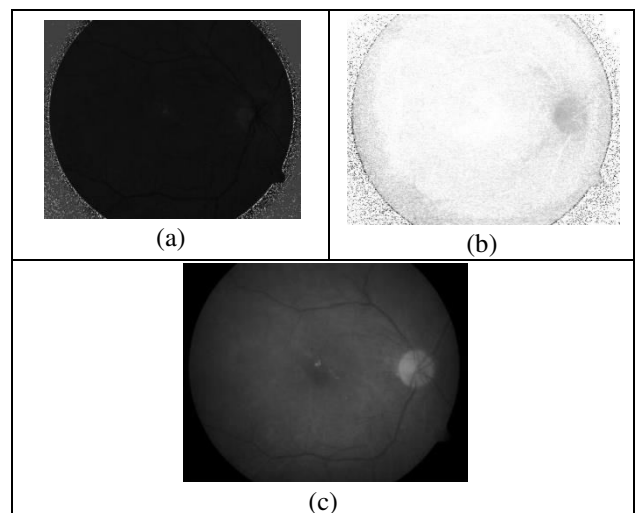
The saturation component is

$$S = 1 - \frac{3}{(r+g+b)} [\min(R, G, B)] \quad (3.3)$$

Finally, the intensity component is

$$I = \frac{1}{3}(R + G + B) \quad (3.4)$$

Figure-6 shows the HIS components of the original RGB image.



**Figure-6.** a) Hue component b) Saturation component c) Intensity component.





Then, the intensity channel I of the HSI image is multiplied with binary final ROI image which is obtained in previous steps to get intensity equivalent of the ROI image.

### Block matching algorithm for OD localization using wavelet

We have developed two different methods for locating the OD using block matching method: a) Radial block matching algorithm and b) Simple block matching algorithm.

**Radial block matching algorithm:** In this step, the centroid of the binary ROI image is calculated first. Then, the ROI intensity image is split into number of small sub blocks of size  $m \times m$  ( $m$  varies from 4, 8, 16 ...). The sub block on which centroid point is located is identified as initial reference block. A wavelet transformation matrix is obtained for this reference block using the equation 1.0. Then, wavelet transformation matrices for 8 neighbor blocks of the reference block are computed and compared with wavelet transformation matrix of the reference block using L2 norm distance value. Blocks which are having minimum distance value are identified as part of the OD and merged with reference block. These newly added blocks will become new reference blocks and the above mentioned radial block matching algorithm will be repeated until no more blocks are identified for further merging. Figure-7 shows the process of radial block matching and Figure-8 shows the OD boundary detected.

**Simple block matching algorithm:** In case the resulting ROI intensity image obtained from the above discussed methods doesn't contains any valid ROI, then, the intensity image is split into number of small sub blocks of size  $m \times m$  ( $m$  varies from 4, 8, 16 ...). The sub block which is in the top left corner will be the initial seed block for searching instead of centroid block of ROI. And the rest procedure is same as used in radial block matching algorithm.

Once the blocks which constitute OD region are merged, the final OD is marked as follows. First, a bounding box is created around the OD by finding top-left and bottom-right corner points of the merged blocks. Then a circular mark is made around the OD using a radius calculated from the center point of the bounding box and its maximum extent from its center point.

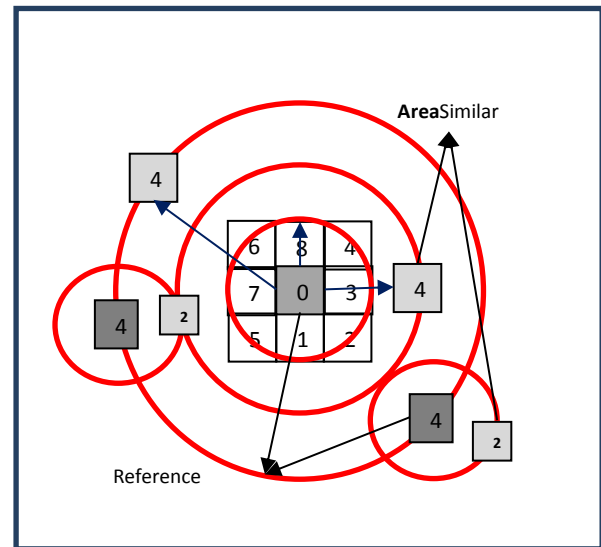


Figure-7. Radial block searching algorithm.

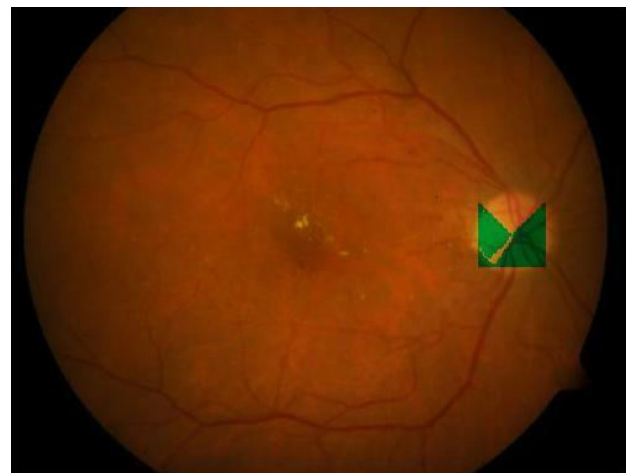
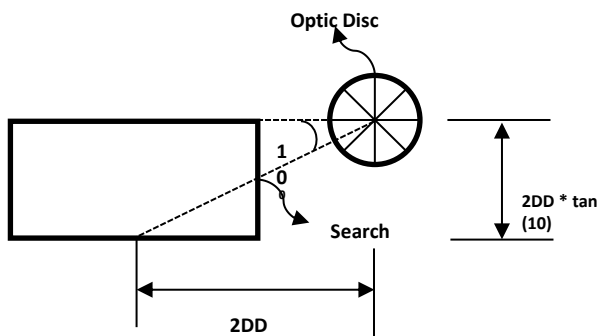


Figure-8. Result of segmented OD boundary using radial block matching algorithm.

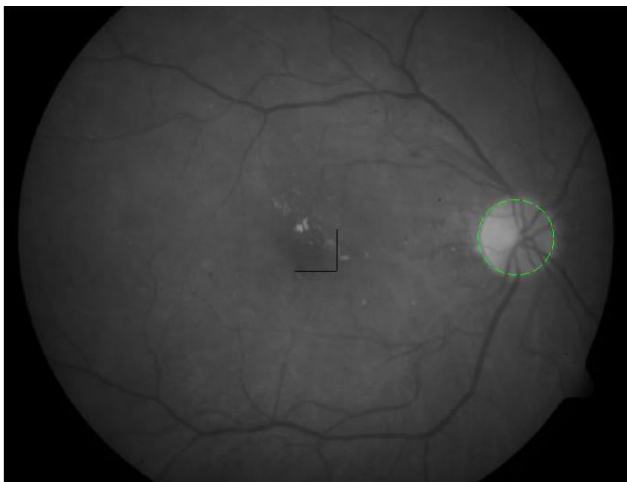
### Macula region detection

The macula region usually has very low contrast in a retinal image. Sometimes, it may be obscured by presence of exudates or haemorrhages in its region. Because of this, obtaining global correlation for macula localization often fails. Therefore, macula is localized based on its distance and position from the OD as it is constant always. So, once the OD is detected, localization of macula is carried out by finding a darkest region within the specified area in the image. Figure-9 shows the process of macula detection.



**Figure-9.** Macula localization process.

In standard retinal images, the mean angle between OD center and macula center is against the horizon is found to be about  $-5.6 \pm 3.3$  degrees and distance is 2 DD (disc diameter) temporal to the OD. Based on this prior knowledge, a rectangular region is formed with 2DD width as shown in Figure-10. A small scan window of size 40x40 is taken to search the entire region and average intensity at each pixel location is calculated. The pixels with lowest average intensity are marked as macula. Figure-10 shows the final OD and macula detection result.



**Figure-10.** Final OD and Macula detection result.

#### 4. RESULTS AND DISCUSSIONS

The proposed method was evaluated using a subset of the DIARETDB0 (Standard Diabetic Retinopathy Database - Calibration Level 0) dataset, containing 81 fundus images of both normal and diseased retinas, and initially used by literature OD detection methods. The OD-center was detected correctly in 80 out of the 81 images (98.77%). To quantify the accuracy of proposed method, the results are compared against the hand labelled ground truth images made by clinician. Equations 4.1 and 4.2 are used to calculate sensitivity and

specificity which are used as the measure to match between two regions in the images.

$$\text{Sensitivity } S_n = \frac{T_p}{T_p + F_n} \text{ and} \quad (4.1)$$

$$\text{Specificity } S_p = \frac{T_n}{T_n + F_p} \quad (4.2)$$

Where  $T_p$ ,  $T_n$ ,  $F_p$  and  $F_n$  are true positives, true negatives, false positives, and false negatives, respectively. Table-1 shows overall sensitivity and specificity for all 148 images in the dataset.

**Table-1.** Performance of optic disc boundary detection.

No. of images	Sensitivity	Specificity
81	91.32±6.01	95.10±5.03

#### 5. CONCLUSIONS

In this paper, we have presented simple and novel optic disc segmentation for color fundus images. The proposed scheme facilitates the segmentation of the OD efficiently using combined image processing methods such as bit-plane slicing, edge direction detection, color space conversion and wavelet based block searching techniques. Our algorithm performs well in publicly available databases. It is hoped that the automatic optic disc segmentation method can assist the ophthalmologist for the early detection of glaucoma and retinopathy diseases.

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