

## Study of the Contour and the Excavation of the Optic Nerve Head

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### Abstract

**Purpose:** To extract the characteristic features of glaucoma automatically and early detection of the excavation of the cup inside papilla to identify the glaucomatous from non-glaucomatous to limit the disease progression.

**Design:** Perspective based on literature review and clinical expertise and analysis a set of clinical retinal fundus images for ophthalmology.

**Methods:** To automatically extract the disc, two methods making use of an edge detection circular Hough transform method and active contours are proposed in the paper. For the cup, excavation, inspection by histogram is used to automatically detect the cup.

**Results:** The value of cup-to-disc ratio CDR which is more than 0.50 is used to assess a patient as a glaucomatous case and the retina images analysis shows other features.

The features are automatically extracted as the area of the excavation, which has evolved over time, helps the ophthalmologist specify the severity of retinal disease.

**Conclusion:** The cup to disc ratio (CDR) and the area cup are important measures of the peril of the presence of glaucoma in an individual. In this study, we have presented an improvement method to calculate the CDR along vertical and horizontal axis automatically from fundus images of retina.

A set of 10 retinal images obtained from Tunisian glaucomatous patient, is used to assess the performance of the determined CDR to the clinical CDR, and it is found that our proposed method provides 98% accuracy in the determined CDR results and screening glaucoma.

**Keywords:** Glaucoma; Excavation; Circular Hough transform; Contours active Chan and Vese model; Combined method CHT and active contour; Segmentation; Cup-to-disc ratio

**Abbreviations:** CDR: Cup-to-Disc Ratio; ROI: Region of Interest; TPF: True Positive Fraction; TNF: True Negative Fraction;  $A_A$ : Automatically calculated image;  $A_G$ : Image with the ground truth labeling; CHT: Circular Hough Transform; AC: Active contours Chan and Vese model; DSI: Dice Similarity Index; r: correlation coefficient; ONH: Optic Nerve Head; NTG: Normal Tension Glaucoma; IOP: Intraocular Pressure

### Introduction

Glaucoma is a disease that is asymptomatic until advanced stages, it is a leading cause of blindness worldwide and early diagnosis is an important objective to achieve the aim that people who have glaucoma maintain the best visual acuity throughout life, improving their quality life.

The CDR evaluation is an important indicator and it has a great significance for the pursuing of the glaucoma. In fact, healthy eyes had a mean vertical CDR of  $0.45 \pm 0.15$  vs.  $0.80 \pm 0.16$  in glaucomatous eyes.

It is for this reason that the determination of this parameter and the sequel of its development during time and by exploiting successions of the set of clinical retinal fundus images for ophthalmology for the same patient can apprise us about the severity of pathology reached by this patient and it is whether in an irremediable phase or not if this ratio is close to the limit values such as 0.8 for example.

Glaucoma patients can significantly benefit from early diagnosis. Thus, the automated accurate screening is increasingly important due to the wide spread of this disease. Previous studies in the automated screening found a precision of 92.6%.

### Description

Glaucoma refers to a group of eye conditions that lead to damage to the optic nerve head with progressive loss of retinal ganglion cells and their axons. This leads to a progressive loss of visual field. There are typical optic nerve changes on slit-lamp examination as shows in Figure 1.

Glaucoma is usually associated with an intraocular pressure (IOP) above the normal range. However,

- 20-52% (this varies between populations) of patients with glaucoma have IOP within the normal range. Patients with normal IOP who develop the characteristic changes associated with open-angle glaucoma are said to have low tension or normal pressure glaucoma.

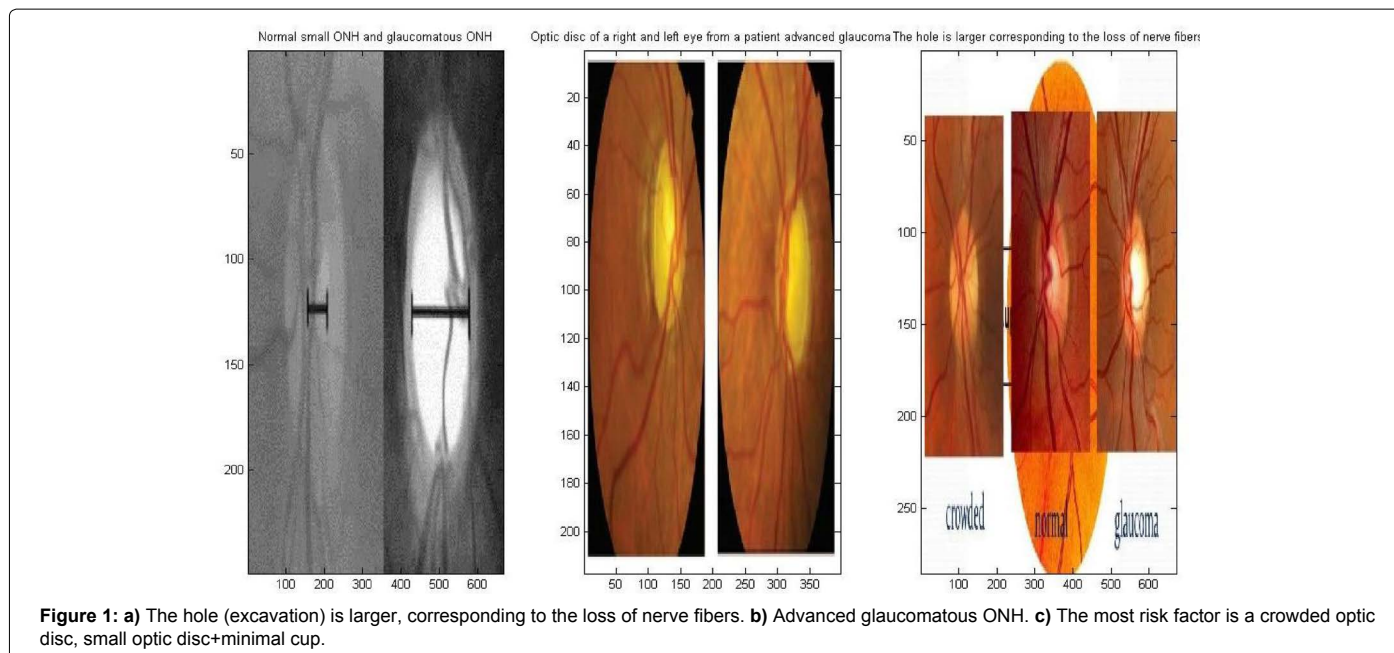
- Many patients have raised IOP for years without developing the changes of glaucoma. This condition is referred to as ocular hypertension.

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Dtabase		Sensitifity		Specificity		Accuracy	
Methods		CA	CHT	CA	CHT	CA	CHT
IM51	1	99.82%	98.03%	99.65%	99.22%	91.43%	80.92%
IM49	2	99.64%	97.20%	99.61%	99.86%	91.28%	97.10%
IM48	3	99.73%	98.07%	99.62%	99.89%	90.74%	97.56%
IM47	4	99.57%	94.32%	99.71%	98.89%	92.55%	99.99%
IM45	5	99.75%	96.43%	99.64%	99.98%	90.93%	99.54%
IM41	6	99.88%	87.33%	99.65%	99.99%	91.36%	99.87%

**Table 1:** Results of Active Contours AC algorithms followed by expert classify using the features described in Table 2 (Tunisian glaucomatous database). Detection of the disc was made with the circular Hough transform CHT used as a mask and we apply the active contours without gradient Van Cheese method. The results are described herein.

Prior to 1978, glaucoma was defined as IOP above 21 mmHg in an eye (the normal range is considered to be 10-21 mmHg with 14 being the average). More recently glaucoma has been understood as an abnormal physiology in the optic nerve head that interacts with the IOP, with the degree and rate of damage relating to both factors [1].

The end stage of glaucoma is referred to as absolute glaucoma. There is no functioning vision, the pupillary reflex is lost and the eye has a stony appearance. The condition is very painful and is treated by destructive processes (Table 1).

### Pathophysiology of Glaucoma

The primary problem in glaucoma is disease of the optic nerve. The pathophysiology is not fully understood, but there is a progressive loss of retinal ganglion cells and their axons. In its early stages it affects peripheral visual field only but as it advances it affects central vision and results in loss of visual acuity, which can lead to severe sight impairment and complete loss of vision [2,3].

For most types of glaucoma, optic neuropathy is associated with a raised IOP. This has given rise to the hypothesis of retinal ganglion apoptosis, whose rate is influenced by the hydrostatic pressure on the optic nerve head and by compromise of the local microvasculature. The resulting optic neuropathy gives rise to the characteristic optic disc changes and visual field loss.

The papillae excavation (“cup” Anglo-Saxon) finally, depression observed at the center of the disc. It is an empty space which, when is large enough, can expose the cribriform plate (with holes greyish white in a structure). It may be non-existent in small papillae, and have the shape of a funneling average taste outgrowth.

When the papillae are larger, it becomes downright cylindrical, usually with a gently sloping bottom and temporal, that high and nasal as shown in Figure 2.

It can be bordered on these big papillae, top or bottom (or both) of a vessel emerging from the central retinal artery called circum-linear vessel, which so perfectly fits the inner edge of the annulus of neuroretinal rim.

This type of vessel is an important reference monitoring; it should be noted when a subject is glaucoma or suspected of being homeless.

### Problem statement

An early detection of glaucoma is particularly significant since it allows timely treatment to prevent major visual field loss and prolongs the effective years of usable vision. The diagnosis of glaucoma can be done through measurement of CDR (cup-to-disc ratio) and the evolution of area’s cup over time. Currently, CDR evaluation is manually performed by trained ophthalmologists or expensive equipment such as Heidelberg Retinal Tomography (HRT). However, CDR evaluation

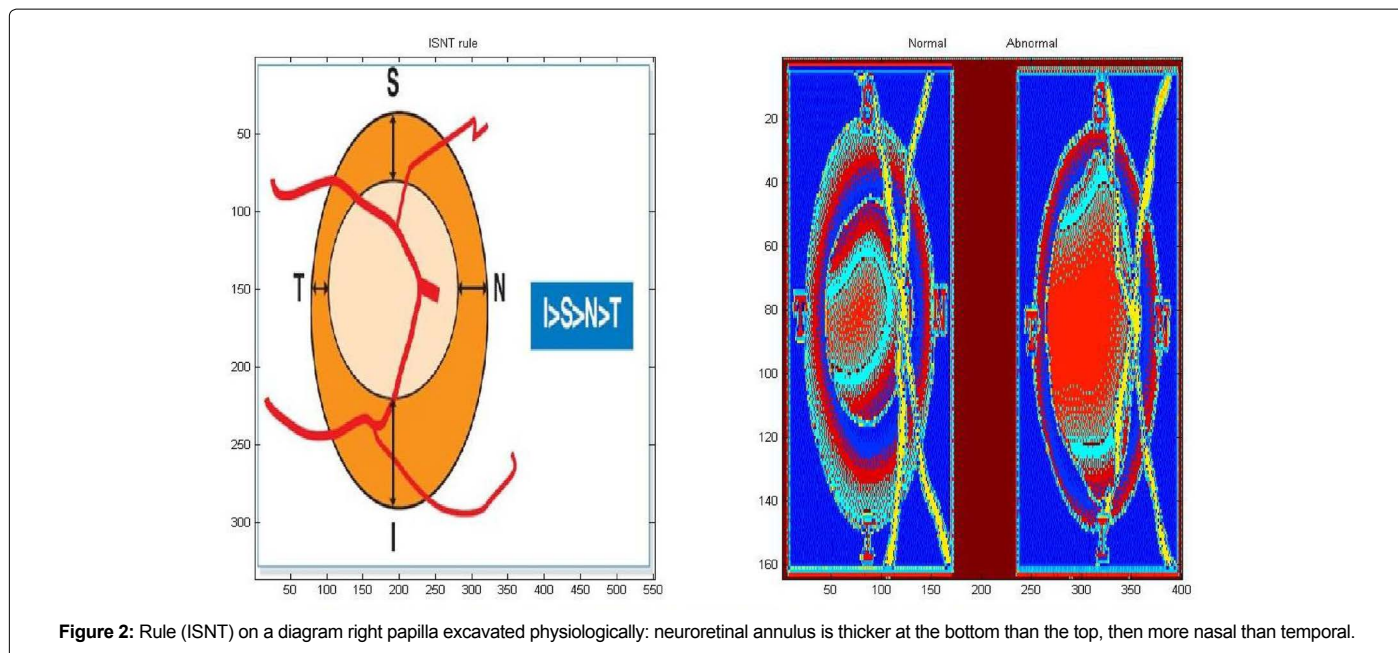


Figure 2: Rule (ISNT) on a diagram right papilla excavated physiologically: neuroretinal annulus is thicker at the bottom than the top, then more nasal than temporal.

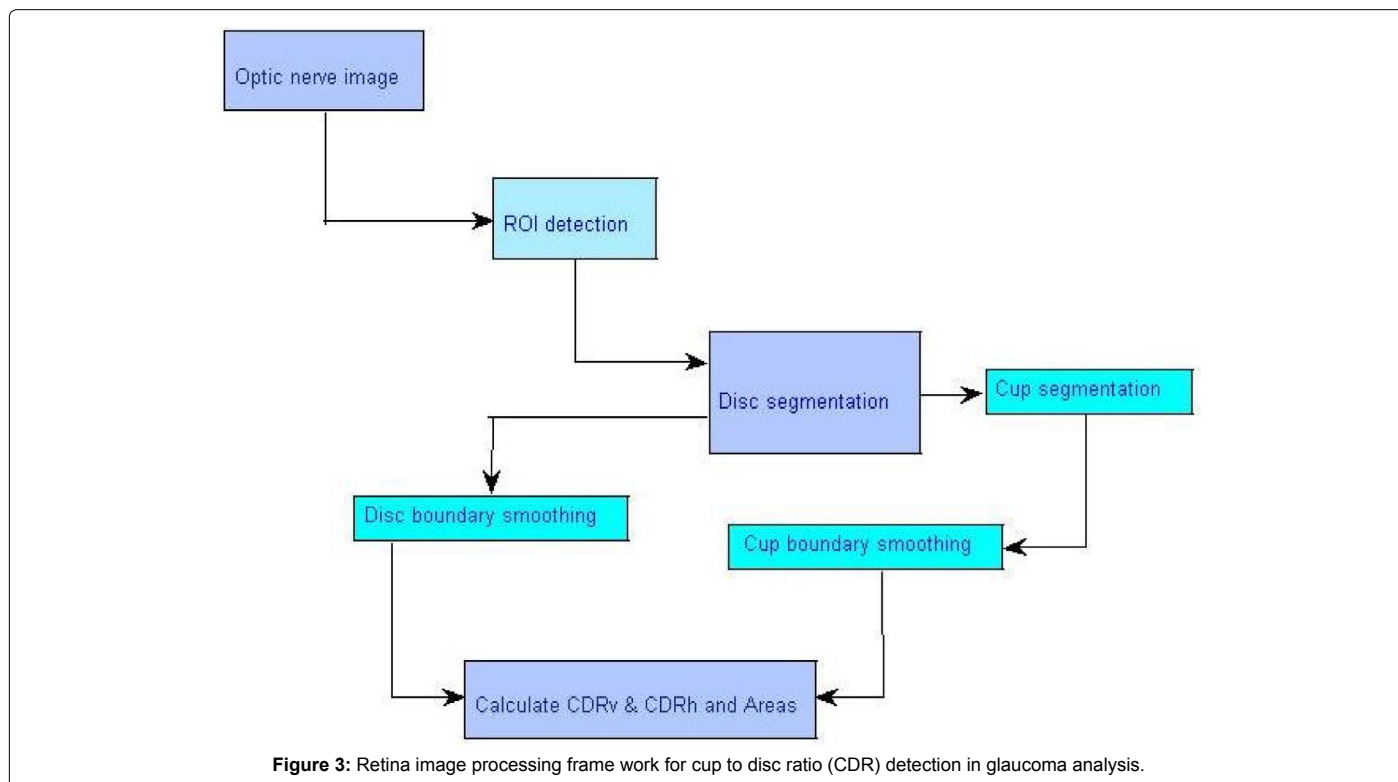


Figure 3: Retina image processing framework for cup to disc ratio (CDR) detection in glaucoma analysis.

by an ophthalmologist is subjective and the accessibility of HRT is very limited [4]. Thus, this paper proposes an intuitive, efficient and objective method for automatically classifying digital fundus images into either normal or glaucomatous types in order to assist ophthalmologists.

### Methodology

To calculate the vertical cup to disc ratio (CDR) along the vertical axis and the horizontal axis, the optic cup and disc first have to be

segmented from the retinal images. Figure 3 depicts the framework for building the proposed detection system.

### The cup-to-disc ratio CDR

It evaluates horizontally and/or vertically at the larger diameter of the optical disc and the wider diameter of the excavation in the same axis. It is expressed in tenths (0/10 to 10/10) or 0.0 (no excavation) to 1.0 (when the excavation is total). It seems more relevant if one wants

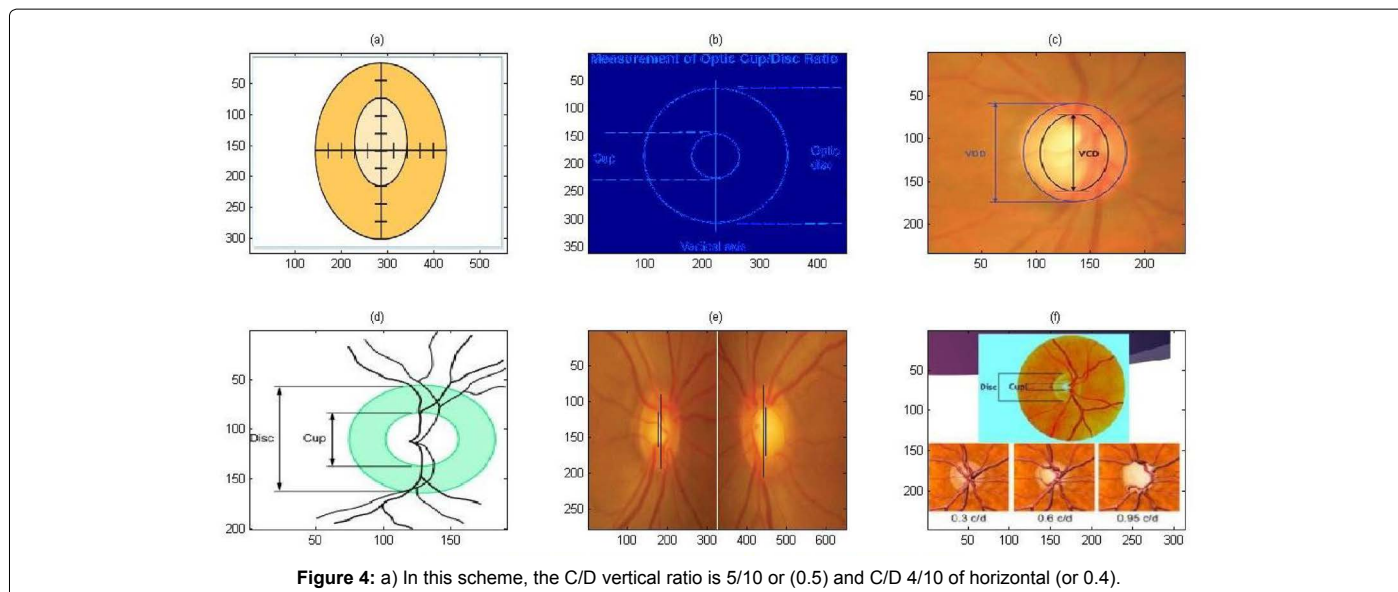


Figure 4: a) In this scheme, the C/D vertical ratio is 5/10 or (0.5) and C/D 4/10 of horizontal (or 0.4).

to keep that value, considering the C/D vertical: in glaucoma, the optic disc was first excavated more vertically than horizontally; and, in case of total excavation, vertical C/D is 10/10... that can be the horizontal C/D, because of the nasal vascular persistence of the emerging packet as shown in Figure 4.

Given the inter-individual variation in the size of the disc and thus the size of the physiological excavation, the gross value of the C/D ratio has no significance.

A ratio C/D to 3/10 can be pathological on a small disc, and a C/D equal to 8/10 on a large physiological papilla.

However, for a given globe, an increase in the C/D ratio reflects thinning of the neuroretinal annulus and thus an increase in the size of the excavation.

However, in normal tension glaucoma (NTG), IOP is in the normal range and this has led to other theories including vascular perfusion problems or an autoimmune component. Others have postulated that the optic nerve head is particularly sensitive in these patients, with damage occurring at much lower IOPs than in normal individuals. This could explain why these patients benefit from IOP-lowering medication [4] (Tables 3 and 4).

### Region of interest detection

Localization of the region of interest ROI since the intensity of the optic disc is much higher than the retinal background, a possible method in order to localize the optic disc is to find the largest clusters of pixels with the highest gray levels.

Therefore, the pixels with the highest 1% gray levels are selected. After this, a clustering algorithm groups the near by pixels into clusters.

Initially, each point is a cluster and its own centroid. If the euclidean distance between two centroids is less than a specified threshold  $\epsilon$ , these clusters are combined to one cluster.

The new centroid  $(C_x, C_y)$  is computed as :

$$C_x = \frac{\sum_{i=1}^n X_i}{n} \quad (1)$$

$$C_y = \frac{\sum_{i=1}^n Y_i}{n} \quad (2)$$

Where  $(C_x, C_y)$  is each cluster point and  $n$  is the number of points of the cluster.

After the combinaison process (Circular Hough transform+Active contours without edges : CHAN & VESE), the cluster with the maximum number of points is selected: ROI.

The points of this cluster correspond with the points of optic disc since the utilized images doesnot have large area of exutates. The region of interest ROI is defined as  $n*m$  rectangle whose center is the centroid of this cluster, the rectangle size depends on the image resolution as shown in Figures 5-8 establish the organigram the processing chain to calculate Cup to Disc Ratio CDR and areas.

### Optic disc segmentation

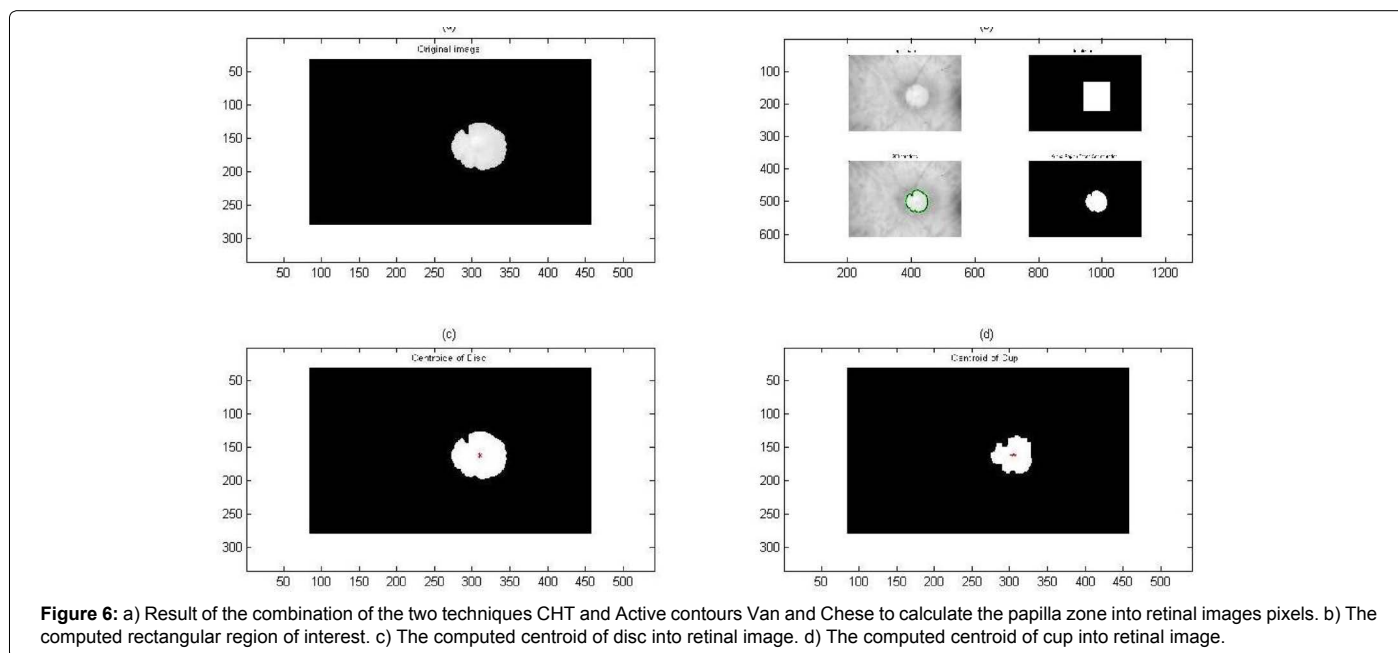
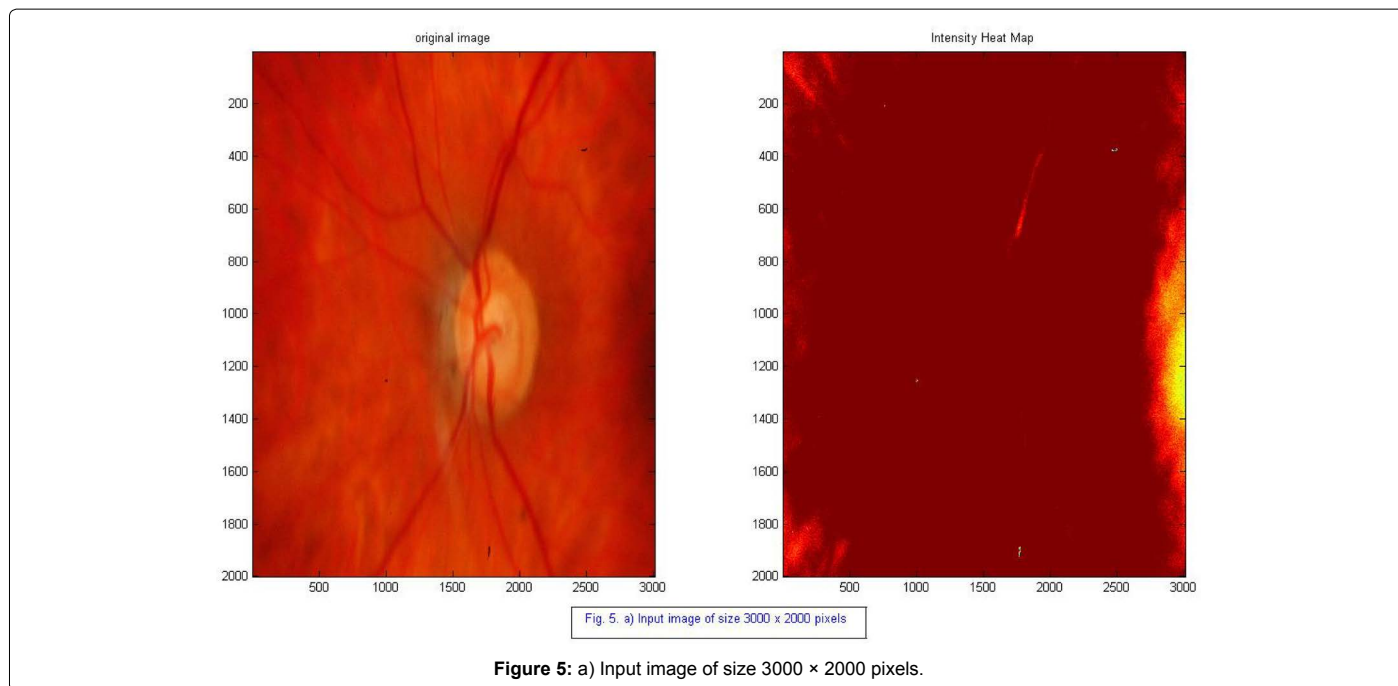
To detect an optic disc boundary, image pre-processing is introduced. Figure 7 shows a simplified workflow of optic disc segmentation.

Firstly, a coarse localization of optic disc region is presented using the red channel, in RGB images (24-bit with 8-bits for each of the red, green and blue channels) are used to show multi-channel images. The colors are designed to reflect genuine colors. The red component (red Channel= $rgbImage(:, :, 1)$ ) is utilized as it is found to have higher contrast and brightness between the optic disc and non-optic disc area than for other channels (The red in an RGB fundus image of retina reflects red color in the papilla where localized the disc and the cup).

To remove the blood vessels, a morphological closing operation is performed.

Closing is defined as dilation followed by erosion, and it tends to enlarge the boundaries of foreground regions in an image and shrink background color holes in such regions.

After performing the closing operation, a median filter is applied to further smoothen the obtained image. The outputs of the image pre-processing are shown in Figure 9.



After the image pre-processing is performed, two techniques combined and assembled for extracting a disc boundary are introduced: Circular Hough transform CHT and active contours without edges (gradient) Chan & Vese Approach.

**Circular Hough transform CHT approach:** A new approach to the concentric circular shape detection of the papilla of the optic nerve head to the surface of the retina is examined to determine the ratio Cup/Disc horizontal and vertical and compare it to the value of 0.5.

Firstly, the image is preprocessed by denoising through applying a median filter  $3 \times 3$ , edge detection and then the circle centers are affected by the Hough transformation gradient, finally, the radius is detected by the improved dimensional Hough transform.

The detection efficiency is enhanced by the discretization of the image and the reduced resolution compared to the circle center detection process and proves that the center of the circle is on the gradient line edge point circle; meanwhile, the beam detection accuracy is improved by merging the similar radius within the range of detection process.

Experimental results show that the combined method with the Hough gradient and active contour Chan and Vese has good reliability is high adaptive noise, distortion, incomplete edge zone, discontinuous. The analysis shows that the new concentric circle detection algorithm reduces the complexity of the time and improving the anti-interferences with respect to the treatment tradition.

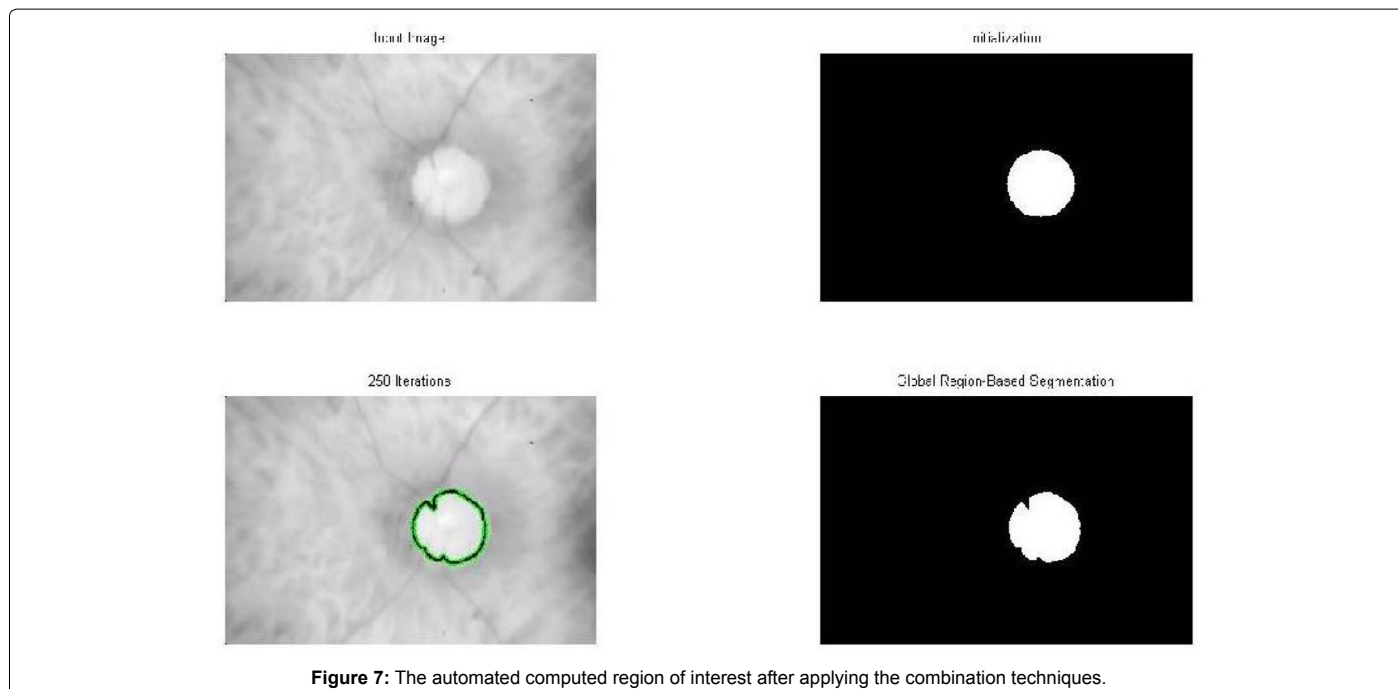


Figure 7: The automated computed region of interest after applying the combination techniques.

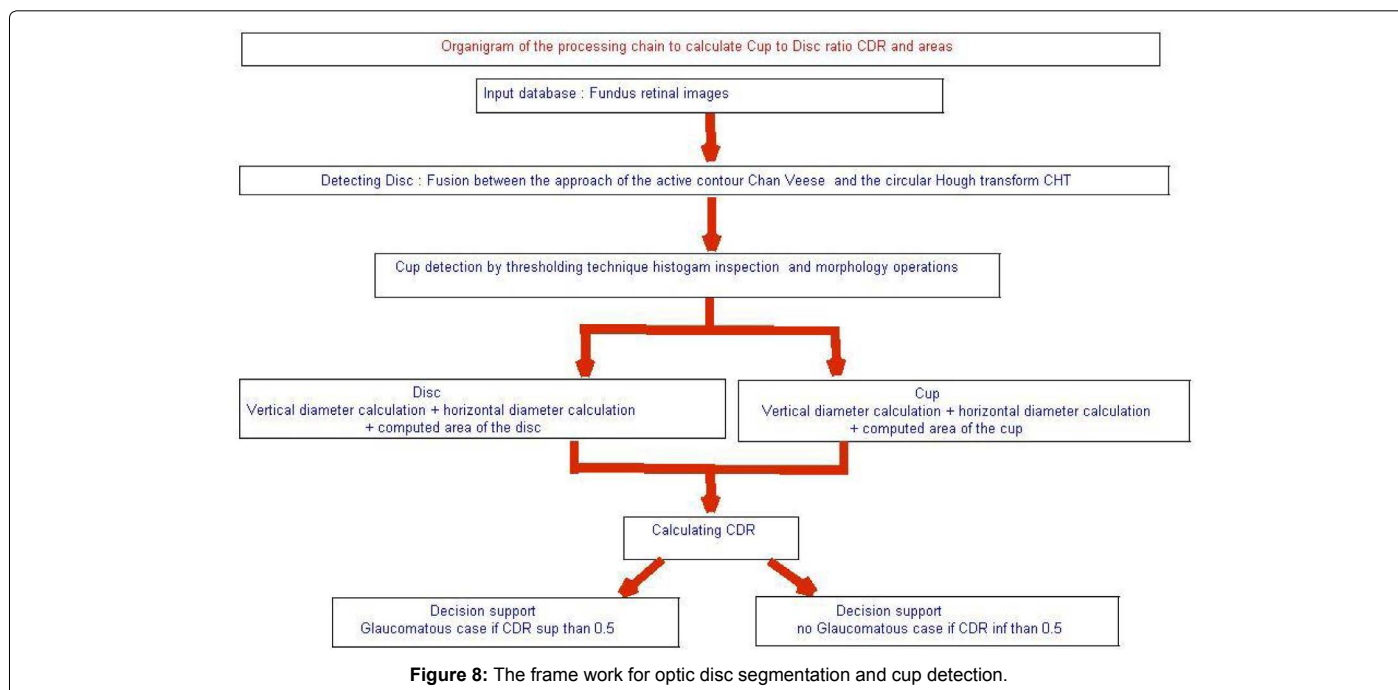


Figure 8: The frame work for optic disc segmentation and cup detection.

The circular Hough transform (CHT) is a feature extraction technique for detecting circles. It is a specialization of Hough Transform. The purpose of the technique is to find circles in imperfect image inputs. The circle candidates are produced by “voting” in the Hough parameter space and then select the local maxima in a so-called accumulator matrix.

A circle in the original image (left). The circle Hough transform is shown in the right. Note that the radius is assumed to be known. For each (x, y) of the four points (white points) in the original image, it can

Database	Sensitivity	Specificity	Accuracy
IM51	55.18%	99.95%	94.20%
IM49	65.19%	99.97%	97.19%
IM48	61.94%	99.98%	99.91%
IM47	67.79%	99.98%	98.63%
IM45	63.85%	99.99%	98.92%
IM41	73.24%	99.99%	98.88%

Table 2: Test results of Cup algorithm detection and one-class Active contours AC (REGION BASED) for One-Tunisian glaucoma patient (six features).

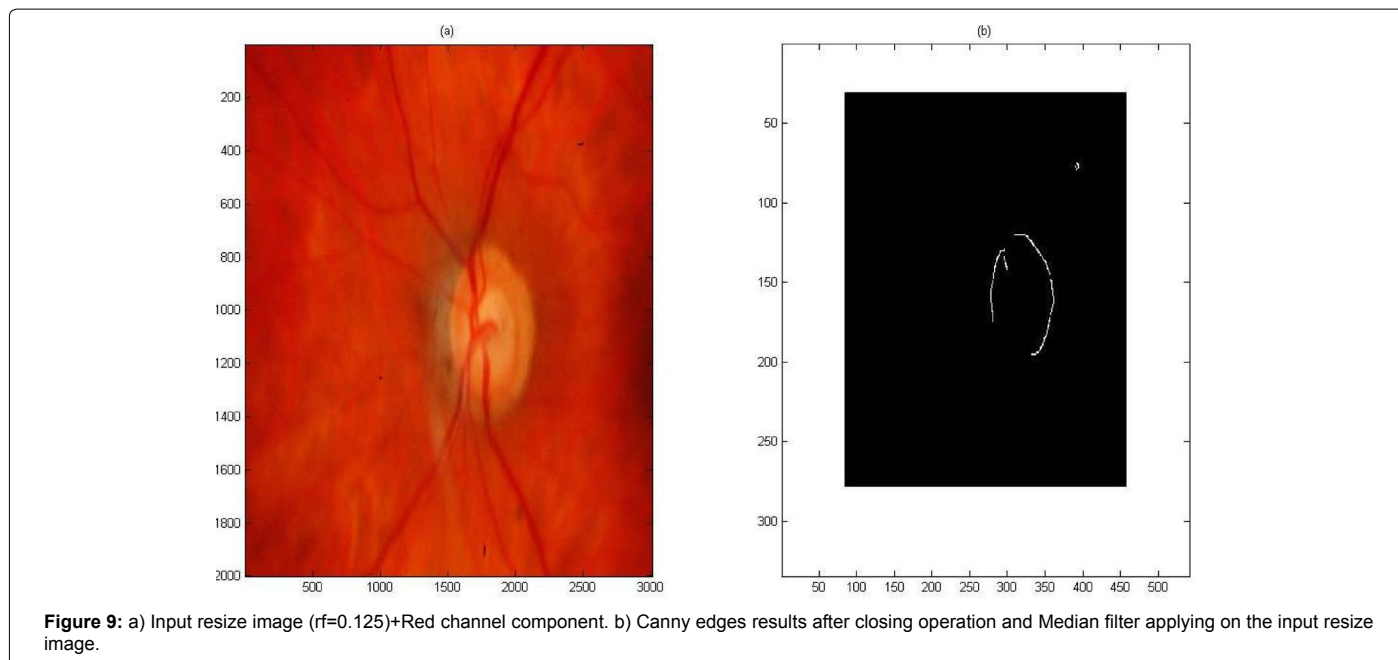


Figure 9: a) Input resize image (rf=0.125)+Red channel component. b) Canny edges results after closing operation and Median filter applying on the input resize image.

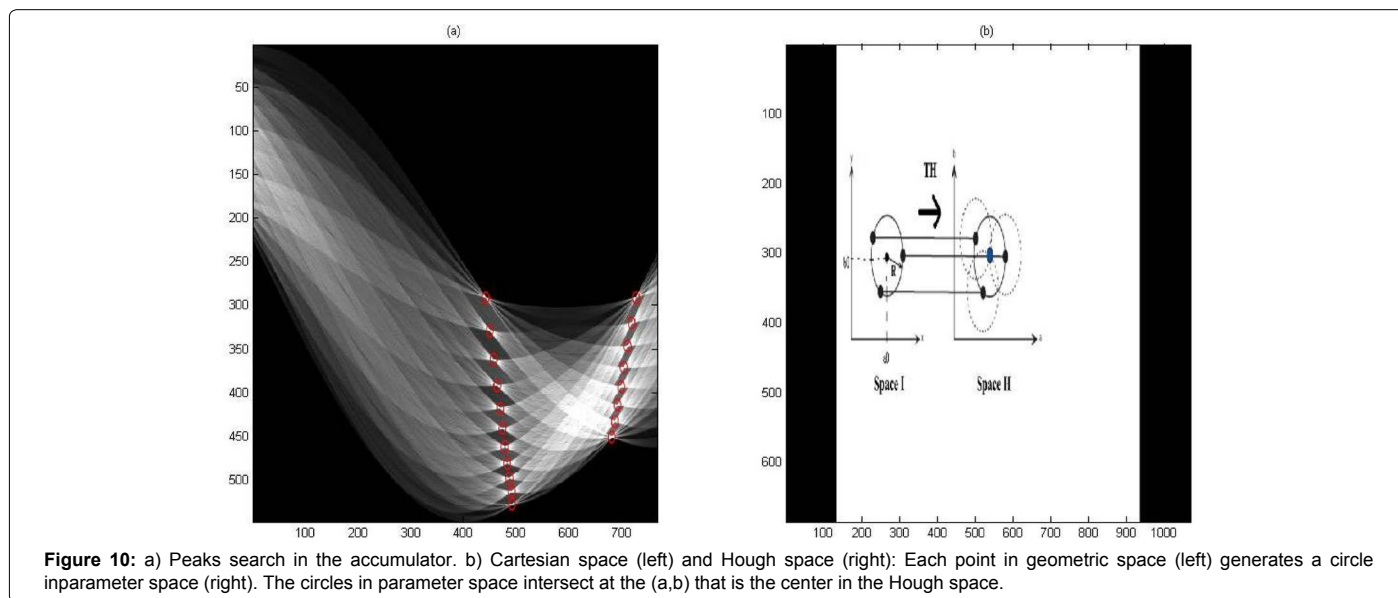


Figure 10: a) Peaks search in the accumulator. b) Cartesian space (left) and Hough space (right): Each point in geometric space (left) generates a circle in parameter space (right). The circles in parameter space intersect at the (a,b) that is the center in the Hough space.

define a circle in the Hough parameter space centered at  $(x, y)$  with radius  $r$ . An accumulator matrix is used for tracking the intersection point. In the parameter space, the voting number of points through which the circle passing would be increased by one. Then the local maxima point (the red point in the center in the right figure) can be found. The position  $(a, b)$  of the maxima would be the center of the original circle as shown in Figure 10.

In practice, an accumulator matrix is introduced to find the intersection point in the parameter space. First, we need to divide the parameter space into “buckets” using a grid and produce an accumulator matrix according to the grid. The element in the accumulator matrix denotes the number of “circles” in the parameter space that passing through the corresponding grid cell in the parameter space. The number is also called “voting number”. Initially as shown in Figure 11, every element in the matrix is zeros.

Then for each “edge” point in the original space, we can formulate a circle in the parameter space and increase the voting number of the grid cell which the circle passing through. This process is called “voting”.

After voting, we can find local maxima in the accumulator matrix. The positions of the local maxima are corresponding to the circle centers in the original space.

The Hough transform can be used to determine the parameters of a circle when a number of points that fall on the perimeter are known. A circle with radius  $R$  and center  $(a, b)$  can be described with the parametric equations:

$$x = a + R \cos(\theta) \tag{3}$$

$$y = b + R \sin(\theta) \tag{4}$$

When the angle  $\theta$  sweeps through the full 360 degrees range the

points  $(x, y)$  trace the perimeter of a circle. If an image contains many points, some of which fall on perimeters of circles, then the aptitude of the search program is to find parameter triplets  $(a, b, R)$  to describe each circle.

The fact that the parameter space is 3D makes a direct implementation of the Hough technique more expensive in computer memory and time.

Search with fixed R:

If the circles in an image are of known radius R, then the search can be reduced to 2D.

The objective is to find the  $(a, b)$  coordinates of the centers.

The locus of  $(a, b)$  points in the parameter space fall on a circle of radius R centered at  $(x, y)$ . The true center point will be common to all parameter circles, and can be found with a Hough accumulation array.

The circular Hough transform applied at the retinal image in some cases can simultaneously detects the disk and the head of the optic nerve cup as shown in the following Figures 12 and 13.

Indeed, as shown in the following figure, the disc of the papilla is not a perfectly circle, but it takes irregular shapes from circles far elliptic of forms and shapes chaotic, so in this study we will introduce the detection of the edges of the papilla by the method active contour without gradient Chan and Vese model approach to optimize disk detection with irregularities.

The number  $n$  is also called “voting number”

In this case, we choose  $n=3$  for Back to detect the outline edge of the disc (disc head of the optic nerve ONH).

**Active contours approach without gradient Chan and Vese model:** The Active contour method without gradient algorithm has been widely used as a global approach for the optimization of active contours for the segmentation of objects of interest from the background [5,6]. In this study, this method is employed by initializing a curve centered at the detected optic disc location. The curve is

evolved based on the average intensity value inside and outside the curve. The curve evolution always converges to the optic disc boundary irrespective of the shape or size of the initial contour. Figure 8 shows a sample evolution result where the initial curve is a rectangle.

The basic idea in active contour models or snakes is to evolve a curve, subject to constraints from a given image, in order to detect objects in that image. For instance, starting with a curve around the object to be detected, the curve moves toward its interior normal and has to stop on the boundary of the object.

Let  $C$  be the evolving curve. We denote by  $c_1$  and  $c_2$  two constants, representing the averages of  $u^o$  “inside” and “outside” the curve  $C$ .

Our model is the minimization of an energy based-segmentation. Let us first explain the basic idea of the model in a simple case. Assume that the image  $u^o$  is formed by two regions of approximately piecewise-constant intensities, of distinct values  $u^i_0$  and  $u^o_0$ .

Assume further that the object to be detected is represented by the region with the value  $u^i_0$  and let denote his boundary by  $C$ . [7]

Then we have  $u_0 \approx u^i_0$  inside the object (inside  $C$ ) and  $u_0 \approx u^o_0$  outside the object (outside  $C$ ). Now let us consider the following “fitting energy”, formed by two terms:

$$F_1(C) + F_2(C) = \int_{inside(C)} |u_0 - c_1|^2 dx dy + \int_{outside(C)} |u_0 - c_2|^2 dx dy \quad (4)$$

where  $C$  is any other variable curve. We say that the boundary of the object  $\zeta$  is the minimizer of the F fitting energy:

$$\inf\{F_1(C) + F_2(C)\} \approx 0 \approx F_1(C) + F_2(C) \quad (5)$$

This can be seen easily. For instance, if the curve  $C$  is outside the object, then  $F_1(C) > 0$  and  $F_2(C) \approx 0$ . If the curve  $C$  is inside the object, then  $F_1(C) \approx 0$  but  $F_2(C) > 0$ . Finally, the Fitting energy will be minimized if the  $C = \zeta$ , i.e. if the curve  $C$  is on the boundary of the object. These remarks are illustrated in Figure 14.

Therefore, in our active contour model we will minimize this fitting energy and we can add some regularizing terms, like the length of  $C$  and/or the area inside  $C$ . We introduce the energy  $F(C, c_1, c_2)$  by:

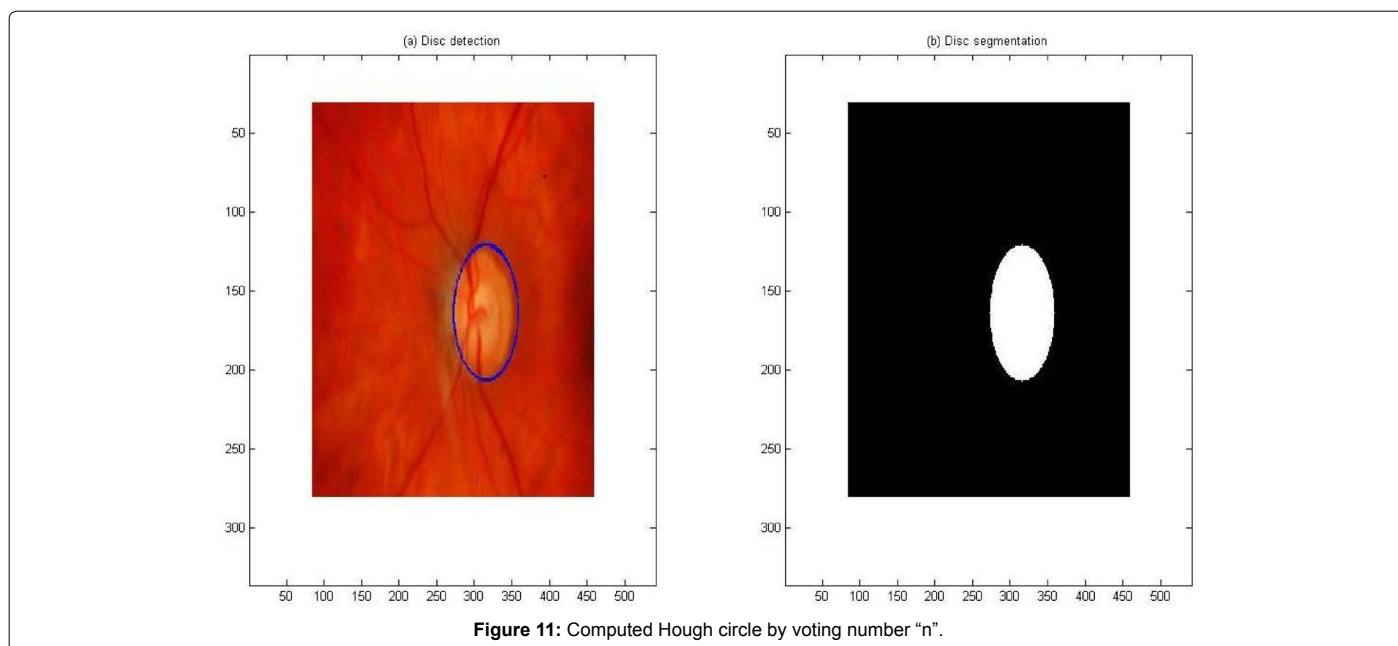


Figure 11: Computed Hough circle by voting number “n”.



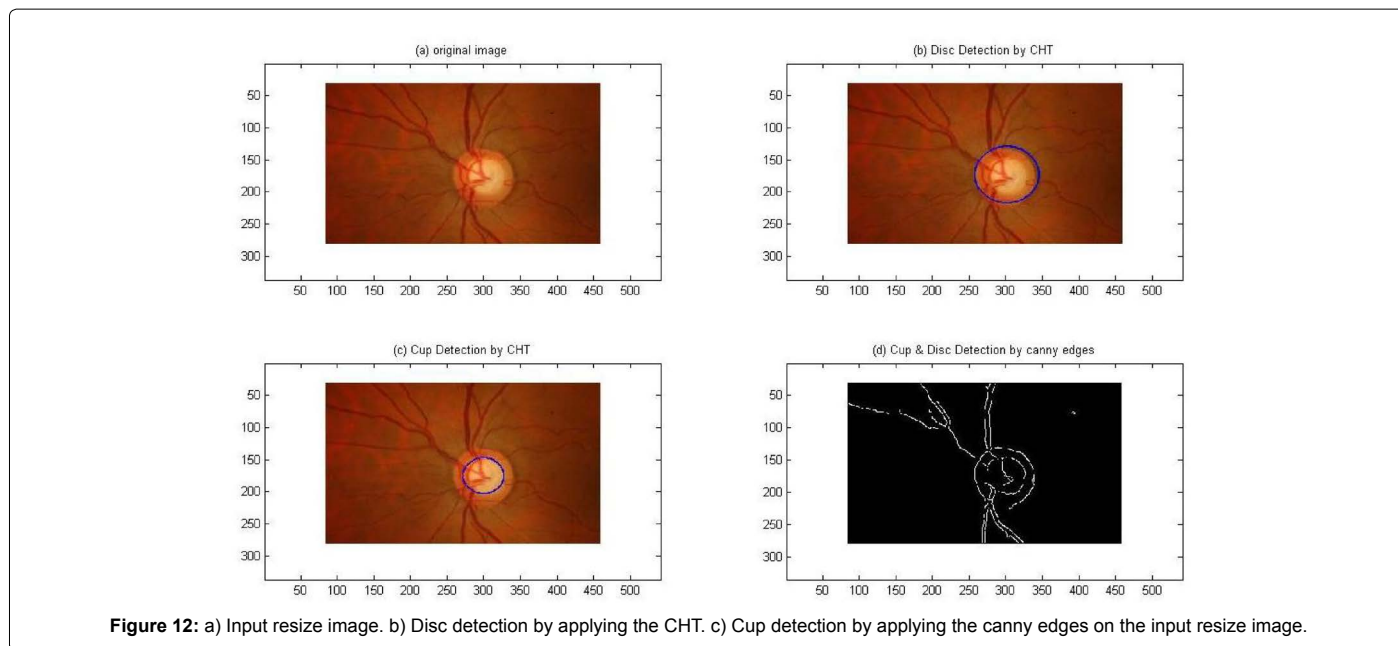


Figure 12: a) Input resize image. b) Disc detection by applying the CHT. c) Cup detection by applying the canny edges on the input resize image.

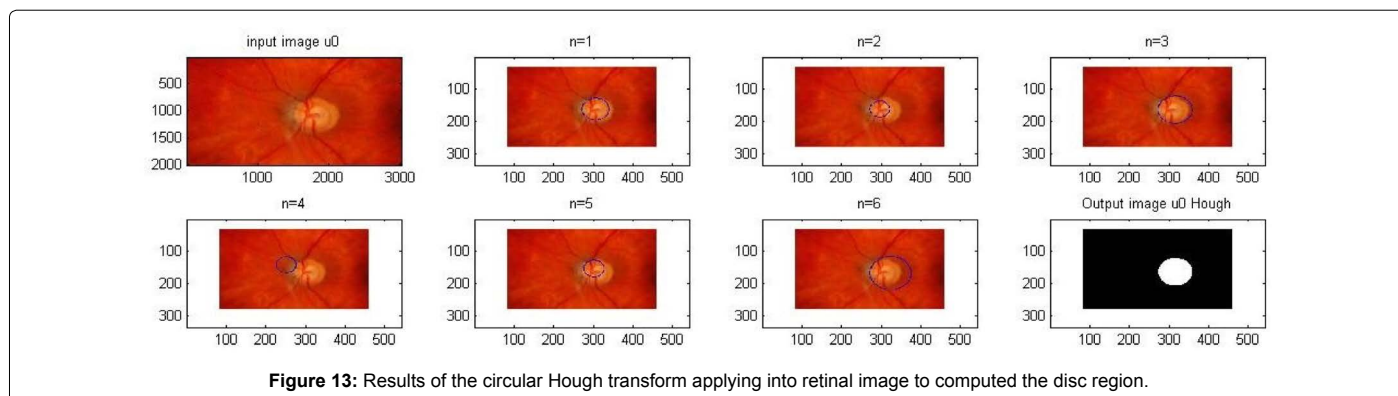


Figure 13: Results of the circular Hough transform applying into retinal image to computed the disc region.

Author	Dataset	Date	Sensitivity	Specificity	Accuracy	Calculation time
Rached et al.	Glaucomatous images (10 Fundus images)	2017-03-28	69.00% ± 3.29%	98.38% ± 0.69%	97.79% ± 1.46%	10 mins

Table 3: Since the algorithms are tested on different hardwares using matlab programming language and optimization, the calculation times are rough approximations of the time needed to process a set image in average.

$$F_1(C, c_1, c_2) + F_2(C) = \lambda_1 \int_{\text{inside}(C)} |u_0 - c_1|^2 dx dy + \lambda_2 \int_{\text{outside}(C)} |u_0 - c_2|^2 dx dy + \mu \cdot \text{length}(C) + v \cdot \text{area}(C). \quad (6)$$

where  $c_1$  and  $c_2$  are constant unknowns, and  $\lambda_1, \lambda_2 > 0, \mu > 0, v \geq 0$  are fixed parameters.

In almost all our computations, we take  $v=0$  and  $\lambda_1=\lambda_2$ . Of course, that one of these parameters can be removed, by fixing it to be 1. In almost all our computations, we take  $v=0$  and  $\lambda_1=\lambda_2$ .

The area term in the energy can be used for instance when we may need to force the curve to move only inside.

Finally, we consider the minimization problem:

$$\inf F(C, c_1, c_2). \quad (7)$$

$$C, c_1, c_2$$

and the results as shown in Figure 7.

### Optic cup segmentation

Compared to the extraction of the optic disc, optic cup segmentation is more rigid due to a cup inter weavement with blood vessels and surrounding tissues. This study presents two simultaneous steps approaches for cup segmentation, which are the inspection by histogram approach and detection's cup by applying the active contours Chan and Vese approach [7,8].

**Inspection by histogram approach:** A histogram counts and graphs the total number of pixels at each grayscale level. From the graph, you can tell whether the image contains distinct regions of a certain gray-level value. A histogram provides a general description

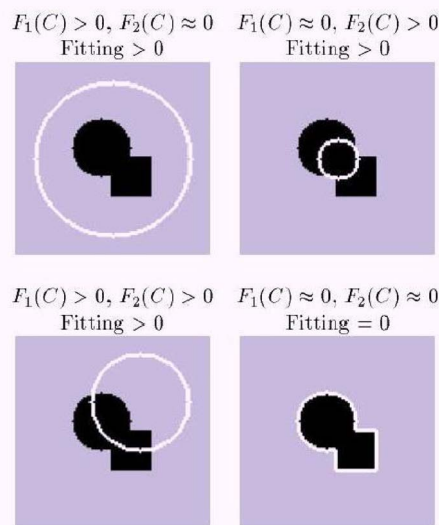


Figure 14: Consider all possible cases in the position of the curve. The "fitting energy" is minimized only for the case when the curve is on the boundary of the object.

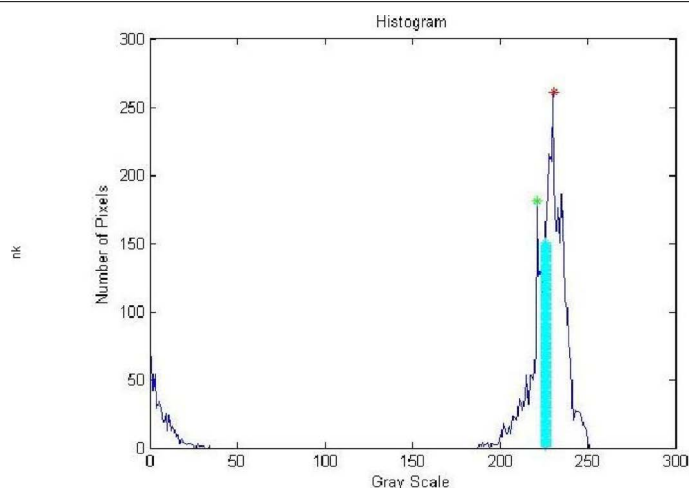


Figure 15: The normalized cumulative histogram of red channelled image.

Database	Vertical cup diameter*	Vertical disc diameter*	CDR <sub>v</sub>	Horizontal cup diameter*	Horizontal disc diameter*	CDR <sub>h</sub>	Area of the cup**	Area of the Disc**
IM1	52	72	0.6267	47	75	0.7222	2406	4388
IM2	58	77	0.7051	55	78	0.7533	2670	4434
IM3	52	71	0.7333	55	75	0.7324	2505	4357
IM4	55	78	0.7375	55	78	0.7051	2586	4780
IM5	55	73	0.7778	56	72	0.7534	2610	4294
IM6	52	71	0.7895	60	76	0.7324	2776	4271

\* Values in pixel unit.  
 \*\* Values in pixel<sup>2</sup> unit.

Table 4: CDR Metric values obtained after the calculus of the cup and disc diameter along vertical & horizontal axis.

of the appearance of an image and helps identify various components such as the background, objects, and noise.

The histogram is a fundamental image analysis tool that describes the distribution of the pixel intensities in an image. Use the histogram to determine if the overall intensity in the image is high enough for our inspection task. We use the histogram to determine whether an image contains distinct regions of certain grayscale values.

- Lack of contrast-A widely-retina image contains a lack of contrast between cup and disc, that is why in our type of imaging application, involves inspecting and counting parts of interest in a background of retina. A strategy to separate the cup from the background relies on a difference in the intensities of both, for example, a bright part and a darker background. In this case, the analysis of the histogram of the image reveals two or more well-separated intensity populations.

- The histogram is the function  $H$  defined on the grayscale range  $[0, \dots, k, \dots, 255]$  such that the number of pixels equal to the gray-level value  $k$  is  $H(k)=n_k$

Where  $k$  is the gray-level value,  $n_k$  is the number of pixels in an image with a gray-level value equal to  $k$ , and  $\sum n_k$  from  $k = 0$  to  $255$  is the total number of pixels in an image.

The histogram plot in the Figure 15, reveals which gray levels occur frequently and which occur rarely in background retina image region of interest papilla who contains cup and disk.

This region presents our area of interest and contains the optical Cup with maximum intensity (red dot form) and the optical disk with a more moderate intensity (green dot form).

To separate the two regions and finally detect the Cup we use the threshold of technical inspection by the histogram.

This technique will automatically choose a threshold from the histogram to extract the region of the optical Cup.

In each histogram on our region of interest (ROI), we could observe two peaks: the first is on the disk and the second is on the Cup as shown in the previous figure.

After statistical studies it appears that the threshold above which the pixels of the Cup we can get is the median between the two aforementioned peaks. When segmenting our ROI by thresholding referring to the peak value calculated, we obtain our Cup segmented as shown in the Figure 16.

**Contours fitting for optic disc and cup:** The active contours Chan & Vese algorithm can be used to find the fitting contours to disc and cup boundary. Firstly, this technique is semi-automatic and requires medical intervention. In addition, it requires time to execute the algorithm with a number of iterations over 200 iterations.

Our objective is to automate the active contour detection technique Chan Vese and minimize further the number of iterations of the active contour algorithm to detect boundaries of disc & cup.

Following the separation of the two parts of the Cup and the disc (see figure below), would be asked to calculate the ratio of the Cup/Disc

in terms of surface and vertically and horizontally with reference to the centroid as shown Figure 17.

## Result and Analysis

### Glaucoma diagnosis

To evaluate the effectiveness of our proposed method, Figure 18 is plotted. Figure 18 shows the detection of glaucoma based on our proposed method and the clinical method. The value of CDR which is more than 0.50 and close to 0.8 is used to assess a patient as a glaucomatous case and shows other features.

Figure also shows other parameters be automatically extracted as the area of the excavation, which has evolved over time, helps the ophthalmologist specify the severity of retinal disease.

### Evaluate the glaucoma diagnosis

To evaluate the performance of our approach, we used a set of 10 fundus images from one Tunisian patient.

We used ten fundus images of the retina of a Tunisian patient with glaucoma obtain in at time intervals equal to track changes and severity of the excavation of the optic nerve head.

When we use a segmentation method; it is necessary to compare the results with other methods or other works. Thus, we need some measurement to evaluate the accuracy of segmentation. Here we present some measurements frequently used by researchers. These measurements compare algorithm results with the ground truth labeling. The first one is the Dice Similarity Index (DSI), which quantifies the region overlap between the automatic and manual segmentation: DSI

$$DSI = \frac{2|A_A \cap A_G|}{|A_A + A_G|} \quad (8)$$

$A_A$ : Automatically calculated image (by Hough approach and Chan-V approach).

DSI=0.90 Average value.

The four other measurements are true negative fraction (TNF), false negative fraction (FNF), true positive fraction (TPF), and false positive fraction (FPF). These measurements are define as follows:

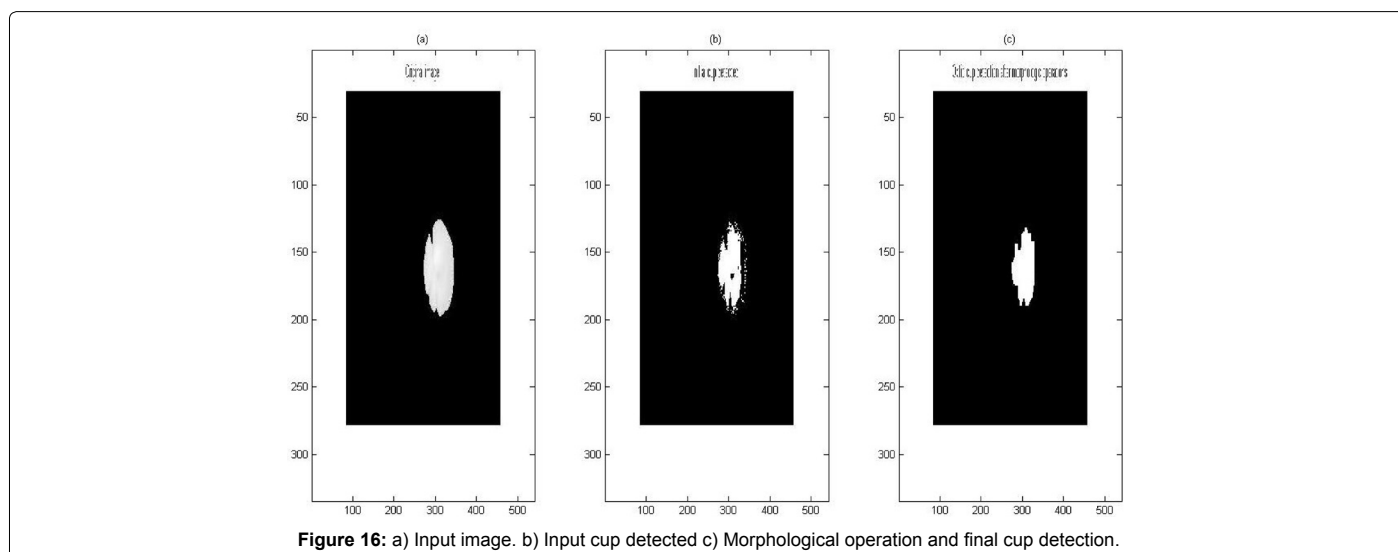
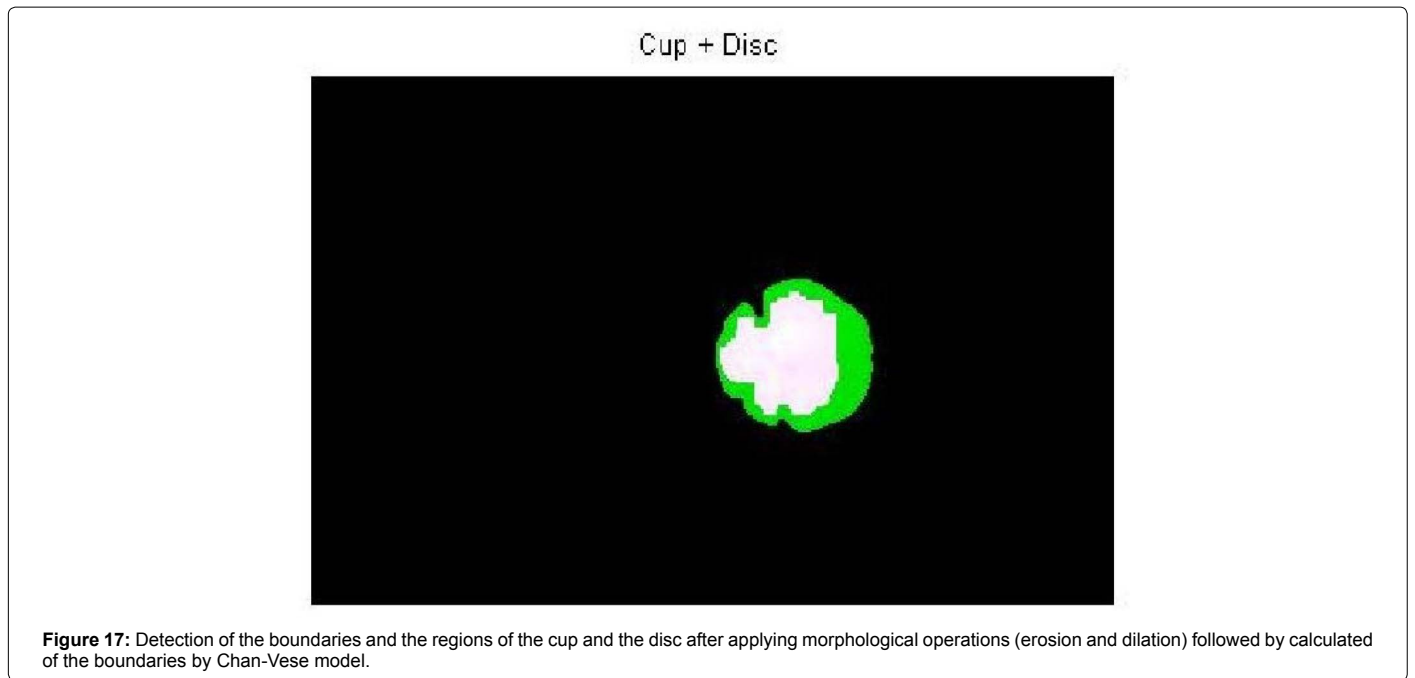


Figure 16: a) Input image. b) Input cup detected c) Morphological operation and final cup detection.



$$TPF = \frac{|A_A \cap A_G|}{|A_G|} \quad (9)$$

$$FPF = \frac{|A_A - A_G|}{|A_G|} \quad (10)$$

$$TNF = \frac{|A_A \cup A_G|}{|A_G|} \quad (11)$$

$$FNF = \frac{|A_A - A_G|}{|A_G|} \quad (12)$$

Where  $A_G$  and  $A_A$  indicate the region of ground truth of the foreground (manually) and the region of segmentation of the foreground by the proposed algorithm (automatically), respectively.

To assess classifier performance, it is necessary to quantify the sensitivity, specificity and accuracy. In glaucoma tic classification problem, sensitivity measures the accuracy of the classifier to identify glaucoma in the set of fundus images, and specificity measure the accuracy of classifiers for identifying healthy people in the set. The validation is performed by using the following amounts:

1. True positive (TP): Diagnosis of patients correctly classified as glaucomatous.
2. Faux-positive (FP): Diagnosis of patients classified as glaucomatous.
3. True negative (TN): Diagnosis of patients correctly classified as non-glaucomatous.

Sensitivity:  $TP/(TP+FN)$

Specificity:  $TP/(TP+FN)$

and accuracy of the classifier is defined by:

Accuracy:  $(TP+TN)/(TP+TN+FP+FN)$

At this point, the set of 10 test images are processed using the approach outlined earlier in order to obtain the CDR value, CDR Automated, and the area of the optic cup (excavation),  $Area_{Automated}$ . For the ground truth, the optic cup and disc boundaries are assessed and annotated by a senior ophthalmologist based on the retinal fundus images as shown in Figure 19, and the vertical CDR for each image,  $CDR_{Clinic}$ , was determined, as shown in the following figures. The evaluation of the performance of our approach is divided into 3 parts, which are the performance of the optic disc boundary detection, the performance of the optic cup boundary detection, and the vertical cup-to-disc ratio (CDR).

Then applying different parameters for assessing the diagnostic of glaucoma, we obtain the compared results prepared in the following two tables:

It can be seen that the edge detection approach provides a better result when compared with the optic cup and disc boundaries those who are assessed and annotated by a senior ophthalmologist based on the retinal fundus images.

In addition, the performance of the edge detection method is easier to understand in terms of MATLAB code. The time for running MATLAB code of this method is about 20 seconds per image for CHT method as shown in the following figure while the active contour method takes about 35 seconds per image.

### Evolution of the vertical cup-to-disc ratio (CDR) over time

As a result of running time and ease of understanding, the fusion between the two methods, CHT and Chan-Vese model, is appropriate for CDR calculation and screening glaucoma pathology.

Since CDR is an important indicator used for glaucoma detection, this metric is chosen to evaluate our results. The CDRs (vertical and horizontal) are computed from the obtained cup and disc diameter from the chosen method.

The Correlation between the excavation of the cup along the vertical direction, and that horizontal is obtained from the following formula:

$$r = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sqrt{\sum(X - \bar{X})^2} \times \sqrt{\sum(Y - \bar{Y})^2}}$$

$r=0.1957$

Where X and Y are respectively the CDR<sub>v</sub> and CDR<sub>H</sub> Values (observations).

It can be seen from these results that there is no strong correlation between the excavation of the cup along the vertical direction, and that horizontal ( $r \ll 1$ ).

According to the variations, the previous curves shows that the evolution of the excavation is more monotonous, proving that the excavation of the cup of the optic nerve head depends on intrinsic factors such as intraocular pressure IOP that one must consider in the study of the excavation of ONH that generates glaucoma.

### Conclusion and Further Research

The cup to disc ratio (CDR) and the area cup are important gauges of the risk of the presence of glaucoma in an individual. In this study, we have presented a method to calculate the CDR along vertical and horizontal axis automatically from fundus images of retina.

The image pre-processing is the first step to localize the optic disc and cup. The optic disc is extracted using edge detection by applying the circular Hough transform approach and an active contours approach (CHAN & VESE model) simultaneously. The optic cup is then segmented using an inspection by histogram method to separate the cup from the disc and Chan & Vese model method. After obtaining the contours, an automated step is introduced to design the different features.

Using 10 images obtained from a clinical case of a Tunisian glaucomatous, the performance of our approach is evaluated using the proximity of the calculated CDR to the manually graded CDR. The results indicate that our approach provides 98% accuracy in glaucoma analysis. As a result, this study has a good potential in automated screening systems for the early detection of glaucoma.

The further developments for this study are to boost the performance of the cup segmentation method by including a method of vessel detection and vessel in image using the Gabor filter bank (Analysis by wavelet approach). In addition, machine-learning techniques will be applied in order to find the suitable parameters in several formulas, including edge detection by CHT approach and active contours Chan-Vese approach.

### Declarations

#### Author's contributions

I.J., I.M. and R.B conceived and designed the experiments; I.J. and R.B. performed the experiments; I.M., R.B and I.J. analyzed the data; H.T., I.J. and R.B. contributed reagents/materials/analysis tools; R.B. wrote the paper; H.T., I.M. and I.J. discussed and proof-read the manuscript.

#### Competing interests

The authors declare that they have no competing interests.

#### Ethics approval and consent to participate

Written informed consent was obtained from the patients for publication of this manuscript and any accompanying images.

#### Availability of data and materials

Please contact the author (rabelg@live.fr) for requests about the fundus retinal images for ophthalmology.

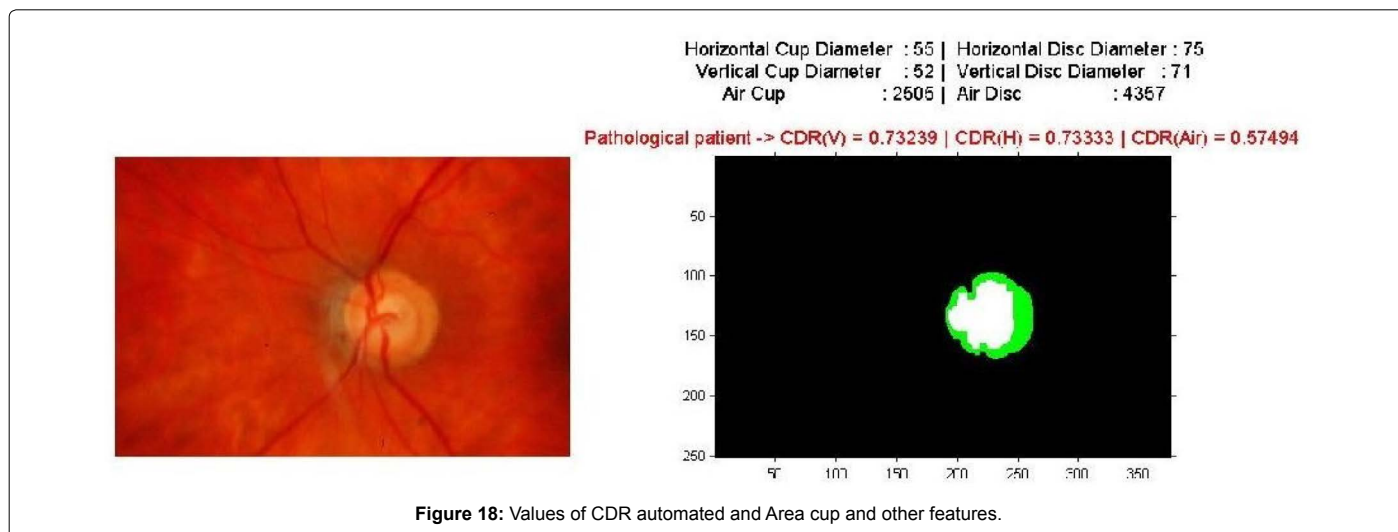
#### Funding

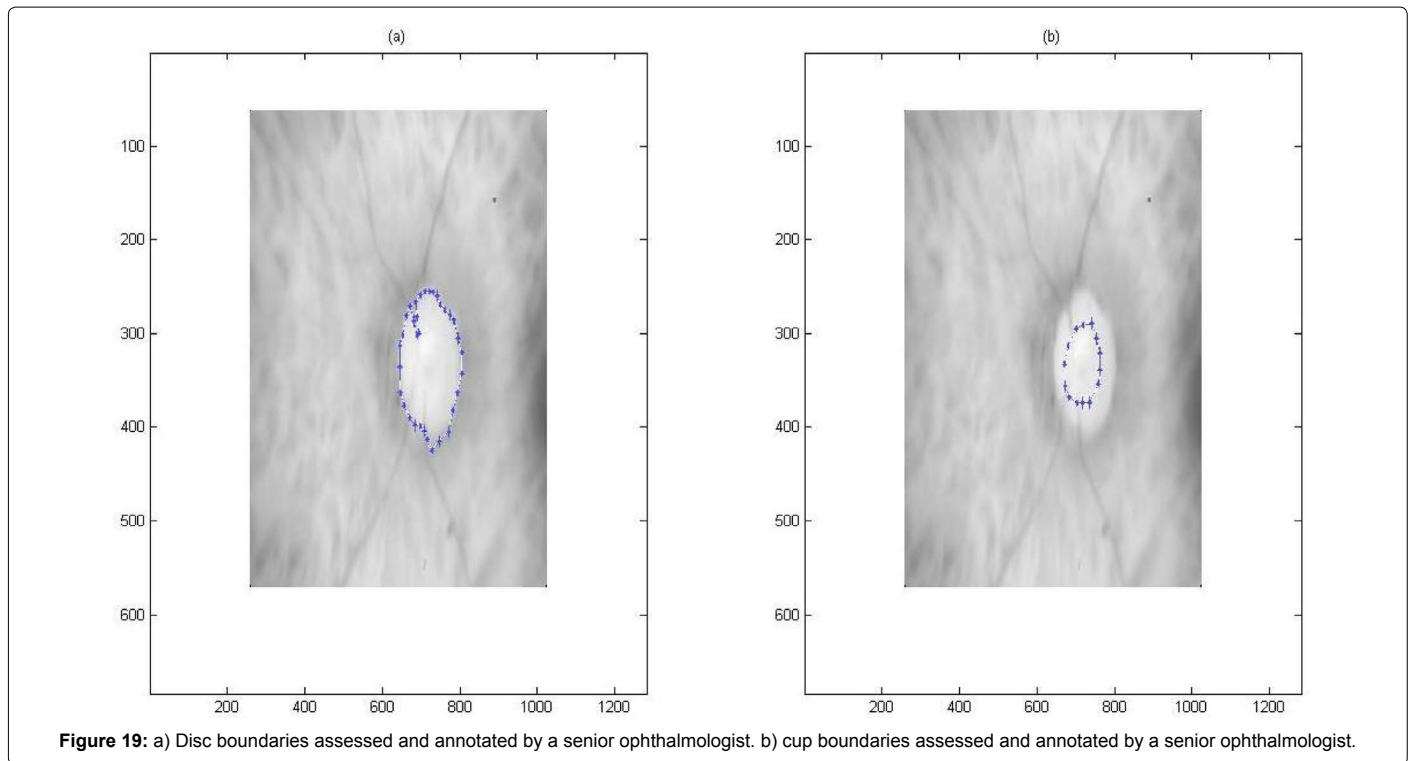
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#### Further reading

Glaucoma Focus; Royal National Institute of Blind People (RNIB) and International Glaucoma Association (IGA)

Assessing fitness to drive: guide for medical professionals; Driver and Vehicle Licensing Agency

Glaucoma referral and safe discharge - A national clinical guideline; Scottish Intercollegiate Guidelines Network - SIGN (March 2015)

#### References

1. Kass MA, Heuer DK, Higginbotham EJ, Johnson CA, Keltner JL, et al. (2002) The Ocular Hypertension Treatment Study: a randomized trial determines that topical ocular hypotensive medication delays or prevents the onset of primary open-angle glaucoma. *Arch Ophthalmol* 120: 701-713.
2. Heijl A, Buchholz P, Norrgren G, Bengtsson B (2012) Rates of visual field progression in clinical glaucoma care. *Acta Ophthalmol*. 91: 406-412.
3. Broman AT, Quigley HA, West SK, Katz J, Munoz B, et al. (2008) Estimating the rate of progressive visual field damage in those with open-angle glaucoma, from cross-sectional data. *Invest Ophthalmol Vis Sci* 49: 66-76.
4. Burana-Anusorn C, Kongprawechnon W, Kondo T, Sintuwong S, Tungpimolrut K (2011) Image Processing Techniques for Glaucoma Detection Using the Cup-to-Disc Ratio. *Adv Comp Commun* 2011: 365-373.
5. Wong D, Liu J, Lim J, Jia X, Yin F, et al. (2008) Level- set based automatic cup-to-disc ratio determination using retinal fundus images in ARGALI. *Eng Med Biol Soc* 2008: 2266-2269.
6. Kavitha S, Karthikeyanand S, Duraiswamy (2010) Early Detection of Glaucoma in Retinal Images Using Cup to Disc Ratio. *Comp Commun and Network Technol (ICCCNT)*. 1-5.
7. Zhao HK, Chan T, Merriman B, Osher S (1996) A Variational Level Set Approach to Multiphase Motion. *J Computat Phys* 127: 179-195.
8. Zhao HK, Osher S, Merriman B, Kang M (1998) Implicit, Nonparametric Shape Reconstruction from Unorganized Points Using A Variational Level Set Method. *UCLA CAM Report* 97-98.