ISSN: 0975-766X
CODEN: IJPTFI
Available Online through **Research Article**
www.ijptonline.com

MEASUREMENT OF OPTIC CUP VOLUME USING FUNDUS AND OPTICAL COHERENCE TOMOGRAPHY IMAGE FOR GLAUCOMA DETECTION

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Received on: 03-02-2017 *Accepted on: 12-03-2017*

Abstract

Glaucoma is a common disease of blindness. It may lead to progressive degenerating of optic nerve fibers and structural changes in it, which in turn may lead to failure in function of the vision. Glaucoma is usually asymptomatic in beginning stages hence vision loss associated cannot be recovered. Therefore early detection of the disease followed by immediate medical treatment is always necessary to prevent subsequent visual damage. This paper uses a novel feature called optic cup volume to detectthe glaucoma. The optic cup volume is determined by fundus image and optical coherence tomography (OCT) image. In fundus image, optic cup is segmented by fuzzy local information c means (FLICM) clustering and area is calculated. In OCT image,retinal vitreal (RV) boundary and retinal choroid (RC) boundary are segmented by morphological method. Using RV and RC boundary, cup depth is calculated. Cup volume is determined by taking the product of cup area and cup depth computed using fundus image and OCT image respectively.

Keyword: Cup to disc ratio, Cup depth, Glaucoma, Optical coherence tomographyimage, Cup volume.

Introduction:

A small depression called the optic cup can be seen in the fundus image in front of the optic nerve head. The diameter of the cup is usually smaller than that of the optic disc. When glaucoma disease progresses, the neural tissues may die and the layer of nerve fiber may get thinner thus the cup to disk area ratio (CDR) also increases.

The OCT is an imaging technique with high resolution in the structure of retina. It is used for the diagnosis of a variety of diseases like macular degeneration, Glaucoma and macular edema [1]. The OCT imaging techniques are used to analyze the properties of retinal nerve fiber layer, thickness of retina and changes in contour of optic disc. The CDR is used popularly by ophthalmologists for observing the problems in optic nerve head. This ratio is usually minimum for normal patients but, there may be a slight variation found in the normal eyes; direct and more extensive characterization of nerve head geometry, and its change over time, can mitigate this limitation. As glaucoma progresses the death of the nerve tissue leads to shrinkage of optic nerve shrinks and also causes the expansion of optic cup.

In [2], authors have proposed an automatic optic disc parameterization technique based on segmented optic disc and cup regions obtained from monocular retinal images. Automatic disc segmentation method is proposed which integrates the local image information around each point of interest in multi-dimensional feature space to provide robustness against variations found in and around the optic disc region. The cup segmentation method is also proposed which is based on anatomical evidence such as vessel bends at the cup boundary. A multi-stage strategy is employed to derive a reliable subset of vessel bends called r-bends followed by a local spline fitting to derive the desired cup boundary.

In [3], the authors presented an optic disc and optic cup segmentation using super pixel classification for glaucoma screening. In [4], a unique method for detection of glaucoma using fundus images has been proposed. For automatic detection of optic disc, blood vessels etc.,and their features, the digital image processing methods like preprocessing, morphological operations or thresholding may be used. By using these methods, CDR, ratio of the distance between optic disc center and optic nerve head to diameter of the optic disc, and the ratio of area of blood vessels in inferior-superior side to that of the blood vessel area in the nasal-temporal side can be extracted. The extracted are then validated by separating them as normal image and glaucoma image using the neural network classifier.

In [5], a report about the OCT, its usage in macular pathology and optic nerve disorder diagnosis in glaucoma have been proposed.

A Cross section of the optic nerve head and nerve fiber layer using OCT is necessary for analysing the clinical problem that originates from the optic nerve. In [6], the authors have presented another method for complete automated segmentation of the optic nerve head region by using morphological operators to examine the parameters indicating the symptoms of glaucoma.

The goal of this paper is to (i) determine the CDR from retinal fundus images, (ii) to determine cup depth from OCT images and (iii) to determine the feature cup volume from fundus and OCT images.

Subject and Methods

The optic cup volume is one of the most important symptom of the presence of glaucoma in an individual. In this work, optic cup from fundus image is segmented by FLICM clustering and optic cup depth from OCT image is segmented by morphological techniques to compute the optic cup volume.

A. Segmentation of optic cup from fundus image using FLICM clustering

The retinal fundus image of size 1000 *1050 is used in this work and it is obtained from Aravind eye hospital in Pondicherry.In order to compute optic cup volume, the area of the optic cup has to be calculated.Fig. 1 shows the input fundus image.

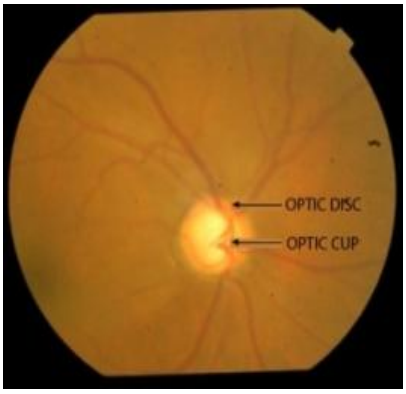

Fig. 1. Input Fundus Image.

The ROI of size 360x360 pixels is approximately selected in the brightest part of the green (G) plane in the seen fundus image. Fig. 2 is an ROI image.

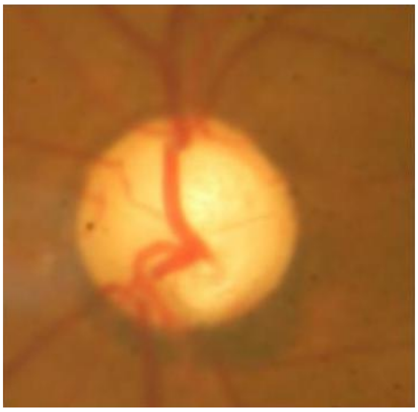

Fig. 2 ROI Fundus Image.

The ROI image not only contains the region of optic disc and cup but also the blood vessels. First the blood vessels should be removed from the image for a better segmentation of both regions. Wavelet transform is used for blurring the blood vessels and morphological closing operation in addition are used. In this, initially the FCM clustering techniques [7],[8] are used for extracting the two regions automatically. The optic cup region in the FCM technique will not show the full contour and so an error is possibly seen in the optic cup area. This can be observed in Fig. 3.

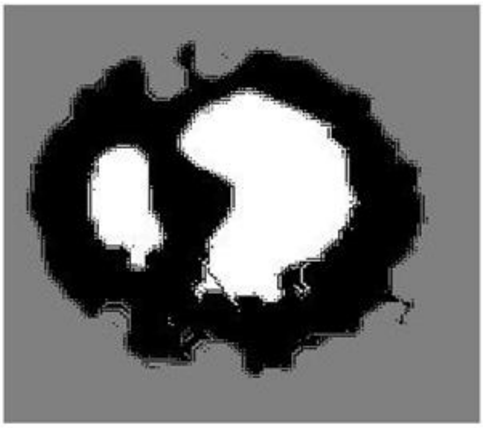

Fig. 3 Result of FCM.

The spatial information of pixels is not considered in FCM due to which the segmentation result is affected. Therefore to improve the segmentation results, spatially weighted fuzzy C-mean (SWFCM) clustering is applied as an improvement over simple FCM clustering technique. One main characteristics of the image is that the neighboring pixels will be highly correlated in SWFCM method. SWFCM enhances insensitiveness to noise to some extent. Fig. 4 shows the result of SWFCM.

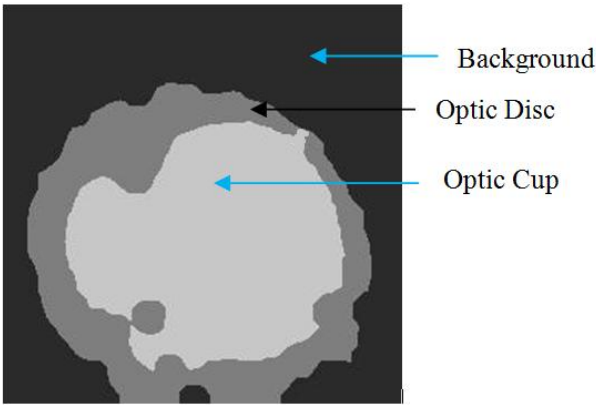

Fig 4 Result of SWFCM.

But in the detected optic cup cluster, some small extra regions are found due to the overlapped intensity variations in the cup region. This region affects the CDR determination, which is considered in fuzzy local information C-mean (FLICM) method.

In the fundus image, the pixels in the optic cup and optic disc regions are correlated in their respective regions. The optic cup is the excavation of nerve fiber and the neuro retinal rim which is the area between optic cup and disc is formed by nerve fiber and glial cells. The contour of the optic disc is the outer contour of neuro retinal rim. Thus when imaged, pixels in the cup region will be highly correlated among them, compared to the above said region namely the neuro retinal rim. Thus in this work, FLICM is used as a novel method to detect optic cup and disc. This FLICM method is utilized by the previous researchers [9], [10] for natural image segmentation. Though the quality of fundus image will not be as good as the natural image, FLICM method is adopted as a novel method in this work for optic cup and disc segmentation by exploiting the inter-pixel correlation in the corresponding region.

The FLICM is then applied to the obtained images with blood vessels that are already blurred. Noise immunity is an important characteristics of the FLICM. It preserves the image details free of parameter selection.

FLICM incorporates local spatial and gray level information into its objective function defined terms of

$$J_m = \sum_{i=1}^{N} \sum_{k=1}^{c} [U_{ki}^{m} \|x_i - v_k\|^2 + G_{ki}] \qquad (1)$$

where G =fuzzy factor

$$G_{ki} = \sum_{\substack{j \in N_i \\ i \neq j}} \frac{1}{d_{ij}+1} \left(1 - U_{kj}\right)^m \left\|X_j - V_k\right\|^2 \quad (2)$$

Where the i-th pixel is the center of the local window, k is the reference cluster and the j-th pixel belongs to the set of the neighbours falling into a window around the i-th pixel (Nj). di,j is the spatial Euclidean distance between pixels i and j, U_{kj} is the degree of membership of the j-th pixel in thek-th cluster , m is the weighting exponent of fuzzy membership and V_k is the prototype of the center of cluster k.

$$U_{ki} = \frac{1}{\sum_{j=1}^{C} \left(\frac{\|x_i - v_k\|^2 + G_{ki}}{\|x_i - v_j\|^2 + G_{ji}} \right)^{\frac{1}{m-1}}} \quad (3)$$

$$V_k = \frac{\sum_{i=1}^{N} U_{ki}^{m} x_i}{\sum_{i=1}^{N} U_{ki}^{m}} \qquad (4)$$

Thus, the FLICM algorithm is given as follows:

Step1. Set the number c of the cluster prototypes, fuzzification parameter m and the stopping condition.

Step2. Initialize randomly the fuzzy partition matrix.

Step3. Set the loop counter b = 0.

Step4. Calculate the cluster prototypes using 20

Step5. Compute membership values using 19

Step6. If max {U (b) − U (b+1)}< ε then stop, otherwise,

set b = b + 1 and go to step 4.

When the algorithm converges, a defuzzification process is done to convert the fuzzy partition matrix U to a crisp partition FLICM. Fig 5 shows the result of FLICM clustering.

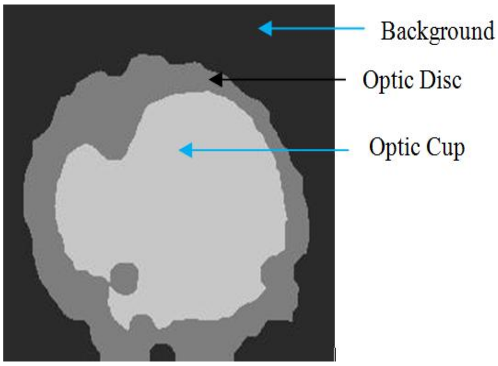

Fig.5. Result of FLICM.

The clustered image has three forms of cluster namely background, optic disc and optic cup. From the clusters, the optic cup is identified by selecting the cluster index at the location of the brightest point in the ROI image because the optic cup belongs to higher intensity regions. Fig 6 shows the segmented optic cup region being shown on the original ROI image.

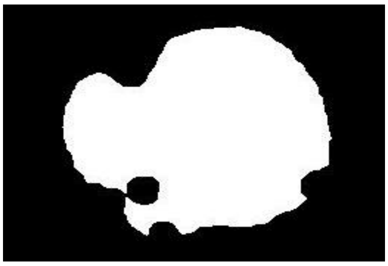

Fig. 6 Segmented optic cup.

After extracting the optic cup from the clusters, morphological operations are applied to compute the area of the optic cup. The identified cup region from the clusters may have holes and they have to be filled up for correct area calculation. So morphological dilation is performed on this identified cup region to fill the holes and one such image is shown in Fig.7. The area of the resultant image is computed in terms of number of pixels in cup region.

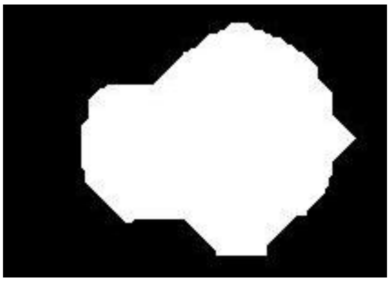

Fig. 7 Segmented Optic Cup using Morphological Method.

B. Detection of Cup Depth Using OCT Image

In this section, the calculation of cup depth from OCT image is presented. Here a morphological technique to extract the RV boundary and RC boundary is analyzed. These two boundaries are then used to obtain the lateral extent of the cup depth.

The basic mathematical morphology operators are erosion, dilation, opening and closing. A good image segmentation algorithm can be obtained by combining these operators effectively. As the basic operators are translation invariant, the segmentation will not createartifacts. In this work, morphological techniques are used to extract RV and RC boundary automatically. Hence for the detection of cup depth, it becomes necessary to find the retinal vitreal boundary and edge of choroid.

2.2.1 Extracting the Retinal Vitreal Boundary

The RV boundary is the boundary between the retina and vitreous. The boundary detection algorithm comprises three basic operations:

1. Noise reduction
2. Morphological filtering
3. Edge detection

The input OCT optic nerve head color image is first converted into grayscale image, and then gray scale OCT image is converted into binary image by applying Otsu's thresholding method. In this image, the RV boundary is first detected from the first transition of black to white pixel level when scanned from top to bottom. In such cases, the presence of noise appears as bright dots in the image and will lead to improper detection of RV boundary. So this noise can be reduced by 2D median filtering on the binary image. Fig. 8shows median filtered image. Though it is inferred that the noise is reduced greatly, still some noise is present which appear as small objects in the image Fig. 8

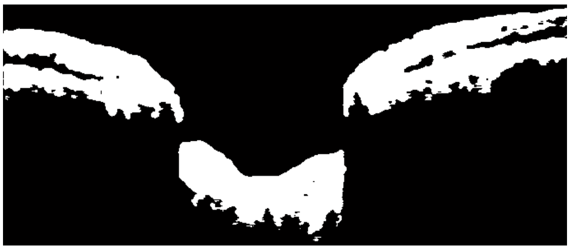

Fig. 8 Median filtered image.

So after median filtering, morphological opening is used to remove these small objects and the result is shown in Fig. 9.

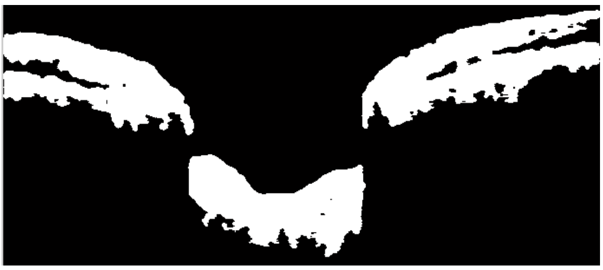

Fig. 9 Image after removing small objects

The initial RV boundary points are chosen by searching column wise for first non- zero pixel position. Such detected edge points will not form a smooth curve if connected. So in order to get the smoothened RV boundary, Bezier curve fitting is used this work. Fig. 10shows the RV boundary.

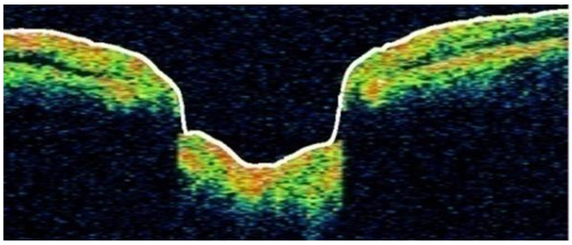

Fig. 10 Smoothed edges of RV boundary obtained by Bezier curves.

2.2.2 Extracting the Retinal Choroid Boundary

The retinal choroid boundary is the boundary between retina and choroid area. This edge is needed to find the extents of cup depth. The boundary detection algorithm comprises the following steps.

Step1: Convert the input RGB image to gray scale image.

Step2: 2D median filtering is applied to the gray scale image to reduce speckle noise.

Step3: Multi level threshold technique is applied to median filtered image. Thresholding methods are applied for image segmentation where a clear back ground and foreground relationship exists. However, a complex image like OCT, leads to poor segmentation as there is no clear background and foreground relationship existing especially in the area near choroid region. Hence, it is proposed to use multi-level thresholding[10] as a novel method for detection of RC boundary. This method is chosen since it is an automatic and iterative procedure wherein the threshold value is automatically computed. Image obtained as a result of multi-threshold is shown in Fig 11.

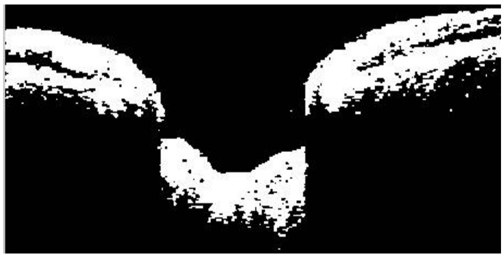

Fig. 11 Image after Multi-thresholding.

Step 4: After multilevel thresholding, morphological opening is used to remove the small objects as shown in Fig 12.

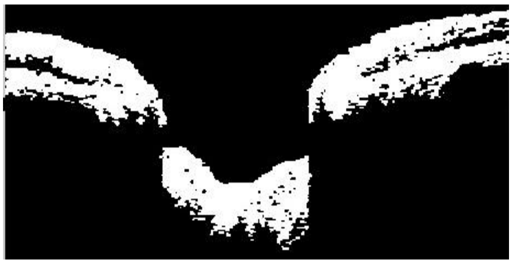

Fig. 12 Removal of small objects.

Step 5: The image after removing small objects shown in Fig. 14 is considered for further processing.

- After analyzing 20 OCT images, shape of the structure element (B) of line having width two anddegree zero is selected to erode the processed image X.

$$Y = X \ominus B \quad (5)$$

where Y is the eroded image.

- The processed image (X) is subtracted with the eroded image (Y) to get boundary of the objects. The boundary detection is given in the Equation 4.5.

$$Boundary = X - Y \quad (6)$$

From this boundary image, the retinal boundaries are removed by searching the true pixel column wise from top to bottom and vice versa. The resultant image consists of choroid regions as well as small unwanted regions as shown Fig. 13.

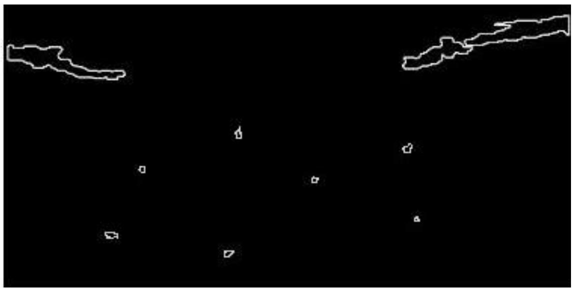

Fig. 13 Edges of retinal choroid regions with small regions.

- After calculating area of each region, only the large region is chosen as the region of interest for identifying the edges of the choroid. All other regions are removed. The boundary of choroid regions is shown in Fig. 14.

Fig. 14 Boundary of retinal choroid.

2.2.3 Determination of Cup Depth

The procedure to calculate the cup depth [11] is as follows: Two horizontal lines are drawn from these edges of choroid. The lines are intersecting the RV boundary at twopoints and this row is known as upper boundary of the optic cup. The row wise last true pixel in the RV boundary is the lower boundary of the optic cup. The cup depth is computed as the distance between the upper and lower boundaries of the optic cup.

By using RV boundary the depth of cup is calculated because for glaucoma the cup size increases. Fig. 15(a) shows the OCT image of a normal person and Fig. 15(b) shows the image of person affected by glaucoma. Cup depth is shown as number of pixels and the extent of this depth is also shown. The resolution factor for the collected OCT image is found to be 10 micron/pixel. The cup depth thickness measurement is given by Equation 1.

$$\text{hickness in microns} = \text{Resolution factor} * \text{Cup depth in number of pixels} \qquad (7)$$

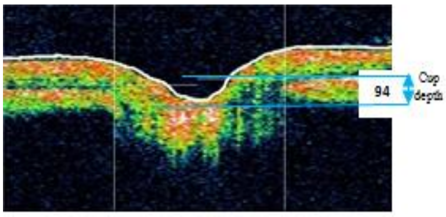

Fig .15(a) Normal Image.

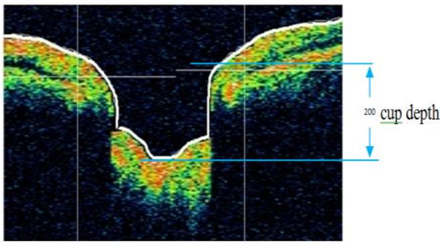

Fig .15(b) Glaucoma Image.

C. Cup Volume

In the fundus image of diabetic patients the regions of cup and disc are merged. Hence, CDR cannot be computed in fundus image for such patients [12]. In such cases, only the CDR value computed from OCT images [13] is available for diagnosis of glaucoma. But this alone is not enough because for some subjects, larger cup in a small optic disc will show higher CDR value and hence gives a false alarm. In order to overcome these conditions, novel feature namely cup volume is utilized in the proposed work.Cup volume is obtained by product of optic cup area in fundus image and cup depth from OCT image.

$$\text{Cup Volume} = \text{cup area} * \text{cup depth} \qquad (8)$$

From the results, cup volume value for normal images range from 0.015 to 0.134 and for abnormal images it ranges from 0.082 to 1.311 µm.

Results and Discussion

Cup volume is obtained by product of cup area in fundus image and cup depth in OCT image.The developed algorithm tested on 10 normal images and 40 glaucoma images. The Fig. 16 (a and b) shows the optic cup for normal and glaucoma image . fig 17(a and b) shows cup depth for normal and glaucoma image. boundary marked by ophthalmologist manually and results obtained using proposed method. In these images, for comparison purpose, the results of ophthalmologist and proposed method for cup regionand cup depth in the imageare shown. White color contour indicates the result of proposed method and green colour contour indicates the boundary marked by ophthalmologist.

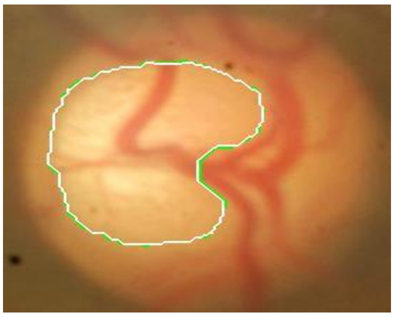

Fig. 16(a) Normal image

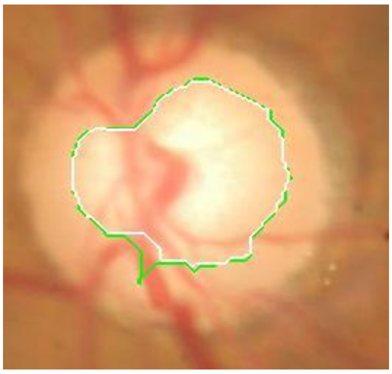

Fig .16(b) Glaucoma condition

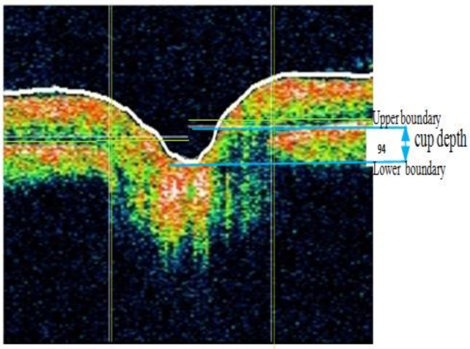

Fig .17(a) Normal Image

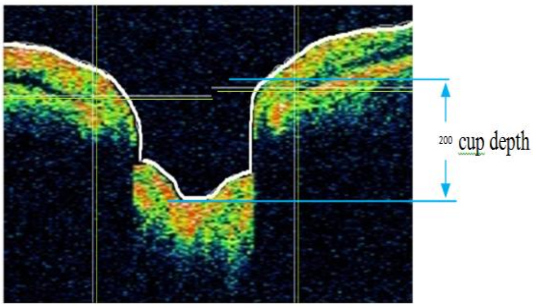

Fig .17(b) Glaucoma

An overlap measure of the match between the ground truth region and detected region (R) by the proposed method is used to measure the accuracy (M) as follows [14],

$$M = \frac{\text{Area } (T \cap R)}{\text{Area } (T \cup R)} \quad (9)$$

The other 2 accuracy measures used are

$$\text{Sensitivity(S)} = \frac{TP}{TP+FN} \quad (10)$$

$$\text{Specificity} = \frac{TN}{TN+FP} \quad (11)$$

Where true positive TP = $R \cap T$

False Positive FP = $R - (R \cap T)$

False Negative FN =$T - (R \cap T)$

The number of the true negatives, i.e. the number of pixels that are not classified as bleb boundary pixels, neither by the grader nor by the algorithm is very high. So the specificity is always near 100%. This is not very meaningful. Thereforean alternative solution is to calculate the Predictive Value (PV) using Equation (12),

$$PV = \frac{TP}{TP+FP} \quad (12)$$

PV is the probability that a pixel that has been classified as bleb is really a bleb. The overall Accuracy, Sensitivity, Predictive value are listed in Table 1.

Table 1.

S.No.	Parameters	Sensitivity	Accuracy	Predictive value
1	Cup Area	95.34 %	96 %	92.13%
2	Cup Depth	96.87 %	96.94%	94.13%

The cup volume values computed by the corresponding algorithm are shown as a part of the result and the segmented contour is shown on the original image and the gold standard value is also given for comparison.

To have a concise result, the scatter plot has been used. The scatter plot of computed cup volume vs gold standard values is generated by Minitab statistical software. Fig 18 shows the scatter plot of cup volume using gold standard and proposed algorithm. The regression equastion(13) is given by

Gold Standard 0.0454 + 0.942 proposed Method (13)

Correlation Coefficient =0.954

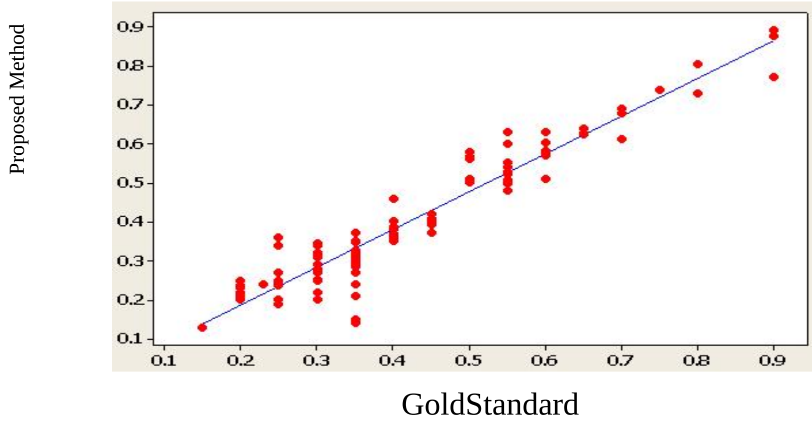

Fig .18 Scatter plot analysis for cup volume.

Conclusion

The cup volume indicator the risk of the presence of glaucoma in any individual. In this paper, a method to calculate the cup volume from fundus and OCT image is presented. In fundus image, optic disc and optic cup are segmented by using FLICM clustering. A morphological method is used to detect RV and RC boundary in OCT image. By using RV and RC boundary cup depth has been calculated. The results of the proposed method, for normal and glaucoma images have been presented and discussed. The performance of the proposed method is tested on 100 images and their cup volume is calculated.

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