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Segmentation approaches of optic cup from retinal images: A Survey

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ABSTRACT

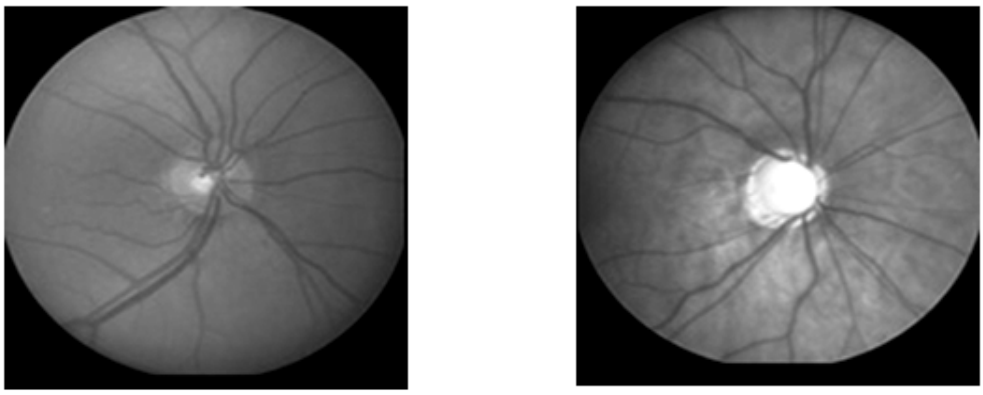
Eye is a sensitive organ of human body which is infected with many diseases. Glaucoma is one of the groups of eye diseases in which blockage of the eye's optic nerve leads to irreversible and continuously developing loss of vision. Ophthalmologists use retinal fundus images for assessment of this disease by manually outlining the cup and disc for analysis of the abnormality. Various parameters such as disc damage likelihood (DDLS), cup to disc ratio (CDR) and glaucoma risk index (GRI) are used for diagnosis of glaucoma. The aim of this paper is to survey different existing approaches proposed so far for optic cup segmentation from retinal images and analyze the challenges so as to improve it further for accurate diagnosis.

***Index Terms*:** Segmentation, optic cup, glaucoma, retinal image.

1. INTRODUCTION

Glaucoma is a retinal disease which occurs due to damage of the optic nerve that carries visual information to brain from the retina. It occurs due to increase in the pressure of eye thereby causing permanent and irreversible blindness also known as optic nerve cupping. Major symptoms of glaucoma that needs immediate diagnostic measures include sudden vision loss of one eye, appearance of blurred vision, black spots or light flashes and rainbows around eyes [1]. Damage to the optic nerve of eye is known as optic nerve cupping. The optic nerve is the carrier of impulses to the brain from the retina of the eye for visualization of outside world. It comprises of millions of nerves that exits the eye from a location called optic disc. This disc has a depression of variable size within it known as optic cup. In the patients with glaucoma size of optic cup increases with the increase in pressure inside the eye thereby causing blindness.

Figure 1 shows the difference between normal eye and glaucoma eye with advancement in the size of optic cup in case of glaucoma eye. [2]



(a) Normal eye **(b) Glaucoma eye**

Figure 1: Optic nerve [2]

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Most of the people do not recognize glaucoma at their earlier stages as it has no symptoms initially, but with the progression of this disease its influence increases until given a preventive measure. Ophthalmologists follow a sequence of steps such as tonometry to measure pressure within the eye, gonioscopy to analyse the drainage angle of eye, ophthalmology for evaluation of optic nerve and perimetry for testing of visual field [1]. According to existing studies researchers have used various diagnostic parameters such as cup to disc ratio, glaucoma risk index (GRI), disc damage likelihood scale (DDLS) and ISNT rule calculated from features of optic disc and cup. Hence a segmentation approach for optic cup and disc are of utmost importance. As, segmentation of optic cup is considered more prominent than optic disc due to presence of retinal vessels. This survey includes different approaches of segmentation used for optic cup to analyze the gaps in the literature and formulate the improved segmentation approach for optic cup as, more appropriate is the segmentation better is the diagnosis.

2. LITERATURE REVIEW

Various approaches proposed so far for segmentation of optic cup are as given below:

Liu et al. (2008) initially extracted region of interest (ROI) for optic cup segmentation. Due to involvement of vessels in the retinal image color intensity based threshold and level set based approach was used for cup segmentation followed by ellipse fitting to smoothen the boundaries. On comparing the results it was analyzed that variational level set approach along with thresholding based cup segmentation improved its performance as compared to existing approaches but has degraded its performance in case of either large or small CDR values [3].

Wong et al. (2008) used green channel of RGB color image for optic cup segmentation. Optic cup segmentation was carried out by applying thresholding based level set approach from normalized commutative intensity. Finally, ellipse fitting was used for smoothening the boundaries of optic cup and improving the accuracy of segmentation. It was analyzed that the proposed approach outperforms the existing approaches for both normal and abnormal cases [4].

Zhang et al. (2009) detected optic cup for glaucoma diagnosis using multi modality based fusion approach. They started with detection of region of interest by applying mask to remove non uniform illumination and segmented it using existing approaches. For segmentation of optic cup, intensity based approach was used to analyze the color histogram in combined channels and thresholded the optic cup. Variational level set approach was then used to detect cup boundary using histogram analysis based on optimal color channels and ellipse fitting using direct least square fitting algorithm and convex hull based ellipse optimization was applied to smoothen the cup boundaries. On performance analysis level set based approach outperformed the intensity based approach but it lacks testing on large scale clinical database [5].

Kavitha et al. (2010) initially used morphological operations for processing to remove the vessels that create problem in segmentation. It then selected Region of interest from green channel of RGB image and performed component analysis approach for optic cup segmentation. Finally for diagnosis of glaucoma parameters such as neuroretinal rim assessment using ISNT rule, cup to disc ratio and disk damage likelihood (DDLS) was used with the help of segmented optic disc and cup regions. On analysis, proposed approach gave better estimation of CDR which can be used for large scale clinical evaluation [6].

Joshi et al. (2010) presented regional information based optic cup boundary detection. For segmentation of optic cup ‘a’ color plane of ‘Lab’ color space was used for pre-processing by using morphological closing with circular structuring element. Intensity normalization followed by thresholding was used for cup segmentation and knowledge based on structure was applied to find out the nasal and temporal regions of optic cup with ratio of cup to disc utilized for diagnosis of glaucoma. The proposed approach improved

the performance of existing approaches but needs to be further improved for cup segmentation to diagnose glaucoma more accurately [7].

Joshi et al. (2011) presented an optic cup segmentation approach for glaucoma diagnosis by calculating CDR and CAR. For segmentation of optic cup information about vessel bends with the help of medial axis were taken into consideration to avoid problems due to large intensity differences in the cup region and later applied 2D interpolation to get final segmented optic cup. On analysis of the proposed disc and cup segmentation approach it was found that this approach outperformed various existing approaches [8].

Joshi et al. (2012) presented a cup segmentation based approach using depth discontinuities associated with boundaries. Circular hough transform was used for localization of optic disc to get the desired region of interest for optic cup. Green channel of RGB image was thereafter considered for pre-processing due to its highest contrast. Displacement field was calculated by taking pixel intensities from reference and floating images at particular location to perform registration and optimally align them. Integration of occlusion points at vessels with other maps helps to get occlusion points of the boundary. Therefore, Histogram was then computed to determine peaks that represented the radius of multiple circles. Finally cup boundary was estimated using maximum confidence limit of sectors of circles followed by its smoothening. This approach reduced the error rate as compared to existing approaches but needs to be improved by including characteristics other than motion [9].

Yin et al. (2012) gave an improved optic cup segmentation approach for glaucoma diagnosis. Boundary of optic disc was used as initial contour for segmentation of optic cup. They started with removal of blood vessels by applying intensity based median filter to smoothen the image. Active shape model was then applied to get optic cup from green channel of input RGB image. On performance analysis of the proposed approach it was analyzed that this approach outperformed the level set approach and Active shape model [10].

Xu, Yanwu, et al. (2013) presented reconstruction based learning approach for optic cup localization using codebook of manually labeled reference images. Green channel of input retinal image was then used for localization of cup and mean value of optic disc image was subtracted from every pixel to eliminate non uniform illumination. Codebook was then generated by random sampling of manual labelled images and cup descriptors were identified from it. Descriptors were later reconstructed and cost function was evaluated using hadamard product. Finally objective was minimized by using Lagrange multiplier with kronecker product and Gaussian distance. Also, cup to disc ratio was thereafter calculated for glaucoma diagnosis. But this had a limitation of performance degradation in case of dimensionality reduction and error alignment [11].

Cheng Jun, et al. (2013) proposed an optic cup segmentation approach for glaucoma diagnosis using super pixel classification based approach. Segmentation of optic cup was carried out by using simple linear iterative clustering (SLIC) to form the super pixels until the distances between previous and new centre pixels become small enough. Contrast was then enhanced using histogram equalization of R, G and B channels of input image followed by inclusion of saturation and hue components of HSV colour spaces to generate five channel maps with histogram component (HIST). Centre surround statistics (CSS) was then computed to include features that include optic cup region by generation of nine spatial scale dyadic Gaussian pyramid which are low pass filtered channels. Morphological processing, elliptical hough transform and active shape model was finally used to get optic cup boundary. Distance between superpixels D along with HIST and CSS were used as features to be classified with cup to disc ratio as screening parameter for glaucoma diagnosis using SVM classifier. The proposed approach outperformed existing approaches in terms of improved area under curve. But it either overestimated or underestimated the cup of small and large sizes [12].

Xu Yanwu, et al. (2014) presented an improved unsupervised optic cup segmentation approach for diagnosis of glaucoma with low rank representation of super-pixel. Input disc was initially divided into super-pixels using simple linear iterative clustering. Also low rank based labeling was applied to classify super-pixels as rim or cup followed by linear kernel with low ranks for efficient computation of the proposed approach. To avoid data corruption reconstruction error was penalized using squared forbenius norm. Also N cut labels were used followed by majority voting for classification of super-pixel. Finally analysis was carried out and it was realized that proposed approach improved the cup segmentation by reducing non overlap ratio [13].

Khalid et al. (2014) presented an improved fuzzy clustering based segmentation approach for optic cup. For pre-processing the input image they selected region of interest by cropping the image followed by calculation of min, max and mean values. Green channel of input retinal image was then used due to its good contrast followed by removal of vessels using dilation and erosion. After that fuzzy c mean clustering was used for optic cup segmentation using the concept of sum of squares by weighting membership functions. The proposed approach of segmentation with morphological operation gave better results than that of segmentation approach without morphological operations [14].

Rao et al. (2015) proposed an optic cup segmentation approach for diagnosis of glaucoma. Z-score normalization of input image was initially used for pre-processing followed by k mean clustering for segmentation of optic cup. Then for extraction of features, separable filters were applied across rows of one dimensional discrete wavelet transform to convert it into two dimensional discrete wavelet transform. After that short and long windows were applied across high and low frequencies for analysis of multiresolution. For selection of features to be used for training classifiers various averaging functions were used thereafter. Finally for classification, multilayer perceptron and artificial neural network were used to classify it as abnormal or normal case. Hence an improved detection system was formed which had capability to segment and classify both normal and abnormal cup. But it still needs to be tested on other classifiers so as to improve the performance [15].

Mittapali et al. (2016) proposed an optic cup based segmentation approach for glaucoma diagnosis. They started with the removal of blood vessels by applying Gaussian function as kernel to match filter for highlighting the suppressed vessels that create problem in segmentation. Then they thresholded the image to create the vessels maps and thereafter intensity of vessel pixels were replaced by non vessel pixels followed by use of median filter to smoothen the image. For segmentation of optic cup they used spatially weighted fuzzy clustering (SWFCM) based thresholding that used spatial distribution of gray levels. Finally their horizontal length, vertical length and areas were used to calculate the horizontal cup to disc ratio, vertical cup to disc ratio and area cup to disc ratio. Other parameters used for diagnosis were ISNT rule that is the relation between interior, superior, nasal, temporal length and DDLS that analyze that severity of disease [16].

Table 1 lists the above discussed approaches with their performance evaluation.

From the literature survey carried out, following gaps and challenges have been identified that supports further research in the field of optic cup segmentation.

- There remains a challenge to avoid under segmentation or over segmentation of cup with large or small sizes.
- Presence of retinal vessels and peripapillary atrophy deteriorate the performance of segmentation. Hence an improved pre-processing approach is required to solve these problems.
- Existing approaches of segmentation lacks testing on large scale dataset.
- Morphological approaches and various filters are used for pre-processing the retinal image to remove vessels present in the images, which create difficulty in segmentation.

Table 1
Comparison of segmentation approaches

Authors/Year	*Datasets used*	*Segmentation Approach*	*Performance Parameters*
Liu et al. [3] 2008	Local dataset of 73 images	Thresholding and level set based approach	79% avg. acceptable CDR for CIT and 97% and TLS
Wong et.al [4] 2008	Local dataset of 104 images	Thresholding based level set approach	95.2% inter observer variability and 86.5% intra observer variability
Zhang et al.[5] 2009	Local dataset of 71 images	Intensity based approach, Variational level set approach	Accuracy of 97.2%, Acceptable CDR ratio of 0.18
Joshi et al. [7] 2010	Local dataset of 170 images	Intensity normalization, thresholding	Rms Error of 0.100 and Standard deviation of 0.34
Joshi et al. [9] 2012	Local dataset of 150 images	Depth discontinuity based segmentation	Error reduction of 16% for CDR
Yin et al. [10] 2012	ORIGA-light dataset	Active shape model	Relative area difference of 32 % and CDR mean absolute error of 0.100
Xu Yanwu et al.[11] 2013	ORIGA-light dataset	Reconstruction based learning approach	Non overlapping ratio of 22.5% and Absolute CDR error of 0.071
Cheng, Jun, et al. [12] 2013	Local dataset of 2326 images	Super pixel classification, Simple linear iterative clustering	Area under curve of 0.80, Mean CDR error of 0.107 and 0.077 for normal and abnormal case.
XuYanwuet al. [13] 2014	ORIGA-light	Simple linear iterative clustering	1.8% avg. relative error reduction of and 2.7% absolute CDR error
Khalid et al. [14] 2014	Local dataset of 27 images	Fuzzy clustering based segmentation	Sensitivity of 80.63%, Specificity of 99.89 % and Accuracy of 90.2%
Rao et al. [15] 2015	Local dataset of 300 images	k mean clustering	89.96% accuracy for Naive Bayes and 97.6% for MLP-BP classifier.
Mittapali et.al [16] 2016	RIM-ONE and Local dataset of 59 images	Spatially weighted fuzzy clustering based thresholding	Avg. F-score of 0.89 and Avg. correlation of 0.835

3. CONCLUSION

This paper presents the existing approaches used so far for the segmentation of optic cup. From the survey, it has been identified that optic cup segmentation deals with the challenge of under segmentation and over segmentation of cup with large or small sizes. Segmentation is also considered a challenging task in low contrast images due to invisible boundaries of disc and cup. Less work has been done on segmentation of optic cup. Hence an improved segmentation approach of optic cup is required for diagnosis of glaucoma. Studies show that green channel is more suitable for segmentation of optic cup due to high contrast of this channel as compared to other channels. Also morphological approaches and various filters are used for pre-processing the retinal images to remove vessels present in the images and refine the difficulty of segmentation.

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