A Multiple Retinal Normal and Abnormal Anatomical Structures Segmentation Using Hybrid Morphological and Fuzzy Local Adaptive Thresholding

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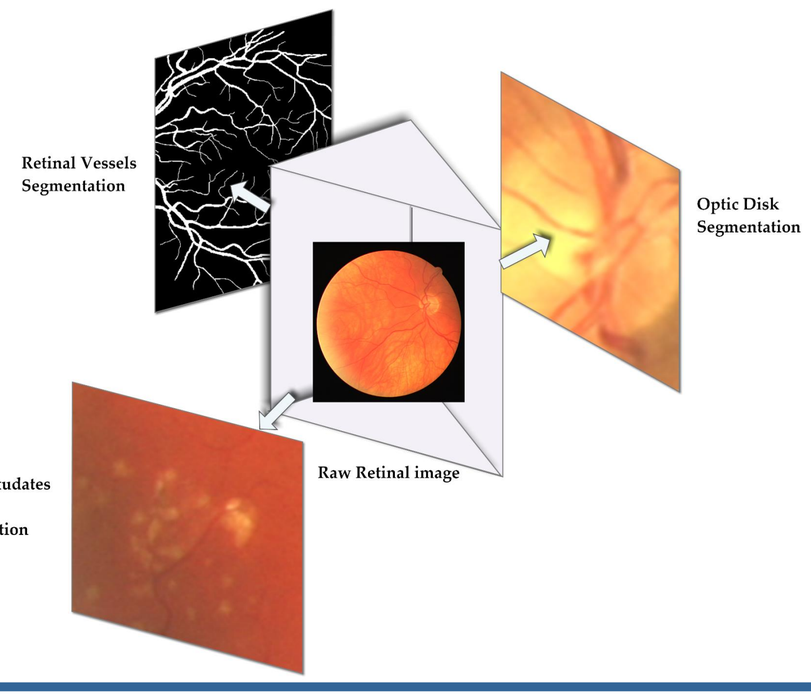
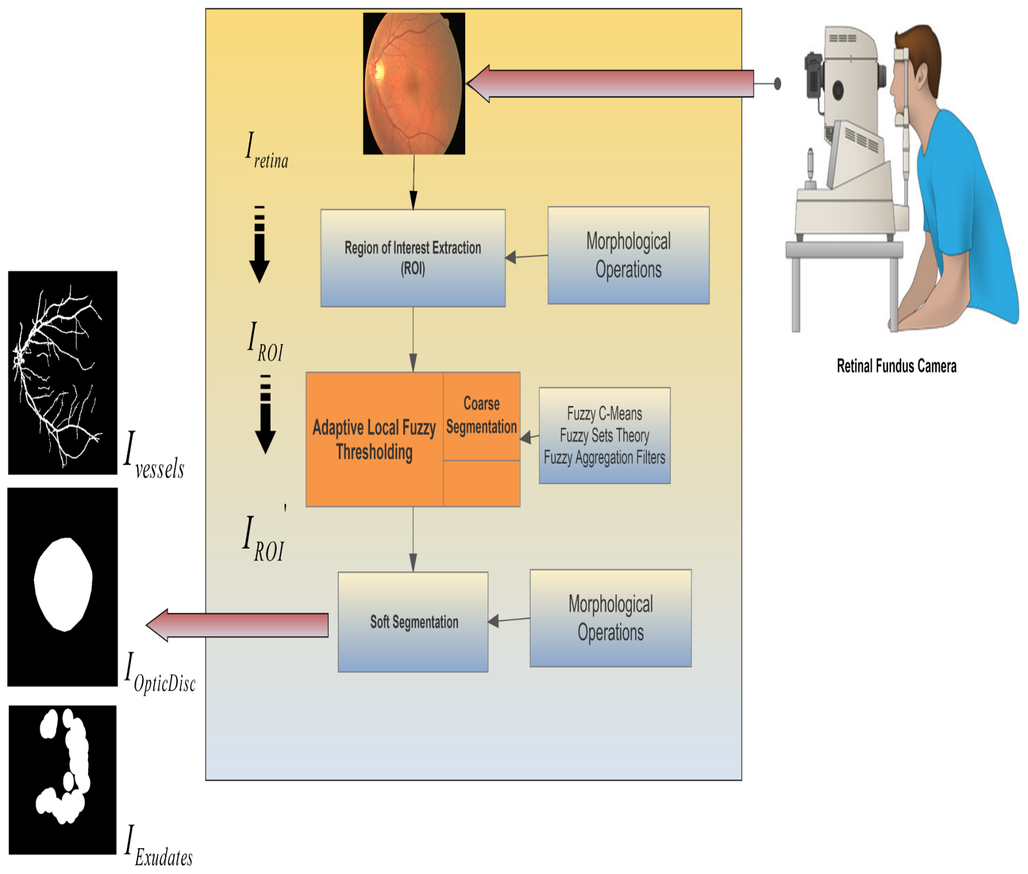
Introduction:

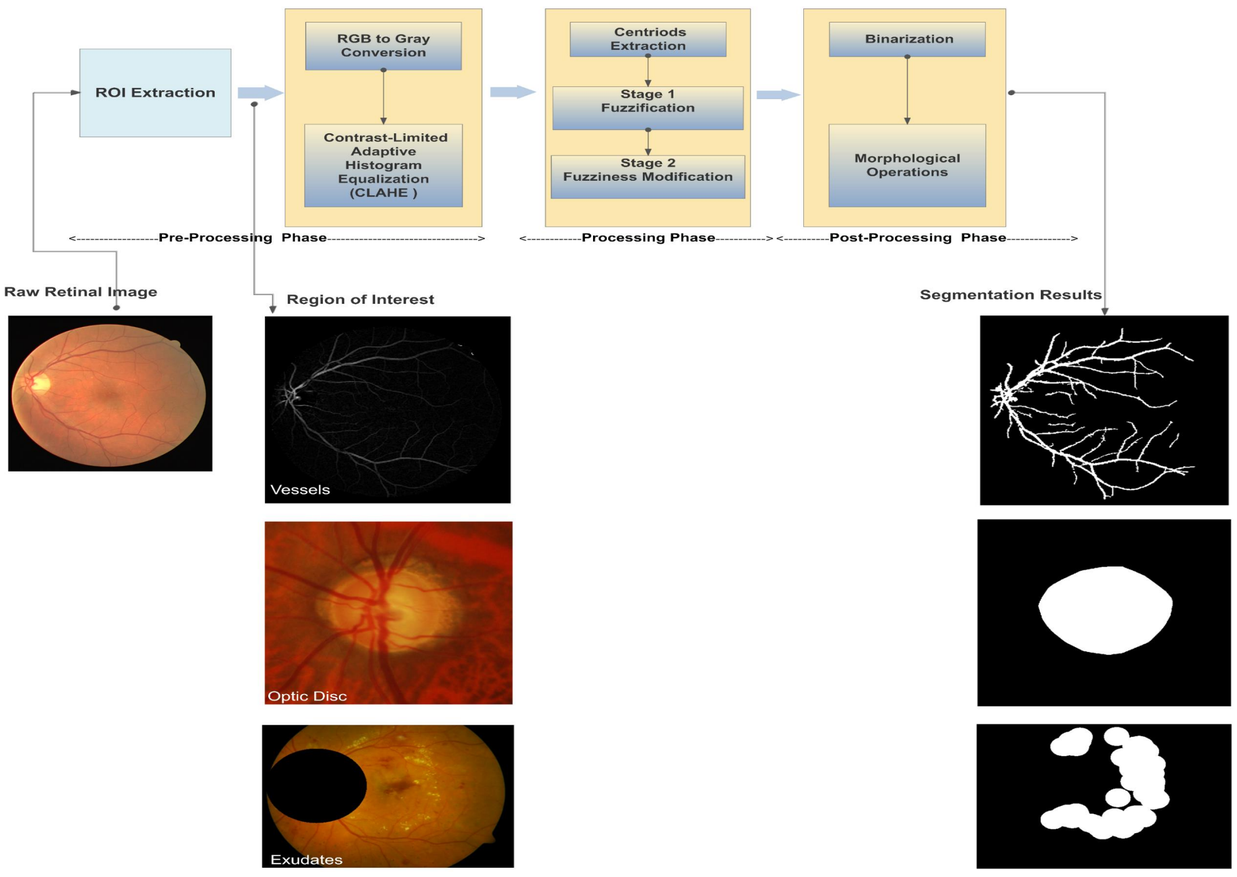
Eye exam can be as efficacious as physical one in determining health concerns. Retina screening can be the very first clue to detecting a variety of hidden health issues including pre-diabetes and diabetes. Through the process of clinical diagnosis and prognosis; ophthalmologists rely heavily on the binary segmented version of retina fundus image; where the accuracy of segmented vessels, optic disc and abnormal lesions extremely affects the diagnosis accuracy which in turn affect the subsequent clinical treatment steps. This paper proposes an automated retinal fundus image segmentation system composed of three segmentation subsystems follow same core segmentation algorithm. Despite of broad difference in features and characteristics; retinal vessels, optic disc and exudate lesions are extracted by each subsystem without the need for texture analysis or synthesis. For sake of compact diagnosis and complete clinical insight, our proposed system can detect these anatomical structures in one session with high accuracy even in pathological retina images. The proposed system uses a robust hybrid segmentation algorithm combines adaptive fuzzy thresholding and mathematical morphology. The proposed system is validated using four benchmark datasets: DRIVE and STARE (vessels), DRISHTI-GS (optic disc), and DIARETDB1 (exudates lesions). Competitive segmentation performance is achieved, outperforming up-to-date systems and demonstrating the capacity to deal with other heterogenous anatomical structures.

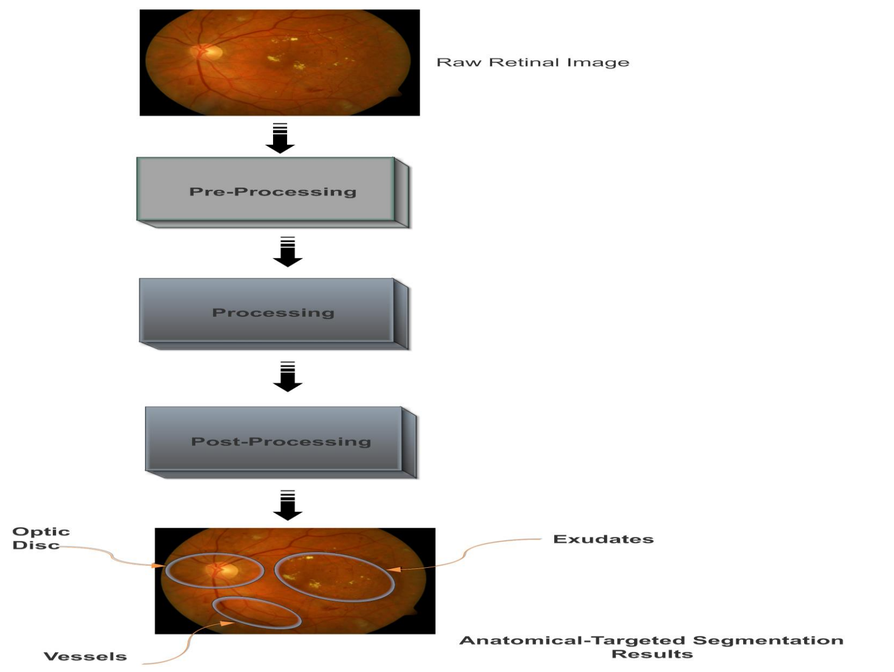


Proposed Method:

we propose a system that involves new hybrid thresholding algorithm combines two powerful techniques: adaptive local fuzzy thresholding (coarse segmentation) and mathematical morphology (soft segmentation). The general flowchart of the proposed system, without regarding the acquired anatomical retinal structure. Morphological operators are used in the pre-and post-processing phases of system algorithm, whereas adaptive local fuzzy thresholding is used in the processing phase, which means that it represents the core of the segmentation algorithm, even though morphological operators are considered more than complement steps. irrespective of the target anatomical structure, our proposed system involves three major phases: Region Of Interest (ROI) extraction, coarse segmentation and soft segmentation. In the first phase, the target region of interest is extracted out of the raw retina image I_{retina} in order to enhance the segmentation accuracy of the target retinal anatomical structure (vessels, optic disc or exudates lesions) and lower the computational cost, then I_{ROI} image undergoes a set of pre-processing steps involving major morphological operations that lead to initial identification of the target area. Although this phase is a preliminary one, it has a dramatic effect on the final segmentation accuracy of the fuzzy processing phase. The I_{ROI} forms the input for local adaptive fuzzy thresholding, which yields the I'_{ROI} hard-segmented image. Another set of morphological operations are applied on I'_{ROI} in the soft segmentation stage followed by binarization and convex-hull transform smoothing steps produced the final segmented image: I_{vessel},$I_{Optic\ Disc}$, or $I_{exudates}$, depending on the target retinal anatomical structure.







Performance Evaluation:

In this section, our system results for each anatomical structure are compared to separate benchmark methods and systems. We report the results of experiments conducted using our proposed subsystems (vessel extraction, optic disc extraction, and exudate extraction subsystems) and compare them with existing up-to-date techniques and methodologies.

Performance Comparison of Proposed Vessel Segmentation Methods based on DRIVE Dataset

Method	Sensitivity	Specificity	Accuracy
Second Human Observer	0.7761	0.9725	0.9473
Zhang *et al.* (2010)	0.7120	0.0276	0.9382
Dizdaro *et al.* (2012)	0.7181	0.9743	0.9412
Akhavan *et al.* (2014)	0.7252	0.9733	0.9513
Zhang *et al.* (2015)	0.7508	0.9656	0.9521
Borges *et al.* (2015)	-	-	0.9489
Zhang *et al.* (2015)	0.7812	0.9668	0.9504
GeethaRamani *et al.* (2016)	0.7079	0.9778	0.9536
Singh *et al.* (2016)	0.7594	0.0292	0.9522
Mapayi *et al.* (2016)	0.7302	0.9651	0.9444
Jiang *et al.* (2017)	0.9159	0.9559	0.9538
Proposed System	**0.8065**	**0.9729**	**0.9588**

Optic Disc Segmentation Methods Comparison

Method[a]	Sensitivity	Specificity	PPV
Stapor *et al.* (2004)	84.98%	99.64%	80.34%
Seo *et al.* (2004)	61.03%	99.87%	88.78%
Lupascu *et al.* (2008)	68.48%	99.69%	81.17%
Kande *et al.* (2008)	88.08%	98.78%	54.48%
Bharkad *et al.* (2017)	74.60%	99.61%	74.96%
Proposed System	**93.13%**	**97.09%**	**90.15%**

Performance Comparison of Proposed Vessel Segmentation Methods based on STARE Dataset

Method	Sensitivity	Specificity	Accuracy
Hoover et al (2000)	0.6747	0.9565	0.9275
Kande *et al.* (2008)	-	-	0.8976
Zhang *et al.* (2009)	0.7373	0.0264	0.9087
Yin *et al.* (2015)	0.8541	0.9419	0.9325
Singh *et al.* (2016)	0.7939	0.0624	0.9270
Proposed System	**0.7611**	**0.9551**	**0.9402**

Performance Comparison of Exudates Lesions Segmentation Methods on Pathological Images of DIARETDB1 Dataset

Method	Sensitivity	Specificity	Accuracy	PPV
Sopharak *et al.* [a] (2009)	97.2%	85.4%	85.6%	7.9%
Welfer *et al.* (2010)	70.48%	98.64%	-	21.32%
Harangi and Hajdu (2014)	73%	-	-	69%
Liu *et al.* (2017)	83%	75%	79%	-
Fraz *et al.* (2017)	92.42%	81.25%	87.72%	87.14%
Proposed System	**75.80 %**	**85.7%**	**83.4%**	**41.67%**

Conclusion:

We have proposed a generic system for automatic detection, localization and extraction of three retinal anatomical structures using a hybrid of fuzzy set theory and morphological operations. From a clinical point of view, the extraction of retinal structures is the first step in the design and development of computer-assisted diagnostic systems for ophthalmic issues. The outputs of these proposed subsystems (vessels detection subsystem, optic disc subsystem, and exudates lesions subsystem) are integrated in a compact manner to capture the clinical information that they contain. From a research point of view, our work makes two major contributions. First, our proposed system eliminates the need for designing a separate system for detecting each retinal anatomical structure; one compact novel system was used to extract three different anatomical structures with various features and textures. Building upon this system, a hybrid framework for performing detection and extraction tasks for other anatomical structures either inside the retina or other organs can be developed. Second, the proposed system is highly robust and accurate as well, as it has been shown to perform better than the state-of-art on the public DRIVE, STARE, DRITSHTI-GS, and DiaRetDB1 retinal datasets. In addition, it performs well at extracting vessels and optic disc from pathological retinal images. Therefore, it can be considered ideal for real-life diagnosis applications. Experimental results showed that for the same dataset used, our proposed system has achieved superior results in terms of specificity, sensitivity and accuracy. This is a clear indicator of the powerful system that can be yielded when a highly discriminative operator such as morphological operations combined in a hybrid manner with highly nondiscriminative ones such as fuzzy sets. This hybrid combination can be viewed as some sort of trade-off between the crisp world and the fuzzy one.

Reference:

J. Almotiri, K. Elleithy, and A. Elleithy, "Retinal Vessels Segmentation Techniques and Algorithms: A Survey," *Applied Sciences*, vol. 8, p. 155, 2018.