GENERATIVEADVERSARIALNETWORKSFORRETINAL IMAGE ENHANCEMENT WITH PATHOLOGICAL INFORMATION

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ABSTRACT

Age-related macular degeneration (AMD) is a disease of the central retina, which is one of the main reasons for vision loss of elderly people. To monitor the level of AMD, the doctors mainly use the retinal fundus images. However, the quality of retinal images can be affected during the imaging process. It leads to low contrast and blurry images. Those bad quality images cannot be used for analyzing and diagnosis. For that reason, there are many studies about image enhancement in order to improve the quality of retinal photography. However, previous methods could not guarantee to keep the disease information after the enhancement process. Therefore, we introduce a generative adversarial model for AMD retinal image enhancement with additional factors to preserve the disease information. By exploiting drusen segmentation masks, our proposed model can enhance retinal photography quality and keep the pathological information.

INTRODUCTION

Age-relatedmaculardegeneration(AMD)encompassesavarietyofdiseasesandconditions. It is a group of optic nerve diseases, with 'characteristic' progressive structural changes leadingtolossofvisualfunctionina'characteristic'way.AMDisthesecondleadingcause of blindness worldwide. The retina is the innermost layer in the eye and the retinal nerve fiberstransmitthevisualsignalfromthephotoreceptorsintheeyetothebrainviathebundle goingoutoftheeye,knownastheopticnerve.AMDleadstocontinuousandspeedydamage of the retinal nervefiber layer and hence can lead to permanent blindness.The progression ofthenervefiberlayerlosscanbeeffectivelystoppedbytreatmentconsistingofmedication orsurgerytoreducetheintraocularpressure.HencethediagnosisofAMDatanearlierstage is very important for its treatment.

A major concern with AMD detection is that the disease has no particular set of physical causes or symptoms that doctors can recognize to detect the disease in an early stage.ThemainfocusinAMDdiagnosisistodetectchangesinthevisualfunctioningofthe eye at early stages of the disease so that vision can be protected and preserved through medicaltreatment.Ithasbeenprovedthatthedevelopmentofvisualfielddefectsispreceded by RNFL damage in Age-related macular degeneration (AMD).

Studiesshowthatasmuchas40%ofretinalnervefiberintheeyecanbelostwithout the detection of characteristic visual defect inAMD patients. Hence it is believed that the detection of damage in nerve fiber layer can lead to an early detection of AMD. Several computer-assisted imaging technologies for detecting the structural changes in the retinal nervefiberlayerhavebeendeveloped.Theassessmentoftheganglioncellstructureisbased on measuring the thickness of the retinal nerve fiber layer.

One such device, the Scanning Laser Polarimeter (GDx-VCC, Laser Diagnostic Technologies,Inc.,SanDiego,CA)isbasedontheprincipleofmeasuringthechangeinthe polarization of light exiting the eye. The retinal nerve fiber layer consists of parallel structures of diameter smaller than the wavelength of light, which makes it a birefringent structure.Abirefringentstructurehastheabilitytochangethepolarizationofpolarizedlight

doublepassingit.[7]Theamountofchangeinthestateofpolarization(retardation)canbeThe device provides a large array of points corresponding to retinal.

This is found to be proportional to the thickness of the nerve fiber layer. This retardation(degrees)informationisconvertedtothickness(microns)throughtheconversion factor based on the histologic comparison with monkey eyes.Anew version of the device (GDx-VCC)isdesignedtoindividuallycompensatefortheeffectsofbirefringentproperties of other parts of the eye like the cornea. The device provides a large array of points correspondingtoretinal neverfiberlayerthicknessateachrespectivepoint acrosstheback of the eye. The scans thus available are in the form of 128 X 256 images or gray-level thickness maps.The goal of this thesis is to analyze these scans and develop classification techniques for them.


Photograph of a Scanning Laser Polarimetry Device (Courtesy: Laser Diagnostics, SanDiego, CA)

The first step in a classification problem is to extract useful features from the setof givendata.Theoriginal scan is used to derivepatternsorfeatures that can separatethe two classes. The feature extraction step is to obtain a feature vector, a set of different useful features, which reduce the dimension of the original data while keeping all the essential informationcontainedinthedata. Thenextstepafterobtainingdistinguishableandreliable set of features is to make them statistically independent. A very effectivewaytoachieve this end is to perform Principal component analysis on the feature set. This will help in reducing feature dimension by eliminating redundancy caused by interdependencies in the featurevector.Thelaststepistheclassificationofthedatasetintothetwoclasses.Fisher's Linear DiscriminantAnalysis (LDF) provides an easy and robust way.

OBJECTIVE

The primary objective of this research is to design and implement a Generative Adversarial Network (GAN)–based approach for retinal image enhancement with a special emphasis on preserving pathological information. The proposed system aims to:

1. **Enhance Retinal Image Quality** – Improve the visual clarity, contrast, and resolution of retinal images affected by noise, blur, or low illumination.
2. **Preserve Pathological Features** – Ensure that clinically significant features such as lesions, exudates, hemorrhages, and microaneurysms remain intact during enhancement for accurate diagnosis.
3. **Assist Medical Diagnosis** – Provide ophthalmologists and automated diagnostic systems with high-quality images that support effective detection and classification of retinal diseases.
4. **Develop Robust GAN Architecture** – Utilize adversarial training strategies to generate realistic, high-fidelity images while minimizing information loss.
5. **Evaluate Performance** – Validate the enhanced images using both quantitative metrics (PSNR, SSIM, etc.) and qualitative expert evaluations to confirm diagnostic reliability. Dey,N,Roy,A.B.;Das,A.;Chaudhuri,S.S:Opticalcuptodiscratiomeasurementfor glaucoma diagnosis using Harris corner

In this paper, Glaucoma is physiologically described as the deterioration of optic nerve cells, and is characterized by alterations in the optic nerve head and visual field.The measurement of neuro-retinal optic cup-to-

disc ratio (CDR) is an important index of Glaucoma, as the increased excavation of the optic cup occurs because of Glaucomatous neuropathy increasing the CDR. Currently, CDR evaluation is manually performed by ophthalmologists.

EleesaJacob,R.Venkatesh:AMethodofSegmentationforGlaucomaScreeningUsing Superpixel Classification

In this paper, an optic disc and optic cup segmentation is used to identify the glaucoma disease in time. In optic disc and optic cup segmentation, super pixel classification for glaucomascreeningisproposed.Inopticdiscsegmentation,histogramsandcentresurround statistics are used to classify each super pixel as disc or non-disc. A self-assessment reliability score is computed to evaluate the quality of the automated optic disc segmentation. In optic cup segmentation, the location information is also included into the feature space for better performance in addition to the histograms and centre surround statistics. The segmented optic cup and optic disc is then used to compute the cup to disc ratio for glaucoma screening. From the cup to disc ratio. analysis is performed to identify whether the given image is glaucomatous or not. The segmentation can be analyzed using the MATLAB.

PROPOSED SYSTEMS

RetinalNerveFiberLayerandScanningLaserPolarimetry

The retinal nerve fiber layer is composed of about 1.2-1.5 million ganglion cell axons originating in the retina. The axons are distributed in a characteristic pattern. The axons originating in the region nasal to the optic disc as well as in the macular area run directly towardtheopticnervehead,whiletheaxonsoriginatinginthetemporalsectionruntowards the superior or inferior poles of the optic disc before converging to the nerve head. These fibers are known to be most susceptible to earlyAMD retinal image damage.

The peripheral ganglion cell axons travel to the optic nerve head in the peripheral position while the central axons take a more superficial path and follow the innermost part within theopticnervehead. Dueto the characteristicpatternofthenervefiberlayer axons, the thickness of the nerve fiber layer on the vertical poles of the optic disc is much higher than in the nasal and temporal optic disc poles.

The importance of the detection of RNFL damage as an early sign ofAge-related maculardegeneration(AMD)hasbeenconfirmedbynumerousstudies.HoytandNewman firstdescribeditin1987[25,26].Histologicalstudiesshowthatasmuchas40%ofretinalnerve fiber in the eye can be lost without the detection of characteristic visual defect in AMD patients[6].ThefindingsofSommerandcolleaguesshowedthatRNFLdamagecouldprecede visualfieldlossbyupto5years[27].Henceitisbelievedthatthedetectionofdamageinnerve fiber layer can lead to an early detection ofAMD.

RNFL defects related to Age-related macular degeneration (AMD) can be either diffused or localized. Localized defects generally include slit-like or groove-like defects in theRNFL.Whentheseslitlikedefectsextendtothediscmarginorthewedgeshapeddefects are seen as notches in the neuroretinal rim in inferior or superior regions, it is judged as a sign of AMD retinal image abnormality.

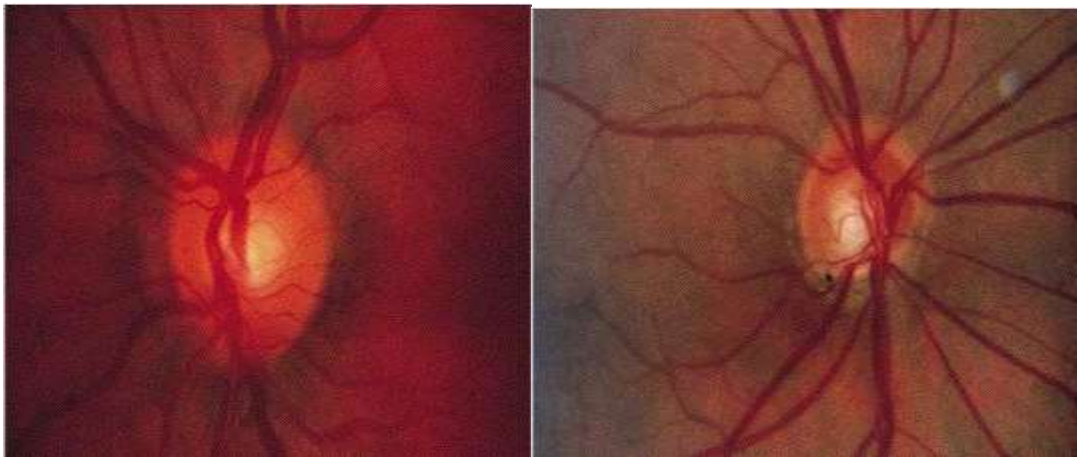
Althoughlocalizeddefectsareeasiertodetect,diffuseRNFLlossismorecommon and difficult to diagnose. The second order retinal vessels, which are normally well concealed by the retinal nerve fiber layer, start to be seen in this kind of defects. The progressive loss of RNFL thickness in the superior and inferior poles is a sign of AMD retinal image damage.

There are several different techniques for the qualitative examination and quantitativemeasurement ofnervefiberdamage causedbyAMD.The qualitativetechniques include examination of the retina through a dilated pupil using an ophthalmoscope or by usingared-freecameraorusinghigh-resolutionblackandwhitephotographs.Theseareall, however, limited by the pupil size and media optics and tend to have high intra- and interobserver variability. To reduce these difficulties and provide more quantitative measurements of the nerve fiber layer, different devices have been developed. Several instrumentshavebeendevelopedthatfocusonimagingofthefundus(amirrorlikestructure just behind the retina which acts as a light amplifier) and analyzing the topography of the retinal surface. These methods attempt to quantify the three-dimensional size and shape of the optic disc, which is considered to represent the bulk of the retinal nerve

fibers (Figure 3.1).Stereoscopicfundusphotographyusesphotographsoffundusunderdifferentanglesto obtain topographic information of the disc.

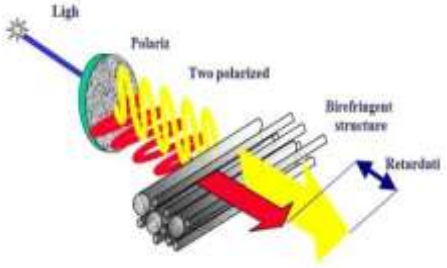
Confocalscanninglaserophthalmoscopytriestoobtainopticalsectionimagesofthe retinabyscanningalaserbeamacrosstheeyefundusintwodimensionsandprovidesvideo images on a monitor. These methods include instruments like the Topcon Imagenet, the Rodenstock Optic Nerve Analyzer (Rodenstock Instruments, Munich, Germany) and Heidelberg Retina Tomograph (Heidelberg Engineering, Heidelberg, Germany).Although these methods are a reasonable indicator of the condition of the optic disc, the analysis of the topography of the fundus is an indirect measure of the nerve fiber layer and is only suggestive.

Furthermore,theultimateresolutionofthesemethodsislimitedbytheproperties of the ocular media. Hence these kinds of imaging systems are not suitable for accurate measurement of the retinal nerve fiber layer thickness.



Exampleofopticdiscphotography*a)*normaldisc*b)*notchinginopticdisc(Courtesy: Handbook of Age-related macular degeneration (AMD) (Azuara-Blanco Augusto)

Scanning Laser Polarimetry (SLP) is a technique of providing a more quantitative measureofthethicknessoftheRNFL.Themethodisbasedontheprincipleofusingimaging polarimetry to detect the birefringence of the retinal nerve fiber layer[7,9] (Figure 3.2). This techniqueutilizesthepolarizationpropertiesoftheretinalnervefiberlayer.Thenervefiber layer and other regions of the retina have been known to have polarization properties or birefringent properties. Form birefringence occurs when a medium consists of parallel cylindricalstructurewithdiameterssmallerthanthewavelengthoflightpassingthroughit. Abirefringentstructurehastheabilitytochangethepolarizationofapolarizedlightdouble passing it[29].



ScanningLaserPolarimetryDevice-Principle(Courtesy:LaserDiagnostics,SanDiego,CA)

The Scanning Laser Polari meter uses this principle to scan the thickness of the retinal nerve fiberbyemployingalowpowernearinfraredlaserbeamtoilluminatethehuman retina.

Amongthenumberofsoftware-generatedparametersprovidedbythecompany,the main ones are 'the number'and the 'NFI'(nerve fiber indicator). The parameter "number" is obtained through a neural network, which is fed with around 100-200 features from the scanned image. The NFI is obtained through a support vector machines recognizer and is available in the newer versions of the device. The latest version of the device implements thecorrectionforthebirefringentpropertiesofthepartsoftheeyeotherthanthenervefiber layerand is called GDxVCC. Currently doctors usetheabove-mentioned factors fromthe device along with other tests and gauge.

GrayscalerepresentationoftheRNFLthicknessmapimage

DESIGN APPROACHES ARCHITECTURE

1.Overall Architecture

The proposed system is built on a **Generative Adversarial Network (GAN)** framework, consisting of two main components:

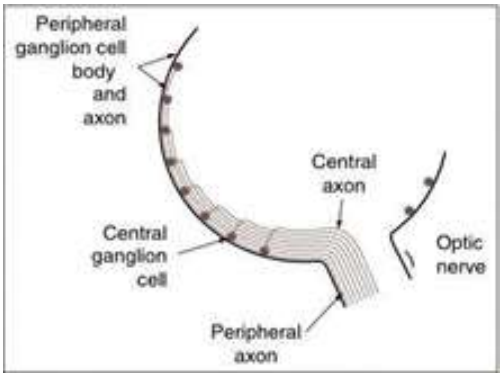
- **Generator Network**
  - Enhances low-quality retinal images.
  - Improves sharpness, illumination, and contrast.
  - Ensures pathological features such as lesions, exudates, hemorrhages, and microaneurysms remain intact.
- **Discriminator Network**
  - Differentiates between real high-quality images and GAN-enhanced images.
  - Provides feedback to improve the generator's accuracy.

2. Design Approach

1. **Data Input & Preprocessing**
   - Retinal fundus images acquired from scanning laser polarimetry and fundus photography.
   - Noise reduction, normalization, and augmentation techniques are applied.
2. **Feature Extraction**
   - Segmentation masks (e.g., drusen masks) highlight pathological regions.
   - Feature maps are extracted to guide GAN training.
3. **GAN Training Strategy**
   - **Adversarial Loss**: Encourages realistic image generation.
   - **Content Loss (MSE/MAE)**: Maintains structural integrity.
   - **Perceptual Loss**: Preserves pathological information important for diagnosis.
4. **Validation & Testing**
   - Enhanced outputs compared using **PSNR, SSIM, and VIF**.
   - Ophthalmologists verify the medical significance of preserved features.

3.System Workflow (Architecture Diagram Explanation)

Although the PDF contains textual description, the conceptual architecture can be summarized as



Exampleofopticdiscphotography*a)*normaldisc*b)*notchinginopticdisc(Courtesy: Handbook of Age-related macular degeneration (AMD) (Azuara-Blanco Augusto)

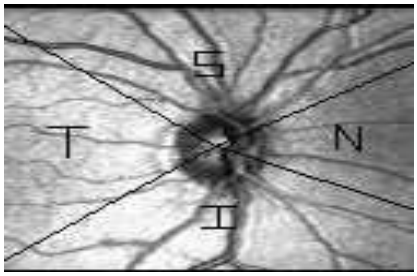
The ganglion axons that constitute the nerve fiber layer are essentially cylindrical rod-

likestructuresthatareparalleltotheretinalsurfaceandhaveextremelysmalldiameters. Whenalightbeam,perpendiculartoitssurface,isimpingedontheretina,thereflectedlight issplitintotworaysthattravelatdifferentvelocitie

WORKING

1.Input Acquisition

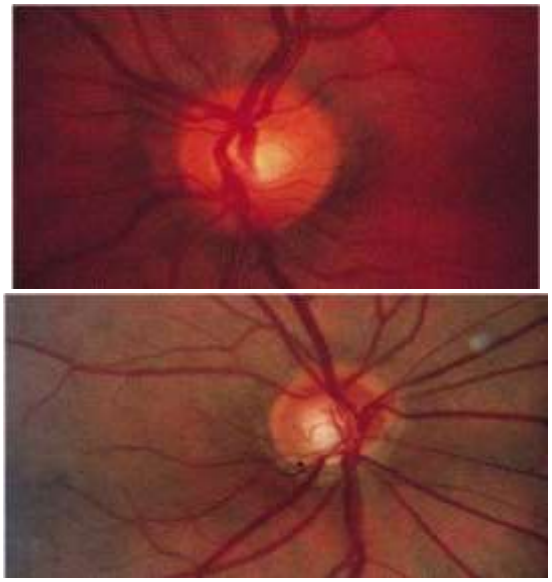
- Retinal fundus images are collected using scanning laser polarimetry and other retinal imaging devices.
- These images often suffer from low contrast, blur, and noise.



Photographoftheopticnervewithopticdiscinthecenterandtheareasarounditdivided into the four sectors – Temporal, Superior, Nasal, and Inferior

Preprocessing

- The images are digitized and normalized.
- Segmentation masks (like drusen masks) are used to mark pathological regions for preservation



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GAN Model Implementation

- **Generator:** Enhances low-quality retinal images (sharpness, contrast, clarity).
- **Discriminator:** Differentiates between real high-quality images and GAN-enhanced images.
- Training uses adversarial loss + perceptual/content loss to ensure enhancement **without losing pathological details**.

This section provides an introduction to MATLAB's desktop tools. You can also use MATLAB functions to

perform most of the features found in the desktop tools. The tools are:

- CurrentDirectoryBrowser
- WorkspaceBrowser
- ArrayEditor
- Editor/Debugger
- CommandWindow
- CommandHistory
- Launch Pad
- Help Browser

CommandWindow

UsetheCommandWindowtoentervariablesand runfunctionsandM-files.

CommandHistory

Lines you enter in the CommandWindow are logged in the Command History window. In the Command History, you can view previously used functions, and copy and execute selectedlines.TosavetheinputandoutputfromaMATLABsessiontoafile,usethediary function.

Processing and Enhancement

- GAN iteratively improves images while referencing segmentation masks so that disease features (lesions, hemorrhages, microaneurysms) are preserved.
- Enhanced images are visually and statistically compared with original

Evaluation

- Metrics: PSNR, SSIM, VIF used for quantitative analysis.
- Ophthalmologists verify whether pathological information is retained.

Output

- High-quality retinal images with preserved pathological regions ready for diagnosis and computer-aided systems

Healthyretina

RESULT

Our present sample consists of SLP scans of 92 AMD retinal image eyes and 92 normal eyes, obtained from 47Age-related macular degeneration (AMD) patients and 45 healthy people. Dr. Michael Sinai of

Method	Sensitivity	Specificity	Area under ROC curve
FT of 90° projection	75.12%	99.15%	0.7789
Wavelet analysis with FT of 90° projection	58.7%	89%	0.8235
Ring data from 2D FT	74.92%	91.5%	0.7813
Correlation coefficient with pattern image	67.5%	82%	0.8287
Combined Feature set	84.78%	91.3%	0.8433
FFTA – based on previously performed analysis	76.09	91.3	0.8588

PerformanceevaluationofthedifferentfeaturesetsbasedontheROCanalysis

Laser Diagnostics made the data set and its diagnosis (classificationbasedonclinicalfindings)availabletousforresearchpurposes.Thissetwas dividedrandomlyanduniformlyintotwosubsets.Onesubsetwasusedasatraineesetfor

+the classifier while the other was used as a test set. After the classification results were obtained, the ROC

analysis for performance evaluation.

APPLICATIONS

Detection and diagnosis of Age-related Macular Degeneration (AMD): Utilizing computer-assistedimagingtechnologiestodetectstructuralchangesintheretinalnervefiber layer for early AMD diagnosis.

Glaucomascreeninganddiagnosis:Developingautomatedsystemsforglaucoma detectionusingimageprocessingandanalysisofretinalimages.

Retinalimageanalysis:Processingretinalimagestoassistclinicaldiagnosisand treatment, with a focus on automated diagnosis of retinal fundus images.

ADVANTAGES

- Itdiscussestechniquesthat"aidaphysicianindetectingpossiblesubtle abnormalities."
- Theapplicationofdigitalimagingtoophthalmologyoffersthepossibilityofprocessing retinal images to assist clinical diagnosis and treatment.
- The development of anautomated system for analyzing the imagesof the retina willfacilitate computer-aided diagnosis of eye diseases.
- Theautomatedsystemcandetectglaucomaefficientlyandinless time.

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