Deep Learning Algorithms and Glaucoma Detection: A Review

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Abstract - *Glaucoma is a chronic eye disease that leads to irreversible vision loss. Glaucoma detection is a significant problem to be solved in medical field. Few research works have been designed to detect glaucoma in its early stage. But, performance of glaucoma disease detection using existing techniques was not effectual. Moreover, time complexity of conventional glaucoma disease detection was more. Glaucoma detection in color fundus images is a challenging task that requires expertise and years of practice. Deep learning algorithms, in particular convolutional networks, have rapidly become a methodology of choice for analyzing medical images. In this study we exploited the application of different Convolutional Neural Networks (CNN) schemes to show the influence in the performance of relevant factors like the data set size, the architecture and the use of transfer learning vs newly defined architectures at an early stage with higher accuracy and a lower time. Glaucoma is an optic neuropathy characterized by progressive degeneration of retinal ganglion cell. There are many different types of glaucoma, with a variety of etiologies and pathogenic factors, but all have in common typical changes in the structure and la function of the optic nerve. Deep learning algorithms, in particular convolutional networks, have rapidly become a methodology of choice for analyzing medical images. This paper reviews the major deep learning concepts pertinent to medical image analysis and summarizes the contributions to the field, most of which appeared in the last year. We survey the use of deep learning for image classification, object detection, segmentation, registration, and other tasks. Concise overviews are provided of studies per application area. We end with a summary of the current state-of-the-art, a critical discussion of open challenges and directions for future research.*

Key Words: Deep learning, Convolutional neural network, Glaucoma, Medical images

1.INTRODUCTION

Glaucoma disease detection based on optic disc features of retina. Glaucoma cause blindness and therefore early discovery of disease safeguards the patients from temporary or permanent blindness. Therefore, Glaucoma disease identification is the most difficult process in the image processing and analysis field. A lot of research works have been introduced in existing works using various data mining techniques for performing the glaucoma detection. However, the accuracy of glaucoma disease detection using conventional techniques was not sufficient. Besides, the amount of time needed to detect the presences of glaucoma disease in input fundus image was more. Therefore, there is a requirement for novel technique for performing effective glaucoma disease detection. Our eye has pressure just like our blood which is called intraocular pressure. When this intraocular pressure (IOP) increases to a certain level, it damages the optical nerve. This can result in decreased peripheral vision and eventually blindness. Manual analysis of eye images is fairly time consuming and the accuracy of parameters measurements varies between experts. Hence, there arises the need for an automated technique. Automatic Computerized examination of retina pictures is turning into a significant screening instrument now days. This strategy identifies different sort of dangers and ailments of eyes. There are essentially two kinds of glaucoma one is open point or interminable glaucoma and another is shut edge or intense glaucoma, both are answerable for expanding the intraocular pressure. In beginning time of glaucoma, Patients don't for the most part have any visual signs or indications.[35] As the illness progress it reasons for losing the vision and the patients may experience the ill effects of limited focus (being just ready to see halfway). Thusly early identification of this malady is basic to anticipate the changeless visual deficiency.

This disease happens due to the increase in Intraocular Pressure. Early detection of this disease is indispensable to prevent the interminable blindness. Screenings of glaucoma based on digital images of the retina have been performed in the past few years. Several procedures are there to distinguish the abnormality of retina due to glaucoma. The significant image processing techniques are image registration, image fusion, image segmentation, feature extraction, image enhancement, morphology, pattern matching, image classification, analysis, and statistical measurements.

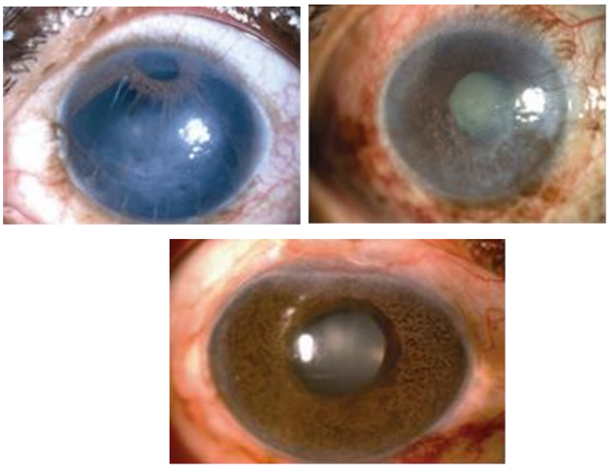

Fig -1: Syndrome of glaucoma image

The foremost idea behind this paper is to describe a system that is mainly based on image processing and classification techniques for detection of glaucoma by comparing and measuring different parameters of fundus images of glaucoma patients and normal patients.

There are essentially two kinds of glaucoma one is open point or interminable glaucoma and another is shut edge or intense glaucoma, both are answerable for expanding the intraocular pressure. In beginning time of glaucoma, Patients don't for the most part have any visual signs or indications. As the illness progress it reasons for losing the vision and the patients may experience the ill effects of limited focus (being just ready to see halfway). Thusly early identification of this malady is basic to anticipate the changeless visual deficiency. There are a few computerized glaucoma discovery strategies effectively accessible. In this investigation, we are attempting to do a survey of each one of those accessible systems. Every one of the systems has a few favorable circumstances just as burdens. In view of this investigation, we can figure out which method can be applied in which situation to get the ideal outcome.

2. DEEP LEARNING ALGORITHM FOR GLAUCOMA DETECTION

Retinal fundus image analysis without manual intervention has been rising as an imperative analytical approach for early detection of eye-related diseases such as glaucoma and diabetic retinopathy. For analysis and detection of Glaucoma and some other disease from retinal image, there is a significant role of predicting the bounding box coordinates of Optic Disc (OD) that acts as a Region of Interest. A Convolutional Neural Network (CNN) has trained on full images to predict bounding boxes along with their analogous probabilities and confidence scores. The publicly available MESSIDOR and Kaggle datasets have been used to train the network. We adopted various data augmentation techniques to amplify our dataset so that our network becomes less sensitive to noise. From a very high-level perspective, every image is divided into a 13 X 13 grid. Every grid cell envisages 5 bounding boxes along with the corresponding class probability and a confidence score. Before training, the network and the bounding box priors or anchors are initialized using k-means clustering on the original dataset using a distance metric based on Intersection of the Union (IOU) over ground-truth bounding boxes. During training in fact, a sum-squared loss function is used as the prediction's error function. Finally, Non-maximum suppression is applied by the proposed methodology to reach the concluding prediction [1].

Retinal nerve fiber layer defect (RNFLD) provides an early objective evidence of structural changes in glaucoma. In this regard, we propose a novel automatic method for RNFLD detection and angular width quantification using cost effective red free fundus images to be practically useful for computer-assisted glaucoma risk assessment. After blood vessel inpainting and CLAHE based contrast enhancement, the initial boundary pixels are identified by local minima analysis of the 1-D intensity profiles on concentric circles. The true boundary pixels are classified using random forest trained by newly proposed cumulative zero count local binary pattern (CZC-LBP) and directional differential energy (DDE) along with Shannon, Tsallis entropy and intensity features. Finally, the RNFLD angular width is obtained by random sample consensus (RANSAC) line fitting on the detected set of boundary pixels [2].

Glaucoma is a neuro-degenerative disorder of the eye and it leads to permanent blindness when untreated or detected in the later stage. The main cause of glaucoma is the damage of the optic nerve, which occurs due to the increase of eye pressure. Hence the early detection of this disease is critical in time and which can help to prevent further vision loss. Optic disk segmentation is done by using Fuzzy C-Means clustering method and Otsu's thresholding is used for optic cup segmentation. The assessment of optic nerve head using fundus images is more beneficial than the raised intra ocular pressure assessment in population-based glaucoma screening. This work proposed a novel method for glaucoma identification based on time-invariant feature cup to disc ratio and anisotropic dual-tree complex wavelet transform features. [3].

Many health-related problems arise with aging. One of the diseases that is prevalent among the elderly is the loss of sight. Various eye diseases, namely age-related macular degeneration (AMD), diabetic retinopathy (DR), and glaucoma are the prime causes of vision loss as we grow old. Nevertheless, early detection of such eye diseases can impede the progression of this problem. Therefore, the elderly is encouraged to attend regular eye checkups for early detection of eye diseases. However, it is time consuming and laborious to conduct a mass eye screening session frequently. Hence, we proposed a novel approach to develop an automated retinal health screening system in this work. This paper discusses a retinal screening system to automatically differentiate normal image from abnormal (AMD, DR, and glaucoma) fundus images. A novel approach to develop an automated retinal health screening system using PHOG and SURF features extracted from fundus images. images are subjected to the pyramid histogram of oriented gradients (PHOG) and speeded up robust features (SURF) techniques. Then, the extracted data are subjected to adaptive synthetic sampling to balance the number of data in the two classes (normal and abnormal). Subsequently, we employed the canonical correlation analysis approach to fuse the highly-correlated features extracted from the two (PHOG and SURF) descriptors [4].

The study develops an objective machine-learning classification model for classifying glaucomatous optic discs and reveals the classificatory criteria to assist in clinical glaucoma management. All the images of these eyes were captured using optical coherence tomography and laser speckle flow graph to quantify the ocular structure and blood flow-related parameters. Machine-learning classifiers, including the neural network(NN),naïve Bayes(NB),support vector machine(SVM) and gradient boosted decision trees(GBDT) were trained to build the classification models, and a hybrid feature selection method that combines minimum redundancy maximum relevance and genetic-algorithm-based feature selection was applied to find the most valid and relevant features for NN,NB and SVM[5].

Glaucoma is a chronic eye disease that leads to irreversible vision loss. The cup to disc ratio (CDR) plays an important role in the screening and diagnosis of glaucoma. Thus, the accurate and automatic segmentation of optic disc (OD) and optic cup (OC) from fundus images is a fundamental task. Most existing methods segment them separately, and rely on hand-crafted visual feature from fundus images. A deep learning architecture, named M-Net, which solves the Od and OC segmentation jointly in a one-stage multilabel system. The proposed M-Net mainly consists of multi-scale input layer, U-shape convolutional network, side-output layer, and multi-label loss function. The multi-scale input layer constructs an image pyramid to achieve multiple level receptive field sizes. The U-shape convolutional network is employed as the main body network structure to learn the rich hierarchical representation, while the side-output layer acts as an early classifier that produces a companion local prediction map for different scale layers. Finally, a multi-label loss function is proposed to generate the final segmentation map. For improving the segmentation performance further, we also introduce the polar transformation, which provides the representation of the original image in the polar coordinate system [6].

Glaucoma is a chronic eye disease that leads to irreversible vision loss. Most of the existing automatic screening methods firstly segment the main structure, and subsequently calculate the clinical measurement for detection and screening of glaucoma. However, these measurement-based methods rely heavily on the segmentation accuracy, and ignore various visual features. In this paper, we introduce a deep learning technique to gain additional image-relevant information, and screen glaucoma from the fundus image directly A novel Disc-aware Ensemble Network (DENet) for automatic glaucoma screening is proposed, which integrates the deep hierarchical context of the global fundus image and the local optic disc region. Four deep streams on different levels and modules are respectively considered as global image stream, segmentation-guided network, local disc region stream, and disc polar transformation stream. Finally, the output probabilities of different streams are fused as the final screening result [7].

A major cause of irreversible visual impairment is angle-closure glaucoma, which can be screened through imagery from Anterior Segment Optical Coherence Tomography (AS-OCT). Previous computational diagnostic techniques address this screening problem by extracting specific clinical measurements or handcrafted visual features from the images for classification. In this paper, we instead propose to learn from training data a discriminative representation that may capture subtle visual cues not modeled by predefined features. Based on clinical priors, we formulate this learning with a presented Multi-Context Deep Network (MCDN) architecture, in which parallel Convolutional Neural Network are applied to particular image regions and at corresponding scales known to be informative for clinically diagnosing angle-closure glaucoma [8].

A robust method for glaucoma screening from fundus images using an ensemble of convolutional neural networks (CNNs). The pipeline comprises of first segmenting the optic disk and optic cup from the fundus image, then extracting a patch centered around the optic disk and subsequently feeding to the classification network to differentiate the image a diseased or healthy. In the segmentation network, apart from the image, we make use of spatial co-ordinate (X & Y) space so as to learn the structure of interest better. The classification network is composed of a DenseNet201 and a ResNet18 which were pre-trained on a large cohort of natural images. [9].

Glaucoma is one of the leading causes of visual impairment in the world. It deteriorates the optic nerve fibers over time, and cannot be cured once it reaches the later stages. Hence early detection is of utmost importance for the aging society. A novel deep learning multi-model network termed G-EyeNet for glaucoma detection form retinal fundus images. G-EyeNet consists of a deep convolutional autoencoder and a traditional convolutional neural network (CNN) classifier sharing the encoder framework. The multi-model network is jointly optimized for minimizing both image reconstruction error and the classification error based on a multi-task learning procedure. Extensive training experiments are performed on publicly available datasets HRF, DRISHTI-GS, RIM ONE v.3. and evaluated on the publicly available DRIONS-DB dataset. Unsupervised training of the encoder framework helps in learning a good distribution of the input, which helps in classification. This architecture is especially effective when the training dataset is small, which is usually the case in medical imaging [10].

In medical field, diagnoses of diseases are competently carried out by using the image processing. human eye is an important organ that reacts to light and has several purposes. The eye has a number of components but it is not limited to the cornea, iris, pupil, lens, retina, and macula, optic nerve, choroid and vitreous. Retinal images play vital role in several applications such as disease diagnose and human recognition. Retinal image analysis is particularly a complicated task because of the variability of the images in terms of the color, the morphology of the retinal anatomical pathological structure and the existence of particular features in different patients, which may lead to an erroneous interpretation. Image processing techniques were used for dark object detection to analyze the condition of the input image, to enhance the input image in order to make it suitable for processing of the retinal image, to improve visibility of Micro aneurysm in color fundus images. K-nearest algorithm is used to detect the blood vessels effectively for segmentation process and Deep Neural algorithm is used to classify the diagnose the diseases such as stroke, heart attack and cardio-vascular disease by segmenting optic disc and to predict retinal disease using Ellipse Fitting method [11].

Glaucoma is an incurable eye disease and the second leading cause of blindness in the world. Until 2020, the number of patients of this disease is estimated to increase. This paper proposes a glaucoma detection method using statistical features and the k-nearest neighbor algorithm as the classifier. We propose three statistical features, namely, the mean, smoothness and 3rd moment, which are extracted from images of the optic nerve head. These three features are obtained through feature extraction followed by feature selection using the correlation feature selection method. To classify those features, we apply the k-nearest neighbor algorithm as a classifier to perform glaucoma detection on fundus images [12].

Since the proposal of a fast learning algorithm for deep belief networks in 2006, the deep learning techniques have drawn ever-increasing research interests because of their inherent capability of overcoming the drawback of traditional algorithms dependent on hand-designed features. Deep learning approaches have also been found to be suitable for big data analysis with successful applications to computer vision, pattern recognition, speech recognition, natural language processing, and recommendation systems. In this paper, we discuss some widely-used deep learning architectures and their practical applications. An up-to-date overview is provided on four deep learning architectures, namely, autoencoder, convolutional neural network, deep belief network, and restricted Boltzmann machine [13].

Conventionally, glaucoma is diagnosed on the basis of visual field sensitivity (VF). Using retinal thickness(RT) for glaucoma diagnosis is currently desirable. Thus, a new methodology for estimating VF from RT in glaucomatous eyes. The key ideas are to use our new methods of pattern-based visualization(PBV) with convolutional neural networks(CNNs). PBR effectively conducts supervised learning of RT–VF relations in combination with unsupervised learning from non-paired VF data. We can thereby avoid overfitting of a CNN to small sized data. PBV visualizes functional correspondence between RT and VF with its nonlinearity preserved [14].

Detection of glaucoma eye disease is still a challenging task for computer-aided diagnostics (CADx) systems. During eye screening process, the ophthalmologists measures the glaucoma by structure changes in optic disc (OD), loss of nerve fibers (LNF) and atrophy of the peripapillary region (APR). In retinal images, the automated CADx systems are developed to assess this eye disease through segmentation-based hand-crafted features. The convolutional neural network (CNN) unsupervised architecture was used to extract the features through multilayer from raw pixel intensities. Afterwards, the deep-belief network (DBN) model was used to select the most discriminative deep features based on the annotated training dataset. At last, the final decision is performed by softmax linear classifier to differentiate between glaucoma and non-glaucoma retinal fundus images. To evaluate the performance of Glaucoma-Deep system, the sensitivity (SE), specificity (SP), accuracy (ACC), and precision (PRC) statistical measures were utilized [15].

Glaucoma is the most common optic neuropathy characterized by normal to raised intraocular pressure (IOP), visual field defects, loss of retinal nerve fiber layer, thinning of the neuro retinal rim, and cupping of the optic disc. Machine learning for glaucoma diagnosis has achieved great development in recent years. In machine learning domain, learning using multimodal data has attracted much attention due to its superior performance. For instance, for the diagnosis of disease. In this paper, we propose a convolutional neural networks (CNN) approach to diagnosing glaucoma using multimodal data from retinal fundus images and achieve high classification accuracy A Convolutional Neural Network (CNN)approach to diagnose glaucoma using multimodal data from retinal fundus images and achieve high classification accuracy is proposed. We develop a network with CNN architecture that avoid the classical handcrafted features extraction step, by processing features extraction at one time within the same network of neurons and consequently provide a diagnosis automatically and without user input [16].

Optic disc (OD) is a key structure in retinal images. It serves as an indicator to detect various diseases such as glaucoma and changes related to new vessel formation on the OD in diabetic retinopathy (DR) or retinal vein occlusion. OD is also essential to locate structures such as the macula and the main vascular arcade. Most existing methods for OD localization are rule-based, either exploiting the OD appearance properties or the spatial relationship between the OD and the main vascular arcade. The detection of OD abnormalities has been performed through the detection of lesions such as hemorrhages or through measuring cup to disc ratio. Thus, these methods result in complex and inflexible image analysis algorithms limiting their applicability to large image sets obtained either in epidemiological studies or in screening for retinal or optic nerve diseases. In this paper, we propose an end-to-end supervised model for OD abnormality detection. The most informative features of the OD are learned directly from retinal images and are adapted to the dataset at hand [17].

Deep Retinal Image Understanding, a unified framework of retinal image analysis that provides both retinal vessel and optic disc segmentation. We make use of deep Convolutional Neural Networks (CNNs), which have proven revolutionary in other fields of computer vision such as object detection and image classification, and we bring their power to the study of eye fundus images' uses a base network architecture on which two set of specialized layers are trained to solve both the retinal vessel and optic disc segmentation [18].

Glaucoma is one of the common causes of blindness worldwide. It leads to deterioration in vision and quality of life if it is not cured early. This paper addresses the feasibility of developing an automatic feature learning technique for detecting glaucoma in colored retinal fundus images using a deep learning method. A fully automated system based on convolutional neural network (CNN) is developed to distinguish between normal and glaucomatous patterns for diagnostic decisions. Unlike traditional methods where the optic disc features are handcrafted, the features are extracted automatically from the raw images by CNN and fed to the SVM classifier to classify the images into normal or abnormal.[19].

Deep learning algorithms, in particular convolutional networks, have rapidly become a methodology of choice for analyzing medical images. This paper reviews the major deep learning concepts pertinent to medical image analysis and summarizes over 300 contributions to the field, most of which appeared in the last year. We survey the use of deep learning for image classification, object detection, segmentation, registration, and other tasks. Concise overviews are provided of studies per application area: neuro, retinal, pulmonary, digital pathology, breast, cardiac, abdominal, Musculoskeletal [20].

Glaucoma is the second leading cause of blindness all over the world, with approximately 60 million cases reported worldwide in 2010. If undiagnosed in time, glaucoma causes irreversible damage to the optic nerve leading to blindness. The optic nerve head examination, which involves measurement of cup-to disc ratio, is considered one of the most valuable methods of structural diagnosis of the disease. Estimation of cup-to-disc ratio requires segmentation of optic disc and optic cup on eye fundus images and can be performed by modern computer vision algorithms. This work presents universal approach for automatic optic disc and cup segmentation, which is based on deep learning, namely, modification of U-Net convolutional neural network [21].

Glaucoma is an ocular disorder caused due to increased fluid pressure in the optic nerve. It damages the optic nerve subsequently causes loss of vision. The available scanning methods are Heidelberg Retinal Tomography (HRT), Scanning Laser Polarimetry (SLP) and Optical Coherence Tomography (OCT). These methods are expensive and require experienced clinicians to use them. So, there is a need to diagnose glaucoma accurately with low cost. We have presented a new methodology for an automated diagnosis of glaucoma using digital fundus images based on Empirical Wavelet Transform (EWT). The EWT is used to decompose the image and chronotropy features are obtained from decomposed EWT components. These extracted features are ranked based on value feature selection algorithm. Then, these features are used for the classification of normal and glaucoma images using Least Squares Support Vector Machine (LS-SVM) classifier. The LS-SVM is employed for classification with Radial Basis Function (RBF), Morlet wavelet and Mexican-hat wavelet kernels. [22].

Glaucoma is a progressive optic neuropathy with characteristic structural changes in the optic nerve head reflected in the visual field. The visual-field sensitivity test is commonly used in a clinical setting to evaluate glaucoma. Standard automated perimetry (SAP) is a common computerized visual-field test whose output is amenable to machine learning. We compared the performance of a number of machine learning algorithms with STATPAC indexes mean deviation, pattern standard deviation, and corrected pattern standard deviation. The machine learning algorithms studied included multilayer perceptron (MLP), support vector machine (SVM), and linear (LDA) and quadratic discriminant analysis (QDA), Parzen window, mixture of Gaussian (MOG), and mixture of generalized Gaussian (MGG). MLP and SVM are classifiers that work directly on the decision boundary and fall under the discriminative paradigm. Generative classifiers, which first model the data probability density and then perform classification via Bayes' rule, usually give deeper insight into the structure of the data space [23].

Glaucoma is one of the main causes of blindness today. It is basically a group of eye diseases that leads to the optic nerve damage and arises mostly due to the increases in the Intraocular Pressure (IOP) within the eyes. The early detection as well as diagnosis of this disorder is very important as at the later stages it leads to complete loss of vision. In this paper we reviewed different glaucoma detection procedures by digital image processing of fundus of eye. This paper also proposes a very simple method for the screening of glaucoma [24]. A novel classification-based optic disc (OD) segmentation algorithm that detects the OD boundary and the location of vessel origin (VO) pixel. First, the green plane of each fundus image is resized and morphologically reconstructed using a circular structuring element. Bright regions are then extracted from the morphologically reconstructed image that lie in close vicinity of the major blood vessels. Next, the bright regions are classified as bright probable OD regions and non-OD regions using 6region-based features and a Gaussian Mixture Model classifier. The classified bright probable OD region with maximum Vessel-Sum and Solidity is detected as the best candidate region for the OD. Other bright probable OD regions within 1-disc diameter from the centroid of the best candidate OD region are then detected as remaining candidate regions for the OD. A convex hull containing all the candidate OD regions is then estimated, and a best-fit ellipse across the convex hull becomes the segmented OD boundary. Finally, the centroid of major blood vessels within the segmented OD boundary is detected as the VO pixel location [25].

GLAUCOMA is a chronic eye disease that can damage optic nerve. According to WHO It is the second leading cause of blindness, and is predicted to affect around 80 million people by 2020. Development of the disease leads to loss of vision, which occurs increasingly over a long period of time. As the symptoms only occur when the disease is quite advanced so that glaucoma is called the silent thief of sight. Glaucoma cannot be cured, but its development can be slowed down by treatment. Therefore, detecting glaucoma in time is critical. However, many glaucoma patients are unaware of the disease until it has reached its advanced stage. In this paper, some manual and automatic methods are discussed to detect glaucoma Manual analysis of the eye is time consuming and the accuracy of the parameter measurements also varies with different clinicians. To overcome these problems with manual analysis, the objective of this survey is to introduce a method to automatically analyze the ultrasound images of the eye. Automatic analysis of this disease is much more effective than manual analysis. [26].

The review paper describes the application of various image processing techniques for automatic detection of glaucoma. Glaucoma is a neurodegenerative disorder of the optic nerve, which causes partial loss of vision. Large number of people suffers from eye diseases in rural and semi urban areas all over the world. Current diagnosis of retinal disease relies upon examining retinal fundus image using image processing. The key image processing techniques to detect eye diseases include image registration, image fusion, image segmentation, feature extraction, image enhancement, morphology, pattern matching, image classification, analysis and statistical measurements [27].

A Glaucoma literature search on PubMed using the following terms: glaucoma, automated perimetry, optic nerve imaging, optical coherence tomography, glaucoma structure and function, intraocular pressure, central corneal thickness, glaucoma medical therapy, neuroprotection, glaucoma laser treatment, secondary glaucoma, glaucoma surgery, and miscellaneous topics in glaucoma [28].

Glaucoma is an eye disorder that causes irreversible loss of vision and is prevalent in the aging population. Glaucoma is indicated both by structural changes and presence of atrophy in retina. In retinal images, these appear in the form of subtle variation of local intensities. These variations are typically described using local shape-based statistics which are prone to error. We propose an automated, global feature-based approach to detect glaucoma from images. An image representation is devised to accentuate subtle indicators of the disease such that global image features can discriminate between normal and glaucoma cases effectively [29].

To compare the performance of two machine learning classifiers (MLCs), artificial neural networks (ANNs) and support vector machines (SVMs), with input based on retinal nerve fiber layer thickness (RNFLT) measurements by optical coherence tomography (OCT), on the diagnosis of glaucoma, and to assess the effects of different input parameters. Performance of MLCs was compared using conventional OCT RNFLT parameters plus novel parameters such as minimum RNFLT values, 10th and 90th percentiles of measured RNFLT, and transformations of A-scan measurements. For each input parameter and MLC, the area under the receiver operating characteristic curve (AROC) was calculated [30].

Glaucoma is a complex condition of the eye. It is an ophthalmic neurodegenerative condition and is characterized by raised intraocular pressure. When left untreated, patients may gradually experience visual field loss, and even lose their sight completely. It is the second leading cause of blindness around the globe [31].

An evaluation of the efficacy and tolerability of generic prostaglandin analogues (PGAs) compared with their original counterpart. This systematic review was initiated to enlighten ophthalmologists and patients in the use of original and generic ophthalmic solutions. A literature search was conducted on PubMed, EMBASE, MEDLINE, and the World Health Organization International Clinical Trials Registry Platform, along with a manual search, from the marketing of the first PGA, latanoprost, in 1995 to the present. Randomized controlled trials comparing an original PGA with its generic counterpart were included. The last literature search was conducted in June 2019. Risk of bias was assessed by 2 independent reviewers using the Cochrane Handbook for Systematic Reviews Tool. The primary outcome was reduction of intraocular pressure (IOP) from baseline. Secondary outcomes included tolerability, ocular surface health, quality of life, disease progression, and cost-effectiveness. Meta-analysis of the primary outcome was planned [32].

The prognostic significance of choroidal microvasculature dropout (MvD) that predict the future rate of progressive retinal nerve fiber layer (RNFL) thinning in eyes with primary open-angle glaucoma (POAG). The peripapillary microvasculature was evaluated by examining en face OCTA images. Choroidal MvD was defined as a focal sectoral capillary dropout with no visible microvascular network in the choroidal layer. The rate of RNFL thinning was determined by linear regression of serial OCT RNFL thickness measurements [33].

Automated segmentation of optic disc in fundus images plays a vital role in computer aided diagnosis (CAD) of eye pathologies. In this paper, a novel method is proposed which detects and excludes the blood vessel for accurate optic disc segmentation. This is achieved in two steps. First, an effective blood vessel detection and exclusion algorithm is developed using directional filter. In the second step, a decision tree classifier is used to obtain an adaptive threshold in order to detect the contour of optic disc. The proposed method aids in computationally robust segmentation of optic disc even in fundus images having illuminations, reflections and exudates. The proposed method is tested on two different datasets which includes 300 fundus images collected from Kasturba Medical College (KMC) Manipal and also the publicly available RIM-ONE database [34].

Instinctive analysis of retina images is becoming an important screening tool nowadays. This technique helps to detect various kinds of risks and diseases of eyes. One of the most common diseases which because blindness is Glaucoma. This disease happens due to the increase in Intraocular Pressure. Early detection of this disease is indispensable to prevent the interminable blindness. Screenings of glaucoma based on digital images of the retina have been performed in the past few years. Several procedures are there to distinguish the abnormality of retina due to glaucoma. The significant image processing techniques are image registration, image fusion, image segmentation, feature extraction, image enhancement, morphology, pattern matching, image classification, analysis, and statistical measurements. The foremost idea behind the proposed idea is to describe a system that is mainly based on image processing and classification techniques for detection of glaucoma by comparing and measuring different parameters of fundus images of glaucoma patients and normal patients [35].

Glaucoma detection is a significant problem to be solved in medical field. Few research works have been designed to detect glaucoma in its early stage. But, performance of glaucoma disease detection using existing techniques was not effectual. Moreover, time complexity of conventional glaucoma disease detection was more. In order to overcome such limitations, Damped Least-Squares Recurrent Deep Neural Classification (DLRDNC) Technique is proposed. The DLRNL Technique designs DLS-Recurrent Deep Neural Classifier in order to increase the prediction performance of glaucoma disease at an early stage with minimal time. The DLRNL Technique conducts simulation process using metrics such as disease detection accuracy, disease detection time and false positive rate with respect to different number of fundus image [36].

Glaucoma is a disease characterized by damaging the optic nerve head, this can result in severe vision loss. An early detection and a good treatment provided by the ophthalmologist are the keys to preventing optic nerve damage and vision loss from glaucoma. Its screening is based on the manual optic cup and disc segmentation to measure the vertical cup to disc ratio (CDR). However, obtaining the regions of interest by the expert ophthalmologist can be difficult and is often a tedious task. In most cases, the unlabeled images are more numerous than the labeled ones. The proposed work is an automatic glaucoma screening approach named Super Pixels for Semi-Supervised Segmentation "SP3S", which is a semi-supervised super-pixel-by-super-pixel classification method, consisting of three main steps. The first step has to prepare the labeled and unlabeled data, applying the super pixel method and bringing in an expert for the labeling of super pixels. In the second step, We incorporate prior knowledge of the optic cup and disc by including color and spatial information. In the final step, semi-supervised learning by the Co-forest classifier is trained only with a few numbers of labeled super pixels and a large number of unlabeled super pixels to generate a robust classifier. For the estimation of the optic cup and disc regions, the active geometric shape model is used to smooth the disc and cup boundary for the calculation of the CDR [37].

Glaucoma is a neuro-degenerative disorder of the eye and it leads to permanent blindness when untreated or detected in the later stage. The main cause of glaucoma is the damage of the optic nerve, which occurs due to the increase of eye pressure. Hence the early detection of this disease is critical in time and which can help to prevent further vision loss. The assessment of optic nerve head using fundus images is more beneficial than the raised intra ocular pressure assessment in population-based glaucoma screening. This work proposed a novel method for glaucoma identification based on time-invariant feature cup to disk ratio and anisotropic dual-tree complex wavelet transform features. Optic disk segmentation is done by using Fuzzy C-Means clustering method and Otsu's thresholding is used for optic cup segmentation [38].

The review paper investigates the use of fractal analysis (FA) as the basis of a system for multiclass prediction of the progression of glaucoma. FA is applied to pseudo 2-D images converted from 1-Dretinal nerve fiber layer data obtained from the eyes of normal subjects, and from subjects with progressive and non-progressive glaucoma. FA features are obtained using a box-counting method and a multi fractional Brownian motion method that incorporates texture and multi-resolution analyses. Both features are used for Gaussian kernel-based multiclass classification. Sensitivity, specificity, and area under receiver operating characteristic curve (AUROC) are computed for the FA features and for metrics obtained using wavelet-Fourier analysis (WFA) and fast-Fourier analysis (FFA). The novel FA-based features achieve better performance with fewer features and less computational complexity than WFA and FFA [39].

Effective diagnosis of glaucoma mainly relies on the analysis of optic disc characteristics of retina. Glaucoma is considered as second leading cause of blindness and its early detection prevents patients from temporary or permanent blindness. It effects the intensity and shape near optic disc of the retina. Fundus photography has revolutionized the field of ophthalmology and helped in visualizing the structure of optic disc. The proposed work aims to develop an automated diagnostic system based on fundus images for glaucoma disease. It focuses on extraction of GIST and pyramid histogram of oriented gradients (PHOG) features from preprocessed fundus images. The extracted features are ranked and selected through principal component analysis (PCA) to choose significant features. The classification into glaucomatous images is done with SVM classifier on fundus images of Drishti-GS1 and HRF databases [40].

The review paper proposes a novel Adaptive Region-based Edge Smoothing Model (ARESM) for automatic boundary detection of optic disc and cup to aid automatic glaucoma diagnosis. The novelty of our approach consists of two aspects: 1) automatic detection of initial optimum object boundary based on a Region Classification Model (RCM) in a pixel-level multidimensional feature space; 2) an Adaptive Edge Smoothing Update model (AESU) of contour points (e.g. misclassified or irregular points) based on iterative force field calculations with contours obtained from the RCM by minimizing energy function (an approach that does not require predefined geometric templates to guide auto-segmentation). Such an approach provides robustness in capturing a range of variations and shapes [41].

Glaucoma is the second leading cause of blindness worldwide. It is a disease in which fluid pressure in the eye increases continuously, damaging the optic nerve and causing vision loss. Computational decision support systems for the early detection of glaucoma can help prevent this complication. The retinal optic nerve fiber layer can be assessed using optical coherence tomography, scanning laser polarimetry, and Heidelberg retina tomography scanning methods. In this paper, we present a novel method for glaucoma detection using a combination of texture and higher order spectra (HOS) features from digital fundus images. Support vector machine, sequential minimal optimization, naive Bayesian, and random-forest classifiers are used to perform supervised classification [42].

Glaucoma is an asymptomatic disease caused by damage to the optic nerve due to elevated intraocular pressure. With early diagnosis, the chances of controlling progression are greater. Glaucoma is a major global health problem as a cause of blindness, second only to cataracts. This paper presents the development of a method for the automatic detection of glaucoma in retinal images using a deep learning approach together with the exploration of texture attributes through phylogenetic diversity indexes. The methodology employed is as follows: First, image acquisition is done from the RIM-ONE, DRIONS-DB, and DRISHTI-GS databases, followed by training the convolutional neural network for optical disk segmentation. After this segmentation, it is necessary to perform removal of the blood vessels after which feature extraction is applied to the images generated from the RGB channels and the gray levels. The extracted attributes are based only on the features of texture using phylogenetic diversity indexes. Classification was performed using an approach based on the convolutional neural network [43].

Glaucoma is a chronic disease often called “silent thief of sight” as it has no symptoms and if not detected at an early stage it may cause permanent blindness. Glaucoma progression precedes some structural changes in the retina which aid ophthalmologists to detect glaucoma at an early stage and stop its progression. Fundoscopy is among one of the biomedical imaging techniques to analyze the internal structure of retina. Our proposed technique provides a novel algorithm to detect glaucoma from digital fundus image using a hybrid feature set. This paper proposes a novel combination of structural (cup to disc ratio) and non-structural (texture and intensity) features to improve the accuracy of automated diagnosis of glaucoma. The proposed method introduces a suspect class in automated diagnosis in case of any conflict in decision from structural and non-structural features [44].

Glaucoma is a class of eye disorder; it causes progressive deterioration of optic nerve fibers. Discrete wavelet transforms (DWTs) and empirical wavelet transforms (EWTs) are widely used methods in the literature for feature extraction using image decomposition. However, to increase the accuracy for measuring features of images a hybrid and concatenation approach has been presented in the proposed research work. DWT decomposes images into approximate and detail coefficients and EWT decomposes images into its sub band images. The concatenation approach employs the combination of all features obtained using DWT and EWT and their combination. Extracted features from each of DWT, EWT, DWTEWT and EWTDWT are concatenated. Concatenated features are normalized, ranked and fed to singular value decomposition to find robust features. Fourteen robust features are used by support vector machine classifier [45].

Glaucoma is rated as the leading cause of irreversible vision loss worldwide. Early detection of glaucoma is important for providing timely treatment and minimizing the vision loss. In this paper, we developed a robust segmentation method for optic disc and cup segmentation using a modified U-Net architecture, which combines the widely adopted pre-trained ResNet-34 model as encoding layers with classical U-Net decoding layers. The advantage of the proposed method is the combination of the pre-trained ResNet and U-Net, which avoids training the network from scratch, thereby enabling fast network training with less epochs, thus further avoids over-fitting and achieves robust performance [46].

Glaucoma is a chronic and irreversible neuro-degenerative disease in which the neuro-retinal nerve that connects the eye to the brain (optic nerve) is progressively damaged and patients suffer from vision loss and blindness. The timely detection and treatment of glaucoma is very crucial to save patient’s vision. Computer aided diagnostic systems are used for automated detection of glaucoma that calculate cup to disc ratio from colored retinal images. In this article, we present a novel method for early and accurate detection of glaucoma. The proposed system consists of preprocessing, optic disc segmentation, extraction of features from optic disc region of interest and classification for detection of glaucoma. The main novelty of the proposed method lies in the formation of a feature vector which consists of spatial and spectral features along with cup to disc ratio, rim to disc ratio and modeling of a novel medoids based classier for accurate detection of glaucoma. The performance of the proposed system is tested using publicly available fundus image databases along with one locally gathered database [47].

Effective feature selection plays a vital role in anterior segment imaging for determining the mechanism involved in angle-closure glaucoma (ACG) diagnosis. This research focuses on the use of redundant features for complex disease diagnosis such as ACG using anterior segment optical coherence tomography images. Both supervised [minimum redundancy maximum relevance (MRMR)] and unsupervised [Laplacian score (L-score)] feature selection algorithms have been cross-examined with different ACG mechanisms. An AdaBoost machine learning classifier is then used for classifying the five various classes of ACG mechanism such as iris roll, lens, pupil block, plateau iris, and no mechanism using both feature selection methods [48].

Most of the algorithms for automated glaucoma assessment using fundus images supported segmentation, which are suffering from the performance of the chosen segmentation method and therefore the feature extraction process. Among other characteristics, convolutional neural networks (CNNs) are known because of their ability to learn highly discriminative features from raw pixel intensities. Recently, the attention mechanism has been successfully applied in convolutional neural networks (CNNs), for boosting the performance of many computer vision tasks. Unfortunately, some of the medical images are incorporate in CNNs. In particular, there exists high redundancy in fundus images for glaucoma detection, such the eye mechanism has potential in improving the performance of glaucoma detection using CNN. The proposed project is a U-net CNN for glaucoma detection. It is use to detect the exact place where the glaucoma occurs in our eye, using the U-net model. U-net is the advance version of the CNN model the algorithm is simple and it is 92.5% efficient than CNN model. The image are separate by using preprocessing, segmentation method, feature extraction and classification this are the step which was followed in this U-net[49].

This study aimed to develop a machine learning-based algorithm for glaucoma diagnosis in patients with open-angle glaucoma, based on three-dimensional optical coherence tomography (OCT) data and color fundus images. In this study, 208 glaucomatous and 149 healthy eyes were enrolled, and color fundus images and volumetric OCT data from the optic disc and macular area of these eyes were captured with a spectral-domain OCT (3D OCT-2000, Topcon). Thickness and deviation maps were created with a segmentation algorithm. Transfer learning of convolutional neural network (CNN) was used with the following types of input images: (1) fundus image of optic disc in grayscale format, (2) disc retinal nerve fiber layer (RNFL) thickness map, (3) macular ganglion cell complex (GCC) thickness map, (4) disc RNFL deviation map, and (5) macular GCC deviation map. Data augmentation and dropout were performed to train the CNN. For combining the results from each CNN model, a random forest (RF) was trained to classify the disc fundus images of healthy and glaucomatous eyes using feature vector representation of each input image, removing the second fully connected layer. The area under receiver operating characteristic curve (AUC) of a 10-fold cross validation (CV) was used to evaluate the models. The 10-fold CV AUCs of the CNNs were 0.940 for color fundus images, 0.942 for RNFL thickness maps, 0.944 for macular GCC thickness maps, 0.949 for disc RNFL deviation maps, and 0.952 for macular GCC deviation maps. The RF combining the five separate CNN models improved the 10-fold CV AUC to 0.963. Therefore, the machine learning system described here can accurately differentiate between healthy and glaucomatous subjects based on their extracted images from OCT data and color fundus images. This system should help to improve the diagnostic accuracy in glaucoma [50].

3. RESEARCH DIRECTIONS

In the future, the Glaucoma-Deep system will be tested on large-scale glaucoma-datasets to test its applicability in practice. A more efficient data augmentation and data sampling approached can also be used to obtain higher performance measured in terms of accuracy, sensitivity, specificity and other metrics. These improvements and other are currently part of the on-going research of the authors.

In the future we aim to improve the specificity of the model by exploiting another CNN and auto-encoder architecture. We also aim to investigate the influence of pre-training and data augmentation and considering multiple classifiers.

In the future, we anticipate that a GPU implementation should greatly accelerate the learning process.to conclude, we have shown that CNNs have the potential to be trained to identify the features of Glaucoma in fundus images. CNN's have the potential to be incredibly useful to Glaucoma clinicians in the future as the networks and the datasets continue improving and they will offer real-time classifications.

Future work may include; A) extension to RT time series prediction. B) extension to a framework using non-paired RT data; and C) further validation of the practical usefulness of our methodology on the basis of an external dataset.

In future work, various features can be used or the features of texture, shape, and color can be combined to overcome the erroneous classifications and improve accuracy.

In future, we can extend the framework to improve the accuracy in various kinds of datasets and try to analyze parallel processing approach and include other performance metrics.

In future, we plan to use deep learning method in the automated detection of normal and abnormal fundus images. Also, we intend to extend this work to automatically classify the fundus images in to normal, AMD, glaucoma and DR classes.

Future exploration could be stretched out by utilizing the publicly available database in order to validate the features. The method can be extended to the other eye disease detection like Diabetic Retinopathy, Macular Edema and Retinal hemorrhage.

4. CONCLUSION

This review tries to address different kinds of applications of deep learning methodologies in glaucoma diagnosis. Glaucoma is one of the crucial elements adding to the majority of visual impairment all around. It is important to build up some modest computerized procedures for the exact discovery of various phases of glaucoma. These systems will be of bizarre assistance in underdeveloped nations where there is an intense lack of ophthalmologists. It is quite prominent from the survey that deep learning applications in retinal images are quite useful and effective. It reduces the need of manual feature extraction as the methodologies are mainly data-driven Deep learning is a data-driven approach hence need of large amount of annotated medical data is required to develop a robust model.

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