A Cloud–based System for Automatic Glaucoma Screening

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Abstract—In recent years, there has been increasing interest in the use of automatic computer-based systems for the detection of eye diseases including glaucoma. However, these systems are usually standalone software with basic functions only, limiting their usage in a large scale. In this paper, we introduce an online cloud-based system for automatic glaucoma screening through the use of medical image-based pattern classification technologies. It is designed in a hybrid cloud pattern to offer both accessibility and enhanced security. Raw data including patient's medical condition and fundus image, and resultant medical reports are collected and distributed through the public cloud tier. In the private cloud tier, automatic analysis and assessment of colour retinal fundus images are performed. The ubiquitous anywhere access nature of the system through the cloud platform facilitates a more efficient and cost-effective means of glaucoma screening, allowing the disease to be detected earlier and enabling early intervention for more efficient intervention and disease management.

I. INTRODUCTION

Glaucoma is a chronic eye disease in which the optic nerve is progressively damaged. Advanced glaucoma leads to total irreversible blindness. Worldwide, it is the second leading cause of blindness, affecting 60 million people by 2010, and responsible for approximately 5.2 million cases of blindness [1]. Although glaucoma cannot be cured, early treatment can slow down progression of the disease. Hence, early detection is critical to prevent blindness.

Current methods to detect glaucoma include assessment of raised intraocular pressure (IOP), assessment of abnormal visual field and assessment of damaged optic nerve. However, IOP measurement is neither specific nor sensitive enough to be an effective screening tool and visual field testing requires special equipment only present in tertiary hospitals and special clinics. In contrast, assessment of the optic nerve is more convenient and accurate. Optic nerve assessment can be done by ophthalmologists, or using specialized imaging technologies such as Heidelberg Retinal Tomography (HRT) [2], Optical Coherence Tomography (OCT) [3] and fundus imaging. However, the cost of obtaining 3D HRT and OCT images is still high due to the hardware cost and lack of trained professionals.

Automatic analysis of fundus images for glaucoma screening has been a popular research topic in recent years due to its speed, accuracy, objectivity and labour saving. In 2D fundus images, the vertical cup-to-disc ratio (CDR) is widely used in clinical practice to assess the risk of glaucoma (Fig. 1). A larger vertical CDR value corresponds to higher level of damage of the optic nerves, and hence indicating higher risk of glaucoma. A number of methods have been proposed to extract optic disc features and compute CDR from fundus images for glaucoma screening. Wong et al. proposed a method to segment the optic and optic cup using a variational level set method followed by ellipse fitting [4]. The enforcement of a shape model in the post-processing step can help in handling local minima. One problem of this method is that other techniques are needed to handle the vessel occlusion problem. Yin et al. proposed a method based on the active shape model (ASM) [5]. A statistical model was first trained to contain shape and grayscale variations. The model is then applied to a new fundus image with blood vessels removed to search for the optic cup. The performance of this method is highly dependent on the initialization of the optic disc and cup. Cheng et al. proposed a super-pixel classification based method [6]. Superpixels clustered based on colour, local texture, etc. are classified as disc/non-disc or cup/non-cup using features extracted from the superpixels. Subsequently, a deformation step is used to fine tune the disc and cup boundaries. However, the method tends to under-estimate very large optic cups and over-estimate very small ones. Recently, Xu et al. [7] proposed a linear reconstruction based method. A set of ground truth is used to form the codebook and train an optimal linear reconstruction coefficient. In the reconstruction process, a cost/penalty term is introduced to the objective function to do the reconstruction with less but more related images in the codebook. This method is fast, robust and less sensitive to disc localization error in terms of glaucoma diagnosis.

Fig. 1: Structure of an optic disc (Vertical CDR is computed as \(h_c/h_o\))

Although many automated glaucoma detection methods are well tested and validated, it is still challenging to implement an efficient and effective way of screening the population due to the local nature of these software systems. Only very limited personnel have access to those systems as they locate in their respective laboratories.
In order to meet the demands of the general population, we propose a cloud-based glaucoma screening system that take advantage of the rapid growing cloud resources as well as advanced pattern classification based glaucoma assessment technologies. The system extends the cloud concept of Software as a Service (SaaS), and combines with other features such as medical report generation, record keeping and referral scheme. The rest of this paper is organized as follows. Section II describes the structure and setup of the system. Section III introduces the service model based on the cloud-based glaucoma screening. Section IV discusses about the whole system and related future works. Section V concludes the paper.

II. SYSTEM SETUP

![Flow chart of proposed cloud-based glaucoma screening system](image)

The proposed cloud-based glaucoma screening system aims to provide automatic glaucoma assessment to the general population. Accessibility and security are the most important concerns for such a system. Therefore, we propose a hybrid cloud setup that consists of a public cloud tier and private cloud tier in order to address these concerns. This setup offers anywhere access in the public cloud tier, and stores sensitive patients’ information as well as performs intelligent assessment of the disease in the private cloud tier. The system design is illustrated in Fig. 2.

A. Public Cloud Tier – the Gateway

In the public cloud tier, clinical data including demographic data, medical history and retinal fundus images, are collected from various sources, with different ages, races, jobs and living conditions. In order to increase the covered population, the system offers user access from three different channels: website, mobile apps and third party API. In order to enhance security, very limited information is stored in the public cloud database. The design of the public cloud tier of the system is shown in Fig. 3. While the website and mobile App portal requires fixed inputs and outputs, the third-party API can be customized to cater to different applications.

B. Private Cloud Tier – the Factory

As most of the pattern classification algorithms requires large amount of computing resources and are patented, it is desirable to keep these algorithms in a local cluster of servers. Moreover, scientific algorithms may be developed in various platforms and using different languages, making migration to the public cloud difficult. Therefore, the algorithms are kept in the private cloud.

Patients’ sensitive information including demographical information, medical history and intelligent analysis results is stored in the private database to ensure security. The data can be retrieved from the private cloud tier using each patient’s personal account or the corresponding doctor’s account using the access portal in the public cloud tier.

C. Pattern Classification based Glaucoma Assessment

The proposed system utilizes the reconstruction-based learning method in [7] for glaucoma assessment. The optic disc is first obtained using a method based on the Active Shape Model [8]. Subsequently, each segmented optic disc is normalized to standardize all images and remove influence of illumination variation among images.

For the optic cup segmentation, a codebook is first generated from manually-labeled images with three sub-groups in different CDR ranges. Denoting the codebook image set as:

\[ X = \{ x_1, x_2, \ldots, x_n \} \]

and their corresponding labeled cup set:

\[ C = \{ c_1, c_2, \ldots, c_n \} \]

the way to find the optimal linear reconstruction coefficients \( \omega \) of a given test disc \( y \) is to minimize the reconstruction error

\[ ||y - X\omega||^2. \]

An additional cost \( ||d \circ \omega||^2 \) is included to penalize the use of reference images that are less similar to the test image, where \( d \) is the Gaussian distance of the test image and the reference image. Therefore, the overall objective function is:

\[ \arg\min_{\omega} ||y - X\omega||^2 + \lambda||d \circ \omega||^2, \text{ s.t. } |\omega| = 1 \]

The objective function can be solved in closed form using the Lagrange multiplier method. Finally, the cup location of the test image can be estimated as \( \hat{y} = C\omega \).
Experimental results based on a codebook of 99 images show that the areas under the receiver operating characteristic curve (AUCs) on ORIGA [9] and SCES [10] databases are 0.823 and 0.866, respectively. The performance may be further improved by optimizing the size and selection of the codebook.

III. CLOUD-BASED GLAUCOMA SCREENING SERVICE MODEL

The current manual procedure of glaucoma screening is very labor intensive, requiring many trained graders and doctors. Further, the turnover time for the process can range from a few days for normal patients to months for high risk patients who need referral of specialists. This situation makes it difficult for a large scale screening program, which is critical as most of glaucoma suspects are unaware of the disease until very late stage.

As depicted on Fig. 4, the proposed glaucoma screening service model provides an integrated ecosystem that connects patients, screening service providers and doctors. In this system, the turnover time can be significantly reduced. Moreover, the automated process operates 24 hours daily, increasing the throughput greatly. In addition, the proposed ecosystem reduces manpower requirement significantly, which also lowers the cost. Overall, the system makes it possible to conduct a large scale glaucoma screening program.

A. Throughput Analysis

It takes a trained grader 5 to 10 minutes to analyze one fundus image to determine the risk of glaucoma. Normally, a grader can analyze up to 50 images a day. In comparison, it takes an average of 30 seconds to process an image for a high performance server in our private cloud when 10 images are processed concurrently. Therefore, the daily throughput of a single server is 28800 images. There are currently 8 servers in our private cloud setup.

B. Medical History and Record Keeping

There are many factors that affect the development of glaucoma including high intraocular pressure, poor blood flow, genetic inheritance, age, race, etc. Thus, demographic data and medical history is important in improving the accuracy of the automatic assessment. The proposed system utilizes such information together with risk parameters generated from fundus images to give a holistic analysis of the disease.

The system also provides record keeping facilities so that patients can easily trace their health conditions. A list of medical records is depicted on Fig. 5. Patients can view the details of each record using their own accounts.

C. Medical Report Generation

For each submitted image, the system will generate a customized, personalized report for the individual. The report, which can be delivered over-the-air to the individual across any device accessing the cloud, will consist of the CDR value, the diagnosis, as well as meta-heuristic contextual information regarding the diagnosis. This includes customized statistics which will report on the prevalence and likelihood of the disease based on such data as the age, gender, ethnicity, locality, as well as other clinical and lifestyle factors. With this report, an individual can be empowered to take charge of his or her own healthcare and match to the clinical providers which best suit his or her needs or relying on the auto-referral engine built in the system. Fig. 6 shows a portion of the sample medical report.
D. Patient Referral Scheme

A standard referral is the recommendation of a medical or paramedical professional. A referral to ophthalmology, for example, is a recommendation to the eye doctor. In managed care schemes, a referral is usually necessary to see any practitioner or specialist other than the primary care physician (PCP). The referral is obtained from the PCP, who may require a telephone or office consultation first. In this model, patients leave to the GP to decide on the expert and whom to refer.

In the proposed system, depending on the analysis of the pathologies, the appropriate and suitable ophthalmologists specialized in the different diseases will be suggested, leaving the patient the final decision to decide which specialist to approach. If the patient decides otherwise, the system can recommend. In this way, they system can empower patient in the further treatment of his own disease.

IV. DISCUSSIONS

The focus of the proposed cloud-based glaucoma screening system will be directed towards glaucoma tele-screening, through automatic analysis and assessment of retinal fundus images. The cloud-based nature of the system provides highly accessible, data-driven, patient-centric and objective diagnosis options to advance current diagnosis procedures in healthcare systems. The following features of the system further enhance its usability.

Access Anytime Anywhere. The system will be a fully online telemedicine platform that can be accessed any time of the day to deliver detailed automatic analysis reports round the clock.

Reliability and Accuracy. In the assessment of the diagnostic power of an analysis system, the most frequently cited mechanism is the Receiver Operating Characteristic (ROC) Curve, which plots the tradeoff between the system sensitivity and specificity as a continuous curve. Using the ROC, we aim have achieved AUCs of 0.823 and 0.866 for two population-based eye studies.

Interfaces. The system makes use of industry standard interfaces so that it can be deployed and accessed easily. This will enable stable and scalable functionality to users.

Cross-platform Support. The system can be accessed on any devices which are browser-compliant to major browsers such as Internet Explorer, Chrome, Firefox and Safari. In addition, mobile apps on iOS and Android platforms have also been developed to allow flexible access.

Future works to improve the system include increasing the number of hospitals and doctors involved for a better referral scheme, engaging more participating clinics for batch-based screening, and migrating automatic detection systems for other major ocular diseases to the cloud platform.

V. CONCLUSION

Current glaucoma screening methods require extensive human resources. It limits the scale of the screening especially in developing countries where medical resources are very limited. In this paper, we proposed a cloud-based system for automatic glaucoma screening through the use of fundus image-based pattern classification technologies. By combining value-added features such as medical report generation, medical record keeping and patient referral scheme, the system helps to form an integrated ecosystem that connects patients, screening service providers and doctors in a more efficient way. The ubiquitous anywhere access nature of the system through the cloud platform facilitates a more efficient and cost-effective means of glaucoma screening, allowing the disease to be detected earlier and enabling early intervention for more efficient intervention and disease management.

REFERENCES