ORIGA^{-light} : An Online Retinal Fundus Image Database for Glaucoma Analysis and Research

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Abstract — **Retinal fundus image is an important image modality to document the health of the retina and is widely used to diagnose ocular diseases such as glaucoma, diabetic retinopathy and age-related macular degeneration. However, the enormous amount of retinal data obtained nowadays mostly remains locally; the valuable clinical knowledge is not efficiently exploited. In this study we present an online depository, ORIGA^{-light}, which aims to share clinical ground-truth retinal images with the public, providing open access for researchers to benchmark their computer-aided segmentation systems. We developed an in-house image segmentation and grading tool to facilitate the construction of ORIGA^{-light}. We proposed a quantified assessment method for objective benchmarking, focusing on optic disc and cup segmentation and Cup-to-Disc Ratio (CDR). Currently, ORIGA-light contains 650 retinal images annotated by trained professionals from Singapore Eye Research Institute. The images cover a wide collection of image signs which are critical for glaucoma diagnosis. We will update the system continuously with more clinical ground-truth images. ORIGA^{-light} is available for public access upon request.**

I. Introduction

Fundus photography is a highly specialized form of medical imaging. Taken by fundus camera operated by ophthalmologists, retinal fundus images (retinal image hereafter) are important means to document the health of the optic nerve, vitreous, macula, retina and its blood vessels. The photographs are used for diagnosing eye diseases, e.g. glaucoma. Figure 1 shows examples of retinal images taken from healthy eye, glaucomatous eye and eye with age-related macular degeneration (AMD).

a b c

Figure 1. Examples of a retinal fundus images. a) Fundus of healthy eye; b) Fundus of the eye with Glaucoma; c) Fundus photo showing neovascular, or wet, age-related macular degeneration (AMD)

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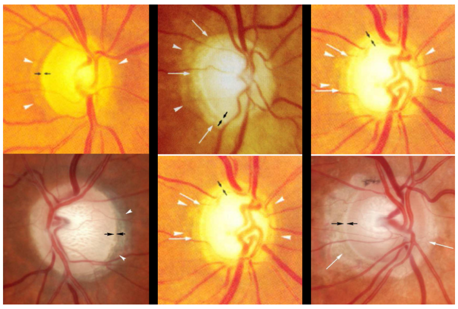
The enormous amount of retinal data obtained nowadays comprises a huge quantity of clinical knowledge that is not efficiently exploited. Although some peer-reviewed retinal image databases are available, for example DRIVE database [1], the number of cases and the variety of pathologies are far from enough for research. The majority of the information remains locally in hospitals and clinics without being shared. There are several challenges for sharing medical images: firstly, the vast amount of data related to particular study lacks proper indexing or categorizing; secondly, no adequate tools are available for clinicians and researchers to share information at a larger scale. A well designed image database needs to take into consideration on all aspects of image annotation, and to facilitate recording and retrieving of image segmentation.

Retinal image based glaucoma diagnosis is comprehensive, depending on various image signs. Among them, the retinal optic nerve head cup-to-disc ratio (CDR) has been regarded as an important indicator for detecting the presence of glaucoma in a patient, as well as the extent of glaucoma optical neuropathy. Researchers have focused their efforts on the automatic segmentation of the optic disc [2, 3]; with some groups worked towards the detection of the optic cup [4, 5, 6]. The accurate segmentation of the optic cup and disc is crucial to the calculation of the CDR, and thus the diagnosis of glaucoma [7].

Other than CDR, retinal images possess numerous pathological signs that are often referred by ophthalmologists for glaucoma diagnosis. For instances, the following signs usually suggest high chances of glaucoma: present of disc haemorrhages; thinning of neuroretinal rim (NRR); NRR thickness not follow the ‘ISNT Rule’ [8]; nerve fiber layer defect; peripapillary atrophy (PPA) and notch in NRR etc. Currently, these signs are observed and annotated by trained professionals (call graders) working in eye research institutes. Figure 2 gives an example on how PPA is presented in retina optic disc area. The grading process is labor intensive, time consuming and costly. Furthermore, grading results are saved offline without proper categorizing and sharing, which hinders the image processing researchers from developing algorithms detecting such image cues automatically.

In view of above needs, we developed ORIGA^{-light} database based on retinal image data collected from Singapore Malay Eye Study (SiMES) [9], conducted by Singapore Eye Research Institute. ORIGA^{-light} presents a collaborative environment that assists image grading, image segmentation and categorizing specially for glaucoma research. It enables ophthalmologists and graders to share retinal image analysis and its corresponding diagnosis. As an online depository of clinical ground-truth retina images, ORIGA^{-light} serves as a benchmarking resource for researchers to evaluate image processing algorithms that detect various image cues highly related to glaucoma diagnosis.



a b c

Figure 2. Grading of PPA. Black arrows represent the scleral ring; white arrows represent beta-PPA; and white arrow-heads alpha-PPA. a) no beta-PPA; b) mild beta-PPA; c) beta-PPA

Continuous effort will be put into the enrichment of ORIGA^{-light}, not only the number of annotated images but also the input from the community. ORIGA^{-light} aims to help researchers to optimize their image processing technologies and to develop next generation glaucoma mass screening tools.

II. METHODOLOGY

A. Data Source

The presented work is based on retinal images collected in a population based study, Singapore Malay Eye Study (SiMES) [9]. SiMES is a large-scale population based study to assess the causes and risk factors of blindness and visual impairment in Singapore Malay community. It was conducted over a 3 year period from 2004 to 2007 by Singapore Eye Research Institute and funded by the National Medical Research Council. SiMES examined 3,280 Malay adults aged 40 to 80, from which, 149 are glaucoma patients. Retinal fundus images for both eyes were taken for each subject in the study. All retinal images have been deidentified by removing any individually identifiable information.

B. Image Grading Tool for Ground Truth Building

To construct ORIGA^{-light}, we developed an in-house retinal image grading tool, ORIGA^{-GT}, to provide a graphic user interface (GUI) for image segmentation as well as grading, as shown in figure 3.

As we know, glaucoma can be diagnosed through measurement of neuro-retinal optic cup-to-disc ratio (CDR). Calculation of CDR requires detection of optic disc region of interest (ROI), optic disc and cup. ORIGA^{-GT} provides a smooth workflow for such task.

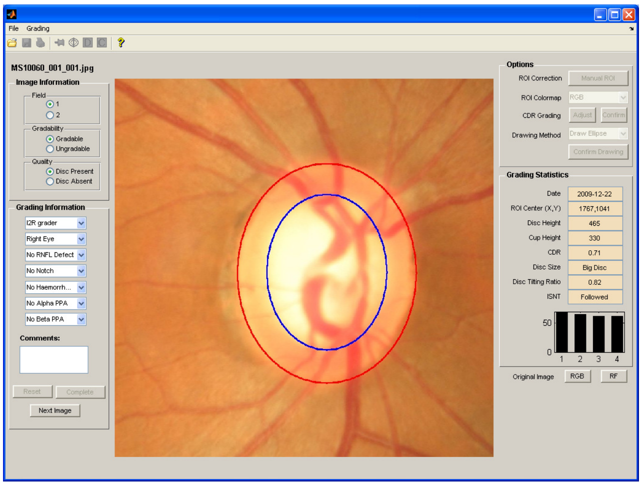


Figure 3. ORIGA^{-GT} – tool for manual segmentation and grading. Top image is the input image, with ROI automatically picked up by ORIGA^{-GT}. Blue ellipse – cup boundary; red ellipse – disc boundary; All fields listed on right side are automatically calculated. Fields at left side needs user input.

1) Automatic ROI detection

Instead of letting user manually choose optic disc region, ORIGA^{-GT} incorporates an intelligent ROI detection module, based on our previous work [10]. The method introduced a image preprocessing step called “fringe removal”, based on the observation that failures in optic disc ROI detection is usually caused by the unbalanced brightness in fringe at the rim (as shown in figure4.a left side), which was introduced during the fundus image capturing when the patient did not place their eyes tightly against the acquiring device. A trimming circle can be expressed as:

$$X^2 + Y^2 + aX + bY + c = 0 \quad (1)$$

We use a least-squares fitting method [11] to find the values of a, b and c. The center of the trimming circle (C_x, C_y) and estimated radius r is given by:

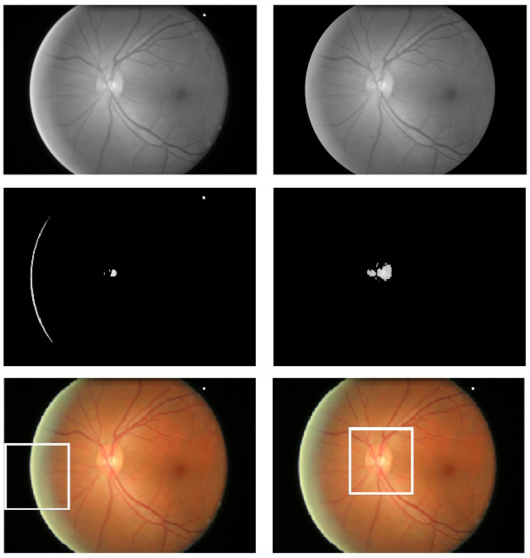
$$C_x = -\frac{a}{2} \quad (2)$$

$$C_y = -\frac{b}{2} \quad (3)$$

$$r = \sqrt{\frac{a^2 + b^2}{4 - c}} \quad (4)$$

The trim radius is set to be slightly smaller than the estimated radius so as to remove the bright fringe. We then proceed to trim away the fringe from the fundus image. Next, we locate the area where 0.5% of the bright spots are concentrated in the trimmed image. The centroid of the bright spots is marked as the center and a circle with radius twice the typical optic disc is drawn at the disc center to determine the boundary of the ROI. Figure 4 shows the ROI localization with and without fringe removal. After image trimming and fringe removal, the bright spots are found to be concentrated mostly in the optic nerve head region.

ORIGA^{-GT} can detect a perfect ROI in more than 96% cases. In cases that input image quality is bad, the user can manually adjust the ROI.



a b

Figure 4. ROI detection (a) without fringe removal (b) with fringe removal

2) *Disc and Cup Boundary Smoothing*

Manually drawing ellipse-like boundaries is a challenging task and it is hard to achieve satisfactory result. ORIGA^{-GT} eases the pain of boundary drawing by employing "key nodes" solution. The "key nodes" are actually the important landmarks along the disc boundary and cup boundary, for example, the place where blood vessel cross the disc, or where blood vessel kinks [5] at the cup. With these "key nodes", ORIGA^{-GT} generates the boundary for cup and disc based on ellipse-fitting algorithm.

Ellipse fitting is usually based on least square fitting algorithm which assumes that the best-fit curve of a given type is the curve that has the minimal sum of the deviations squared from a given data points (least square error). Here we implemented Direct Least Square Fitting Algorithm (B2AC) [12]. Instead of fitting general conics or being computationally expensive, B2AC minimizes the algebraic distance subject to a constraint, and incorporates the ellipticity constraint into the normalization factor. It is ellipse-specific, thus the effect of noise can be minimized while forming the ellipse.

3) *Image Annotation Following Grading Protocol*

Once the disc/ cup boundaries are generated, ORIGA^{-GT} automatically calculates disc height, cup height, CDR, ISNT rule compliance, Disc tilting ratio etc. The figures are displayed in the right side bar, as shown in figure 3.

ORIGA^{-GT} then records other pathological signs presented in the retinal images, such as notch, haemorrhage and PPA etc. The grading process follows the protocol in "Assessment of Glaucomatous Optic Disk Signs" [8] defined by Center for Eye Research Australia. Table 1 shows a list of the terms annotated in ORIGA^{-light}.

C. *Implement Online Database*

TABLE I
GRADING INFORMATION IN ORIGA^{-LIGHT}

Annotation Term	Details
Eye	Left eye / Right eye
Image Quality	Disc presented / No Disc presented
Gradability	Gradable / Not gradable
Field	Retina image taken in Field 1 - 6
Disc Size	Large Disc / Middle Disc / Small Disc
Disc Tilting Ratio	Automatically calculated based on Disc segmentation
CDR	Cup-to-Disc Ratio, automatically calculated
ISNT rule	Follow ISNT rule / Not follow ISNT rule
RNFL	Retinal Nerve Fiber Layer thinning / Not thinning
Notch	Yes / No
Disc Haemorrhage	Presented / not presented
Alpha PPA	Presented / not presented
Beta PPA	Presented / not presented
Comments	Additional information

*PPA – peripapillary atrophy, Alpha-PPA represents advanced stage compare to Beta-PPA

*Notch – notch in neuroretinal rim

*ISNT – The neuroretinal rim (NRR) is usually broadest inferiorly, followed by superiorly, then nasally, and finally temporally. The rule is called ISNT rule.

To compose the database, we randomly picked 650 images from SiMES study. Each image was then annotated by trained professionals from Singapore Eye Research Institute using ORIGA^{-GT}. The results of image segmentation and annotation were stored in a centralized server via network connection. Web interface was implemented to provide online access of the information, including browsing, searching and downloading. Figure 3 shows the data acquisition workflow of ORIGA^{-light}.

In the centralized database, we simplified the storage of image segmentation information. For example, for ROI, only the coordinates of the ROI center is saved; for disc, only the coordinates of several "key nodes" are saved. The result segmented image will be recomposed on the fly.

ORIGA^{-light} database is implemented in Linux server, built on Apache web server, MySQL relational database and PHP.

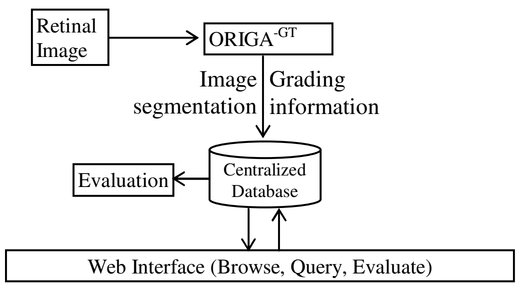


Figure 5. Data acquisition in ORIGA^{-light}

D. *Evaluation system*

We defined a measurement score, G-score, to evaluate the performance of CDR algorithm. G-score is composed of three parts, which measures disc segmentation, cup segmentation and CDR respectively.

In the following measurements, 'reference' stands for the ground truth data and 'segmentation' stands for the result obtained using automatic segmentation algorithm.

Disc and cup segmentation are scored using 'area overlap score', where the number of pixels in the intersection of segmentation and reference, divided by the number of pixels in the union of segmentation and reference, and is multiplied by 100. This value is 100 for a perfect segmentation and has 0 as the lowest possible value, when there is no overlap at all between segmentation and reference.

$$S1 = (Seg \bigcap Rseg)/(Seg \bigcup Rseg) \times 100 \quad (5)$$

Where *Seg* and *Rseg* are the segmentation and reference voxels respectively, *S1disc* and *S1cup* were obtained for disc and cup segmentation.

We also calculate 'CDR difference score'. CDR is calculated for both reference and segmentation data, based on the vertical height of optic cup and disc. S2 is calculated based on the absolute value of CDR difference divided by reference CDR. The score is 0 if a perfect CDR obtained.

$$S2 = (|CDRseg - CDRref|/CDRref) \times 100 \quad (6)$$

G-score is defined to take into consider all above scores:

$$G = (S1cup + S1disc)/2 - S2 \quad (7)$$

G-score is 100 if the algorithm results perfect segmentation.

III. Result and Discussion

A. *ORIGA-light database*

The ORIGA-light database contains 650 annotated retina images. Each image is tagged with grading information as shown in table 1, and manually segmented result of optic disc and cup. Table 2 shows a summary of images available in different grading categories.

Through the web interface, users can browse the categorized images, or query for the specific ones based on the grading information. Users can contact authors for batch downloading the entire database.

TABLE II

Categorized Retinal Images in ORIGA-light

CATEGORY	NO. OF IMAGES	CATEGORY	NO. OF IMAGES
CDR≥0.65	168	CDR<0.65	382
Disc Haemorrhage	13	Disc Notch	8
Follow ISNT rule	186	Not follow ISNT rule	464
RNFL defects	21	No RNFL defects	629
Alpha PPA	175	Beta PPA	89
Left eye	336	Right eye	314

B. *Potential use of ORIGA-light database*

Potential use of ORIGA-light can be foreseen in several aspects: 1) The data can be used to develop various image processing algorithms, for instances, left-eye / right-eye differentiation; disc boundary blood vessel junction detection; disc haemorrhage detection; PPA detection etc. To our best knowledge, such information has never been available publicly to the image processing community; 2) Proper extraction of image features from the data can be used for machine learning algorithms to build computational models; 3) The evaluation system can be used as a benchmarking platform for researcher assess their computer-aided system. 4) ORIGA-light can serve as a collaborative apprenticeship tool for retina image graders, information such as "key nodes" contains valuable clinical knowledge, making it a rich resource for teaching and case study.

C. *Future Work for ORIGA-light*

ORIGA-light aims to help researchers optimizing their image processing technologies and developing next generation glaucoma mass screening tools. We will use the evaluation G-score defined in ORGIA-light to assess our previous work, ARGALI [4], in a systematic manner. Continuous effort will be put into the enrichment and upgrading of ORIGA-light, not only with the number of annotated images but also the feedback inputs from the community.

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