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Intraocular Pressure Measurement, Image acquisition and Processing system as a Support for early Diagnosis of Eye Disease

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Abstract— Eye disease leading to blindness affect mostly elder people especially those in the developing world. Among several types of eye diseases glaucoma, age related macular degenerative disease and cataract are common. These diseases can be prevented or treated if detected at their earlier stage. But due to lack of screening systems and less organized healthcare set-up, the habit of early checkup before the disease aggravate is very less in low resource settings. Moreover, diseases like glaucoma and retinopathy do not show symptoms at the early stage and could be irreversible. Ophthalmoscopy, slit-lamp microscopy, Gonioscopy and manual optical devices are few technologies that are used to screen the eye. The quality of images acquired using imaging modalities found in low resource settings is very less and high-resolution imaging methods like funds-camera are not available in most health facilities. In this study, a digital eye disease diagnosis support system that includes image acquisition, enhancement, retinal vessel extraction, segmentation and cup to disk ratio calculation integrated with intraocular pressure measurement is proposed.
Test results of the proposed design show our method's potential to be used an eye disease diagnosis support system. The developed system will have a great impact in supporting physicians in their decision in the diagnosis of eye disorders.

Index Terms— Cup-to-disk ratio, Eye screening, Glaucoma, Intraocular pressure, Image processing, Vessel extraction.

1 Introduction

Human eye is a vital organ of vision which reacts to light and pressure. It gives us the sense of sight, allow us to see and interpret colors and dimensions of objects. Various things affect structure of the eye, causing visual impairment and blindness. Most common visual disorders, which are leading causes of blindness worldwide, are glaucoma, cataract, age related macular degenerative disease (AMD) [1].

Glaucoma is an acquired disease of the optic nerve characterized by specific changes of the optic nerve and by visual field defects that correspond to the areas of optic nerve structural damage. It is a worldwide leading cause of irreversible vision loss if not detected and treated in at early stage [2]. It is often associated with the increased in the intraocular pressure (IOP) of the fluid known as aqueous humor in eye. High eye pressure, or intraocular pressure, is often present and is the only modifiable risk factor for glaucoma [3]. Cataracts are a clouding of the lens, resulting in a blurred image. Oxidative damage caused by free radicals is considered to be an important factor in aging and the development of chronic diseases, including cataract formation [4]. Severe cataracts are a major cause of blindness throughout the world [5]. In Age-related macular degeneration, clumps of yellowish material known as drusen gradually accumulate within and beneath the retinal pigmented epithelium (RPE).

The RPE cells may die and therefore no longer support the photoreceptors, which then cannot function, resulting in loss of vision in that part of the retina [6]. AMD is a leading cause of vision loss in including industrialized countries which is estimated to affect 288 million people by the year 2040 [7, 8].

Ophthalmoscopy slit lamp microscopy, gonioscopy, perimeter are few devices and methods that are commonly used to diagnosis eye disorders. High-tech devices are not accessible in most health facilities because of their expensive cost. Moreover, access to traditional tabletop imaging methods is limited by their bulky design and need for skilled operators. Slit-lamp microscopy is the most used method for eye screening in low resource settings. Because of unavailability of automated devices eye screening at low resource setting is done by manual observation which requires subjective decision making. This subjective decision-making process is prone to error leading to misdiagnosis.

Smartphone-based retinal imaging approaches with wireless data transfer capabilities to capture diagnostic images have been proposed in few literatures [9-12]. Even though these approaches make eye screening less expensive and accessible to various populations, they are limited with image quality and processing capability. Furthermore, a complete standalone eye disease diagnosis requires measurement of important parameters like intraocular pressure (IOP), which is missing in smart phone-based imaging techniques. Intraocular pressure is the fluid pressure of the eye. It is a measurement involving the magnitude of the force exerted by the aqueous

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humor on the internal surface area of the anterior eye. IOP is determined by the balance between the rate of aqueous secretion and aqueous outflow. It gives an estimate of the pressure inside the anterior eye based on the resistance to flattening of a small area of the cornea. Distribution of IOP is within a range of 11-21mmHg [13]. If the value is above this range it viewed with suspicion. Abnormal IOP could indicate the development of glaucoma, uveitis, and retinal detachment [14, 15]. Normal IOP varies with the time of day, heartbeat, blood pressure level and respiration

In this study, simple, cost effective and portable digital eye disease diagnosis support system that includes image processing and IOP measurement is proposed. This project enables the physician to store diagnosis results allowing further analysis it is needed. This device could be used in a variety of settings, including rural health centers, outpatient and inpatient areas, emergency departments, and screening clinics. In addition, being a digital system with image saving feature, it is potentially suitable for telemedicine application.

2 Materials and Methods

The proposed design includes image acquisition, enhancement and extraction system integrated with IOP measurement.

the LCD. The traditional criterion for the presence of glaucoma is generally an IOP higher than 22 mm Hg [16, 17]}. Moreover, cup-to-disk ratio (CDR) is calculated from the segmented image as a means of diagnosis support for glaucoma detection. Figure 1 and 2 demosntrate the overall features and flow chart of our propsed system

2.1. Image acquisition and Enhancement

Retinal image of an eye is acquired by camera. The camera is attached with a 3D lens with 90 diopters using a properly designed wood stand. Adjustable chin support allows images to be acquired without a cost of patient comfort. The image enhancement feature includes adjustment of brightness and contrast of the acquired image.

The luminance generated by a display device is generally not a linear function of the applied voltage signal. Because of this the exact brightness variation in a displayed digital image will not be reproduced. Gamma correction is used to correct the differences between the way a camera captures content, the way a display displays content and the way our visual system processes light [18, 19]. Histogram equalization, filtering and gamma correction are used for this purpose.

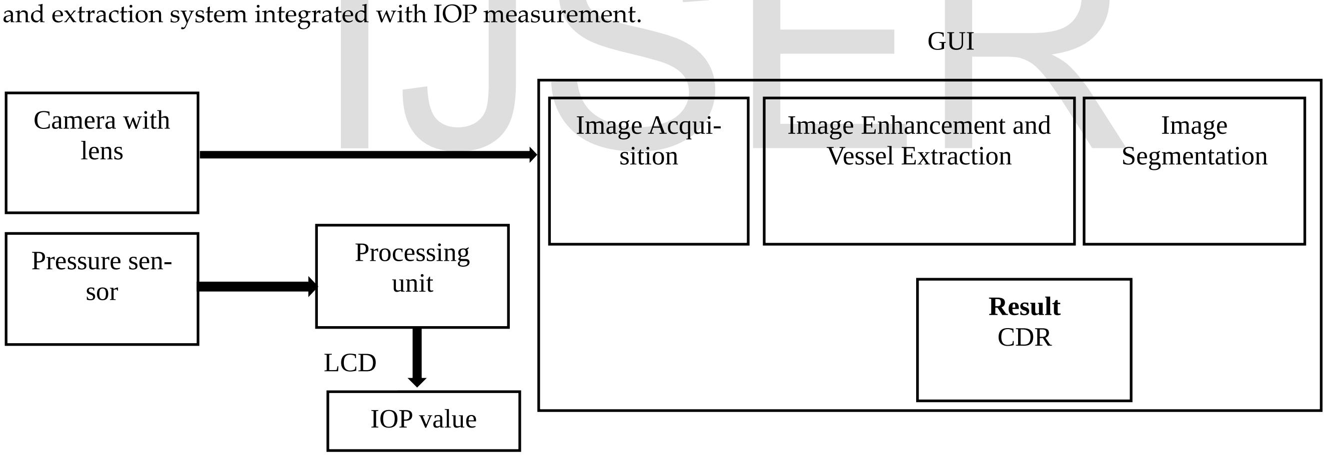

Figure 1: Block diagram of the proposed design: camera with lens acquires high-resolution images and the pressure sensor is input is analyzed and converted to IOP in the processing unit. IOP value is displayed in LCD. The GUI provides user-friendly image enhancement, vessel extraction, segmentation and CDR calculation features.

For image acquisition a 3D lens, which is commonly used in slit-lamp microscopy, is attached with a high-resolution camera to acquire high-quality images of the retina. The acquired images are then enhanced, segmented and vessels are extracted. In addition, sharp infrared (IR) sensor with Arduino microcontrolller is incorporated to acquire intraocular presure. Graphical user interface (GUI) allows the user to easly acquire image and IOP results, as well as to enhance and exract the required image feature. Based on IOP value, hint results will be displayed as normal or abnormal on

2.2. Retinal Vessel Extraction

The change in morphology and branching pattern of retinal blood vessels is an important sign of various clinical disorders of the eye [20]. Retinal vessel appearance is an important indicator for many diseases such as diabetic retinopathy, stroke, hypertension, arteriosclerosis, cardiovascular diseases [21]. Edge detection is an important image processing operation to detect vessels. The goal of edge detection algorithms is

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to find the most relevant edges in an image or scene. Edge detection of the input retina image is done with the Kirsch's Templates [22] in different orientations followed by thresholding, resulting in the extracted blood vessels.

2.3. Image segmentation and Cup-to-Disk Ration (CDR) calculation

Segmentation is the process of partitioning an image into a set of no overlapping regions whose union is the entire image. A watershed transform and k-means clustering image segmentation approached is used in the current work. To reduce oversampling due to watershed transform, smoothing operation is applied. The segmentation algorithm is used to detect the optic disk (OD). The optic disk is considered to be elliptical in shape. Its size can also vary significantly. After segmentation of OD the CDR (the vertical cup to disk ratio) is calculated. The CDR compares the diameter of the "cup" portion of the optic disk with the total diameter of the optic disk. The normal cup-to-disk ratio is 0.3 [23]. A large CDR may imply glaucoma or other pathology. At present CDR is calculated manually by ophthalmologist. This may result misdiagnosis. In the current work, a statement about the presence of glaucoma based on the CDR values is displayed.

2.4. Intraocular Pressure (IOP) measurement

Intraocular pressure is an important parameter that is used to estimate the development of glaucoma, uveitis, and retinal detachment [14, 15]. In this study, a sharp infrared sensor is used to determine the intraocular pressure of the eye. This was calculate by using the young's modulus of the cornea, length from the cornea to the eyelid and change in length of cornea with respect to the original length. The initial length is calculated by adding the mean distance value from the sensor to the eyelid (10 cm) to the mean distance value of cornea to the eyelid (0.03) [24]. A mean young's modulus value of 7500.6 mmHg is used for the cornea [25].

Distance value (hence change in length) can be acquired from sharp IR sensor and the real-time stress (pressure) is calculated by using the biomechanics principle ($\sigma = \Delta l * \varepsilon / l$, where σ is stress, Δl is change in length, ε is elastic modulus, and l is length). The values are analyzed using Arduino microcontroller and displayed on LCD.

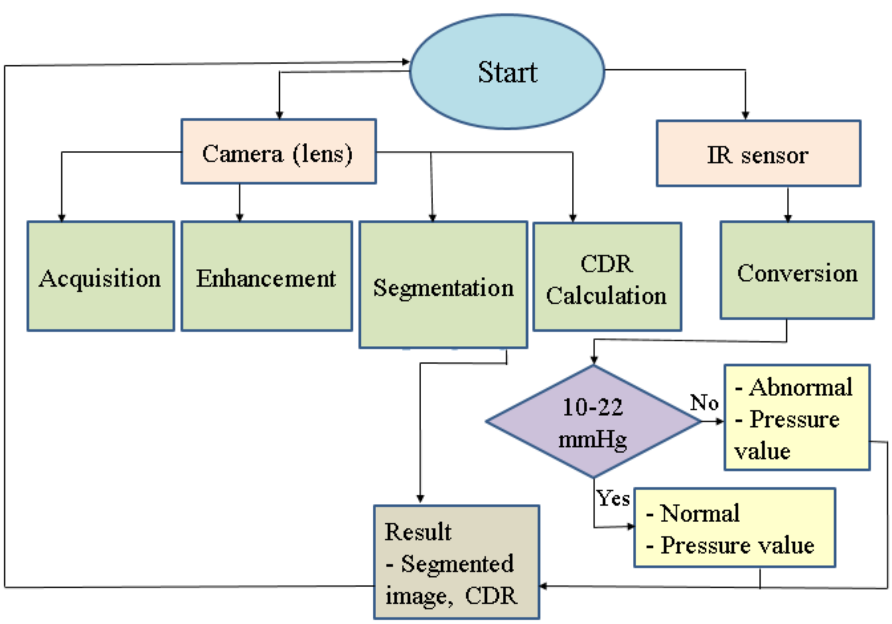

Figure 2: Flow chart of the proposed design

3 Results and Discussion

Human eye is a vital organ of vision which reacts to light and pressure. The eye plays a very important role not only in life but also in human body. It gives us the sense of sight, allow us to see and interpret colors, dimension of object. There are various things that affect structure of the eye, cause visual impairment and blindness. Among them, glaucoma, cataract, age related macular disease, and retinopathy are the main cause of blindness. The existing eye disorder diagnosis methods commonly found in low-resource settings are manual, time wasting and physically uncomfortable for the physician. Manual diagnosis is subjective in its nature which is prone to error and lead to misdiagnosis. The current method presents digital eye screening support technique which can be used to diagnose common eye diseases at their early stage.

The proposed system is a dual function system that includes the image processing and the pressure measurement. The pressure measurement system was first simulated using a simulation software. IR sensor from Proteus is used to simulate the pressure sensor. The output of the IR sensor is fed to the Arduino. Young's modulus of the cornea is used to convert the measured distance into pressure using biomechanics principle. The output pressure is displayed in LCD. Figure 3 shows results of the simulation. After simulation, a lot of iterations has been conducted to construct the prototype.

A graphical user interface (GUI) has been developed using Matlab for ease of use of the image processing part. This includes Image acquisition and preview, image enhancement, vessel extraction, segmentation and analysis. In addition, the image saving feature that helps physicians to store images for later use is incorporated.

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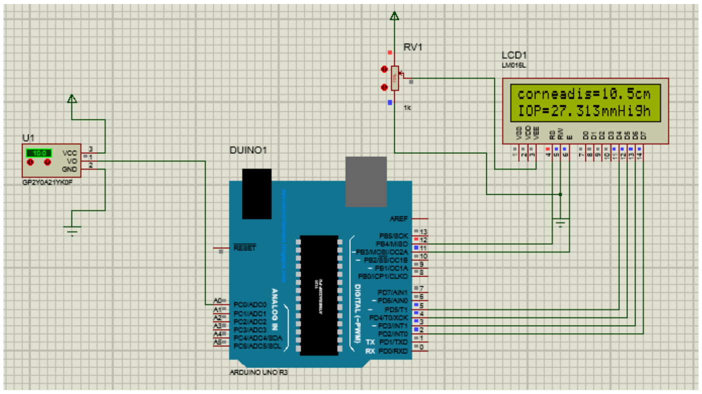

Figure 3: Simulation result of the IOP measurement

Figure 5 shows the image acquisition, saving, image processing and analysis parts of the GUI. The macula and optic disk are better demonstrated in the enhanced and segmented image. The segmentation algorithm is able to identify the optic disk and the macula as shown in Figure 5b. The vessel extraction provides clear vessel structures highlighting the central retinal artery and vein branches emanating from the optic disk. The calculated CDR values for the given images is 0.4, which is more than the average normal (0.3) value and may imply a presence of glaucoma. However, research findings shows that clinical assessment of CDR measurements should not be used as the sole method for detection of glaucomatous progression [26]. The final prototype that includes the IOP measurement and Image processing part is demonstrated in Figure 4. Results of IOP, CDR value and extracted vessels together give vital information for the physician regarding disorders in the eye.

Tests	Method	Design specification	Result
Cost	Total cost was added	< 500 USD	335.56 USD
Accuracy (IOP)	Non-contact tonometry (or air-puff tonometry)as reference.	95%	96.2%
Screening Time	Stop watch	< 1minute	40sec
User friendly	Train the physicians and see how they understand it	Can be understandable by ophthalmologists	Simple to use

Table 1: Testing plan and results

To ensure that a system meets its designed specifications and other requirements, a test plan was designed based on design criteria that includes accuracy, cost, portably, easy to use and sensitivity. The cost of the prototype (excluding the computer) including the 3D lens, camera, Arduino, LCD, IR sensor and support system 335.56 USD.

This makes the design to be easily accessible, including for low-resources settings. For accuracy test non-contact tonometry (or air-puff tonometry) was used as reference. The test was conducted on five volunteers. A 96.2% accuracy has been achieved using our IOP method. Table 1 shows the tests conducted, method of testing, design specifications and results.

Figure 4: The Final Prototype of the eye screening support system.

4 Conclusion

The proposed method was able to acquire and process images and analyze the result based on intraocular pressure values and cup-to-disk ratio. The image saving capability also makes the system suitable for telemedicine applications. The proposed method can also be used as a computer-aided diagnostic tool to assist the fundus image extraction and evaluation process. Specifically, the extracted vessels and CDR calculation can be applied in a clinical setting of computer assisted diagnosis. The proposed method has a potential to be used as a decision support system in diagnosis of eye disorders in areas where both the resources and experts are in scarce.

Our future work includes automatic diagnosis of eye disease through deep-learning techniques. Incorporating both the IOP measurement and Image processing system with smartphone application will also make the propose system more suitable for telemedicine applications. In addition, including temperature variation with IOP measurement will make the system more accurate.

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(a)

(b)

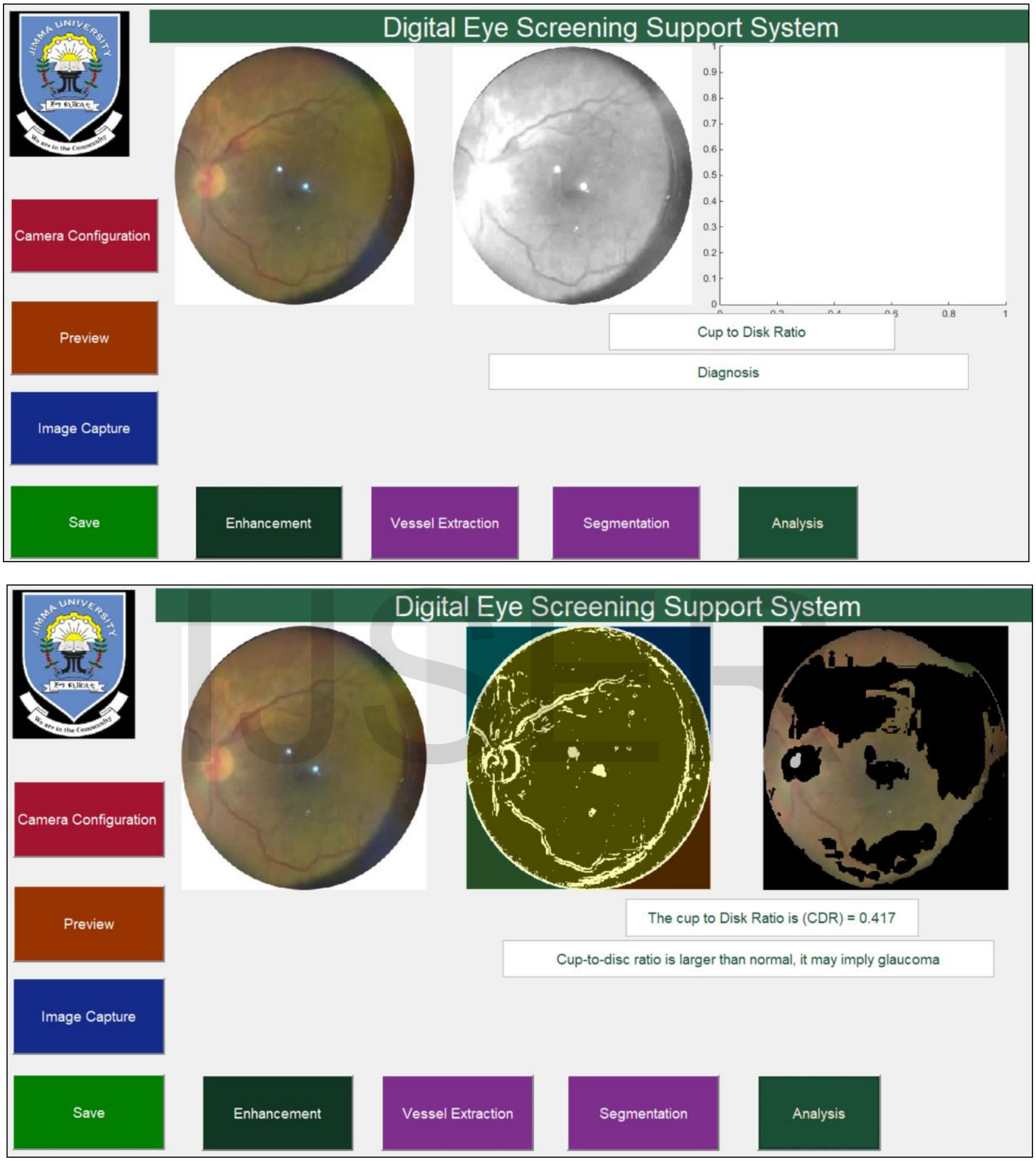

Figure 5: A GUI demonstrating (a) parts of image acquisition and enhancement (b) parts of the vessel extraction, segmentation and analysis. The calculated CDR value for the given images show 0.4 which may imply glaucoma.

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