

AEGIS - Augmented Eye Laser Treatment with Region Guidance for Intelligent Surgery

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Abstract: This paper presents an augmented reality platform for eye laser treatment with region guidance for intelligent surgery. The proposed method aims to assist doctors to plan the surgery, semi-automatically detect and protect sensitive regions within the retina and guide the laser during photocoagulation treatment for Diabetic Retinopathy. In the pre-surgical phase, we mosaic multiple retina fundus images to form a reference image. We then perform automatic optic disc and macula detection to mark out these sensitive regions. During the laser operation, we detect the aiming spot of the laser and track it on the reference image. Alerts are given out when the laser moves near the sensitive areas, and the laser function is disabled when the laser is within the sensitive regions. The proposed method can help doctors to perform laser surgery confidently without harming the patient.

1. Introduction

Diabetic retinopathy (DR) is a complication of diabetes and it can seriously affect vision and lead to blindness. According to studies from WHO, it is estimated that diabetic retinopathy is responsible for 4.8% of the 37 million cases of blindness throughout the world [1] and is the 7th leading cause of blindness in the world [2]. Poorly controlled diabetes can cause many problems. One of these is thickening of the wall of small blood vessels and subsequently the narrowing of their lumen (the internal space of the pipes through which the blood flows). Because of this narrowing, which can result in a complete blockage, not enough blood gets to certain parts of the body and this can affect the function of certain organs. One of the areas where this problem becomes very obvious is the retina.

retinopathy (PDR) more severe type that appears as the condition progresses. Figure 1 shows the various stages of severity in DR.

Laser treatment is very effective in preventing loss of vision although special care needs to be taken to prevent accidental burns to certain areas such as the optic disc and macula regions. This process is called photocoagulation and is useful to prevent vessels leakage and removal of abnormal and fragile vessels. Accidentally damaging these areas can potentially result in permanent vision loss. However, during the laser eye surgery operation, the surgeons are usually looking through a slit lamp, which drastically lowers their field of view. With increasing diabetics and aging population, the demand for precise laser systems is on the rise.

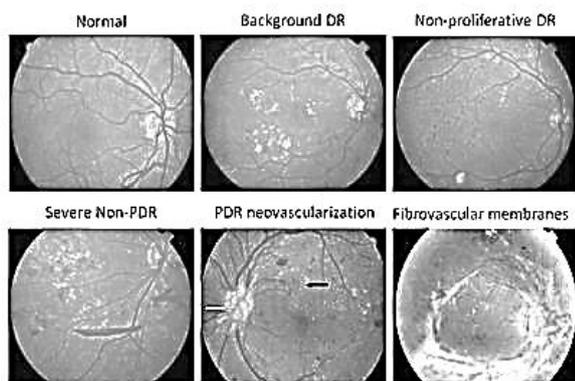


Fig. 1. The various stages of severity of diabetic retinopathy, ranging from normal (top left) to end stage disease with severe scarring (bottom right).

There two types of diabetic retinopathy, non-proliferative/background diabetic retinopathy (Non PDR) type, which is the milder form that appears in the early stages of retinopathy and the proliferative diabetic

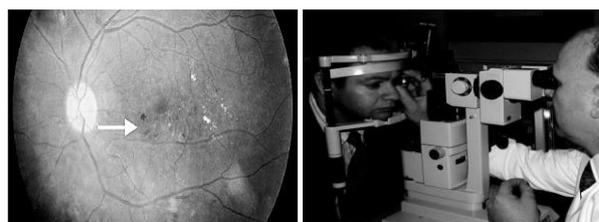


Fig. 2. (left) Focal laser treatment for diabetic macular edema leaves behind laser scars which are seen as black marks on the macula (white arrow). (right) Clinical Setting showing laser treatment

This paper presents an augmented reality platform for eye laser treatment to assist surgeons during live surgery. As most laser surgery is manually performed, clinical judgment plays an important role in the surgical outcome. Our proposed system aims to guide the laser to prevent accidental burns to the sensitive areas of the patient's retina resulting in irreversible scotoma and assist the surgeons during the photocoagulation operation.

2. Related Works

At the moment, state-of-the-art systems such as PASCAL Streamline 577 [3] and Navilas [4] are primarily manually operated laser systems. PASCAL[3] technology deploys a proprietary semi-automated pattern generation method using short laser pulse durations of typically 20 ms

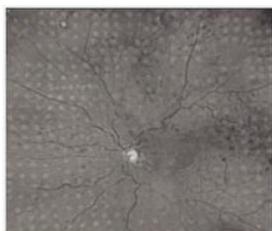


Fig. 3. OptiMedica's PASCAL Pattern Scan Laser Photocoagulator can deliver as many as 25 spots in just 0.5 seconds.



Fig. 4. Available patterns in PASCAL Streamline 577

(five times shorter than conventional systems). These laser pulses are delivered in a rapid pre-determined sequence resulting in precise even burn patterns as well as improved safety, patient comfort, and a significant reduction in treatment time when compared to single-shot photocoagulation. Clinicians determine when to fire the laser and at what power level. There is no safety net to fall back to. They will need to be completely focused and take extra precautions not to fire the laser at the sensitive areas of the patient's retina, which can result in irreversible scotoma.



Fig. 5. Surgeon selecting targets before the treatment

Navilas [4] is a computerized platform for surgeons to manage the process of retinal photocoagulation. Navilas first captures the retina images. Then the surgeon marks the desired targets as well as any areas to avoid. Figure 2 shows the machine carries out the laser burning while the surgeon watches the action unfolding on a screen. Feedbacks from clinicians indicate that there is a lack of

control of the surgery, relying solely on the ability of the machine to carry out the task.

Other works include Semi-automated ophthalmic photocoagulation method and apparatus [5] which involves the generation of a treatment laser light based on a pre-defined template. The control electronics control the delivery system to project the treatment light onto the patient's eye in response to both activation trigger and the alignment with target tissue specified in the template. Figure 6 show some of the templates.

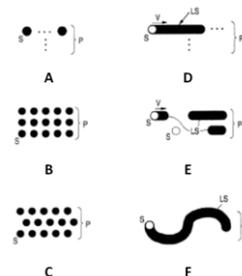


Fig. 6. Semi-automated ophthalmic photocoagulation method and apparatus

Selective Photocoagulation [6] is another system which aims to prevent collateral damage in laser surgical techniques by using shorter laser pulses to target pigment epithelial cells with instantaneous control over the laser dosimetry to ensure that laser energy reaches the threshold require for retinal pigment epithelial (RPE) cell killing but avoids damage adjacent cells.

Process for controlling the photocoagulation of biological tissue [7] is a method to automatically adjust the parameters of photocoagulation, including power, focus or sighting. In this method discrete portions of the retina in the eye are projected by a lens system in an array to generate electrical signals related to the light intensity reflected from a corresponding portion on the retina being treated.

However there is still a need to automatically and precisely demarcate the regions of interest (e.g. macula or optic disc areas) for laser treatment. Also multi-modal imaging overlay to assist the surgeon in deciding areas of treatment is required and there is also a need for an automated system with a warning signal (e.g. laser cut-off, alarms) when laser approaches or enters a marked area protected regions.

3. Proposed Solution

The goal of our proposed solution AEGIS (Augmented Eye Laser Treatment with Region Guidance for Intelligent Surgery) is to develop and validate an augmented reality platform to assist surgeons in pre-planning of laser treatment as well as react and response during live surgery. Our main contribution is a an augmented reality assistance solution consisting of algorithms for multi-modal image registration, automatic optic disc and macula segmentation, and video tracking that are useful for assisting eye surgeons during live surgery. The solution aims to semi-automatically detect and protect sensitive regions within the retina and guide the laser during photocoagulation treatment for Diabetic Retinopathy

thereby assisting eye surgeons by preventing accidental burns and as a result provide better surgical outcomes for patients. Some of the key novelties of the proposed solution are as follows

- 1) Fully automatic detection of sensitive regions reduces clinician workload over current manual methods.
- 2) Automatic avoidance of sensitive areas improves patient safety and reduces risk of damaging vision-critical sensitive regions during laser treatment.
- 3) Augmented retinal image with overlay of detected sensitive regions for real-time monitoring during treatment.

3.1 Solution Overview

The diagram shown in Fig. 7 illustrates our proposed application framework. First, retinal fundus images from the patient are inputted into the system and automatically mosaicked to form a reference image which serves as a retinal map for the surgery. The reference image may be fine-tuned further using manual adjustment of automatically detected matching key points. The optic disc and macula region are detected automatically and demarcated. These two regions may be adjusted manually. In addition, surgery related sensitive regions can be demarcated manually depending on the needs of the surgeons.

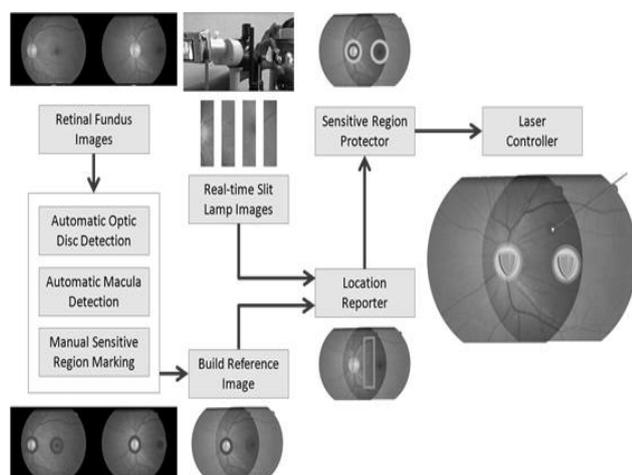


Fig. 7. Proposed application framework

During actual surgery, live video inputs from a slit lamp will be inputted into the system. The first portion of the video follows a clinically-defined protocol to assist the system to register the optic disc and macula region. For example, the protocol may involve moving from the optic disc to the macula and back, followed by tracing the main vessels in the superior and inferior regions. Once calibrated, a location reporter will be able to track the user's current field of view which will detect the laser firing spot from the slit lamp image and track it on the reference image. When the laser firing spot is near sensitive regions, a protector module will be triggered and alert the user. When the laser firing spot is within sensitive

regions, the sensitive region protector will turn off the laser to prevent any potential harm to the patient. More details on the above algorithms are provided in the following sections.

3.2 Image Mosaicking

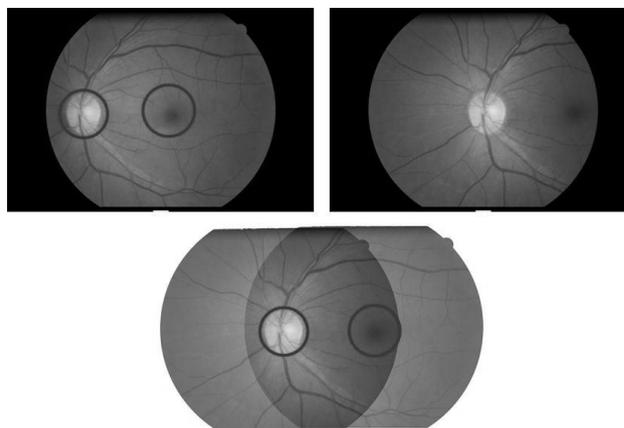


Fig. 8. Reference image created from multiple images

Multiple retinal fundus images of a patient are mosaicked together to form a reference image for the location reporter. Landmarks such as optic disc, macula and blood vessels are detected and compared in order to register and align the images. The images are then mosaicked into a larger image which will be used as the reference image for the location reporter. The reference image main alignment criteria are to ensure that the optic disc, macula and major blood vessels are in alignment. Sensitive regions marked earlier are then transferred to the reference image. In our experiment, we classify a mosaic to be successful if the displacement of matched points compared to marked ground truth is less than five pixels. From a set of 20 patients' images, we extract feature points using the Scale-Invariant Feature Transform (SIFT) algorithm [8]. Features are detected and compared in order to register and align the images. Partial Intensity Invariant Feature Descriptors (PIIFD) [9] centered on the SIFT features is estimated. Thereafter, we perform a putative feature point matching using the nearest neighbour criterion on the PIIFD descriptors. Next, we perform an outliers' elimination process to prune putatively matched feature points using our proposed robust outliers' elimination technique that enforces an affine transformation geometric constraint. The outliers' elimination and affine transformation parameters' estimation are achieved using our proposed adapted Least Trimmed Squares (LTS) [10] coupled with iteratively reweighted least squares method.

By comparing the matched points in the mosaic, we can determine the misalignment between the points. The reference image main alignment criterion is to ensure that the optic disc, macula and major blood vessels are in alignment. We achieved a successful rate of 90%. We apply a linear time heuristic algorithm, which is described by Dobkin and Snyder [11], to find a quadrilateral with

maximal area among a set of points. Basically, this heuristic proceeds by first finding the convex hull of the set of points, and then iteratively improving an initial solution from common approach until no more increase can be gained. Since it considers only the points on the convex hull, it is required that the convex hull consists of at least four points. We choose this algorithm as it is fast in linear time and conjectured to find the maximal quadrilateral. The user can further fine-tune the reference image by manually adjusting the four detected matching key points. The above multi-modal image registration process is used during the laser treatment pre-planning phase. This will allow eye doctors to plan treatment on both types of images simultaneously by overlaying and/or fusion.

3.3 Detection of Optic Disc and Macula

In our previous work, we have developed technologies that can be used in the proposed solution. We used techniques in [12] to automatically detect the optic disc and macula. For optic disc detection, we select candidates from regions corresponding to top percentile of the grayscale intensity of the image. Constraints such as eccentricity and size are used to select the best candidate. The center of the candidates region is used in a region growing method to obtain the optic disc. For macula detection, we make use of structural information to statistically determine the location of the macula relative to the optic disc. Using the optic disc as a point of reference and the side of the eye for orientation determination, a region of interest (ROI) around the typical macula location is extracted. This ROI derived from on a ground truth database of 650 manually labeled retinal fundus images. Using this prior data, we statistically determined the average unsigned distance (μ_x , μ_y) of the macula with respect to the optic disk centroid, along with the range of variation (Δx , Δy), as follows, using the orientation information,

$$X = \begin{cases} \{x \in \mathbb{Z}^+ : x = x_{OD} + \mu_x \pm \Delta x\}, & \text{left side} \\ \{x \in \mathbb{Z}^+ : x = x_{OD} - \mu_x \pm \Delta x\}, & \text{right side} \end{cases}$$

$$Y = \{y \in \mathbb{Z}^+ : y = y_{OD} + \mu_y \pm \Delta y\}$$

X, Y represent the range of coordinates for ROI extraction, and γ represents an additional buffer margin, and x_{OD}, y_{OD} represent the x and y coordinates of the optic disk centroid respectively.

3.4 Demarcation of Sensitive Regions

The optic disc and macula are classified as sensitive regions automatically using the method described in section 3.3. Additional sensitive regions can be added manually using our tools. It involves adding points to sufficiently define a particular region that needs to be protected. The demarcated regions appear as overlays on top of the reference image. The clinicians can make use of them in their pre-surgery planning.

3.5 Slit Lamp Image Registration

We discuss with clinicians to develop a viable protocol to help to register the slit lamp to the reference image. It is agreed that it is necessary to visit all major landmarks within a retina image to improve the registration accuracy. A typical protocol involves starting at the optic disc and gradually moves towards the macula and back, followed by tracing the two major vessels in the superior and inferior regions. The optic disc region is detected from the slit lamp image by comparing the top percentile of the grayscale intensity level. The detected optic disc is then registered to the reference image. The SIFT feature points [8] are extracted from slit lamp video frame and reference fundus image. SIFT key points' matching are performed. Outliers' elimination step similar to our multi-modal registration stage is performed to obtain only the correctly matched points (See Fig. 9). Note the difficulty in outliers' elimination here because of the very large number of outliers present. Nevertheless, our proposed approach, being able to handle up to 90% of outliers, works well here. Slit lamp video frame is registered to fundus image.

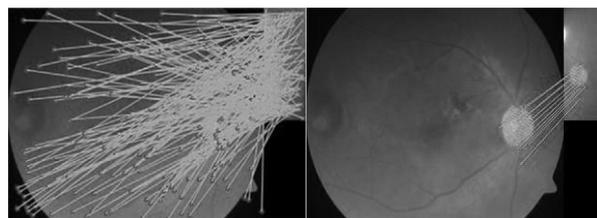


Fig. 9. (left) Putative matches; (right) Matches with outliers eliminated.

The features of regions in the vicinity of the two major vessels are computed and registered to the reference image. The protocol provides the system with sufficient coverage of the major landmarks in a retina fundus image. Tracking of slit lamp video frame on the reference fundus image is then performed (see next section).

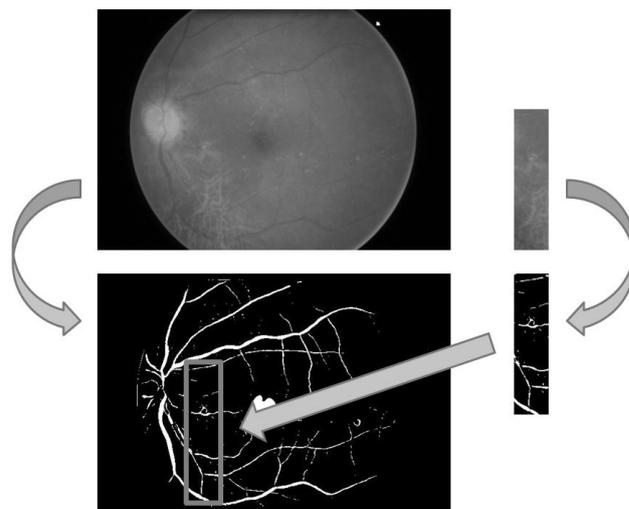


Fig. 10. Image matching and alignment process

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