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SYMPOSIUM

DrishtiCare: A Telescreening Platform for Diabetic Retinopathy Powered with Fundus Image Analysis

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Abstract

Objective:

Diabetic retinopathy is the leading cause of blindness in urban populations. Early diagnosis through regular screening and timely treatment has been shown to prevent visual loss and blindness. It is very difficult to cater to this vast set of diabetes patients, primarily because of high costs in reaching out to patients and a scarcity of skilled personnel. Telescreening offers a cost-effective solution to reach out to patients but is still inadequate due to an insufficient number of experts who serve the diabetes population. Developments toward fundus image analysis have shown promise in addressing the scarcity of skilled personnel for large-scale screening. This article aims at addressing the underlying issues in traditional telescreening to develop a solution that leverages the developments carried out in fundus image analysis.

Method:

We propose a novel Web-based telescreening solution (called DrishtiCare) integrating various value-added fundus image analysis components. A Web-based platform on the software as a service (SaaS) delivery model is chosen to make the service cost-effective, easy to use, and scalable. A server-based prescreening system is employed to scrutinize the fundus images of patients and to refer them to the experts. An automatic quality assessment module ensures transfer of fundus images that meet grading standards. An easy-to-use interface, enabled with new visualization features, is designed for case examination by experts.

Results:

Three local primary eye hospitals have participated and used DrishtiCare's telescreening service. A preliminary evaluation of the proposed platform is performed on a set of 119 patients, of which 23% are identified with the sight-threatening retinopathy. Currently, evaluation at a larger scale is under process, and a total of 450 patients have been enrolled.

Conclusion:

The proposed approach provides an innovative way of integrating automated fundus image analysis in the telescreening framework to address well-known challenges in large-scale disease screening. It offers a low-cost, effective, and easily adoptable screening solution to primary care providers.

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Abbreviations: (CSME) clinically significant macular edema, (DR) diabetic retinopathy, (NPDR) nonproliferative diabetic retinopathy, (PDR) proliferative diabetic retinopathy

Keywords: computer-aided diagnosis, diabetic retinopathy, fundus image analysis, screening, telescreening

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Introduction

Diabetes is a complex, chronic disease that requires lifelong care. Most diabetes patients are at high risk of developing diabetic retinopathy (DR), which is a well-characterized, sight-threatening microvascular complication associated with diabetes.[1,2] In a typical screening program, each patient is screened for the presence of DR via a slit-lamp examination by an experienced ophthalmologist,[3] after dilation of pupils. Given that DR is a common cause of preventable blindness (if treated adequately), it is important to establish effective screening programs for its detection.[3,4]

A majority of diabetes patients do not receive regular ophthalmologic care and are typically diagnosed after the onset of partial vision loss. For eye health care providers, it is very difficult to cater to this vast set of diabetes patients, primarily because of high costs in reaching out to patients and a scarcity of skilled personnel.[5] Agencies such as eye hospitals, nongovernmental organizations, and government and private institutions that work toward preventing blindness need solutions that (a) can enable ophthalmologists to handle more patients without compromising the quality of care, (b) are cost-effective in terms of cost incurred per patient, (c) are scalable and can have a wide reach, and (d) could be easily integrated with the current workflows.

Digital fundus-imaging-based screening procedures for DR (with nonmydriatic and mydriatic digital cameras) are now well defined and have been shown to be sensitive and specific when compared with the gold standard of the seven-field stereoscopic standard 35 mm photographs.[6–10] These procedures offer new screening solutions with potential to address the requirements mentioned earlier, and consequently, efforts toward developing screening solutions are built around digital fundus imaging. These efforts have mainly focused on developing (a) telescreening solutions[11–15] and (b) automated fundus image analysis-based solutions for DR screening.[6–8]

In a typical telescreening solution, digital fundus images of patients are captured at a remote location and electronically transmitted or transferred through the Internet to a skilled grader. After the grading, the findings and related medical advice are electronically transferred back to the patient site. Telescreening can be an attractive alternative for experts to overcome limitations in *accessibility*.[12,13] Although there is consensus concerning the cost-effectiveness of telescreening solutions, the scarcity of skilled personnel continues to limit the rate at which grading can be done and thus the scalability (in terms of number of patients) of the screening service.[6,7]

A strategy to address this problem has been to employ a prescreening procedure that is performed by a "reader" who is trained to grade DR.[7] During this prescreening, the patients who are identified with the presence of DR are referred to experts with adequate experience for detailed examination and further medical advice. This prescreening enables experts to handle more patients who require attention. However, subjectivity introduced in the prescreening affects the quality of care.

Early studies and developments in automated fundus image analysis have shown potential to achieve objective and quantitative analysis without recourse to observer-driven methods that are more prone to fatigue and bias and are more time-consuming.[6] Automated analysis of fundus images for DR has been studied from two usage perspectives.[6,7,16] The first form of usage is as a prescreening system, whose purpose is to determine whether or not an image is normal, i.e., free of DR-related abnormality. The achieved performances for such systems are comparable to that by medical experts.[7] The second form of usage is as a tool to assist experts during image examination. The assistance is provided by performing an automatic detection and highlighting of abnormalities from a given fundus image to draw the expert's attention. Such tools can also help quantify the presence and progression of DR in an image. The performances achieved by these tools, under different screening settings, are not satisfactory enough to be recommended for clinical practice.[6]

To recap, in large-scale DR screening programs, the number of fundus images that need to be examined by ophthalmologists is usually high. There is consensus concerning the cost-effectiveness of telescreening solutions, but scarcity of experts makes this solution inadequate at a larger scale.[7] On the other end, independent screening solutions based on automated fundus image analysis are suitable for large-scale screening, but their performance is not yet adequate for inclusion in clinical practices.[6]

In this article, we propose a hybrid telescreening solution for DR, which synergizes ongoing developments in two different directions. We incorporate various fundus image analysis components under a telescreening framework to address the underlying limitations of a traditional telescreening solution. In the next section, we present the proposed screening solution and related details.

Methodology

Our solution uses a Web-based telescreening framework and introduces various fundus image analysis features within this framework. **Figure 1** shows a complete illustration of the proposed solution. The screening workflow of this platform is as follows:

a. **Patient enrollment and fundus imaging.** A diabetes patient gets enrolled in a remote site under a screening program. Digital fundus photographs of the left and right eyes of the patient are acquired under a fixed, predetermined imaging protocol. These images are taken by a trained technician using a fundus camera. A user interface provided at the remote site aids in recording of patient clinical data and to facilitate Web-based communication for the screening process. **Figure 2** shows a screenshot of the user interface provided at the imaging end.

b. **Image quality assessment and data compression.** Due to various imaging factors, the acquired images are often below the grading standard in the sense that they do not provide any meaningful information for examination by a medical expert. Such cases remain unscreened. Past studies have shown that, in telescreening, between 11% and 15% of the transferred images are below the grading standard because of poor imaging.[17] This can be redressed by employing an *automatic* image quality assessment module. Some example techniques for automatic image quality assessment have been proposed previously.[18,19] If the quality of taken images is found to be poor, then reimaging instruction is given to the technician. The incorporation of this component thus ensures

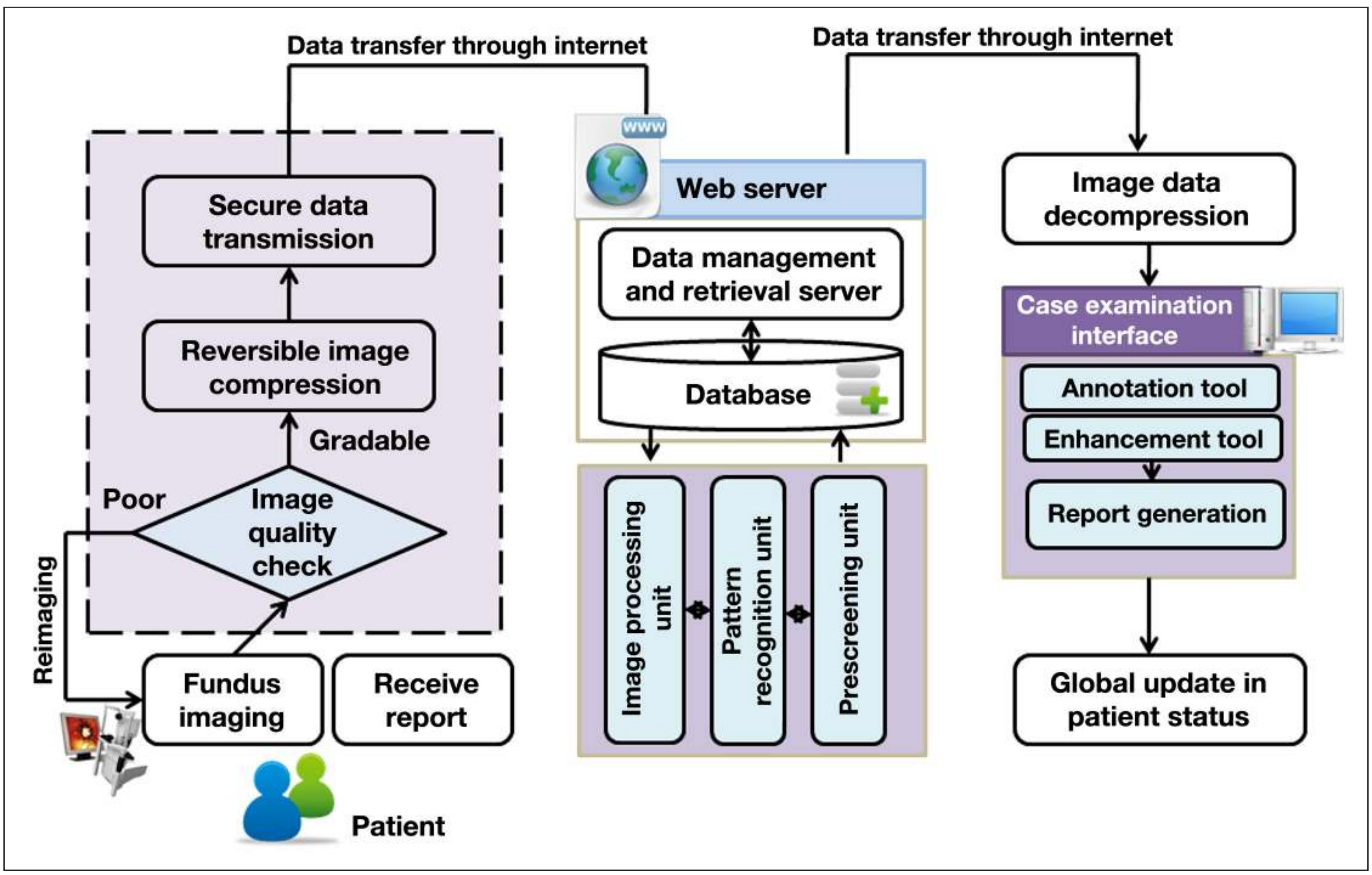

Figure 1. Functional diagram of the DrishtiCare platform.

acquisition of good quality images at the remote site. Next, the patient data that comprise clinical and image data are compressed to make them suitable for low-bandwidth network connectivity.

c. **Data transmission to servers.** Patient data are transmitted to DrishtiCare servers via the Internet. The remote site receives an acknowledgement on the completion of data transfer.

d. **Prescreening system at server site.** An important feature of our platform is the inclusion of a module at the server site that can automatically categorize a case (uploaded patient's record) as normal or abnormal using fundus image analysis. An example of an algorithm that can perform this task can be found in the work of Philip and colleagues.[7] If a patient's fundus images do not have any visual abnormality such as microaneurysms, hemorrhage, or exudates related to DR, then the case is declared as normal. Cases identified as abnormal undergo further processing. For the normal case, a report is automatically generated with a 1-year follow-up suggestion and sent back to the remote site.

Typically, the number of images without any sign of DR in a screening setting is over 90%.[6,7] Therefore, an automated prescreening system that can determine whether or not any suspicious signs of DR are present in an image can significantly reduce the workload of expert; only those patients deemed suspect by the prescreening system would then require examination by an expert.

e. **Image processing for visualization at server site.** Before sending a case record to an ophthalmologist, few image processing steps are applied to the fundus images. Additional information is automatically derived through these processing steps and sent to the expert along with the patient data. For instance, best image viewing settings such as brightness and contrast are recorded to provide better quality of image during examination. The potential locations of different visual abnormalities associated with DR are also computed and recorded to draw the attention of the expert to subtle abnormalities that can be potentially missed during manual examination. This information is used to give experts enhanced visualization of images.

f. **Case examination at expert center.** An intuitive and easy-to-use examination interface is provided for case examination. A sample screenshot of the same will be shown later. Clinical details and fundus image of the patient are displayed on the left and right side, respectively, of the interface.

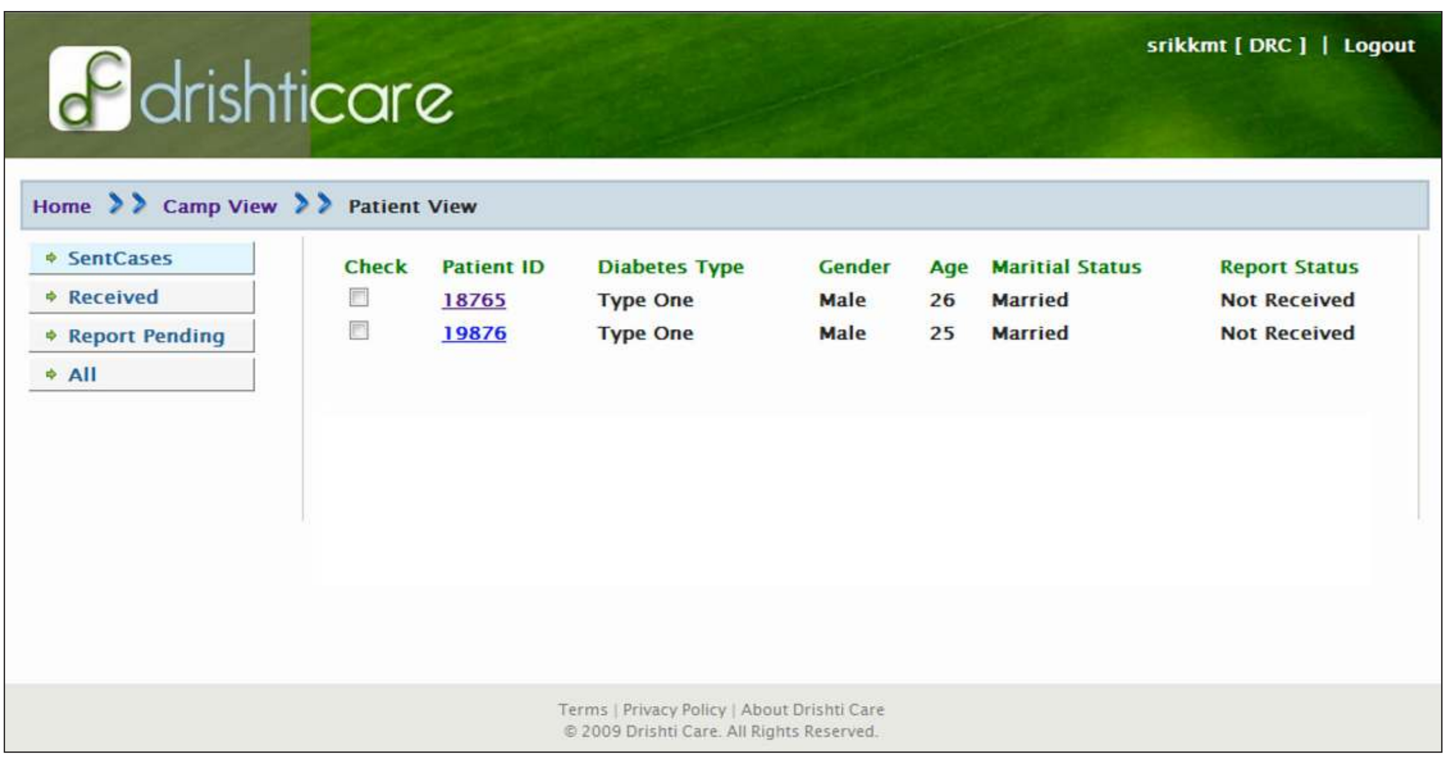

Figure 2. User interface for the patient registration.

Images of the left and right eye can be examined in a sequence and findings can be recorded by the expert. The interface provides the following features to aid examination via a single-click: (i) visualize better quality image, (ii) zoom in to an image region for a close look, (iii) view potential locations of DR-related abnormalities, and (v) generate a case report after completion of grading.

g. **Dissemination of findings and medical advice to the patient.** A report comprising findings and medical advice given by the expert is sent to the DrishtiCare server. This is made available to the patient at the remote site through their interface.

Next, the specification and functional details of individual steps are presented in detail.

Patient Registration Interface

The remote sites that participate in a DR screening program are given login details to use the DrishtiCare Web-based telescreening service. The interface allows a user to upload new patient's clinical data and fundus images. Comprehensive clinical information such as personal details, diabetes history, past history of ocular treatment, visual acuity, and blood investigation can be recorded through the interface. This interface supports uploading of images taken under the Early Treatment Diabetic Retinopathy Study imaging protocol. A report with diagnosis and medical advice can also be received through this interface and given to the patient. **Figure 2** shows a screenshot of the interface.

Automatic Quality Assessment

Studies indicate that approximately 11–15% of cases have to be discarded, being unfit for diagnostic evaluation.[17] In a telescreening scenario, the expert sitting in a remote location has access to patient data (both image and nonimage data) only, and thereby it is imperative that the images transmitted are reliable and optimal for diagnosis. An automatic image quality assessment module will ensure that the images transmitted for diagnosis conform to prescribed gradable standards. This module evaluates the images, taken by the technician in real time, for adherence to specified quality parameters. One set of parameters is intended to assure the right region of interest in the retina is being captured, while another assures the clarity of the captured image. The former is specified in terms of the field of view, which specifies the area (e.g. 15° or 30°) and the part of the retina (e.g. optic-disk- or macula-centric view) covered by the fundus image. The clarity of the image is assessed on the basis of the visibility of important features such as vessels in a fundus image.[17] In the event of failure of an image to pass the quality test, the module will prompt the technician to take corrective measures. **Figure 3** shows samples of gradable and upgradable fundus images. The patient data, including clinical history and fundus images, are compressed prior to sending to the data server. Data compression is an essential step to make the platform suitable even for low-bandwidth Internet connectivity.

Server-Based Prescreening of Patients

The function of this component is to determine whether or not the uploaded fundus images of a patient are normal (free of DR-related abnormalities) or abnormal (contain one or more abnormalities). A number of successful studies have shown high and clinically acceptable performance for such systems, which is evaluated against multiple experts.[7,8] We introduce a novel way to integrate such prescreening systems in the telescreening framework to address the scarcity of the experts. Only those patients who are found at risk for DR (abnormal) are referred to the expert. This integration is more appropriate in a screening scenario where 80–90% of the screened patients are normal.[7] Examination of every patient by eye experts, regardless of whether they are affected by DR or not, is not practical for large-scale screening. Automatic processing to select the abnormal cases for further scrutiny thus significantly reduces the workload of experts and allows them to see a large number of patients who *require* care.

Image Processing for a Better Image Visualization

The abnormal cases identified by the prescreening module are sent to the expert for examination. Before transferring the fundus images of these cases, a set of image processing steps is performed at the server to

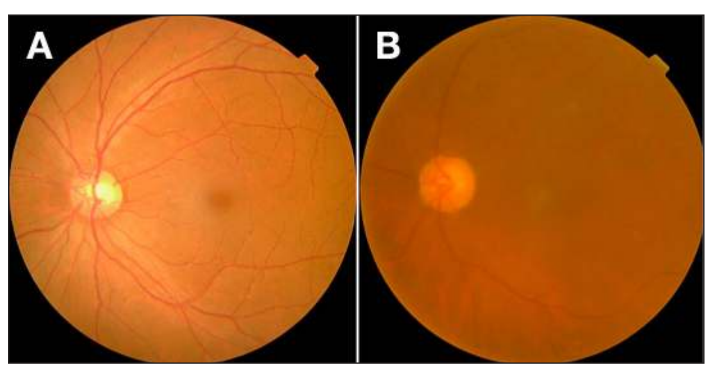

Figure 3. Sample images (macula-centric view) taken during DR screening. **(A)** Image up to the grading standard. **(B)** Sample image with poor clarity.

derive information from the fundus image to be sent along with the images. This additional information will be used by the case examination interface to provide features that enhance diagnostic content in the images.

Image Quality Parameters

Due to the complex imaging setup in various cameras and/or improper pupil dilation, fundus images often have poor illumination and contrast. These distortion factors can be estimated using various techniques, including one previously presented.[20] These factors can then be used to automatically enhance the visual quality (brightness and contrast) of fundus images. In the proposed platform, we send the estimated correction factors and provide a single-click option in the interface for case examination to enhance images in real time. **Figure 4** shows some samples of acquired fundus images (first column) and corresponding enhanced results (second column) using a technique described previously.[20]

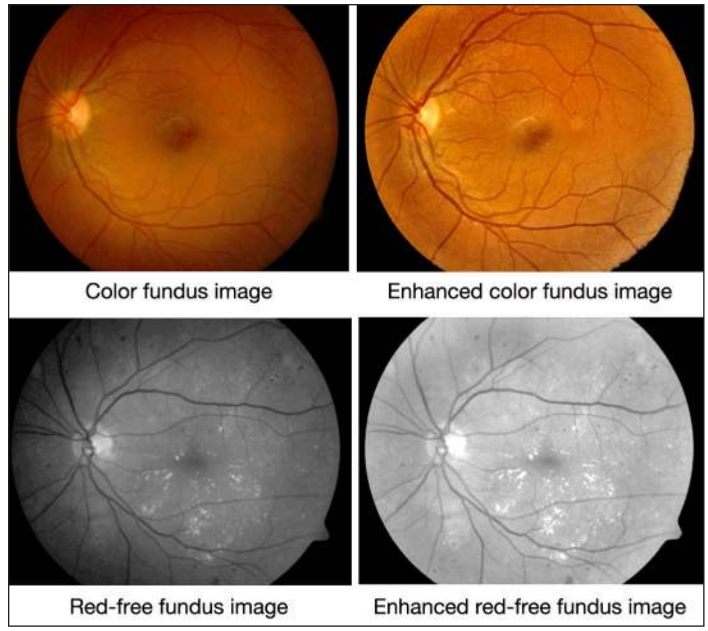

Figure 4. Sample results of automatic and single-click image enhancement.

Detection of Abnormalities

The purpose of this processing component is to detect abnormalities related to DR such as microaneurysms, hard/soft exudates, and hemorrhages. An extensive amount of work has been reported on detecting of these lesions.[6,16,21] In this platform, we incorporate these detection modules and get potential locations of the lesions of interest. The locations of individual lesions are sent to the case examination interface where an expert can view, with a single click, the highlighted lesions. **Figure 5** shows the highlighted lesions on fundus images. Here, each microaneurysm is indicated with a small square while clusters of hard exudates are highlighted with a blue box around the cluster. The green concentric circles around the macula (of diameter *kd*, where *d* is the diameter of the optic disk, and $k = 1,2,\ldots,5$ provide a way to visually asses the severity of the abnormality.

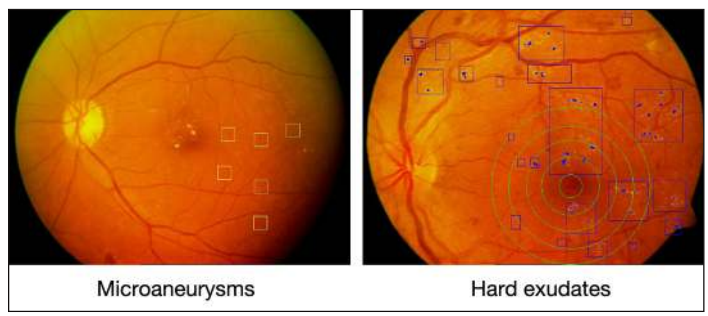

Figure 5. Sample fundus images with highlighted lesion locations.

In summary, the enhancement module helps to improve the definition of the image structures and present superior quality images for expert examination. The detection module highlights the potential locations of abnormalities. Both modules aid an expert in examination and help in seeing subtle information in the images. We believe such value-added processing and visualization can significantly reduce interobserver variation reported in past studies.[6,16]

Case-Examination Interface

A Web-based user interface is designed to ease grading process for the experts. Login details are given to experts who are registered with this platform to access the Web-based interface. An expert can browse patient cases that are assigned to him/her and can select one to start grading. A few main features of interface are as follows:

Single page overview of patient data: On patient click, interface displays all patient information in a single page, which helps the expert in getting a complete overview of a case. This provides a better user experience compared to a style that uses multiple pages. **Figure 6** shows the screenshot of the interface in which fundus images from both eyes are displayed along with patient clinical history to the expert.

Single-click image enhancement: An option to view enhanced fundus images is provided with the interface. It uses the quality parameters estimated at the server site to enhance the images without any manual adjustment.

Figure 6. Single view of complete patient information.

Highlight potential locations of abnormalities: The locations of lesions detected at the server site are used to highlight the potential location of lesions. An expert can quickly view those locations and validate the detected location. This is an optional feature aimed at reducing interobserver variability in examination. **Figure 7** illustrates the examination interface in which various interface features are highlighted.

Zoom in to an image region: The zoom-in option in the left panel can be used by an expert to have a closer look at an image region.

Report generation: Diagnostic information can be recorded using a set of radio buttons by the expert for both the left and the right eye. These findings are utilized to generate a report summarizing the findings and the suggested medical advice from the expert.

Results

During an initial pilot phase, a total of 119 diabetes patients have been examined using the DrishtiCare platform. Patient data were collected from three local eye hospitals and transferred to an ophthalmologist for examination through the proposed platform. The prescreening component of the proposed platform was not included for this phase. Of the 119 patients, the clinical findings were as follows: 36 normal; 33 *mild* nonproliferative diabetic retinopathy (NPDR), 23 *moderate* NPDR, 9 *severe* NPDR, 3 proliferative diabetic retinopathy (PDR), and 15 clinically significant macular edema (CSME). Thus 30.3% of the cases were normal while 22.7% cases were identified with sight-threatening retinopathy that includes severe NPDR, PDR, and CSME. Currently, the proposed platform is under large scale evaluation where performance of prescreening component is also being recorded. In this phase, a total of 450 patients were enrolled until May 2010.

Conclusions and Future Directions

A solution for telescreening is proposed in the form of a platform called DrishtiCare. The proposed platform is designed to include automated fundus image analysis capability to address the underlying limitations of the traditional telescreening platform. An increase in the throughput of the screening has been achieved in DrishtiCare by the inclusion of (a) an automatic quality assessment module that helps prevent transfer of ungradable images and (b) a prescreening component at the sever site that helps filter out normal cases and transfer only abnormal cases.

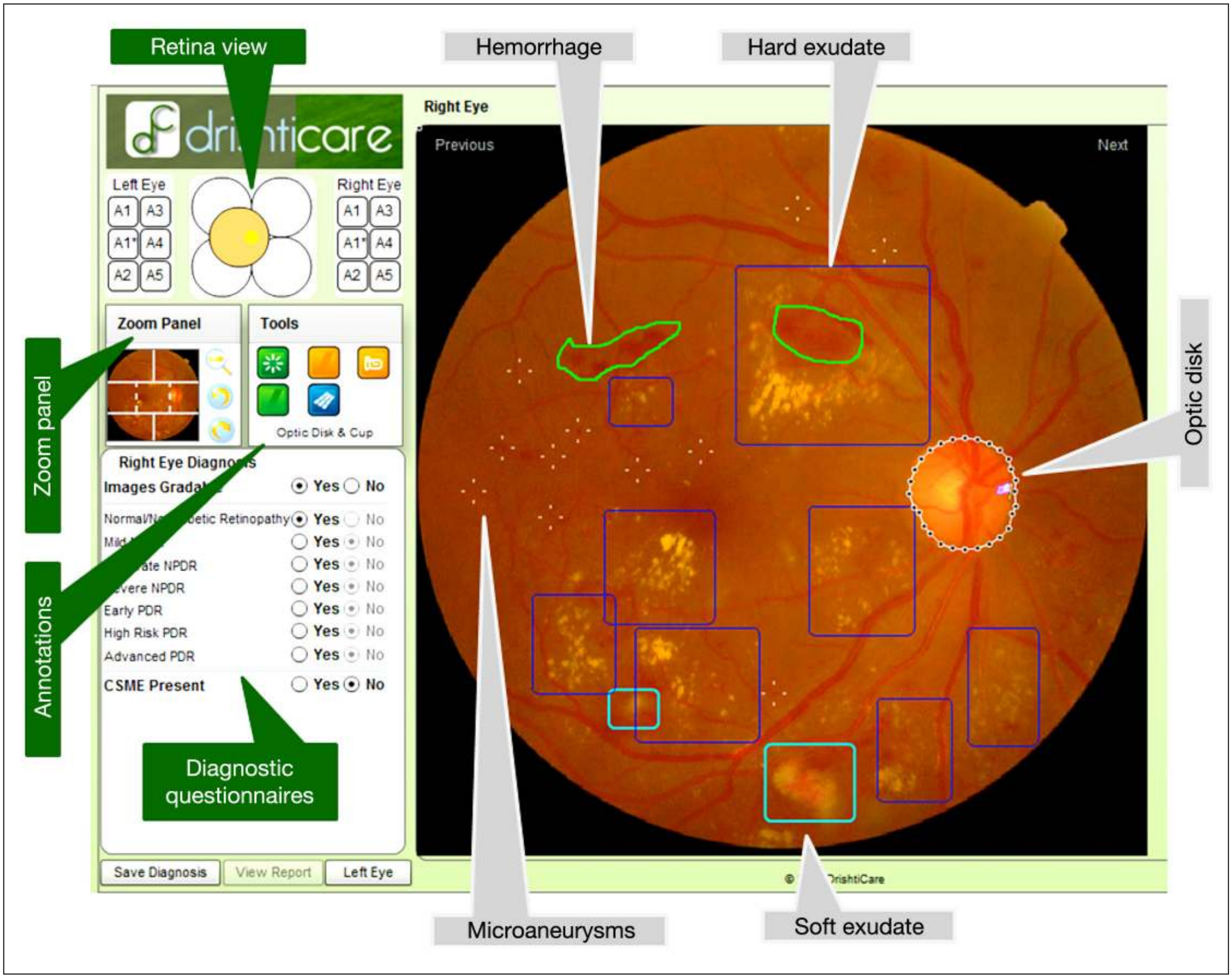

Figure 7. Screenshot of case examination interface.

In our preliminary test of the platform with 119 patients, 36 were found to be normal by the experts. This implies that, with the inclusion of the prescreening module (which can automatically identify and stop transfer to experts), up to a 30% reduction in the workload of the experts can be achieved. This, in turn, should increase the throughput of the telescreening, which is very encouraging.

Feedback obtained from experts indicated that inclusion of image visualization features in the interface at the expert end was helpful. This has the potential to make the examination more objective. The choice of a Web-based platform should help in making telescreening service cost-effective, easy to use, and scalable.

The proposed idea of integrating various fundus image analysis components renders the screening solution to become highly scalable. As techniques for automated fundus image analysis mature, the performance of the proposed system can be further improved.

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