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OIPAV: An Integrated Software System for Ophthalmic Image Processing, Analysis and Visualization

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ABSTRACT

OIPAV (Ophthalmic Images Processing, Analysis and Visualization) is a cross-platform software which is specially oriented to ophthalmic images. It provides a wide range of functionalities including data I/O, image processing, interaction, ophthalmic diseases detection, data analysis and visualization to help researchers and clinicians deal with various ophthalmic images such as optical coherence tomography (OCT) images and color photo of fundus, etc. It enables users to easily access to different ophthalmic image data manufactured from different imaging devices, facilitate workflows of processing ophthalmic images and improve quantitative evaluations. In this paper, we will present the system design and functional modules of the platform and demonstrate various applications. With a satisfying function scalability and expandability, we believe that the software can be widely applied in ophthalmology field

Keywords: Software platform, Ophthalmic image, Image processing, Computer aided diagnosis, Image visualization

1. INTRODUCTION

Ophthalmic images greatly help ophthalmologist and researchers analyze and diagnose ophthalmic diseases. Optical coherence tomography (OCT), magnetic resonance (MR) and fundus photography play an indispensable role and have been widely used and in ophthalmology field. There is a strong demand for a software system to assist researchers and clinicians to process ophthalmologic images.

Although a number of softwares and toolkits for medical image processing and visualization have been proposed, there is no commonly known software system especially oriented to ophthalmic image. Typical examples include Osirix [1], 3D Slicer [2] and Paraview [3], which are application system based on Visualization Toolkit (VTK) [4] and Insight Toolkit (ITK) [5]. Other softwares such as MITK [6] and MeVisLab [7] are aimed to offer frameworks to help researchers build specific applications. They all provide rich functionalities, however, they are more suitable for general medical image rather than particular ophthalmic images.

Comparing to general medical image, processing, analyzing and visualizing ophthalmologic images are different and require targeted algorithms as well as special software design. First, there is no standard for transferring ophthalmic images and associated information between devices manufactured by various venders. Second, ophthalmic imaging and processing involve many different kinds of datasets which require an appropriate data management mechanism and corresponding rendering modes. Third, because of the difference in the ophthalmic imaging principle and structures, suitable image processing techniques are necessary such as OCT image segmentation, quantitative assessment for ophthalmic diseases, etc. Forth, it's challenging to design the algorithms of automatic ophthalmic diseases detection and integrate them into the software system to meet the practical and clinical requirements. Finally, reliable and efficient methods of data analysis are essential to assist users to quantitatively analyze ophthalmic data. To deal with these problems, therefore, we design and implement the integrated cross-platform software system OIPAV which is focus on ophthalmic images processing, analysis and visualization.

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2. METHODS

OIPAV is oriented to ophthalmic images processing, analysis and visualization. It is written entirely in C/C++ and can run on Windows, Linux and MacOS platforms with sharing a single code base. we follow the modularity in developments for software stability and components reusability. The system encompasses six groups of operations: data I/O, image processing, interaction, ophthalmic diseases detection, data analysis and visualization. More details are given as following:

2.1 System Design and Architecture

OIPAV is a sophisticated system that involves different aspects for retinal imaging, therefore we adopt the modular design method to implement layers of abstractions and componentized functional units. Fig. 1 shows the general architecture of the software system. From top to bottom, the general architecture of the system can be divided into applications, development modules, high level libraries, low level libraries and hardware level. In the layer of high-level libraries, a number of popular medical programming toolkits including ITK, DCMTK [8], VTK and vtkINRIA3D [9] support base processing and visualization functions for higher layers. In order to reduce the coupling among different modules, in the development modules, we employ a plugin mechanism to infrastructure an extensible and flexible framework for developing and assembling various functional blocks. The applications level integrates rich functions concentrated on ophthalmic image processing, analysis and visualization. By this module design method and plugin mechanism, software system can be extensible, reuse and customization for different needs. In addition, develops can also easily develop new functionalities for requirements and combine existing function plugins into the platform without changing the framework code.

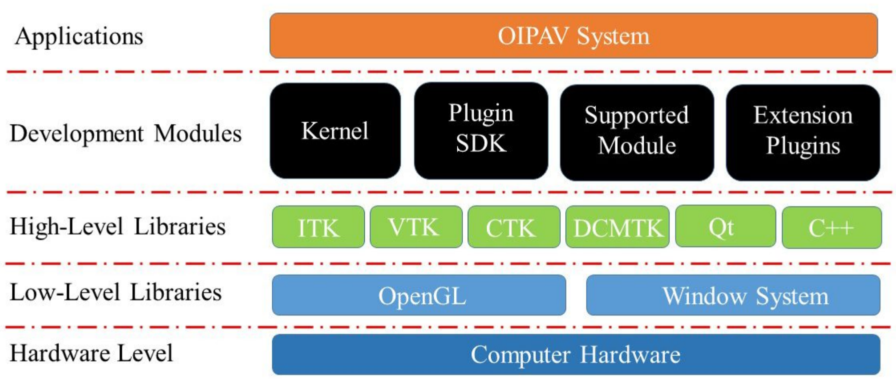

Fig. 1 General architecture of the system.

2.2 Ophthalmic Data I/O

In consideration of no unified standards and formats for the ophthalmic image, OIPAV supports various 2D/3D ophthalmic images. To the specific ophthalmic image data formats such as FDS from Topcon, we design algorithms to parse and convert them to other common formats. Now our system can read the OCT image data of Topcon and other manufactures. Besides the DICOM file formats support, OIPAV also supports other common 2D/3D medical image file formats such as Raw, VTK, Analyze, TIFF, JPEG, etc. Besides, OIPAV supports local/remote database communications which means that the system provides networking DICOM image querying and retrieving by connecting to the picture archiving and communication system (PACS) [10] or local SQL database. Meanwhile, the files conforming with DICOM standards can be constructed by combining image data and related information inputted and transferred to DICOM server. Fig. 2 shows the data flow in the system.

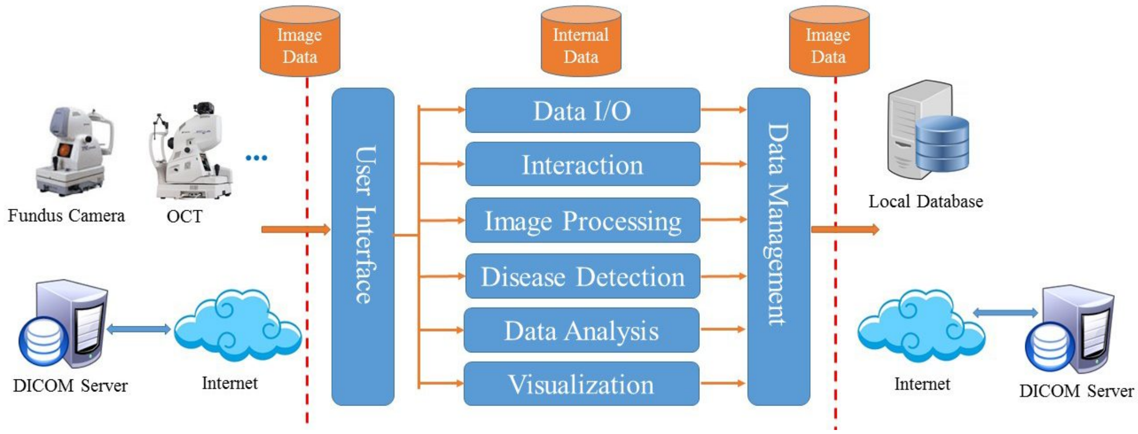

Fig. 2 The data flow in OIPAV system

2.3 Data Object and Visualization

Regarding representation and rendering of different kinds of data in ophthalmic images, OIPAV defines three standard data types based on VTK and PluginSDK: ImageData, SurfaceData and VolumeData. The ImageData represents a vtkImageData and has a geometric structure that is a topological and geometrical regular array of points. 2D/3D ophthalmologic images are mostly included in this type. The VolumeData carries a vtkPolyData object with a geometric structure consisting of vertices, lines, polygons, and/or triangle strips. The lesion areas in ophthalmic images like exudation and artificial objects like painted areas or segmentations are encapsulated into the VolumeData type. The SurfaceData supports vtkUnstructuredGrid objects representing any combinations of any cell types including 3D retinal layers, lamina cribiosa layers, etc.

The data tree is responsible for organizing all data objects hierarchically in a rendering scene at run-time. The tree contains the properties of the data such as orientation and position and assigns corresponding rendering mode to each tree node for optimal display effects. We implement the multi-tab viewer design to display images and interact with a data tree or branches of a data tree in multiple viewer pages in the software window. Each viewer page contains a classic four-window layout, where the axial, sagittal, coronal and 3D windows are arranged in a grid pattern of resizable windows. This gives users a similar experience to browse web pages and facilitate the navigation through multi-groups images.

OIPAV provides different types of visualization according to the data types. For image data, multiplanar reconstruction (MPR) [11] is used for rendering in 2D mode. 3D surfaces are rendering by machine cube algorithms [12] and sufficient hardware-accelerated volume rendering algorithms, including the ray casting algorithm [13] and 3D texture mapping [14] algorithms are used for rendering image data in 3D mode. Furthermore, OIPAV offers multiple display modes to assist users to evaluate eye structures including the optical intensity view, the fusion image of optical intensity and retinal layer thickness, the 3D pseudo color image in the maximum intensity projection techniques, etc.

2.4 Ophthalmic Image Processing and Interaction

The key image processing operations commonly employed can be divided into six groups: geometric transformation, filtering, image algebra, image morphology, segmentation and registration. Especially in segmentation, automatic processing functions are essential to free users from work of time-consuming manual image segmenting and reduce subjectivity. Therefore, our system provides a variety of functions of automatically recognizing and segmenting eye structures including the automated 3-D retinal 11-layer segmentation of macular OCT images [15], the identification of Bruch's membrane opening (BMO) reference plane, the segmentation of the anterior lamina cribrosa surface [16, 17], as well as optic cup (OC) and optic disc (OD). We implement these automatic processing based on some algorithms including Graph-Cut [18], Support Vector Machine (SVM) [19], Adaboost [20], Random Forest [21], etc.

In interaction, OIPAV follows the concepts used in VTK to structure and standardize the manipulation of data in 2D/3D views. We use the observer/command design pattern to provides varieties of tools for conventional 2D/3D interactive manipulation to facilitate and improve the navigation and image manipulation, including image browsing, length/angle measurement, window width/level adjusting, zoom, pan, manual painting/erasing etc. For more accurate segmentation results and regions of interests of ophthalmic images, OIPAV integrates some new interactive functions including manual extraction of a volume of interest (VOI), adjustment of retinal layers and relocation of BMO reference plane etc.

2.5 Ophthalmic Diseases Detection and Analysis

Computer-aided detection (CADe) is indispensable in the medical applications and effective CADe systems. It's significant in speeding up the medical diagnostic process, reducing diagnostic errors and improving quantitative evaluations. Combining with our laboratory research experience of many years on ophthalmic diseases detection and analysis [15] [22-32], we implement automatic detection algorithms for multiple ophthalmic diseases in the system including branch retinal artery occlusion (BRAO), symptomatic exudate-associated derangements (SEAD), pigment epithelial detachment (PED), micro aneurysm, exudation, etc. From the prospect of convenience, we pre-train all algorithms to provide the "one button" solutions without any parameter optimization. The lesion areas will be directly displayed in ophthalmic images for observation by represented in managed internal standard data.

OIPAV offers reliable and efficient analysis functionalities to assist users to analyze ophthalmic data quantitatively. The analysis module includes automatic important parameters measuring, lesion areas assessing, recovery tracking, and diagnostic report generating. The key parameters include the anterior lamina cribrosa surface depth (ALCSD), the length of BMO reference plane, the rim area, the volume of optic cup and cup/disc area ratio etc. For quantitative assessments of lesion areas in prevalence analysis and treatment, OIPAV will automatically detect the data of lesion areas such as the number, area, volume etc. after eye disease detection processing. When loading multiple sets of image of the same patient over time, users can track the lesion areas in the ophthalmic image over times and get a diagram of the detailed statistics with 3D image models. Importantly, after the whole workflow of preprocessing, segmentation, disease detection and data analysis, the system will generate the auxiliary diagnostic report in the form of Microsoft Word Document which includes all significant data and views.

3. RESULTS

We have successfully developed an integrated software system for ophthalmic image processing, analysis and visualization. The main functions of six groups (data I/O, image processing, interaction, ophthalmic diseases detection, data analysis and visualization) are completed and have satisfied performance. The ophthalmic image data involved in testing mainly include 2D/3D OCT images, 2D colorful fundus images, 2D/3D MRI images of various file formats. As a highly portable desktop system, OIPAV runs on three major operating systems: Windows, Linux and Mac OS sharing single code base. The software system has been tested on the following standard computer: two Intel Core i7-4790 3.60 GHz CPU, two 8 GB RAM, 1 TB Hard Disk and a NVIDIA GTX 745 graphics. Figure 3-6 demonstrate some experiment examples using the software system.

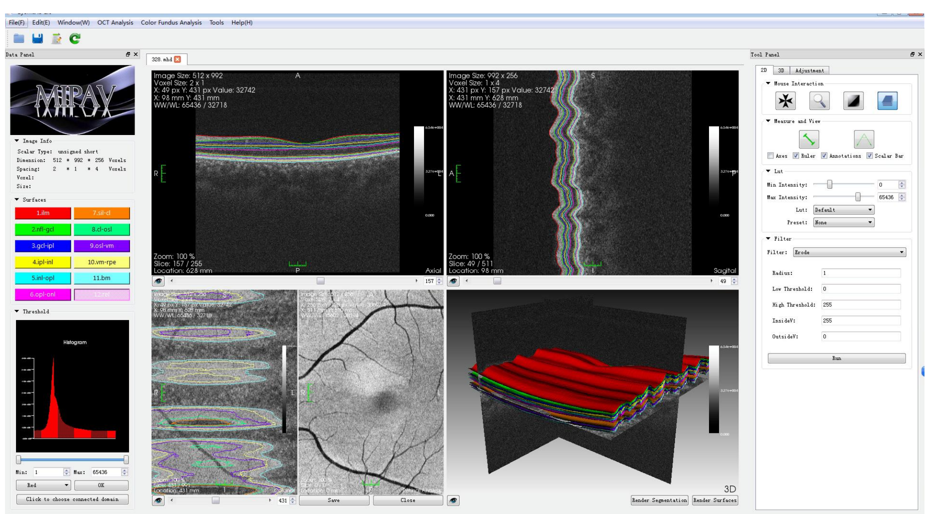

Fig. 3 The main GUIs of OIPAV. It illustrates retinal resliced and multiplanar reconstruction (MPR), retinal optical intensity and retinal layer surface rendering. The data is Topcon OCT image data.

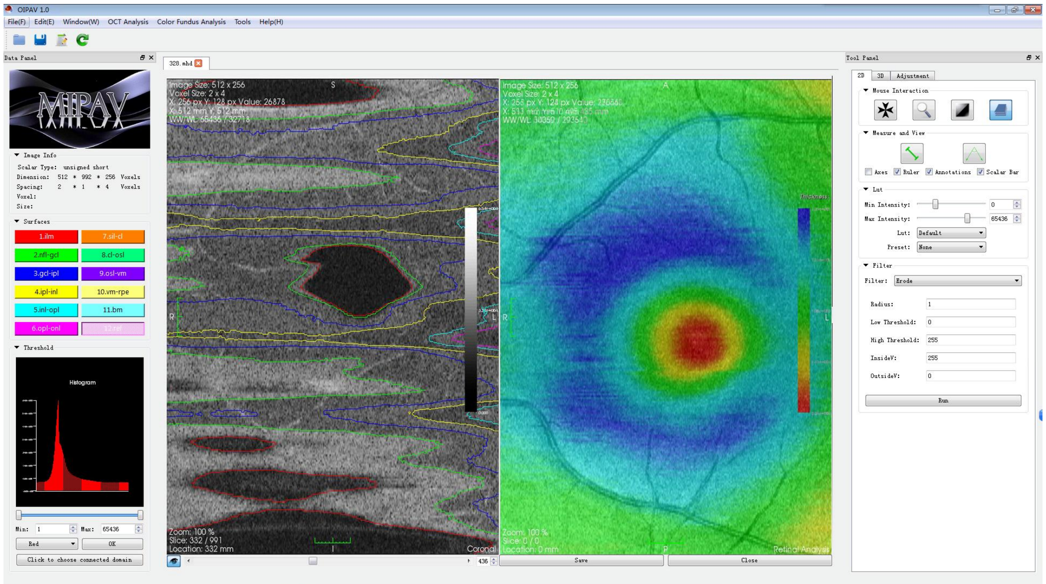

Fig.4 The fusion view mode of optical intensity and retinal layer thickness of OCT image with 12 retinal layers

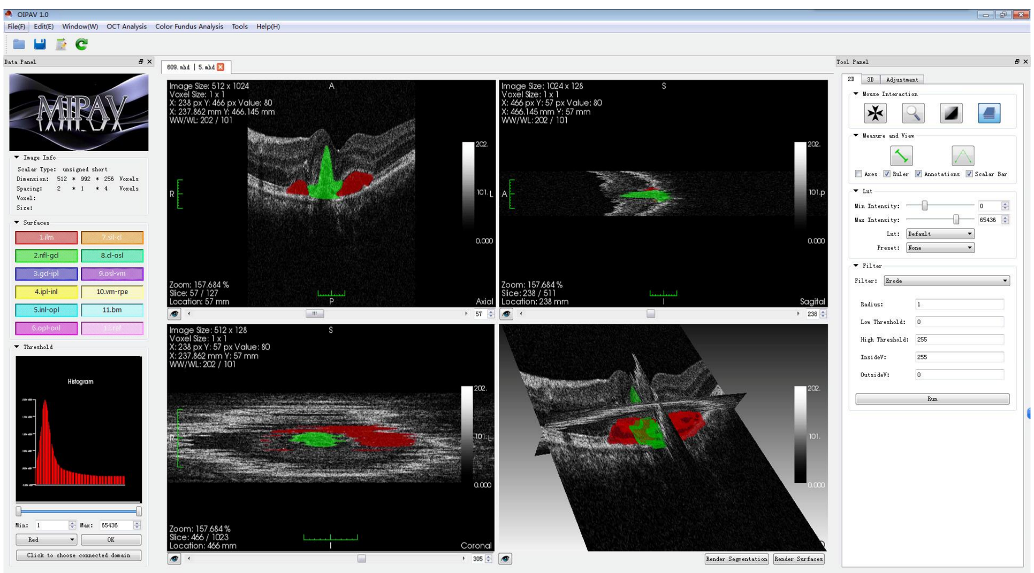

Fig. 5 The results of automatic AMD detection in the 3D OCT image.

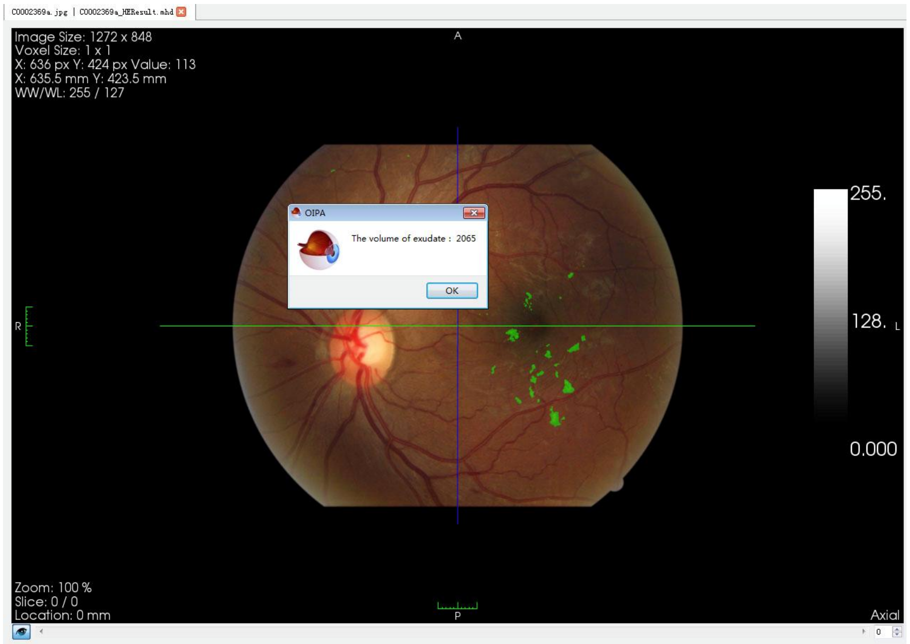

Fig. 6 The results of automatic exudate in the 2D fundus image.

Most of users make positive evaluations to our work and consider that the software system is advantageous in easy-using, functionality and practicability. And during use of OIPAV, five main requirements are implemented:

- It supports various ophthalmic image file formats. Besides the DICOM files, it can deal with the ophthalmic data from different ophthalmic equipment manufacturers and it provides local/remote database communications.
- It provides the comprehensive solutions for standardizing and visualizing multiple types of data in ophthalmic images. The design of the data tree and the multi-tab viewer facilitate the navigation through images and it provides more targeted display modes to display ophthalmologic images features more intuitively.
- It integrates the functionalities to recognize and segment anatomical and pathological structures of eyes automatically which free user from time consuming manual label work.
- It provides the "one button" solutions for various eye disease detection with professional algorithms based on our laboratory previous work. That helps to speed up the medical diagnostic process, reduce diagnostic errors and improve quantitative evaluations.
- It provides rich automatic data analysis functions to measure important parameters, assesse lesion areas, track recovery and generate auxiliary diagnostic reports. That helps users master situation of eyes accurately, reduce diagnostic errors and improve quantitative evaluations as well as diagnosis efficiency.

4. CONCLUSION

This paper introduces a comprehensive cross-platform software system especially for ophthalmic images processing, analysis and visualization. The overall design, system architecture, functional module description and application examples are demonstrated in this paper. Benefited from the module design and plugin mechanism, the software system can be easily extended by the addition of new functionalities into the existing flexible framework. OIPAV has advantages in easy-using, functionality and practicability and has been experimentally confirmed that it is applicable for dealing with various ophthalmic images. We believe that OIPAV possesses many key features that, taken together, make it a unique and valuable tool for the ophthalmologic imaging society.

We will consider providing a free trial version of the software by inviting other researchers in the near future at our website (http://mipav.net) for further improvements on reliability and practicability.

5. ACKNOWLEDGMENTS

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