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IMAGE DATABASE SYSTEM FOR GLAUCOMA DIAGNOSIS SUPPORT

OBRAZOVÝ DATABÁZOVÝ SYSTÉM PRO PODPORU DIAGNOSTIKY GLAUKOMU

DIPLOMOVÁ PRÁCE
MASTER´S THESIS

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Abstract

This master thesis describes a conception of standard and advanced eye examination methods used for glaucoma diagnosis in its early stage. According to the theoretical knowledge, a web based information system for ophthalmologists with three main aims is implemented. The first aim is the possibility to share medical data of a concrete patient without sending his personal data through the Internet. The second aim is to create a patient account based on a complete eye examination procedure. The last aim is to improve the HRT diagnostic method with an image registration algorithm for the fundus and intensity images and create an optic nerve head web based 3D visualization. This master thesis is a part of project based on DAAD co-operation between Department of Biomedical Engineering, Brno University of Technology, Eye Clinic in Erlangen and Department of Computer Science, Friedrich-Alexander University, Erlangen-Nurnberg.

Keywords

Glaucoma, optic nerve head, retinal nerve fibre layer, GDx, OCT, HRT, image-registration, web-based visualization, applet signing, SSL, bump mapping, ImageJ, DAAD

Abstrakt

Tato práce popisuje přehled standardních a pokročilých metod používaných k diagnose glaukomu v ranném stádiu. Na základě teoretických poznatků je implementován internetově orientovaný informační systém pro oční lékaře, který má tři hlavní cíle. Prvním cílem je možnost sdílení osobních dat konkrétního pacienta bez nutnosti posílat tato data internetem. Druhým cílem je vytvořit účet pacienta založený na kompletním očním vyšetření. Posledním cílem je aplikovat algoritmus pro registraci intenzitního a barevného fundus obrazu a na jeho základě vytvořit internetově orientovanou tři-dimenzionální vizualizaci optického disku. Tato práce je součásti DAAD spolupráce mezi Ústavem Biomedicínského Inženýrství, Vysokého Učení Technického v Brně, Oční klinikou v Erlangenu a Ústavem Informačních Technologií, Friedrich-Alexander University, Erlangen-Nurnberg.

Klíčová slova

Glaukom, optický disk, vrstva nervových vláken sítnice, GDx, OCT, HRT, registrace obrazů, internetově orientovaná vizualizace, podepsání appletu, SSL, bump mapping, ImageJ, DAAD

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Declaration

I hereby declare that the thesis "Image database system for glaucoma diagnosis support" is my own, unaided thesis, supervised by the supervisor of the thesis. I have used the professional literature and other informational sources; all of them are quoted in the thesis and mentioned in the list of literature at the end of the thesis. As the author of this thesis I also declare that I have not infringed the copyright of the third parties, especially that I did not illicitly interfere with alien personal copyright and that I am fully aware of the consequences of to a possible breach of the provisions of Sec. 11 and the following Copyright Act No. 121/2000 Coll., including the possible criminal consequences resulting from the provisions of Sec. 152 of Penal Code no. 140/1961 Coll.

Prohlášení

Prohlašuji, že svou diplomovou práci na téma Obrazový databázový systém pro podporu diagnostiky glaukomu jsem vypracoval samostatně pod vedením vedoucího diplomové práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce. Jako autor uvedené diplomové práce dále prohlašuji, že v souvislosti s vytvořením této diplomové práce jsem neporušil autorská práva třetích osob, zejména jsem nezasáhl nedovoleným způsobem do cizích autorských práv osobnostních a jsem si plně vědom následků porušení ustanovení § 11 a následujících autorského zákona č. 121/2000 Sb., včetně možných trestněprávních důsledků vyplývajících z ustanovení § 152 trestního zákona č. 140/1961 Sb.

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V Brně dne 23. července 2008 Roman Peter

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Poděkování

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1. Introduction

Glaucoma has been nicknamed the silent sight thief because the loss of visual field often occurs gradually over a long time and may only be recognized when it is already quite advanced. Once lost, this damaged visual field can never be recovered. Worldwide, it is the second leading cause of blindness, according World Health Organization study [1].

Exact diagnosis is based on anamnesis to identify risk factors, on careful examination of anterior chamber angle (gonioscopy), intraocular pressure (tonometry) and missing areas of vision (perimetry) and on examination of optic nerve head and retinal nerve fiber layer using advanced imaging methods (HRT, OCT, GDx). A definite answer to the causation of this disease is unknown. In this stadium, it is necessary to have as much information as possible to improve common methods.

1.1 Medical background

For glaucoma, it is the characteristic atrophy of eye nerve fibers, which results in optic nerve head (ONH) changes and blindness. ONH is known as the blind spot, papilla or optic disk. This is the place, where the eye nerve fibers come together and continue to the brain. Internal margin of Elsching's ring defines the border of the ONH, which is not always obvious. In addition, to the ONH structures are the neuroretinal rim and the cup determining excavation; see below (Fig. 1, 2 and 3)

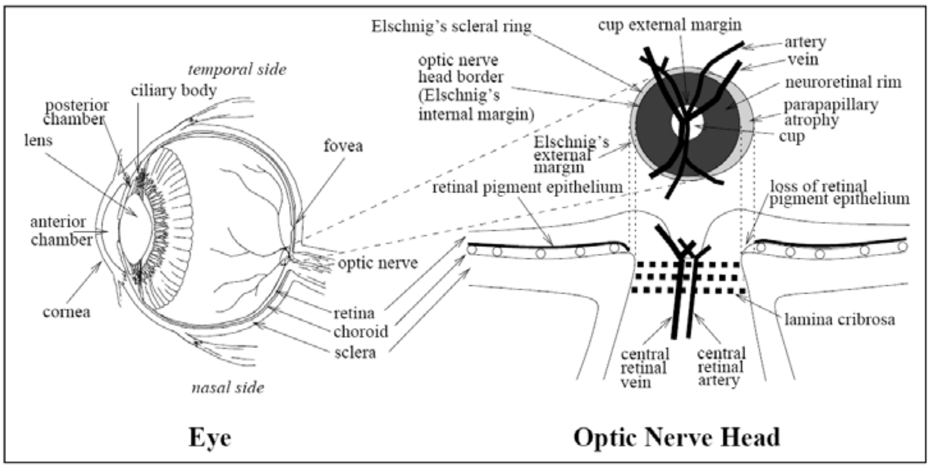


Figure 1: Schematic anatomy of the eye and the optic nerve head [25]

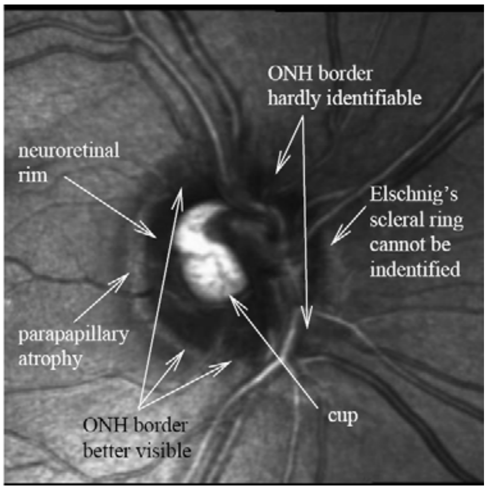


Figure 2: Iintensity image provided by SLT [25]

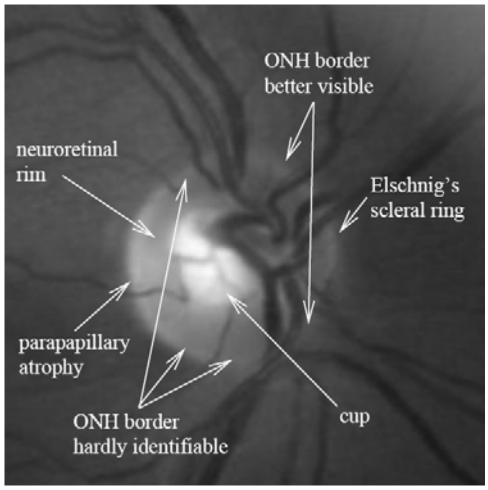


Figure 3: Green channel of registered color fundus photograph [25]

1.2 Problem description

The objective for this master thesis was to describe methods used for glaucoma diagnosis with an attention to 2D and 3D image processing and according to this theoretical information try to implement a web based information system for ophthalmologists with the aim to support the diagnosis process.

Glaucoma diagnosis is based on a set of various parameters and investigation results. This data is acquired by more than one eye examination usually. In this case, it is necessary to identify a concrete patient to update his profile. The only possibility of being able to identify a patient is by using his personal data such as name, surname and unique national personal identification number ID (e.g. SSN, DNI, National Number, Uniform Civil Number, SIN, RUT, SOTU, PKZ, HKID, PAN, PPS No, PESEL, CNP, ISS, NRIC, Birth Number, DNI, NINO, …). Common web information systems are based on posting information using a web form where this information is processed on a web server. In this case, the doctor would disturb patient personal data protection, because he would send it to the Internet. The first aim of this project is to create the possibility to share medical data of concrete patient without sending his personal data through Internet.

The use of some advanced imaging techniques is preferred for glaucoma diagnostic process. They are able (%) to identify glaucoma in early stage, which is very important for successful treatment. One of these methods uses a volume rendering technique based on a number of optic nerve head scans. Unfortunately, this method doesn't implement real colours of the eye ground, which could cause inexact diagnosis.

The second aim of this thesis is to implement image registration algorithm for fundus and intensity images.

Optic nerve head 3D visualization is based on two images: height map and texture. Height map also gives the information about the Z position. Texture gives the information about colour of each pixel in the image. The third aim of this thesis is to create an optic nerve head 3D visualization presented to the end user through WWW.

The general conception of an eye examination is based not only on image data, but also on anamnesis and other investigation results based on examination such as tonometry, gonioscopy, ophtalmoscopy, perimetry, pachymetry and other methods. The fourth aim is to implement the conception of eye examination.

The last aim is a presentation of results such as displaying selected parameters in time graph, or displaying details of each image with the possibility to download it.

1.3 Glossary of terms

ACG	Angle Closure Glaucoma
API	Application Programming Interface
CSRF	Cross-Site Request Forgery
DAAD	Deutscher Akademischer Austausch Dienst
DCT	Dynamic contour tonometry
DOM	Document Object Model
ERD	Entity Relationship Diagram
FK	Foreign Key
FOV	Field of View
GNU GPL	General Public Licence GNU
HRT	Heidelberg Retinal Tomograph
HTML	Hypertext Markup Language
HTTP	Hypertext transport protocol
IOP	Intraocular pressure
IS	Information System
ITK	Insight Segmentation and Registration Toolkit
JOGL	Java OpenGL
JRE	Java Runtime Environment
JVM	Java Virtual Machine
LUT	Look Up Table
MRA	Morfield Regression Analysis
NFI	Nerve Fibre Index

OAG	Open Angle Glaucoma
OCT	Optical Coherence Tomography
ONH	Optic Nerve Head
OOP	Object Oriented Programming
OPD	Optical Path Difference
OS	Operating System
PHP	Hypertext Pre-processor
PK	Primary Key
POAG	Primary Open Angle Glaucoma
QPL	Q Public License
RNFL	Retinal Nerve Fiber Layer
ROC	Receiver Operating Characteristic
SAX	Simple API for XML
SESSION	Semi-Permanent Interactive Information Exchange
SGML	Standard Generalized Markup Language
SID	SESSION ID
SSL	Secure Sockets Layer
SSN	Social Securitu Number
TLS	Transport Layer Security
TSNIT	temporal-superior-nasal-inferior-temporal
URI	Uniform Resource Identifier
VTK	Visualization ToolKit
XHTML	Extensible Hypertext Markup Language
XML	Extensible Markup Language
XSS	Cross-Site Scripting
XST	Cross-Site Tracing

2. Conception of Glaucoma diagnosis

As said in introduction, the general conception of eye examination is based on as much information as possible. New methods are continually emerging and the conception is still under development.

2.1 Anamnesis

Anamnesis is the information gained by asking specific questions with the aim of obtaining information useful for diagnosis. It is well known that glaucoma is related to the glaucoma history in family, race, gender, age and to some illnesses.

a) Gender

Women are more affected by glaucoma because of their greater prevalence of ACG, as well as their relatively greater longevity. Since women are estimated to have twice as much visual impairment and blindness overall compared to men [13], more attention should be placed on the delivery of eye care services to women. [12]

b) Human race

People of African, or Afro-Caribbean origin tend to have a greater chance of developing chronic glaucoma. People of Asian origin are more likely to develop acute glaucoma. [11]

c) Age

Other risk factor of glaucoma is age: African-Americans over age 40, Hispanic over the age 65 and everyone over the age 60. [7] Chronic glaucoma becomes much more common with increasing age, but structural abnormalities that impede fluid drainage in the eye may be present at birth, resulting in symptoms by about 5 years of age, which is called primary congenital glaucoma. [6]

d) Family and genes

Mutations in the CYP1B1 and MYOC genes cause early-onset glaucoma. Approximately 10 percent to 33 percent of people with juvenile open-angle glaucoma have mutations in the MYOC gene and between 20 percent and 40 percent of people with primary congenital glaucoma have mutations in the CYP1B1 gene. [6]

e) Illness

To define which illness has an effect relating to the glaucoma is still under study. Research suggests that people with diabetes are more likely to develop glaucoma than those without this condition. [11] There are also discussions about a connection with obesity and glaucoma and Thyroid disease and glaucoma.

2.2 Standard eye examination methods

Standard eye examination methods are currently the first in line for complete eye examination. They are more usual and financially acceptable than advanced imaging techniques described in Chapter 2.3. Because of that, they have great importance in glaucoma diagnostic process.

2.2.1 Tonometry

A tonometer is the instrument used to measure intraocular pressure (IOP). Tonometry is one of the most important eye examination methods, because the loss of nerve fibre layer is mostly caused by high IOP. During the day, the IOP value fluctuates thus it is important to take repeated measurement of it and create daily tonometric curves. Eye hypertension means that the IOP value is more than 21 mmHg, which is only a statistically determined value. Goldmann applanation tonometry is the widely accepted method of determining approximate intraocular pressure. Dynamic contour tonometry (DCT) based on contour matching tries to eliminate systematic errors of applanation tonometry. Transpalpebral Diaton Tonometry measures intraocular pressure through the eyelid. There are also other methods like Pneumatonometry, Rebound tonometry or Eletronic indendantion tonometry.

2.2.2 Ophthalmoscopy

It is used to detect and evaluate symptoms of retinal detachment or eye disease such as glaucoma using magnifying instrument called ophthalmoscope and a light source. There are two types of ophthalmoscopes: direct used for routine examination and indirect, which allows wider view of the eye ground.

2.2.3 Corneal pachymetry

Pachymetry is another essential examination method based on contact-less corneal thickness measurement, which is used especially to detect glaucoma in its early stage. Central corneal thickness may be a risk factor for the development of glaucoma, independent of its effect on IOP measurement. [15]

2.2.4 Gonioscopy

Gonioscopy is a method used for viewing the anterior chamber angle, especially its width and pathologic changes such as pigmentation, pseudoexfoliation and neovascularization. It is also used to distinguish open angle glaucoma from angle closure glaucoma.

2.2.5 Perimetry

The aim of this method is to check the eye for missing areas of vision called scotoma. Paracentral scotomas being in the area 10-20° are usually the first symptoms of glaucoma. Periodic testing can be used to see if treatment for glaucoma is preventing further vision loss. For early diagnosis, colour perimetry is used for blue-yellow frequency area in last few years.

2.2.6 Blood pressure measurement

The result of Rotterdam Study [17] says that systemic blood pressure and hypertension are associated with IOP and high-tension glaucoma and that there is no association found between blood pressure and normal-tension glaucoma.

2.2.7 Psycho-physiologic examination

Investigation of colour mechanisms may allow detection of POAG at an earlier stage than conventional perimetry but standard clinical colour vision tests do not have high enough sensitivity and specificity to act as screening techniques at earlier stages of the glaucoma. [16]

Visual acuity test measures the ability to identify black characters on a white background, mostly using the Snellen chart. This examination can be also used to assess glaucoma presence and progression.

Glaucoma patients exhibit abnormal contrast sensitivity. Testing gauges the ability to see objects in terms of size and contrast. Even if the visual acuity is 6/6 (20/20), the contrast sensitivity can be poor.

2.3 Advanced imaging methods

To these methods, which provide essential information about the optic disc and retinal nerve fiber layer, belong Scanning laser tomography (HRT), Scanning laser polarimetry (GDx) and Low-coherence interferometry (OCT). All are noninvasive and each is based on different physical principles. These methods provide information that should be integrated with other investigation results such as IOP, visual field and other. On their own, they are not diagnostic, because the structural measurement is related to normative data of normal and glaucoma-positive eyes. Because of that, the classification (using e.g. Morfields Regression Analysis) is just statistical and based on probability limits, see [19]. Nevertheless, these methods have great potential based on the detection of glaucomatous progression. A study [18], trying to determinate these imaging methods says:

"Although the area under the ROC curves was similar among the best parameters from each instrument, qualitative assessment of stereo photographs and measurements from the OCT and HRT generally had higher sensitivities than measurements from the GDx.

2.3.1 Heidelberg Retina Tomograph (HRT)

The Heidelberg Retina Tomograph is a confocal laser scanning system used for acquisition of 2D images at equidistant and different depths from within 1-4 mm depth in the retina to reconstruct 3D surface map of the posterior eye segment. Reconstruction is based on a series of 32 to 64 images at intervals of 1/16 mm. The image field is 15°x15° with a density of 384x384 pixels.[27] For each pixel (x,y) in the transversal section, the reflectance intensity is determined as a function of scan depth, z. The depth position of the peak in the axial intensity distribution versus depth is then used to build a topography map. [23]

By collecting a sum of voxels along the depth, coordinate intensity image is created. The intensity value of each pixel on coordinates (x,y) is equal to depth-position of maximal value of voxel on the same coordinate.

The result of topographic analysis is colour coded topographic image, where an ophthalmologist has to define the optic nerve head (ONH) margin using contour line placing in the inner margin of Elschnig's ring. A fundus image is a color photograph of retina, which is usually needed for comparing the ONH margin.

Glaucoma classification is based on reference plane. The reference plane is an imaginary plane parallel to the retinal surface within a topographic image and is defined in HRT operating software. Most of stereometric parameter values (such as rim area and volume) are dependent on the position of this plane. Parameters that are independent of the reference plane include the disk area, height variation contour and cup shape measure.[27] Morfield Regression Analysis (MRA) tries to determine structural damages at the ONH and distinguish between a healthy and glaucomatous eye. Six sectors of the optic disk are automatically defined and classified according to normative database. This classification is based on clinical data availability.

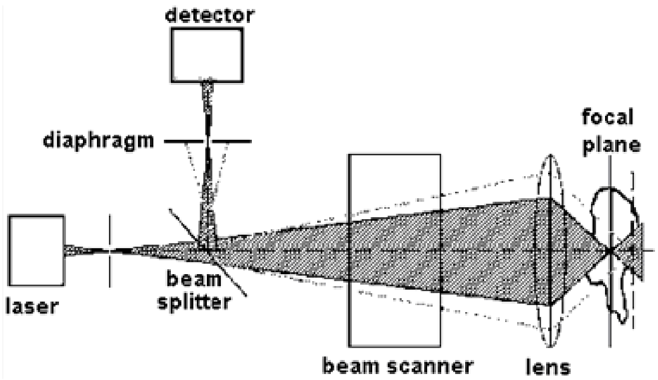


Figure 4: The principle of the work of HRT [22]

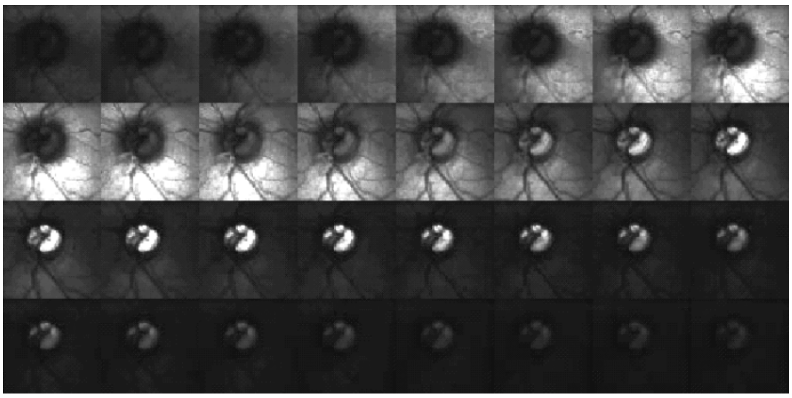


Figure 5: 32 2D images of optic nerve head getting from various focal planes [22]

HRT3 is currently (2008) available, one study [20] of its probability score says:

HRT 3 baseline results were predictive of visual field loss in glaucoma suspects. These findings suggest that objective optic disc assessment with the HRT could potentially assist as a predictive tool for estimating the likelihood of a glaucoma suspect patient developing visual field loss.

2.3.2 Optical coherence tomography (OCT)

A method of higher resolution imaging of the retina is optical coherence tomography. In OCT, the depth exploration is obtained by scanning the optical path difference (OPD) between the object path and reference path in an interferometer illuminated by a low coherence source. A maximum interference signal is obtained for OPD=0. For an OPD larger than the coherence length of the source used, the interference signal diminishes considerably. [23] Using superluminescent diodes (super-bright LEDs: GaAs 800nm) or lasers with extremely short pulses (femtosecond lasers), the depth resolution can be less than 20 µm. A basic OCT system (Huang et al 1991) based on fiber-optic Michelson interferometer, see below (Fig. 6).

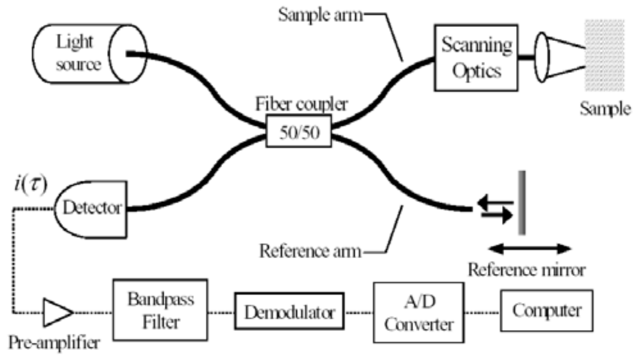


Figure 6: Optical Coherence Tomography system configuration

The beam is split into two arms, one passing to the retina and the other to the reference mirror, which translates back and forth. Reflected light is re-combined at an interferometer. Constructive interference occurs between the back-reflected light pulses from retinal structures and from the reference mirror, only if these light pulses reach the interferometer at the same time (within the coherence length) and only then, a signal and the resulting intensity can be detected. An A-scan is acquired by moving the reference mirror while detecting the interferometric signals and to acquire B-scan (the tomograph), the focused beam is scanned across the retinal location of interest. A-scans are acquired by a rate of 400 per second. Various options for A-scan density are available: up to 512 per B-scan.[24] For glaucoma built-in scan acquisition, protocols called (Fast) RNFL Thickness and (Fast) Optics Disk and scan analysis protocols divided into Quantitave Analysis and Image Processing Protocols are included.

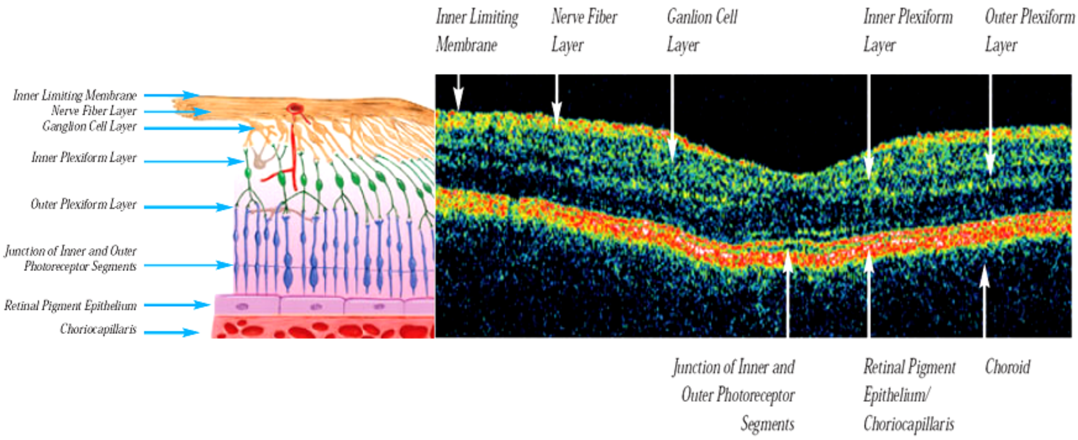


Figure 7: OCT, Carl Zeiss Meditec AG

2.3.3 Nerve fiber analyzer (GDx VCC)

Substantial linear birefringence of RNFL (retinal nerve fiber layer) provides a basis for Scanning laser polarimetry (SLP) to access the RNFL thickness by measuring total retardation in the light reflected from the retina. This retardation is proportional to the RNFL birefringence and the RNFL thickness. The GDx VCC (Carl Zeiss Meditec Inc., Dublin, CA, USA) SLP system is a confocal scanning laser ophthalmoscope integrated with a polarimeter.

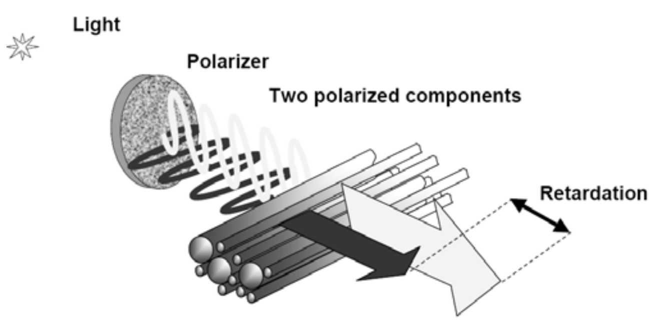


Figure 8: Physical principle used in GDx VCC [27]

Images of the ocular fundus are formed by scanning the beam of a near-infrared laser (780nm) in a raster-pattern. The scan raster covers an image field of 40° horizontally and 20° vertically in the eye, covering both the peripapillary region around the ONH and the macular region around the fovea. The eye is treated as a partial depolarizer and a retarder. A measurement is made with linearly polarized light. Light returned from the eye is usually elliptically polarized and separated into two channels with linear analyzers polarized parallel and perpendicularly to the incident beam. The plane of polarization and the two analyzers rotate to produce a series of images, which is used to compute retardation image. Variable corneal compensator (VCC) is used to neutralize the anterior segment birefringence.

The result of this examination method is fundus image created by monochromatic scanning laser, retardation and deviation map, the TSNIT graph and six parameters related to this graph. The retardation map reflects the phase shift of polarized laser light passing through the RNFL, which is proportional to the thickness. The amount of phase shift is converted to a thickness measure and colour-coded according to the current scale. Yellow, orange and red represent thicker areas; black and blue colours represent thinner areas and the RNFL loss. The deviation map compares the retardation value of super-pixels with corresponding areas in the age- and ancestry-matched database. Each super-pixel represents the average of 16 individual pixels (4x4). Only super-pixel whose value is bellow the 5th percentile is colour-coded: dark-blue for those bellow the 5th percentile, light-blue bellow the 2nd percentile, yellow bellow the 1st and red bellow the 0.5th. The TSNIT (temporal-superior-nasal-inferior-temporal) plots reflect the peripapillary RNFL thicknes along the measurement circle, which is approximately 3.2mm in diameter in an emmetropic eye. Six parameters are constructed from data along the circle and compared with the normative data, where the most important NFI (Nerve Fibre Index) represents the output of a Support Vector Machine that has been trained with hundreds of normal and glaucomatous scans. [24]

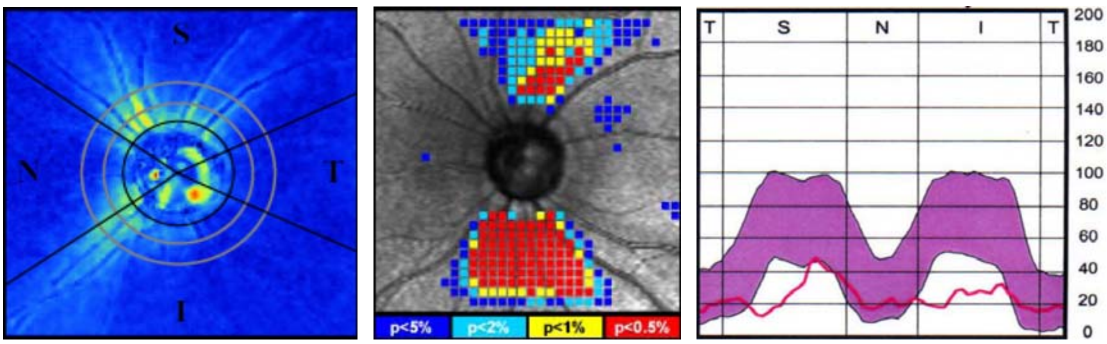


Figure 9: thickness map, deviation map, TSNIT graph [27]

3. Conception of glaucoma internet information system

3.1 IS model

Information system (IS) is a web-based application that is accessed via a web client over a network such as the Internet or an Intranet. It is also a computer software application that is coded in a browser-supported language and reliant on a common web browser to render the application executable. Though many variations are possible, a Web application is commonly structured as a three – tiered application: client – server – database as bellow (Fig. 10).

The client is usually software installed on a user computer, which presents data sending from server as a respond. There are three types of clients – Thin-, Fat- and Hybrid-client. The Thin-client relies on most of the function of the system being in the server. The point of this client is to present data without distributing and installing software on the user computer. Fat-client is the opposite of thin-client. Most of the application logic is implemented inside. Hybrid-client is a combination of both types. The server is a middle tier which services the client's request by making queries and updates against the third tier – database.

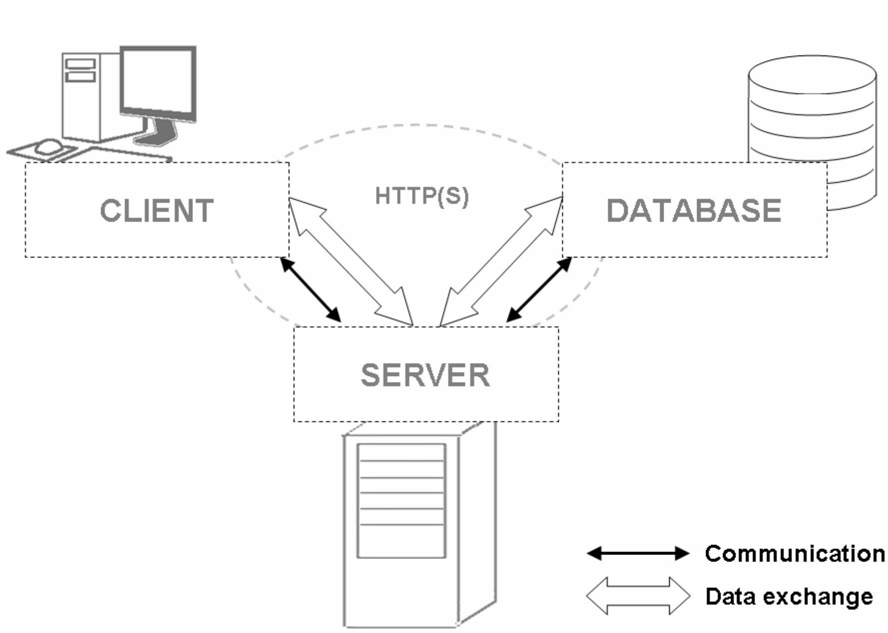


Figure 10: HTTP three-tier model

3.2 Hypertext Transfer Protocol

HTTP is a communication protocol used for data transfer over the Internet using request/response HTTP messages. HTTP contains eight methods: HEAD for retrieving meta–information written in response header, GET method to request a representation of the specified resource; the request is included in the URL address, method POST submits data to be processed to the identified resource; the request is specified in the body of the request and the PUT method uploads a representation of the specified resource. Other methods are: DELETE, TRACE, OPTIONS and CONNECT.

The HTTP is a stateless protocol but the possibility of permanent information exchange between client and server is needed for IS. This problem is solved by using SESSION (semi-permanent interactive information exchange) variables. The most efficient and without security risk is using HTTP session token. This is a unique identifier generated by a Hash function and sent from server to a client to identify the current interaction session. The client usually stores and sends the token as a HTTP cookie, which expects that that user has allowed his client browser to use cookies. Otherwise, it is possible to send this token as a parameter in GET or POST queries. Other possibilities are using server side or client side sessions.

To encrypt the communication between client and server is a necessity for security reasons. The common dominant method of how to establish secure HTTP connection is using the HTTPS URI scheme. It signals to the browser to use an added encryption layer of SSL/TLS to protect the traffic over Internet. Transport Layer Security and its predecessor Secure Socket Layer are cryptographic protocols that provide communication on the Internet and can provide protection even if only one side of the communication is authenticated. In case of IS, the server is authenticated by the client examining the server's security certificate.

3.3 Internet technologies

This part gives a brief summary of Internet technologies used in this project. Description of all features is not the aim of this project.

Apache

Apache HTTP server is a web server available for a wide variety of OS developed by an open community Apache Software Foundation. It supports a variety of compiled modules like MOD_ACCESS, MOD_AUTH, and MOD_SSL for authentication and other extensions.

PHP

Hypertext Pre-processor is a server-side scripting language based on OOP (since PHPv5). It is designed for producing dynamic web pages to client. PHP can be deployed on most web servers and OS. It provides many useful extensions like PHP_ZIP, PHP_BCOMPILER, PHP_GD2, and PHP_MYSQL.

MySQL

MySQL is a cross-platform relational database management system with more than 11 million installations [2]. The program runs as a server providing multi-user access to a number of databases. There are non-commercial tools for administration available such as phpMyAdmin implemented in PHP.

HTML

Hypertext Markup Language is a predominant markup language used for web pages. Each web page has to contain a declaration tag <!DOCTYPE> at the beginning that specifies which HTML or XHTML will browser use. While HTML is an application of SGML - a very flexible markup language, XHTML is an application of XML, a more restrictive subset of SGML. HTML 4.01 document specifications can be Strict, Transitional or Frameset.

Java

Java is a programming language originally developed by Sun Microsystems. Java application is compiled to a byte code that can run on any JVM regardless of computer architecture. JRE is the software required to run any Java application. Sun distributes JRE for end-users in software package and a web browser plug-in, which is in web browsers usually not included by default.

Java applet is a program embedded in a web page. Its code is downloaded from a web server and result is displayed in a web browser. In general, applets loaded over the Internet are considered untrustworthy and prevented from reading and writing files on client file system and from making connections except to the originating host server. The security measure is called sandbox and relies on a three-tiered defence: byte code verifier, applet class loader and security manager.

Web based medical image processing

Java applet allows the opportunity to process medical images online and to present the result in World Wide Web to end-users.

a) Java3D

Low level 3D scene-graph based graphics programming API for java language. It provides routines for creating 3D geometries in a scene-graph structure that is independent of the underlying hardware implementation for real-time programming. The class libraries exist under the javax.media.j3d top level package as well as utility classes provided in javax.vecmath.

b) ImageJ

ImageJ is a public domain Java image processing program, which was designed with an open architecture that provides extensibility via Java plug-ins. User-written plug-ins make it possible to solve a lot of image processing or analysis problems. The source code is freely available, licensed under GNU General Public License (GPL), GNU Library or Lesser General Public License.

c) Java + VTK / ITK

The Visualization ToolKit (VTK) is an extensible object-oriented toolkit that implements a rich set of visualization classes and data structures for 3D graphics, image processing and visualization. The source code is freely available. VTK consists of C++ class libraries and several interpreted interface layers including Tcl/Tk, Java, and Python. CMake is software for generating native makefiles and workspaces that can be used in the compiler environment of Java.

d) JOGL

Java OpenGL is a wrapper developed by Game Technology Group at Sun Microsystems. It provides full access to the APIs in the OpenGL 2.0 specification. There are projects to build scene graphs over the top of the various Java OpenGL bindings, e.g. Aviatrix3D, jME, Xith3D, etc.

e) Bump mapping

Bump mapping is texture technique, which creates illusion of surface roughness without changing geometry. This illusion is made by changing the normal line in each pixel of the surface depending on a light location and intensity. Information about the roughness of object is stored in height map, which is a greyscale image.

JavaScript

JavaScript is a scripting language most often implemented for client-side web development. The primary use of JavaScript is to write functions that are included from HTML pages and can interact with the DOM of the web page, which means quick respond to user actions on a web page. It is useful e.g. for form input validation, opening a popup window with an alert and so on.

XML

XML is classified as an extensible language, which allows the user to define his own elements. Because of this ability it facilitates to share data across different IS, which is used particularly via the Internet. XML supports the direct use of almost any Unicode character, which means almost any information in any human language. Raw data is rendered by most web browsers. For XML processing three traditional techniques are used: SAX API, DOM API and a transformation engine with a filter. DOM is supported in Java in packages org.v3c.dom.

3.4 Types of security attack

This Chapter gives just a brief summary of different types of security attacks [4].

a) Cross-site scripting (XSS) – JavaScript code injection into some webpage to bypass access controls such as the same origin policy
b) Cross-zone scripting - the attack allows content (scripts) in unprivileged zones to be executed with the permissions of a privileged zone
c) Session hijacking – attacker uses a packet sniffing to read network traffic to steal the session cookie
d) Session fixation - attacker attempts to exploit the vulnerability of a system, which allows one person to fixate another person's session identifier (SID)
e) Session poisoning – attack caused by insufficient input validation in server applications which copies user input into session variables
f) Replay attack – a type of network attack where valid data transmission is fraudulently repeated or delayed

g) Reflection attack – when the same challenge-response protocol is used by each side to authenticate the other side, idea of the attack is to trick the target into providing the answer to its own challenge
h) SQL injection - when the PHP input is either not filtered for string literal escape characters embedded in SQL statements or is not strongly typed and thereby unexpectedly executed
i) E-mail injection – attacker may through a web form exploit the MIME format to append additional information (Headers) to the message being sent as email
j) HTTP response splitting – this attack consists of making the server print a carriage return line feed sequence followed by content supplied by the attacker in the header section of its response
k) REFERER spoofing – attacker sends incorrect REFERER information with an HTTP request
l) Cross-site request forgery (CSRF) - works by including a link or script in a page that accesses a site to which the user is known to have authenticated
m) Cross-site cooking - a type of browser exploit which allows a site attacker to set a cookie for a browser into the cookie domain of another site server
n) Cross-site tracing (XST) - XST scripts exploit ActiveX, Flash, Java or any other controls that allow executing an HTTP TRACE request, which can get all the HTTP headers with authentication data and cookies
o) Brute-force attack - trying a large number of possibilities
p) Dictionary attack – this attack tries possibilities which are most likely to succeed, typically derived from a list of words in a dictionary

4. Server configuration

4.1 SSL certificate for HTTP

Step 1: Creating a server key with 1024 bits encryption

```
openssl genrsa -des3 -out server.key 1024
```

Step 2: Removing the pass phrase from the RSA private key (copy to the `server.key.org` at first)

```
openssl rsa -in server.key.org -out server.key
```

Step 3: Creating a self-signed Certificate (X 509 structures) with the RSA key

```
openssl req -new -x509 -nodes -sha1 -days [int] -key server.key -out
server.crt -config apache_folder\conf\openssl.cnf
```

4.2 Certificate for java applet

Step 1: Create a key store and a certificate

```
keytool -genkey -alias [alias] –keypass [password required to access
the public-private key pair] –keystore [path/name] –storepass
[password required to access the keystore] –validity [number of days
before certificate expiration]
```

Extra parameters:

`-storetype`: format of the keystore (`JKS` by default, which is a proprietary keystore format of Sun Microsystems)
`-keysize`: size of the public and private key (`1024` bits by default)
`-keyalg`: algorithm used to generate the public-private key pair (`DSA` by default)
`-sigalg`: algorithm used to sign certificate (`SHA1withDSA` by default)

Result:

```
Keystore type: JKS
Keystore provider: SUN
Your keystore contains 1 entry

Alias name: ophtalmo
Creation date: 9.7.2008
```

```
Entry type: PrivateKeyEntry
Certificate chain length: 1
Certificate [1]:
Owner: CN=DBME, OU=Department of Biomedical Engineering, O=Brno University of Technology, L=Brno, ST=Czech Republic, C=CZ
Issuer: CN=DBME, OU=Department of Biomedical Engineering, O=Brno University of Technology, L=Brno, ST=Czech Republic, C=CZ
Serial number: 4874d2eb
Valid from: Wed Jul 09 17:02:03 CEST 2008 until: Sat Jul 07 17:02:03 CEST 2018
Certificate fingerprints:
MD5:  97:DA:0E:93:03:CE:6A:B9:07:6A:6E:F0:CF:32:84:DE
SHA1: 7:6A:3D:24:F3:F0:87:74:87:E4:41:4E:72:9E:4B:2D:69:F1:1C:75
Signature algorithm name: SHA1withDSA
Version: 3
```

Step 2: Sign an applet

```
jarsigner.exe –keystore [path/name of keystore] - storepass [password required to access the keystore] –keypass [password required to access the public-private key pair] "[path to jarfile]" [alias]
```

Step 3: Export the certificate to file

a) Binary format

```
keytool –keystore [path/name of keystore] –storepass [password required to access the keystore] -alias [alias] –export -file [path/name.cer]
```

b) Text format

```
keytool –keystore [path/name of keystore] –storepass [password required to access the keystore] -alias [alias] –export –rfc -file [path/name.cer]
```

4.3 Configuration files

httpd.conf

LoadModule ssl_module modules/mod_ssl.so

```
Include conf/extra/httpd_ssl.conf
LoadModule rewrite_module modules/mod_rewrite.so
```

Enables HTTPS and redirecting HTTP to HTTPS:

```
<Directory>
RewriteEngine On
```

```
RewriteCond %{HTTPS} on
RewriteCond %{REQUEST_URI} !^/Erlangen.*
RewriteRule .* - [F,L]

RewriteCond %{HTTPS} off
RewriteCond %{REQUEST_URI} ^/Erlangen.*
RewriteRule (.*) https://%{HTTP_HOST}%{REQUEST_URI} [L]
</Directory>
```

httpd_ssl.conf

Configuration file, where it is necessary to locate already created `SSLCertificateFile`, `SSLCertificateKeyFile` and all necessary `log files` such as PHP error log, Apache error log, …

php.ini

Most of the settings and extensions are set by default after easy installation of some web-triad package, which includes Apache, PHP and MySQL, e.g. WAMP or XAMP.

Enables using SSL:
`extension=php_openssl.dll`

Enables ZIP archiving:
`extension=php_zip.dll`

Enables byte code compiling:
`extension=php_bcompiler.dll`

Sets the maximum execution time of each script:
`max_execution_time = 180`

Turns off all error reporting to client:
`error_reporting = 0`

Enables session encoding using hash function 1: SHA-1 (160 bits)
`session.hash_function = 1`

4.4 Additional extensions

Even if PHP5 offers a lot of useful functions and extensions by default, to solve e.g. image format conversion from TIFF to another one, to generate different kinds of graph or to detect and automatically install latest version of JRE, is not possible to use it at this moment. In such a case, it is necessary to use additional web extension tools like ImageMagick, JpGraph, deployJava etc.

ImageMagick

ImageMagick is a software suite to create, edit, and compose bitmap images. Its functionality is utilized from the command line or from programs written in programming language with an interface such as MagicWand for PHP, IMagick, JMagick, Magic++, etc. Its license is compatible with GPL.

JpGraph

JpGraph is an Object Oriented PHP5 Graph Plotting library. The library is Copyright (C) 2000-2007 Aditus Consulting, released under dual license QPL 1.0 for open source and educational use and JpGraph Professional License for commercial use.

Thickbox and jQuery

ThickBox is a webpage UI dialog widget used for images display and slideshows. It is written in JavaScript on top of the jQuery library, which performs Ajax interactions on web pages. jQuery library is available for use under both MIT and GPL licenses.

JRE detection

As explained in Chapter 3.3.5, to init and start java applet in client web browser, JRE is needed. To detect the presence of the JRE or install the latest one is possible to use a JavaScript function called deployJava.js distributed by Sun Microsystems, Inc.

5. Database structure

Database structure is represented by the ERD model (Fig. 11), which is an abstract conceptual representation of database structure. There are nine entities (tables) in the model of glaucoma database. An entity is an object which is distinguishable from other objects and is represented by a set of attributes (columns). Between entities can be an association called relationship. The types of relationships between the two entities are called identifying, non-identifying, self-identifying or m-ways identifying. The relationship between the two entities defines cardinality, which can be M: N, 1: N, N: 1 or 1:1. The primary key (PK) is a candidate key, which uniquely identifies each row in a table. The foreign key (FK) identifies a column(s) in the referencing table that refers to a column(s) in the referenced table. For the attribute candidate key integer type with auto incremented value is usually used.

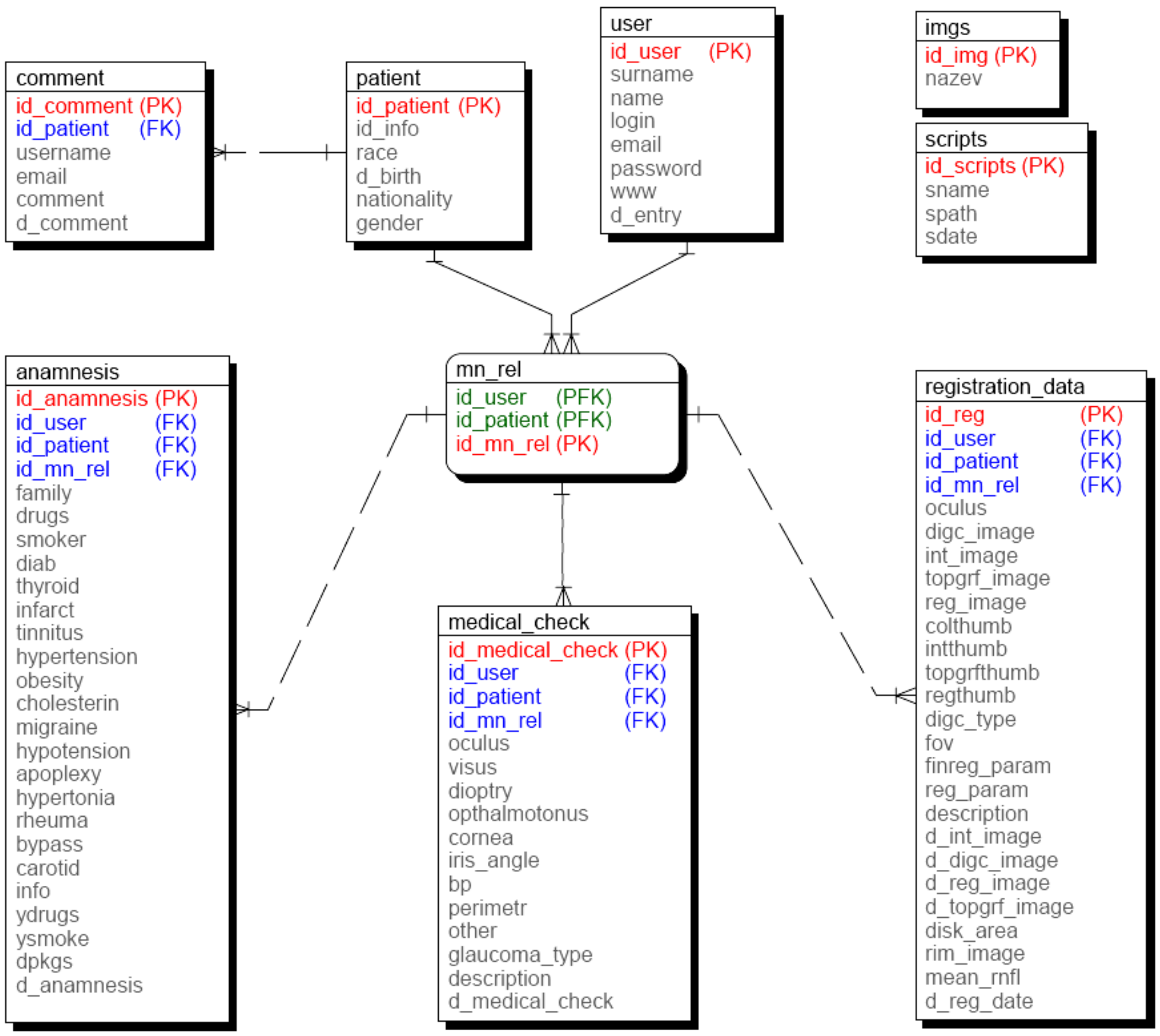


Figure 11: ERD created using Toad Data modeller.

Entity USER

The entity called USER is a table with user personal and login data. The attribute PASSWORD contains the SHA-1 hash code of the user password. The user's last login date is stored into attribute D_ENTRY. Value of attribute called EMAIL has to be unique and is validated by new user registration process.

Entity PATIENT

The entity PATIENT contains patient's basic data and a unique identification. Included in the basic data are race, gender, date of birth and nationality. (Chapter 2.1) The attribute ID_INFO is the unique SHA-1 hash code generated from the patient's name, surname and unique number.

Entity MN_REL

This entity represents the connection between patients and users through M: N cardinality. One user (doctor) can take care of more patients but also one patient can be cared for by more than one doctor. M: N value is used to determine user's right to edit and delete selected patient's protocol.

Entity ANAMNESIS

The anamnesis data contains information about factors, which can lead to glaucoma, such as glaucoma history in family, etc. and these are stored in this entity. (Chapter 2.1)

Entity MEDICAL_CHECK

Investigation results such as IOP, blood pressure, description of perimeter examination, etc. (Chapter 2.2.) are stored in entity MEDICAL_CHECK. The user can also select one of the glaucoma types and append some additional information.

Entity REGISTRATION_DATA

The image data specified for the left or right eye are stored in this entity. The fundus image and the intensity image can be registered and saved on the server to the path specified in the attribute REG_IMAGE. Registration parameters are saved into binary attributes called REG_PARAM and FIN_REG_PARAM. If a topographic image has also been uploaded, the user is allowed to display volumetric visualization in applets. Each image is dated and after successfully uploading to the server, a thumbnail is created. All images are saved in their binary form on the server to a specified location, which is represented by the value of each image attribute. Attributes FOV (field of view) and DIGC_TYPE (type of digital Fundus camera) specify the parameters used for image registration. Attributes RIM_AREA, DISK_AREA and MEAN_RNFL specify values measured by HRT.

Entity COMMENT

Each registered user is allowed to comment on each patient. The attributes username and email are used for the identifying user, who has commented.

Entities SCRIPT and IMGS

The path to the application for image registration is saved into the entity called SCRIPT. From the table called IMGS are randomly generated images used as an anti-spam control in the new user registration process. These entities are not related to the patient or user.

6. User account processing

6.1 New user registration

To register the new user it is necessary to go through spam control, which is based on image random generating. The user needs to select the right description to the generated image. There is also the possibility to generate a combination of number and alphabet characters (ImageMagick) to create images with an additional noise. This solution is not ideal, because of some web robots, which are able to read this number code also in case, when a real user is not. Email has to be in the format as below (using a regular expression).

```
"/^[A-z0-9\._-]+" . "@". "[A-z0-9][A-z0-9-]*". "(\.[A-z0-9_-]+)*".
"\.([A-z]{2,6})$/"
```

This validity-process is client independent, because it is solved on a server side. It is also possible to check user input on client side using JavaScript, which is unreliable in case that user denies using it.

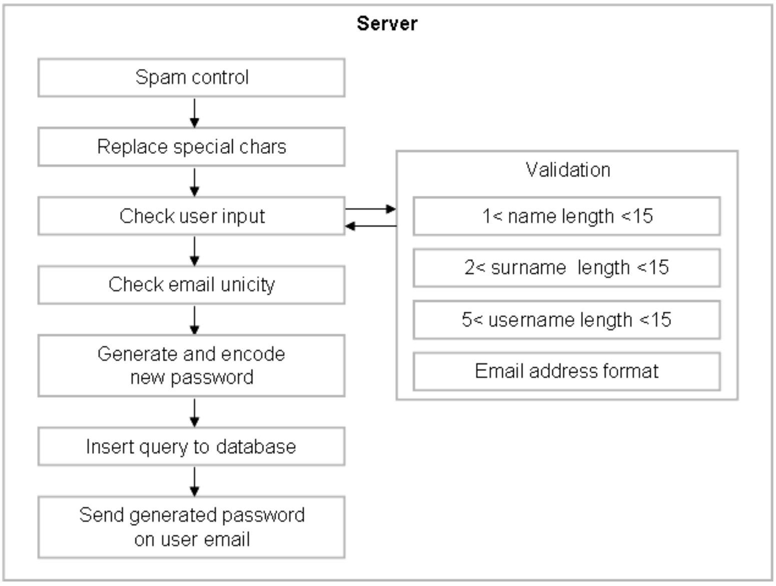


Figure 12: New user registration

6.2 User login

Login is based on check up on user account. If the combination of username and password is correct, the timer is set to 900s and the user is redirected to his account. The date of user's last login to the system is updated.

6.3 Send new password

In the case of the user forgetting his password, he can ask for new one. To generate a new password the user must know his username and email, which are required by his new registration too. Username length and email format are validated. If the formats of both inputs are correct, the server checks this combination in the database. After that, the server will generate and encode a new password and send it in an email to the user.

6.4 Timer and Logout

The timer is based on the time of the user's activity and is included in each web page except pages using the Thickbox extension. It is usually to set the maximum time to 15 minutes (900s). After the expiration, sessions are unset and destroyed and the user is redirected to the main page. A similar process is used when the user logs out manually.

6.5 Change user password

To change the user password, it is necessary to know the old one and the username. This combination is checked in the database. The process will continue to a validation of a new password. The length of the new password has to be at least 8 characters with the following format (using a regular expression): [A-z] + [0-9] + [A-z]. Numbers must be between the alphabet characters. The user must retype password in the control field and both passwords must correspond. After that, is the new updated password and it is then sent to the user email.

6.6 Change user personal data

User personal data is data given by the registration of the new user such as name, surname, email and user web address. There is the same type of user-input validation like in Chapter 6.1.

6.7 Add new patient

The main model of internet communication between the client-side application (java applet) and the server (PHP scripts) by adding a new patient is below (Fig. 13). Communication is based on an SSL encryption. Patient personal data is not sent through the internet, but are encoded by using the unidirectional hash function SHA1 on the client machine, which will create the patient's unique identification. The hash function takes the original string of any length and creates the output fixed length string. The output of SHA1 is 40 characters.

The request message containing this identification is then sent to the server. The server response message is created after checking the identification's uniqueness. In case that this patient has been created before, the server responds with the message "exists". User can decide either to continue to this patient's account or not. If the patient is not found, server stores this unique identification in a SESSION variable (see chapter 3.2) and responds with the message "success". The user will be automatically redirected to the next step called "Add basic data".

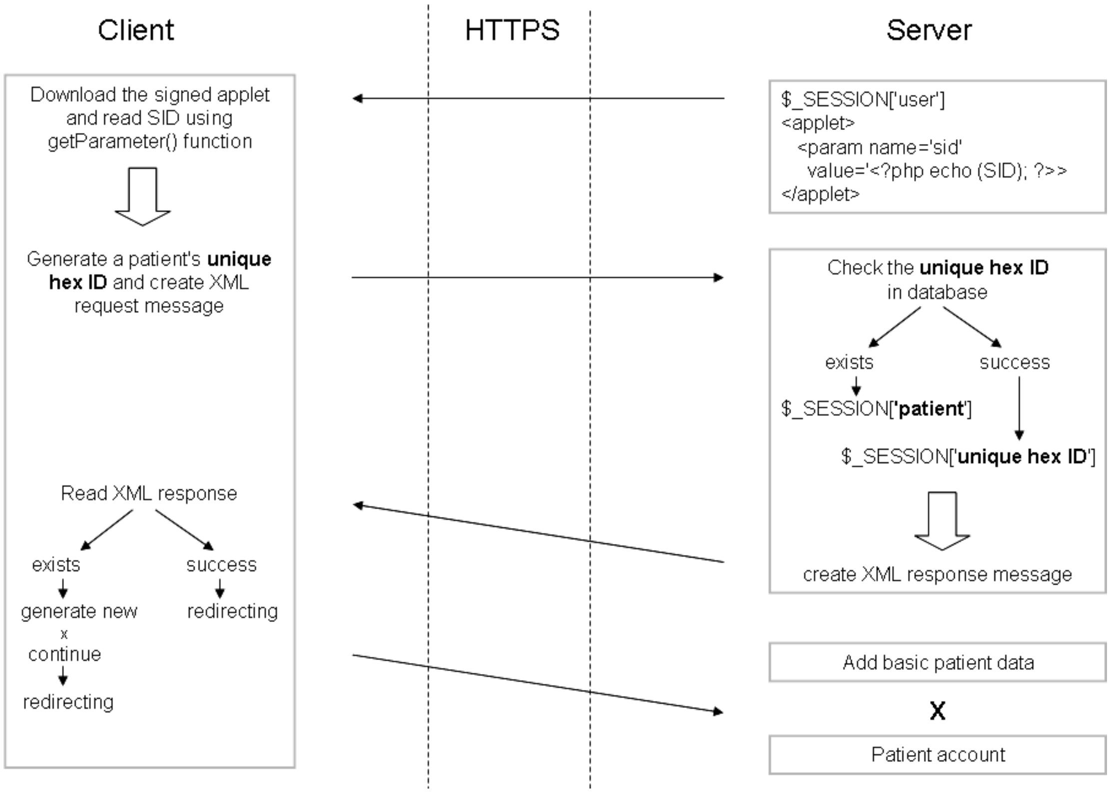


Figure 13: Add new patient

Step 1: Create encoded patient identification:

The first thing to do is to check the input and replace all special characters (see below) and spaces from the user inputs. Because SHA-1 is case sensitive, it is also necessary to convert the string to lower case. To encode this modified string using a hash SHA-1, which is an instance of MessageDigest class, it is necessary to convert this string into raw byte data first. To present final byte code it is converted to hex string.

Special characters and numbers to remove from patient's name and surname:

```
"[()\"0123456789!#$%&'*+,./:;<=>?@^_`{|}~€,„…†‡‰‹ ‛′‟″•––
™›˘˘Ł¤Ą¦§¨©Ş«¬-®°±˛ł´µ¶·¸ąş»˝Đ÷]"
```

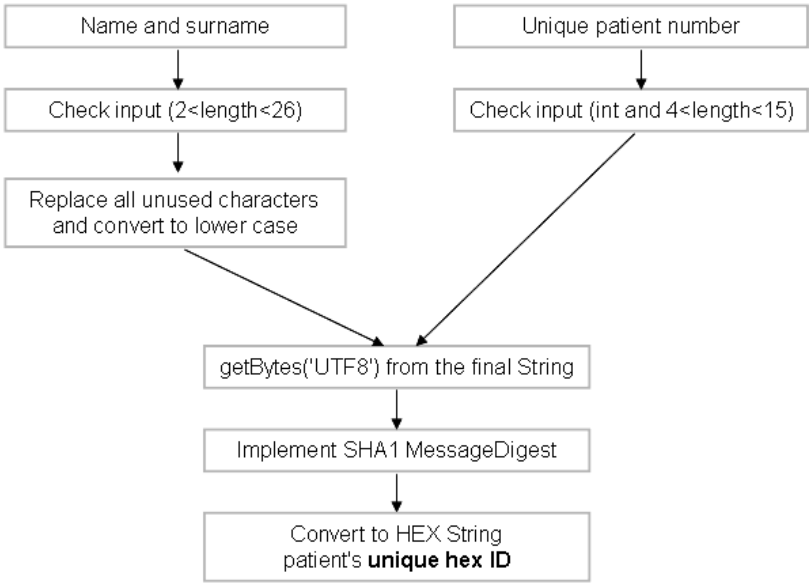


Figure 14: Encode the patient's personal data

Examples of using SHA-1 digest to encode given strings:

```
In:  Roman Peter; 12345
Out: FDFADEE1 3ED1E1A2 D35A8F42 BF9FC474 07602EA8

In:  Roman Peter; 123456
Out: 2CE1D46C 9D0EB84E 4B348523 B3916656 0635BB80
```

Step 2: Client request to server

The request message is based on XML format and is sent to the server using HTTP POST method using a DataOutputStream object. After that, the output stream is flushed and the server reads the response using a DataInputStream object (Fig. 15).

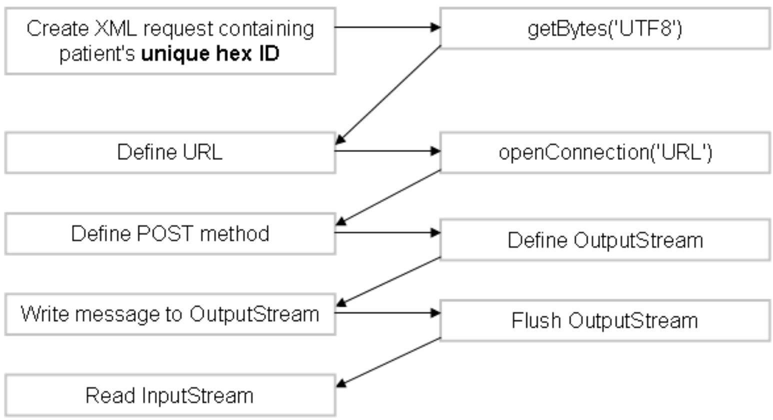


Figure 15: Client request to the server

Step 3: Create server XML response message

The presence of patient's unique identification is checked after the server receives a XML request message from the applet. The XML response message is generated and sent to the output (Fig. 16).

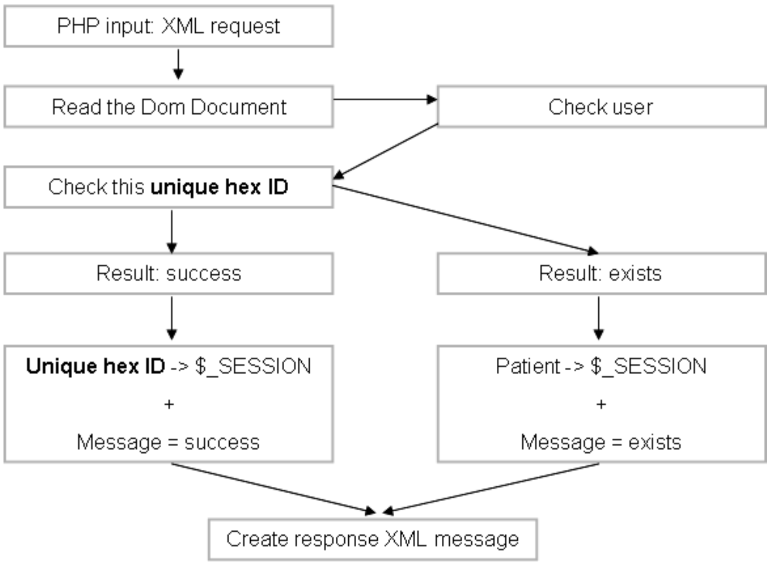


Figure 16: Create the XML response message

Step 4: Read XML response message

The DOM specifies a NodeList interface to handle ordered lists of Nodes, such as the children of a Node, or the elements returned by the getElementsByTagName method of the Element interface.

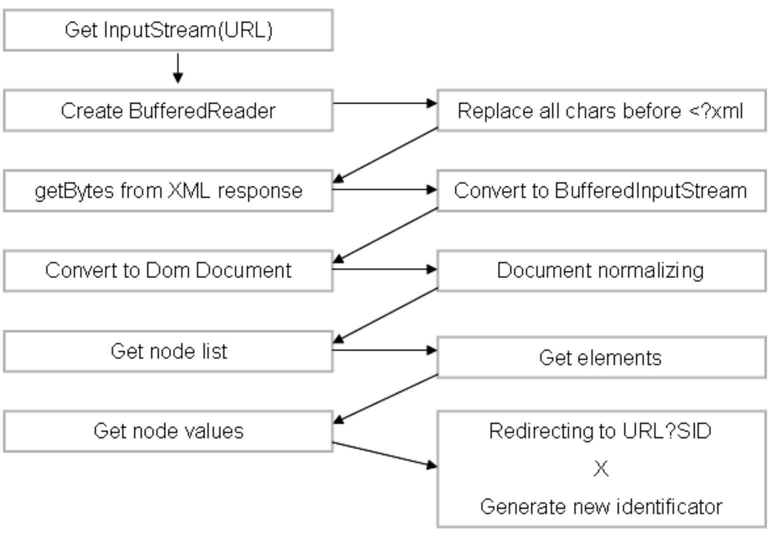


Figure 17: Read the XML response

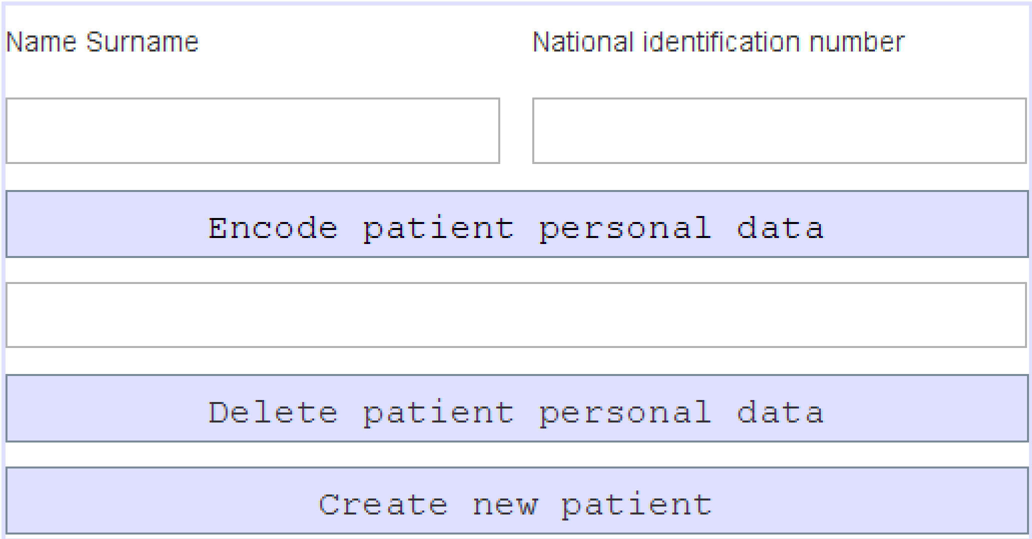


Figure 18: Java applet to create new patient

Step 5: Basic patient data

At this point, any information about the patient is still saved in the database although the unique identification string is generated. Basic data is the first concrete information about patient, which will be presented to all users. There are selectable input fields like gender, race, nationality and the patient's date of birth in this web form.

By limiting the criteria to such traits as skin pigmentation, colour and form of hair, shape of head, stature, and form of nose, there is an existence of three relatively distinct race groups: the Mongoloid, the Negroid, the Caucasoid [5] and three most usually mixed-race forms: Mestizo (European and Native American), Mulatto (European and African) and Zambo (Native American, European and African). Nationality input field is designed using ISO 3166-1-alpha-2 standard. User can not continue with future date of birth. All inputs are required in this form.

6.8 Find patient

The main page of this procedure contains two parts. To find a concrete patient using a java applet, the user has to know his personal data. To use this applet only the registered user is allowed. The second possibility to find the patient is using a special filter.

a) By known patient personal data

This process is very similar to the model of adding a new patient. User has to know name, surname and unique number (e.g. SSN, DNI, National Number, Uniform

Civil Number, SIN, RUT, SOTU, PKZ, HKID, PAN, PPS No, PESEL, CNP, ISS, NRIC, Birth Number, DNI, NINO, …) of the concrete patient. If the patient exists, applet will automatically redirect user to the patient account. Otherwise, applet offers to create this patient by redirecting to 'Add new patient' form, vs. Chapter 6.7.

b) Using a filter

Another possibility to find a patient is by using a filter. This filter creates complicated queries based on data from four entities: PATIENT, ANAMNESIS, MEDICAL_CHECK and MN_REL so the user can find patient by gender, race, age interval, by the type of glaucoma, by selecting one or more of the patient's illnesses, operations or simply using an identification number of the patient. All these parameters are possible to combine. User can also choose to display only his patients (based on M: N relation). User can display maximally ten results on a page, which is based on the limit in query. Values of this limit are changed by browsing, so the response of the database contains always the maximum of 10 patients. See sample of filter diagram below (Fig. 19).

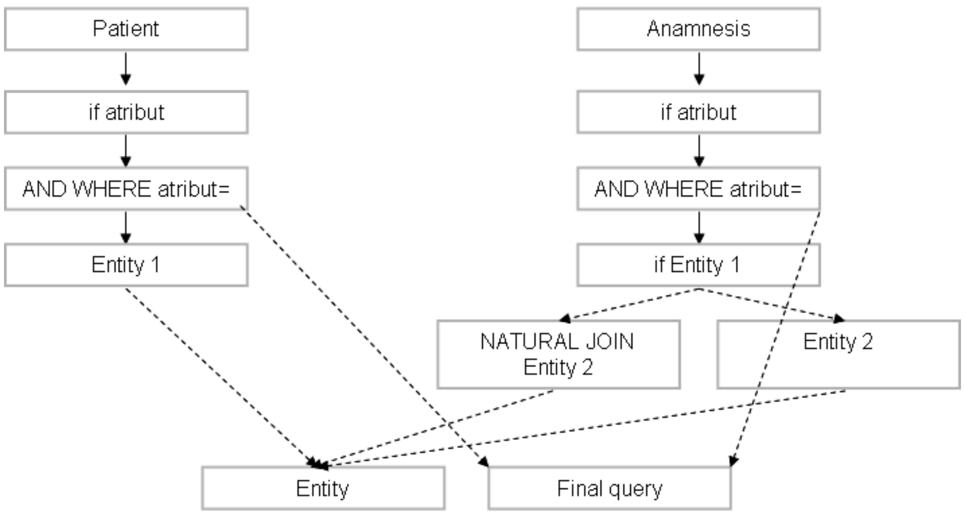


Figure 19: Query to find the patient using filter

7. Patient account processing

The patient's account is composed of six sections. Anamnesis, Investigation results and Image data are related to the examination process. A time line is used for displaying selected parameters in a line graph. Registered fundus images are arranged in order of date. A section called Comments is for the registered user to express his view on a diagnosis.

7.1 Doctor – patient relation

There are four mechanisms for manipulating patient's data (protocols) based on existence of M: N relation, image below:

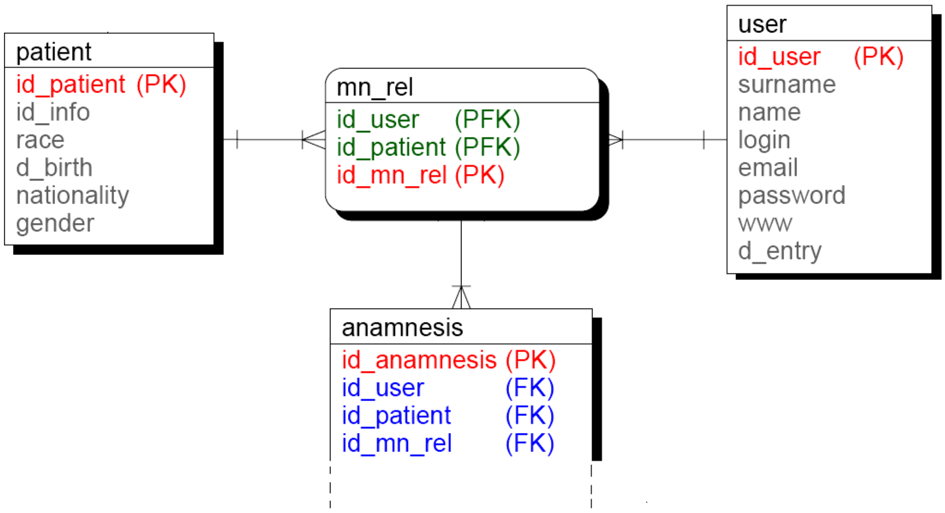


Figure 20: The doctor-patient relation

- To view patient's data is allowed by everyone i.e. an unregistered user (guest).

- To add new data to a concrete patient is allowed only by the registered user after successfully logging in. If there is no M: N relation between patient and the doctor, who wants to add new data to this patient account, the relation will be created.

- To update / edit patient data is allowed only by the doctor, who has created this concrete protocol, not anybody else.

- To delete patient data is allowed only the doctor, who has created this concrete data.

7.2 Anamnesis

This section of patient account is based on anamnesis data obtained during an eye examination (vs. chapter 2.1). It is possible to create new anamnesis protocol and edit or delete current protocol depending on the M: N relation. To display, edit or delete concrete protocol, user has to select it first from the list and then press the button called SELECT. User can use the possibility to display only own protocols with the button called ONLY MINE. After that, the server will check if this selected protocol is editable with the current user. To delete whole anamnesis protocol the user confirmation is needed.

7.3 Investigation results

To create new investigation results and edit or delete current protocol depending on M: N relation the user has to go to this section. To display, edit or delete concrete protocol, user has to select it and press the button called SELECT at first. To display only own protocols there is a button called ONLY MINE. After that, the server will check if this selected protocol is editable with the current user. User can store data such as intraocular pressure value, blood pressure, iris angle, cornea thickness, dioptre value and visual acuity. There is also text field to describe the perimeter investigation result, a field where the user can select the type of glaucoma, a field for the user's expert opinion about the diagnosis and a field for additional information. An intraocular pressure value is required. All numeric values and text are validated. For more details about standard eye examination methods see Chapter 2.2.

7.4 Image data

Image data is represented by images acquired using a digital fundus camera and Heidelberg Retinal Tomograph (Chapter 2.3.1). User can create new protocols and edit or delete own protocols in this section. The right to edit and delete protocols is based on M: N relation.

In the section called "New image data" the user can upload all images (fundus, intensity and topographic). The user is allowed to create a registered image only if the fundus and the intensity images have been already uploaded. To display java applets for the 3D visualization to identify an optic nerve head border, the registered image has to be created and the topographic image stored at the server. The 3D visualization is available in all Image data subsections. To edit an image, user has to delete the actual one before. The protocol is removed completely, if the user deletes last image from this protocol. After that, the server checks if there is any other relation between current user and this patient and if it is not, the server removes this relation. To remove the whole protocol by its owner a confirmation is needed.

7.4.1 Image upload

Image data is sent to the web server using an upload form, where the input field is managed using a global variable FILES. There are three types of images, which the user can store to the server: a fundus, intensity and a topographic image. (See Chapter 2.3.1 - HRT) Size of each uploaded image should be between 100KB and max. 3MB. User can upload image in format PNG (Portable network Graphics), JPEG, BMP (Windows Bitmap) or TIFF (Tag Image File Format – not presentable using standard web browsers). To upload image, the user has to select eye (dexter or sinister), locate the image, and select a date of acquisition. To upload the fundus image the user has to select the digital fundus camera and the field of view, which is than used for the image registration settings.

7.4.2 Image format conversion

All images in formats JPEG, BMP and TIFF are converted to PNG format with 100% quality using ImageMagick software and a server command line.

7.4.3 Thumbnails

A thumbnail is a small representation of each uploaded image and is presented as a preview for the user. Each thumbnail image is resized using ImageMagick software and the server command line to 100px width and calculated height and then saved to a special folder on the server.

7.4.4 Image registration

The image registration is defined as a searching for the best geometric transform, which describes the relationship between the reference image and the registered image. The used affine transform T is supposed to depend on a vector parameter α, encompassing shift, rotation, scale and skew. The parameter is found by optimization:

$$\alpha_0 = \arg\{\min_{\alpha} C(R, T_{\alpha}(F))\}$$

R is the reference image and F is the floating image to be registered, which is transformed by $T_{(\alpha)}$ to coordinates of the reference image. The registration quality, corresponding to the transform T, is evaluated by the criterion function C. $T_{\alpha 0}$ is then the optimal registering transform with respect to the criterion. [28] Image registration is necessary, when the data has been obtained from different measurements, in this case the HRT and the Digital Fundus camera. (Fig. 21)

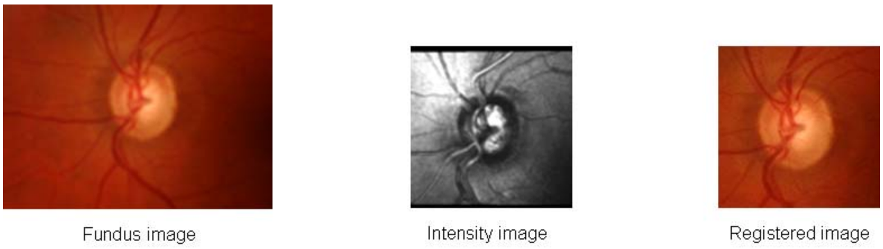


Figure 21: Input and output images of the image registration

To register the fundus image and the HRT intensity image algorithm is used, which was created in the Department of Biomedical Engineering, Brno University of Technology by Ing. Libor Kubečka, Ph.D. The registration process is executed using PHP and the server command line and is available only if the fundus and the intensity images have been already uploaded. Registration parameters are stored in text files, archived and stored in the database. Process on figure 22:

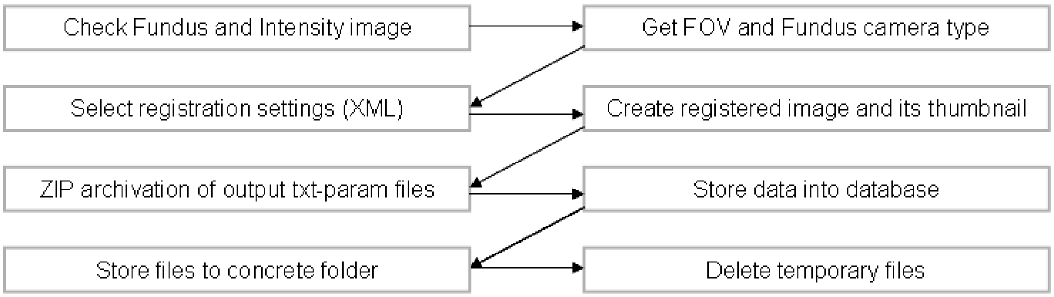


Figure 22: The registration procedure

7.4.5 Visualization

Visualization is available only when the registered and the topographic images are stored in the server. Java bump mapping algorithm (Jawed Karim) and Interactive 3D surface plot plug-in for ImageJ (Prof. Dr.-Ing. Kai Uwe Barthel) are used in this project. Both algorithms are modified and converted to an applet to display the result for end-users in their web browsers. JRE installed on client PC is required for this reason. Both applets are digitally signed.

a) Bump mapping

The height map is represented by greyscale topographic image, the texture by a registered image. By changing the normal line in each pixel of a surface depending on a light location and intensity, the surface roughness is presented. (Chapter 3.3.6) See result below (Fig. 23).

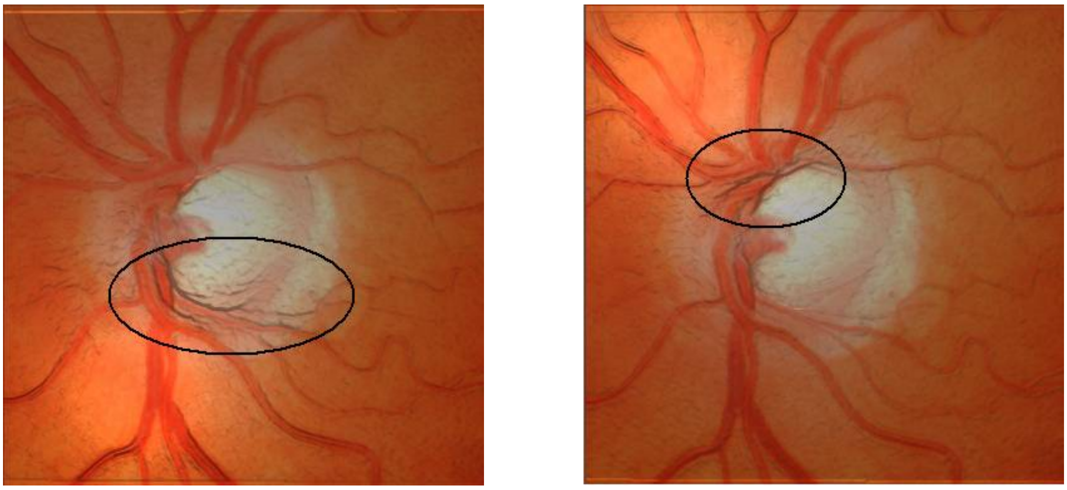


Figure 23: The result of Bump mapping

b) ImageJ surface plot

The registered and the topographic images are loaded from server to the ImagePlus object using the getParameter function. The topographic greyscale image is a height map, used to compute the Z coordinate of each pixel in the image, where the black one represents the minimum and the white one maximum. The texture is represented by registered image.

JRenderer3D class is used to set volume and surface parameters. Parameter such as grid size = 384x384, inversion = true, plot LUT = ORIGINAL and plot mode = FILLED are set by default. User is allowed to modify interactively smooth, light and scaling values. See results (Fig. 24) bellow.

Some of JRenderer3D methods:

Sets the surface grid size (sampling rate)

```
setSurfacePlotGridSize(int, int)
```

Set one image for a surface plot

```
setSurfacePlot(ImagePlus())
```

Sets the surface plot mode
`setSurfacePlotMode(MESH/FILLED/ISOLINIES/LINES/DOTS/DOTSNOLIGHT)`

Sets the rotation on x-, y- and z-axis
`setTransformRotationXYZ(int x, int y, int z)`

Applies a smoothing to the surface plot data
`setSurfaceSmoothingFactor(float)`

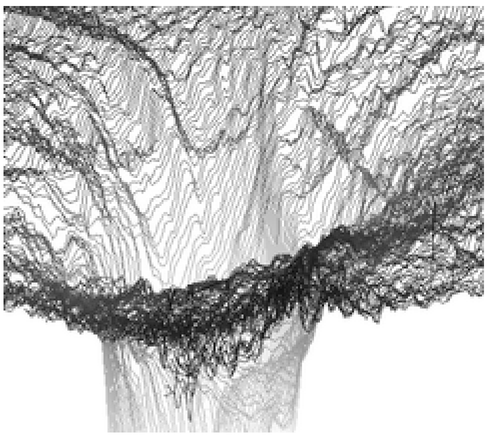
Sets the lightning for the surface plot illumination
`setSurfacePlotLight(float)`

Sets a scale factor
`setTransformScale(float)`

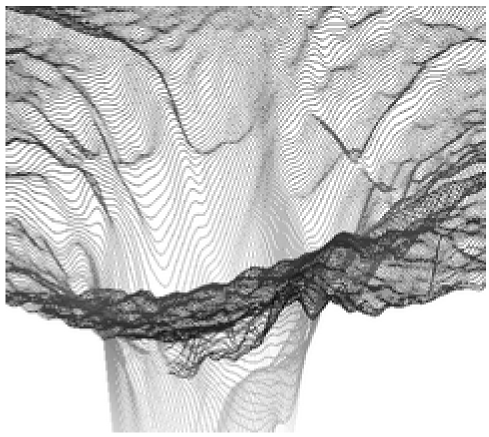
Sets rotation angles (in degrees)
`setTransformRotationXYZ(80, 0, 160)`

Sets the colour LUT for the surface plot
`setSurfacePlotLut(ORIGINAL/GRAY/FIRE/BLUE/SPECTRUM/THERMAL/BLACK)`

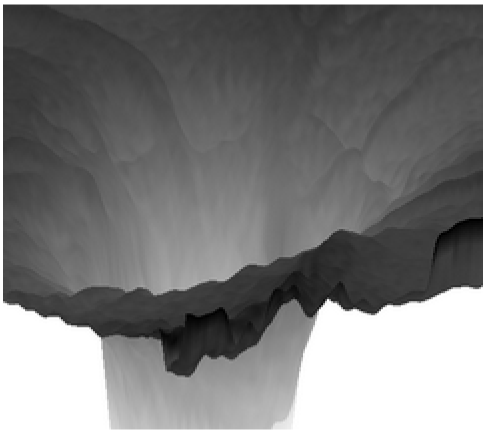
Creates the surface plot with texture
`setSurfacePlotTexture(ImagePlus())`



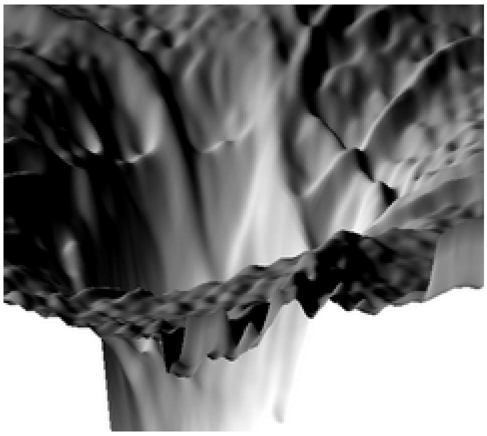
a) ~~FILLED~~, smooth 0.0, light 0.0, scale 3.0, ~~TEX~~



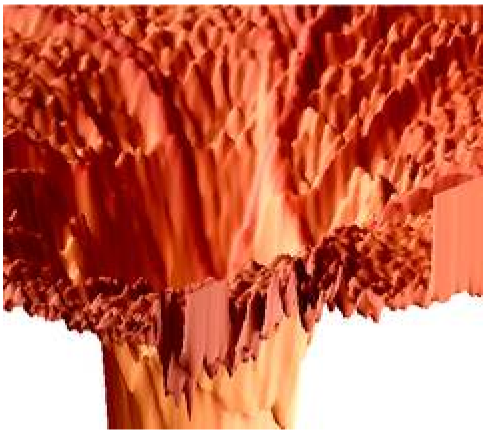
b) ~~FILLED~~, smooth 4.0, light 0.0, scale 3.0, ~~TEX~~



c) FILLED, smooth 4.0, light 0.0, scale 3.0, ~~TEX~~



d) FILLED, smooth 4.0, light 0.5, scale 3.0, ~~TEX~~



e) FILLED, smooth 0.0, light 0.5, scale 3.0, TEX

f) FILLED, smooth 4.0, light 0.2, scale 3.0, TEX

Figure 24: Using ImageJ plugin for the 3D visualization

7.4.6 Image download

Guest as well as registered users are allowed to download images from the server. The image is sent to the user web browser with the parameters below. The variable `$img` represents the path of the concrete image.

```
header('Content-Description: File Transfer');
header('Content-Type: application/octet-stream');
header('Content-Disposition: attachment; filename='.basename($img));
header('Content-Transfer-Encoding: binary');
header('Expires: 0');
header('Cache-Control: must-revalidate, post-check=0, pre-check=0');
header('Pragma: public');
header('Content-Length: ' . filesize($img));
ob_clean();
flush();
readfile($img);
exit;
```

7.5 Time line

To display the time progress of the selected parameter of the concrete eye such as intraocular pressure extension library called JpGraph is used (chapter 4.4). There must be more then one not-null value to display the graph. JpGraph is completely written in PHP and supports various types. The time x-axis is commented using the first three letters of a month and the last two letters of year of each eye examination. See example (Fig. 25).

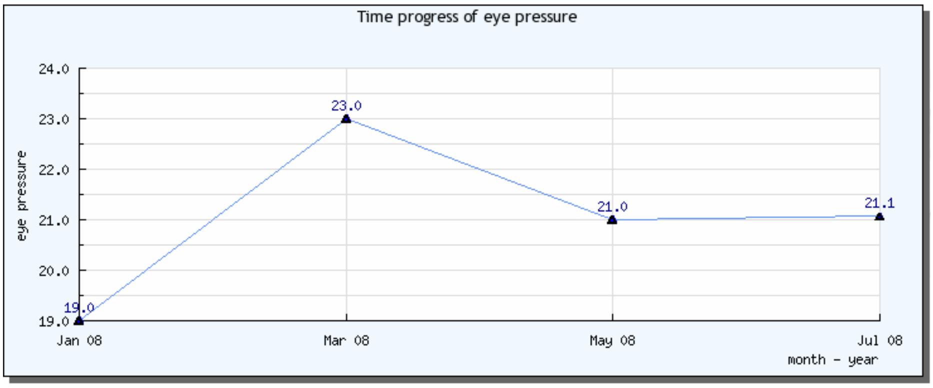


Figure 25: The time progress graph of the IOP

7.6 Registered images in timeline

This function gives the user an overview of all patient registered fundus-images of each eye ordered by date. Using the Thickbox function, the user can get information about the date of the selected image, the type of fundus camera and the field of view.

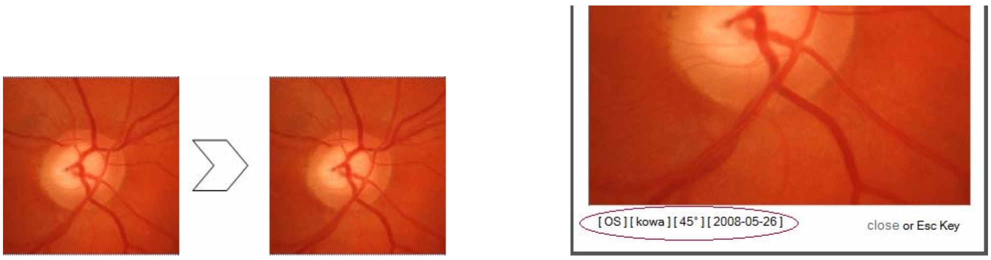


Figure 26: Details of registered image

7.7 Comments

Each registered user can comment about each patient in the database. Username, email, date and time and the possibility to delete this comment by its owner is automatically added. For presentation, the Thickbox extension is used.

7.8 Guest account

The guest is not allowed to manipulate the patient's account, cannot upload images, add new, edit or delete eye examination protocols and create comments. The guest cannot search the patient using his personal data. The guest can display all investigation results, anamnesis, image data and 3D visualization ONH.

8. Conclusion

The result of a population based study [12] in 2005 with the aim to estimate the number of people with open angle (OAG) and angle closure glaucoma (ACG) in years 2010 and 2020 says:

There will be 60.5 million people with OAG and ACG in 2010, increasing to 79.6 million by 2020, and of these, 74% will have OAG. Women will comprise 55% of OAG, 70% of ACG, and 59% of all glaucoma in 2010. Asians will represent 47% of those with glaucoma and 87% of those with ACG. Bilateral blindness will be present in 4.5 million people with OAG and 3.9 million people with ACG in 2010, rising to 5.9 and 5.3 million people in 2020, respectively.

There are glaucoma treatments available in the developed world that reduces glaucoma disability. It is important to improve diagnostic and therapeutic approaches to OAG and ACG that can be applied worldwide.

The main prerequisite to improve current diagnostic methods in this field is the information availability. This information system is implemented for the possibility to share ophthalmologic data of the defined patient without invasion of patient's right of privacy. The patient's account is made for the complete eye examination based on anamnesis data, investigation results and images acquired using advanced examination method – HRT. The diagnosis procedure is improved by using special registration algorithm and the result is possible to present to an end-users via interactive 3D visualization java applet.

9. Further studies

1. Implementation of other modules, e.g. for OCT images
2. Implementation of other image processing tools for ophthalmologic data such as automatic detection ONH and blind spot (macula lutea), Morfield classification, …
3. Visualization for perimetry examination
4. Patient search filter improvement
5. Graphs displaying more parameters
6. Statistical treatment

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