

ELECTRONIC DEVICE FOR SCANNING IMAGES OF THE RETINA AND IRIS

SUMMARY

This paper describes design and construction of a new device for automatic capturing of eye retina and iris. This device has two possible ways of utilization – either for biometric purposes (persons recognition on the base of their eye characteristics) or for medical purposes as supporting diagnostic device.

Key words: eye retina, eye iris, device, acquisition, image

Čes. a slov. Oftal., 71, 2015, No. 6, p. 302–308

INTRODUCTION

In the following text we shall focus on the construction and utilisation of a device which is suitable for scanning the iris and retina of the human eye, including subsequent processing of the images obtained. First of all, however, we shall begin with an overview of the current methods of scanning.

The basic ophthalmoscopic methods of examining the anterior and posterior sections of the eye include direct and indirect ophthalmoscopy, and naturally today probably the most widely used examination method using a slit lamp, thanks to which we are able to examine not only the anterior segment but also perform an examination of the posterior segment of the eye with the help of “biomicroscopy”. In today's digital age there are several firms operating on the market with a wide portfolio of instrument technology, of which a part is designated for digitisation/photo-documentation. Together with the supplied software, it is possible to edit and archive medical findings, which may be important for diagnostic, therapeutic, didactic and also forensic reasons.

Slit lamps are a combination of a binocular microscope and an illumination unit. We can divide them into two types according to the location of the light source. The first group is Haag Streit type lamps with an upper light source (see: Examples of slit lamps.), in which the rays are reflected into the eye of the patient with the help of a mirror. The second group is Zeiss type lamps with a lower source (see : Examples of slit lamps.), in which a prism is used for bending the light in the direction towards the eye.

The light source is one of the important fundamental conditions for obtaining a quality photograph or video recording. For this reason, firms sometimes supply slit lamps with an external light source. On many slit lamps it is possible to attach a model (specified by the manufacturer) of a digital camera or video camera regardless of the location of the light source, but only few cameras can be attached to a slit lamp. Such hardware-upgraded slit lamps enable the recording of a static or dynamic image from the slit lamp during the course of examination of the patient. The first ever mentions of a stereoscopic iris camera date back to the end of the 1820s, in the

past a classic 35mm camera was used for capturing a static image, and a CCD video camera with analogue readout for dynamic images.

Today digital display technology predominates within this specialised field, most frequently utilising CCD chips enabling the creation of images with a resolution exceeding 10 Mpix or the compilation of FullHD videos at a recording speed of 15-30 fps. A “beam separator” is inserted between the lens and the enlarger, which determines the ratio between the light flow deflected into the video adaptor and the flow continuing into the eye piece (eye of the examiner). We most frequently encounter beam separators with the following ratios: 70:30, 50:50, 30:70. The ideal solution is a 70:30 beam separator with the option of simple closing of the video adaptor, upon which 100% of the light flow is directed into the eye piece.

Images of the anterior segment of the eye can be obtained in diffuse, direct, indirect or filtered, focal or slit lighting, and with various options for enlarging the image and various light intensities. Photo-documentation of the retina upon bio-

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Picture 1.: Examples of slit lamps.

microscopy of the fundus can be obtained also on such slit lamps, e.g. using a Volk 90D lens, but priority is mostly given to a fundus camera.

A fundus camera, sometimes also referred to as a retinal camera, is a special and very sophisticated instrument, serving for the display of mainly the posterior segment of the eye – the papilla of the optic nerve, macula and peripheral part of the retina (see: Non-mydratric fundus camera NIDEK AFC-230/210.). It works on the principle of indirect ophthalmoscopy, in which a source of primarily white light is built into the device. The light may be modified by various types of filters (blue, green, red...) and is focused with the help of an optical system into the patient's eye, where it is reflected from the retina and directed back into the lens of the fundus camera. Here the image is adjusted again with the help of a further optical system, and can subsequently be recorded on 35mm cine film, or today is most frequently digitised using CCD chips with a resolution of up to 18Mpix. Enlarging of the image (most frequently 2.5 – 5x) is dependent on the width of the photographic image. The usual scanning range of fundus cameras is up to 45-50°, but a panoramic image can be created using software, displaying the ocular fundus within a range of more than 100°. There are also special fundus cameras available on the market which are capable of displaying the ocular fundus at once upon smaller enlargement within a width of up to 130° (RatCam Shuttle). Thanks to the sophisticated technology, today examination of the ocular fundus in mydriasis is no longer a condition, since many of today's cameras offer a non-mydratric mode, in which scotopic conditions and pupil width of 3.5mm are sufficient for a quality image. In the case of these images too, the photo-documentation can be edited, analysed and subsequently archived if applicable printed, thanks to the supplied software.

As mentioned at the beginning of this chapter, our device enables us to scan two of the characteristics of the human eye – the iris and retina. The main principle is based on optics, camera systems, illumination modules and an adjustable plat-



Picture 2: Non-mydratric fundus camera NIDEK AFC-230/210.

form inside the instrument, a combination of which enables us to obtain both characteristics with the help of one compact device. There are two main options for the use of this device – either for biometric purposes or within the field of ophthalmology.

Biometric systems: Within the field of security and access to buildings, computer systems etc., there is currently a move towards the use of biometric characteristics instead of authentication using passwords and identifying objects [4, 10]. Biometric characteristics such as fingerprints, pattern of the iris or vocal characteristics are unique, non-transferable and difficult to reproduce. A device for reading the iris and retina can be used for verifying the identity of a person in security applications. A biometric system based on the iris and retina is in the form of a small, compact device which may be affixed to the wall in an area with restricted access, such as a nuclear power station, munitions store or bank. After acquisition of the images of the iris and retina within the relevant resolution, the (pre) processing and extracting the biometric features begins. For biometric purposes the images may be of a lower quality (i.e. camera resolution need not be high), because rough information is sufficient for biometric identification. After acquisition of the biometric data, the user is either registered (added to the database as a new user) or forwarded for recognition (comparison with saved template). After successful identification the user is granted access, otherwise access is denied. The entire system incorporates a device, firmware and biometric software for identifying the person on the basis of the iris and retina.

Ophthalmology: If we scan images of the iris and retina in high quality (resolution), the device may serve for medical purposes in ophthalmology. This medical instrument is an independent device which can be placed on a table. The instrument enables the ophthalmologist to acquire images of the iris and retina using a single tool (furthermore it is possible to integrate further functions into the device, such as measurement of intraocular pressure – potential extensions will be discussed in the conclusion). The device includes software based on an expert system which helps the doctor determine a diagnosis and distinguish the ocular pathology. One of the functions of the program enables teaching the expert system the features of a new pathology so that it is able to distinguish it automatically next time. The obtained patient data can be saved and compared with images acquired later, which enables observation of the course of the pathology.

The process of recording the eye is composed of the following three steps: (i) To start recording it is necessary for the user to come into contact with the device. The distance of the user is automatically monitored, i.e. the instrument knows the user's correct head and eye position. As soon as the head is in the correct position, the user is guided into the corresponding eye position; (ii) The process of recording the iris then begins. The eye is first of all illuminated with visible light in order for the pupil to contract (in order to ensure that the iris covers the largest possible area) and subsequently illuminated with infrared light (which is not unpleasant), after which the iris is scanned. Recording of the iris is possible under both infrared and visible illumination, or illumination

may also be prepared according to requirements; (iii) The device is then switched into the mode for scanning the retina. The optical axis of the eye must be set in vertical position (which is automatically performed by an adjustable platform inside the device). The eye is illuminated with infrared light (the iris does not contract) and the lens of the camera system is focused. The ocular fundus is then briefly illuminated with visible (but subdued) light and an image of the retina is acquired.

Konstrukce zařízení

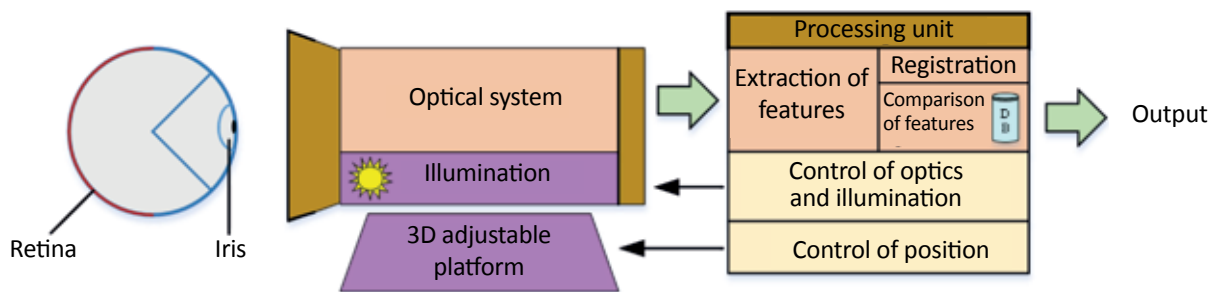
At present we have a complete design of the inner construction of the device, of the optical system, the camera systems with lenses and adjustable platform, including the device cover, which enables fixing of the head position in such a manner as to ensure that the eye remains in a static position after placing on the eye piece [3]. We also have a finished physical construction of a laboratory sample of the device, for which we have verified the functionality of recording the iris and retina both on a simulation of the eye and on real eyes. In the immediate future the device cover with mechanisms for fixation of the head shall also be completed. This section shall present below a description of the individual components of the device. A block diagram of the entire device is presented at: Block diagram of designed system..

The optical system is responsible for recording the image and enables correct focusing of the iris and retina. The integrated light source works both with visible and infrared light. The entire optical system (see example at : Example of laboratory device, first version (left) and second version (right).) is

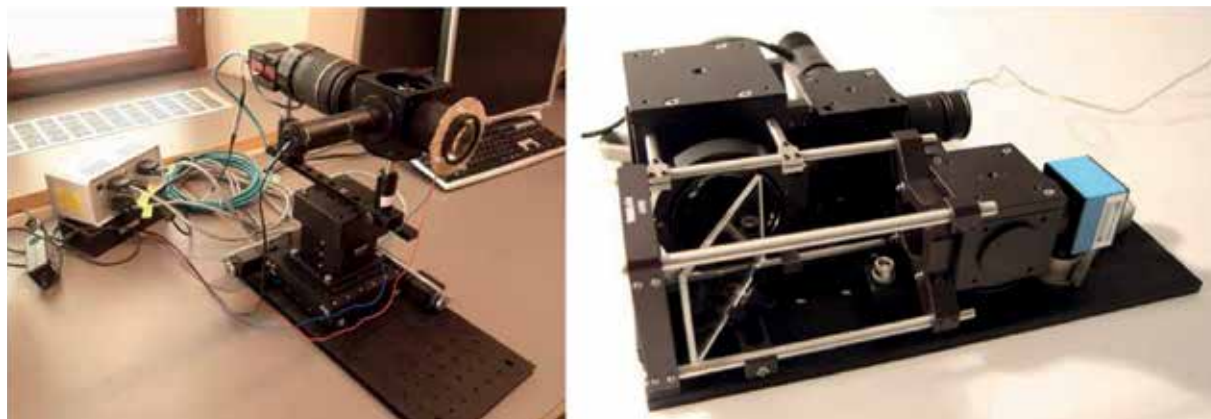
attached to an adjustable 3D platform, which is controlled by feedback on the basis of the image from the camera system. The algorithm for setting the position adjusts the optical axis of the camera system according to the optical axis of the eye. Thanks to the adjustable platform in 3 axes, it is thereby possible to increase user-friendliness, in which the time for the actual recording can also thus be radically reduced, as stated e.g. in [9].

The central element of the system is the unit for processing signals. It acquires and processes images from the optical system. After a quick appraisal of the quality of the recording, this unit sends the image to the output device (e.g. computer or access system). The fundamental modules of the unit are the features extractor (which extracts features from the images of the iris and retina) and the template generator (either a biometric template or medical metadata). In the case of a biometric device a registration module is also applied, which enters the user's template and metadata into the system database, then the module for comparison of templates (comparison of features from currently acquired patterns with features from saved templates). Another part of the unit is the module for controlling optics and intensity of illumination on the basis of feedback from the camera system. The module for determining position ensures alignment of the optical axis of the camera system with the optical axis of the recorded eye, for which it uses the adjustable platform. Information about position is again acquired through feedback from the camera system.

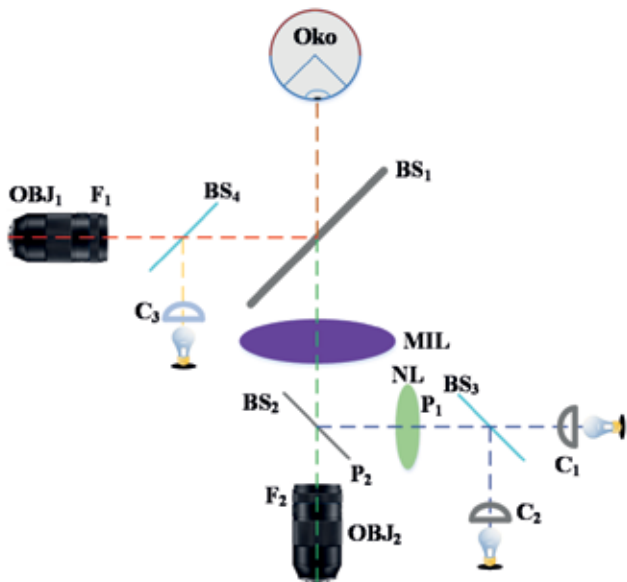
The original concept of the optical system was published in [2].



Picture 3.: Block diagram of designed system.



Picture 4.: Example of laboratory device, first version (left) and second version (right).



Picture 5. : Diagram of optical system of device

Optical system

The parameters of the optical system are designed in such a manner as to meet both the requirements ensuing from the physiological qualities of the human eye, and also the requirements of medical examination of the eye or suitability for biometric identification of persons. These requirements place emphasis on display of the largest possible surface of the iris and retina, combined with data processing on computer, which leads to a design of an optical system composed of a camera system and lens which focuses on the correct level in the eye (iris or ocular fundus). Similar configurations have been proposed also in the past [7, 9], nevertheless the construction of a single device incorporating both configurations

for the retina and iris, including miniaturisation and reduction of costs for the construction is unique, and relies on our utility sample [2].

The requirements for the optical system have been derived from the physiology of the human eye – and especially in the case of the human eye from the most common deviations – refractive error (myopia and hypermetropia). By using an interval of these two deviations we came up with a design of a device which is usable for the overwhelming majority of the population [8].

All these requirements, together with the fundamental principles of optical imaging, have been incorporated into a computer module within the ZEMAX® environment. A Gullstrand-Le Grand eye model was used for simulation of the optics of the human eye during the course of processing the design [6].

: Diagram of optical system of device. presents a diagram of the optical system, which is composed of two basic optical axes formed by an R50T50 semi-permeable mirror (designation BS1). BS1 is a fundamental component of our new approach. It enables us to work with two practically independent optical systems in BS1. The position of the conjugated levels in the optical schemas of the iris and retina are designed in such a manner as to prevent interference with the display level of the other part of the optical system.

The position of BS1 is relatively close to the eye, which is caused by the diametrical conditions in the simulation of both optical branches. It is possible to assert that the placement of BS1 at a greater distance from the eye would lead to an enlargement of the displayed part of the face on the level of the iris, thus to the possibility of using a smaller BS1, which would in its result lead to a reduction on costs. Nevertheless, at the same time there applies a second condition that it is necessary to display a sufficiently large surface of the retina,

Table 1

Risk	Wavelength range [nm]	Quantity	Eye	Skin
Actinic UV skin and eye	200 - 400 (weighted)	Irradiance	Photokeratitis ¹ Conjunctivitis ² Cataracts	Erythema ⁴ Elastosis ⁵
UVA eye	315 - 400	Irradiance	Cataracts	---
Retinal Blue light	300 – 700 (weighted)	Radiance	Photoretinitis ³	---
Retinal Blue light small source	300 – 700 (weighted)	Irradiance	Photoretinitis ³	---
Retinal thermal	380 – 1,400 (weighted)	Radiance	Retinal burn	---
Retinal thermal weak visual stimulus	780 – 1,400 (weighted)	Radiance	Retinal burn	---
Infrared radiation eye	780 – 3,000	Irradiance	Corneal burn	---
Thermal skin	380 – 3,000	Irradiance	Cataracts	Skin burn

¹ Symptoms of sunburn of cornea include pain, swelling and increased tear production

² Swelling of inner eyelid

³ Damage of retina

⁴ Reddening of skin

⁵ Degeneration of skin elasticity

Table 2

Risk group	Philosophical basis
Exempt	No photobiological risk
Group 1 (Low risk)	No photobiological risk under normal behavioral limitations
Group 2 (Moderate risk)	Does not pose a risk due to aversion response to bright light or thermal discomfort
Group 3 (High risk)	Hazardous even for momentary exposure

Table 3

Hazard	Exposure time before hazard exceeded (in seconds)			
	Exempt	Group 1	Group 2	Group 3
Actinic UV	30,000	10,000	1.000	---
UVA hazard	1,000	300	100	---
Blue light radiance	10,000	100	0.25	---
Blue light small source	10,000	100	0.25	---
Retinal Thermal	10	10	0.25	---
Retinal thermal weak visual	1,000	100	10	---
IR eye	1,000	100	10	---

which requires the placement of the micro incision lens (MIL) as close as possible to BS1 in order to prevent enormous dimensions (and thus unavailability) of the MIL. We considered both of the above reasons (costs and available dimensions of both elements of BS1 and MIL) and decided in favour of a larger BS1 at a closer distance to the eye, which enables us to use a commercially available of a MIL at an affordable price.

Reading of iris

Recording of the iris in our configuration corresponds to the principles of classic macro-photography, in which the iris is illuminated by infrared light in an electromagnetic spectrum [1] [5]. The part of the light reflected and dispersed from the iris (and the adjacent part of the face) is reflected back to BS1 and passes in virtually unchanged form through an R20T80 semi-permeable mirror (designation BS4). When the light reaches the broadband filter F1 (prism filter, 800 nm), the part of the spectrum of light up to 800 nm is filtered and only infrared light passes into the OBJ1 lens, which has a focal length of 12 mm and F1,6. The lens is attached to a monochromatic camera with autofocus (this is not illustrated in: Diagram of optical system of device.) with a display surface of 1/2.5" CMOS and an autofocus range of 1.25 mm. The CMOS technology has sufficient quantal effectiveness precisely in the area of infrared light, so this camera is a variant suitable for use.

Reading of retina

The retina is recorded in both infrared and visible light. The MIL lens has 20D (f = 50 mm) and is used as a foundation stone of the display branch for the retina. The light reflected from the retina passes through the optical system of the eye. Part of this passes via BS1 and continues further along the optical axis through the MIL, a R30T70 semi-permeable mirror (designation BS2), a linear polarisation filter P2 (in order to prevent undesirable reflections from the surface of the eye

within the vicinity perpendicular to the optical axis [9]), a narrow-band infrared filter F2, and enters the lens OBJ2, which has a focal length of 8 mm and F1,6. The lens is attached to a colour camera with autofocus (this is not illustrated at : Diagram of optical system of device.) with a display surface of 1/2.5" CMOS and an autofocus range of 1.25 mm.

We took the individual norms for illuminating LED IR units from the source materials of document EN 62471:2008 Photobiological safety of light sources and systems of light sources, which processed on the basis of the International Commission on Illumination (CIE) and the use of source materials from the American norm ANSI/IESNA RP-27.1.

The norm describes not only UV and the visible spectrum of electromagnetic radiation (light), but also infra radiation on a wavelength of 780 to 3000 nm and its possible risks in connection with the occurrence of thermal damage to the cornea, retina or formation of secondary cataract. Incandescence limits have been set for IF LED (Ee = 100 W/m²) at the incandescence value of le = 4 W/sr measured at a distance of 0.2 metres from the source. Evaluation of further limit conditions such as thermal damage to the retina and the effects of blue light were not taken into consideration, since they are do not present risks at higher values of wavelengths λ > 850 nm. Only for the wavelength λ = 830 nm for thermal risk there was a slightly reduced value of risk incandescence to le = 3,77 W/sr.

Illumination of iris

The iris and adjacent region of the face in the surrounding area of the eye are illuminated by infrared light (maximum intensity 820 nm) with the help of LEDs which are located in an illumination ring around the display part of the optical system, with the centre in the optical axis (in : Diagram of optical system of device. they are illustrated as two light bulbs in the vicinity of BS1). This ring contains a number of white LEDs for the purpose of controlling pupil contraction.

Table 4 Properties of proposed optical system

Property	Iris acquisition	Retina acquisition
Displayed area:	65 × 60 mm ²	∅ 8,0 mm
Resolution:	> 32 pixelů/mm	> 250 pixelů/mm
Colour depth:	monochromatic (8 bit)	monochromatic (8 bit) colour (24 bit)
Possible eye position change corrected by autofocus:	limited by branch for retina imaging	± 15 mm
Possible refractive error corrected by autofocus:	not available	± 8 D 90 % populace
Dominant optical deviation:	barrel shape due to iris curvature	needle shape due to retina curvature

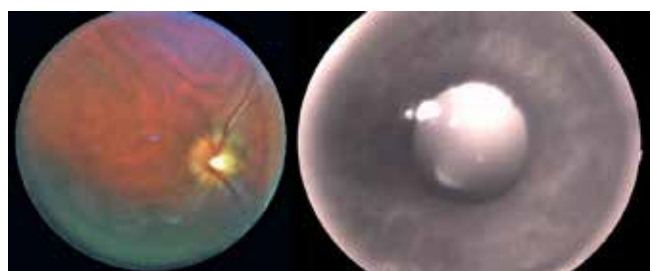
Half of the light from the illumination ring is reflected with the help of BS1 to the iris, and the reflected light from the iris is retroactively recorded by the optical system.

Illumination of retina

The retina is illuminated with infrared light (maximum intensity 780 nm) with the help of LEDs which are located in the surrounding area of the condenser C1 and by visible light with the help of LEDs located in the surrounding area of the condenser C2. The light passes from both diodes evenly before a diffuser, screen (for removing undesirable falling light on the surface of the eye perpendicular to the optical axis of the eye) and a condenser for the purpose of creating a parallel beam of light. Both light beams meet at BS3 and continue together via the linear polariser P1, which alters the illumination wave to a linear polarised wave, and with the help of P2 (which can be understood as an analyser) creates a second obstacle for reflections from the surface of the eye. The screen is then displayed by a negative lens NL and MIL into the level of the iris, with a slightly smaller diameter than the diameter of the human pupil. The light beyond the level of the iris creates a divergent cone, which together with the intraocular dispersion of light creates a uniform illumination of the retina, which is suitable for display and reading purposes.

Navigation of eye

For the eye to be stably placed in the required position during reading, a system for navigation (fixation) and monitoring of the position of the eye has been designed. With the help of LED along the diffuser, the fissure of the size of 1 mm and condenser C3 creates a small spot of light which is displayed on the level of the eye in infinitude. The correct



Picture 6.: Image of retina (left) and iris (right) from our laboratory device.



Picture 7.: Simulation model of new optical system.

position of the source of this navigation light enables us to retain the optical axis of the eye, which is identical to the axis of the display system of the iris and retina.

Required parameters

The proposed optical system described above has the parameters presented below. These properties were first simulated within the ZEMAX® environment and subsequently tested on a laboratory sample of the device. These are summarised in Table 1.

Experimental results

: Image of retina (left) and iris (right) from our laboratory device. displays the resulting images from the first version of our device. In the image of the retina (left) the disc of the optic nerve and the vascular channel in the surrounding area are clearly visible. The displayed field is comparable with a standard fundus camera. The image was recorded in a visible spectrum – short light pulse, in order to ensure there was no contraction of the iris (narrowing of the pupil) and thus subsequent reduction of the visual field. In the image of the iris (right) it is possible to see artefacts, nevertheless in some parts the image is sharpened, thanks to the lower depth of the focusing level of the optical system (version 2 contains a correction). These images are suitable prima-

rily for biometric purposes, since it is possible to find distinguishing features in them for automatic identification of persons. The image of the iris was recorded in infrared light (wavelength 780 nm). Retinal reflection and corneal reflection of the pupil is evident in the image.

In order for us to improve the quality of the recorded images, we designed a new optical system, which was schematically illustrated at: Diagram of optical system of device., in which a simulation model of the new optical system which increases the quality of the recorded images of the iris and retina is presented at : Simulation model of new optical system.. This system is constructed in the form of a laboratory experimental device, in which we are now optimising and testing the device, and will soon proceed to recording the basic database of images of the iris and retina of a smaller group of users.

DISCUSSION AND CONCLUSION

The article presented a new system for recording the iris and retina of the eye. This system is suitable both for biometric purposes (identification of persons) and for medical purposes. At present we are performing essential adjustments in order to improve the quality of the recorded images, and at the same time to improve user comfort upon

recording (e.g. head fixation). In parallel an expert system is being created for ophthalmological purposes, which shall enable assistance in determining the diagnosis of the finding on an image of the retina or iris. This shall be taught to recognise basic ocular pathologies, in which it shall offer the doctor suitable candidates which it learned from the previous images for the given type of damage to the eye. The system can naturally be taught to recognise new pathologies and images. It is also possible to extend the existing system with new elements, e.g. illumination of the eye by precisely defined wavelengths, type of illumination, direction of light etc. It is also possible to add also further measurements, e.g. intraocular pressure etc. In the case of interest it is possible to arrange an appropriate adjustment of the given functional sample into a form which complies with the specific use in medical practice.

Thanks

This study was realised with the support of the following projects: "Brno University of Technology – Security and defence – Devices for reading and identifying the iris and retina" – Ministry of Education, Youth and Sports ED3.1.00/13.0271 (2012-2015); "Centre of excellence IT4Innovations" – Ministry of Education, Youth and Sports ED1.1.00/02.0070 (2011-2015) and "Reliability and security in IT" – VUT FIT -S-14-2486 (2014-2016).

LITERATURA

1. **Daugman J.:** How iris recognition works. *IEEE Transactions on Circuits and Systems for Video Technology*, 2004, pp. 21–30.
2. **Drahanský M., Provazník I., Kolář R., Hájek J.:** Oftalmologické diagnostické zařízení, užitný vzor, ÚPV UV-26535, 2014, <http://spisy.upv.cz/UtilityModels/Full-Documents/FDUM0026/uv026535.pdf>.
3. **Hájek J., Drahanský M., Kolář R.:** Experimental ophthalmic multimodal imaging system for iris and retina. In: *Proceedings of IIAI 3rd International Conference on Advanced Applied Informatics*. Kitakyushu: IEEE Computer Society, 2014, pp. 676-679. ISBN 978-1-4799-4174-2.
4. **Holmes J.P., Wright L.J., Maxwell R.L.:** A Performance Evaluation of Biometric Identification Devices, Sandia National Laboratories, Technical Report SAND91-0276, 1991.
5. **Moreno R.P., Gonzaga A.:** Features Vector For Personal Identification Based On Iris Texture. *Proceedings of the Irish Machine Vision and Image Processing Conference*, Dublin, 2004.
6. **Navarro R., Santamaria J., Bescos J.:** Accommodation-Dependent Model of the Human Eye with Aspherics, *JOSA A* 2 (8), 1985, pp. 1273–1281.
7. **Rabbetts R.:** Bennett and Rabbett's Clinical Visual Optics, 4th Ed., Hodder & Stoughton General Div, 2007.
8. **Risovic D., Misailovic K., Eric-Marinkovic J., Kosanovic-Jakovic N., Milenkovic S., Petrovic L.:** Refractive errors and binocular dysfunctions in a population of university students. *European Journal of Ophthalmology*, 18, 2008, 1–6.
9. **Schwiegerling J.:** *Field Guide to Visual and Ophthalmic Optics*. Society of Photo Optical, 2010, ISBN-10: 0819456284.
10. **Usher D., Tosa Y., Friedman M.:** *Ocular Biometrics: Simultaneous Capture and Analysis of the Retina and Iris*. *Advances in Biometrics Sensors, Algorithms and Systems*, Springer Publishers, 2008, pp. 133–155.