Bimodal Eye imaging system

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This paper describes a new bimodal approach for acquisition of human eye iris and eye retina. A short state of the art is described, followed by recent references oriented on iris and retinal characteristics. The brief description of our proposed bimodal system is also described with experimental results of scanned eye's retina and iris. The main part is focused on enhanced optical setup for the iris/retina acquirement of a human eye. This unique combination in one particular apparatus can be used for medical (ophthalmology) as well as for biometric purposes. Scan in one cycle can significantly save the work time in comparison with separate scanning of each part separately.

Retina recognition; iris recognition; bimodal biometric system

I. INTRODUCTION

Biometric identification systems have become a usual part of requirements for increasing security needs, also in strictly protected areas such as nuclear plants, military facilities, and scientific laboratories; however they are used in common life as well. Iris or retina recognition is not a new idea but if we consider this as a multimodal system this gives us a totally different view to the security and reliability.

Iris recognition is currently available technology for access systems. Due to the fine and unique texture of iris, the probability of having the same iris texture is around 1 in 1078 [6], thus ensuring sufficient coverage of population. However, the fact that the iris is located visibly and it is possible to take a photo from a distance of some meters, the risk of the iris pattern copy and subsequent counterfeit is relatively high. Hence, there should always be some additional security mechanisms (e.g. liveness detection) for high-secured access.

On the other side, the retina recognition is not currently used in practice at all. This is caused by several factors, e.g. complicated optical system, price, and low user-friendliness. Retinal recognition has clear advantages in uniqueness, number of features compared to other biometrics (up to 400), and also that it is the only place in the human body with the possibility to observe the blood vessels non-invasively [7]. Tests of the first constructed device for retinal recognition reported no false accepts and three attempt false reject error rate (the user is rejected if a match is not found in three tries) of less than 1% [8]. Any counterfeit of the retinal recognition system is very difficult, because in the first step the attacker should get a retinal image, which is not possible without user cooperation. In the second step, the attacker should imitate an optical system of the eye so that the biometric system could perform a scan of the retina fake.

Biometric systems in real-world applications are usually unimodal and thus can handle only one single biometric source of information (biometric characteristic). Unimodal systems are susceptible to variety of issues such as intra-class variations, inter-class similarities, noisy data, non-universality, and spoofing. By combining iris and retina into one solution, it is possible to get very robust biometric recognition. In addition, the anatomic position allows capturing both images at once. An advantage of a bimodal system is also the variability of modes it can operate in. In the case of requirement for high secure system, both biometric characteristics can be processed on the same level of protection. In another case, the quality of scanning can be weighted, e.g., if one of these biometric characteristics is evaluated as less reliable (e.g. because of low-quality image acquisition), the second one is preferred if scanned properly. It also leads to a significant improvement of FMR (False Match Rate) and FNMR (False Non-Match Rate) and higher reliability for the user– if there is not possible to acquire one of the biometric characteristics from any reason, the system is still able to recognize him / her on the base of the second biometric characteristic.

Nevertheless, the first concept of the simultaneous iris and retina recognition in a one single device was published by David B. Usher et al. in 2008 [7]. However, the algorithms were not described in detail and the preliminary results were focused mainly on image acquisition. The first device combining iris and retina in one single device was introduced by Retica Systems Inc. [8]. However, it was probably a marketing issue only because the device codenamed Cyclops had never been introduced and brought to the market.

This paper describes in the following chapter a new proposal for a bimodal biometric eye recognition system, based on eye iris and eye retina. These both biometric characteristics could be acquired simultaneously and recognized in one standalone device.

II. DESIGN OF IRIS AND RETINA BIOMETRIC SYSTEM

A practical design of the eye bimodal biometric system is briefly described in this chapter. The device was developed at the Brno University of Technology (CZ). Currently a mechanical design and advanced optical system are under development. We provide brief description of our system in this chapter, together with brief description of current iris and retina biometric approaches and their possibilities of fusion.

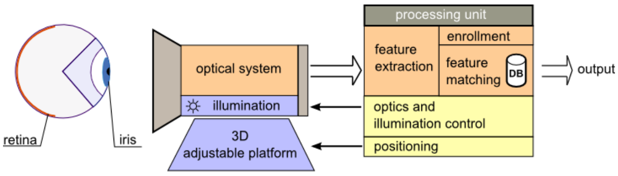

Figure 1. The block diagram of proposed system.

The optical system is responsible for image acquisition and allows the focusing on iris and retina. Integrated illumination source operates at both visible and near-infrared light. The whole optical system is mounted on an adjustable 3D platform which is controlled by a feedback from the camera image. The positioning algorithm adjusts the optical axis of the device according to the optical axis of the eye. Thanks to the 3D movable platform, we assume that the proposed biometric system will be more user friendly and in addition, the time of scanning will be much less than in case of system described by Usher [7].

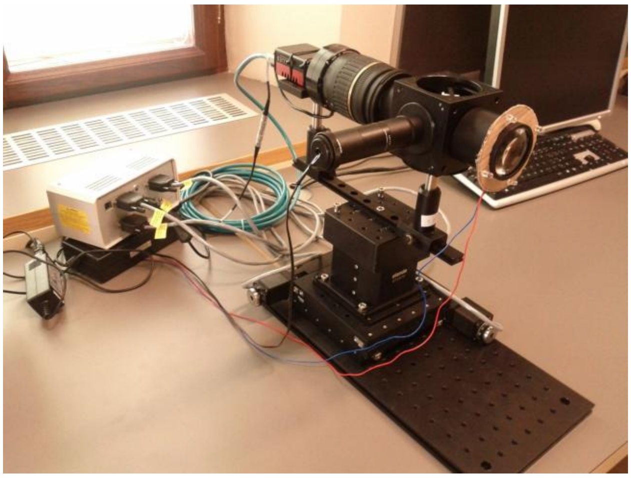

Figure 2. A real design of the proposed device.

Central component of the system is signal processing unit. It receives and processes output images from the optical system. After evaluation, the unit sends the result to the output (e.g. computer, access system). Fundamental modules of the unit consist of Feature extraction module which extracts features from retinal and iris images provided by the optical system. Subsequently a biometric template is generated. Enrolment module allows enroll a new user to the system. A template is stored in a database located locally on the device or remotely (e.g. via ethernet connection). Feature matching module – matches just extracted template with the templates stored in a database. Optics and illumination control module controls optical system (retina and iris focus, aperture) depending on the feedback from the camera. This module also controls source and intensity of illumination. Positioning module allows move the optical system in three axes in order to align optical axis of the eye and optical axis of the device. Positioning is controlled by the feedback from the camera image.

Original proposed optical system for this device was described in [10], results are also shown on **Chyba! Nenalezen zdroj odkazů.**. There can be seen iris artefacts, however in some parts the image is blurred due to small depth of field of the optical system. On the same figure the retinal image is rather dark, however there can be clearly seen the optic disk and the blood vessels around. The field of view is comparable with standard fundus cameras. Due to low quality of result images we devided to propose a new more sophisticated optical setup.

III. OPTICAL SYSTEM

Optical setup itself is designed to fulfill requirements resulting from both physiological properties of a human eye and needs for medical eye examination or biometric pattern recognition. These requirements place emphasis particularly to imaging of relatively large areas of human eye iris and retina combined with computer processing and thus to optical design integrating digital imaging cameras and pertaining optics allowing creation of the image in the plane where the camera active element is placed. Similar setups were already reported many times [1][2] but the design of one multimodal device represents quite new approach of integration, miniaturization and cost reduction.

Requirements for the optical design were derived from human physiology and – especially in the case of human eye – from the most conventional deviation – refractive disorder (myopia & hyperopia). Following the interval of these deviations allow us to design the device, which is usable for the vast majority of human population (Milenkovic et al. 2008). All these requirements together with the principles of optical imaging were included to the computational model in the ZEMAX® environment. The Gullstrand-Le Grand [4] eye model was used to simulate human eye optics during the designing process.

The optical setup, understandably, consist from two essential optical axis which are created by R50T50 plate beamsplitter (BS1) (fig. 1). The BS1 is the most fundamental part of this novel approach. It allows us to deal in with two practically independent optical systems behind the BS_1. Position of conjugated planes in optical schemas of both iris and retina are designed to do not interfere with the imaging area of other part of the system.

Position of BS_1 relatively close to the eye is the result of contradictory conditions in simulations of both optical branches. One could argue that placement of the BS_1 further from eye could lead to increase of the displayed face area in the iris plane and thus to possibility to use smaller BS_1, what could lead to lower costs. The second condition – to display sufficiently large area of the retina – however, requires to place main imaging lens (MIL) as close as possible to avoid enormous dimensions (and thus unavailability) of MIL. Therefore, taking into account the costs and available dimensions of elements suitable for BS1 and MIL, we used rather large BS1 relatively close to the eye which allows us to use MIL commercially available with acceptable price.

A. Iris imaging

The iris imaging in this setup follows classic macrophotography principles and the iris is shown in IR part of the electromagnetic spectrum [5]. Part of the light scattered from iris (and adjacent part of the face) is reflected on BS1 and propagates almost unchanged thorough R20T80 beamsplitter BS4. When light reaches longpass filter F1 (edge filter, 800 nm), the part of the spectrum up to 800 nm is cut-off and only IR part of the spectra pass to the objective. Objective OBJ1 has focal length 12 mm and F1.6. Objective is mounted to monochrome autofocus camera (not plotted in the figure) with 1/2.5'' CMOS imaging area and 1.25 mm autofocus range. CMOS technology has sufficient quantum efficiency even in near IR region, so this camera is an applicable variant.

B. Retina Imaging

The retina could be shown in both IR and VIS part of the light spectrum. The 20D (f' = 50 mm) MIL is used as a cornerstone of the retina-imaging branch. The light scattered from retina propagates via optical system of the eye. Part of it passes through BS_1 and propagate along the optical axis via MIL, R30T70 beamsplitter BS_2, linear polarizer P_2 (to avoid the reflection from eye surface nearly perpendicular to optical axis [1]), shortpass IR filter F_2 and enters to objective OBJ_2. OBJ_2 has focal length 8 mm and F1.6. Objective is mounted to color autofocus camera (not plotted in the figure) with 1/2.5'' CMOS imaging area and 1.25 mm autofocus range.

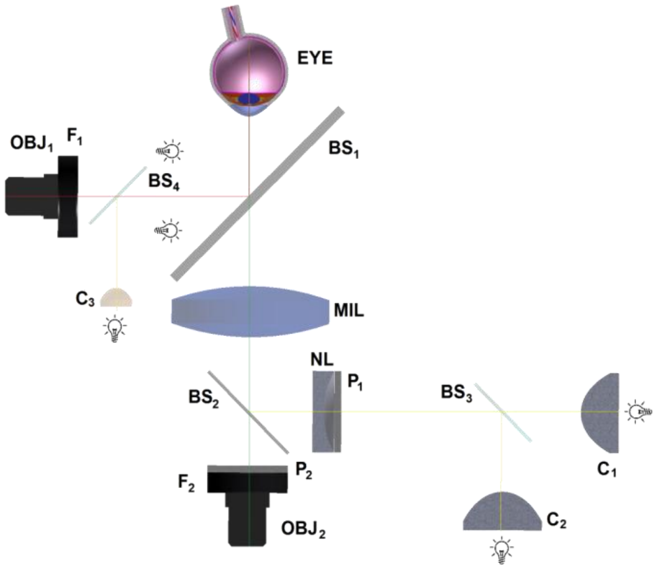

Figure 3. Optical setup of bimodal iris & retina camera (illustrative, not in scale). Optical axes of iris (red) and retina (green) imaging and (yellow) illuminating branches. BS1: main beamsplitter; BS4: eye navigation beamsplitter, C3: eye navigation condenser, diffuser and diaphragm; F1: longpass IR filter (edge 800 nm); OBJ1: iris camera objective; MIL: main imaging lens; BS2: imaging/illumination beamsplitter; P2: linear polarizer; F2: shortpass VIS filter (edge 800 nm); OBJ2: retina camera objective; NL: negative lens; P1: linear polarizer; BS3: IR/VIS illumination beamsplitter; C1: retina VIS illumination condenser, diffuser and doughnut-shaped diaphragm; C2: retina IR illumination condenser, diffuser and doughnut-shaped diaphragm.

C. Iris illumination:

Iris and adjacent part of the face around the eye is illuminated by IR (intensity peak: 820 nm) light-emitting diodes (LEDs) placed on illuminating ring around the iris-imaging branch's axis (plotted as two light bulbs close to BS_1). This ring also contains several white LEDs to control the iris aperture for retina imaging purposes. 50 % of light from illuminating ring is reflected by BS_1 on the iris and scattered light can be collected by iris-imaging system.

D. Retina illumination:

Retina is illuminated in IR part of the spectrum by IR (intensity peak: 780 nm) LED placed behind condenser C_1 and in VIS by white LED placed behind condenser C_2. The light from both diodes propagates equally via diffuser, doughnut-shaped diaphragm (to remove unwanted light incidents to perpendicular-to-optical-axis surface of the eye) and condenser to create parallel beam of light. Both beams meet on BS_3 and continue together via linear polarizer P_1. The P_1 change the illuminating wave to linear polarized and with P_2 (could be understood as analyzer) creates the second hurdle to eye surface reflections. The doughnut-shaped diaphragm is then displayed by negative lens NL and MIL to the iris plane with the diameter slightly smaller than diameter of eye pupil. The light beyond the iris plane creates divergent cone, which with scattering in vitreous creates retina illuminated uniformly enough for the imaging purposes.

E. Required properties

The optical system designed in form described above has properties required from the very beginning. These properties with simulated values are plotted in table I.

TABLE I. PROPERTIES OF PROPOSED OPTICAL SYSTEM – SIMULATION IN ZEMAX® ENVIRONMENT.

Property:	**Iris-imaging:**	**Retina-imaging:**
Displayed area:	65 x 60 mm2	Ø 8.0 mm
Resolution:	> 32 px./mm	> 250 px./mm
Color depth:	monochrome (8 bit)	monochrome (8 bit) color (24 bit)
Possible eye position displacement corrected by autofocus:	restricted by retina-imaging branch	± 15 mm
Possible refractive disorders corrected by autofocus:	N/A	± 8 D 90 % of population [3]
Dominant optical aberration:	barrel distortion caused by iris curvature	pincushion distortion caused by retina curvature

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In the figure **Chyba! Nenalezen zdroj odkazů.**, the results from our proposed device are shown. On the retinal image there can be clearly seen the optic disc and the blood vessels around. The field of view is comparable with standard fundus cameras. The images were taken in a visible spectrum of light, respectively, by a short-term light pulse to avoid pupil contraction and thus, it resulted in a reduction of field of view.

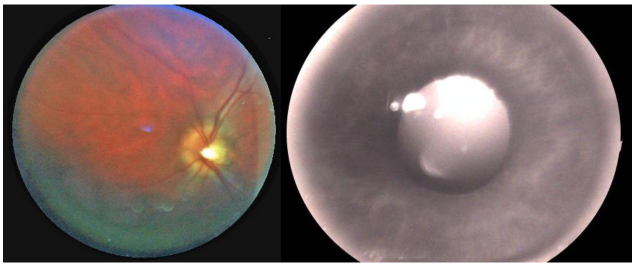

Figure 4. Original Retinal and iris images from proposed device.

The iris images have been taken in infrared light spectrum of 780 nm. There are obvious retinal red reflex and corneal reflexes in the pupil. In addition, some iris artefacts can be seen, however in some parts of the image are blurred due to small depth of field of the optical system. This will be solved in the new version of an advance optical system.

A model of new proposed optical system is shown in the **Chyba! Nenalezen zdroj odkazů.**. Although we do not have satisfying results for biometric purposes yet, based on previous experimentation, new results are more promising than older version of optical setup.

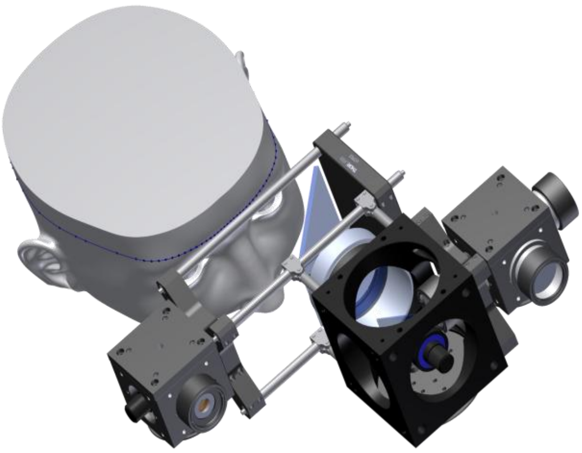

Figure 5. Model of experimental setup scaled to human head.

V. Conclusion

The main goal of this project is to develop a multimodal biometric system for simultaneous iris and retina recognition and the optical setup is the one of the key parts. Although designed mainly for biometric use, thanks to its universality can be also easily used for medical purposes. The use for ophthalmologist may be by enhanced by an expert system, where the extracted features for the known eye retina and iris diseases will be stored. The semi-automatic recognition system will offer a list of possible eye diseases which could be found on the base of the acquired image analysis.

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