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EyeGuidance – a computer controlled system to guide eye movements

Abstract: The densely innervated human cornea is the only superficial tissue of the human body in which nerve fibres are accessible *in vivo* by corneal confocal microscopy (CCM). Morphological parameters of the corneal sub-basal nerve plexus (SNP) derived from CCM images can potentially serve as a sensitive biomarker for early diagnosis of various neurodegenerative diseases. The evaluation of a single image with a typical field of view of 0.16 mm^2 is insufficient for robust morphometric assessment. Mosaicking approaches have therefore been proposed to examine the SNP on a larger scale. Here we present a highly automated technique that significantly facilitates the generation of mosaic images of the SNP and is suitable for clinical tests.

Keywords: cornea; guided eye movements; image registration; *in vivo* confocal microscopy; mosaicking; sub-basal nerve plexus.

1 Introduction

The cornea is one of the most densely innervated superficial tissues in the human body. Being nearly perfectly transparent, the cornea is also the only part of the human body in which nerve structures are accessible *in vivo* to microscopic imaging techniques, such as confocal microscopy. While corneal confocal microscopy (CCM) has been used for *in vivo* imaging of cellular structures throughout the entire depth of the cornea, its highest potential may be in imaging the corneal sub-basal

nerve plexus (SNP). CCM of the SNP represents a novel, non-invasive means to directly assess and quantify nerve fibre damage and repair. Numerous studies have been aimed at establishing morphometric features of the SNP as a sensitive marker for various ocular and systemic disorders [1]. However, due to high local variance of the nerve fibre distribution [2], evaluation of a single image with a typical field of view of 0.16 mm^2 is insufficient for reliable morphometric characterization of the SNP. In [3] we described the EyeGuidance (EG) system, which uses an additional display in front of the non-examined eye to guide the patient's gaze direction. It implements a highly automated technique to facilitate the acquisition and the generation of a mosaic image of an extended area of the SNP. This contribution presents a novel, enhanced EG setup with improved image quality of the display and simplified system handling.

2 Material and methods

A confocal microscope HRT (Heidelberg Retina Tomograph) in conjunction with the Rostock Cornea Module (both Heidelberg Engineering GmbH, Heidelberg, Germany) is used for CCM. A display showing a moving fixation target is arranged in front of the non-examined eye (see Figure 1). The position and track of the fixation target is controlled and can be adapted online by the EG software. Due to the synchronous eye movements, the gaze direction of the eye examined by CCM can thus be controlled indirectly.

2.1 Hardware

The feasibility study described in [3] was conducted using a small display that had been dismantled from multimedia video glasses (Cinemizer, Carl Zeiss AG, Oberkochen, Germany). Based on these experiences and results obtained during that study, we specified the requirements for a system suitable for a clinical study:

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Georg Bretthauer, Klaus-Martin Reichert, Ingo Sieber, Lorenzo Toso and Stephan Allgeier: Karlsruhe Institute of Technology (KIT), Institute for Applied Computer Science, POB 3640, D-76021 Karlsruhe, Germany
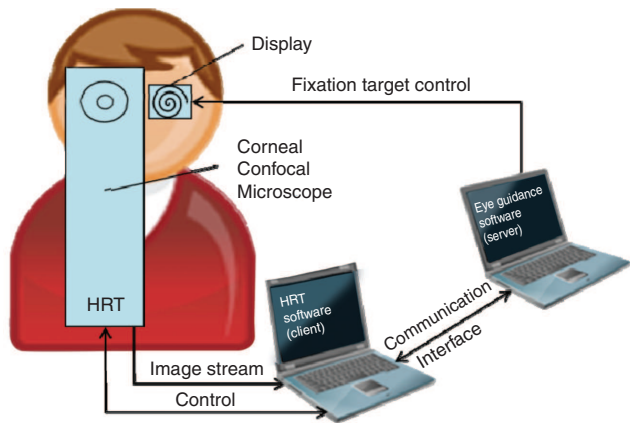**Rudolf F. Guthoff and Oliver Stachs:** University of Rostock, Germany

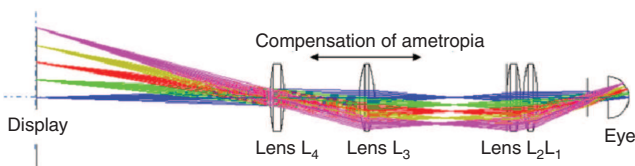**Figure 1:** Schematic illustration of the EyeGuidance setup.

Figure 2: Optical layout of the EyeGuidance system simulated by ZEMAX V.13.

– ciliary muscle of the eye should be relaxed viewing the EG display
– ametropia should be compensated in the range of ± 10 dioptres
– angle of view $>35°$
– display size: 4″–5.5″
– length of the optical path <400 mm
– no restriction on CCM operation
– easy alignment in front of the non-examined eye
– easy change of the examined eye (left, right)

A lens combination that meets the optical requirements was determined using the simulation software ZEMAX (Zemax LLC, Kirkland, Washington, DC, USA). The resulting optical setup is composed of a system of four convex lenses (see Figure 2). The lenses L_1, L_2 and L_4 are fixed in their position. The lens L_3 can be moved linearly along the optical axis to compensate refractive errors in the specified range of ± 10 dioptres. In order to minimize intrusion of the EG hardware into the geometrical space required for CCM handling, the major part of the optical setup is arranged vertically by means of a mirror located between the lenses L_2 and L_3 (see Figure 3).

A smartphone (Motorola Moto G, Motorola Mobility Germany GmbH, Idstein, Germany) is used as display. The 4.5″ display has a pixel resolution of 1280 × 720 and
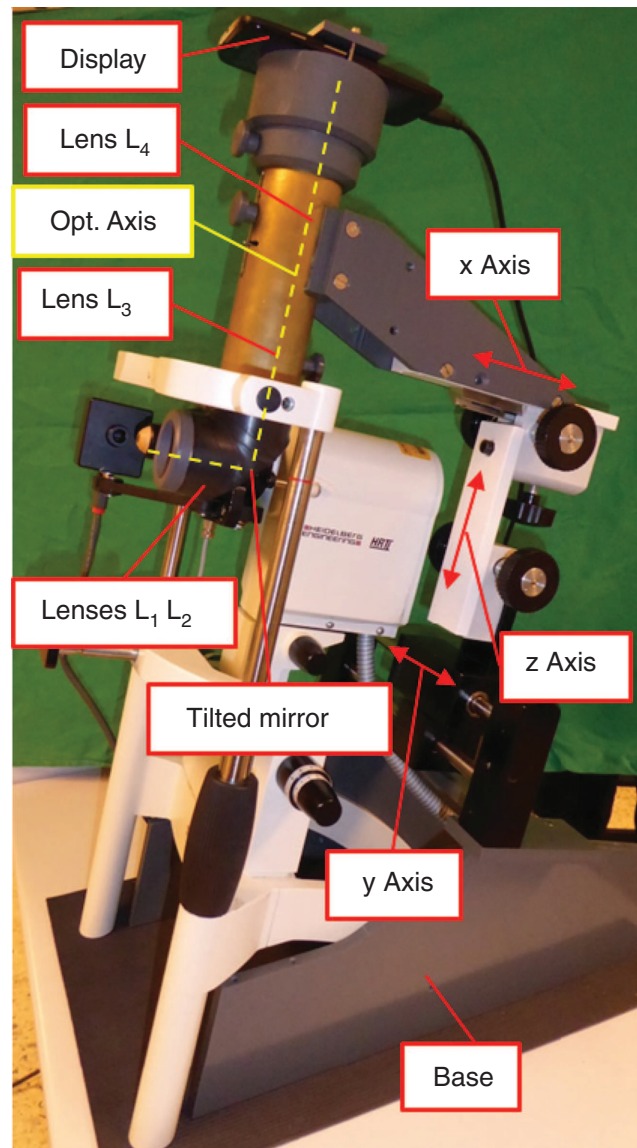

Figure 3: EyeGuidance hardware setup.

although the lenses have a magnifying effect, no individual pixels are recognizable because of the high pixel density (329 ppi) of the display.

2.2 Alignment process

Using the three axes (see Figure 3), the EG system can be aligned in front of the non-examined eye. Whereas the patient's participation was helpful, if not necessary, for the precise alignment in the feasibility study [3], the operator is supported by a camera of a second, identical smartphone (EG camera in Figure 4) in the present setup. The smartphone used as display (EG display in Figure 4) has to be rotated sideways (see Figure 4) to make use of the EG
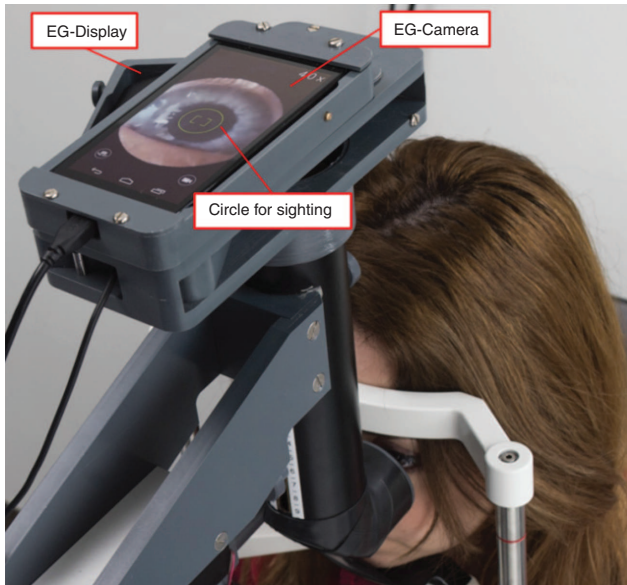
Figure 4: Alignment of the EyeGuidance system.

camera; the operator can observe the alignment of the EG system using the camera App of the EG camera. The zoom factor of the camera should be set to $4.0\times$ for this purpose and the graphical circle defining the central focus area of the camera can be used as an alignment aid. The EG system is well aligned when the pupil is located centrally (concentric with the graphical circle) while the viewing direction of the patient is straight ahead. After the alignment procedure the smartphone for the display is rotated back in.

2.3 Image recording and mosaicking

The image recording process is completely controlled via the HRT computer using specially adapted HRT software. After focussing the HRT on the SNP layer the operator starts the image acquisition and recording process. Being automatically triggered via the built-in communication interface (see Figure 1), the fixation target starts moving in a spiral pattern [3] on the EG display while the image data is concurrently streamed to a file with 30 fps. During the recording process the HRT software calculates a continuously increasing mosaic image and the operator can assess the image size and quality. As soon as the mosaic image size is large enough or an error occurs (no further growth of the mosaic image size, imaging other tissue than SNP, lost contact of the examined eye) the operator stops the recording process.

The final, high-quality mosaic image is calculated from the recorded image sequence in a post-processing step using the algorithms described in [4, 5].

3 Results and conclusion

The new EG system fulfils the requirements specified in Section 2.1 and we successfully tested the system with 13 volunteers. Compared to the first prototype system described in [3] the alignment process is simplified significantly by the new three axes system and the introduction of the EG camera. The new EG display has a much higher resolution and increased brightness and contrast. Furthermore the optical setup provides an extended field of view and the ability to compensate refractive errors in the range of ±10 dioptres.

The EG system is intended to be applied without establishing physical contact between the patient and any part of the EGM hardware. However, the ocular needs to be positioned in close proximity to the contralateral eye in order to achieve the specified field of view. Depending on individual facial anatomy, slight physical contact between the housing of the ocular and the skin in the area of the nose and/or eyebrow cannot be ruled out completely.

This contribution presents a highly automated technique that significantly facilitates the generation of extended mosaic images of the SNP. With the novel setup the EG system is ready for clinical use.

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