An efficient intelligent analysis system for confocal corneal endothelium images

M.S. Sharif [a,*], **R. Qahwaji** [a], **E. Shahamatnia** [b], **R. Alzubaidi** [a], **S. Ipson** [a], **A. Brahma** [c]

[a] *School of Electrical Engineering and Computer Science, University of Bradford, Bradford, UK*
[b] *Universidade Nova de Lisboa/FCT-UNINOVA, Caparica 2829-516, Portugal*
[c] *Manchester Royal Eye Hospital, Central Manchester University Hospitals NHS Foundation Trust, Manchester Academic Health Science Centre, Manchester M13 9WL, UK*

ARTICLE INFO

ABSTRACT

A confocal microscope provides a sequence of images of the corneal layers and structures at different depths from which medical clinicians can extract clinical information on the state of health of the patient's cornea. A hybrid model based on snake and particle swarm optimisation (S-PSO) is proposed in this paper to analyse the confocal endothelium images. The proposed system is able to pre-process images (including quality enhancement and noise reduction), detect cells, measure cell densities and identify abnormalities in the analysed data sets. Three normal corneal data sets acquired using a confocal microscope, and three abnormal confocal endothelium images associated with diseases have been investigated in the proposed system. Promising results are presented and the performance of this system is compared with manual and two morphological based approaches. The average differences between the manual and the automatic cell densities calculated using S-PSO and two other morphological based approaches is 5%, 7% and 13% respectively. The developed system will be deployable as a clinical tool to underpin the expertise of ophthalmologists in analysing confocal corneal images.

1. Introduction

The cornea is the transparent surface component of the eye covering important internal structures including the iris, lens, and anterior chamber as illustrated in Fig. 1. Damage to the cornea caused by disease or injury can critically affect the quality of vision. The cornea comprises proteins, fibrils and various cells in a highly organised structure [1]. The fixed focusing power provided by the air to cornea surface is one of the cornea's major functions, which together with the contribution provided by the adjustable internal lens causes the light rays passing through to produce a sharp image on the retina. Another function of the cornea is to protect the retina by filtering dangerous ultraviolet light. The cornea also works as a shield to protect the internal structures from attack by microorganisms.

The cornea joins smoothly with the non-transparent sclera and has lateral dimensions of around 12.6 mm in the horizontal direction and 11.7 mm in the vertical direction. The thickness of cornea varies and ranges from about 520 μm at the centre to about 650 μm at the periphery [2,3]. The cornea

* *Corresponding author at*: School of Electrical Engineering and Computer Science, University of Bradford, Bradford, UK.
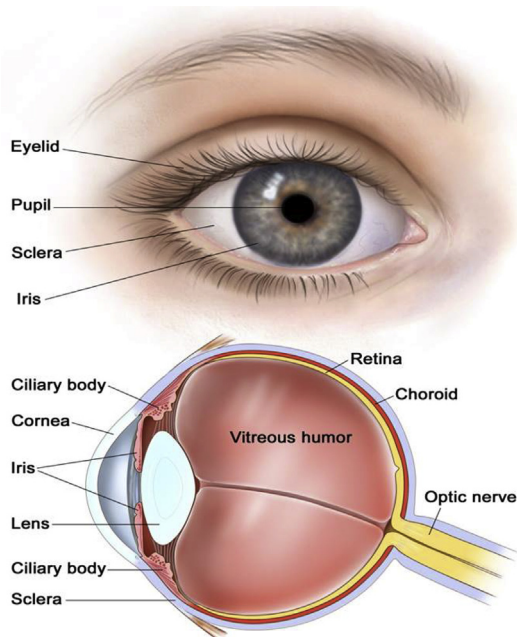Tel.: +44 1895 265349.

Fig. 1 – Human eye structure [12].

has a tear film on its front surface and three main internal layers separated by two thin membranes. The corneal structure is shown in Fig. 2. The corneal layers are the outermost epithelium layer, separated by Bowman's membrane from the central stroma layer, which is separated in turn by Descemet's membrane from the innermost endothelium layer.

Confocal microscopy of the cornea offers several advantages over conventional microscopy. It provides images showing the cell structures in different corneal layers, which can be obtained with typical minimum depth separation of about 5 μm, and they can be immediately viewed and used for diagnostic purposes. The employed images in the current work are from a Confoscan 4 microscope, produced by Nidek, Inc., Freemont, CA. During a typical scan, the microscope locates the rear of the cornea (no signal back from
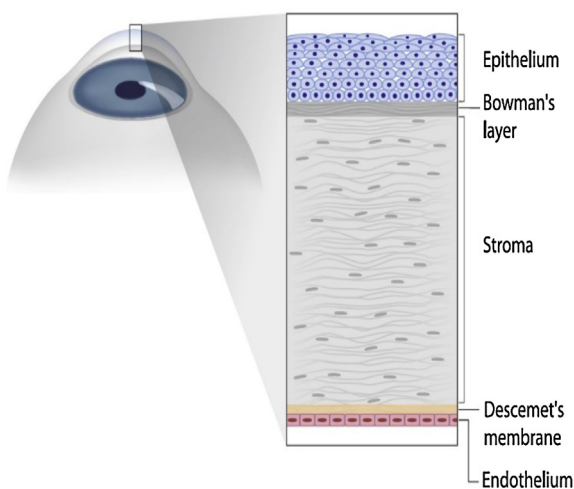

Fig. 2 – Cornea structure.

aqueous humour) and steps forward by the specified increment until it reaches the anterior surface of the cornea (no signal back from the tear layer). This cycle is repeated 3 times during a 20 s scan providing around 350 images. The acquired two-dimensional images are useful to provide important clinical information on the corneal state of health and to analyse corneal structures in the whole volume of the cornea, not just at a specific depth. Because of the spherical shape of corneal layers, which causes non-uniform reflection of illumination light in the different corneal areas, and the different attenuation of light along the various illumination paths; acquired images do not usually have a uniform luminosity and contrast, exhibiting darker areas in the peripheral regions of the images [4].

Confocal microscopy offers clinicians one of the most detailed views of corneal structures and pathologies. It helps clinician to establish the presence of ophthalmic pathology caused by bacterial, viral, parasitic and fungal infections [5,6]. It provides detailed images of each layer of the cornea. The endothelial cells are located immediately posterior to Descemet's membrane, and are characterised by a regular hexagonal hyper-reflective pattern or regular honeycomb mosaic, surrounded by hypo-reflective borders without obvious nuclei reflections. No vessels or nerves are present in this layer. Sometimes, the nuclei of the cells may be visualised [7–10]. Examples of corneal original images of stroma and endothelium layers are shown in Fig. 3(a) and (b) respectively.

Injuries, infections, dystrophies and ocular diseases (such as lattice dystrophy), dry eye, genetic conditions and changes due to ageing can all reduce the ability to see clearly, sometimes causing pain and discomfort as well. It is possible to see some of these corneal conditions developing, while others are difficult to monitor. Treatments can involve eye drops, other medications, contact lenses, surgery (such as corneal graft operations), etc. Small changes in the cornea can significantly affect its visual performance [11]. Therefore, it is important to analyse the endothelium cells count and density, as they may affect the cornea transparency and the visual quality.

The confocal microscope's generation of a large number of images per patient per scan, makes their analysis a challenging task for an ophthalmologist with a large number of patients in a busy clinical setting. Ophthalmologists could use an efficient system to reduce the analysis time and speed up the treatment process, by giving them the opportunity to look at individual layers on demand, leading to faster and more accurate diagnosis. Our research aim is to develop an as yet unavailable complete analysis system for the main corneal layers (epithelium, stroma and endothelium). Due to the nature of these layers and the information (clinical parameters) required from each of them, the developed system has four main parts. First, pre-process (quality enhancement, noise removal) the data sets provided to the clinicians by the confocal microscope (this step is shared between the three main parts) and classify the corneal layers. Second, analyse stroma data and visualise stroma corneal images as well as each individual keratocyte cell as a volume for further clinical analysis. Third, analyse the epithelium layer and detect nerves. Fourth, analyse the endothelium layer which is presented in this paper.