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Preparation of 2D sequences of corneal images for 3D model building

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ABSTRACT

A confocal microscope provides a sequence of images, at incremental depths, of the various corneal layers and structures. From these, medical practioners can extract clinical information on the state of health of the patient's cornea. In this work we are addressing problems associated with capturing and processing these images including blurring, non-uniform illumination and noise, as well as the displacement of images laterally and in the anterior–posterior direction caused by subject movement. The latter may cause some of the captured images to be out of sequence in terms of depth. In this paper we introduce automated algorithms for classification, reordering, registration and segmentation to solve these problems. The successful implementation of these algorithms could open the door for another interesting development, which is the 3D modelling of these sequences.

1. Introduction

The cornea is the clear outer layer covering the front of the eye comprising a collection of cells, fibrils and proteins that constitute a very highly organized structure. The cornea must remain transparent to allow light to enter the eye and the curvature of its outer surface accounts for much of the focusing power required to properly form images [1–3]. The flexible crystalline lens then further refracts the incoming light and provides the remaining focusing power required to achieve a sharp image on the light sensitive retina. The cornea also works as a protective membrane to the human eye, among other things helping to screen out the ultraviolet wavelengths which are found in sunlight and prevent the lens and the retina from being damaged by these wavelengths [4]. The cornea joins smoothly with the non-transparent conjunctiva and has lateral dimensions, on average of, 12.6 mm in the horizontal direction and 11.7 mm in the vertical direction. The thickness of the cornea is non-uniform, ranging from about 520 μm at the centre to about 650 μm, at the periphery. The cornea has a tear film on its front surface and three main internal layers separated by two thin membranes. The outermost layer is the epithelium, which is separated by Bowman's membrane from the central stroma layer, which is separated in turn by Descemet's membrane from the innermost endothelial layer as shown in Fig. 1.

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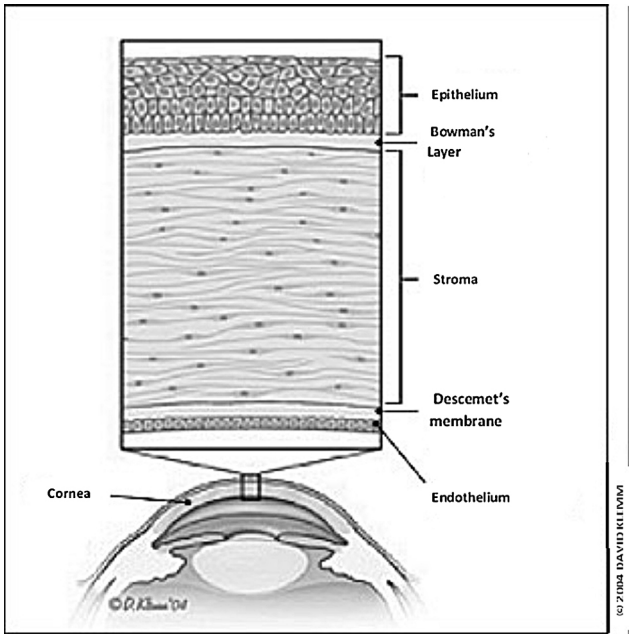

Fig. 1 – The corneal layers [5].

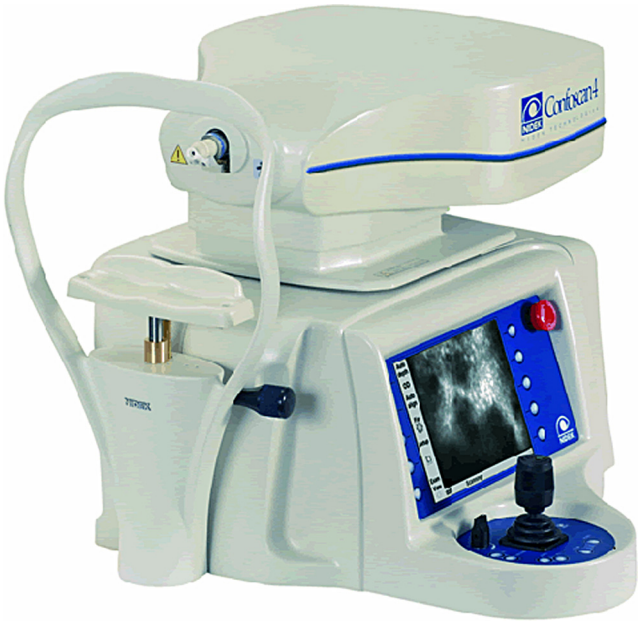

Fig. 3 – ConfoScan 4 confocal microscope [11].

A number of injuries, dystrophies and ocular surface diseases (keratoconus, lattice dystrophy, dry eye, conjunctivitis, etc.) may lead to opacities in the cornea, which can severely impair vision. In addition some diseases of the cornea cause severe pain and chronic discomfort [3]. The slightest changes in the shape of the corneal can clearly diminish visual performance of the eye.

The various layers and structures of the cornea can be studied in vivo using a confocal microscope to provide a sequence of images at different depths, as illustrated in Fig. 2. The use of the confocal microscope, such as that shown in Fig. 3, has provided a better understanding of the microstructure of the cornea's cells (normal, postsurgical and diseased), and, from these images, Ophthalmologists can extract clinical information on the status of the cornea. To the best of our knowledge, the analysis of these images are currently based on manual inspection or aided by semi-automatic methods. Individual corneal images in these sequences are often noisy and sometimes dark or contain no data [6,7]. Images display non-uniform illumination caused by factors such as: the spherical shape of the corneal layers, which causes non-uniform reflection of the illumination light from the different areas of the cornea, and the different attenuation of light along the different paths of illumination.

The confocal microscope enables images of the cornea to be scanned at different depths (default layer separation 5 μm, minimum separation 1 μm) and immediately viewed for diagnostic purposes. During a scan, the instrument locates the rear of the cornea (no signal back from the vitreous humour) and then steps forward in 5 μm steps until it reaches the front surface of the cornea (no signal back from the tear layer). This cycle is repeated 3 times during a 20 s scan which provides about 350 images [6].

Although the confocal microscope, as shown in Fig. 3, has a head rest supporting chin and forehead, one of main problems with these types of images is caused by movements of the eye during the scanning process. Respiration, cardiac pulse and other factors cause images of adjacent layers to be displaced laterally with respect to each other and may cause images in the capture sequence to be out of sequence in terms of depth. This also means that the difference in depth between captured layers is not necessarily uniform or the same as the instrument setting. The amount of movement varies from patient to patient and from scan to scan. The confoscan 4 confocal microscope used in the current study can optionally incorporate a z-ring adapter detachable contact element as shown in Fig. 4. The z-ring adapter maintains a small constant pressure on the cornea, so that it and the connected objective lens

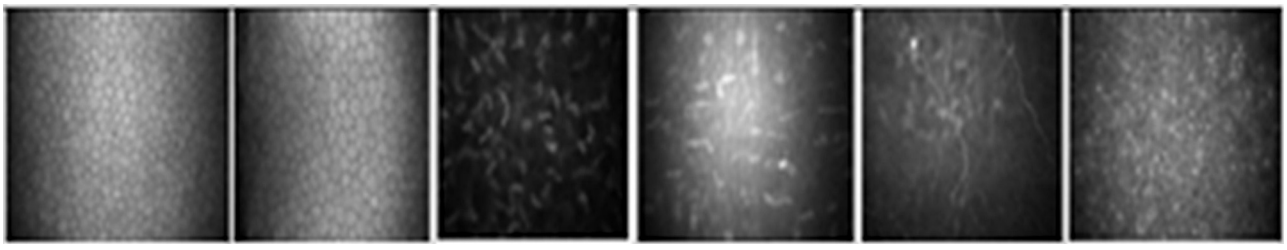

Fig. 2 – A short sequence of corneal images showing example pairs, from left to right of the endothelium, stroma and epithelium layers [8].