

A novel confocal system to provide high precision non-contact measurements of optical media applied to the human eye.

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Abstract: There are few affordable devices for the non-contact measurement of corneal thickness. This paper introduces a low cost instrument capable of measuring the position of interfaces within the human eye with micron level precision.

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1. Introduction

There are few instruments available in the market today with the ability to measure the thickness of the human cornea via a non-contact process. Contact pachymeters are much more common, usually taking the form of an ultrasound probe. The procedure required for the use of these instruments is complicated, requiring the eye to be anesthetized and the procedure carries the unnecessary risks of indentation, epithelial damage and infection [1]. The ocular hypertension treatment study acknowledged a widespread need for corneal thickness measurement for the treatment of glaucoma [2] and an alternative confocal technique was presented [3]. This paper introduces a device which can measure corneal thickness accurately with the potential for low cost production.

2. Instrument design

2.1 Confocal system

The confocal system produces a focal spot which is axially scanned through a transparent media and detects the signal returned from any interfaces of differing refractive index. A pinhole provides axial resolution (which is inversely proportional to its diameter) when placed at the conjugate plane of the focal spot. A system such as this can non-invasively measure the thickness of the cornea by detecting the reflected signal from the change in refractive index at the interface of the air-cornea and cornea-aqueous humour. The basic optical layout of the instrument is shown in Figure 1.

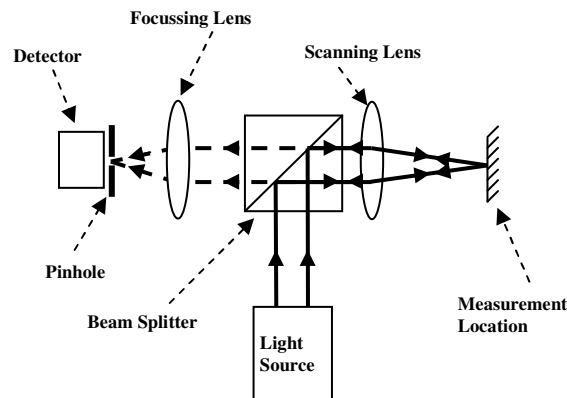


Figure 1. The basic optical layout of the confocal instrument.

2.2 Alignment to instrument

The interaction between the user and the instrument is key to the alignment process. It is imperative that the user's alignment to the instrument is repeatable to provide consistent measurements. A novel technique has been developed to ensure the correct alignment to the apex of the cornea is achieved each time.

When scanning the human eye a degree of movement is inevitable which can result in a large measurement error, even if the subject is aligned correctly. To overcome this, the subject focuses on a fixation target at infinity and the instrument employs an active curve selection algorithm.

Modeling has shown that the peak shape at the interfaces of an optical medium is highly dependent on the angle of incidence. By characterizing the peak shapes at different angles it is possible to determine the optimum geometry that corresponds to the desired alignment.

Figure 2 shows the expected peak shapes at varying angles of incidence.

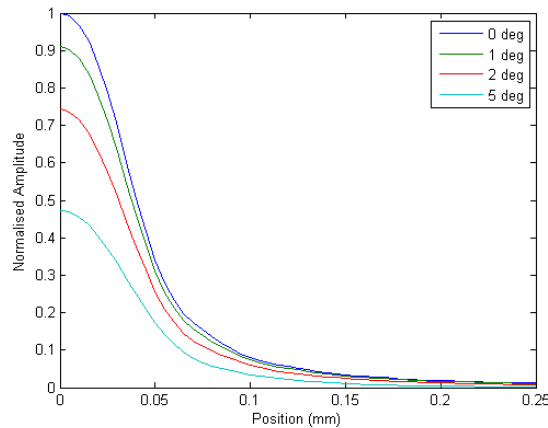


Figure 2. Modeled peak shape from a Gaussian measurement beam at varying angles of incidence.

Using modeled and empirical data an automatic curve selection algorithm was developed and implemented to actively select scans taken perpendicularly to the apex of the cornea, thus providing the most consistent measurement of central corneal thickness.

3. Results

The system currently scans at 5 Hz. As such a set of 30 scans of the anterior segment of the eye takes approximately 6 seconds. An example dataset is shown in figure 3.

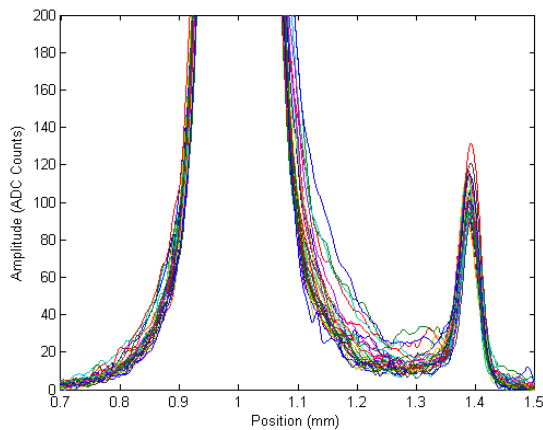


Figure 3. An example of 30 scans through the human cornea

The graph shows the region representing the cornea and shows the position of the anterior interface centered on 1 mm followed by the posterior interface. The separation of the peaks is then multiplied by the refractive index of the cornea to find the actual thickness. The average thickness measured in this example was 534 μm with a standard deviation of less than 3 μm .

Table 1 shows a series of consecutive measurements taken a few minutes apart to demonstrate repeatability of alignment. Each sample is the average of 30 individual scans. Between each sample the subject moved away from the instrument, then returned and realigned. The results in Table 1 show sub-micron repeatability between samples and a precision of better than $\pm 4 \mu\text{m}$.

Table 1. Consecutive corneal thickness measurements.

Sample	Sample Size	Mean (μm)	Standard Deviation (μm)	Standard Error (μm)
1	30	534.6	3.3	0.8
2	30	534.0	3.3	0.6
3	30	534.4	2.9	0.5
4	30	534.0	3.8	0.7
5	30	534.5	3.3	0.6

4. Discussion

In measurements of optical media using this device have demonstrated that the thickness of an optical medium can be measured to sub micron levels of both accuracy and precision. Due to the relatively high degree of movement of the eye and the non-uniform nature of the human cornea this level of accuracy is difficult to achieve in vivo. With the alignment procedure outlined above we have achieved a level of precision of $\pm 4 \mu\text{m}$ with a repeatability of less than $\pm 0.5 \mu\text{m}$.

Due to the simple nature of the device it lends itself well to both miniaturization and bulk manufacture greatly reducing the cost of the device. Owing to the fact that it is a non-contact device the cost of ownership is significantly reduced as minimal consumables are required. The intelligent nature of the alignment technique and the curve selection employed also make the device very simple to use for both the operator and the user.

5. Acknowledgements

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6. References

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