In Application

Elastic Stiffness Characterization using Three-dimensional Full-field Deformation obtained with Optical Coherence Tomography and Digital Volume Correlation

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Introduction

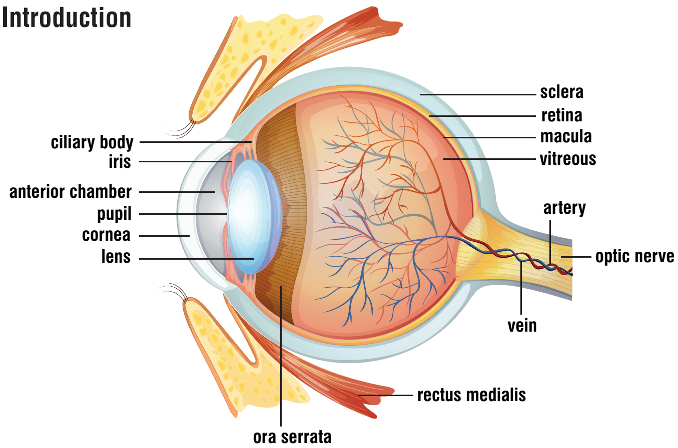

Figure 1: *Illustration of the human eye showing cornea*

For materials with complex structures, such as biological tissues and composites, surface measurements are not really adequate to address their complete mechanical behaviour since the deformation may vary significantly between the bulk and the surface. In this case, a depth-resolved three-dimensional (3-D) full-field measurement of the deformation is highly desirable. Thanks to the development of the various tomographic techniques, Digital Volume Correlation (DVC) has become a popular measurement technique for depth-resolved 3-D deformation fields.

The specimens under study were silicone rubber phantoms which simulate real cornea. Usually X-ray computed tomography is used to generate the volumes required for DVC however, for soft biological tissues such as cornea, arteries, or skin, Optical Coherence Tomography (OCT) is a more suitable technique. This study is novel in that DVC has been coupled with a single channel OCT system to obtain full-field displacement and strain measurements.

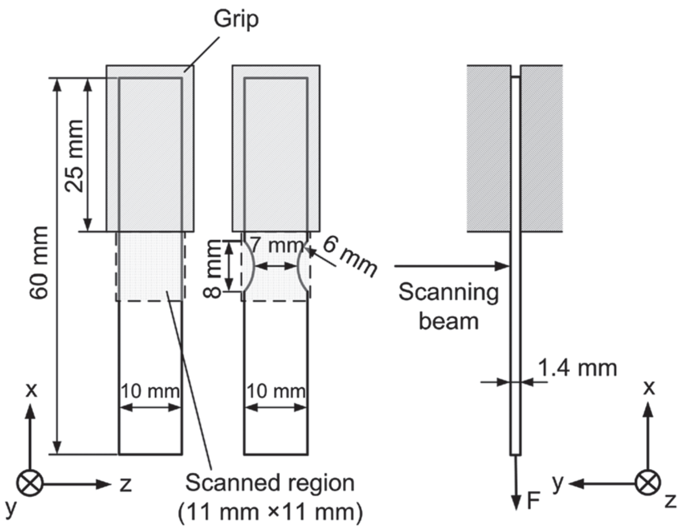

Figure 2: *Schematic of the fabricated silicone rubber phantom strips and the loading configuration*

Experimental Setup

Two rectangular flat phantom strips fabricated using silicone gel (MM240-TV) were used. Copper particles were seeded into the silicone gel to provide the necessary internal speckle pattern for DVC. One specimen contained a notch as shown in Figure 2. The specimens were secured with one end in the fixture and the other end loaded by a 10 g dead weight.

Volumes were acquired using a Thorlabs SS-OCT system and volumes of 1024 x 512 x 1024 voxels were used for analysis. Along lateral scanning directions, x and z, the reconstructed voxel size was 10.7 µm whilst the through-thickness y direction (corresponding to the optical path) was 4.1 µm. Figure 3 shows a typical reconstructed volume.

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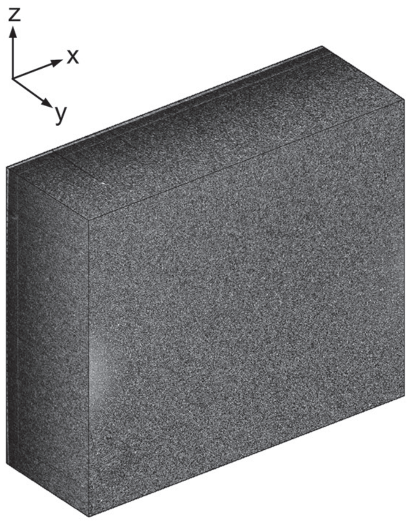

***Figure 3:** Typical reconstructed image volume*

Results

The optimal sub-volume size was determined via stationary and rigid body tests. An optimal sub-volume of 36^3 voxels with 50% overlap was used meaning a volume contained 55 x 18 x 50 measurement points. For these settings the strain resolution for the stationary test was generally between 1.5×10^{-4} and 2.5×10^{-4} without any smoothing which was satisfactory compared with the strain levels obtained in the tensile test.
For the actual test results Pre-smoothing of the images using a Gaussian filter proved effective in reducing interpolation bias.

For the notched strip, the ε_{xx} strain maps showed positive results, while the ε_{yy} and ε_{zz} showed negative values consistent with the Poisson's effect. A strain concentration was observed near the top notch tip of the strip for the normal strain component which was consistent with the larger x-displacement found in that region. The elastic stiffness components of rectangular and notched silicone rubber phantoms were extracted from the full-field data using the Virtual Fields Method (VFM). In both tensile tests the Young's Modulus and Poisson's ratio values obtained from the VFM were consistent with each other.

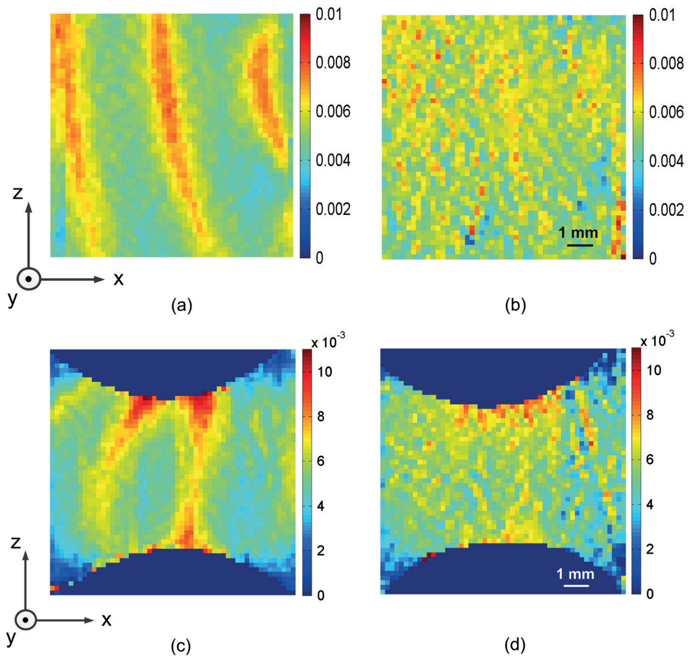

***Figure 4:** Spatial distributions of the normal strain ε_{xx} obtained at central y slice 10 for phantom strips under tension (load step 1).*
(a) Rectangular, no presmoothing.
(b) Rectangular, with presmoothing.
(c) Notched, no presmoothing. (d) Notched, with presmoothing.

This study coupled DVC with a single channel OCT system to obtain full-field displacement and strain measurements.
It demonstrates the power of DVC to calculate full field strain data from different types of volume imaging techniques with good accuracy and resolution and demonstrates the possibilities of coupling DVC with advanced calculation techniques such as the Virtual Fields Method. Exciting work continues in this area and the group have successfully obtained results on real corneas (to be published soon).

For further details the reader is referred to Fu J., Pierron F., Ruiz P.D., Elastic stiffness characterization using three-dimensional full-field deformation obtained with optical coherence tomography and digital volume correlation, Journal of Biomedical Optics 18 (12), 121512 (Dec 2013), DOI: 10.1117/1.JBO.18.12.121512

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