doi:10.1017/S1431927610063178
Microsc. Microanal. 16 (Suppl 2), 2010

A Low Error Reconstruction Method for Confocal Holography using Limited View Tomography to Determine 3-Dimensional Properties

P.B. Jacquemin and R.A. Herring
CAMTEC, Mechanical Engineering, University of Victoria, Victoria V8W 3P6 Canada

A new method to reconstruct the three-dimensional (3D) refractive index or temperature of a specimen with limited viewing confocal holography is presented here. Scanning is restricted to a single viewpoint window with a scan angle that is limited to the cone angle of the probe beam within the specimen. Tomographic reconstruction typically uses a 160° to 360° scan angle with small angle increments for low reconstruction error. The confocal holography microscope does not allow rotations of the specimen or the microscope optics which restricts the scan angle to 28° for reconstruction. Scanning by translating the focal point of the probe beam within the specimen along the optical propagation axis produces a singular non-invertible reconstruction matrix. Increasing the number of scan positions within the specimen produces redundant data and an ill-conditioned reconstruction matrix with excessive reconstruction error. The reconstruction problem is overcome by combining a particular scanning geometry with boundary conditions. The volume of the specimen is scanned by translating the focal point of the probe beam in *xyz*-directions within the specimen. The specimen is a BK7 refractive index matching liquid in a 5x5x45mm fluid-cell cuvette. The boundary conditions are defined by the temperatures along the side walls of the fluid-cell. The novel reconstruction algorithm is called "wily" because the sparse reconstruction matrix contains not a single non-zero diagonal element and yet it is well conditioned for inversion. Negligible reconstruction error is important to improve the accuracy of the microscope since it is sensitive to minute phase-shifts or fringe translations in holograms.

The confocal holography microscope was originally designed to non-intrusively measure the three-dimensional temperature and composition of transparent solids and fluids [1]. An object beam that propagates through the specimen is combined with a reference beam to form a hologram. The fringes in the hologram translate as a phase-shift in response to a change in temperature or composition. Both temperature and composition can be determined from the index-of-refraction [2]. Refractive index information is contained within the scanned holograms. A convergent beam for a single scan position is shown in Fig 1 where a small sphere is positioned at the focal point and another sphere that partially intercepts the central rays is positioned off to the side. The difference in information between the two positions is detected in the holograms. The simulated hologram of Fig 2 shows the phase shifts of the fringes for a high refractive index sphere centered at the focal point of the convergent beam. Fig 3 shows the fringe shift pattern for the sphere that is off to the side from the focal point of the convergent beam. The horizontal lines are due to the wave interference of the overlapping beams outside the sphere region. A cone beam angle of 28º is seen in Fig 1 for a single scan position and in Fig 4 for multiple scan positions.

Applying standard methods of limited viewing tomography produces an unacceptable index reconstruction error of 10^{-3}. Small increases in cone angle will not sufficiently reduce this reconstruction error when using a single observation window. The "wily" matrix is generated from the propagation of the marginal rays through a 6-row x 8-column grid where the top and bottom rows are boundary conditions as shown in Fig 4. The "wily" algorithm uses the marginal rays of the convergent beam for each scan position through the specimen. Translational scanning of the beam is along the $i-1$ and $i+1$ positions and step-wise down the optical propagation axis. The scan position for each of the marginal rays within the grid produces a 32x32 path length matrix. Every

ray has an Optical Path Length (*OPL*) through the specimen which produces a phase-shift within the hologram. The hologram contains refractive index information in the form of a Radon line integral or the cumulative *OPL* for any ray within the beam. The optical path length is defined by $OPL = [wily] \times \vec{n} + OPL_{BC} = \lambda \cdot \vec{\phi}_{obj}$ which is equal to the wavelength times the phase-shift vector. The "wily" matrix is a function of geometric path length which is inverted to produce the internal index-of-refraction. The scanning geometry and computational domain grid-mesh space affects the linear independence of the line integral equations which constitute the cumulative refractive index times the path length through the specimen region. The "wily" matrix reconstruction method produces an RMS refractive index error less than 10^{-5} which was recently achieved. A centered point source heater in a fluid-cell produces a negative Gaussian refractive index profile as shown in Fig 5. Applying the "wily" algorithm to this heated specimen produces a very low refractive index reconstruction error such that an accurate internal temperature profile can be determined for our experiments. There are many applications for the "wily" algorithm which can be applied to stationary specimens or rotational scanning limitations.

[1] P. Jacquemin, R. McLeod, S. Lai, D. Laurin, R.A. Herring, *Acta Astronautica,* 60 (2007) 723.
[2] R.A. Herring, *Optik* 105 (1997) 65.

Funding from UVic, NSERC, CFI and BCKDF are greatly appreciated.

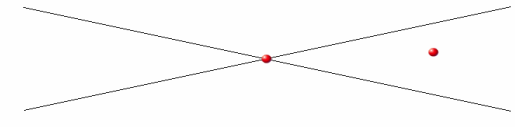

Figure 1. Focusing Beam onto High Refractive Index Sphere at and away from Focal Point

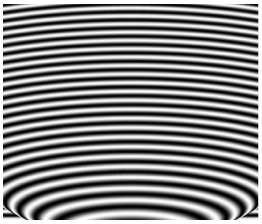

Figure 2. Fringe Shift for Sphere at Focal Point

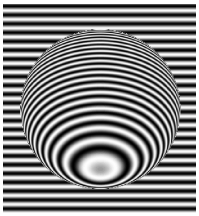

Figure 3. Fringe Shift for Sphere away from Focal Point

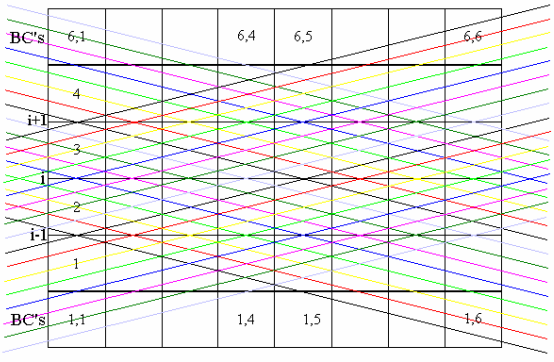

Figure 4. Scanned Rays through Fluid-Cell 6x8 grid-mesh

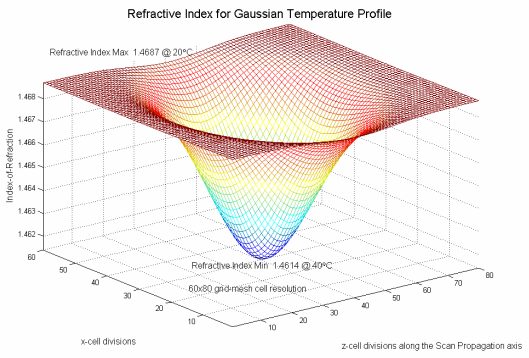

Figure 5. Gaussian Refractive Index Profile through Fluid-Cell

https://doi.org/10.1017/S1431927610063178 Published online by Cambridge University Press