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• Mathematical model of OCT
• K-space analysis of OCT
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• Synthetic aperture OCT
• Diffraction tomography
Optical Coherence Tomography

DAVID HUANG, ERIC A. SWANSON, CHARLES P. LIN,
JOEL S. SCHUMAN, WILLIAM G. STINSON, WARREN CHANG,
MICHAEL R. HEE, THOMAS FLOTTE, KENTON GREGORY,
CARMEN A. PULIAFITO, JAMES G. FUJIMOTO*

A technique called optical coherence tomography (OCT) has been developed for noninvasive cross-sectional imaging in biological systems. OCT uses low-coherence interferometry to produce a two-dimensional image of optical scattering from internal tissue microstructures in a way that is analogous to ultrasonic pulse-echo imaging. OCT has longitudinal and lateral spatial resolutions of a few micrometers and can detect reflected signals as small as $\sim 10^{-10}$ of the incident optical power. Tomographic imaging is demonstrated in vitro in the peripapillary area of the retina and in the coronary artery, two clinically relevant examples that are representative of transparent and turbid media, respectively.
OCT System
Fig. 2. Optical coherence tomograph of human retina and optic disk in vitro (A) and histologic section of the same specimen (B). Eye bank specimens were kept at 4°C and measured within 24 hours after death. (A) Cornea and lens were removed before OCT scanning and the OCT beam was delivered through the vitreous medium and focused on the retina. The tomographic image corresponds to a section of the retina and optic disk along the papillomacular axis. The retina temporal to the disk is on the left. Identifiable structures are, from top to bottom, vitreous, retina (RNFL, red; subjacent retina, yellow to light blue), subretinal fluid (SRF), retinal pigment epithelium (RPE), and choroid and sclera. The RNFL thickness varies between 70 and 90 μm, increasing toward the optic disk. The overall retinal thickness is 220 μm. Blood vessels (BV) in the optic disk appear as characteristic dark spots. The nasal retina appears on the far right. The sampled pixel size is 3.6 (vertical) by 20 (horizontal) μm. Interpolation between pixels was performed to improve image readability. The color scale spans $4 \times 10^{-10}$ (black) to $10^{-6}$ (white) of the incident power. (B) Retinal thickness closely matches those of the tomograph; the SRF is much smaller than in the tomograph because of dehydration during histologic processing. Vitreous (V), retina (R), sclera (S), blood vessel (B), SRF (F). Bar = 300 μm.
Projection Tomography
MRI

Fig. 1: MR scanner
Fig. 1.  L, laser; A, spatial filter; O, object; C, observed point; H, hologram plate; B, point of observation; and D and E, two mirrors. e₀, e₁ and e₂ are portions of ellipsoids perpendicular to the bisector of ACB. while h₀, h₁ and h₂ are portions of hyperboloids parallel to the bisector of CBD. From the intersection of H by h₀, only those parts on O are seen that represent its intersection by e₀, because the pathlength ACB is equal to AEDB.
Holographic model for OCT

\[ |R + s(x)|^2 \]

\[ \omega = 2\pi \frac{\delta}{\lambda} \]

\[ \text{Object} \]

\[ \text{Reference} \]

\[ \boxed{E_{IF} = \hat{R} \hat{k} + \hat{s}^* \hat{s}} \]

\[ + R \hat{s}(v-v_0) \]
Sampling model for OCT

\[ s(x) = \int f(z) \rho(x - \frac{2z}{a}) \, dz \]

\[ r(x) = \rho(x - \frac{2\xi}{a}) \]

\[ I = |s(x) + r(x)|^2 \]

\[ g(\xi) = \rho^*(x - \frac{2\xi}{a}) \int f(z) \rho(x - \frac{2z}{a}) \, dz \]
\[
\hat{g}(\nu) = \frac{\hat{f}(\nu) S(\nu) e^{\frac{2\pi i}{\nu}}}{\nu^2}
\]

\[
P(\tau) = \langle \hat{p}(\nu) \hat{p}(\nu-\tau) \rangle
\]
Resolution and bandwidth of OCT

\[ \Delta z = \frac{c \tau}{2} \]

\[ \Delta v = \frac{1}{\tau_c} \]
K-space analysis of OCT

Fourier space of field

Fourier space of object

Lecture 9. Optical coherence tomography

www.disp.duke.edu/~dbrady/courses/holography
K-space and 3D imaging

Fourier space of field

FS object

Unlimited angles

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3D model for OCT

Inverse scattering for optical coherence tomography

Tyler S. Ralston, Daniel L. Marks, P. Scott Carney, and Stephen A. Boppart

Beckman Institute for Advanced Science and Technology, Department of Electrical and Computer Engineering,
University of Illinois at Urbana-Champaign, Urbana, Illinois 61801
Fig. 1. (a) Typical Michelson interferometer for use in OCT. BS is the beam splitter, P_s is the sample path, P_r is the reference path, and $h$ is the distance traveled by the reference mirror. (b) Interferogram of an impulse response for an OCT system with a low-coherence source having a Gaussian spectrum and a full width at half-maximum (FWHM) coherence length $L_c$.

Fig. 2. Geometry of a Gaussian beam for low- and high-numerical-aperture (NA) lenses. These geometries are contrasted with the assumption of a collimated axial OCT scan. $b$ is the confocal parameter, $w_0$ is the beam radius at the focus, and $L_c$ is the coherence length of the source.
\[ S(\mathbf{r}_0, k) = i2\pi A(k)k^{-1} \int d^3 r f(\mathbf{r} - \mathbf{r}_0, k)^2 \eta(\mathbf{r}), \]

\[ U(\mathbf{r}, \mathbf{r}_0, k) \]

\[ g(\mathbf{r'} - \mathbf{r}_0, k) \]

\[ \eta(\mathbf{r'})G(\mathbf{r'}, \mathbf{r}, k) \]
General problem of holographic diffraction tomography
General problem of holographic diffraction tomography