Lecture 15: Optical Coherence Tomography Resumé

Contents

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Optical Coherence Tomography (OCT)

- 3-D imaging method based on visible light
- increasingly relevant in medical imaging:
  - ophthalmology (eyes, in particular retina)
  - histology/pathology (tissue)
- uses back-scattered light
- reconstruction similar like in ultrasound imaging

Optical Coherence Tomography (2)

Why Is Skin Intransparent?

Objects in general are intransparent by two mechanisms:

- Absorption
- Scatter

Skin and some other soft tissues absorb only small portions of incident light on short distances. The main reason why we can't see through skin is scatter.

Back-scattered light from **below** the surface, up to several millimetres in depth, contributes essentially to the visual impression of skin.

Optical coherence tomography is able to extract information from this back-scattered light.

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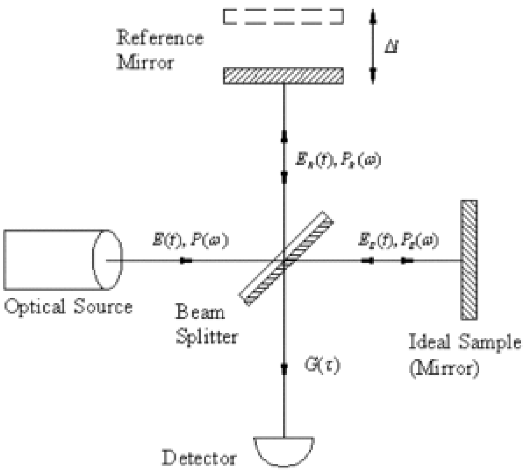
Optical Coherence Tomography (3)

Interferometric Measurements

A beam is split into two parts. Both partial beams remain capable of interference provided that their travelled distances are approximately equal. (The maximal tolerable pathlength difference is called *coherence length*. It depends on the light source (long for lasers).)



Michelson interferometre. Interference patterns are observed at the detector if both partial beams have equal pathlengths, with differences not larger than the coherence length. *(Wikipedia)*

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Optical Coherence Tomography (4)

Imaging Principle

- Optical coherence imaging relies on the detection of photons that have been **back-scattered exactly once** in the probe.
- The decreasing part of such single-scatter photons with increasing depth limits penetration depth to ca. $2\,\mathrm{mm}$.
- Light with short coherence length (in the range of micrometres) is used.
- The beam is split into one beam sent to the object, and one reference beam that is reflected by a mirror at defined distance. Only back-scattered photons which have travelled the same pathlength contribute to interference. *The intensity of interference phenomena therefore allows a depth resolution (axial resolution) in the order of magnitude of the coherence length.*
- Transversal resolution is determined by the focussing of the beam.
- Transversal and axial resolution rely on different mechanisms and are therefore decoupled.
- Among the typical light sources are specific diodes, and as detectors one can use e.g. photodiodes.

Optical Coherence Tomography (5)

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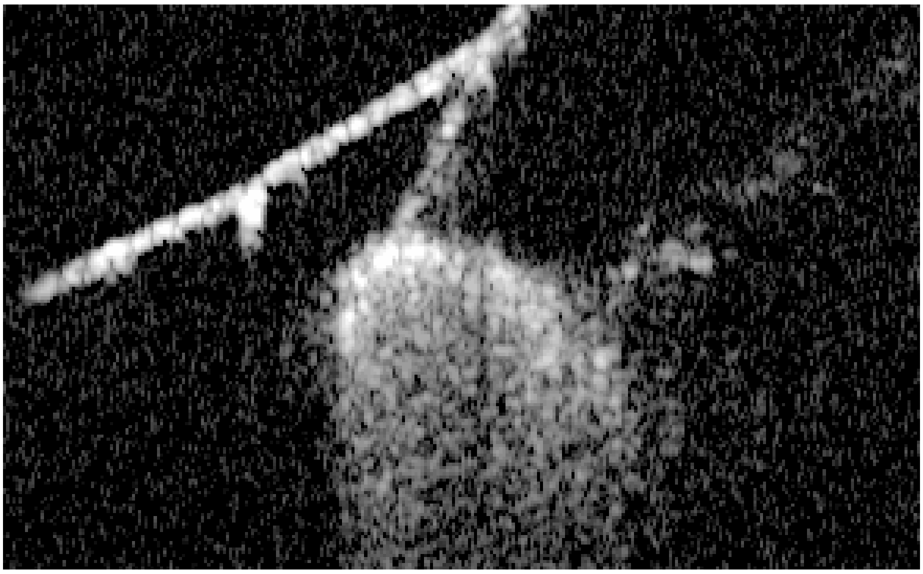
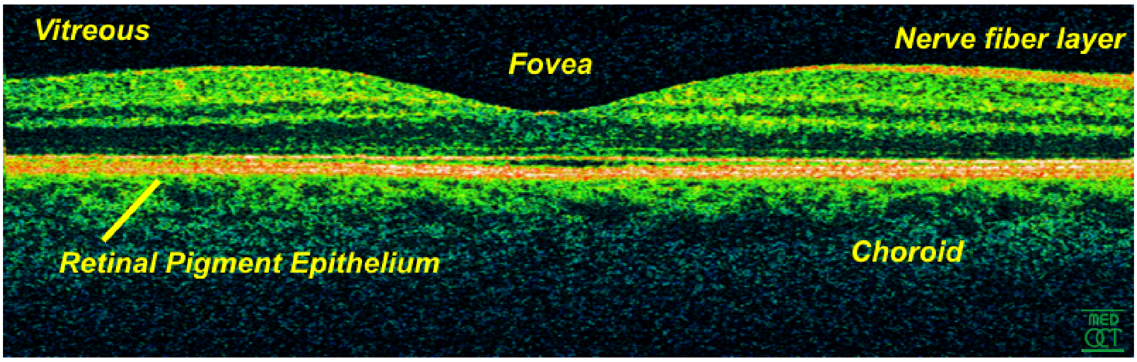
Examples



Optical coherence tomogram of human middle ear. Top left: the eardrum, below: part of the hammer bone. *(Laser Research Lab, University Hospital Munich, http://laser.klinikum.uni-muenchen.de/)*

Optical Coherence Tomography (6)



Optical coherence tomogram of human retina, pseudocolour representation. *(Vienna Medical University, medOCT group, copied from Wikipedia)*

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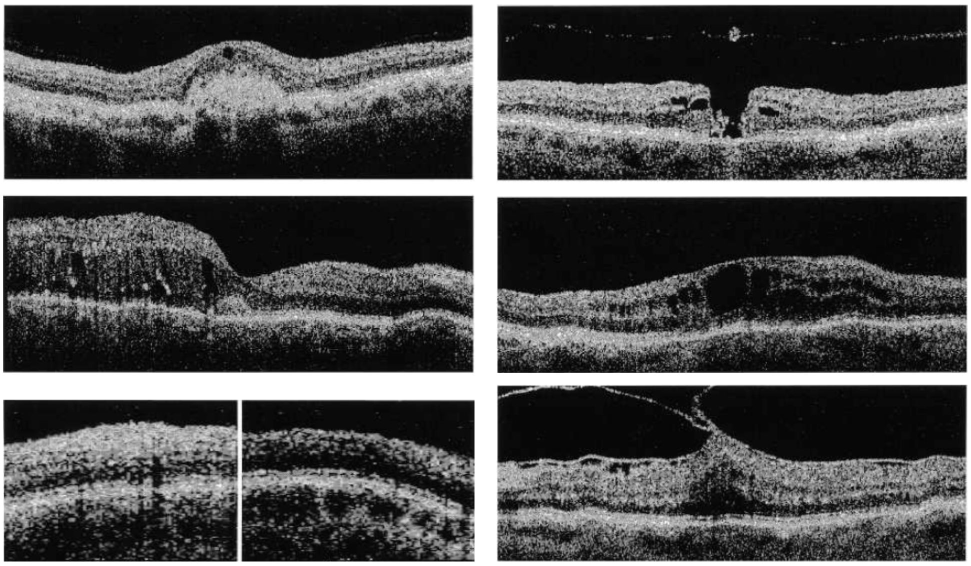
Optical Coherence Tomography (7)



Human retina with different defects and degenerations. *(J. and J. Garus, Pfaffenhofen)*

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Summary

- Optical coherence tomography (OCT) is a 3D imaging method based in visible light.
- It uses back-scattered light and measures depth in a interferometric process.
- main application: retina

References

- A. F. Fercher, W. Drexler, C. K. Hitzenberger, T. Lasser: Optical coherence tomography – principles and applications. *Reports on Progress in Physics*, 66:239–303, 2003

Summary of the Entire Class

The following overview of topics is updated from Lecture 1.

Lecture 1: Introduction and Basic Concepts

- Introductory examples – What do we mean by an image?
- Basic definitions and distinctions

Lecture 2: Basic Concepts

- Mathematical tools (Fourier transform, convolution)
- Sampling (sampling theorem, aliasing, PSF, deconvolution problem)
- Sensor fusion (incl. image registration problem)

Lecture 3: Electromagnetic Spectrum

- Electromagnetic waves
- The spectrum

Lecture 3–6: Imaging by Visible Light

- Basic visible light optics
- Lens optics, camera models
- Measuring and perceiving light
- Image sensorics (photochemical emulsions, electrophotography, semiconductor-based sensors)
- Colours (spectrum, retinal colour perception, colour spaces)
- Extensions: UV and IR imaging
- Telescopes
- Mirror optics
- Microscopy
- Dual photography
- Triangulation methods (active, passive=stereo vision)
- Holography

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Summary (3)

Lecture 7: X-Ray and Gamma Ray Imaging in 2D

- Sources of X-rays and gamma rays
- Transmission radiography
- Emission radiography
- X-ray astronomy

Lecture 8: Microwave and Radio Wave Imaging

- Radio waves and microwaves
- Antennas
- Radioastronomy (radiotelescopes, radio interferometry)
- Radar
- Terahertz imaging

Summary (4)

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Lecture 9–10: Computerised X-Ray Tomography (CT)

- Motivation and principle of X-ray transmission tomography
- Basic modelling and naive back-projection
- Radon transform, Fourier Slice Theorem
- Tomographic reconstruction
- CT scanner technology
- Visualisation of CT data
- Artifacts and noise in CT
- Single photon emission computerised tomography (SPECT)
- Positron emission tomography (PET)

Summary (5)

Lecture 11–12: Magnetic Resonance (MR) Imaging

- Physical principle of nuclear magnetic resonance imaging
- Line integral measurement and Fourier measurement
- different measurement modi
- Image degradations: artifacts, distortions
- Functional MRI
- Diffusion MRI (diffusion-weighted images, diffusion tensor images)

Summary (6)

Lecture 13: Electron Microscopy

- Electron radiation
- Interaction with matter
- Electron optics
- Transmission electron microscopy (TEM)
- Scanning transmission electron microscopy (STEM)
- Scanning electron microscopy (SEM)
- Scanning tunneling microscopy (STM)

Summary (7)

Lecture 14: Acoustic Imaging

- Acoustic waves
- Interaction with matter
- Sonar
- Ultrasound imaging

Lecture 15: Supplements

- Optical coherence tomography (OCT)

Summary (8)

What We Have Done

- **Overview over different imaging methods**
  - Systematised by the medium through which information is transferred from objects to sensors
- **For each class of methods**
  - Basic physical principles
  - Mathematical modelling of the imaging process
  - Meaning of image information
  - Limitations and problems
  - Main representative covered in detail
  - Important modifications introduced in short

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What Is Missing ?

- **Further Modifications.**
  There exist a number of modifications of the methods shown here. Many of them rely on ideas that have been shown exemplarily in one class of methods.

- **Further Basic Principles.**
  There are a few further physical principles which are exploited in (indirect) imaging methods, e.g. imaging by seismic waves.

- **More details.**
  Discussion of the several aspects of the imaging methods had to remain fragmentary, e.g.
  - Mathematical modelling
  - Discussion of noise statistics

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Upcoming Classes

Having learnt how images are made, you are encouraged to learn how to process them. In the summer term our group offers the following classes:

- **Differential Equations in Image Processing and Computer Vision**
  Lecture (4+2) by Joachim Weickert
  ▶ *Specialised lecture reaching out to central research topics of our group.*

- **Numerical Algorithms for Visual Computing I**
  Lecture (2+2) by Michael Breuß
  ▶ *Specialised lecture with focus on numerics.* –

- **Correspondence Problems in Computer Vision**
  Lecture (2+2) by Andrés Bruhn
  ▶ *Specialised lecture.*

- **Differential Geometric Aspects of Image Processing**
  Lecture (2+1) by Martin Welk
  ▶ *Specialised lecture.*

- **Integral Equations for Visual Computing**
  Lecture (2+2) by Bernhard Burgeth
  ▶ *Specialised lecture.*

Further information:
http://www.mia.uni-saarland.de/teaching.shtml

More classes offered by other groups:
http://master-visual-computing.de

Exam and Self Test Problems

- first exam: Wednesday, February 27, 2008, 2:00–4:00 pm
- second chance: Thursday, April 10, 2008, 2:00–4:00 pm
- These are closed book exams, i.e. lecture notes and books are not permitted.
- Everybody who registered for these classes may participate.
- You may participate in both exams, and the better grade counts.
- Self test problems similar in style will be available on the web page as of tomorrow.

Thank you, and much success !

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