Tomographic Imaging
EE 4354 and EE 5354
Syllabus

Spring 2015

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1 General Information

Course ID: Tomographic Imaging, EE 4354 (CRN 26812) and EE 5354 (CRN 26849)

Lecture: Monday and Wednesday 10:30 am to 11:50 am

Textbook [KS01]

Classroom: Miners Hall 300

Prerequisites: Digital signal processing EE 4383 or instructor approval

Instructor: R. von Borries – rvonborries@utep.edu

Office: Engineering Building 313

Office Hours: Monday and Wednesday 12:00 pm to 1:00 pm and 6:00 pm to 7:00 pm

Version: February 24, 2015

2 Objective

Study of physical and mathematical principles used in tomography. Topics include mathematical model for tomography with non-diffracting as well as diffracting sources, Radon transform, Fourier transform, Hilbert transform. Algorithms for image reconstruction from projections, filtered back-projection algorithm, algebraic reconstruction algorithms. Problems associated with data acquisition in computed tomography such as finite beam width, aliasing artifacts and noise. Prerequisite: EE 4383 or instructor approval.

3 Outcomes

The course is divided into five main modules listed below with their respective expected outcomes for EE4354 (undergraduate level, U) and EE5354 (graduate level, G). Both groups, undergraduate (U) and graduate (G), are exposed to the same course content through the textbook, lectures and complementary reading; however, graduate students are expected to do additional course work covered in more advanced complementary research papers.

- Mathematical background (U+G)
  - To apply mathematical and engineering principles: convolution, filtering, Fourier transform, Hilbert transform, linear equations. (U+G)
  - To identify and formulate engineering problems: computed tomography, the radon transform and reconstruction algorithms. (U+G)
- Radon transform (U+G)
  - To apply mathematics and engineering principles, to analyze and interpret data: Radon transform and its inverse. (U+G)
- Reconstruction in tomography (U+G)
  - To conduct experiments, analyze and interpret data, to identify, formulate and solve engineering problems: algorithms for parallel beam geometry. (U+G)
  - To conduct experiments, analyze and interpret data, to identify, formulate and solve engineering problems: algorithms for fan beam geometry, diffraction tomography. (G)
- Imaging artifacts in tomography (U+G)
  - To conduct experiments, analyze and interpret data: algorithmic artifacts (point spread function) and measurement errors, limited angle tomography, beam hardening. (U+G)
  - To identify, formulate and solve engineering problems: algorithmic artifacts (point spread function) and measurement errors, limited angle tomography, beam hardening. (G)
- Engineering applications (U+G)
  - To apply mathematical and engineering principles: ground penetrating radar, microwave tomography. (U+G)
  - To identify, formulate and solve engineering problems: microwave tomography, ground penetrating radar, synthetic aperture radar, medical imaging. (G)

4 Tentative Syllabus

4.1 A Basic Model for Tomography

First, we discuss some of the mathematical concepts underlying image reconstruction and signal processing. The material in this section is usually presented in undergraduate courses in linear algebra, digital signal processing and multivariable calculus. Our study of tomography begins with a mathematical model of the measurement process used in x-ray tomography: the Radon transform of two-dimensional slices. We then develop the mathematical tools needed to invert the Radon transform.

– Tomography
– The Fourier transform
– The Hilbert transform
– The Radon transform
– The Back-projection formula

4.2 Tomographic Imaging with Non-Diffracting Sources

This module proves the central slice theorem, establishing a connection between the Fourier and Radon transforms. The central slice theorem is then used to derive the filtered back-projection formula, which provides an exact inverse for the Radon transform. The filtered back-projection formula is built out of three basic operations: the Hilbert transform, differentiation, and back-projection. The back-projection formula is the basis of essentially all reconstruction algorithms used in x-ray computed tomography today. After analyzing the exact inversion formula, we consider methods for approximately inverting the Radon transform that are relevant in medical imaging.

– Basic setup in x-ray tomography
– The Radon inversion formula
– The central slice theorem
– Filtered back-projection
– Parallel beam reconstruction
– Fan beam reconstruction

4.3 Imaging Artifacts in X-Ray Tomography

In this module, we analyze the algorithms to approximate reconstruction from the sampled Radon transform using a more realistic model for the measurement process. We consider effects of finite beam width, aliasing artifacts and noise.

– The effect of a finite width x-ray beam
– The effect of insufficient data in the measurements
– The effects of noise in the measurements

4.4 Tomographic Imaging with Diffracting Sources

In this module, we study the basics of diffraction tomography, which is an alternative to straight line tomography. Diffracting sources include acoustic and electromagnetic radiation. In x-ray tomography, the projection yields the Fourier transform of the object over a straight line, while in diffraction tomography, the projection yields the Fourier transform of the object over a semicircular arc.

– The Fourier diffraction theorem
– Filtered back-projection

4.5 Algebraic Reconstruction Algorithms

The algebraic reconstruction algorithms for image reconstruction are based on iterative procedures for solving a system of linear equations. These techniques have no direct connection to the Radon inversion formula.

4.6 Applications of Tomography

Microwave tomography, ground penetrating radar, synthetic aperture radar, medical imaging.

5 Grading

5.1 Homework

Weekly homework, 50% of the final grade.

- Analytical and programming (Matlab) problems. (U+G)
- Advanced analytical and programming (Matlab) problems. (G)

5.2 Exam

Four exams, 50% of the final grade.

- Analytical and programming (Matlab) problems. (U+G)
- Advanced analytical and Matlab problems. (G)

5.3 Final Grade

$A = 100 - 90\%$, $B = 90 - 80\%$, $C = 80 - 70\%$, $D = 70 - 60\%$ and $F = 60 - 0\%$.

6 Accommodations and Support Services

If you have a disability and need classroom accommodations, please contact *The Center for Accommodations and Support Services (CASS)* at 747-5148, or by email to `cassutep.edu`, or visit their office located in UTEP Union East, Room 106. For additional information, please visit the CASS website at `www.sa.utep.edu/cass`.

A References

[Cie11] R. Cierniak. *X-Ray Computed Tomography in Biomedical Engineering*. Springer London, 2011.

[Eps08] C. L. Epstein. *Introduction to the Mathematics of Medical Imaging: Second Edition*. Society for Industrial and Applied Mathematics (SIAM, 3600 Market Street, Floor 6, Philadelphia, PA 19104), 2008. https://books.google.com/books?id=-_sdsL5d6fIC.

[Fee10] T. G. Feeman. *The Mathematics of Medical Imaging: A Beginner's Guide*. Springer Undergraduate Texts in Mathematics and Technology. Springer New York, 2010.

[Her80] G. T. Herman. *Image Reconstruction from Projections: The Fundamentals of Computerized Tomography*. Computer Science and Applied Mathematics Series. Academic Press, 1980.

[Her09] G. T. Herman. *Fundamentals of Computerized Tomography: Image Reconstruction from Projections*. Advances in Computer Vision and Pattern Recognition. Springer, 2009.

[JWE+11] C. V. J. Jakowatz, D. E. Wahl, P. H. Eichel, D. C. Ghiglia, and P. A. Thompson. *Spotlight-Mode Synthetic Aperture Radar: A Signal Processing Approach: A Signal Processing Approach*. Springer US, 2011.

[KS01] A. C. Kak and M. Slaney. *Principles of Computerized Tomographic Imaging*. Classics in Applied Mathematics. Society for Industrial and Applied Mathematics, 2001. https://books.google.com/books?id=Z6RpVjb9_lwC.

[Mar06] A. Markoe. *Analytic Tomography*. Number v. 13 in Analytic tomography. Cambridge University Press, 2006.

[MS12] J. L. Mueller and S. Siltanen. *Linear and Nonlinear Inverse Problems with Practical Applications*. Computational Science and Engineering. Society for Industrial and Applied Mathematics, 2012. http://books.google.com/books?id=P62t2uxPEYAC.

[Ros02] K. M. Rosenberg. CTSim − The open-source computed tomography simulator. http://ctsim.org, 2002.

[Zen10] G. Zeng. *Medical Image Reconstruction: A Conceptual Tutorial*. Higher Education Press, 2010.

B Calendar

January

M	T	W	R	F	S	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

2015

February

M	T	W	R	F	S	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	

2015

March

M	T	W	R	F	S	S
						1
2	3	4	5	6	7	8
					14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

2015

April

M	T	W	R	F	S	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

2015

May

M	T	W	R	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

2015

Exam 1
February 16
Exam 2
March 18
Exam 3
April 13
Exam 4
May 15, 10:00 am to 12:45 am
Spring Break: No classes
March 9 to 13