Unifying Framework for Subsurface Sensing & Imaging Textbook

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Unifying Framework
& Subsurface Imaging Textbook

1. A unified theory of SSI that integrates previously separate topics
& a systematic process for solving SSI problems

2. A taxonomy classifying the diverse SSI problems into fewer categories based on underlying physical, mathematical, and engineering principles

3. A set of demonstrated similar solutions to diverse problems

4. A new multidisciplinary field to be infused into the engineering curriculum
   - SSI courses
   - SSI Textbook

Preface

This textbook is suitable for a course on subsurface imaging (SSI) serving seniors or first-year graduate students in EE, ME, BME, Physics, Geoscience, or CS.

Course Objectives
- To introduce the field of subsurface imaging (SSI), its methods, applications, and research.
- To develop unified models for electromagnetic, optical, and ultrasonic SSI, including 2D and 3D conventional, scanning, confocal, interferometric, and tomographic imaging configurations.
- To describe analytical and numerical methods for image reconstruction and inversion, using real data with available toolboxes.
- To help prepare students for further graduate study or employment in government and industry in areas including environmental, medical, biological, and underwater applications.
Introduction to Subsurface Imaging

Chapter 1. Overview of Subsurface Imaging
Chapter 2. Physical Models of Subsurface Imaging
Chapter 3. Localized Subsurface Imaging
Chapter 4. Multiview Tomography
Chapter 5. Digital Subsurface Imaging
Chapter 6. Multispectral Subsurface Imaging
Chapter 7. Mosaicing & Multiple-Sensor Imaging
Chapter 8. Computational Simulation of Subsurface Imaging
Chapter 9. Guide to Subsurface Imaging

Appendices
Toolboxes

Chapter 1
Overview of Subsurface Imaging
1.1 Definition & Scope
1.2 Examples of Applications
1.3 Taxonomy of Subsurface Imaging
   1.3-1 Imaging scales
   1.3-2 Taxonomy of probes
   1.3-3 Taxonomy of probe-target interactions
1.4 Probing Configurations
   1.4-1 Localized Imaging
   1.4-2 Multiview tomography
   1.4-3 Multimodal & multispectral imaging
1.5 Systems Description
   1.5-1 Subsurface imaging as a system
   1.5-2 Classes of inversion techniques

Chapter 2
Physical Models of Subsurface Imaging
2.1 Waves (Electromagnetic and Acoustic)
2.2 Wave Interaction with Media
   2.2-1 Reflection & refraction
   2.2-2 Absorption
   2.2-3 Diffraction
   2.2-4 Scattering
   2.2-5 Diffusion
   2.2-6 Fluorescence
   2.2-7 Magnetic resonance
2.3 Sources and Detectors
   2.3-1 EM transmitters & receivers
   2.3-2 Optical sources & detectors
   2.3-3 X-ray sources & detectors
   2.3-4 Acoustic sources & detectors
   2.3-5 Phase-array scanners and detectors
2.4 Imaging Impediments
   2.4-1 Beam diffraction
   2.4-2 Pulse dispersion
   2.4-3 Rough surfaces

Chapter 3
Localized Subsurface Imaging
3.1 Transverse Imaging
   3.1-1 Gazing systems (Optical & ultrasonic imaging)
   3.1-2 Scanning systems (Laser scanning systems)
3.2 Linear Models of Imaging Systems
   3.2-1 Point spread function & transfer function
   3.2-2 Diffraction-limited imaging & resolution
   3.2-3 Incoherent imaging
3.3 Axial Imaging
   3.3-1 Spatial localization (Confocal microscopy)
   3.3-2 Temporal localization (Ultrasonic imaging, radar imaging)
   3.3-3 Interferometric localization (OCT)
3.4 Phase Imaging
   3.4-1 Interferometric Imaging (Phase contrast microscopy)
   3.4-2 Differential interferometric Imaging (DIC microscopy)
Chapter 8
Computational Simulation of Subsurface Imaging

8.1 Modeling of Realistic Geometries
8.2 Computational Analysis Methods
   MoM, FEM, Modal, Finite Diff., T-Matrix
8.3 Discretization
   8.3-1 Linearization
   8.3-2 Computer implementation
8.4 Limitations
   8.4-1 Matrix size, pts./wavelength of feature
   8.4-2 Stability
   8.4-3 Absorbing grid termination boundaries
   8.4-4 Time duration, frequency range
   8.4-5 Dispersion
8.6 Computational Validation
   8.6-1 Oversized grid boundary
   8.6-2 Higher resolution tolerance analysis
   8.6-3 FFT frequency behavior analysis
   8.6-4 Extreme parameter values limiting behavior

Chapter 9
Guide to Subsurface Imaging Systems

9.1 Motivating Applications for End-to-End Systems
9.2 Choice of Subsurface Probe(s)
   Material Properties: Target, medium, interfaces
   Penetration and target contrast for various probes
   Probe configuration: Localized vs tomographic
   Transverse and axial resolution
9.3 Forward Modeling
   Sensitivity analysis
   Sensor configuration optimization
   Computational simulation (Simulation Toolbox)
9.4 Image Reconstruction
   Localized probing
   Multi-view tomography (MVT toolbox)
9.5 Classification/Discrimination
   Shape (resolution)
   Spectral discrimination
   Sensor fusion (Registration toolbox)

Appendices

A1. Linear systems (continuous, 1D, 2D, 3D)
A2. Discrete Signals & Linear Systems
A3. Visualization
   1) 2D: field plots, quiver, contours, animation
   2) 3D: slices, mesh/surface, isosurface, polarization components vs. power flow

Toolboxes

T1. Multiview Tomography
T2. Hyperspectral Image Analysis
T3. Generalized Registration
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