KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DEPARTMENT OF MATHEMATICS

DHAHRAN, SAUDI ARABIA

Term 242

MATH 585: Computational Inverse Problems.

Instructor: Rachid Ait-Haddou

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Office Hours: Monday and Wednesday, 9:00 am to 11:00 am or by appointment

Prerequisite: Graduate Standing

Credit Hours: (3-0-3)

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Textbook/References:

1. Richard Aster: Parameter Estimation and Inverse Problems. (Main)
2. Christian Hansen, Discrete inverse problems - insight and algorithms, 2010
3. William Menke: Geophysical Data Analysis: Discrete Inverse Theory.

Course Description: This course introduces students to fundamental concepts in linear and nonlinear inverse problems. Emphasis is placed on describing how to integrate various information sources from measured data and prior knowledge about the inverted model. Subjects studied will include topics and tools such as: Regression, Least squares, Maximum likelihood estimation, Rank deficiency, Ill-conditioning, Generalized and Truncated SVD solutions, Regularizations (Tikhonov, spectral filtering), proximal and primal-dual iterative schemes, Nonlinear inverse (gradient-based and global optimization methods), OCCAM method. Computer lab sessions will be organized to combine classroom learning with hands-on applications.

Prerequisites by Topics: Calculus, Linear Algebra, Probability and Statistics, Programming skills

Computer Usage: Computer software is essential for this course. Mainly we will be using Python as the computational platform.

Attendance: Based on KFUPM attendance policy.

Communication: For regular announcements, students are advised to check Teams and Blackboard regularly.

Academic Integrity: All KFUPM policies regarding ethics and academic honesty apply to this course

Attendance: (As per KFUPM policy) **DN** is assigned for 20% (9) unexcused absences and 33% (15) overall absence (excused and unexcused)

Grading:

Activity	Weight
Assignments (Including programming tasks):	25%
Project(s)	20%
Midterm exam	25%
Final Exam	30%

Course Objectives:

Introduce students to fundamental concepts in linear and nonlinear inverse problems
Introduce data scientific software, toolboxes, and libraries
Solve problems in linear algebra and optimization topics related to data science.
Application of mathematical topics to basic neural network design.

Student Learning Outcomes: After completion of the course, the students should be able to

Explain how to set the inverse problems
Solve well posed and ill posed problems
Apply various regularization methods and how to choose the regularization parameters
Apply different linearization techniques for solving nonlinear inverse problems.

SCHEDULE and COVERAGE of MATERIAL

Week No. (Dates)	Reference	Topics
Week 1	**Chapter 1** **Chapter 1**	**Introduction** • What is an inverse problem • Continuous vs Discrete inverse problems • Linear vs Nonlinear inverse problems **Discretizing Integral Equations** • Application to continuous inverse problems (CIPs)
Week 2	 **Chapter 2** 2.1	**Code Illustration** Implement the midpoint discretization of CIP **Linear Regression** • Least Squares
Week 3	**Chapter 2** 2.2 2.5	 • Weighted Least squares • L1-Regression •
Week 4	**Chapter 3** 3.1	**Rank Deficiency and Ill Conditioning** • SVD and Generalized Inverse

	3.2	• Resolution of Generalized Inverse Solution
Week 5	3.3 3.5	• Instability of the generalized inverse solution • Discrete Ill-Posed Problems
Week 6	Truncated Singular value decomposition **Chapter 4** 4.2 4.3	**Tikhonov Regularization** • SVD implementation of Tikhonov regularization • Resolution of Tikhonov Solution
Week 7		**Code Illustration**: • Solving rank-deficient systems by SVD • Solving ill-conditioned systems by TSVD, Tikhonov regularization Goal: This illustrates what we have learned in chapters 3 and 4 with respected dealing with rank-deficient system and Ill-conditioning.
Week 8	**Chapter 6** 6.3 6.4	**Iterative Methods** • Gradient descent method and Stochastic gradient descent method • Conjugate gradient descent method
Week 9	6.4 6.6	• Conjugate gradient descent method • Resolution Analysis for iterative methods
Week 10		**Code Illustration**: • Implement the iterative algorithms for linear systems as well as regularized linear systems
Week 11	**Chapter 7** 7.1 7.3	**Sparsity Regularization** • Sparsity regularization • Sparse representation and compressed sensing
Week 12	**Chapter 9** 9.2 9.3	**Nonlinear regression** Newton's method for solving nonlinear equation GN and LM methods for solving nonlinear least squares
Week 13	**Chapter 9** 9.3	**Nonlinear Regression** GN and LM methods for solving nonlinear least squares **Code Illustration**: • Implement the GN and LM methods for estimating parameters in a nonlinear regression model
Week 14	**Chapter 10** 10.1 10.2	**Nonlinear Inverse Problem** Regularizing Nonlinear least squares problem OCCAM's Inversion

Week 15		**Project Presentation**
Final Project report submission		