Sensing Techniques & Data Analytics for Engineering Systems

Instructors

Principal Instructor: Mohammad Talebi-Kalaleh, M.Sc., Ph.D. Candidate

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Academic Details

Item	Specification
Level	Graduate (MSc / PhD) – open to Civil, Mechanical, Aerospace students
Credits	3 (3-0-0) • 3 -hour lecture / lab each week, 11 weeks
Term	Fall 2025
Prerequisites	Linear Algebra, Statistics, Introductory Structural Dynamics; Basic MATLAB & Python proficiency

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Learning Outcomes

By the end of the course, students will be able to:

1. Plan and implement optimal sensing strategies using strain, acceleration, fiber-optic, wireless and contactless technologies.
2. Process and interpret high-volume time-series data in time and frequency domains.
3. Develop data-driven models (ARMAX, Kalman filter, auto-encoders) for anomaly detection and system identification.
4. Apply advanced machine learning techniques for pattern recognition and anomaly detection in time-series data.

Course Structure

Week	Theme	Core Topics & Skills
1	Introduction & Motivation	Why Structural Health Monitoring (SHM) matters; typical data streams in civil engineering systems; the end-to-end SHM workflow; lessons from landmark SHM projects
2-3	Sensor Technologies	Strain gauges, accelerometers, fiber-optic sensors, acoustic-emission transducers, wireless/IoT nodes, vision-based sensors, smartphone sensors; practical DAQ design
3-4	Time-Domain Signal Processing	Time-series basics, correlation & convolution, impulse response; statistical descriptors; data cleaning, detrending, digital filtering, sampling theory, anti-aliasing, and robust handling of outliers / missing data
5	Frequency-Domain Analysis	Mathematical transforms for SHM: FFT, PSD, STFT and wavelets; non-parametric modal identification
6-7	Advanced Time-Series Models	Parametric AR/ARMA/ARMAX models; state-space model; Kalman Filter for virtual sensing and system parameter identification
8	Feature Engineering & Statistical Anomaly Detection	Damage-sensitive features in time and frequency domains; PCA; Feature extraction from digital images; feature fusion; statistical novelty metrics
9-10	Machine-Learning Feature Extraction	ML fundamentals; k-means clustering; deep unsupervised models (auto-encoders and GANs) for subtle anomaly detection and data augmentation
10-11	Optimization & System Identification	Gradient-based and derivative-free optimization; D-optimal sensor placement; finite-element model calibration; system identification with physics-informed neural networks (PINNs)

Signature Learning Activities

Activity	Timing	Purpose
Individual Project (3 phases)	Weeks 1–12	End-to-end SHM workflow on real dataset
Mini-labs	biweekly	Hands-on tasks using MATLAB & Python notebooks

Assessment Scheme

Component	Weight
Mini-labs (4)	20 %
Project – Phase 1 (proposal)	10 %
Project – Phase 2 (intermediate)	20%
Project – Phase 3 (final report + presentation)	30 %
Final take-home	20 %

Teaching Approach

Hybrid theory-practice: concise derivations followed by live coding on engineering datasets, with interactive apps to play with deferent aspects of data analytics. Course notebooks provide starter code; students extend and critique results.

Learning Resources

Primary textbook: Farrar & Worden, Structural Health Monitoring: A Machine-Learning Perspective (Wiley, 2013).

Supplementary chapters/papers from current journal articles.

Software: MATLAB (Signal & System ID toolboxes), Python (NumPy, SciPy, scikit-learn, PyTorch), optional FE in OpenSeesPy.