UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Environmental Monitoring and Management

2526-2-F9102Q011

Aims

The aim of this course is to provide students with a comprehensive understanding of radar remote sensing for environmental monitoring, with a particular focus on the physical principles, signal processing techniques, and interpretation of Synthetic Aperture Radar (SAR) data. The course will begin by introducing the essential elements of signal theory that are necessary to understand how SAR systems function. Students will then explore SAR data formation, processing, and the extraction of meaningful information from radar signals.

The applications considered in the course will cover a wide range of environmental domains, including land cover analysis, vegetation and soil moisture monitoring, urban mapping, change detection, and hydrological applications. By the end of the course, students will be equipped to critically assess SAR-based environmental data products and understand how radar remote sensing contributes to Earth observation strategies.

Contents

The course delivers theoretical foundations and practical tools for using spaceborne SAR data in environmental monitoring. Emphasis is placed on understanding SAR signal formation, radar- environment interactions, and the steps required to process raw radar data into actionable information.
Students will be guided through the fundamentals of signal processing as they relate to radar systems, with particular attention to the mechanisms behind resolution, coherence, speckle, and backscatter. A variety of data products (amplitude, interferometric, polarimetric) and their environmental relevance will be examined.
Practical sessions using open-source tools and GIS platforms will support the application of concepts through real-world examples.

Detailed program

1. Introduction to Environmental Monitoring with Remote Sensing

- Role of satellite Earth observation in environmental monitoring
- Overview of active vs. passive remote sensing
- Advantages and limitations of radar for environmental applications

2. Fundamentals of Signal Theory (for Radar Understanding)

- Signals and systems: basic definitions and properties
- Fourier transform and spectral representation
- Time-frequency analysis concepts
- Matched filtering and correlation
- Basics of wave propagation and time delay in radar systems

3. Radar Remote Sensing and SAR Imaging

- Principles of radar: pulse transmission, reflection, and return
- Synthetic Aperture Radar: geometry and signal acquisition
- Resolution in range and azimuth: how SAR achieves high resolution
- SAR signal compression and Doppler effect
- From raw data to image: focusing algorithms and SAR processing levels
- Physical interpretation of radar backscatter (surface roughness, dielectric constant, geometry)

4. SAR Data Processing and Information Extraction

- Pre-processing: calibration, speckle filtering, and terrain correction
- Interferometric SAR (InSAR): basics, coherence, phase unwrapping
- Polarimetric SAR: basics and classification potentials
- Time-series analysis for change detection
- Amplitude vs. phase-based information extraction
- Use of machine learning and classification in SAR data analysis (overview)

5. Environmental Applications of SAR Remote Sensing

- Land cover classification and monitoring
- Soil moisture and vegetation structure assessment
- Urban area analysis and infrastructure monitoring
- Flood mapping and surface water dynamics
- Change detection in land use and environmental impact assessment

6. Practical Sessions in GIS and Radar Data Tools

- Introduction to SAR data platforms (Copernicus, Alaska Satellite Facility, etc.)
- Accessing and visualising Sentinel-1 SAR data
- Basic SAR image interpretation and processing with SNAP and QGIS
- Thematic map production from SAR data (amplitude and coherence products)
- Case studies from diverse environmental contexts

Note: The order and content of topics may be adjusted to better fit the background of students and to keep the information current.

Prerequisites

Students should have a basic understanding of remote sensing or geospatial analysis. Prior coursework in environmental science or Earth observation is useful. No prior knowledge of radar or signal theory is required, but a general comfort with quantitative reasoning is expected. Basic familiarity with GIS tools (e.g., QGIS) is recommended. No programming background is required.

Teaching form

The course includes lectures covering theoretical aspects of radar systems, signal theory, SAR data formation, and environmental applications, and hands-on sessions where students will process real SAR data, extract information, and produce spatial analyses using GIS and radar software tools.

Textbook and teaching resource

Radar and SAR: theory, signals and data

- Curlander, J. C., & McDonough, R. N. (1991). Synthetic Aperture Radar: Systems and Signal Processing. Wiley - A classical text to understand SAR data formation, the radar system, and applied signal theory.
- Henderson, F. M., & Lewis, A. J. (Eds.). (1998). Manual of Remote Sensing: Principles and Applications of Imaging Radar, Vol. 2. Wiley - Extensive coverage of the physics of radar reflectance, radar-surface interaction, and environmental applications. Great for exploring the physical significance of backscatter as well.
- Moreira, A., Prats-Iraola, P., Younis, M., Krieger, G., Hajnsek, I., & Papathanassiou, K. P. (2013). A Tutorial on Synthetic Aperture Radar. IEEE Geoscience and Remote Sensing Magazine, 1(1), 6–43 - Widely cited, accessible article with detailed explanation of SAR operation, polarimetry and interferometry. Perfect for students as a first technical but not overly mathematical approach

Radar data processing, environmental applications

- Richards, J. A. (2009). Remote Sensing with Imaging Radar. Springer - Well-organized text covering the processing of SAR data (focusing, speckle, classification) and a wide range of applications including use in urban environments, vegetation and hydrology.
- Schubert, A., & Small, D. (2017). A Survey of Geocoding and Terrain Correction of SAR Data. IEEE Transactions on Geoscience and Remote Sensing - Excellent addition to lessons on geocoding, orthorectification and spatial recording of SAR data.
- ESA (European Space Agency). Sentinel-1 Technical Guide: https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-1-sar A free, official resource. Essential to understand the specifications of SAR Sentinel-1 data, product structure and processing levels.

Complementary material and software

- SNAP Toolbox (ESA) – Open source software for processing Sentinel-1 data. Used
- in tutorials. https://step.esa.int/main/toolboxes/snap/
- QGIS + SAR plugins (e.g., SARscape, but also open-source options) – GIS used for
- visualization and thematic analysis.
- OpenSARLab – Online platform by Alaska Satellite Facility with tutorials and datasets for the study of SAR. https://opensarlab.asf.alaska.edu

Semester

Second semester

Assessment method

Oral exam. Minimum sufficient mark is 18 out of 30, maximum mark is 30 out of 30 with honours.

Office hours

By appointment set via e-mail. One-on-one meetings are offered through video- or audio-conferencing or at the premises as described below.

Fabio Dell'Acqua
Office: floor H
Department of Electrical, Computer, Biomedical Engineering
University of Pavia
via Adolfo Ferrata 5, 27100 Pavia
Phone: +39-0382-985664
Email: fabio.dellacqua@unipv.it
Web: http://tlclab.unipv.it/index.php/people/the-team/23-people/75-fabio-dell-acqua

Sustainable Development Goals

CLIMATE ACTION