Syllabus: Remote Sensing and Cosmology

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I. COURSE DESCRIPTION

This is a 4 credit semester long course on remote sensing for undergraduate senior-year students in the engineering and technology program.

A. Overview

The course introduces the science of remote sensing that emphasizes methods to detect weak signals from a distant source. The class material is presented to give the students a physical perspective of the topics. Observing physical systems from a great distance and from a spatially remote location only became possible in the last part of the twentieth century. Recently, in the early part of the twenty first century, remote sensing has become a rapidly expanding field of science. Viewing physical systems from afar provides a unique global perspective of the large-scale dynamical behavior of those systems. So the tools of remote sensing have become indispensable to scientific exploration of our world at large scales, ranging from the study of the Earth to the Universe at large.

B. Applications

Remote sensing began with defense applications such as stand-off data collection and early warning, first with aircraft and then with space-based satellites. Instead of reviewing the history of remote sensing, this course places its emphasis of the study on the scientific principles upon which remote sensing is based. This course begins with the scientific applications of understanding the geophysics of the Earth, which became particularly precise with the launch of the geosynchronous satellite that can fix its view over long periods of time over a particular region of the Earth. Yet, in the last couple decades, remote sensing has undergone a revolution by pointing the satellite's detector (or Earth-based detector not necessarily based on light detection) away from the Earth. Today remote sensing includes detecting different kinds of weak signals, for example including gravitational waves in addition to weak electromagnetic waves. So this course reviews some new remote sensing applications to study the world at large, including those useful for understanding black holes and the cosmology of the Universe. In addition to studying the Earth, reviews of remote sensing applications for the heliophysics of the Sun and planetary physics (particularly that of Mars) will be addressed too, time permitting.

A main objective of this course is to help the student begin to grasp electromagnetism and gravity. The course spans subject matter from remote sensing of the Earth to sensing at the cosmological frontiers. To this end, this course reviews Maxwell's equations, the electromagnetic radiation field and wave spectrum, the electromagnetic wave equation, photon polarization, Planck's blackbody radiation, the Stefan-Boltzmann law, and cosmic microwave background radiation. The course introduces the notion of the gravitational metric field and gravitational radiation, and gives an accessible overview of the Einstein equation as a first introduction to gravity. This course highlights the similarities between electromagnetic and gravitational radiation. Then, the course reviews the interaction of light and matter, on the small scale including the scattering of light by atoms (e.g. Raman scattering and Mie scattering as parametric processes, and Rayleigh scattering and Brillouin scattering as nonparametric processes), nonlinear optics, and light propagation through the atmosphere. Yet, on the large scale, light also interacts with matter via gravitational lensing.

In passive remote sensing, the detection of extremely weak signals from a distant source depends on ultra sensitive detectors. So the course reviews electromagnetic detection devices (e.g. photometers, radiometers, aperture arrays, charge coupled devices) and gravitational detection devices (e.g. laser interferometers as gravitometers). This course also introduces atom lasers that presently serve as one of the newest remote sensing technologies based on matter wave interferometry (e.g. accelerometers based on atomic matter waves). In active remote sensing the source of the radiation is man made. For this purpose, this course reviews laser technology (stimulated emission of monochromatic and directed radiation) with applications to LiDAR, laser interferometry, and new quantum interferometry techniques.

Finally, the course provides laboratory hands-on applications of the concepts and theories presented in each class throughout the semester. The course uses technologies and physical analysis relevant to Hawaii's high-tech industries and scientific communities.

C. Course plan

Students should have facility with Signals and Systems and Digital Signal Processing as well as the ability to carryout symbolic mathematical calculations on a computer. Demonstrations in the class will use Mathematica and this symbolic mathematics software application is highly recommended for the students as an aid to accomplishing the assigned weekly problem sets.

Each student will select a remote sensing topic of their choosing for a Final Project.

The Final Project will entail:

1. reviewing an existing remote sensing system that is in the public domain
2. obtaining experimental discrete time series image data from the respective open access database
3. analyzing the digital data or imagery with tools and methods presented in the class
4. and reviewing the scientific progress achieved with respect to the comparison of analytical predictions with the observed behavior of the large physical system.

Each student will summarize his or her remote sensing study in written Technical Report form for turn in as a final project.

A basic review/refreshers for vector calculus is provided at the outset as needed.

The class meets Monday 12:30-3:15pm and Wednesday 12:30-3:15pm (via VTC).

Office Hours: Immediately following class Monday and Wednesday and by appointment

Prerequisites: ETRO 450 with grade C or better. — This prerequisite cannot be waived.

D. Mathematical skill set

Signals and systems, digital signal processing, and symbolic computation.

II. PROSPECTUS

1. Introduction
   - Introduction to remote sensing
2. Introduction to electromagnetic radiation
   - Maxwell's equations, electric and magnetic fields, complex electromagnetic field of radiation
   - Wave equation, vector calculus identities, solenoidal (divergence free) fields, and plane-wave solutions
   - Photon polarization, spin-1 representation, Stokes parameters
   - Stefan-Boltzmann law, radiant exitance, thermodynamic temperature, Planck's constant, radiance, emissivity, luminosity, effective temperature, and irradiance
3. Introduction to gravity
   - Gravity field of the Earth and Sun, Kepler orbits, satellite orbits, and numerically-computed orbits
   - Gravitational metric field, Friedmann-Lemaître-Robertson-Walker metric, Einstein's equation, gravitational waves, and polarization tensors of transverse-traceless gravitational plane waves
4. Interaction of light and matter
   - Interaction of electromagnetic radiation and matter with an introduction to scattering theory and dielectric polarization
   - Light-atom scattering, including Rayleigh and Mie scattering as parametric processes, and Raman and Brillouin scattering as nonparametric processes
   - Nonlinear optics processes, including frequency-mixing processes, self-focusing, and optical solitons
   - Light propagation through the atmosphere, Fresnel free-space optical transfer function in the paraxial approximation, and optical turbulence in the troposphere
5. Midterm
   - Midterm exam (compilation of assigned Problem Sets up to middle of the semester)
   - In-class review of the solution set
6. Sources of radiation
   - Solar electromagnetic radiation
   - Cosmic rays and Cherenkov radiation from air showers generated by cosmic rays
   - Lasers, stimulated emission of monochromatic electromagnetic radiation
   - RADAR, LiDAR, and Synthetic aperture array RADAR
7. Detection of weak signals
   - Electromagnetic detection devices (photometers, radiometers, aperture arrays, charge coupled devices)
   - Gravitational detection devices (gravitometers, laser interferometer gravitational-wave observatory, accelerometers based on atomic matter waves)
8. Applications (time permitting)
   - Satellite systems for geophysics, e.g. Landsat, AVHRR, MODIS, GOES, ASTER
   - Systems for gravitational mapping, e.g. BEC interferometers
   - Systems for cosmic microwave background (CMB), e.g. WMAP and Planck spacecraft
   - Systems for weak gravitational waves, e.g. LIGO
9. Final project
   - Final exam (May — complete compilation of assigned Problem Sets) and Student Project submitted in Technical Report format

III. PROBLEM SETS

Problem sets are assigned as needed and tailored to the students' progress. Students generally have one week to complete any given assigned problem set.

Selected Problem Sets will be submitted in Technical Report format using scientific typesetting software. Students should be familiar with technical and scientific writing.

IV. COURSE REQUIREMENTS AND EVALUATION

Labs, written exercises, and computer problems: 30%
(e.g. assigned Wednesday and due the following Wednesday)
Midterm examination: 30%
Final project: 30%
Class participation: 10%

V. METHOD OF INSTRUCTION

- Scientific presentations
- Internet-based video teleconference
- Mathematica demonstrations
- Class discussions
- Weekly office hours following the class end and can be scheduled on a weekly basis by e-mail request

VI. RESOURCES

- Text book:
  There is no assigned textbook for this course.
- Additional reference book:
  W.G. Rees, "Physical Principles of Remote Sensing", 3rd Edition, Cambridge University Press (2013)
- Wikipedia provides many helpful overviews, including for the respective lectures presented in the course:
  1. Maxwell's equations
  2. Electromagnetic radiation
  3. Planck's law
  4. Cosmic microwave background
  5. Stefan-Boltzmann law
  6. Kepler's laws
  7. Numerically-computed orbits in an inverse-square potential
  8. Metric tensor field
  9. Einstein's equation
  10. Friedmann-Lemaître-Robertson-Walker metric
  11. Friedman equation
  12. Gravitational radiation
  13. Interaction of radiation with matter
  14. Linear optics
  15. Nonlinear optics
- Mathematical physics developments will be provided in class tailored to the skill of the students.

VII. DISABILITY STATEMENT

1. If you have a disability and have not voluntarily disclosed the nature of your disability and the support you need, you are invited to contact Lisa Deneen - Disabilities Coordinator at 984-3227 or Telecommunication Device for the Deaf (TDD) 984-3325 or the Text Telephone (TT) replay service at 643-8833.

2. Reasonable accommodations will be provided for students with documented physical, sensory, systemic, cognitive, learning and psychiatric disabilities. If you believe you have a disability requiring accommodations, please notify Lisa Deneen - Disabilities Coordinator at 984-3227 or Telecommunication Device for the Deaf (TDD) 984-3325 or the Text Telephone (TT) replay service at 643-8833. The Disabilities Coordinator will verify your disability and provide the course instructor with recommendations for appropriate accommodations.