Syllabus for Principles of Experimental Research (ECE 446)

Prof: Lynford Goddard, lgoddard@illinois.edu, Micro and Nanotechnology Lab 2254
Lectures: MWF 11-11:50am in ECEB 4070
Lab: F noon-2:50pm (Section AB1) or F 3-5:50pm (Section AB2) in ECEB 3077
– Additionally, the lab is open for us to use on M 6-9pm and W 6-9pm

Units: 4 hours of graduate or undergraduate credit

Grading Policy:

Homework	15%
Labs	20%
Project: Proposal, Paper, and Poster	25%
Conference Talk	10%
In-class Quizzes	20%
Final	10%

"Principles of Experimental Research" is an interdisciplinary course designed primarily for first year graduate students and advanced undergraduates in engineering and science. It has been approved as an ECE departmental laboratory elective and as a professional development course for the ECE M.Eng. degree. The prerequisite is ECE 313. It is recommended that the student have knowledge of ECE 310, ECE 329, and MATH 415.

The course draws on laboratory problems in engineering and covers topics in: (1) design of experiment, (2) prevalent experimental techniques and instrumentation, (3) data collection, organization, and statistical analysis techniques, (4) oral and written presentation of scientific material, and (5) scientific computing languages and software. Open-ended labs and an independent project reinforce concepts discussed in class. Students will build and test: (1) a software based lock-in amplifier in LabVIEW using a DAQ card, (2) a PID motor controller in LabVIEW using table top instruments, (3) audio and optical heterodyne systems, and (4) an electrical time domain reflectometer. They will also carry out an experimental project of their own design that determines and models the main effects and their statistical significance in a multivariable experiment. Students will present scientific material in three common formats: at a poster session, at a conference talk, and in a journal paper. The main course objective is for students to develop the basic skills needed for pursuing a career or an advanced degree involving experimental research. The course topics include:

1. Course introduction and laboratory safety including how to define a safety plan (1 lecture)
    a. Integrated Safety and Management (define scope of work, identify hazards, select protective equipment, perform the work, and provide feedback on lessons learned)
2. Automated data collection in LabVIEW (3 lectures)
    a. Basic structures, the GUI, Controls and Indicators, Debugging, XY Graphs
    b. Using Pre-written VIs, Control loops, Send/Read on GPIB, Save XY to files, Acquiring signals with a DAQ card
    c. Signal processing, analysis, and display in LabVIEW, MathScript, Express VIs, Advanced data flow constructs, Instrument control
3. Gaining pre-experiment insight (1 lecture)
    a. Back of the envelope calculations
        i. Estimation for feasibility

ii. Dimensional analysis and the Buckingham π theorem (Identifying the key dimensionless parameters from a list of variables)

4. Planning a research project (1.5 lecture)
   a. Performing literature searches; writing a good statement of work
      i. Common weaknesses of failed research proposals
   b. Project charts
      i. Penta chart (A single PowerPoint slide that describes a proposed research project and why the research should be conducted)
      ii. Gantt chart and critical path analysis (CPA)
   c. Documentation and technical reports
5. Design of experiments (DOE) (6 lectures)
   a. Selecting a design to meet the objectives of the experiment (1.5 lectures)
      i. Sampling (simple random sampling, stratified random sampling, block design, and matched pair)
      ii. Critical thinking, deductive and inductive logic, scientific method
      iii. Selecting a domain
   b. Full factorial designs
   c. Fractional factorial and Plackett-Burman designs
   d. Initial analysis of DOE data (0.5 lectures)
   e. Analysis of a full factorial experiment
   f. Analysis of a fractional factorial experiment
6. Preparation of results for publication (1 lecture)
   a. Abstracts, poster sessions, conference talks, journals, and patents
   b. Manuscript guidelines, style, editing, clarity versus conciseness
   c. Being a referee for an article and responding to referee remarks
7. Project evaluation (1 lecture)
   a. Earned Value Management
8. Data organization and statistical analysis techniques (13 lectures)
   a. Sources of error, confidence intervals, propagation of error, systematic and random components of uncertainty, and graphs/data representation (scatter-plot, box-plot, 2D intensity, histogram, normal probability)
   b. Linear regression without and with error in the x-coordinate; multivariate linear regression (0.5 lectures)
   c. Polynomial regression; robust linear fitting and estimation techniques for data with statistical outliers
   d. Hypothesis testing; tests of significance; student t-distribution, comparison to the null hypothesis (1.5 lectures)
   e. Type I/II errors and receiver operating characteristics (ROC)
   f. Analysis of variance (ANOVA) (1.5 lectures)
   g. Nonlinear curve fitting techniques
   h. Testing goodness of fit; cross validation
   i. Interpolation/extrapolation, numerical integration/differentiation, Runge-Kutta
   j. Noisy data, Averaging, Wiener filtering, and Savitzky-Golay smoothing
      i. Boxcar averagers
   k. Finding extrema and points of inflection in noisy data (0.5 lectures)
   l. Monte Carlo techniques
      i. Experimenting via simulation
      ii. Bootstrapping
   m. Principal component analysis

9. Experimental techniques and instrumentation (7.5 lectures)
    a. Null, differential, direct/indirect and lock-in measurements (0.5 lectures)
        i. Wheatstone bridge (null)
        ii. Interferometers (null)
        iii. Oscilloscopes (differential)
        iv. Small signal modulation-response analysis (differential)
        v. Ground loops and returns
    b. Static and dynamic characteristics of instruments
        i. Accuracy, precision, resolution, tolerance, sensitivity, span, linearity, dynamic range, drift of the zero offset and response slope, etc.
        ii. Zero, first, and second order instruments
    c. PID control systems
    d. Heterodyne detection
        i. Lock in amplifiers
        ii. Electrical spectrum analyzers
        iii. Laser linewidth
        iv. Laser Doppler vibrometers
    e. Self-calibration
    f. Pump-probe experiments (0.5 lectures)
    g. Electrical and optical time domain reflectometry (0.5 lectures)
    h. Temperature dependent studies (0.7 lectures)
        i. Exploration of physical phenomena
        ii. Arrhenius plots
    i. Wavelength modulation spectroscopy (0.7 lectures)
    j. Cavity ringdown spectroscopy (0.6 lectures)
10. Guest lectures (2 lectures)
    a. Ethics in research
    b. Machining
        i. Dimensioning of drawings, AutoCAD, choice of materials and tools, working with ECE professional machine shop, access to student shop
11. Reviews (2 lectures)
12. No-class days due to outside class activities (2 lectures)
13. In-class quizzes (2 lectures)