Syllabus for Principles of Experimental Research (ECE 498LG)

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Office Hours for weeks with no labs: Mon and Fri Noon-1PM in MNTL 2254
Office Hours for weeks with labs: Mon and Fri Noon-1PM and Tues 10-11AM in Everitt 251

Course Webpage: https://wiki.engr.illinois.edu/display/ece498LGFA11/Home

Lectures: MWF 11-11:50A in Everitt 241
Lab: With a buddy, 24/7 keycard access in front half of Everitt 251
– ECE 420 and 453 also use this lab at specific times each week
– ECE 420 meets: Tue 2:30-4:30PM and Wed 2-4PM. We can't use the lab these times.
– ECE 453 meets: Tue/Thur 9A-noon and Tue 3-6P. They use the front half of the lab for ~30 minutes at the beginning of the time slot and the back half during the remaining time. We can use the lab when they're in the back half.
Access to course software is available in all Engineering workstation locations

Units: 4 hours of graduate or undergraduate credit

Grading Policy:

Homework	15%
Labs	20%
Project 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. ECE 313 or equivalent is a prerequisite. 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. Students will carry out: (1) four open-ended labs where they build and test: a software based lock-in amplifier in LabVIEW using a DAQ card, a PID motor controller in LabVIEW using table top instruments, audio and optical heterodyne systems, and an electrical time domain reflectometer, and (2) an experimental project of their own design that determines and models the main effects and their statistical significance in a multivariable experiment. They will also 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 (1 lecture)
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 lectures)
    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 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)

Proficiency in multiple scientific computing languages and programs is a skill required of today's experimentalist. Some students already have significant experience either thru formal classes or independent learning, while others are still learning. To address the differences in needs, this course will offer optional demo style discussions occasionally on Fridays during the semester noon-1PM (instead of office hours) to discuss sample code in LabView, Origin, and Matlab, and to a lesser extent AutoCAD, Mathematica, and SAS JMP. In addition, the website will contain links to tutorials. Homework assignments, exams, and regular lectures will generally require basic knowledge of the first three topics. If there is sufficient interest, C and LaTeX can also be discussed during the optional sessions.

The class will have four open-ended labs, one independent experiment, two conference style presentations, some homework assignments, two in-class quizzes, and a final quiz. There will be two no class days to offset the poster session and the conference talk, which are required class events held outside of normal class hours. All assignments are due at 11pm. Most homework assignments are due on Wednesdays. Assignments should be compressed into a single .zip or .rar file and submitted via the ECE 498LG tab in my.ece or may be handed in during class.

The lab in Everitt 251 has basic equipment: DMMs, oscilloscopes, multifunction data acquisition cards, computers, etc. and will be available (usually 24/7 with keycard access) for students to complete the labs and to develop their independent experiment.

The first two labs are in weeks 2 through 5. Students will write LabView software to control the output of lab instruments and collect data automatically. They will do a 10 minute demo of their experiment and submit their code.

The main project is an individual lab experiment consisting of designing, planning, and performing a simple multivariable screening experiment. Each student will submit a research proposal consisting of a 150 word abstract in week 6 and a penta chart, safety assessment, a Gantt chart with CPA and estimated cost, and a statement of work at the end of week 6. In week 10, each student will submit a draft of a two page paper describing their experiment, analyzing the data and trends through graphs, and conforming to IEEE journal style guidelines. After receiving feedback, they will submit the final version in week 11.

The first conference style presentation, in week 12, will be a poster session (either during class hours or 4-5PM in MNTL Atrium) where each student will present the results of their independent project. A 50 word abstract will be due in week 10 for inclusion in an abstract booklet. The poster session will be open to the public. Students and faculty from outside the course are encouraged to attend.

The third lab is in weeks 12-13. Students will lay out optical components and build and test a table top optical homodyne system to measure laser cavity length and vibrations in a mirror caused by sound waves and will write LabView code for automated data collection.

The second conference style presentation will be a 15 minute talk (12 minute presentation, 3 minute Q/A) in week 13. Depending on enrollment, the class will be divided into one or more sessions held during the week and each student will present a summary of an experimental technique from the literature on a topic outside those listed in the syllabus. A 150 word abstract will also be submitted and will be printed in an abstract booklet. The conference talks (in MNTL 1000) will also be open to the public.

The fourth lab is in weeks 15-16. Students will configure an experimental setup for performing electrical time domain reflectometry and determine the impedance and fault locations of various cables.

The four lab exercises and the main project are open-ended. Graduate credit will require demonstration of additional functionality or performance of additional analysis beyond what is described in the general assignment for at least two of the labs or one lab plus the main project. For example, the lock-in lab can be expanded to demonstrate derivative spectroscopy (harmonic detection); the PID motor lab can be expanded to perform PID temperature control; the electrical time domain reflectometer can be expanded to perform cavity ringdown analysis of the loss in a cable; the heterodyne lab can be expanded to build a laser Doppler vibrometer or to perform laser linewidth measurements; the main project can be expanded from a 3-variable full factorial design to a more difficult 5 or more variable fractional factorial experiment.

In this class, students are encouraged to perform experiments or present topics related to their graduate research or senior thesis projects with the one caveat that the work must be new, i.e. not simply a derivative of past work.

The required course textbooks are:

1. Principles of Experimental Research Course Packet, F&S Printing Department, 2011.
2. Data Reduction and Error Analysis for the Physical Sciences by Philip R. Bevington and D. Keith Robinson (publisher: McGraw-Hill), 3rd edition, 2003.
3. NIST/SEMATECH e-Handbook of Statistical Methods, available free of charge online at: http://www.itl.nist.gov/div898/handbook/

Optional, but highly recommended textbooks (to be available on reserve in Grainger library) are:

4. Statistical Quality Design and Control by Richard E. DeVor, Tsong-how Chang, and John W. Sutherland, (publisher: Prentice Hall), 2nd edition, 2007.
5. Numerical Recipes: The Art of Scientific Computing by William H. Press, Saul A. Teukolsky, William T. Vetterling, and Brian P. Flannery, (publisher: Cambridge University Press), 3rd edition, 2007.

Additional references:

6. Introduction to Engineering Experimentation by Anthony J. Wheeler and Ahmad R. Ganji (publisher: Prentice Hall), 2nd edition, 2003.
7. The Practice of Statistics by Dan Yates, David S. Moore, and Daren S. Starnes (publisher: W. H. Freeman & Co.), 2nd edition, 2002.
8. Practical Research: Planning and Design by Paul D. Leedy and Jeanne E. Ormrod, (publisher: Prentice Hall), 8th edition, 2004.
9. Handbook of Software for Engineers and Scientists by Paul W. Ross, (publisher: CRC-Press), 1st edition, 1995.

For the lab projects, students will need the following required hand tools: screwdriver, diagonal cutters, needle nose pliers, and wire strippers. Students may request components and parts for their projects from EL265.

For the class, students will need the following software: LabView 2010 SP1 (released Spring 2011 – do not download LabVIEW 2011), Matlab, Origin Pro 8.5, and Microsoft Project. Most, if not all, of this software is free to students through http://webstore.illinois.edu/ and the donated LabView Student Edition CDs that will be distributed in class. Engineering Workstations will also have these programs available. Microsoft Office, specifically Word and Excel, Mathematica, and AutoCAD are recommended; compilers for C or C++ and LaTeX are suggested. These programs are available through the webstore. SAS JMP is also available through the webstore, for purchase, but it will only be used for a few weeks during the course.