PHYS 523 - Instrumentation and Applied Physics Project

Course description

In this two-semester course students will engage in the collaborative design and execution of a year-long Instrumentation and measurement-intensive technical project. Required activities will include a written project proposal of work to be undertaken, informal group-generated oral presentations on technical issues, periodic formal written progress reports, a final project oral presentation, and a final project paper. The set of projects might include investigations suggested by industry partners. There will be two class meetings per week, each of three hours duration. In addition to the project work, we will bring in local experts to discuss a number of relevant topics with the class; these are shown in the syllabus, below. Note that readings will consist primarily of technical materials and documentation by the producers of components used by individual projects. As a result, readings and external materials will vary from group to group.

Credit and grading

Students must register for this course in consecutive fall and spring semesters for a total of 8 credit hours. Grading is by letter.

Meeting times

Students will spend approximately six hours per week in lecture and faculty-supervised laboratory work. Additionally, individual project groups will have formal conferences with course staff throughout the semester (approximately five additional contact hours).

Learning objectives

As a result of completing this course, students will be able to

- Conceive, propose, plan, and execute technical projects using a wide range of laboratory tools, instrumentation, and analysis techniques.
- Recognize relevant technical problems and associated measurement modalities.
- Analyze measurement data and communicate conclusions in oral and written form.

Technical skills mastered by students during the course of a two-semester project

Supported two-semester projects will require students to master all of the following technical skills:

- Development of a detailed project proposal, including overall goals, a budget, timelines, dependencies, and to-be-resolved technical uncertainties and risks. We expect that students will become familiar with basic principles of project management and project planning software.
- Construction of (breadboarded) proof-of-concept circuits as embedded systems built around a suitable microcontroller. This will combine hardware activities, data acquisition code development, and creation of offline analysis software to verify the properties of the project's hardware components, sensors, and data analysis algorithms.
- Design of all necessary circuits for the full project, layout of printed circuit boards, and submission to a commercial fabrication firm of the PCB definition files. Acquisition of parts from commercial providers, and construction of the PCB-based devices required by the project.
- Design and fabrication (through in-house 3D printing when possible) of enclosures and other mechanical infrastructure for the project.
- Field testing, troubleshooting, debugging, calibrating the project's hardware.
- Analyzing and interpreting data; proposing adjustments and future modifications (and extensions) to the project.

Each project will be a "one-off," a unique investigation that might have the practical impacts of improved efficiencies and profitability for a commercial venture. To be more concrete, here is one particular project a group could pursue.

Some sections of the railroad tracks between Chicago and New Orleans are so uneven that a passenger standing in the aisle of a passenger train can be thrown off his or her feet. Intelligent trucks—the wheel assemblies upon which trains ride—could be programmed to compensate for track irregularities if detailed (and frequently updated) maps of track imperfections were available. But another approach might be to measure irregularities in real time with sensors in the lead car, then transmit the information to the trucks in successive cars. The effect of roadbed imperfections might depend on load, train speed, recent weather conditions, and a whole host of other variables. It would be interesting to instrument a passenger train to investigate the feasibility of this approach.

A project group could install on a passenger train a dozen data loggers, each with a GPS module, a "9-axis accelerometer," and other sensors. The precise cross timing of multiple GPS-enabled devices might yield accelerometer data that would allow determination of the feasibility of a no-map correction system. This project would be well-suited for collaborative investigation by four M. Eng. students. Two semesters should be an adequate amount of time for them to design and execute the project.

Other projects should be designed with similar scope and complexity. It will be important for course staff to offer guidance and suggest adjustments early in the first semester as each group constructs a project proposal, timelines, dependencies, and so forth. This will allow us to make sure projects are appropriate for the M. Eng. degree.

Syllabus: topics covered, spanning two semesters

Unit 1: Introduction to the course and the projects available to students (1 week)

- Discussion of projects;
- Self-organization into project groups; choose a project;
- Intra-group discussions of scope and techniques appropriate for the project;
- Guest lecture: Principles of project management;
- Introduction to project management and tracking software;
- Installation of software tools: Anaconda Python, Arduino IDE, EAGLE PCB, Tinkercad.

Unit 2: Defining the project (2 weeks)

- Further discussion of project methodology;
- Guest lecture: Issues in close collaboration including matters of ego, trust, and sharing of responsibilities;
- Identification and further clarification of hardware and software to be used in the project;
- Develop a plan for testing/verifying the performance of the project's devices and techniques;
- Identify risks and develop stubs of alternative design paths that might be necessary;
- Create a draft project timeline, with dependencies;
- Procurement: identify sources for parts and materials, generate purchase orders, and enter

information into the project’s order tracking system; order components;
- Guest lecture: Safety concerns in electrical, chemical, mechanical, and radiological domains;
- Begin assembling breadboards and other test facilities (as well as software) for testing performance of components;
- “Technical culture” oral presentation by one group (for example, thermometric methods).

Unit 3: Project proposal and review (2 weeks)
- Create a formal written project proposal that includes timelines, risk, budget estimates, and calibration plans;
- Guest lecture: Clarity in oral and written presentations;
- Project review: Public (to the class) oral presentation of project; public project peer review by
- another student group (and course instructors);
- Project revision in response to review;
- “Technical culture” oral presentation by one group.

Unit 4: Component tests (4 weeks)
- Measure performance of components that are proposed for inclusion in the project;
- Downselect as necessary, and define the final configuration of a prototype for the project;
- “Technical culture” oral presentation by one group.

Unit 5: Prototyping (4 weeks)
- Build all prototypes necessary for the project, including controlling software packages;
- Guest lecture: Building a professional portfolio;
- Field test everything, including preliminary analysis of the data obtained, and calibration of devices;
- Guest lecture: Intellectual property and nondisclosure agreements;
- “Technical culture” oral presentation by one group.

Unit 6: Project status review (2 weeks)
- Create a formal written project status document that includes results to date and differences between the plan submitted in the project proposal and the actual work performed;
- Oral presentation of project status (to the extent allowed by various non-disclosure agreements);
- Project review: peer review by another group (and course instructors);
- Project revision in response to review;
- “Technical culture” oral presentation by one group.

Unit 7: Project construction (4 weeks)
- Design and fabricate any printed circuit boards necessary, then construct robust versions of the breadboarded prototypes;
- Design and fabricate (by 3D printing when possible) cases, housings, enclosures, etc., for the project hardware;
- Field test the project;
- “Technical culture” oral presentation by one group.

Unit 8: Data and preliminary analysis (2 weeks)
- Take data;

- Run preliminary analyses of the data to verify data validity;
- “Technical culture” oral presentation by one group.

Unit 9: Analysis (4 weeks)
- Perform an extensive analysis (in close consultation with course instructors) of all data;
- Guest lecture: Legal, cultural, and regulatory issues in international collaboration;
- Guest lecture: Matters of scale: managing a billion-dollar project;
- Write a first draft of a final project report;
- “Technical culture” oral presentation by one group.

Unit 10: Outcomes (3 weeks)
- Write a second draft project report after feedback from instructors;
- Oral presentation of project status (to the extent allowed by various non-disclosure agreements);
- Project review: peer review by another group (and course instructors);
- Write final draft project report.

Readings and other sources

Readings will consist primarily of technical materials and documentation by the producers of components used by individual projects. Here is a selection of resources that might be useful.

Units 1 and 2 reading and reference material:
- *About Python,* Python Foundation: https://www.python.org/about/gettingstarted/
- *Getting Started with Arduino Products,* Arduino: https://www.arduino.cc/en/Guide/HomePage
- *How to Install and Setup EAGLE,* https://learn.sparkfun.com/tutorials/how-to-install-and-setup-eagle
- *Using EAGLE: Schematic,* Jim Blom: https://learn.sparkfun.com/tutorials/using-eagle-schematic
- *Using EAGLE: Board Layout,* Jim Blom: https://learn.sparkfun.com/tutorials/using-eagle-board-layout
- *Learn how to Tinker,* Autodesk Tinkercad: https://www.tinkercad.com/learn/designs
- *An Introduction to Project Management, Sixth Edition,* Kathy Schwalbe (2017).

Units 3 – 5 reading and reference material:
- *Adafruit Explore & Learn,* Adafruit Inc.: https://learn.adafruit.com/
- *Sparkfun Learn,* Sparkfun, Inc.: https://learn.sparkfun.com/
- *The Art of Electronics 3rd edition,* Paul Horowitz and Winfield Hill, Cambridge (2015).

Units 6, 9, and 10 reading and reference material:
- *How to Present a Physics Talk,* Celia M. Elliott: https://courses.physics.illinois.edu/phys398dlp/sp2020/documents/Celia_Elliott_398DLP.pdf
- *How to Get Started if you Hate to Write,* Celia M. Elliott: https://courses.physics.illinois.edu/phys398dlp/sp2020/documents/Celia_Elliott_398DLP_writing_FA19.pdf

- *Collaboration,* Cynthia D'Angelo: https://courses.physics.illinois.edu/phys398dlp/sp2020/documents/Cynthia_D-Angelo_collaboration.pdf

Units 7 – 10 reading and reference material:

- *Error Analysis,* John R. Taylor: University Science Books (1997).