Computerized Instrumentation Design, Fall 2024

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PHY 215 is an introductory course on the uses of a small computer in the laboratory. Topics include: input and output ports, analog to digital converters, thermistors, timers, stepper motors, nonlinear least squares fitting to experimental data, digital signal processing, numerical integration, temperature measurement and control, and scientific documentation. The course will be held on Tuesday and Thursday from 8:00 am - 10:50 a.m. in room S113 of Generac Hall.

Approximate Semester Calendar

1. **Getting started**
(week 1)
2. **Basic Python programming**
(week 2)
3. **Introduction to microcontrollers**
(week 3)
4. **Digital output**
(week 4)
5. **A little more Python programming**
(week 5)
6. **A/D conversion**
(week 6)
7. **Temperature Measurement and control**
(week 7 -10)
8. **Maybe: Timers, interrupts & web programming**
(week 11)
9. **Thermal diffusion experiments**
(week 12 - 14)
10. **Final report**
(week 15)

Introduction

The primary aims of this course are to teach you (1) how set up a computer–controlled laboratory experiment and (2) how to produce a publication-quality scientific paper detailing your results. Along the way, you will learn a bit about computer system administration and programming, analog and digital electronics, scientific data collection and analysis, temperature measurement and regulation, and the mathematical theory of heat conduction.

During a traditional 15-week semester, students meet with the instructor twice a week for three hour laboratory sessions. Typically, students will need to do three additional hours of work per week outside of scheduled class time in order to complete all of the assignments. Course grades will be assigned based on the completion of laboratory exercises and the submission of a final scientific paper. The final paper is due the week before final examinations. It should clearly, concisely, and completely, describe the final project of the course.

Students enrolled in this course often have a wide range of backgrounds: some come with only a strong desire to learn; others, because of their previous study, could practically teach the course. For this reason, the course is designed to be flexible in that students are encouraged to work at their own pace. Nat- urally, the present laboratory manual cannot cover every problem or challenge that might arise when working with computers in a laboratory setting. So I strongly encourage those of you who are more experienced to share your under- standing with students who have not had as much preparation. Be generous! I think you will find that in explaining concepts to others, you will deepen your own understanding as well.

Motivation

Why set up a computer-controlled laboratory experiment? Primarily for automation. Although an experimenter can certainly record the output of an instrument and record it in his or her laboratory notebook, when this needs to be done ten or a hundred or a thousand times, the chance of a scribal error increases to an unacceptable level. Automation allows for reduction of errors in data collection. Automation also reduces the amount of tedious human labor. The experimenter can do other tasks—often remotely-–while his or her experiment is running instead of focusing on repetitive tasks. In addition, automation allows for performance that is simply unattainable otherwise. A human being can not record a hundred temperature readings every second. A computer can. Finally, automation allows for information to be readily stored in digital form, which is much simpler to manipulate and analyze.

A word of warning about automation, however, is in order. Automation can often introduce systematic errors which, if not detected and corrected in time, can prove catastrophic. To take just one example, consider the loss of NASA's Mars Climate Orbiter in September of 1999. A programming error went undetected and a $330 million dollar science project (in expensive 1999 dollars...) was lost in an entirely automated fashion as it approached surface of Mars. Apparently, there was a programming error due to an incorrect thrust unit conversion from the imperial to metric system. The adage that a computer is only as smart as its designer is entirely appropriate. Automation is not a silver bullet and should not be thought of as such. A great deal of planning and careful experimentation is necessary before a reliably automated system can be produced. Do not be afraid to experiment; trial and error is the way to learn. Hopefully, this course will give you a deeper understanding of computer technology so that you may intelligently use it to your advantage.

Equipment

In this course, we will use an external ESP32 microcontrol unit attached via a USB cable to your personal computer. The ESP32 board is mounted on a prototyping board (protoboard for short), in order to connect auxiliary electronic equipment. On the protoboard, you will be constructing circuits using jumper wires, resistors, capacitors, light emitting diodes (LEDs), field effect transistors (FETs), thermistors, and switches. To operate and test these circuits, you will also need an oscilloscope, a function generator, and a DC power supply. The Python Programming language will be used to communicate with the ESP32 microcontroller.

In addition to the computer and microcontroller, you will be using auxiliary electronic equipment. On the proto-board, you will be constructing simple circuits using resistors, capacitors, light emitting diodes (LEDs), field effect transistors (FETs), thermistors, and switches. To operate and test these circuits, you will also need an oscilloscope, a function generator, and a DC power supply.

Finally, you will need a small block of aluminum to test your temperature measurement and control techniques and a rod of copper to measure its heat capacity and thermal conductivity as functions of temperature (more on this later...).

I. WRITING AND SUBMITTING LABORATORY DOCUMENTATION

The exercises in this manual involve writing computer code, performing calculations, building electronic circuits, collecting and analyzing experimental data, and occasionally answering theoretical questions. I hope you find them interesting! In any case, whenever you complete an exercise, you must documented your work and submit it electronically to the course instructor. In this way, both you and the instructor will have a detailed record of all that you have accomplished in this course. **You will only receive credit for laboratory exercises that are electronically submitted to the instructor in a timely manner.** For consistency, let us now agree to adopt a consistent naming convention for each document that is electronically submitted; if a student with the initials A.C.K is submitting exercise 2.1.1, then his submitted file name should be:

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phy215_ex_2_1_1_ack
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There are many ways to produce appropriate electronic laboratory documentation. Your instructor will provide you with some recommendations and a few example documents to show you what is expected. Generally speaking, the laboratory documentation should provide its reader with enough information that he or she has a fighting chance of reproducing what you did. More specifically, your laboratory documentation should include:

- the exercise number and title (*e.g.* **Ex. 2.1.1: System capabilities**);
- your **name and the date(s)** on which the exercise was performed;
- a concise description of what you have done using complete sentences and correct grammar, spelling, and punctuation;
- neat sketches or photographic images of your laboratory setup;
- proper electronic circuit diagrams;
- clear pseudo-code or code snippets that include appropriate comments;
- mathematical calculations with clear explanation;
- experimental results, data tables, and properly labelled graphs;
- descriptions of difficulties and your solutions or work-arounds;
- any additional thoughts or insights that you think may be helpful.

II. ADDITIONAL COURSE RESOURCES

We will primarily follow the exercises outlined in the Computerized Instrumentation Design manual. This manual was based, in part, on undergraduate courses taught at the University of California at Santa Barbara and at Cornell University. Some sections of this manual are adapted directly from the highly informative *IBM PC in the Laboratory*, by Thompson and Kuckes, the text formerly used at Cornell. Here are a few additional resources that you will find very helpful:

- ESP32 micro-controller documentation, especially the ESP32 data-sheet and the ESP32 getting-started tutorial available for download as pdf files from FreeNove.
- *Python Crash Course, 3rd Edition*, by Eric Matthes. This book provides an excellent and comprehensive introduction to programming in Python.
- *The Art of Electronics* by Horowitz and Hill. This is a classic covering analog and digital electronics.

Course grades

Course grades will be based on the submitted laboratory exercises (80%), and your final paper (20%).