Computerized Instrumentation Design, Spring 2019

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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.

Semester Calendar

1. **System administration**
   (2 weeks)
2. **Analog and digital input/output**
   (4 weeks)
3. **Thermistor experiments**
   (4 weeks)
4. **Thermal Diffusion experiments**
   (4 weeks)

Introduction

The aim of the course is to teach you, the student, how to set up a computer—controlled laboratory experiment "from scratch" and produce a technical paper. Specifically, we will cover the following topics: installation and system administration of a UNIX-like operating system (called QNX), elementary computer programming in "C", input and output ports, analog-to-digital and digital-to-analog conversion, digital signal processing, thermistors, temperature control, least squares fitting to experimental data, heat capacity and thermal conductivity measurements, data analysis, and scientific documentation.

During a traditional 15-week term, the course meets once per week for a one hour lecture and twice per week for three hour laboratory sessions. During a compact, 12-day term (e.g. January-term), the course meets daily for seven hour laboratory sessions. Four hours will be supervised by the instructor, three hours are unsupervised.

Course grades will be based on (i) the exercises completed in your laboratory notebook , (ii) a mid-term paper, and (iii) a final paper. Your laboratory notebook will be checked by the instructor for grading immediately upon completing each exercise. The mid-term paper must be handed in before you begin the thermal diffusion experiments. The final paper is due on the day of the final examination. It should clearly, concisely, and completely, describe the final project of the course.

Students enrolled in the course typically have a wide range of backgrounds. Some students come with only a strong desire to learn how computers work; other students, because of their previous knowledge, could practically teach the course. For this reason, the course is designed to be rather flexible in that students are allowed to work at their own pace. Since the course typically has less than seven students, I encourage those of you who are more experienced to share your knowledge and wisdom 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 use computerized instruments in the laboratory? Primarily, for automation. Automation, first, allows for reduction of errors in data collection. It is true that an experimenter can read an instrument which tells him the temperature of a piece of material and record it in his laboratory notebook, but when he must do so ten or a hundred or a thousand times, the chance of a scribal error increases to often an unacceptable level. Automation also reduces the amount of human labor. The experimenter can do other tasks, often remotely, while his experiment is running, rather than focusing all of his time on repetitive tasks in the laboratory. In addition, automation allows for performance which is unattainable otherwise. For instance, a human being could not record a hundred temperature readings per second; a computer can. Finally, automation allows for information to be readily stored in digital form, which is far easier to handle than in paper-written form.

A word of warning about automation, however, is in order. Automation can often introduce systematic errors which, if not detected and corrected, can prove catastrophic. Consider the crash of NASA's Mars Climate Orbiter in September of 1999: a programming error went undetected and a $330 million dollar science project crashed in an entirely automated fashion onto the surface of Mars. The adage that a computer is only as smart as its designer is entirely appropriate. Automa-

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tion is not a silver bullet and should not be thought of as such. A great deal of planning and careful experimentation is necessary to produce a reliably automated system. Hopefully, this course will give you a deeper understanding of computer technology so that you may intelligently use it to your advantage.

Equipment

We will be using PCs, or personal computers, as opposed to "workstations", for laboratory automation. These are also often called "Wintel" machines since their motherboard was developed around the Intel processor architecture and they often use a Microsoft Windows-like operating system. These PCs are descendants of the original IBM-PC.

You will notice that in this course, we are using rather old computers. In fact, you may feel a bit like you are tinkering around on an old automobile. This is intentional—I want you to feel very comfortable with exploring, without having to worry about breaking a costly new piece of equipment. These computers are inexpensive, so have fun!

The PC which you will be using consists of

- a motherboard containing the microprocessor and a number of other integrated circuit chips (comprising the "chip-set"),
- a power supply,
- a CD-ROM drive,
- a hard disk drive,
- perhaps a floppy disk drive,
- an ethernet card (probably inserted into a PCI slot in your motherboard,
- at least one unused ISA slot,
- a monitor,
- a keyboard, and
- a mouse.

Into the ISA expansion slot on your PC's motherboard you will be installing an interface board, or A/D (A-to-D) board. The interface board is similar to your keyboard, mouse, and monitor, in that it allows your microprocessor to communicate with the outside world. It is unlike these three peripheral devices in that it is not designed to communicate with a human, but rather with a piece of equipment that produces a voltage (*e.g.* the signal from a thermistor) or needs an electronic signal to operate (*e.g.* a light emitting diode).

In addition to the computer and interface board, you will be using auxiliary electronic equipment. On a protoboard (prototyping 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...).

Laboratory Notebook

Each of the exercises performed in this course should be clearly documented in your laboratory notebook. If you have a neatly organized laboratory notebook, you can quickly and easily refer to your previous work for guidance when you later come upon a similar problem. To this end, your notebook should be large enough that you can tape printouts of programs which you have written and graphs of data which you have generated onto the pages of the notebook. You should begin each entry in the laboratory notebook with the current date. Furthermore, I suggest that you not try to conserve paper in your notebook by cramming things together; leave plenty of room between paragraphs so that you (and the instructor) can later make comments on your work; a well organized laboratory notebook is far more valuable than the paper on which it is written. And you can always get another notebook.

Course Literature

There is no single text for this course; we will primarily follow the exercises outlined in this manual. To a large extent, this manual is based on undergraduate courses taught at at the University of California at Santa Barbara and at Cornell University. Some sections of this manual are adapted directly from *IBM PC in the Laboratory*, by Thompson and Kuckes(5), the text formerly used at Cornell. You will need to purchase a copy of *The C Programming Language*, 2nd Edition, by Kernighan and Ritchie(2), which is a (perhaps too) succinct book on programming in C. Information about the QNX Realtime Platform may be found by using the help menu on the QNX graphical user interface, or on the QNX website at http://www.qnx.com. A good overview of real-time operating systems and embedded programming can be found in *An Embedded Software Primer* by David Simon(4). *Upgrading and Repairing PCs*, by Scott Mueller(3), and *The Art of Electronics*, by Horowitz and Hill (1), are classic texts covering personal computers and electronics respectively. For the latest information about computer hardware and software, you may look at various trade magazines. Of course a web search for topics such as "QNX", "computer architecture" or "data acquisition" will also provide you with a great deal of

TABLE I Grading scale

100-93%	A	92-88%	AB
87-80%	B	79-75%	BC
74-67%	C	66-62%	CD
61-54%	D	53-0%	F

information.

Course grades

Course grades will be based on the exercises in your laboratory notebook (70%), your midterm paper (10% and your final paper (20%). Grades will be computed according to Tab. I.

References

[1] P Horowitz and W Hill. The Art of Electronics, 1989.
[2] B Kernighan and D M Ritchie. The C programming Language, 2017.
[3] S Mueller. Upgrading and Repairing PCs, 2003.
[4] D E Simon. An Embedded Software Primer, 1999.
[5] B G Thompson and A F Kuckes. *IBM-PC in the Laboratory*. Cambridge University Press, Cambridge, 2009.