# ME 530.420 Laboratory 10: Independent Design Project:
Revision 2: Nov 30, 2012
See course web site for most recent version.

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## 1 Revision History

1. Rev 02 November 30, 2012 Initial release.

## 2 Problem Statement

The goal of this project is to design, build, and test independent project for EN.530.420 Robot Sensors and Actuators. You can build up a prototype on a proto board in successive laboratory sessions, and, if resources permit, you can build it up on an JHURSAEB, upon checking it out from the master checkout sheet.

The system should provide the following functionality:

1. Use at least three sensors and actuators. A pushbutton switch is not considered a sensor under this requirement.
   (a) This could be two sensors + one actuator ...
   (b) ... or one sensors + two actuators ...
   (c) ... or more!
2. Use at lease one actuator of any type. A relay-driven heater is considered an actuator.
3. Use the JHURSAEB—your program must use variables and conditionals (e.g. "if-then").
4. Have some significant form of human input from the the human operator/user, such as turning a potentiometer (which could count as a sensor) to set the temperature, together with a push-button to set the temperature.
5. Have some form of quantitative display to the human operator/user.
6. Implement PWM.
7. Implement a PID controller (e.g. to control the duty cycle of a PWM input).

## 3 Candidate Projects

### 3.1 Sous Vide

*This is the Default project. No special permission required.*

For this project, you will build a Sous Vides. To do this, you may use one of a variety of possible temperature sensors (detailed below) to measure the temperature. You must also implement a second sensor or actuator. This could be a second temperature sensor (of either the same type or a different type), but it could also be an ultrasonic range sensor, optical encoder, or even just a potentiometer for setting the temperature. Use a circulator pump for even heating of the liquid!

**Requirements**

- A user interface to easily set the temperature. This will be based on some set of buttons and/or a potentiometer or optical encoder system, to set the desired temperature.
- A user interface that displays the "goal" temperature and the "current" temperature.
- No interaction over USB should be required (that is, you should be able to use this as a stand-alone unit with no PC hooked up).
- An LED to indicate when the heating element is being activated.
- Two modes:
  - "Thermostat" mode
  - "PID" mode

  described below in more detail.

**Thermostat Mode** In addition to being able to set the temperature, implement a very simple "thermostat" based control mode. Specifically, implement code for the JHURSAEB that, based on simple logical statements (e.g. "if/then") performs the following actions:

- Turn the heater ON when the temp is too LOW.
- Turn the heater OFF when the temp is too HIGH.

Then, collect data for this operation for at least 10 periods (10 full repetitions of your controller turning "ON" and then "OFF". Completely characterize the dynamics. You should determine

- Total temperature ripple.
- Slope $\Delta T/\Delta t = H$ during heating.
- Slope $\Delta T/\Delta t = C$ during cooling.

These numbers will depend on many factors, including the size of the container, how well insulated it is, how big the heating element is, etc. Verify this by trying it first in a small container (such as a coffee cup), and then in a larger container such as a bowl or pot. Show your data, *plotted and annotated.*

**PWM–PID Mode** Based on the above data, you should now have a VERY local model as follows. Let $k$ be the heater state, i.e. $k = 0$ means the heater is off and $k = 1$ corresponds to the heater being on. Then, we have

$$\frac{dT}{dt} = kH + (1-k)C \tag{1}$$

So, the first term is active (nonzero) during heating but zero during cooling, and the second term is active (nonzero) during cooling but zero during heating. This all assumes that our duty cycle is much shorter than the heating and cooling time constants, which makes things much simpler.

*Revision 2 Update Here:* The above Equation (1) is quite different than Prof. Cowan derived in class. In particular, we had the following

$$\frac{dT}{dt} = \alpha(T - T_{\text{room}}) + kQ_{\text{in}}$$

where $\alpha$ is some scalar term that defines on how fast heat "leaks" from the sous vide and depends on many features such as insulation, thermal inertia, etc, $T_{\text{room}}$ is room temperature, and $Q_{\text{in}}$ is the heat flowing in at time $t$ (technically, it is not just the heat in but takes into account the thermal capacity of the sous vide). The heat flow is gated by the relay state, $k$: when $k = 0$ the heater is off, and when $k = 0$ the heater is on.

BUT, note that in your case, you maintained the temperature approximately constant with your thermostat-based control. Thus

$$\frac{dT}{dt} = \alpha(T_{\text{thermostat}} - T_{\text{room}}) + kQ_{\text{in}} \tag{2}$$

Now, if we set $k = 1$ in both Equation (1) and (2), and set them equal we have

$$H = \alpha(T_{\text{thermostat}} - T_{\text{room}}) + Q_{\text{in}}. \tag{3}$$

Likewise, setting $k = 0$, we have

$$C = \alpha(T_{\text{thermostat}} - T_{\text{room}}) \tag{4}$$

These can now be solved and we can determine $\alpha$ and $Q_{\text{in}}$.

Based on this equation, we can now derive—like in class—a PWM based model which should have the form shown below:

$$\frac{\Delta T}{\Delta t} + \alpha T \quad = \beta u + \text{const.} \tag{5}$$

$$\implies \dot{T} + \alpha T \quad \approx \beta u + \text{const} \tag{6}$$

where $u(t)$ is the duty cycle, and there is a leftover constant on the RHS. Keep in mind this model makes the assumption that one cycle of the PWM signal is "instantaneous" in the sense that the exponential time constants of the heating and cooling dynamics are very long compared to one cycle of the PWM signal.

Quite elegantly, though, we can (and you should from your data!) completely determine the parameters $\alpha$ and $\beta$ of your model from data!

- PWM input to relay, which drives heating element.
- PID control of a PWM signal.
- Step response data of closed-loop system for the system with the following settings – compare your results from each of these conditions in terms of rise time, settling time, overshoot, and steady-state error:
  - Pure "P" control, namely $K_I = K_D = 0$.
  - Pure "PD" control, namely $K_I = 0$.
  - Completely tuned PID controller.

## 3.2 Super Toaster

*This requires permission from the instructor.* Same basic requirements as above, except that you will a type-K thermocouple and the AD595 Thermocouple Amp (see Components, below). Also, Prof. Cowan will provide the toaster.

## 3.3 Salinity Detector

*This was Chef Pelligrino's very good idea!* Build a simple device that attempts to measure salinity of the water based on conductivity. This should be an "add on" to your existing project, since no actuation is required. This could easily satisfy the "extra sensor" requirement.

## 3.4 Available Components

You can use any component that you have used in the course. Other available electronic components (you can find some spec sheets on the course web site, all spec sheets are available at http://digikey.com:

Some additional components that are available include the following:

- 9V Batteries
- Foamcore that you can cut and hot glue guns
- NJU7051 op-amp - low-power, rail-to-rail, and will operate from single supply New Japan Radio Co. Part #NJU7051D-ND Digi-Key Part #NJU7051D-ND.
- Dinsmore Digital Compass Model 1490
- Parallax/Futaba standard (position) servo and Parallax/Futaba Continuous Rotation (velocity) Servo
- Solar Cell 6V 1W 125x63mm: Parallax Part #750-00030, Digi-Key Part #750-00030-ND
- Solar Cell 9V 1W 135x135mm: Parallax Part #750-00031, Digi-Key Part #750-00031-ND
- Omni Electret Condenser Microphone: CUI Part #CMA-4544PF-W, Digi-Key Part #102-1721-ND invented by JHU ECE Professor James West and Gerhard Sessler in 1962 at Bell Labs.
- Humidity sensor: HIH-4000-001[1]
- Pressure sensor: MPX2202ASX[2] ERT-D2FGL153S[3], and ERT-D2FGL102S[4]
- Power Op-Amp – OPA544, LM675,
- Op-Amp – LF411A

[1] http://sensing.honeywell.com/index.cfm/ci_id/140570/la_id/1/document/1/re_id/0
[2] http://www.freescale.com/files/sensors/doc/data_sheet/MPX2202.pdf?srch=1
[3] http://www.panasonic.com/industrial/components/pdf/arg0000ce2.pdf
[4] http://www.panasonic.com/industrial/components/pdf/arg0000ce2.pdf

- Op-Amp – low-voltage micro-power op-amp with rail-to-rail output: NJR Part #NJU7051D, Digi-Key Part #NJU7051D-ND
- Instrumentation Amplifier: Ti INA111
- Comparator – low power: STMicroelectronics Part #LM293N, Digi-Key Part #497-1567-5-ND
- Oscillator/Timer – low power: STMicroelectronics Part #TS555IN, Digi-Key Part #497-2299-5-ND
- 100 KΩpotentiometers: CTS Electrocomponents Part #296UD104B1N, Digi-Key Part #CT2268-ND
- 25 KΩpotentiometers: CTS Electrocomponents Part #296UD253B1N, Digi-Key Part #CT2266-ND
- All components that you have used in previous labs.

**Power Relay** For safety, we have 14 Xantech-81301-AC-Switch's in the lab.[5]

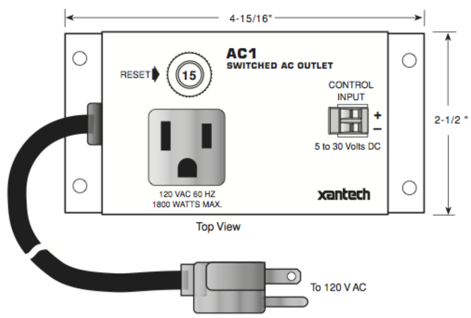


Figure 1: Xantech AC Switch.

**Temperature Sensing**

- Type K Thermocouple with AD595 Thermocouple Amplifier[6]
- DS18B20 Programmable "1-Wire" digital thermometer.[7]
- TMP36[8]

### 3.5 Prototyping

You will have two complete lab periods to design, construct, and test a final design.

**See test procedure checklist document at the end of this document.**

## 4 Teams

This project will be completed in teams of 3 (and in some cases 2) members, not larger, and not smaller.

## 5 Schedule

| | |
|---|---|
| Week of Nov 26: | Circuit design and prototyping. |
| Week of Dec 3: | Full work project should come together! |
| Saturday Dec 8 (12:00–5:00p.m.) | DEMO DAY! (Details will be forthcoming) |
| Sunday Dec 16 ($<$ midnight) | Project reports ($\leq$ 10 pages) and presentations ($\leq$ 10 slides) |
| Mon Dec 17 (1:30-5:30PM ) | Five-Minute Presentations in Hodson Hall 210 |

## 6 Deliverables

### 6.1 Project Demonstration

Due on Saturday, December 8.

[5] https://www.lcsr.jhu.edu/wiki/images/8/82/Xantech-81301-AC-Switch.pdf
[6] https://www.lcsr.jhu.edu/wiki/images/1/12/AD594_595-ThermocoupleAmp.pdf
[7] https://www.lcsr.jhu.edu/wiki/images/2/2a/DS18B20_Thermometer.pdf
[8] https://dscl.lcsr.jhu.edu/wiki/images/b/b4/TMP35_36_37.pdf

## 6.2 Project Report

Due **electronically** to Prof. Cowan on Sunday December 16 before midnight. IMPORTANT: Email your report to ncowan@jhu.edu with the following *subject line*:

**530.420 Final Project Report** *use this subject line, verbatim!*

Or, just follow the following hyperlink:

mailto:ncowan@jhu.edu?subject=530.420%20Final%20Project%20Report.

- Each team member must submit a complete final report.
- Each team member should separately write up the project report Sections.
- You and your partner can include the same photos of your circuit.
- You and your partner can, if you choose, compile a single bill of material and each include a copy of the same bill of material with your project report.
- Please submit your project report in hard copy.
- Final circuit diagrams are required.

  If you submit separate circuit diagrams for different parts of your project, you must make it clear how they connect together to work as a complete circuit.

Your project report should be comprised of the following, numbered, report sections:

1. Very brief introduction. Approximately 1 paragraph and a figure.
2. Circuit Documentation (this is the CRITICAL section)
   (a) Circuit Diagram.
   (b) Brief description of circuit.
   (c) Engineering analysis (show your work) employed in the circuit design. Include the device physical parameters employed in your design analysis. This should include:
      - PWM analysis
      - Plant model (differential equation)
      - Plant model (transfer function)
      - Step response (theoretical)
   (d) Annotated scope plots, sceen shots, video (link to youtube), or other or data tabulation demonstrating the working project.
3. Photograph of the Project. One or more photos as needed to show sufficient detail. A Nikon cool-pix digital camera is available in Wyman 140 — look for the small yellow pelican case. Please be sure to return the camera and all camera accessories to the yellow pelican case when you are done with the camera.
4. (Optional, but fun – please do this if you can!) Description of any food that you made with this project. Include links to online recipes. Or, if you made a super toaster, perhaps you tried a solder reflow?
5. Attribution: If a particular circuit idea came from the textbook, lecture, or your TA, state so. If a particular circuit idea came from you (i.e. you thought it up) state so. If a particular circuit idea came from any 3rd party sources (e.g. the Internet, your roommate, etc.) then state the exact contribution and the exact source. It is OK if you get your ideas from the Internet or other sources, just make sure you cite them or it will be considered *plagiarism!*
6. A bill-of-materials spreadsheet of data for the entire parts list of your design. For each component, your spreadsheet should contain at least the following data **(if purchased in quantity of 100)**:
   (a) Part name (e.g. 1N914)
   (b) Part designation (e.g. R1, R2, C1, D1, D2)
   (c) Manufacturer
   (d) Manufacturer Part Number
   (e) Vendor
   (f) Vendor Part Number
   (g) Part Quantity
   (h) Cost if a quantity of 100 of the part.

(i) Unit cost of an individual part (if purchased in quantity of 100)
(j) Total cost for the entire circuit (if components are purchased in quantity of 100)

Your spreadsheet should also compute the total cost for a completed circuit. Do not include the cost of the breadboard or lab-bench test leads. You MAY share your bom with your teammates.

7. **Extra Credit:** Shoot, edit, and post a you-tube video of 3 minutes or more with "JHU ME 530.420 Fall 2012 Project Video By Your Name, Your Partner's Names" as part of the title in which you and your partner explain your project, briefly explain its design, and demonstrate how it works.

   POST YOUR VIDEO WITH YOUR NAME (or initials), NOT YOUR SECRET CODE!!!!

   DO NOT INCLUDE YOUR SECRET CODE IN THE VIDEO, THE VIDEO DESCRIPTION, OR TITLE.

# REMEMBER

- Note your lab partners' secret codes on your lab report as well as your lab station number.
- Return all electronic test equipment and components to their proper location.
- Remember to show your work.
- Typewritten reports are not required, but messy or disorganized reports are unacceptable.
- Clean up your workstation to perfection when you are done.
- **Get your station checked off by your TA.**

# ME 530.420 Lab 10: Design Project

| | |
|---|---|
| Your secret code | : |
| Your partner's secret code | : |
| Your other partner's secret code | : |
| Lab stations used, date, and time | : |
| Lab stations used, date, and time | : |
| Lab stations used, date, and time | : |
| Lab stations used, date, and time | : |
| Lab stations used, date, and time | : |
| Lab stations used, date, and time | : |

The TA or Instructor must verify the functionality of your project.
Describe briefly what you are demoing to the TA here:

**T.A. Comments, Signature, and Date:**