Fish Tank Project Overview   ME 121

Mechanical Engineering Freshman Curriculum
Portland State University

The fish tank is a small PVC container of water used as a physical model of a saltwater aquarium. The pump that students fabricated in ME 120 circulates water from the tank, through a salinity sensor and back to the tank. Figure 1 is a schematic of the flow loop components of the system.

The fish tank project is an original creation of David Hall and the faculty of Louisiana Tech University, and is a central part of their Living with the Lab Curriculum[1]. The Mechanical Engineering Faculty at Portland State University made some adjustments to design of the fish tank and have developed more extensive documentation including several web pages and the overview that you are reading now.

The fish tank project provides hands-on experience with sensing and control, which are the main themes of ME 121. Students fabricate and calibrate a salinity sensor and a thermistor temperature probe. Those sensors are inputs to a control program that students write for an Arduino microcontroller. Based on sensor inputs and control set points, the Arduino actuates solenoids to adjust tank salinity or a heater to adjust tank temperature.

The fish tank project spans the full 10 weeks of the term. Lecture and homework assignments help students learn the fundamental skills necessary for successful completion of the project. During class periods and as part of homework assignments, student fabricate components of the fish tank, they build electrical circuits for reading sensors and actuating controls, and they write Arduino code to implement the controller.

Figure 1   Schematic of the fish tank flow loop.

This document provides an overview of the fish tank project to help student see how the sequence of weekly assignments lead to a functioning fish tank by the end of the course. Work on the fish tank project can be divided into four phases:

1. Fabrication of the wooden platform, the salinity flow loop, and calibration of the salinity sensor;
2. Assembly of the salinity control system; writing code for salinity control;
3. Assembly of the temperature control system; writing code for temperature control; and
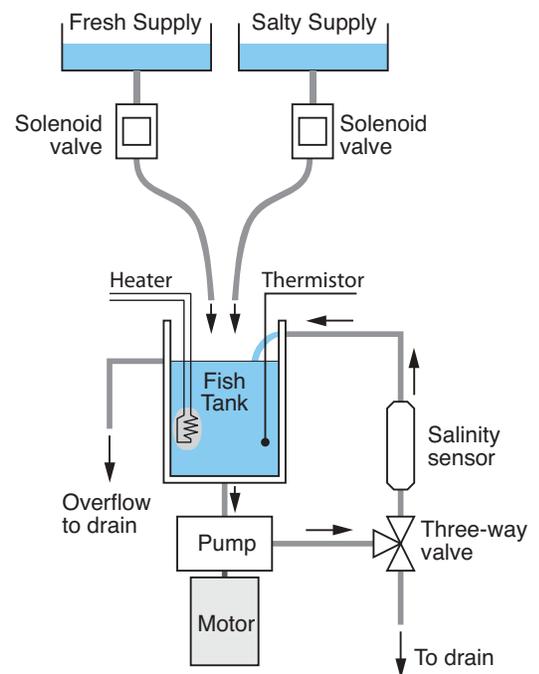4. Integration and testing of the salinity and temperature control systems.

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[1] www.livingwiththelab.com

Attention to details and careful execution of the first three phases will make the final phase – system integration – easier. Additional details about construction, programing and testing of the fish tank are provided on the ME 121 web site, http://web.cecs.pdx.edu/~me121/.

Students work in groups of four to complete a single fish tank system. Coordination and sharing of effort is important, but it is not meant to allow students to specialize on only parts of the curriculum. By the end of the project all group members are expected to have complete knowledge of all subsystems and components of the fish tank.

Checklists for Grading and Organizing Project Work

The complexity of the project requires that students make continuous progress during the course. This overview document includes several checklists for fabrication, assembly, calibration and control stages of the project. During the course, the checklists will be used (perhaps with some modification) in rubrics used to grade progress on the project.

In addition to facilitating grading, the checklists are intended to show how complex projects can (and should!) be executed in an orderly sequence of manageable steps. In other words, we hope that the checklists provide a model that you adopt in your own projects.

Materials and Supplies

Instructors provide most of the material used to fabricate the fish tank system. Students must purchase components and tools listed in following table. Students work in groups of four to complete a single fish tank. Thus, where the *Quantity* column indicates "group of 4" it refers to the number of items required for a single fish tank.

Table 2   Materials and supplies purchased by students. Additional details available at http://web.cecs.pdx.edu/~me121/doku.php?id=equipment.

Item	Quantity per Group of 4	Source
4x20 Character LCD Panel with Serial Backpack	1	Electronics Prototyping Lab, or online vendor
12VDC, 2A (minimum) power supply	1	Electronics supply store, or used equipment store
On/off toggle switches	2	Electronics supply store, or salvaged from old equipment
Barrier strip	1	Electronics supply store
Barrel jack receptacle	1	Electronics supply store
Long breadboard (840 tie pts.)	1	Electronics supply store
Teflon tape	1	Hardware store
Drill bit set: 1/16 to 1/4 inch	1	Hardware store

Phase 1: Fabrication of the Platform, Flow loop and Salinity Sensor

The first phase of fish tank project involves fabrication of the PVC "tank", assembly of the support platform, fabrication of the salinity sensor, and assembly of the recirculating flow loop. Students must purchase a 12 VDC power supply with a minimum 2A capacity to supply electrical power to the pump, the solenoids and the tank heater. A project box or electrical power box with two on/off switches are also required. The switches allow the pump and the control system to be turned on and off independently.

Fabricate the PVC Fish Tank and Salinity Sensor

Instructions for fabricating the PVC fish tank are given on this web page:

http://web.cecs.pdx.edu/~me121/doku.php?id=fish_tank_fabrication_assembly_and_control

Step-by-step instructions for fabricating the salinity sensor are provided in a PowerPoint presentation.

Assemble the Fish Tank platform

The fish tank platform provides the structural support for the plumbing and the electronics. Student teams of four are supplied with the wooden components and other hardware. Detailed instructions for assembling the platform are provided on this web page:

http://web.cecs.pdx.edu/~me121/doku.php?id=assemble_the_wooden_platform

Figure 2 is a photograph of the assembled platform before it is painted.

Figure 2:   Photograph of an assembled fish tank platform before it is painted.

Assemble the primary flow loop

Figure 3 is a schematic of the primary flow loop that circulates water through the salinity sensor. Instructors provide the components for the flow loop, with the exception of the pump that students created in ME 121. Detailed assembly instructions are provided on the web page for the class.

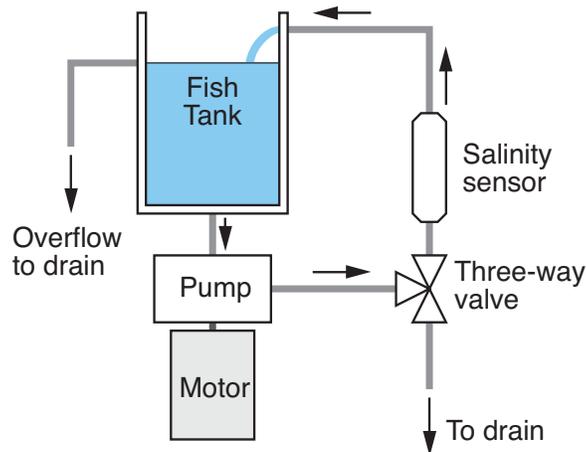http://web.cecs.pdx.edu/~me121/doku.php?id=assemble_the_flow_loop_plumbing

Figure 3.   Schematic of the recirculating flow loop for the salinity sensor.

Checklist for platform and flow loop assembly

[ ] All structural components are securely attached in approximately the correct locations. Allowances are made for creativity and innovation.
[ ] Platform is painted.
[ ] Pump, fish tank, salinity sensor and three-way valve are securely mounted.
[ ] Flow resumes without priming when the pump is turned on and off.
[ ] No leakage is evident while pump is running.

Purchase and Install Components of the Electrical Power System

Students need to purchase the components listed in Table 2 for the electrical system. Attach the electrical power system to the fish tank platform *after* the platform has been assembled and painted.

The electrical subsystem needs to supply 12V DC power to two, independently switchable circuits. One circuit is for the pump and the other circuit is for the controls. The control circuit includes the Arduino microcontroller, three relays and two solenoid valves. Figure 4 is a schematic of the electrical power supply system. The switches allow students to turn the pump on and off independently of the control system, which is *very* helpful during debugging of the system. Detailed instructions for wiring the fish tank are provided in web pages for the class:

http://web.cecs.pdx.edu/~me121/doku.php?id=wire_salinity_sensor
http://web.cecs.pdx.edu/~me121/doku.php?id=wire_power
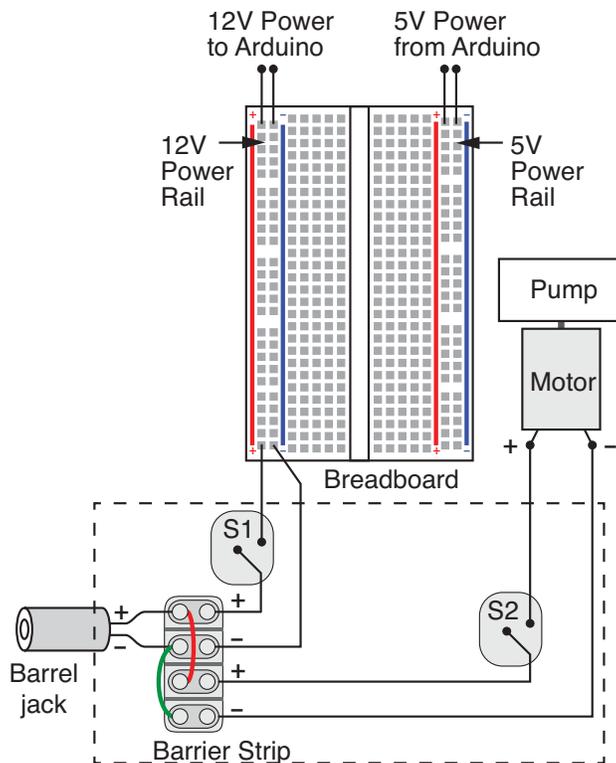http://web.cecs.pdx.edu/~me121/doku.php?id=lecture:solenoid_valves

Figure 4:   Schematic for power supply to the fish tank pump and breadboard. S1 and S2 are switches. The barrel jack provides a quick disconnect to an external 12VDC power supply. The dashed line indicates the components located inside a project box or electrical switch box.

Checklist for electrical power system

[ ] Electrical system has two 12VDC circuits.

[ ] Each 12VDC circuit has an on/off switch.

[ ] Switches, barrier strips and other exposed connections are inside a project box or electrical box.

[ ] Turning pump on and off does not interfere with operation of the control system.

[ ] Turning control system on and off does not interfere with operation of the pump.

Component Sources:

• On-line retail outlets such as Sparkfun, Jameco, Allied Electronics, Digikey and others sell rocker switches or toggle switches.

• Local electronics supply stores like Radio Shack, URS Electronics, and Fry's have project boxes, barrier strips and rocker switches or toggle switches.

• Rocker and toggle switches can also be salvaged from electronic junk, or purchased from electronics surplus stores.

Calibrate the salinity sensor

The salinity sensor measures the electrical resistance of the water circulating in the fish tank. The sensor forms the upper half of a voltage divider as depicted in Figure 5. A digital output pin of the Arduino provides electrical power to the voltage divider when salinity measurements are made. Energizing the voltage divider only when measurements are being made prevents ionic blocking of the measurement probes. Also note that turning on the voltage divider may result in a transient response of the salinity reading. Therefore, it may be necessary to introduce a short delay between turning power on to the voltage divider and recording salinity readings.
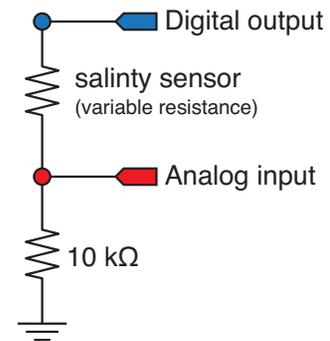

Figure 5   Circuit for the salinity sensor, with power supplied by a digital output pin

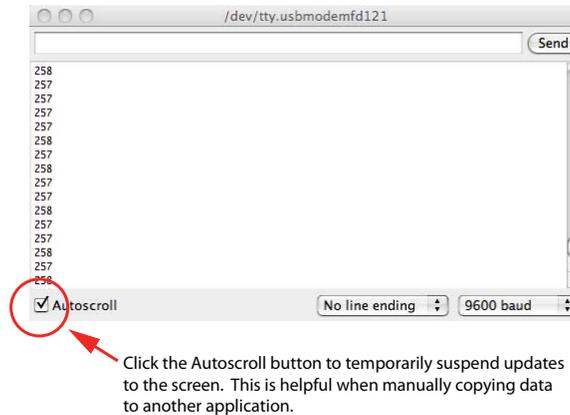To prepare for collecting calibration data:
1. Assemble the voltage divider circuit
2. Write an Arduino program to supply power to the voltage divider and repeatedly measure and display the voltage output to the Serial Monitor.
3. Verify operation with tap water and tap water with table salt added
4. Rinse and purge the system with clean tap water two or more times.

Pre-calibration checklist
[ ] Voltage divider circuit is assembled.
[ ] Arduino code to turn on the salinity sensor, display individual salinity readings on the Serial Monitor is complete.
[ ] All components are verified with tap water and tap water mixed with table salt.
[ ] Water bottles for DI and salty water are obtained.

Procedure for collecting calibration data at four salinity levels (including zero).
1. Rinse and purge the system with DI water.
2. Add sample of calibration water (one of four salinity levels).
3. Collect a large sample of at least 50 readings:
    a. Run data collection program to watch for steady state
    b. After steady state has been achieved, Click the AutoScroll in the Serial Monitor to stop updates. Use Copy/Paste to copy data to a spreadsheet or text file to be read by MATLAB.
4. Return to step 1 until data for all four salinity levels is collected at least once.

Click the Autoscroll button to temporarily suspend updates to the screen. This is helpful when manually copying data to another application.

Calibration checklist

[ ] Raw data is saved to a spreadsheet with clear labels, date, and group name.
[ ] Histogram of readings at each salinity calibration point are created.
[ ] Statistics for each salinity calibration point are computed and tabulated.
[ ] Forward, $S = f(V)$, and reverse, $V = g(S)$, curve fits to the raw data are obtained. Coefficients of curve fits to at least five decimal places are recorded.
[ ] Plots of raw data with superimposed curve fits (forward and reverse) with proper labels are completed.

Phase 2: Salinity control system

The salinity of the water in the fish tank is adjusted by adding fresh or salty water. A reservoir of fresh water and a reservoir of salty water are each connected to solenoids, which are connected to nylon tubes that empty into the fish tank. Figure 6 is a schematic of the flow system that includes the fresh and salty water supply tanks. Figure 7 is a photograph showing the salinity control components of a completed flow system.

Assemble plumbing for the salinity control system

The solenoid valves are mounted on the frame with machine screws that pass through holes in the cross-piece at the top of the wooden frame. Note that the solenoids have a preferred direction as indicated by an arrow on the body.

Preliminary checklist for fabrication of fresh and salty water supply plumbing

[ ] Solenoids are attached to supply reservoirs and oriented in the correct direction.
[ ] Nylon tubing is attached to the solenoid valves.
[ ] Solenoids with supply reservoirs are attached to the platform.
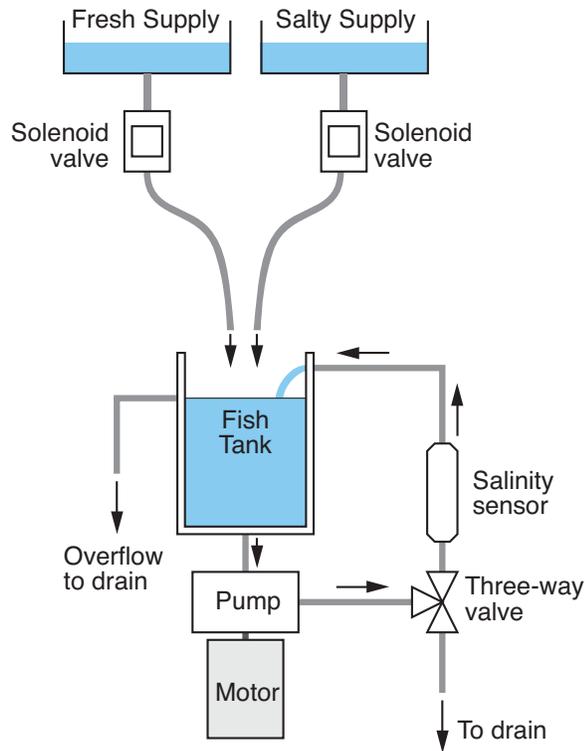[ ] Supply tubes are secured with zip ties.

Figure 6   Flow loop with solenoids and water supply reservoirs used to control salinity of the fish tank.
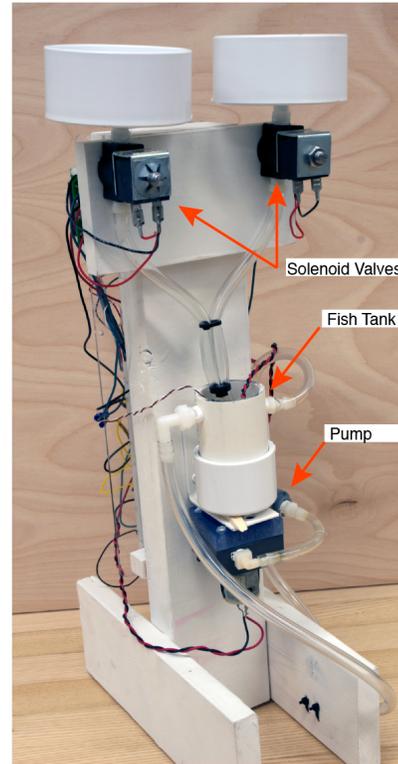

Figure 7   Photograph of completed flow loop with solenoids and supply reservoirs.

Assemble and test the wiring for the salinity control system

The control system for each solenoid requires a transistor and a relay in the cascaded arrangement shown in Figure 8. The transistors and relays are mounted on the large breadboard on the control system support plate.

The base of an NPN transistor is connected to a digital output pin of the Arduino. When that digital output is high (+5V), current from the 5V supply flows through the coil of the normally open relay, closing relay contacts, and allowing current to flow through the coil of the normally closed solenoid valve. When the solenoid coil is energized, the solenoid valve is opened, allowing water to flow from one of the reservoirs to the fish tank. Flyback diodes across the relay coil and solenoid coil provide safe dissipation of energy when current to the coils is switched off. Two of these cascaded control circuits are needed: one for the fresh water supply and one for the salty water supply.
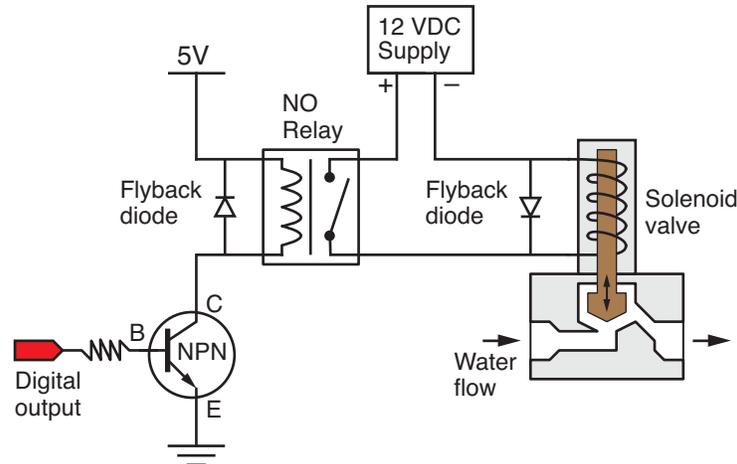
Figure 8   Cascade switching circuit that operates the solenoid valve.

Preliminary checklist for salinity control system

    [ ] Transistors are correctly connected to digital output pins of the Arduino.
    [ ] Transistors are correctly connected to the 5V control side of the relays.
    [ ] Relays are correctly connected to the 12V supply to the solenoid valves.
    [ ] Solenoid valves are correctly connected to the 12V supply from the relays.
    [ ] Both solenoid circuits can be actuated by an Arduino program.

Write Arduino code for the salinity control system

The goal of the salinity control system is to maintain the salinity of the water within specified lower and upper bounds. The following steps give a *simplistic* version of the control algorithm.

1. Measure salinity
2. If salinity is greater than upper limit:
        Add fresh water: open valve, wait, close valve.
3. If salinity is less than lower limit:
        Add salty water: open valve, wait, close valve.
4. Wait for the system to mix
5. Return to step 1.

Although these steps give the basic outline of a control algorithm, at least two important refinements are necessary. First, the "Add fresh water" and "Add salty water" steps do not indicate how much water should be added – or in terms of actuation in the control system, how long the solenoid valves should be left open. To get a better idea of how much water to add (or how long to open the valves), we will create a model of the salinity concentration in the tank. Second, the "Wait for the system to mix" step does not specify how long to wait between salinity measurements. The waiting period will be determined as part of the control algorithm development. Classroom instruction and homework assignments will provide details for implementing the salinity control system.

Checklist for completion of salinity control system

    [ ] Mathematical model of salinity control system is completed.

    [ ] Salinity of water is displayed on the LCD panel.

    [ ] On/off states of solenoids are displayed on the LCD panel.

    [ ] Measurement of flow rate through the salinity control valves is completed (used to calibrate the model).

    [ ] Measurement of transient response of the system is used to determine the delay between actuation (valve open/valve close) and next equilibrium measurement.

    [ ] Salinity control code is completed and submitted for review.

    [ ] In-class verification of salinity control system.

Phase 3: Temperature control system

Fabricate and Calibrate the Temperature Sensor

The temperature of the water in the tank is measured with a waterproof probe using a thermistor supplied by the instructor. Detailed instructions for fabricating the thermistor probe are on the web page for the class:

    http://web.cecs.pdx.edu/~eas199/B/howto/thermistorProbe/

The thermistor output is measured by placing it in one leg of a voltage divider as depicted in Figure 9.

    Students calibrate their thermistor probes with a digital thermometer and water baths at different temperatures. Figure 10 is a sketch of the calibration experiment. To perform the calibration, students need to bring an insulated coffee cup to class. The cup is only used to hold heated tap water, so the calibration process does not damage the cup.
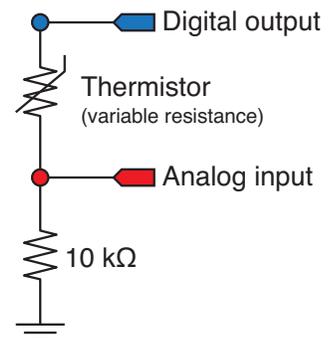
Figure 9   Circuit for the thermistor measurement, with power supplied by a digital output.
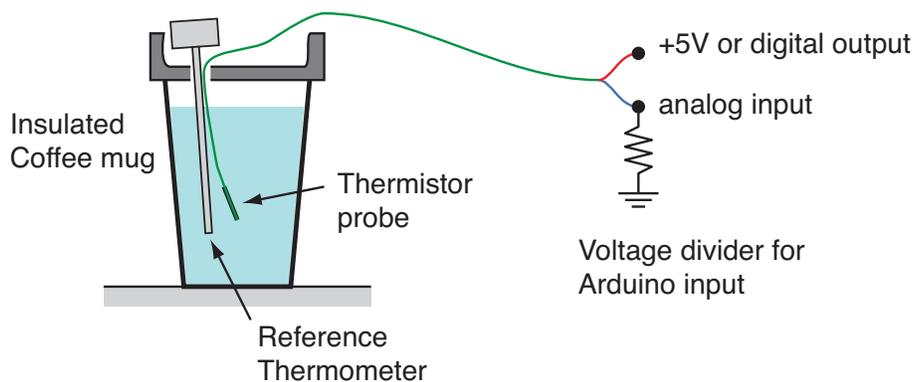
Figure 10 Laboratory set-up for calibration of the thermistor.

Checklist for calibration the thermistor

[ ] Insulated coffee cup is available.

[ ] Thermistor probe is fabricated according to instructions on the class web site.

[ ] Voltage divider circuit for the thermistor is complete and working.

[ ] At least 25 voltage readings are recorded for each temperature.

[ ] Data is collected for at least 10 calibration temperatures.

[ ] Histogram of each calibration point is created.

[ ] Statistics for each calibration point are computed.

[ ] Forward, $T = f(V)$, and reverse, $V = g(T)$, curve fits to the raw data are obtained. Coefficients of curve fits to at least five decimal places are recorded.

[ ] Plots of raw data and curve fits (forward and reverse) with proper labels are completed.

Fabricate the Water Heater

A waterproof electric resistance heater is fabricated from a power resistor and a small section of aluminum bar stock that acts as a heat spreader. The heater is controlled with the cascading circuit depicted in Figure 11. Note that this circuit is the same as that used to control the solenoid valves, with the heater replacing the solenoid. Detailed instructions for fabricating the heater are on the web page for the class:
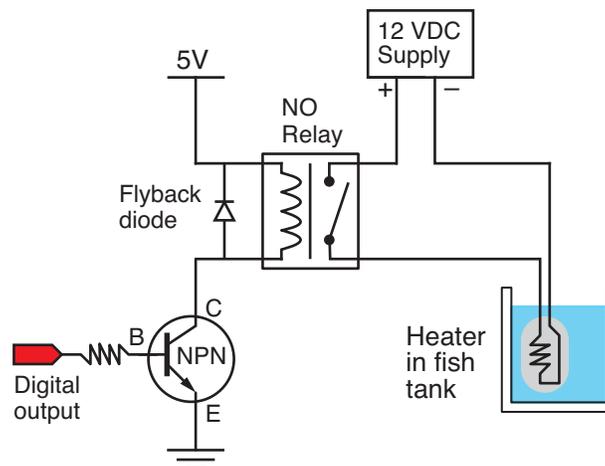
http://web.cecs.pdx.edu/~eas199/B/howto/heater/

Figure 11 Cascade switching circuit that sends power to the heater.

Control the Water Temperature

The following steps give a *simplistic* version of the control algorithm.

1. Measure temperature.
2. If temperature is less than the lower limit:
   > Turn on the heater, wait, turn off the heater
3. Wait for the system to mix
4. Return to step 1.

The final working algorithm will require careful interpretation of these steps.

Checklist for implementation of heater control

[ ] Model of energy balance for the tank is complete.
[ ] Temperature of water is displayed on the LCD panel.
[ ] On/off state of heater is displayed on the LCD panel.
[ ] Measurement of temperature rise rate for constant heater input is completed (used to calibrate the model).
[ ] Temperature control code is completed and submitted for review.
[ ] In-class verification of temperature control system.

Phase 4: System integration

Integration of the salinity and temperature control systems requires merging the code for controlling salinity control with the code for controlling temperature. This is non-trivial because the two control algorithms have different time constants. The salinity in the tank can be changed very quickly by addition of relatively small amounts of salty or fresh water. The temperature of the water changes slowly when power is supplied to the heater.

Getting the two control cycles working together is much easier if the code for the separate systems are written with a clean structure. Specifically, we strongly recommend user-defined sub-functions for sensor measurement, sensor calibration, and LCD updates. Our past experience is that system integration is painful when the salinity control code and/or temperature control code was just hacked together until it works.

Checklist for final system operation

[ ] Salinity control code is combined with temperature control code.
[ ] Salinity and temperature are displayed on the LCD panel.
[ ] Combined control and display code is completed and submitted for review.
[ ] In-class verification of temperature and salinity control system.