MASSACHVSETTS INSTITVTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science
6.01—Introduction to EECS I
Fall Semester, 2007

Assignment 10 - Design Lab, Issued: Tuesday, November 6th

To do this week

...in Tuesday lab

1. Read through the Thursday's design lab and start working on answers to questions 10, 15, 18, and 19.
2. You can take makeup quizzes for Quiz 7 and 8 at the end of Tuesday's lab if you wish.

...before the start of lab on Thursday

1. Review the notes for lecture 9.
2. Finish writing the answers to the four circuit design questions in from Thursday's design lab.
3. Write up your solutions to the homework problem below. There are no on-line tutorial problems this week.
4. Read through the entire description of Thursday's design lab (this handout).

...in Thursday robot lab

1. Hand in your answers to the four circuit problems from Thursday's lab and your solution to the homework problem below.
2. Make sure you have read the lab and understand it before coming to lab! Your partner is counting on you!
3. Answer the numbered questions in the robot lab and demonstrate them to your LA.

...before the start of lecture next Tuesday

1. Do the lab writeup, providing written answers (including any code and descriptions of tests) for **every** numbered question in handout.

On the lab laptops make sure you do:

`athrun 6.01 update`

so that you can get the `Desktop/6.01/lab10` directory which has the files mentioned in this handout.

- For the Thursday software lab, you will need the files `v_oscillo_cntrl.py`, `control.py`, and `NIDAQ.py`.

You will need to use lab laptops for the Thursday design lab.

Homework assignment for Thursday: Analyzing Op-amp behavior using the difference equation model

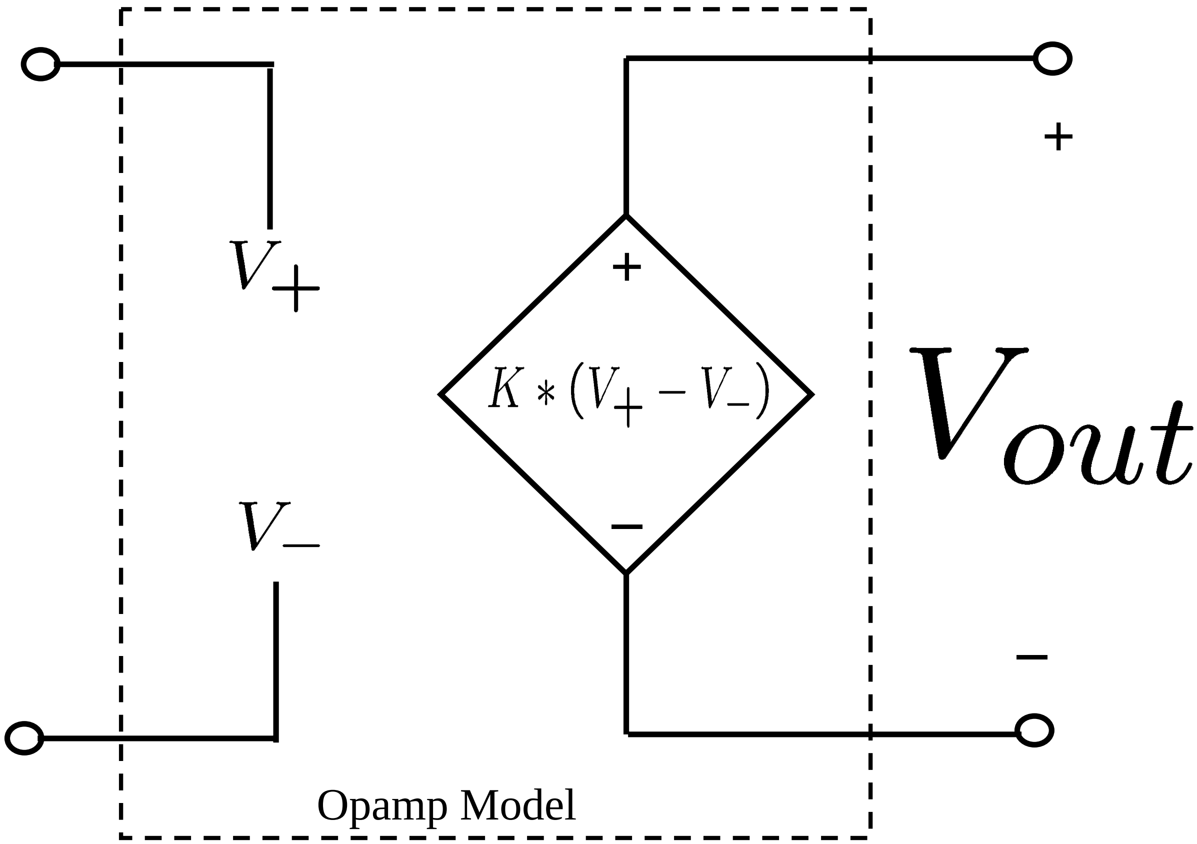

Figure 1: Voltage-Controlled Voltage Source Model of an Op-amp.

We have made use of the voltage-controlled voltage source model of the op-amp, as in figure 1. In that model, we assumed that when the input voltage changed, the output voltage changed instantly. In the sequence of problems below, we will use difference equations to develop a more accurate model of how quickly the op-amp responds to input changes. In particular, we are going to assume that if we sample the opamp output voltage every microsecond (one millionth of a second), then the output at the n^{th} sample will be

$$V_{out}(n+1) = \frac{K-1}{K} V_{out}(n) + (V_+(n) - V_-(n))$$

Question 1. Suppose $V_{out}(0) = 0$ and$(V_+(n) - V_-(n)) = 0.01$ for all n. If

$$\lim_{n\to\infty} V_{out}(n) = 5$$

determine the value of K.

Question 2. Again suppose $V_{out}(0) = 0$ and$(V_+(n) - V_-(n)) = 0.01$ for all n, and K is the value your determined in answering the first question. How many samples, and how many seconds, will it be before V_{out} exceeds 3.3 volts. The easiest way to solve this problem would be write a program to solve the difference equation, or modify one of the difference equation solving programs posted on the course calendar.

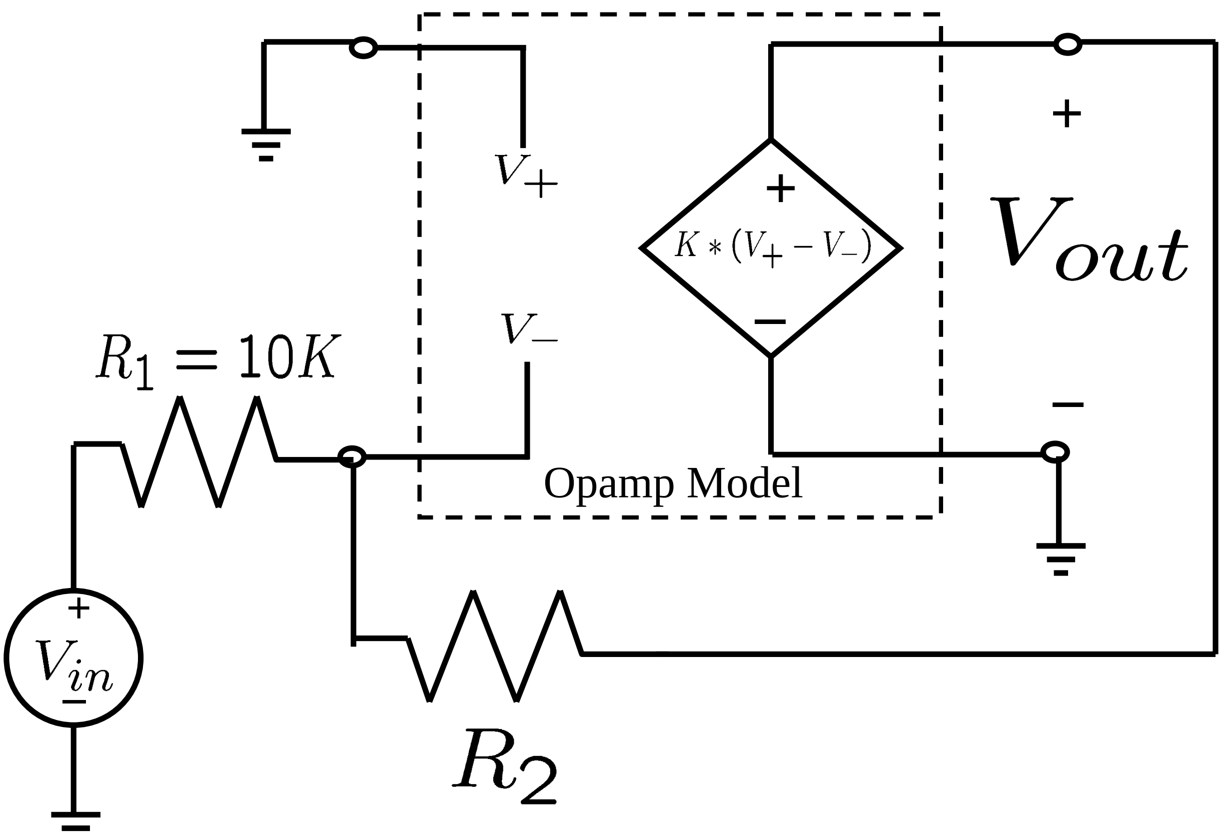

Figure 2: Amplifier using VCVS model of an op-amp.

Question 3. In figure 2, the voltage-controlled voltage-source (VCVS) model of the op-amp has been used to create an amplifier with input V_{in} and output V_{out}. We have learned that the amplifier gain for this kind of circuit is approximately

$$V_{out} \approx -\frac{R_2}{R_1} V_{in}.$$

However, if we now use the difference equation model for the response of the output of the op-amp, then the relationship between V_{out} and V_{in} will also be a difference equation. For what value of R_2 will the difference equation describing the relationship between V_{out} and V_{in} *for the entire circuit* be

$$V_{out}(n+1) = \frac{399}{500} V_{out}(n) - \frac{4}{5} V_{in}$$

Note, you will need the value for the op-amp gain, K, that you computed above.

Question 4. Suppose $V_{out}(0) = 0$ and $V_{in} = 1$ for all n. How many samples, and how many seconds, will it be before V_{out} exceeds 2.6 volts.

Question 5. For each of the above cases where you were asked to compute the time required for the output to exceed a threshold, what is the relationship between the natural frequencies of the associated difference equations and the time required for the output to exceed a threshold?

Question 6. In figure 3, the voltage-controlled voltage-source model of the op-amp has been used to create an amplifier with input V_{in} and output V_{out}, but we have interchanged the positive and negative inputs. Using the difference equation model for the response of the output of the op-amp to its input, then the relationship between V_{out} and V_{in} will also be a difference equation of the form

$$V_{out}(n+1) = \alpha V_{out}(n) + \beta V_{in}$$

Determine the value of α if $R_2 = 10k$.

Question 7. Suppose $V_{out}(0) = 0$ and $V_{in} = 1$ for all n for the op-amp configured as figure 3 with $R_2 = 10k$. Will the $\lim_{n\to\infty} V_{out}(n)$ be finite? Try plotting $V_{out}(n)$. What do you observe about the solution?

To Hand In

Please hand in the solutions to this homework problem along with the answers to questions 10, 15, 18, and 19 at the beginning of lab at 10am on Thursday, November 8th

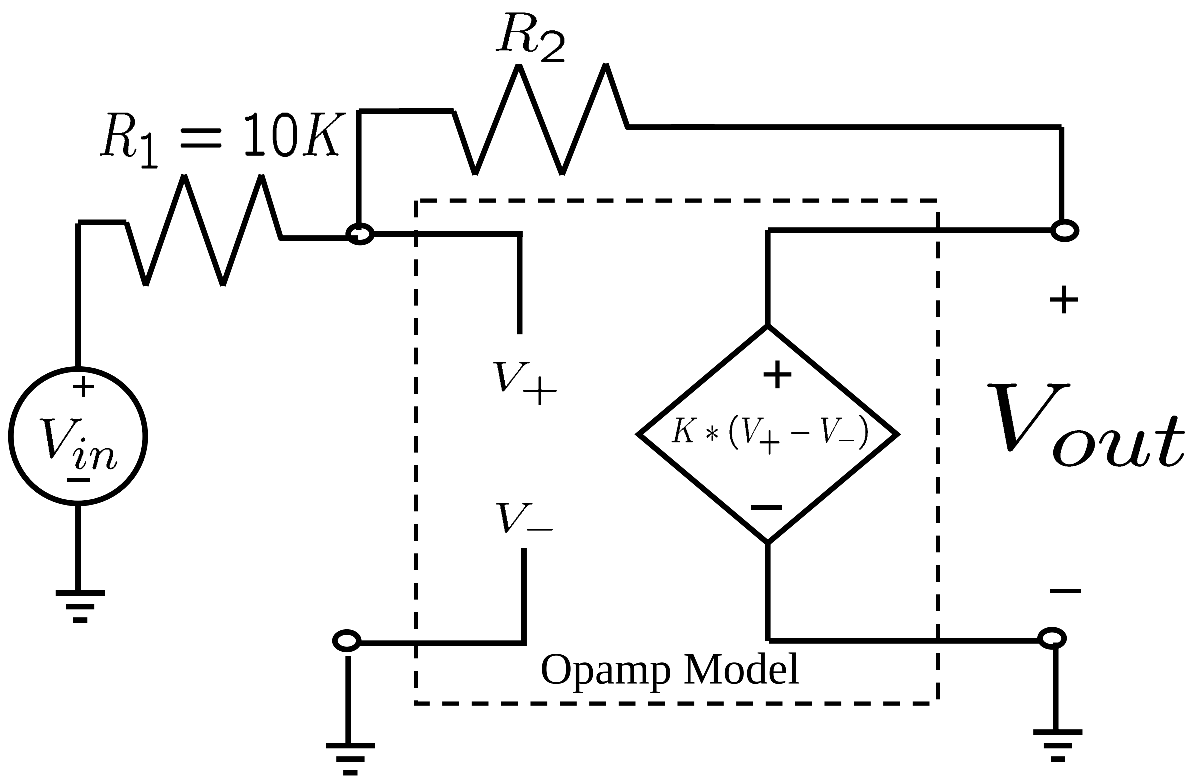

Figure 3: Postive Feedback version of an amplifier.

Thursday Lab - See's the Day

In this lab you will examine multiple alternatives for adding a pair of "eyes" to a robot head and then making the head track a light. Note there are four circuit design questions in this lab that we are asking you to answer and hand in before this lab begins on Thursday. The reason for this is to make sure you are prepared to work efficiently with your partner in the lab on Thursday.

For this lab you will need:

1. Your robot head from last week (with you and your partner's name on it).
2. A voltmeter.
3. A robot with a NI box, or a separate NI Box.
4. A USB cable.
5. A laptop.

6. Two photoresistors.
7. A twisted triple of wire.
8. A project board.

To add eyes to your robot head, you will be using two photoresistors (resistors whose values change with light intensity). You will use these photoresistors, the robot head you modified last week, an NI box, a laptop, and your knowledge of circuits, control, and python to take two approaches to designing a light-tracking robot head. One approach will use just circuits, and the other approach will use circuits, the NI box, the laptop, and a program in python. The reason for trying both methods is that each method has its own merits, and analyzing the tradeoffs will be the subject of your report on this lab.

There are a number of tasks you will need to complete as you use the two methods for making a light-tracking head. They include:

- Interfacing your robot head to the laptop (using the NI Box) so that you can control and sense the head position using a python program.
- Determining how to design a circuit using the two photoresistors to produce two voltages related to light intensity, where the photoresistors are on the swiveling head of the robot and the only electrical connection between the swiveling head and the base plate circuit board is a twisted triple of wire.
- Designing a circuit-only light-tracking head.
- Designing a circuit to interface the photoresistors to the laptop so that you can sense light using a python program.
- Designing a light-tracking head using a python program.

This lab is intended to give you an opportunity to examine the trade-offs between circuit-only and computer-based methods of light tracking, so you will be developing two approaches.

Testing your robot head

Before beginning the lab, please test your robot head (which you should have designed last time to work with a single twelve volt supply) by:

1. setting the variable power supply on the project board to twelve volts,
2. making the connections between the project board power supply and your robot head,
3. testing your robot head to make sure that you can still adjust the head position by turning the hand-adjustable potentiometer.

Interfacing your robot head to the laptop.

For this part, you will be designing the circuitry and calibrating a program so that you can use a python program to control and measure the position of the robot head. You will be using the NI box with the python program `v_oscillo_cntrl.py` and modifying the program in `control.py`.

This new version of the virtual oscilloscope automatically starts the NIDAQ server, and calls the step function in the control class defined in `control.py` about twelve times a second.[1]

You should have all the files you need in the `lab10` directory.

To start the virtual oscilloscope, make sure the USB cable from the NI box on the robot is plugged into the USB port of your laptop (if so, the green light on the NIDAQ will be blinking). In a terminal window, change to the `lab10` directory and type

```
python ./v_oscillo_cntrl.py
```

After a few seconds, an oscilloscope window should appear on your laptop screen, and the first channel (AI0) from the NIDAQ (which may be connected to the first optical sensor) should be plotted in the oscilloscope window. You will be using channels AI5, AI6 and AI7 for this lab. To show additional NIDAQ channels, right click on the display and toggle the desired channels. You can show multiple channels on the oscilloscope. If the oscilloscope does not seem to be working, close the oscilloscope window, unplug the NIDAQ USB connection, wait three seconds, replug the USB connection and restart the virtual oscilloscope.

IMPORTANT: If the virtual oscilloscope crashes, or you kill it, you *must* unplug the USB cable to the NI box. If you just restart the virtual oscilloscope, the program may run but will produce unpredictable nonsense results (such as AIx data showing on channel AIy)!

Recall that last time you noticed that the voltage generated by swiveling robot head potentiometer does not vary all the way from the negative supply rail to the positive supply rail. Please remeasure the voltage range from the robot head potentiometer now that you are using a single twelve volt supply. While your are making this measurement, you will find it easiest to unplug the motor connector cable from the motor while you are rotating the head, as then you can turn the head freely.

Use the results from your measurements, the fact that the NI box input AI5 can read voltages in the range from zero to ten volts, and a modification of the the step function in `control.py`, which is called approximately twelve times a second when the program `v_oscillo_cntrl.py` is running, to design the circuitry and software you need to print out a reasonable approximation to the angle of the head. The angle printed should vary from almost $-\pi/2$ to almost $\pi/2$, where zero is printed when the head is parallel to the straight edge of the grey base plate, $\pi/4$ should be printed when the head is rotated 45 degrees counter-clockwise from parallel to base plate straight edge, and $-\pi/4$ should be printed when the head is rotated 45 degrees clockwise from parallel to base plate straight edge. Note that the motor stops the head from turning far enough to generate angles of $\frac{\pi}{2}$ or $-\frac{\pi}{2}$.

In order to compute and print out the angle of the head, you will be modifying the `step` function of the class `control` in the file `control.py`. When you start the program `v_oscillo_cntrl.py`, an instance of the class `control` is instantiated by `v_oscillo_cntrl.py`, and when the oscilloscope is running (and plotting data on a graph on your laptop), the `step` method for the control class is called roughly every twelfth of a second. The step function is passed the eight values read from NI box inputs `AI0, AI1, ... AI7` in the list `inputValues`. For this entire lab, you will only need to modify the programs in `control.py`.

Note that the program in `control.py` is also generating a sine wave output on the `AO0` output of the NI box. You can see this by connecting the `AO0` output to the `AI7` input and then making sure

[1]This new version of NIDAQ server and virtual oscilloscope was developed by Quentin Smith, and was based on the version originally developed by Karim Liman-Tinguiri, both former 6.01 students.

the `AI7` input is being plotted in the oscilloscope window. Recall that to show different NIDAQ channels (corresponding to different inputs), right click on the display and toggling the desired input.

Question 8. How did you interface the robot head potentiometer to the laptop? Did you need a resistor divider? Why or why not?

Question 9. How did you calibrate the approach you used to convert the potentiometer voltages to robot head angle (use a simple approach that results in accuracy that looks right, you do not need high accuracy)?

Design a circuit so that the AO0 output from the NI box can be substituted for the hand-adjusted potentiometer in your feedback system for controling the robot head position. Show that you can use a python program that takes a head angle (within the range that the robot head can move) and makes the head rotate to that angle. You will need to modify `control.py` and run `v_oscillo_cntrl.py` to execute your controller.

You will have to consider two issues in designing this control program:

- The NI box output generates a signal that varies from zero volts to five volts, but the original control potentiometer that you adjust by hand generates a voltage than varies from zero volts to twelve volts. You will have to think about how to design your interface circuit to rescale the five volt output.
- You will have to think about how to calibrate your control program to convert a requested angle to the appropriate AO0 output voltage.

Question 10. Give a circuit diagram and describe the circuit that you use to control the robot head position from the the AO0 NI box output. This diagram should include the position feedback loop and the modifications to rescale the AO0 voltage from the NI box **YOUR WRITTEN ANSWERS TO THIS QUESTION SHOULD BE HANDED IN THURSDAY MORNING BEFORE LAB**

Question 11. How did you calibrate you control program so that you can specify an angle and have the robot head turn to that angle?

Question 12. Could you have used your calibrated measurement program to help calibrate the control program?

Question 13. Can you use the results from the calibrated measurement program in a feedback system to avoid having to calibrate your control program?

Question 14. Which do you think would be more reliable, using a calibrated control program to move your robot head to the right position, or using the calibrated measurements and a feedback system?

Checkpoint: 11:00

- Demonstrate that you can slowly rotate the head from side to side using a python program.
- Demonstrate that your measurement program can sense the robot head position and print out the angle of the robot head to reasonable accuracy.
- Demonstrate that you can specify a robot head angle in a python program and have the robot head move to that position.

Designing a circuit-only light-tracking head.

As one might expect from the name, photoresistors are resistors whose resistance decreases with increasing light intensity. Ask a staff member for a pair of photoresistors to use as robot eyes, Add the two photoresistors to the circuit board on the Robot head. Use three wires from head to the base board, but think carefully about how to wire the photoresistors so they generate a signal that can be used by your robot head to turn towards the light. Also, we have special wires to make connections between the rotating circuit board and the fixed circuit board that do not strain the robot head motor, notice how the wires are attached in figure 4.

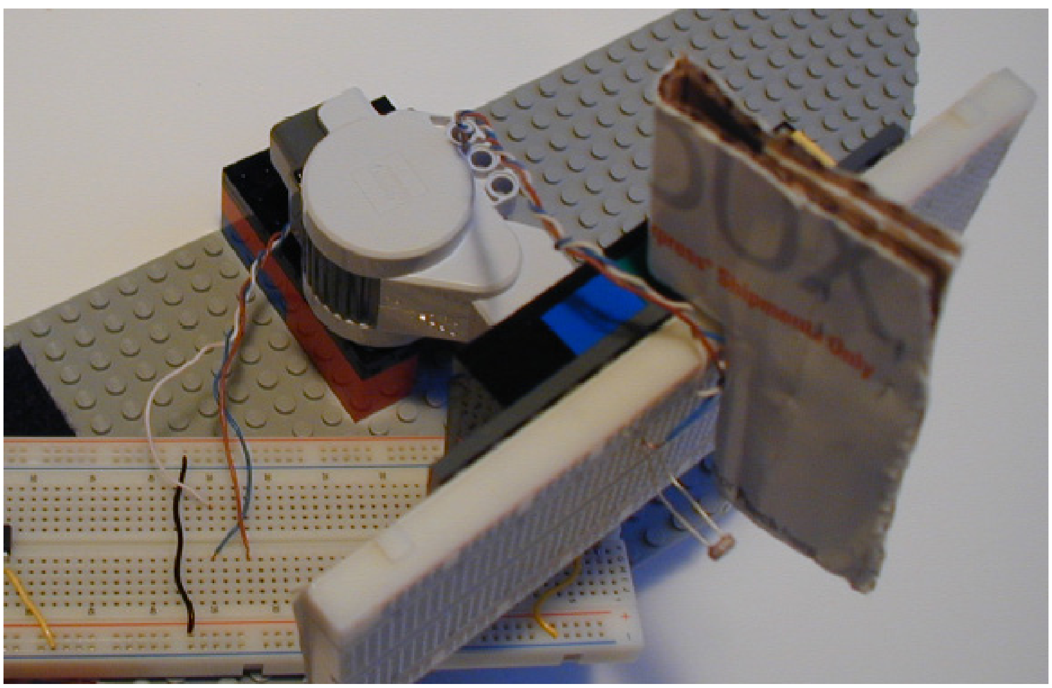

Figure 4: Robot head with photoresistors and twisted triple of wire. Note that the ends of the wires are plugged in to arbitrary locations on the circuit boards. Note the “nose”.

Design a circuit which uses the two photoresistors to replace the hand-adjustable position control potentiometer on your robot head circuit, so that the head turns towards a lamp (this should be a circuit-only solution, you should not need the laptop). If you are clever, you will not need any extra components beyond the two photoresistors.

Determine how accurately your head tracks the lamp. That is, if you hold the lamp straight ahead, does the robot head point straight at the lamp.

Question 15. Give a circuit diagram and describe the circuit for the circuit-only approach to controlling the robot head to turn towards the light **YOUR WRITTEN ANSWERS TO THIS QUESTION SHOULD BE HANDED IN THURSDAY MORNING BEFORE LAB**

Question 16. How accurate is your circuit-only controller? That is, does the robot head point straight towards the lamp?

Question 17. If you are lucky, the circuit-only controller may be reasonably accurate, if so, what happens if you tilt the face of one of the photoresistors? Is the circuit-only controller still accurate?

Checkpoint: 11:30

- Demonstrate using a lamp that your head tracks the light.
- How accurately does the robot head track the light? For example, If the lamp is directly in front of the head, how close does your calibrated position measurement program indicate the head is to zero angle?

Designing a circuit to interface the photoresistors to the laptop

Please design a circuit for converting the changes in light intensity on each of the photoresistors to a pair of voltages. Note that the resistance of the photoresistors vary from about 100 ohms in very bright light, to more than 10K ohms in darkness. As you design your circuit, keep in mind that it will be easiest to interface the voltages to the NI box if your circuit generates voltages that are in the range from zero to ten volts.

Note, you will have to think about how to design a circuit and where you place components so that you only need the three-wire connection between the swiveling head and the base plate.

Question 18. Describe your circuit for converting photoresistor resistance changes due light intensity changes in to voltages. **YOUR WRITTEN ANSWERS TO THIS QUESTION SHOULD BE HANDED IN THURSDAY MORNING BEFORE LAB**

Question 19. How did you place components so that you only needed three wires from the head to the grey base plate? **YOUR WRITTEN ANSWERS TO THIS QUESTION SHOULD BE HANDED IN THURSDAY MORNING BEFORE LAB**

Checkpoint: 12:00

- Demonstrate using a volt meter and a lamp that you can sense both light changes on each of the two photoresistors.

Modify `control.py` to that the light intensities generated by the two photoresistors are read by the program. Calibrate your program to process the readings from the photoresistors, and try compensate for any mismatch between the photoresistors.

Question 20. How did you calibrate your python program to reduce mismatch between photoresistors?

Checkpoint: 12:15

- Demonstrate that your python program generates light intensity results for each photoresistor, and the responses are reasonably accurately matched.
- Demonstrate how wide a range of light intensity you can detect.

Designing a light-tracking head using a python program.

Modify `control.py` so that the program reads the light intensities generated by the two photoresistors and then produces a position command for the robot head so that the head turns towards the light.

Checkpoint: 1:00

- Demonstrate using a lamp that your head tracks the light.
- How accurately does the robot head track the light? For example, If the lamp is directly in front of the head, how close does your calibrated position measurement program indicate the head is to zero angle?

Question 21. Describe your python-based feedback system for controlling the robot head to track the light.

Question 22. How might you construct a difference equation model that describes your python-based robot head controller?

Question 23. (Requires at least a few paragraphs). Please compare the relative merits of the circuit-only and the python-based light tracking head approaches.

Post-Lab Writeup for Thursday's lab: Due before lecture on November13th

All post-lab hand-ins should be written in clear English sentences and paragraphs. We expect at least a couple of sentences or a paragraph in answer to **all** of the numbered questions in the Thursday, including possibly updated answers to the four circuit design questions you had to hand in before lab on Thursday.

Please be sure to include any code you wrote for Thursday's lab, though there will not be much code to write.

Concepts covered in this assignment

Here are the important points covered in this assignment:

- Learn about the various trade-offs between circuit- and computer-based approaches to designing a system.
- Develop more skill at designing circuits.
- Learn how and when to use feedback approaches.