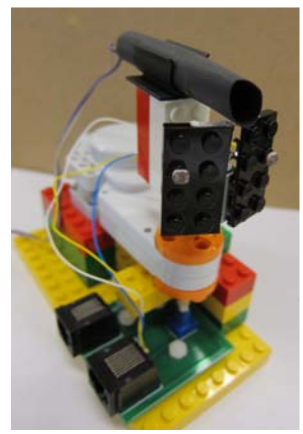
Homework 3: Head Light

This assignment includes all problems in **Wk.8.4**.x in the online tutor.

You can discuss this problem, at a high level, with other students, but everything you turn in must be your own work.

1 Introduction

This assignment continues your work from Homework 2 on a controller that controls a motor to turn a robot "head" (pictured at right) to face a light. You will be using your analysis and code from **Homework 2**, so make sure you have that handy.



The goal of this homework assignment is to design an *electronic* circuit for steering the head motor to seek and track a light source, using the photoresistive eyes as light sensors. This is like part 4 ("Show me the light!") of **Design Lab 8**, where you used a robot brain to provide the feedback between the light sensed and the drive signal to the motor. But in contrast to Design Lab 8, the controller you will design in this homework assignment will be made entirely of electronic components – opamps and resistors – and no software.

The point of doing this is not just to understand how proportional controllers can be implemented in hardware; it is also to appreciate how much faster an analog circuit can respond, compared with the software running in the robot brain. Just as a point of reference, a typical modern op-amp can produce an output signal which changes in response to a step input signal with a delay of less than 10 *nanoseconds*. In comparison, the time-scale of the robot brain is on the order of tens of *milliseconds*.

This homework assignment has two main parts. First, you will design and analyze a suitable light sensor circuit. Second, you will design and analyze the control circuit, based on the model of Homework 2. During Design Lab 9, you will build and test the actual circuit.

1.1 Setup and Resources

We use CMax to layout and simulate the circuit design. **Be sure that your design consists of only short horizontal or vertical wires, and that no wires cross each other**, as this will make building and debugging your circuit much easier.

Get the code distribution (in `Desktop/6.01/hw3/`).

2 Sensor design

The light sensor you devised in **Design Lab 7** used resistive voltage dividers in which one of the resistors in each divider was a photoresistor. It produced two voltages V_L and V_R whose difference $V_L - V_R$ was used as the sensor input signal to the proportional controller for the head motor.

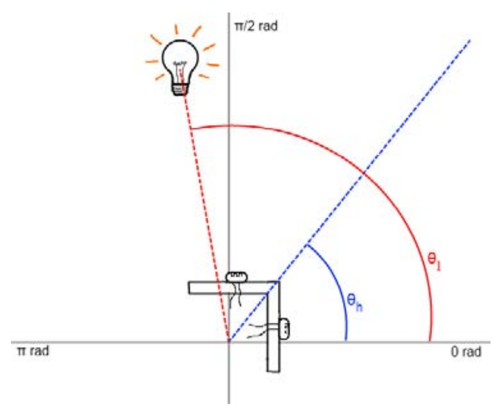
Ideally, the sensor signal would be independent of the overall light intensity, and if the photoresistors were linear then the strategy of Design Lab 7 would be fine. However, in reality the nonlinearity of the photoresistors' response to light leads can lead to reduced performance.

Let us begin by conceptualizing a better approach. Recall the bidirectional motor controller from **Design Lab 8**, in which a potentiometer was used to provide a directional signal for the positive terminal of the motor. Think of how pair of photoresistors could be configured to provide a sensor voltage signal v_s (using the terminology of Homework 2), similar to that of the potentiometer. Keep in mind that a photoresistor's resistance is inversely proportional to the intensity of light incident on it.

Step 1. Design a voltage divider from the photoresistors whose output voltage goes up when the light on the left photoresistor goes up relative to the light on the right.

Wk.8.4.1 Upload a sketch of your sensor circuit diagram. Describe the range of voltage values produced by this divider. What are the minimum and maximum values? What voltage is produced when the head is pointing directly at the light (assuming identical photoresistors)? How does the voltage change as the head turns counterclockwise, so that the right eye is brighter? And when the head turns clockwise?

Recall from Homework 2 that for a light source fixed at some angle θ_l, the sensor voltage signal v_s provides a measure of the head orientation relative to the head, $v_s = k_s(\theta_l - \theta_h)$, as shown in the figure above. The "gain" factor k_s is measured in volts/radian. For the actual photoresistors on the robot heads used in lab, k_s will have to be individually characterized. In the CMax simulation, k_s is around 2.5.



3 The light seeker controller

Let us now design and model the analog controller which turns the head motor to seek and track the light source. This controller should provide four desired properties:

- **Fast**: The head should line up with the light as quickly as possible.
- **Stable**: The head should not oscillate.
- **Uniform**: The behavior of the head should be nearly independent of the brightness of the light and of the distance of the light to the head.
- **Accurate**: The head should point accurately at the light.

There are a few key points to keep in mind when thinking about a design:

- Op-amps can't produce voltage values outside the range of supplied voltages (0V to 10V in our case).
- Think about the analysis in Homework 2 and the constraints on the choice of a gain.

Using the light sensor circuit you just designed, and following the controller ideas from **Design Lab 8**, design a circuit with op-amps and resistors which takes v_s as input, and produces a voltage for (the M+ or M− terminal of) the motor as its output, to drive the head towards the light. This should be a proportional controller, characterized by a gain parameter k_c.

Step 2. Based on what you found about the range of voltages produced by the light sensor, what voltage should the controller output when the head is pointing directly at the light? Can we use a simple inverting or non-inverting amplifier as in the course notes to implement the control circuit? Do the Tutor problem to get an idea of how to tackle this.

Wk.8.4.2	Your circuit design must have bidirectional behavior: the motor must be able to turn both ways. This tutor problem will help you think about the ranges of voltages and ways of introducing gains different from 1.

Step 3. In general we need to know the value of the gain that we're likely to need in our circuit to pick an amplifier circuit. We can use our analysis from **Homework 2** to pick good values for the gain, assuming that we knew all the parameters in our model. In fact, we measure r_m in Design Lab 8 and we know reasonable values for k_m, k_b and T. However, we don't yet know k_s and it is likely to vary between heads because of the variability in the photoresistors.

Wk.8.4.3	Use your system function model from Homework 2 to pick good k_c values for a range of different k_s values.

Step 4. Design a controller circuit that can handle the range of gains that you might need to implement.

Step 5. Use CMax to lay out the **complete** circuit you designed above. It should include the light sensor, the controller and the connections to the motor. Think very carefully about how you should connect your sensor circuit to you controller circuit and how you connect the controller to the motor. You should use a robot connector to supply power and ground, and use the motor on the head instead of a separate motor connector.

Run both of the `eyeServo` simulations with gains 0.5, 2, 3 and 5. and save the resulting plots (that's 8 plots).

Wk.8.4.4	Upload your circuit diagram and paste in your CMax circuit code. Explain your design choices and your simulation results.

Keep your circuit diagrams, a picture of your CMax circuit, and your simulation results for your next interview.