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

Assignment for Week 8

This handout contains

- Software Lab for April 3rd
- Prelab exercises due Thursday April 5th before lab
- Thursday lab using the Robot head.
- Post-lab write-up due Tuesday April 10th in Lecture.

Getting a head with circuits

In all the previous labs, we have mostly abstracted away the electrical nature of the signals being processed and generated by the robot. In this laboratory you will design and build an electrical feedback system which controls a robot "head". In subsequent labs, you will put "eyes" on the head to help your robot "see". As with the previous labs, you will start by building a python tool to help you analyze circuits, and then you will use that tool to help you design an improved robot head controller. So this week you will be extending the constraint resolver, analyzing an electromechanical system, and designing a circuit. Whew!

The summary of tasks for this week are:

- Post-lecture software lab on adding op-amps to the constraint resolver
- Pre-lab tutor exercises to practice on circuits with op-amps.
- Robot head lab on modifying the robot head controller to use on supply.
- Post-lab writeup.

Tuesday's Software Lab: Adding an Op-amp to the Constraint Resolver

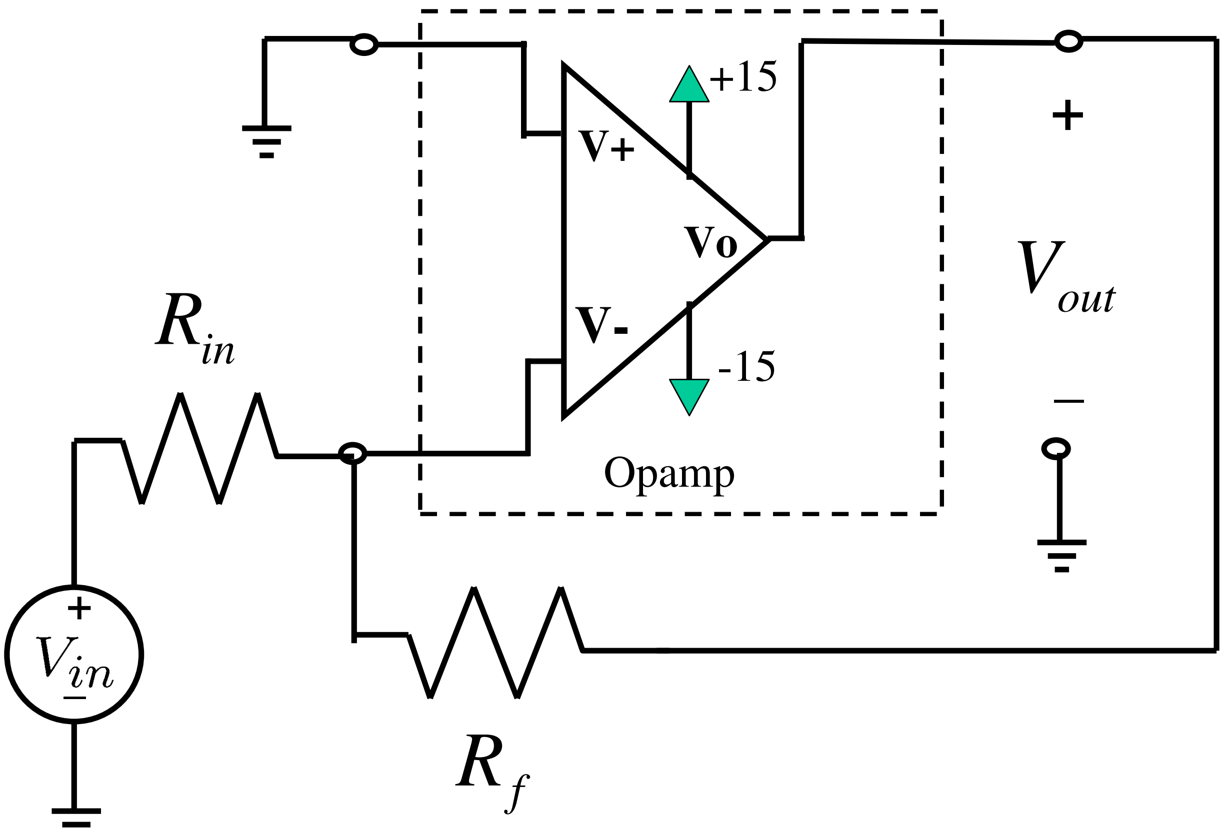
You will be extending the constraint resolver program for analyzing circuits by adding an op-amp model to the program. You can then use your augmented constraint resolver to help you design a circuit to control the motor.

Download and test the constraint system

The procedures for this lab is at the 6.099 web site on the calendar for this week. Download *resolver.tar* (or *resolver.zip*, if you prefer) again and unzip it. Make sure you can run one of the example files.

Add an op-amp model to the constraint resolver

In class we discussed the following operational amplifier circuit, referred to as an inverting amplifier.

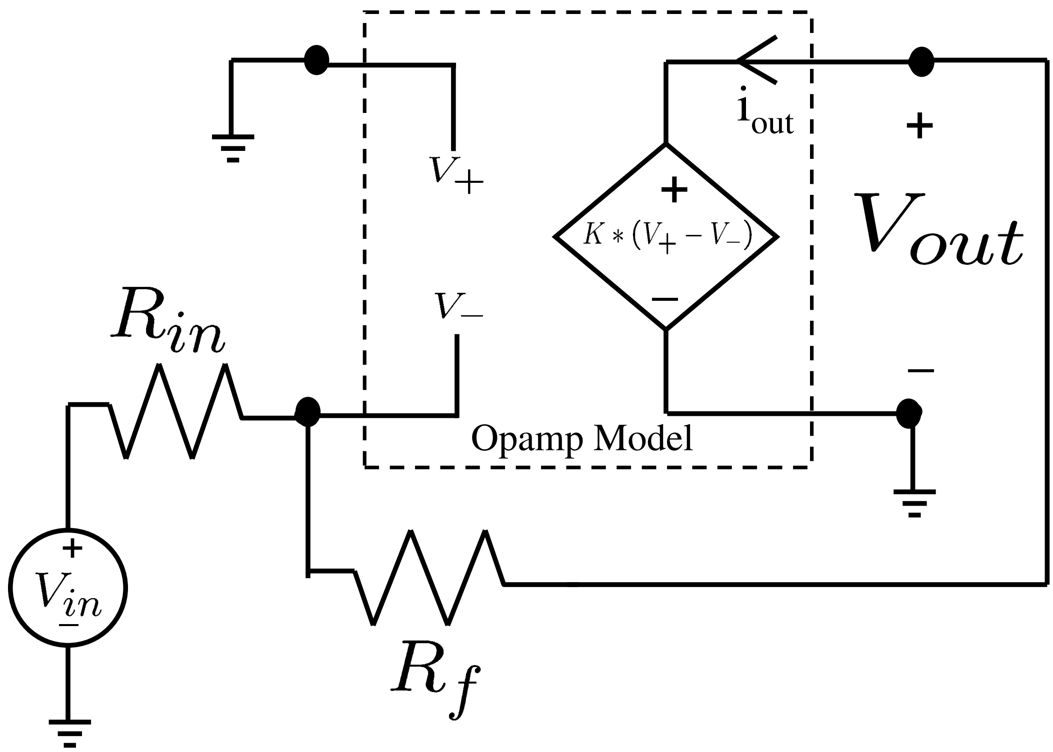


In order to simplify the analysis of the op-amp circuit, we assumed that $V_+ - V_- \approx 0$ and that no current enters the op-amp inputs. Using those assumptions, we determined that the relationship between V_{in} and $V_{out}$was

$$V_{out} = -\frac{R_f}{R_{in}} V_{in}.$$

The main reason we could assume that $V_+ - V_- \approx 0$ was that the op-amp was connected in a feedback configuration and the gain of the op-amp was very large. You will now investigate the accuracy of that approximation using the constraint resolver.

The abstract model we used for the op-amp was a voltage-controlled voltage source model, and using that model in the inverting amplifier yields a somewhat different looking schematic



where the gain of the voltage-controlled voltage source, K, is a very large number. Please add this voltage-controlled voltage source model to the constraint solver, allowing K to be a parameter like resistance is for resistors. Keep in mind that this model has four terminals, but there is only one nonzero current, i_{out}. Therefore, your constraint should involve four voltages and one current. Please carefully consider what to do with i_{out}, the current generated at the output terminals of the op-amp. Note that this output current is not used in the op-amp constitutive relations (recall that the same situation occurs with a voltage source element). What constraint will involve the op-amp current?

Test your implementation by analyzing the inverting amplifier above using $R_{in} = 10,000$, $R_f = 100,000$, and the op-amp gain equal to $K = 1000$.

Finally, roughly determine the smallest value of op-amp gain, K, for which

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

is accurate to within ten percent.

To Hand In

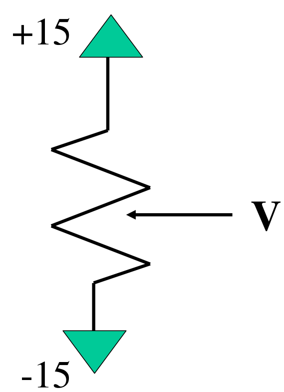
You will need your op-amp extension for Thursday's lab, please be sure to save a copy where you can access it later. You can hand in a description of your op-amp constraint on Tuesday April 10th as part of Thursday's lab write-up.

Exercises with the online tutor

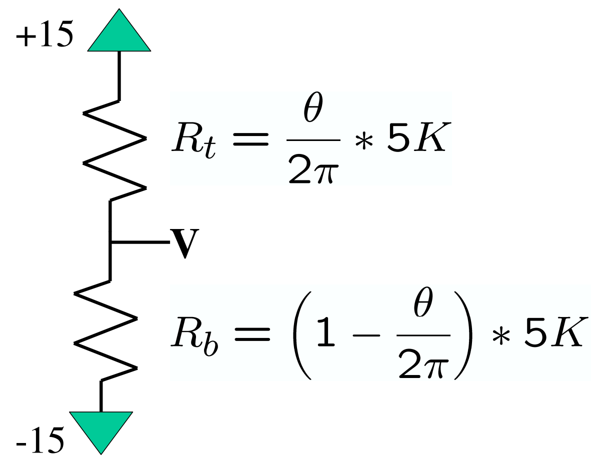
Use the online tutor to complete the tutor problems.

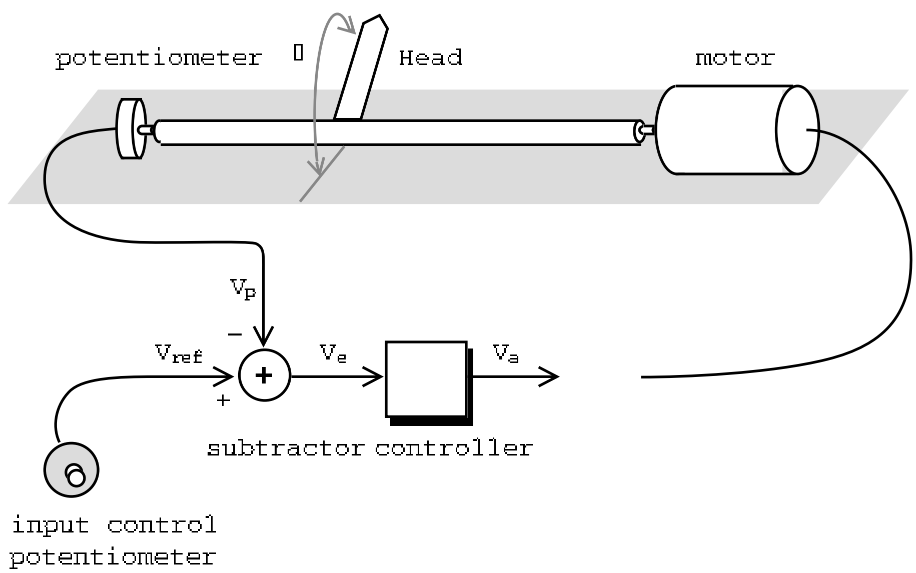
Thursday's Robot Head Lab – Using Op-amp Circuits

The robot head is in four parts: the base (a big flat grey Lego plate), the circuit protoboard which is attached to the plate, the "head" which has a protoboard mounted on a rotating Lego platform, and a the motor driver which is connected to the rotating head. In addition, there is a potentiometer (little blue thingy) on the bottom of the rotating head. The potentiometer shaft is connected to the head so that the shaft rotates with the head, and it is wired to the plate circuit board. The potentiometer is used to measure the head position. Note that one end of the potentiometer is connected to the positive supply and one end is connected to the negative supply. When so-connected, the potentiometer acts as adjustable voltage divider, with the divider output being the center connection to the potentiometer as shown in the following figure.



As the above figure indicates, the voltage at the potentiometer center connection (when measured with respect to ground) will be zero when the potentiometer is in its center position, and will be either plus or minus fifteen volts when the potentiometer is turned all the way clockwise or all the way counterclockwise. The voltage at the center connection of the potentiometer is then related to head angle θ, see below, and so the voltage produced will be proportional to the head angle.

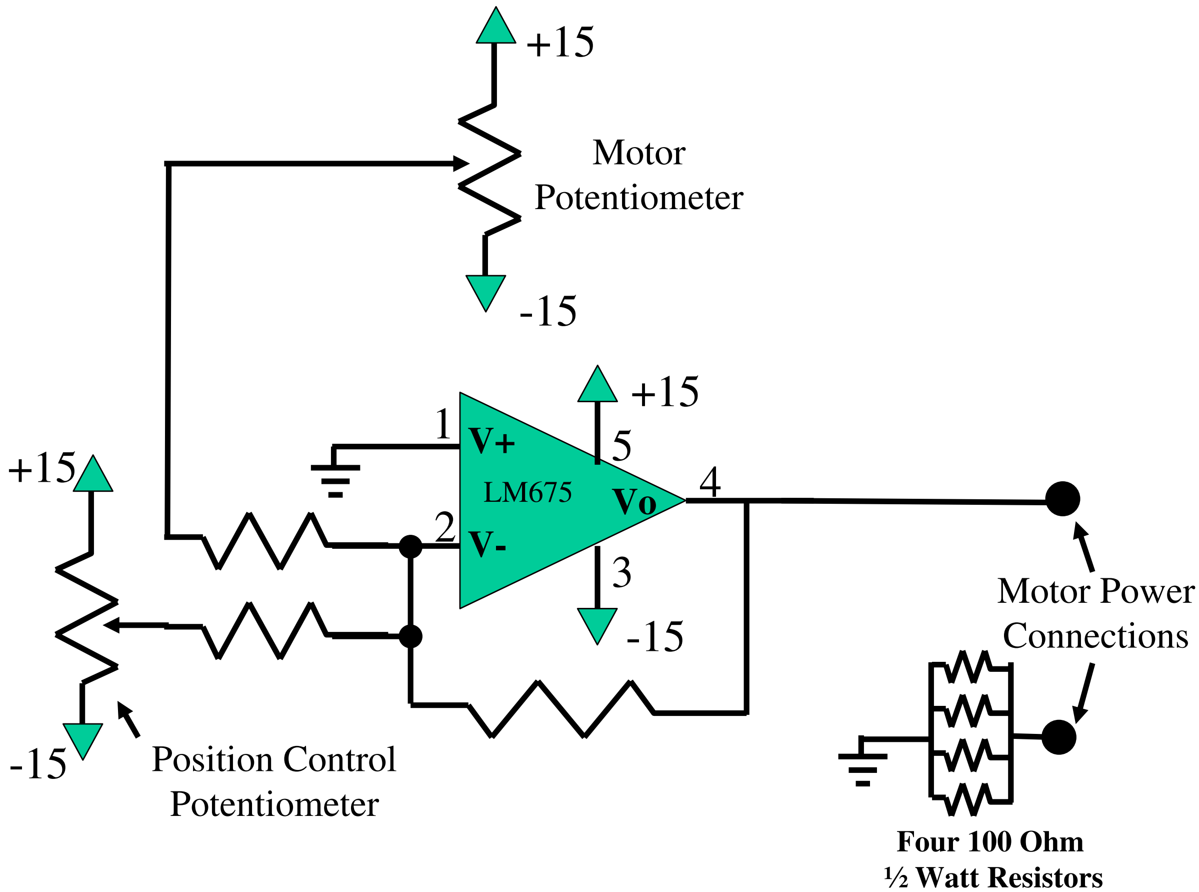




Above is a diagram of the robot head system that we will use. The mechanical portion of the system includes the rotating head, motor, and potentiometer. The head is connected to the shaft of the motor and is directly connected to a potentiometer, so that the head, motor, and potentiometer all rotate in unison. The outer pins of the potentiometer are connected to -15 and +15 volts, respectively. Hence, as the head swings from one end of its range to the other, the voltage at the potentiometer's wiper (middle pin) swings from -15 to +15 volts. This voltage should be proportional to the angular position of the head θ. This *head-position voltage*, V_p, is fed back to the controller. The input to the system is V_{ref}, a voltage generated by another potentiometer. The voltage V_{ref} can be used to select a desired head position. The system is designed so that V_p tracks V_{ref}. Thus, the user controls the position of the arm by changing V_{ref}.

To see how this system works, suppose that initially V_p and V_{ref} are equal, and then V_{ref} is increased rapidly. Just after the increase, V_{ref} will be greater than V_p and so the error signal, V_e, will increase. Because V_e has increased, the controller output voltage V_a increases which increases the current to the motor windings I_a which causes the motor to rotate the head. The motor rotates the head, causing both the head and the potentiometer's voltage V_p to increase. The arm will continue to rotate until the error signal $V_e = 0$, and $V_p = V_{ref}$. That is, when the arm-position voltage equals the desired arm-position voltage. This sequence is reversed if V_{ref} is decreased rapidly. V_e becomes negative, generates a negative motor current, and the motor rotates in the opposite direction to reduce V_p to V_{ref}.

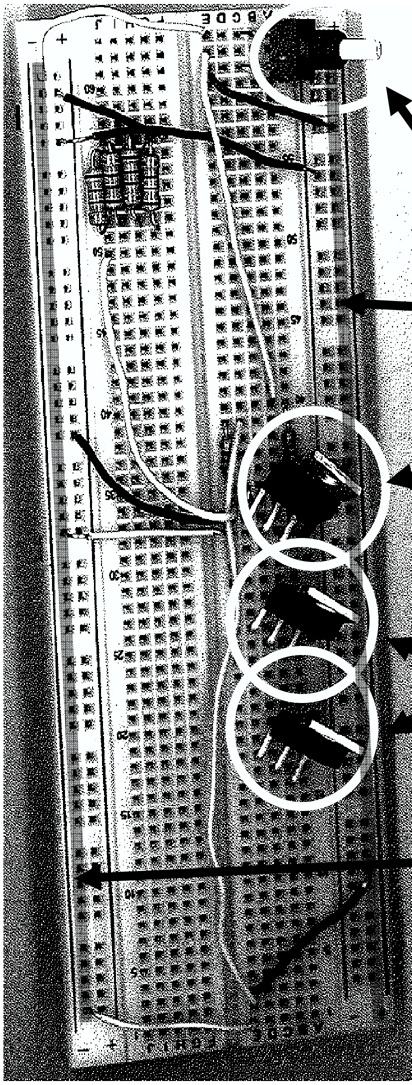
We have constructed the circuit for driving the head motor on the plate protoboard. The schematic diagram for the circuit is



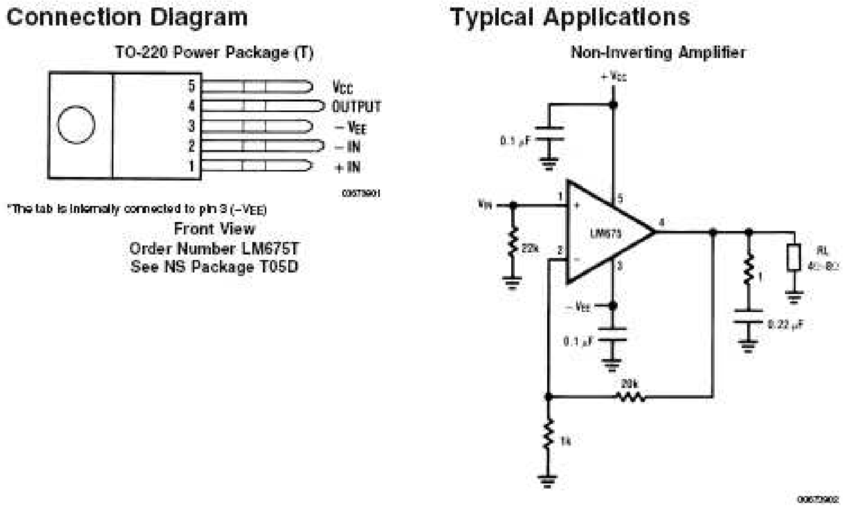
Motor Driver Circuit - Unmarked Resistors are 10k ohms

and an annotated picture of the circuit board (with the motor, motor potentiometer, and head removed) is shown below.

Circuit Board for robot head driver (robot head removed)



Finally, the information about the op-amp and its pin connects is given in the figure below.



Be careful to notice how we plugged the op-amp in to the circuit board. The op-amp is at an angle (the only way it would fit), and the pins are out of order. Make sure you understand how the circuit works and how connections are made using the plate protoboard. Also, note that the four long rails on both sides of your plate protoboard to connect things to +15, −15, and *gnd*. Before you connect things to power, double-check your connections, since it is really easy to blow up an op-amp. For now, to power your circuit, use the +15, *gnd* and −15 power sources on the project board. Make sure the knobs controlling the voltage for both power sources are turned all the way clockwise. As a warning, the op-amp might get hot, so don't touch it when the circuit is on. Finally, test that the circuit works by demonstrating you can change the head position by turning the potentiometer shaft on the plate protoboard.

Note that in the driver circuit, we have four 100 ohm resistors in parallel. They are used to limit the peak motor current to avoid damaging the motor. These resistors are a larger shape than the rest of the resistors as they handle more power. We used four in parallel so that they will share the power. What is the effective resistance of the parallel combination?

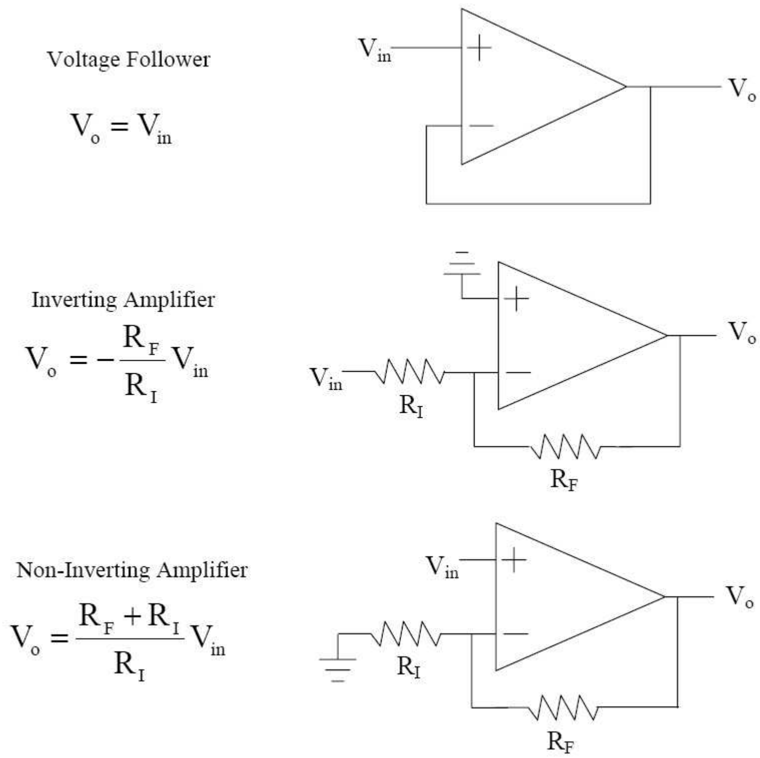
Finally, note that the op-amp in the driver circuit acts to sum the voltages from the input potentiometer (which you can adjust) and the feedback potentiometer (which the motor turns). If the input potentiometer is adjusted so that it generates −2 volts, the motor will turn until the motor potentiometer generates +2 volts.

Checkpoint: 3:00 PM

- Demonstrate that you can control the head position.
- Demonstrate that you understand how the driver circuit works.
- What would happen if the wires orange and green wires connecting the motor to the driver circuit were swapped? Why?

Change the power supply

For the next two sections, as a friendly reminder, here are some op-amp circuits that we learned about in class that you might find useful:



There is a problem in using the above driver circuit for the robot head. The robot only has +12 volts available, but the circuit on the protoboard requires a power supply with +15 and −15. We would like you to design a circuit that will drive the motor but only use a single twelve volt supply. Just using op-amps, you won't be able to increase the voltage range of your circuit past 12 volts, but fortunately the op-amps will run on +6 and −6. You will definitely need at least one more op-amp, and a number of additional resistors. Please do your design on paper, then demonstrate that the design works using the constraint resolver.

Checkpoint: 4:00 PM

- Be able to describe your circuit.
- Demonstrate that the circuit works using the contraint resolver.

Build your circuit on the protoboard and test it using just the +15 volt supply and ground. Test that the circuit works by demonstrating you can change the head position by turning the potentiometer shaft on the plate protoboard. When building your circuit, please clip the wires on the protoboard so that they are no longer than they need to be. This will make debugging your circuit easier.

Finally, you will be using your circuit in subsequent labs, please label your circuit board with your names!

Checkpoint: 4:45 PM

- Demonstrate that you can change the head position by turning the potentiometer shaft, with your circuit powered only by the robot.

Increase the motor voltage range - Optional!

With our modified driver circuit for the robot head, the voltage across the motor ranges from negative seven and half volts to positive seven and half volts. To make the motor response more quickly, we'd like to be able to put either positive or negative fifteen volts across the motor. Can you design a way to still use a single +15 volt supply, but increase the range of voltage across the motor? Hint: right now, the voltage input to the motor is centered around +7.5 volts as a "virtual" ground. If we don't insist on having a fixed ground for the motor, but instead make the motor ground a second input that varies inversely (with respect to the +7.5 volt virtual ground) with the voltage input, the voltage difference as seen by the two leads connecting to the motor can be doubled. If you're not sure where to start, take a look at the op-amp circuits that we learned in class, above.

Optional Checkpoint: 4:45 PM

- Explain how your new circuit works, and demonstrate changing the head position.

To hand in on Tuesday April 10

Write a description of your circuit. Give a complete schematic and describe how you derived the component values. Also, turn in your a description of how you implemented the op-amp in the constraint resolver and the values you determined for the op-amp gains.

Concepts covered in this assignment

Here are the important points covered in this assignment:

- Learn to view circuits as constitutive relations and conservation laws.
- Explore the op-amp as an example of a more complicated circuit element.
- Learn how to design with op-amps.