Last modification: February 1, 2020

RBE 1001: Introduction to Robotics
C-Term 2019-20
Project: Design and construction of a Braitenberg vehicle

Introduction

This is a team effort. **You are expected to work together on every aspect of this assignment.**

Line following is an important and common robot behavior. For example, many industrial robots use line following for navigation in a warehouse or factory – so long as the paths are fixed, line following is a low-cost, but effective way to get a robot from point A to point B (or point C or D or...you get the picture). Even autonomous cars use line-tracking principles to help navigate lanes on the road, though the algorithms are much more complex.

If you've worked with robots before, you may have implemented line following using a microcontroller. Indeed, later assignments will require you to implement line following behavior with your VEX robot. In this assignment, however, you'll build a line following "robot" – we can argue later about whether or not it is a true robot – using only analog electronic components. Such vehicles are called Braitenberg vehicles.

The heart of your device will be the operational amplifier, which you will explore theoretically in homework.

Preparation

- Watch this video on Braitenberg vehicles.
- You will need to solder at least three things for this exercise (two reflectance sensors and a power connector). Each team member is expected to solder one of them. You can solder in the maker space in Foisie; they have resources to get you started, as well.

Resources

- The datasheet for the motor is appended to this document.
- The datasheet for the op-amp is linked within.

Behavior of the vehicle

A Braitenberg vehicle with a pair of motors and a pair of light sensors can exhibit a variety of behaviors, depending on the connections between sensors and motors. Here, you'll make a similar vehicle, but instead of seeking or avoiding light, you'll make one that follows a line (it's still responding to light – in this case reflected light – but the functionality is a bit different than in the video).

Your first task is to determine the basic architecture of a line following vehicle. Consider the following scenario: your vehicle is following a dark line on a light background. Your vehicle will use reflectance sensors from Pololu to detect the line (see Figure 1). Note that this sensor uses a photo*transistor* instead of a photo*resistor* like you used in your homework, but the functionality is essentially the same. For the qualitative analyses below, you can virtually replace the phototransistor with a photoresistor to determine the correct configuration.

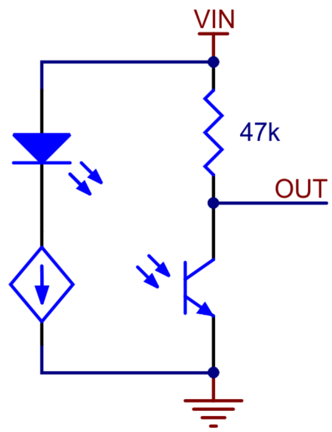


Figure 1: Schematic of the reflectance sensor used in this lab. The left part of the circuit provides the IR light to be reflected; the right part is the sensor circuit. (There's actually a current limiting resistor on the diode side; for some reason, whoever made the figure left it out.)

Procedure

1. In your homework, you built a circuit with the same topology as the line sensor (again, you used a photoresistor, but the behavior is the same with a phototransistor). Using that sensor topology, determine the *functional connections* between the sensors and the motors. That is, determine how the *reflectance* of the ground should affect which motor. Make a sketch of your vehicle in the space in Figure 3 on the attached worksheet (page 5) and draw lines on the sketch between each sensor and a motor, noting if you want to have positive ('+') or negative ('-') coupling. Keep in mind you want your vehicle to drive forward under normal conditions and correct towards the line when it deviates.

Constructing your Braitenberg vehicle

Here you will assemble your Braitenberg vehicle.

Chassis

Using the diagram that came in your kit and/or the first part of this video for reference, assemble the chassis. The battery will be attached to the top plate. You will need to decide where you want to put the breadboard – keep in mind that real estate is a premium on the small chassis.

Connecting the motors

To power the motors, you will use an L272 *power operational amplifier* from ON Semiconductor. “Power”, in this case, refers to the op-amp’s ability to output relatively high currents.

In your homework, you designed a nominal solution for the control circuit using an op-amp wired as a comparator (you built a night light, but the concept is the same). As you may have realized, the ON/OFF nature of the comparator would likely lead to poor behavior of your vehicle; specifically, you might anticipate that the vehicle would move with a noticeably jerky motion. It would be nice to have the a circuit where the response is smooth. For that, you can connect the op-amp as an amplifier instead of as a comparator.

The inverting op-amp

Consider the circuit shown in Figure 2. Here, the op-amp is configured in an inverting configuration, which has two significant advantages:

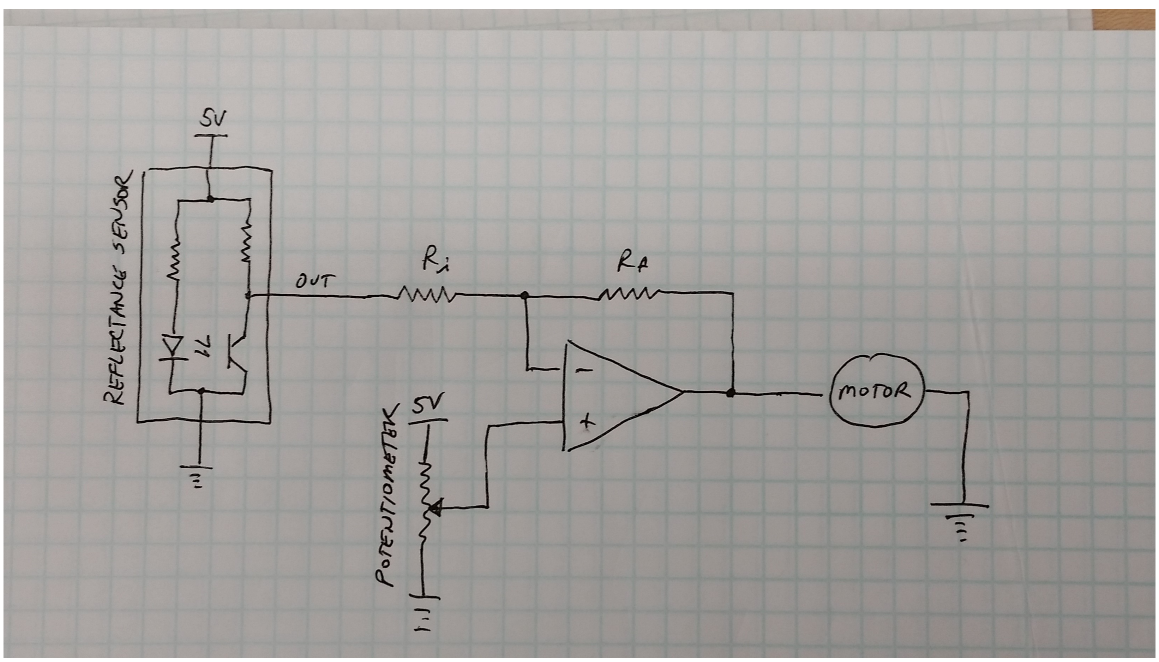


Figure 2: Inverting amplifier for the Braitenberg vehicle. N.b., you’ll use 5V to power your vehicle.

1. The gain can be chosen to be less than 1, if desired.[1]
2. The motor speed can be reduced to very low speeds.

[1] Even though the gain is less than 1, we still use the term "amplifier". It’s just that the amplification is a fractional amount.

Note that a potentiometer has been added to the non-inverting input. This will allow you to easily adjust the reference voltage. A non-zero reference voltage is needed because the op-amp is in an inverting configuration – if the non-inverting pin were connected to ground, the op-amp would try to convert *any* positive voltage to a negative voltage, which it can't produce when the negative power rail is ground. In other words, the motor would never get any power. A standard solution to this problem is to use a reference voltage, which can be thought of as the (non-zero) voltage around which the sensor voltage will be amplified. That is, the reference voltage will allow the output voltage to go both up and down, depending on the sensor output. Using a potentiometer allows you to adjust the reference easily.

Work through the circuit and determine if it will provide the desired behavior. Complete Figure 3 for each part of the the circuit by adding an arrow to indicate the response, and fill in Table 3.

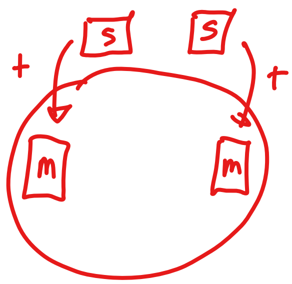
Procedure

1. Construct the circuit in Figure 2. **You will need to solder pins to the reflectance sensors and the USB power interface**. You'll want to use fairly large resistors for the R_i and R_f. Why? 1kΩ for each should be sufficient, but it's more important that they are the same.
2. Assuming a reference voltage of $V_+ = 2.5V$, sketch the output voltage of the op-amp as a function of the input voltage in Figure 4. Label the line "2.5V".
3. Add a line to Figure 4 that corresponds to a reference voltage of 1.5V and label it "1.5V". How will the vehicle dynamics change?
4. Connect the power to your vehicle and do a quick test of your vehicle. Specifically, test it to make sure that each of the motors respond to light and dark as expected (you may need to adjust the reference voltage). Don't worry about line following, yet – you'll start that in lab.

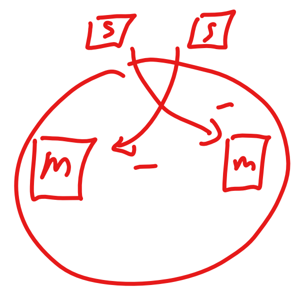
To submit

Submit this worksheet as a .pdf on canvas. You will also demonstrate your vehicle at the start of lab.

1. Draw the functional connections between the sensors and the motors here.



this best - goes faster when on track



this works, but goes slow when on track

Figure 3:

2. According to the datasheet, what is the maximum continuous current allowed from the L272?[2] What is the max current draw of the motors?

   0.7 A (1 A also accepted - different datasheets have different values)

   250 mA

3. Why is it important to use large resistors for the feedback pair?

   So that not much current flows from/to the sensor.

[2]The max current on the datasheet is only reached with proper thermal management. We won't bother with heat sinks here, but a production system would need further analysis to ensure that the chip won't overheat in the long run.

Floor reflectance	Voltage divider voltage	Op-amp output voltage	Motor speed
Light	↓	↑	↑
Dark	↓	↑	↑

Table 1: Table for the conceptual response of your circuit. Add arrows to indicate the change in respective values.

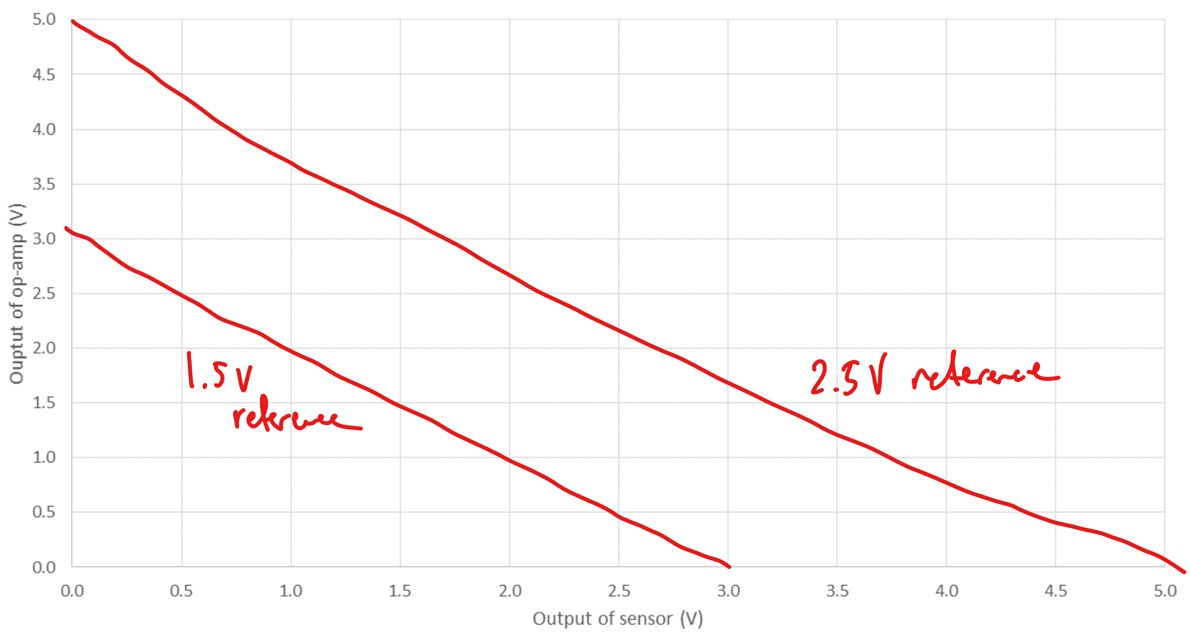


Figure 4: Graph for drawing the voltage response of the op-amp.

4. How will lowering the voltage reference on the non-inverting terminal of the op-amp affect the vehicle dynamics?

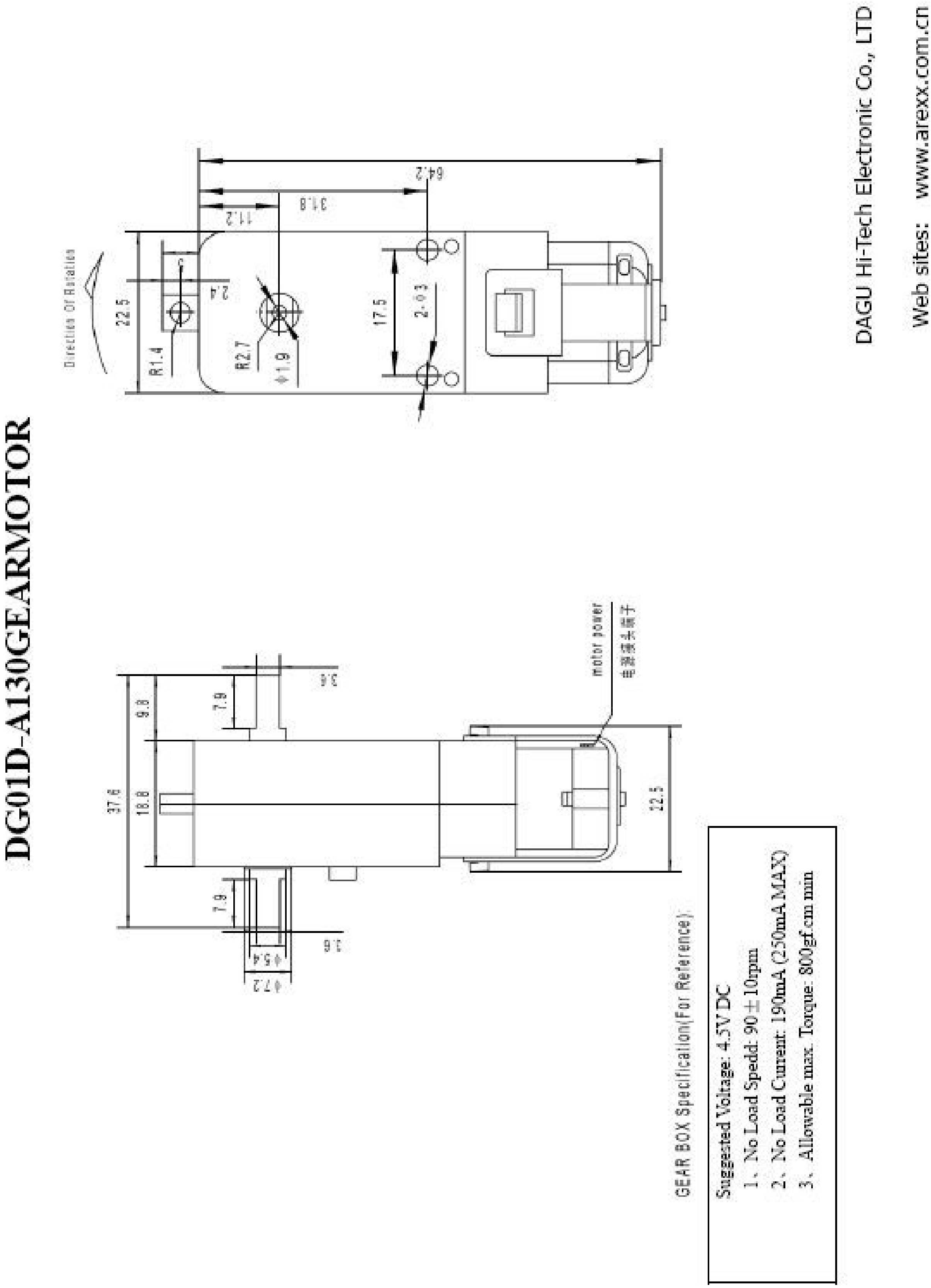


Figure 5: Datasheet for the motors included in your HW kit.