The Mechatronics Revolution: Fundamentals and Core Concepts
Lab Assignment 2

DC Motor Control using H-Bridge Motor Drivers

2.1 Objective

The main objective of this lab is to build an H-bridge motor driver circuit to control the two brushed DC motors of the TI-RSLK-Mechkit robot. To this end, we will build a motor driver circuit using an H-bridge IC on the breadboard attached to the robot. This circuit will be used in the next lab assignments to drive the robot, leading to a remote-controlled obstacle avoiding robot in the final lab. Other objectives of this lab assignment include acquiring experience in building circuits on a breadboard, and to improve your understanding of electrical and electronic components.

In Module 2, we studied the basics of circuit concepts and circuit elements (e.g. resistors, diodes, MOSFETs, etc.), as well as H-bridges and motor driver circuits. Specifically, the fundamental knowledge required for this lab assignment were provided in the following topics of Module 2:

Module 2, Topic 1, Lesson 1	Circuit Elements and Constitutive Relationships
Module 2, Topic 1, Lesson 2	Circuit Analysis and Voltage Regulation
Module 2, Topic 2, Lesson 1	Diodes, LEDs, and Photodiodes
Module 2, Topic 2, Lesson 3	Metal-Oxide Semiconductor Field Effect Transistors (MOSFETs)
Module 2, Topic 3, Lesson 1	H-Bridges and Motor Driver Circuits

2.2 Setup

This lab requires the *TI-RSLK-Mechkit*, and the *circuit components* included in the kit to build an H-bridge motor driver circuit for brushed DC motor control. The main component used in the driver circuit is an H-bridge IC (SN754410) *(a)*. Other components include eight 1N5819 didoes *(b)*, two resistors ($22K\Omega$ and $33K\Omega$) *(c)*, a set of jumper wires *(d)* as well as a general wire kit *(e)*. We will also use the solderless breadboard attached to the TI-RSLK-Mechkit robot. The required parts are shown in Figure 2.

The power line signals on the *TI MSP432 LaunchPad* and the TI-RSLK chassis board will be used to provide power to the circuit on the breadboard.

All components needed for this lab are included in the TI-RSLK-Mechkit. Details on how to assemble the TI-RSLK-Mechkit robot are presented in the Robot Assembly Manual,

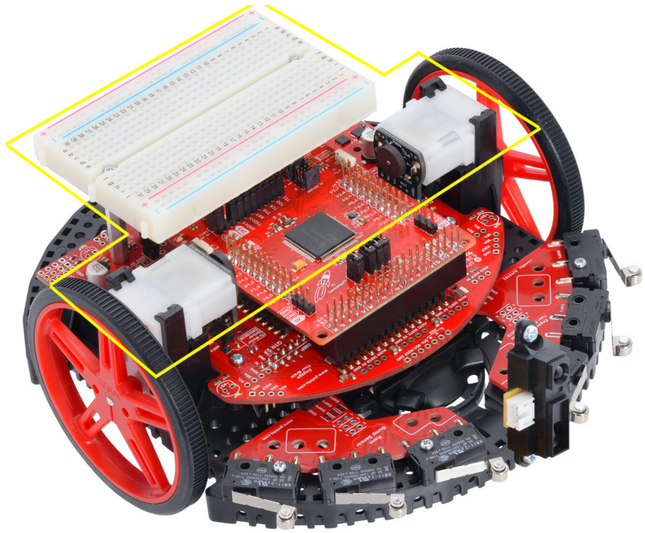


Figure 1: The TI-RSLK-Mechkit includes a breadboard and two brushed DC motors.

available under Course Resources on edX (Robot-Assembly-Manual.pdf). Six AA batteries (not included) will be needed to power your robot. You can use disposable 1.5V alkaline batteries or rechargeable 1.2V NiMH batteries.

Note: Make sure that you have assembled the robot and installed the LaunchPad on the TI-RSLK chassis board before proceeding with the lab assignments, as the LaunchPad will get powered through the TI-RSLK chassis board.

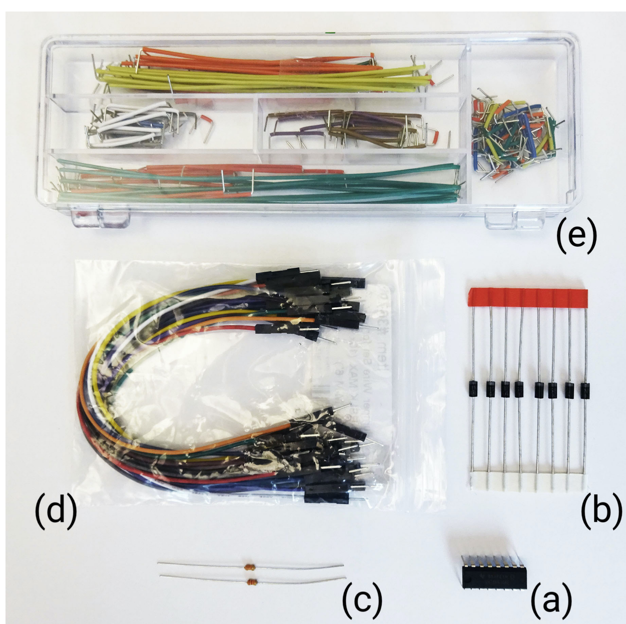


Figure 2: Required parts for Lab Assignment 2, all included in the TI-RSLK-Mechkit.

Warning: Make sure that you have removed the +5V jumper on the MSP432 LaunchPad. Not removing this jumper will cause permanent damage to the LaunchPad and the TI-RSLK chassis board.

Warning: Before starting the Lab 2 assignment, program the MSP432 LaunchPad with the code provided for Lab 1, available under Course Resources on edX (lab1-main.zip). This code calls the `mechrev_setup()` function provided by the `mechrev.h` header file to bypass the motor drivers of the TI-RSLK chassis board (so that there would be no conflict between the motor driver IC on the breadboard and the default motor driver on the chassis board).

2.3 Problem Statement

Build an H-bridge motor driver circuit to control the two brushed DC motors attached to the wheels of the TI-RSLK-Mechkit robot. You need to implement the circuit on the breadboard attached to the TI-RSLK-Mechkit robot. This motor driver circuit will be used in the next lab assignments to control the speed and direction of the motors using your software program and the MSP432 LaunchPad. However, for the purpose of this lab, we will manually turn on/off the DC motors with full-speed.

More details about the hardware requirements will be discussed in the next sections.

2.4 Hardware

2.4.1 Brushed DC Motor

The brushed DC motor is a type of motor that operates on DC voltage and current. It is bidirectional, meaning if the supply terminals are swapped the motor turns in the opposite direction. An H-bridge helps in achieving this functionality without physically having to swap the terminals.

The DC motor assemblies (with gearbox and encoder already installed) used by the TI-RSLK-Mechkit are manufactured by Pololu. Specifications for this motor can be found at: `https://www.pololu.com/product/1520`. This motor is capable of high speeds, with a rated output speed of 150 rpm. Note that the encoders on the motors will not be used in this lab assignment.

For this lab assignment, you will manually connect the two terminals (labeled as M1 and M2) of each DC motor to the H-bridge motor driver circuit. The other 4 pins of the motor are encoder signals, which will not be used in this lab assignment.

2.4.2 H-bridge IC

H-Bridges are commonly used to switch direction of current through a motor. They allow a digital device to activate motor rotation in both directions. The H-bridge IC that we use for

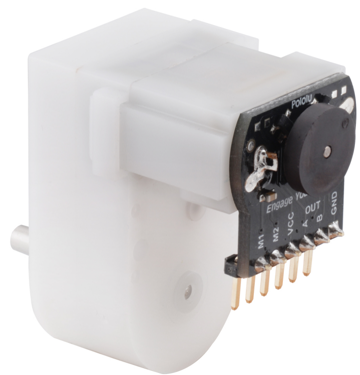


Figure 3: DC motor with encoder assembly (Image courtesy of Pololu).

this lab is the TI SN754410, which is a quadruple half H-bridge driver IC. It has four half H-bridges that can be used either independently for motors with unidirectional applications, or in pairs for motors with bidirectional applications. The datasheet for SN754410 can be found at: http://www.ti.com/lit/ds/symlink/sn754410.pdf

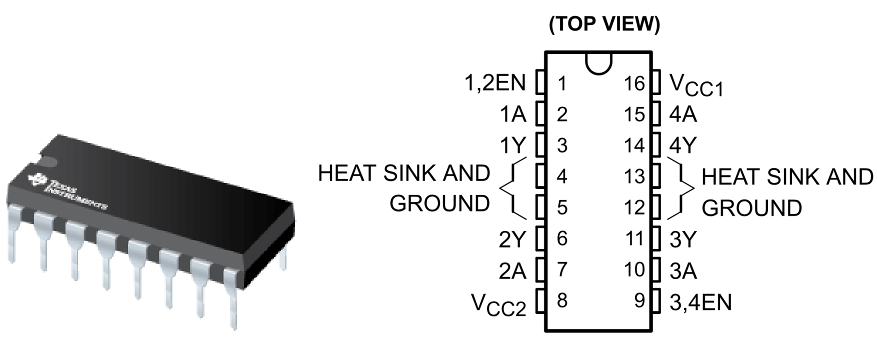


Figure 4: SN754410 pinout (Image courtesy of Texas Instruments).

We will be using all four channels of the H-bridge driver IC, channels 1 and 2 as a pair to control the right motor (MR), and channels 3 and 4 to control the left motor (ML) of the TI-RSLK-Mechkit robot. This setup forms two full H-bridges which enables bidirectional operation of two DC motors independent from each other.

Figure 5 shows the possible wiring configurations that can be used with the SN754410 H-bridge IC. Note that in the figure, the interfaces at ports 3 and 4 are shown for unidirectional operation of two motors. The left side of the diagram (ports 1 and 2) shows the wiring schematic for bidirectional operation of a motor.

Note: For this lab assignment, we will be using **bidirectional configuration** for both sides of SN754410 in order to have bidirectional control of two DC motors.

Note that the SN754410 IC comes in a PDIP package, and has an identifier to help you locate Pin 1 on the chip: There is a Half Circle or Notch on the end of the chip, Pin 1 is to the left of the notch (Figure 5). IC pins are numbered in a counter clockwise fashion from Pin 1.

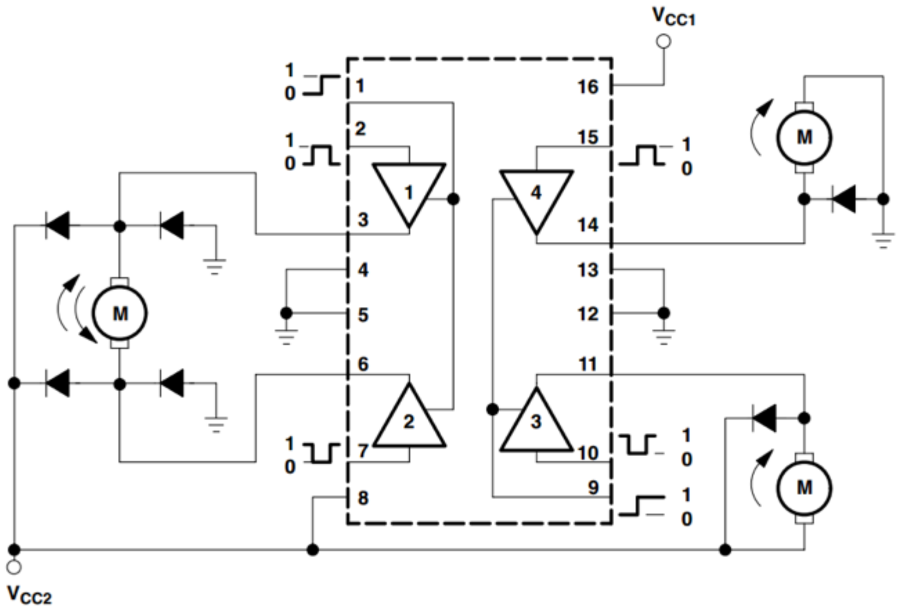


Figure 5: SN754410 functional block diagram (Image courtesy of Texas Instruments).

The pins of the SN754410 H-bridge IC are described in Table 1.

Pin Number	Pin Name	Pin Function
1	1,2EN	Enable signal for driver channels 1 and 2 (active high input)
2	1A	Input control signal for driver channel 1
3	1Y	Output signal to the right motor for driver channel 1
4	Heat Sink/GND	Connect to Ground
5	Heat Sink/GND	Connect to Ground
6	2Y	Output signal to the right motor for driver channel 2
7	2A	Input control signal for driver channel 2
8	VCC2	Power supply for motors (connect to VSW = 7.2V to 9V)
9	3,4EN	Enable signal for driver channels 3 and 4 (active high input)
10	3A	Input control signal for driver channel 3
11	3Y	Output signal to the left motor for driver channel 3
12	Heat Sink/GND	Connect to Ground
13	Heat Sink/GND	Connect to Ground
14	4Y	Output signal to the left motor for driver channel 4
15	4A	Input control signal for driver channel 4
16	VCC1	Power supply for internal logic (connect to 5V)

Table 1: SN754410 Pins Description

To understand exactly what the input control signals do, refer to Figure 5. Setting the enable pins (pin 1 and pin 9) to high will enable the associated driver channels. For this lab assignment, we place two pull-down resistors ($22K\Omega$ and $33K\Omega$) on the enable pins to make them low (i.e. disabled) by default. We then manually enable the driver channels by connecting the associated enable pins to 5V, as will be shown in the circuit schematic in Figure 9.

Setting pin 2 of SN754410 high and simultaneously setting pin 7 of SN754410 low will turn the motor (attached to the output pins 3 and 6) in one direction. To turn the motor in the other direction, pin 2 should be low and pin 7 of SN754410 should be high.

In order to operate the motor in either direction, a high level signal (3.3V) can be applied to one of these two pins while maintaining the other pin low (GND). Pins 10 and 15 have the same function for the second DC motor attached to the output pins 11 and 14.

Note that these input pins can also accept PWM signals from the MSP432 (we will study PWM signals in Module 4 and Lab Assignment 4).

2.4.3 Diodes

Diodes are semiconductor devices used to control the direction of current flow. They are used often in mechatronic devices. The 1N5819 diodes provided with the "TI-RSLK-Mechkit" will be used as flyback diodes for the motor driver. Flyback diodes provide alternative path for current in motor coil and mitigates arcing/excessive current through transistors, to avoid damaging the transistors.

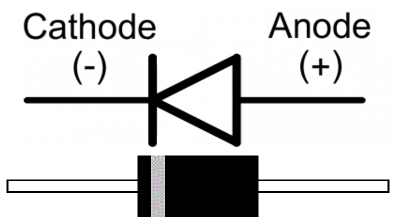


Figure 6: The diode circuit symbol, and the physical shape.

As shown in Figure 6, the silver line on 1N5819 diode indicates the cathode pin, which matches the vertical line in the diode circuit symbol.

2.4.4 400-Point Breadboard

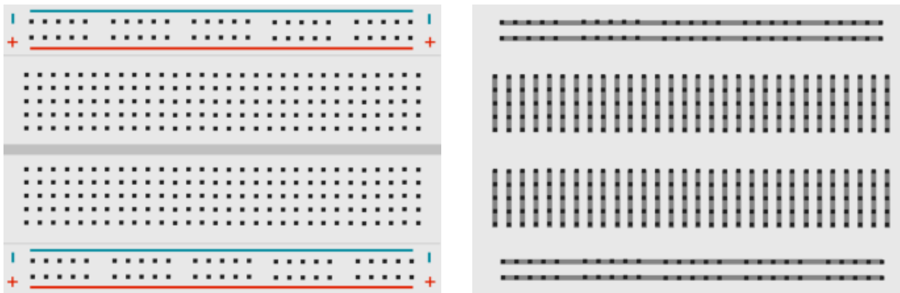
A solderless breadboard is provided with the TI-RSLK-Mechkit. Solderless breadboards are commonly used for prototyping because they allow you to quickly build temporary circuits without soldering.

The pins are arranged in groups of 5. The 5 pins in each group are electrically connected to each other at the back of the board (see Figure 7). You connect leads and cables together by inserting them into pins within the same group.

Power rails at the top and bottom are marked with red (+) and blue (−) stripes. The groups in each rail are electrically connected along the entire length of the stripe. The remaining 5-pin groups on the board are labeled with numbers and letters. Each group is electrically isolated from the others.

The gap at the center of the breadboard allows easy connection of electronic components provided as dual-inline packages, such as the SN754410 IC (see Figure 8).

For best results, use solid wires when breadboarding; you will find a pre-cut jumper wire kit in the “TI-RSLK-Mechkit”.



(a) (b)

Figure 7: (a) Front of solderless breadboard showing power rails and connection pins. (b) Interconnections at back of board (normally hidden). The 5-pin groups in each power rail are interconnected. All other 5-pin groups are isolated (Image courtesy of Texas Instruments).

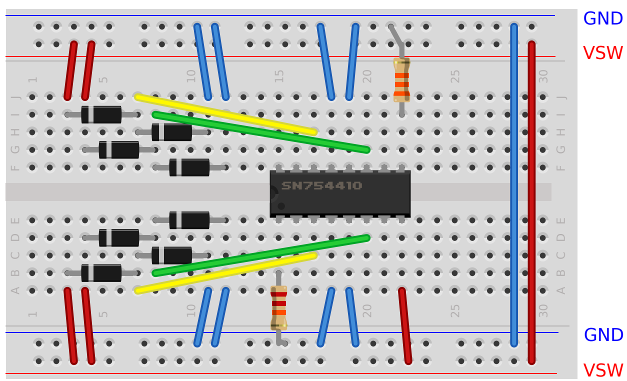


Figure 8: The SN754410 IC must be placed in the middle of the breadboard (between columns E and F). Note that the circuit is not fully implemented in this figure (jumper wires are not connected).

2.5 Circuit Schematic

The schematic of the motor driver circuit used in this lab is illustrated in Figure 9. You need to assemble the circuit as shown on the breadboard attached to the TI-RSLK-Mechkit robot.

> **Note:** The circuit shown in Figure 9 will be used in Lab 4 to interface with MSP432 LaunchPad and control the speed as well as direction of the two DC motors.

The motors are powered via the six AA batteries installed on the robot, which provide a voltage in the range of 7.2V to 9V through the VSW pin of the TI-RSLK chassis board. We recommend to connect the VSW test point on the TI-RSLK chassis board to the (+)

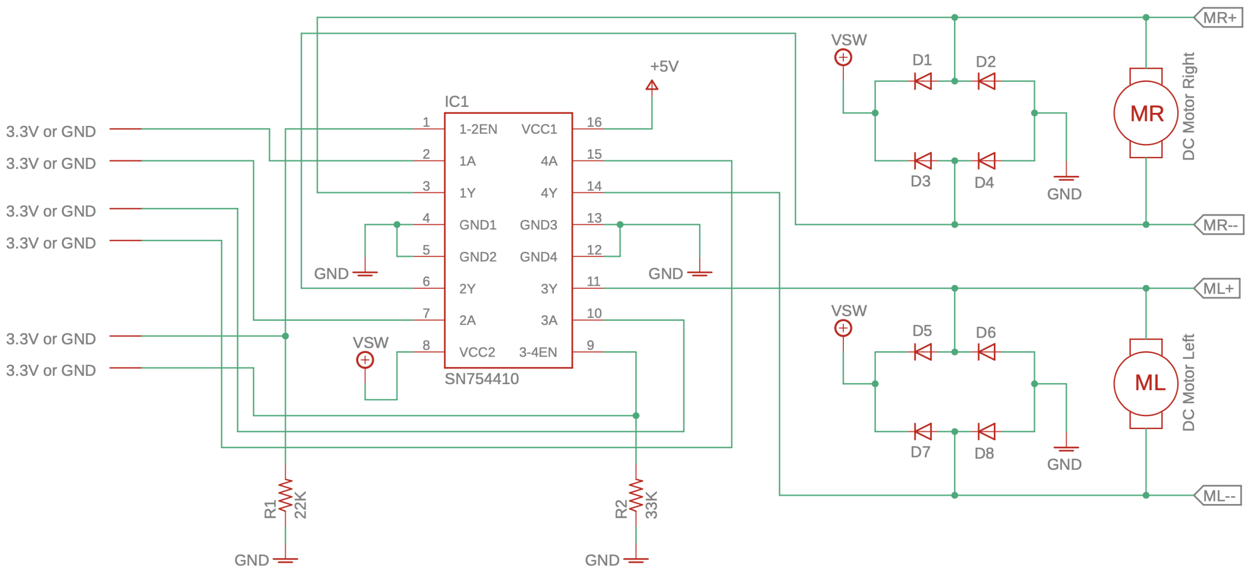


Figure 9: Circuit diagram for the H bridge interface with motor.

power rail of the breadboard using an alligator clip, and then use the power rail for all the pins connected to VSW. Similarly, the GND pin of the MSP432 LaunchPad (attached to the TI-RSLK-Mechkit robot) can be connected to the (−) power rail of the breadboard using a Male-Female jumper wire, so that all the pins connected to the GND can share that power rail. The +5V required for the VCC1 pin of SN754410 (pin 16) can be taken from the 5V pin of the LaunchPad using another Male-Female jumper wire.

The flyback diodes provide paths for current to flow when the drivers are switched off. Pay extra attention to the direction of the diodes when implementing them on the breadboard.

Note: The DC motors provided with the TI-RSLK-Mechkit include an encoder assembly. However, for the purpose of this lab, the encoders will not be used and only the terminals M1 and M2 of each motor (MR+, MR–, ML+ and ML–) will be connected to the circuit via the test points attached to the chassis board and the alligator clips.

As discussed in Section 2.4.2, the DC motors are connected to the SN754410 motor driver via the output pins 3, 6 and 11, 14. Two pull-down resistors ($22K\Omega$ and $33K\Omega$[1]) are connected to the SN754410 enable pins (pin 1 and pin 9) to make them low (disabled) by default. These enable signals are active-high, and will be connected manually to high (3.3V) or low (GND) voltage levels to enable/disable the associated driver channels.

Similarly, the input signals (associated to 1A, 2A, 3A and 4A channels) are connected manually to high (3.3V) or low (GND) voltage levels. We recommend to connect a 3.3V pin of the MSP432 LaunchPad to an available 5-pin group on the breadboard (using a Male-Female jumper wire), and then use that 5-pin group to connect the SN754410 inputs manually to 3.3V.

[1] Resistor color codes: red-red-orange ($22K\Omega$), orange-orange-orange ($33K\Omega$)

Applying 3.3V to pin 1A (pin 2) and GND to pin 2A (pin 7) results in the right motor turning in forward direction. To turn the right motor in backward direction, the pin 1A is connected to GND and pin 2A to 3.3V. The left motor has the same performance through the input pins 3A (pin 10) and 4A (pin 15) of SN754410.

Note: To use the MR+, MR–, ML+, ML– and VSW signals, you need to use the test points and the alligator clips provided with the "TI-RSLK-Mechkit". For more details on how to connect the test points and alligator clips, please see the Robot Assembly Manual, available under Course Resources on edX (Robot-Assembly-Manual.pdf).

2.6 Expected Performance

After building the H-bridge motor driver circuit in Figure 9 on the breadboard, connect the DC motors pins (MR+, MR–, ML+, ML–) to the SN754410 output pins (1Y, 2Y, 3Y and 4Y) using the test points attached to the chassis board and the alligator clips. Similarly, connect the power lines (VSW, 5V, 3.3V and GND) to the breadboard.

Follow the steps described in the Lab Assignment 1 and program the MSP432 LaunchPad with the code provided for Lab 1, available under Course Resources on edX (lab1-main.zip). This code calls the `mechrev_setup()` function provided by the `mechrev.h` header file to bypass the motor drivers of the TI-RSLK chassis board (so that there would be no conflict between the motor driver IC on the breadboard and the default motor driver on the chassis board).

Turn the robot on by pressing the power button on the chassis board, so that the chassis board provides power to the LaunchPad and the motor driver circuit as well.

Enable the H-bridge motor driver IC by connecting the enable pins (pin 1 and pin 9) of SN754410 to 3.3V.

Start your test with having SN754410 input pins (1A, 2A, 3A and 4A) connected to GND via jumper wires included in the kit. The motors should be stopped in this configuration. Disconnect SN754410 pin 2 (1A) from GND and connect it to 3.3V. The right motor should start turning in forward direction with full speed. Now connect SN754410 pin 2 (1A) again to GND and SN754410 pin 7 (2A) to 3.3V. The right motor should be turning in backward direction with full speed.

Continue the test with the left motor inputs: connect SN754410 pin 10 (3A) or pin 15 (4A) to 3.3V, and make sure that the driver is capable of turning the left motor in both directions.

2.7 Troubleshooting

The LaunchPad or the SN754410 IC get hot:

- Double check the power (VSW, 5V, 3.3V) and GND wires connected to the breadboard.
- Verify the direction of flyback diodes. connected to the breadboard.

– Make sure that you have programmed the LaunchPad with the code for the Lab 1 assignment. This code calls the `mechrev_setup()` function to disable the built-in motor drivers on the TI-RSLK chassis board and prevent any conflict between the SN754410 motor driver IC on the breadboard and the default RSLK motor drivers.

Motors not do spin or get hot:

– Remove power and double check the connections.

– Recharge the batteries.

One motor spins faster than the other:

– It is normal for the motor speeds to be $\pm 20\%$ of each other.

– Check for friction on the slower motor.

2.8 Grading

Proceed to the Problems unit of Lab Assignment 2 on edX and answer the questions.