Lab 9: Self-Driving Car

Submission Due Dates:

Demo: 2022/01/04 17:20

Source Code: 2022/01/04 18:30

Report: 2022/01/09 23:59

Objective

1 Getting familiar with Pmod connectors for external devices.

2 Getting familiar with the 3-way track sensor and ultrasonic sensor.

3 Learn how to control the motor with a typical motor driver using PWM signals.

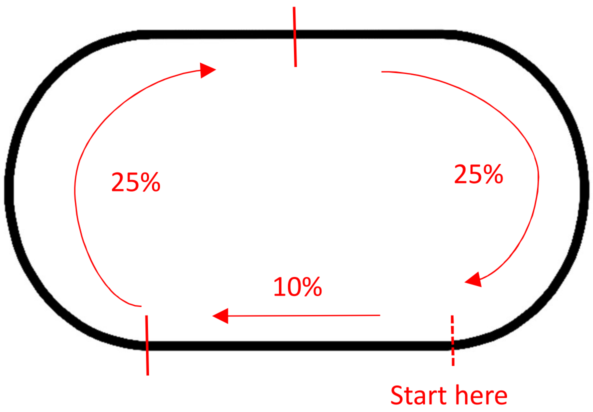
Description

In this lab, you will implement a car that follows a track with a black line and stops when there's an obstacle in front of it. You may trace the code in the template files (`lab9_top.v`, `motor.v`, `tracker_sensor.v` and `sonic.v`) and use it in this lab. Note that there are TODO items in these files. TAs will ask questions about how they work.

Detailed specification:

1. Regular track: (60%)

   The vehicle should follow the black line on the ground and complete the full track at least once. The line is defined by black electrical tape (with the width of 20mm). The geometry and grading of the track are as follows (10% for the straight line; 25% for each curve):



2. Obstacles: (40%)

   TA will put an obstacle at a random location on the track. The car should come to a complete stop before hitting it, and continue on the track when the obstacle is removed. The size of the obstacle will be equal to or larger than the size of the car.

   Demo video:

   https://drive.google.com/file/d/1QCBqZYkLmnYRj-Pv2X-UUJeNgwazLvuG/view?usp=sharing

3. Bonus track: (10%)

There will be a challenging track with undisclosed geometry. The car should follow the black line and complete the full track at least once, along with obstacle avoidance. The challenging track comes with several restrictions:

- The track does not overlap itself.
- There are no square corners.
- There may be sharp turns.

The bonus track will be graded as follows:

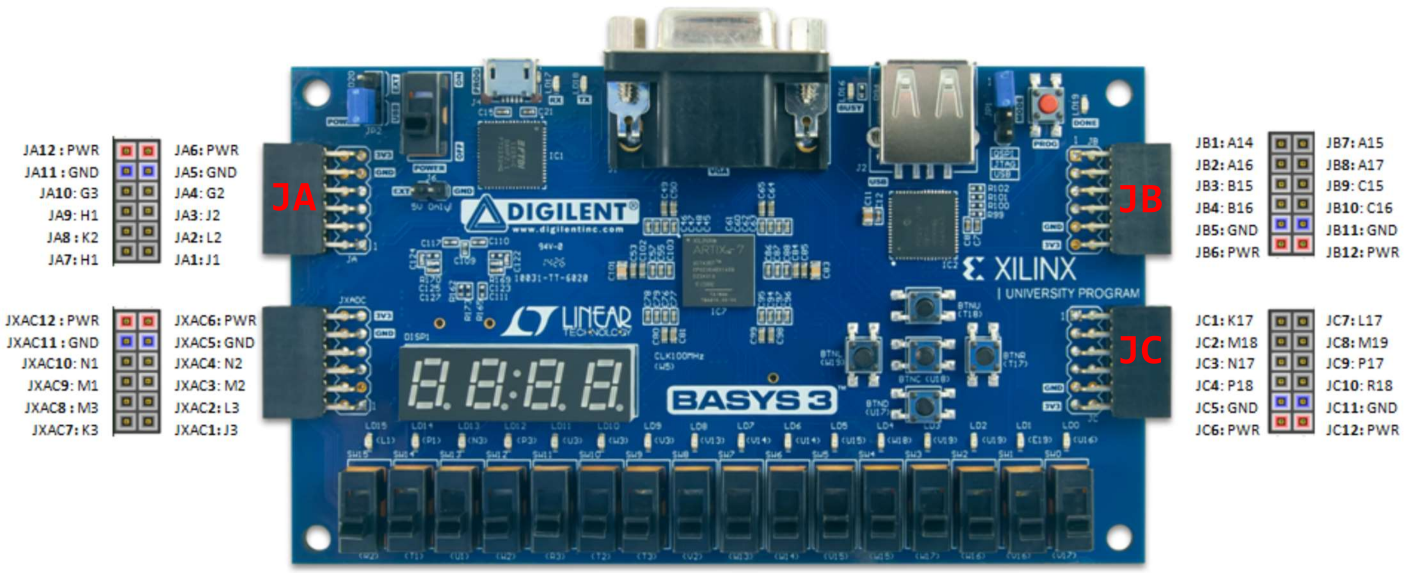
- Complete the track in either clockwise or counter-clockwise. (5%)
- Complete the track in **both** clockwise and counter-clockwise. (3%)
- Avoid obstacles. (2%)

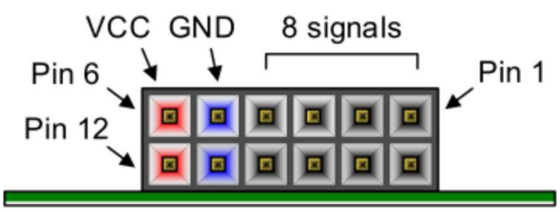
Hardware Details

1. Pmod connectors:

   Here is the Pmod connectors' pin-out diagram for your reference:

Basys3: Pmod Pin-Out Diagram





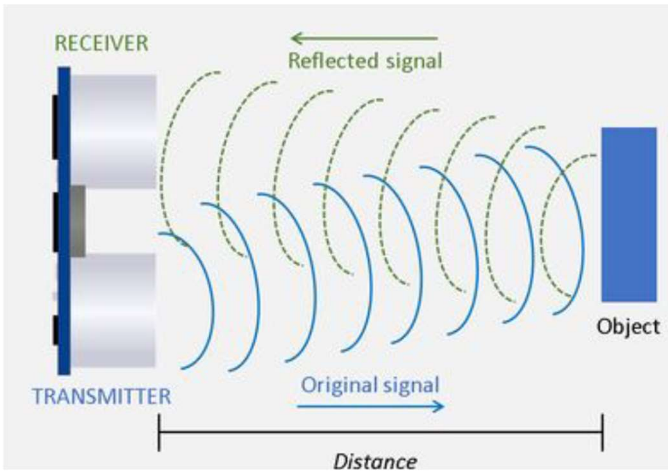
2. 3-way track sensor

This track sensor has 3 independent infrared (IR) sensors. Each IR sensor has an IR blaster and an IR receiver. If the IR is being reflected by the floor, the sensor will output HIGH. Hence, a white floor reflects IR, and the sensor outputs HIGH; a black floor absorbs IR, and the sensor outputs LOW.

Pin connections:

- VCC pin: connects to the supply power provided by the FPGA board.
- GND pin: connects to the ground of the FPGA board.
- L pin: outputs the status of the left IR sensor. You should connect it to an input port.
- C pin: outputs the status of the middle IR sensor. You should connect it to an input port.
- R pin: outputs the status of the right IR sensor. You should connect it to an input port.

3. Ultrasonic sensor

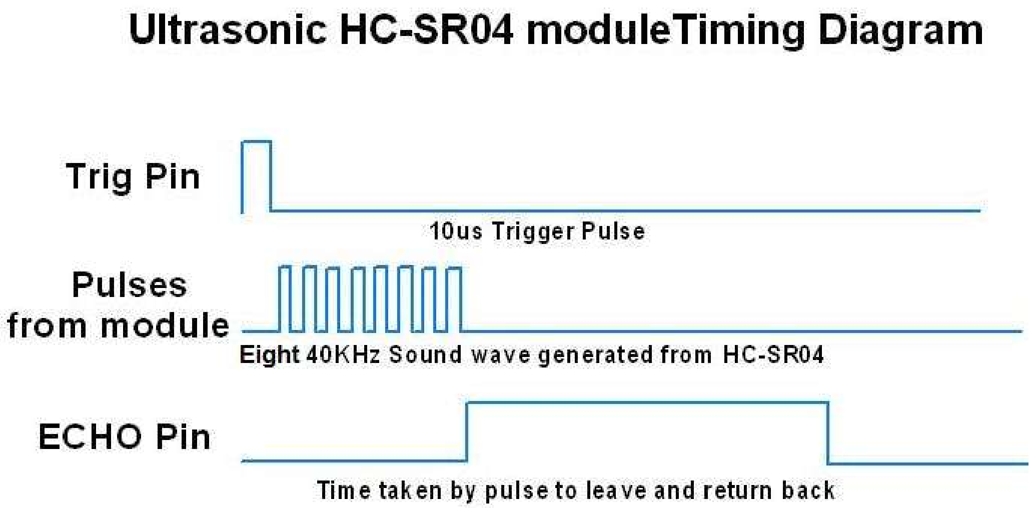


The HC-SR04 Ultrasonic sensor can measure the distance between the sensor module and the object in front of it.

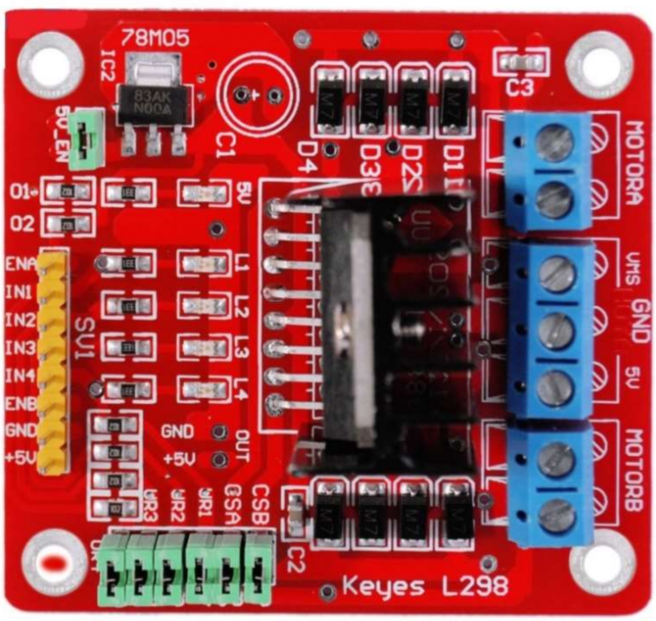
- First, send a 10us pulse to the “Trig” pin to trigger the sensor.
- The sensor will then generate eight pulses of ultrasonic soundwaves and determine the distance.
- After that, the “Echo” pin will output a long pulse. The length of the pulse is equal to the total travel time of the soundwave.
- Calculate the distance, that is, (pulse_length / 2) * 340(m/s) .
- Each measurement should have a >60ms interval for a better accuracy.
- You may use the sample **sonic.v** file to interface with the sensor.

Pin connections:

- VCC pin: connected to the supply power provided by the FPGA board.
- Trig pin: connected to an output pin on the FPGA board to trigger the sensor.
- Echo pin: connected to an input pin on the FPGA board to measure pulse length.
- Gnd pin: connected to the ground of the FPGA board.



4. L298N motor driver and motors



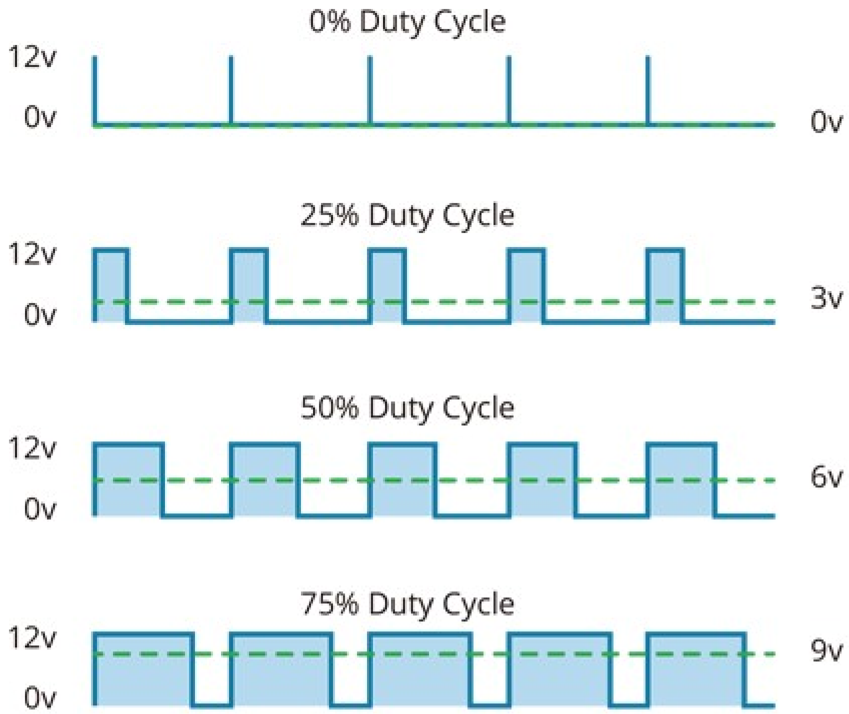
The L298N is a dual H-Bridge motor driver which supports the speed and direction control of two DC motors at the same time. ENA, IN1, IN2 controls the motor A, while ENB, IN3, IN4 controls the motor B. You may use the sample **motor.v** file to interface with the driver.

- Direction controls:

IN1 (IN3)	IN2 (IN4)	Spinning Direction
LOW	LOW	Motor off
HIGH	LOW	Forward
LOW	HIGH	Backward
HIGH	HIGH	Motor off

- Speed controls:

We send PWM signals to ENA and ENB to control the speed. A larger duty cycle results in a faster speed.



*NOTE: If the duty cycle is too small, there may not be enough power to drive the motor and push the car forward. We recommend a duty cycle of 60~80% as a starting point.

Pin connections: (the yellow connections on the left)

- ENA: connects to an output pin of the FPGA board. It controls the speed of motor A.
- IN1, IN2: connect to output pins of the FPGA board. They control the direction of motor A.
- IN3, IN4: connect to output pins of the FPGA board. They control the direction of motor B.
- ENB: connects to an output pin of the FPGA board. It controls the speed of motor B.
- GND: connects to the ground of the FPGA board

- 5V: Provides 5V power to the FPGA board. Connect it to the external power pins on the FPGA board.

Wire terminals: (the blue ones with screws on the right)

- MOTORA: Connects to a pair of positive and negative motor wires of motor A.
- VMS: The power input. Connects to the **positive** terminal of the battery.
- GND: The power ground. Connects to the **negative** terminal of the battery.
- 5V: outputs 5V power. Not used in this lab.
- MOTORB: Connects to a pair of positive and negative motor wires of motor B.

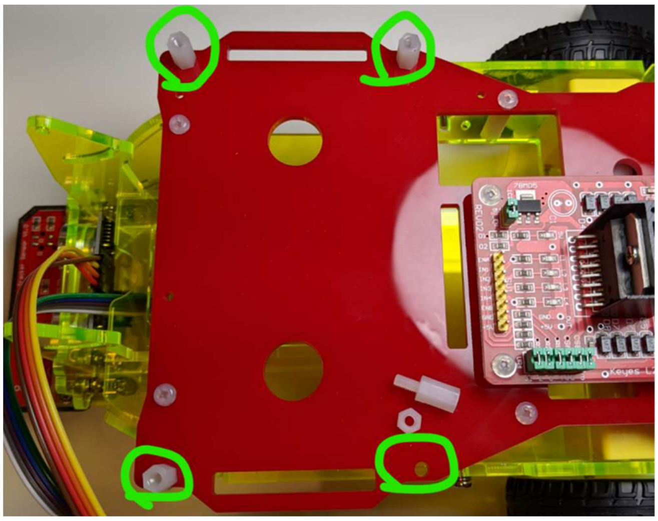
I/O Signal Specification

Here is the I/O connection defined in **lab9_constrains.xdc**. You may change the Pmod connections if necessary.

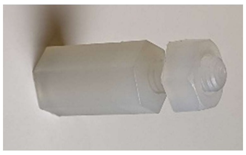
Name	Pin	Description
clk	W5	clock signal with the frequency of 100MHz
rst	btnC (U18)	active-high reset
IN1	JA1 (J1)	connected to “IN1” pin of the motor driver
IN2	JA2 (L2)	connected to “IN2” pin of the motor driver
IN3	JA3 (J2)	connected to “IN3” pin of the motor driver
IN4	JA4 (G2)	connected to “IN4” pin of the motor driver
left_pwm	JA7 (H1)	connected to “ENA” pin of the motor driver
right_pwm	JA8 (K2)	connected to “ENB” pin of the motor driver
trig	JB3 (B15)	connected to “trig” pin of the ultrasonic sensor
echo	JB4 (B16)	connected to “echo” pin of the ultrasonic sensor
left_track	JB8 (A17)	connected to “L” pin of the 3-way track sensor
mid_track	JB9 (C15)	connected to “C” pin of the 3-way track sensor
right_track	JB10 (C16)	connected to “R” pin of the 3-way track sensor

Assembly Instructions

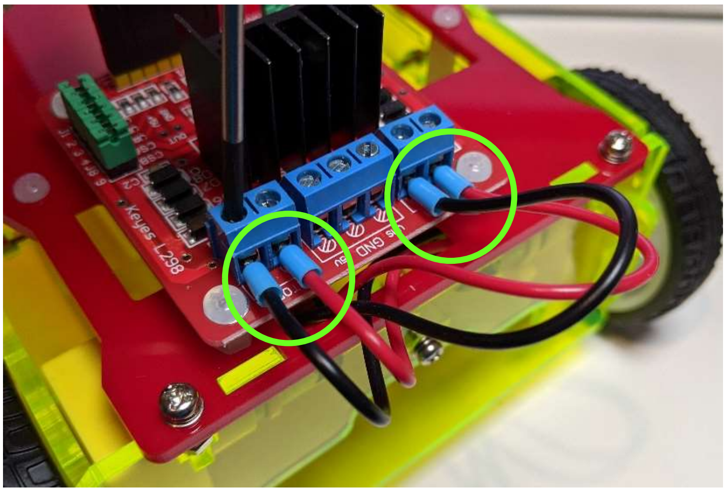
1. Remove four plastic pillars on the car.



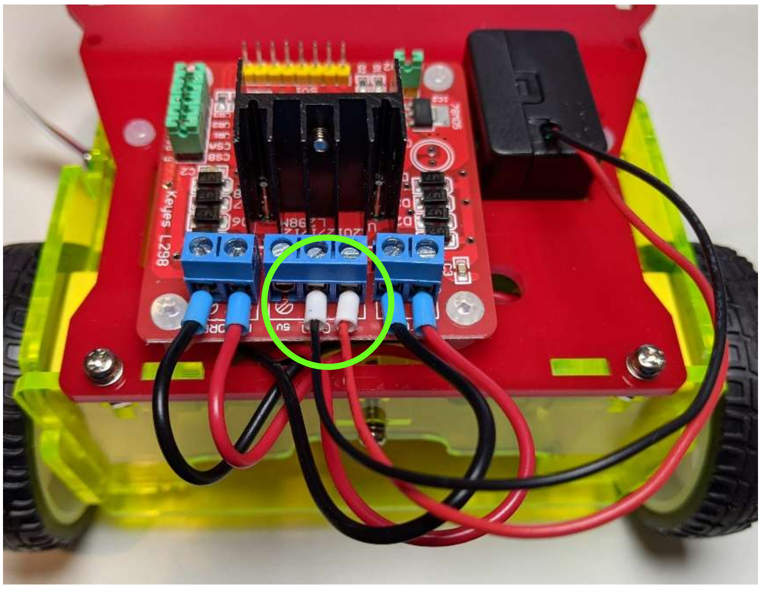
Tip: Put the washer back so you won't lose it.



2. Connect the motor wires to the blue wire terminals. Insert the wire and use a flat-head screwdriver to tighten the terminals. Try to pull the wires gently to ensure they are secure. The polarity of the motor may not matter since we can easily change their spinning direction in Verilog code.

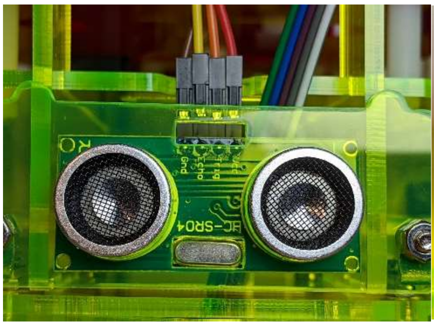
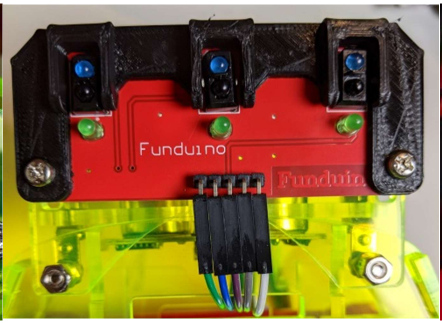


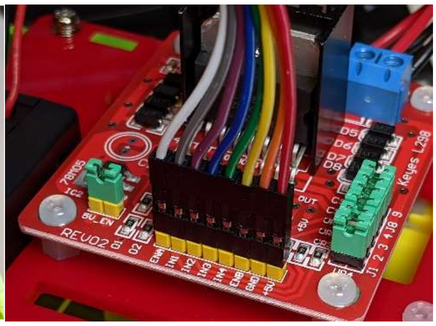
3. Connect the battery wires to the wire terminals in the middle. **The positive (red) wire to VMS, the negative (black) wire to GND**. **Warning:** you WILL damage the hardware if you connect them incorrectly.



4. Connect jumper wires for the ultrasonic sensor, the 3-way track sensor and the motor driver.

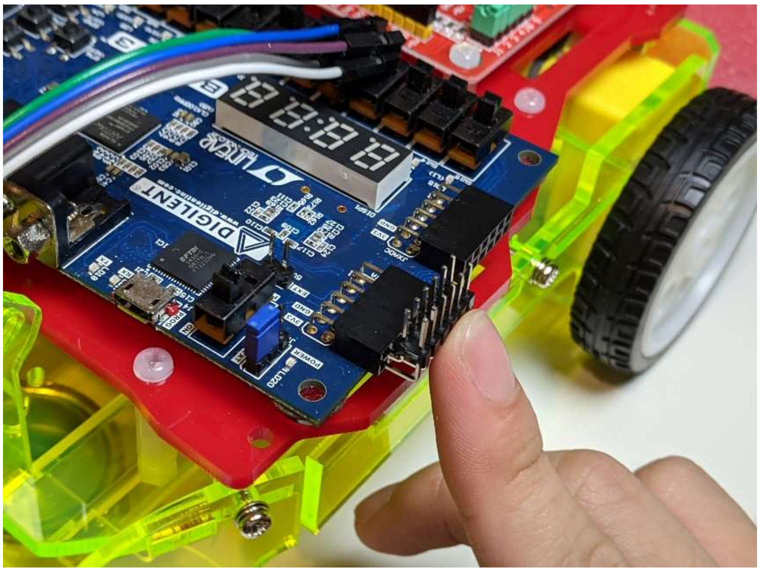
   Note: the jumper wires in each boxset may have different colors from the ones in the photos below. Connect them with caution.

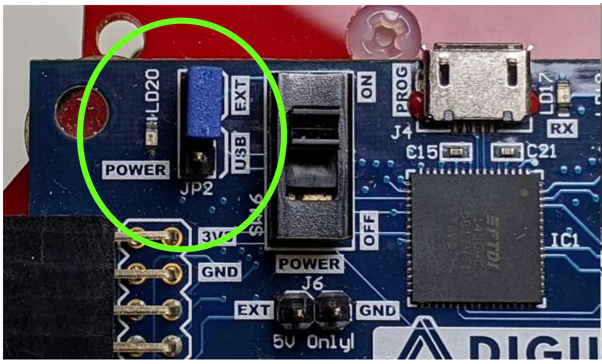


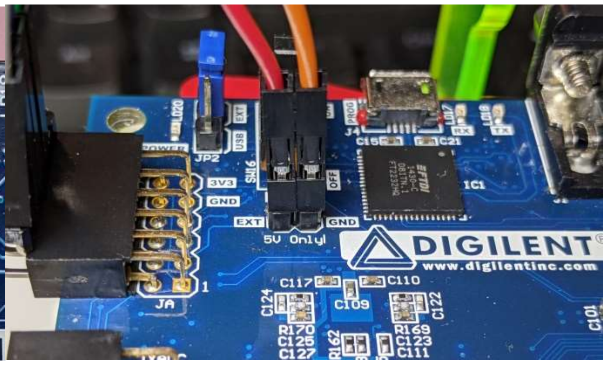
5. Cut 2 groups of six right-angle connectors.

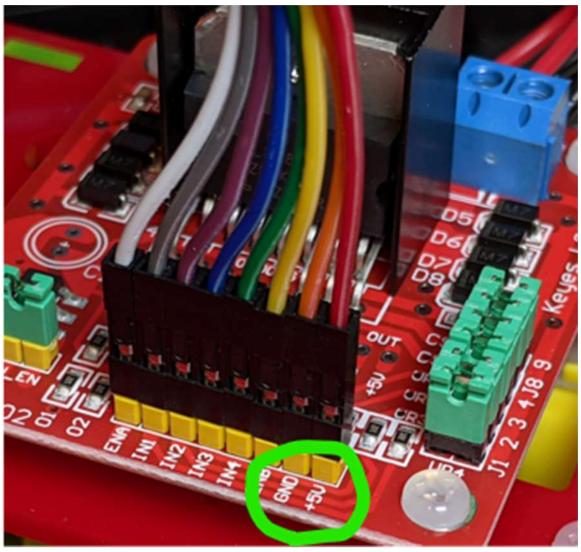
6. Place the FPGA board on top and insert the right angle pins into the Pmod connectors.



7. Move the power jumper to “EXT” to receive the supply power from the external power pins. Then connect the jumper wires from the motor driver’s power output to the FPGA. **Connect 5V to EXT, GND to GND**. **Warning:** you WILL damage your FPGA board if you connect the wrong way.

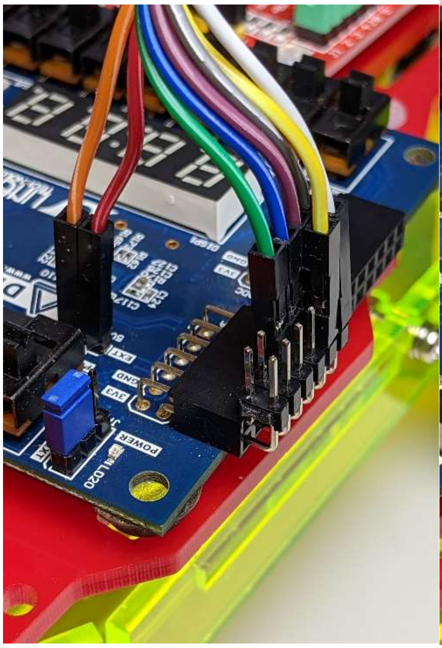






8. Connect the rest of the jumper wires to the Pmod connectors according to the I/O Signal Specification (or your own constrains file). **Be careful with the power connections** (3V3 and GND on the FPGA board). **You need to provide power (connect 3V3 to VCC and GND to GND) to the ultrasonic sensor**

and the 3-way track sensor. **Warning:** you WILL damage your FPGA board and/or your sensors if you connect the wrong way.




9. Insert the battery. **Be careful with the polarity**. **Be sure to double-check all the power-related connections before you turn on the power.** Now flip on the power switch, and you are ready to download your bitstream to the FPGA board!

   Note: If you short-circuit or overload the battery, it may enter an over-current protection state. Connect the battery to a charger to restore it.


Attention

- ✓ You may adjust your design and its parameters during the demo.
- ✓ You can add extra features to aid debugging and tweaking. For example, show the distance on the 7-segment display and show the status of 3-way track sensor on three LEDs.

- ✓ You should hand in only one Verilog file, **lab9.v**. If you have several modules in your design, integrate them in lab9.v. Do not include debounce, one-pulse, and clock divider modules in the file.
- ✓ DO NOT copy-and-paste code segments from the PDF materials. Occasionally, it will also paste invisible non-ASCII characters and lead to hard-to-debug syntax errors.
- ✓ You should also hand in your report as **lab9_report_GroupID.pdf** (i.e., lab9_report_group12.pdf).
  - ☐ This lab is scored by groups.
  - ☐ You must list the group members and describe the job partition in the report.
- ✓ You should be able to answer questions of this lab from TA during the demo.