LAB 3 – Light-Tracking Car (Digital Control)

1. Objective

This experiment is to design and assemble a digital-controlled light-tracking car. The moving direction of the car is determined by the light intensity of the environment. The car will turn to the direction with brighter light environment. The objective of this experiment is to get familiar with an electronic system including sensor circuit, control circuit and the driver circuit.

2. Components

a. DC Motor
b. PCB board with motor drive circuit
c. LDR (Light-dependent Resistor)
d. Breadboard
e. Other electronic components such as LED, VR (variable resistor), switches and jumpers.
f. Arduino Broad
g. Digital Multimeter

3. Background Information

In this experiment, with the help of two Light-Dependent Resistors (LDRs) placed at the left and right sides of the car, the car is able to turn to the direction where guiding light source is located.

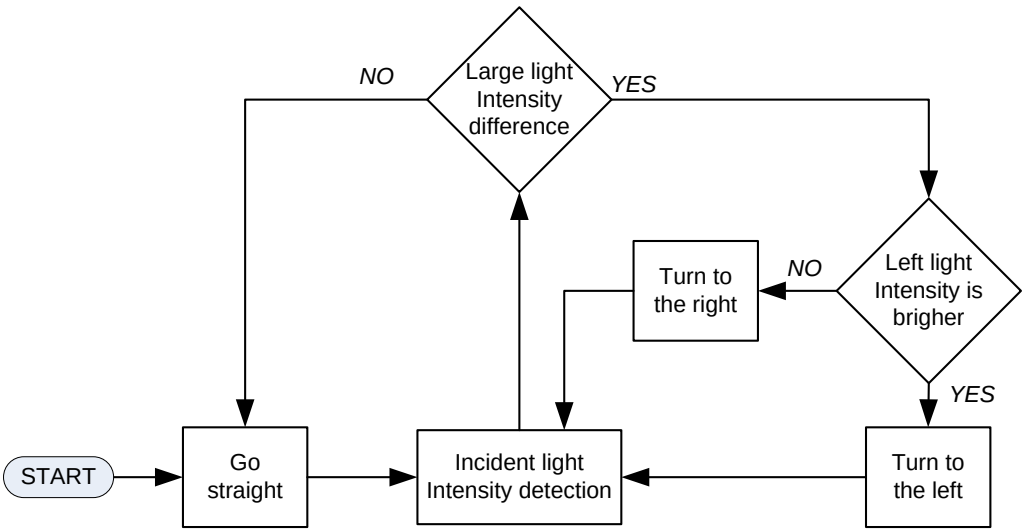


Fig. 1

The LDR on the left and right is to detect the incident light intensity from the left side and the right side of the car, respectively. The incident light intensity directly determines the resistance of LDRs, which will further determine the direction of the car. As shown in Figure 1, the car keeps detecting the incident light intensity from the left side and the right side of the car. When the difference of the light intensities between the left and right side of the car is in an acceptable range, the motor remains its direction to go straight. Otherwise, the motor will turn to the direction with brighter light environment until the difference of the light intensities between left and right is returned to that acceptable range. In the other word, the car always goes straight forward without extra "light guider" or turns to the "light guider" when it exists.

3.1. Feedback

Feedback conception is used in this experiment. Feedback describes the situation when output from an event or phenomenon in the past will influence the same event/phenomenon in the present or future. When an event is part of a chain of cause-and-effect that forms a circuit or loop, then the event is said to *"feed back"* into itself.

The output of this system is the speed of left wheel and right wheel. This output will influence the light intensity detected later, which will further influence the circuit and eventually, again, the speed of left wheel and right wheel. The feedback always works to keep the motor running to the bright direction.

3.2. Introduction to LDR

LDR is a resistor whose resistance decreases with increasing incident light intensity.

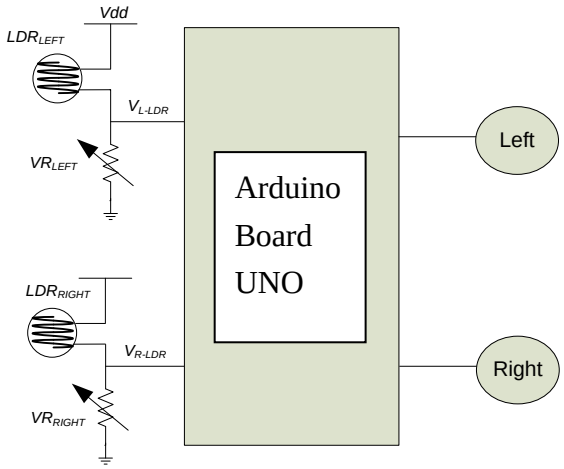


Fig. 2

As shown in Fig. 2, when the light intensity detected by LDR_{LEFT} and LDR_{RIGHT} is different, $V_{L\text{-}LDR}$ and $V_{R\text{-}LDR}$ are different too. $V_{L\text{-}LDR}$ and $V_{R\text{-}LDR}$ will directly influence the behavior of the control circuit. Because of the manufacturing variations, the sensitivity of LDR_{LEFT} and LDR_{RIGHT} may be different. When both of them receive the same incident light intensity, the resistance of them may not be the same. This is the reason why we need variable resistors VR_{LEFT} and VR_{RIGHT} to compromise the variations of LDR_{LEFT} and LDR_{RIGHT}. We have to firstly calibrate VR_{LEFT} and VR_{RIGHT} to make $V_{L\text{-}LDR}$ and $V_{R\text{-}LDR}$ equal.

3.3. Behavior of the motor under different situation

This motor is controlled by a digital control signal. The control signal is either 0 or 1. We use LEDs to visualize the 2 control bits, which control the rotating speed of the left wheel and the right wheel.

When the light intensity is uniform around the path,

	Light Intensity	Resistance of LDR	Control Bit	LED of MSB	Rotating speed of wheel	Operation of motor
Left	uniform	Almost the same	Both 1	Both On	Same	Go straight ahead
Right						

When the light source is on the left side of the path,

	Light Intensity	Resistance of LDR	Control Bit	LED of MSB	Rotating speed of wheel	Operation of motor
Left	stronger	smaller	0	Off	Slower	Turn left
Right	weaker	larger	1	On	Faster	

When the light source is on the right side of the path,

	Light Intensity	Resistance of LDR	Control Bit	LED of MSB	Rotating speed of wheel	Operation of motor
Left	weaker	larger	1	On	Faster	Turn right
Right	stronger	smaller	0	Off	Slower	

3.4. Sensitivity calibration

Why do we need to calibrate the sensitivity of the motor? If the motor is too sensitive to light, the control bits will keep changing between 0 and 1. The motor will proceed with a zigzag path. In contrast, if the motor is not so sensitive to light, it will keep moving straight ahead. Hence, we have to calibrate its sensitivity so that the motor reacts properly to different light intensity.

The sensitivity can be calibrated by the threshold voltage. Threshold voltage V_{th} here means the specific voltage difference between $V_{L\text{-}LDR}$ and $V_{R\text{-}LDR}$ (as shown in Figure 2) which results in the transition of left or right control bit.

	Light source	Control bit		LED of MSB		Operation of motor
		left	right	left	right	
$\lvert V_{L\text{-}LDR} - V_{R\text{-}LDR}\rvert <= V_{th}$	Uniform	1	1	On	On	Go straight ahead
$V_{L\text{-}LDR} - V_{R\text{-}LDR} > V_{th}$	From left	0	1	Off	On	Turn left
$V_{R\text{-}LDR} - V_{L\text{-}LDR} > V_{th}$	From right	1	0	On	Off	Turn right

The threshold voltage is adjusted by variable resistor network as shown in Fig. 3.

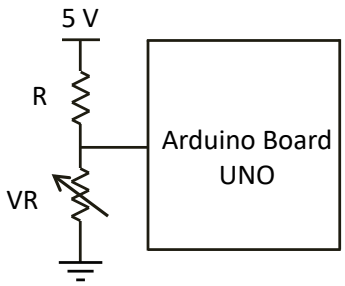


Fig. 3

3.5. Normal speed of the motor

The rotating speed of wheels is controlled by their respective supply voltage. The supply voltage is regulated from the system supply voltage and is controlled by 4 bits, from 0000 to 1111. In other words, the speed of each wheel is controlled by 4 bits. Among these 4 bits, only the MSB (Most Significant Bit) is controlled by the output of the control signal. We name the left MSB as L_bit4. The other 3 bits are preset by the DIP switches. We name them for the left side, from more significant bit to less significant bit, as L_bit3, L_bit2 and L_bit1. We do the same thing to the right part. There are 16 states altogether, from 0000 to 1111, and accordingly mapping to 16 voltage levels. “0000” refers to the slowest speed, which is actually 0; while “1111” refers to the highest speed.

Bits	Voltage level	Speed
0000	0	Slow ↓ Fast
0001	1	
0010	2	
0011	3	
0100	4	
0101	5	
0110	6	
0111	7	
1000	8	
1001	9	
1010	10	
1011	11	
1100	12	
1101	13	
1110	14	
1111	15	

The voltage level and according speed level are decided by “MSB (control bit) + XXX”.

For example, if we set the 3 bits XXX to be “000” by the DIP switches.

a) When the light intensity is uniform ($|V_{L\text{-}LDR} - V_{R\text{-}LDR}| < V_{th}$), the control bits for the left wheel and the right wheel are both “1”. Then the voltage level is “1000” and the according speed level is 8, as shown in the above chart. The normal speed of this motor is level 8.

b) When the light source is on the left ($V_{L\text{-}LDR} - V_{R\text{-}LDR} > V_{th}$), the control bit for the left wheel is “0”, so the voltage level is “0000” and the according speed level is 0; while the control bit for the right wheel is “1”, so the voltage level is “1000” and the according speed level is 8. The rotating speed of the right wheel is faster than that of the left wheel. The motor will turn left, which is the direction where the light source is located.

c) When the light source is on the right ($V_{R\text{-}LDR} - V_{L\text{-}LDR} > V_{th}$), the control bit for the right wheel is “0”, so the voltage level is “0000” and the according speed level is 0; while the control bit for the left wheel is “1”, so the voltage level is “1000” and the according speed level is 8. The rotating speed of the left wheel is faster than that of the right wheel. The motor will turn right, which is the direction where the light source is located.

For another example, if we set the 3 bits XXX to be “111”.

a) When the light intensity is uniform ($|V_{L\text{-}LDR} - V_{R\text{-}LDR}| < V_{th}$), the control bits for the left wheel and the right wheel are both “1”. Then the voltage level is “1111” and the according speed level is 15, as shown in the above chart. The normal speed of this motor is level 15.

b) When the light source is on the left ($V_{L\text{-}LDR} - V_{R\text{-}LDR} > V_{th}$), the control bit for the left wheel is “0”, so the voltage level is “0111” and the according speed level is 7; while the control bit for the right wheel is “1”, so the voltage level is “1111” and the according speed level is 15. The rotating speed of the right wheel is faster than that of the left wheel. The motor will turn left, which is the direction where the light source is located.

c) When the light source is on the right ($V_{R\text{-}LDR} - V_{L\text{-}LDR} > V_{th}$), the control bit for the right wheel is “0”, so the voltage level is “0111” and the according speed level is 7; while the control bit for the left wheel is “1”, so the voltage level is “1111” and the according speed level is 15. The rotating speed of the left wheel is faster than that of the right wheel. The motor will turn right, which is the direction where the light source is located.

All other intermediate values can be decided by you. Considering the accuracy issue, we recommend the initial setting to be MSB+“000”.

4. Prelab

4.1 Read the background information carefully.

4.2 Complete session 5.1 to 5.5.

4.3 Get six AA batteries.

5. Procedure

5.1 Important Rules

5.1.1 You should not use your computer to power up the Arduino UNO board. You should use USB fuse extension cable with the USB cable to connect the Arduino UNO board to the USB power bank (not provided) as shown in Fig. 4.

5.1.2 You should unplug the USB from the Arduino UNO board all the time as shown in Fig. 5. In the manual, it would mention to you, and marked on the top of the page, when you should connect the USB power and test your circuit.

5.1.3 You should keep the battery compartment empty all the time as shown in Fig. 6.

5.1.4 Every time you power up the Arduino UNO board, you should test whether the VDD and GND are shorted or not. If it is not shorted, you can turn it on. If it is shorted, you should not power up and you should check the connection first. You could refer to the video (video1-testing_VDD_and_GND.mp4) for checking shorted circuit.

5.1.5 There is a power LED shown in Fig. 11, 12 to indicate the power is ON. Once the board is powered up, you should always check the status of the power LED. It should be ON all the time. If the LED is suddenly OFF after you inserted something or changed wiring, in that case, you have to immediately unplug the power from the USB power bank and battery compartment, and you should check your circuit. You could refer to the video (video2-power_LED_suddently_OFF.mp4)

5.1.6 If you have fuse broken, you should not continue. You should stop wherever you are. You should contact the TA of the course to check your circuits.

5.1.7 You only power up the Arduino UNO board when you want to test your circuit.

5.1.8 You should power down (Unplug the USB) the Arduino UNO board when you do the wiring and component insertion.

5.1.9 You should follow the instruction in the manual to tell you when you should put the battery in the battery compartment.

5.1.10 During the experiment, you try to touch all the components: resistors, Arduino UNO board, battery, IC and motors, if you could feel that it is hot, please unplug the USB power and disconnect the battery output, and stop the experiment. You should consult TA immediately.

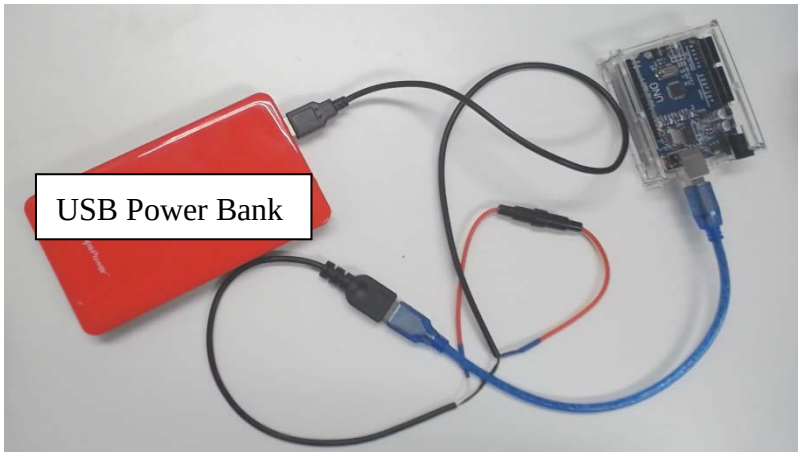


Fig. 4

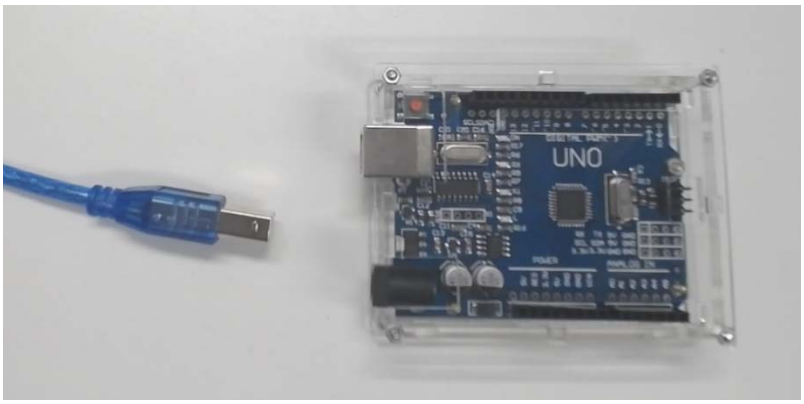


Fig. 5

Fig. 6

5.2 Construct the circuits

5.2.1. Put breadboard and the Arduino UNO labeled as “3” on the car board as shown in Fig. 7.

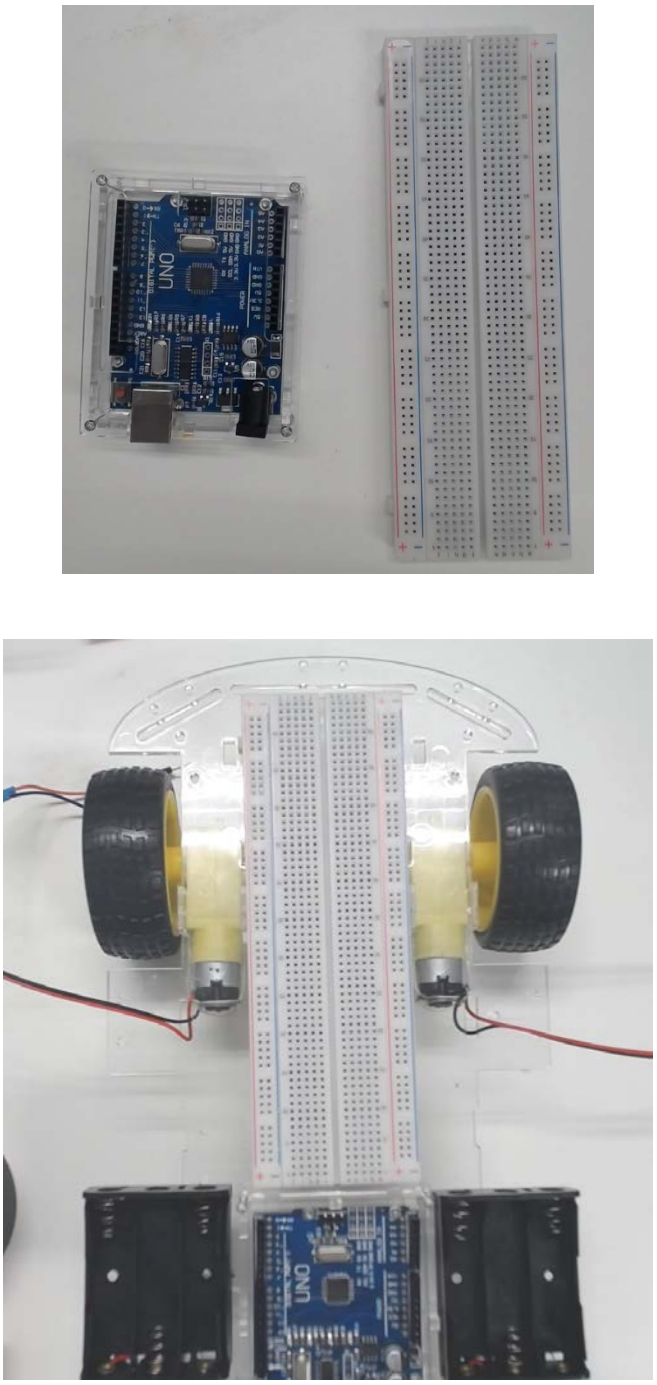


Fig. 7

5.1.2. The power switch, LED, and 330 ohm resistor are shown in Fig. 8. The USB fuse extension cable is shown in Fig. 9. For safety, we have to use the USB fuse extension cable to power up the Arduino UNO board as shown in Fig. 10. Connect power switch with the LED indication, the circuit shown in Fig. 11. and put all the components on the breadboard as shown in Fig. 12, Fig. 13, and Fig. 14. You could refer to the video (video3-power_switch.mp4) for demonstration.

[Check point 1] When the power switch is pressed, the LED will be ON.

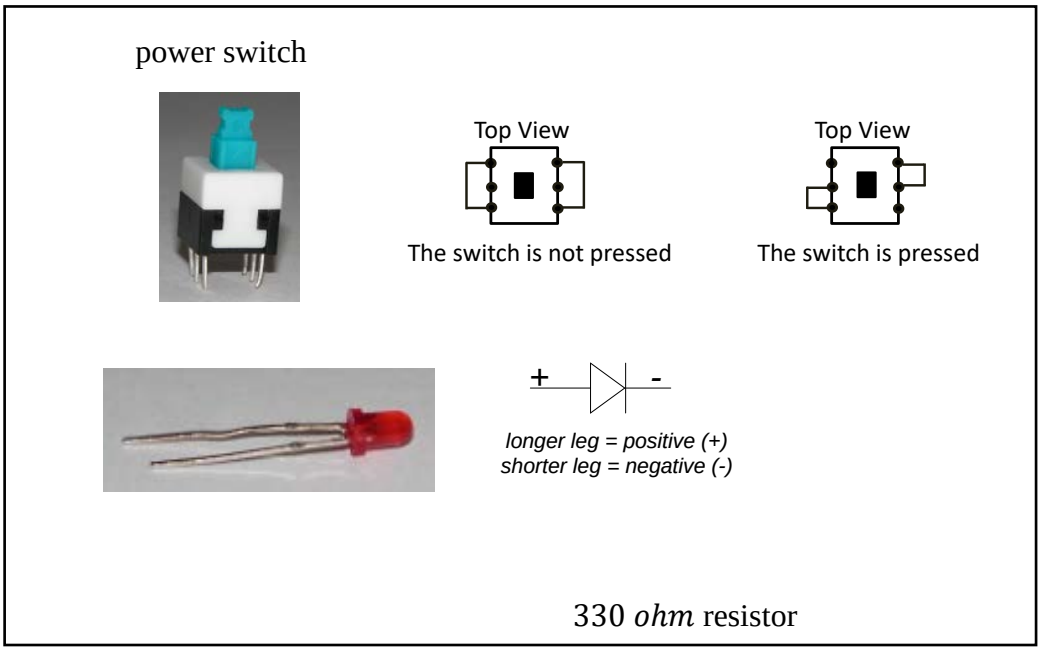


Fig. 8

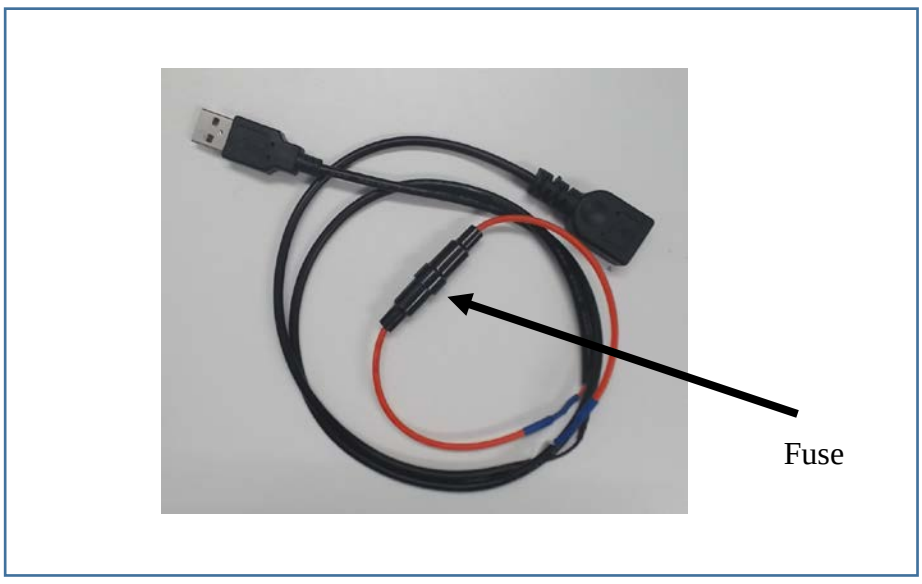


Fig. 9

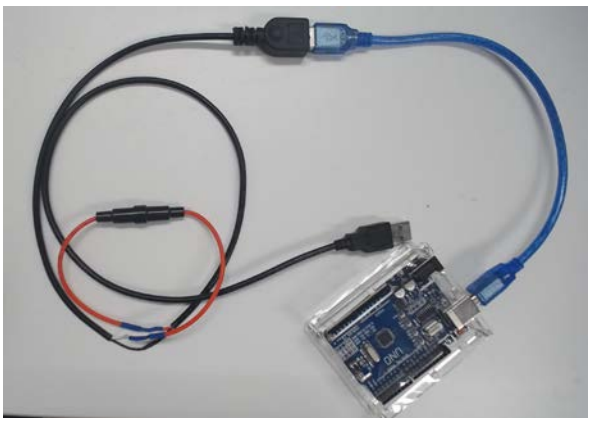


Fig. 10

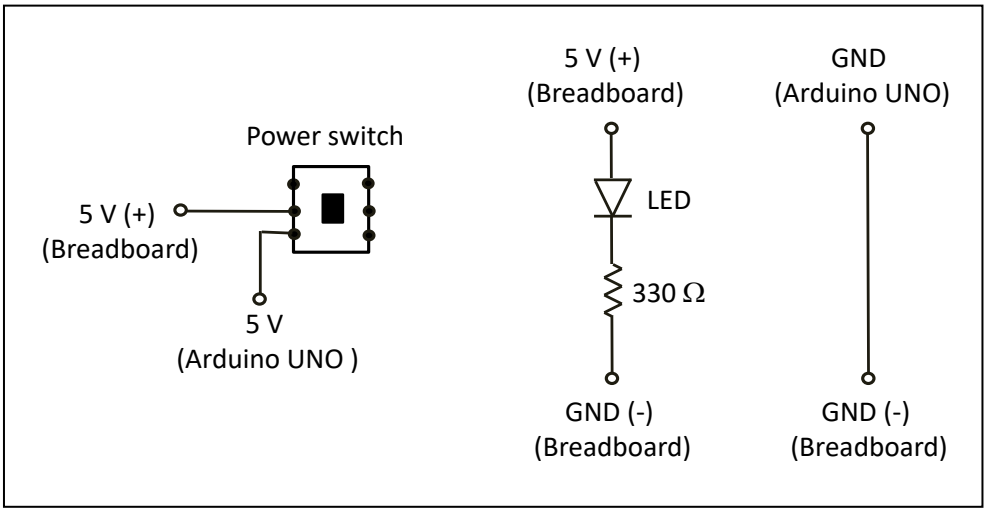


Fig. 11

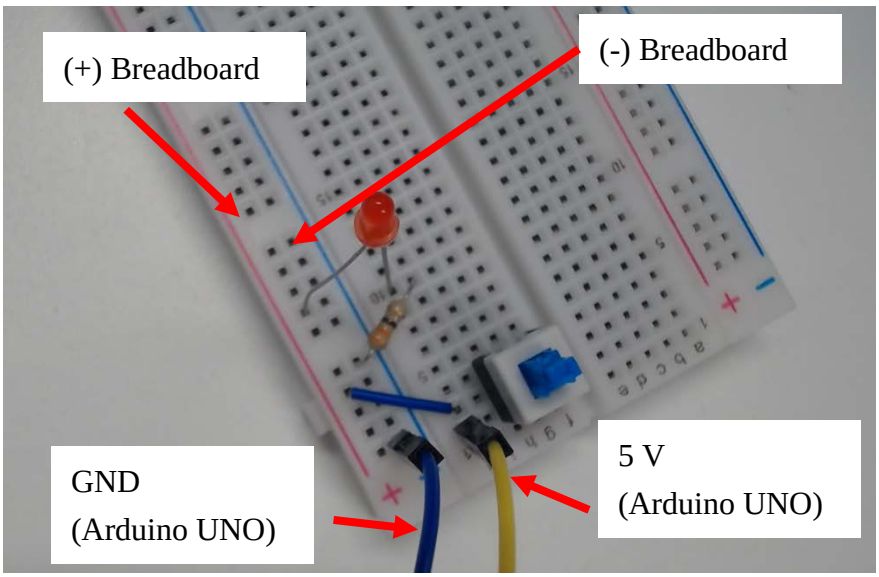


Fig. 12

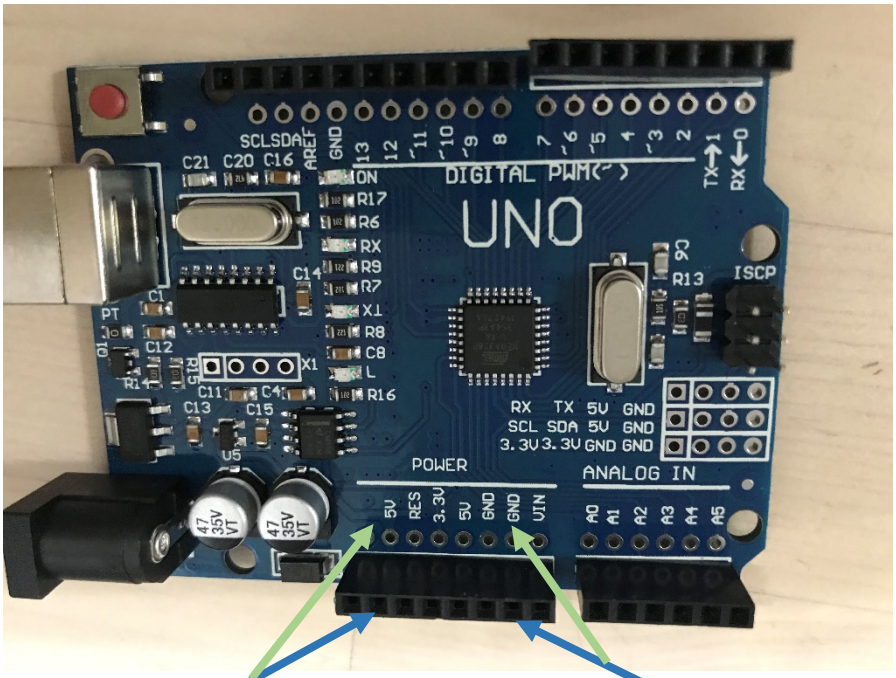

UNO
DIGITAL PWM(~)
POWER
ANALOG IN
ISCP
5 V
(Arduino UNO)
GND
(Arduino UNO)

Fig. 13

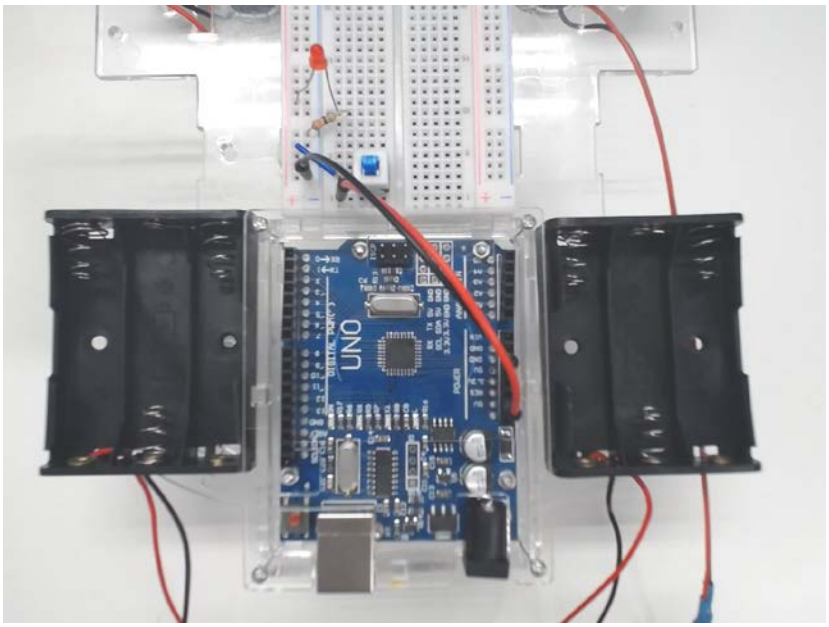


Fig. 14

5.1.3. On the breadboard, connect both “+” columns together, and connect both “-“ columns together as shown in Fig. 15. As such, both “+” columns are connected to 5V, and both “-“ columns are connected to ground (0 V), as shown in Fig. 16.

[Check point 2] Use the digital multimeter to measure the voltage of the node. You could refer to the video (video4-measure_voltage.mp4) for demonstration.

[Check point 3] Use digital multimeter to check both “+” columns are connected to 5V, and both “-“ columns are connected to GND. You could refer to the video (video5-check_5V_and_GND.mp4) for demonstration

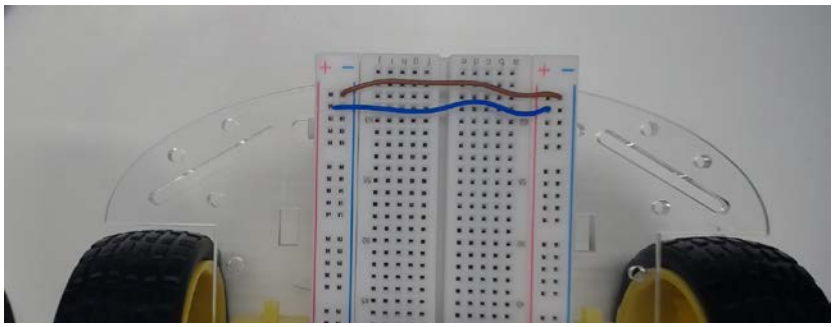


Fig. 15

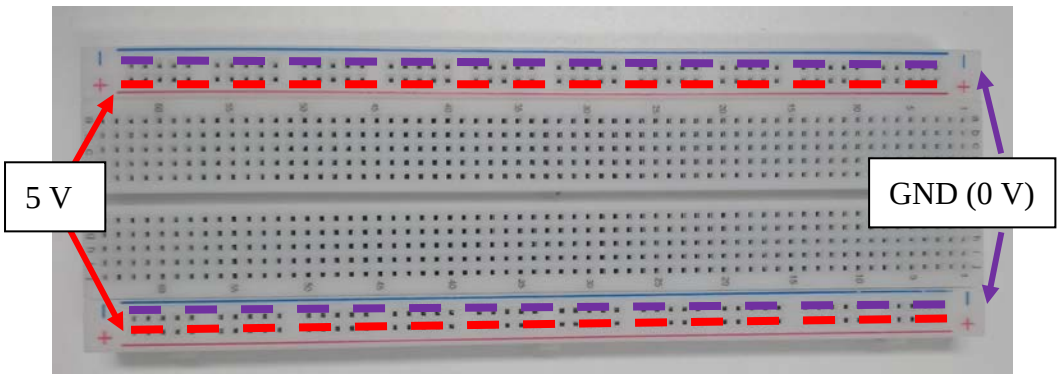
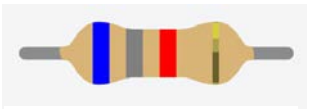


Fig. 16

5.1.4. The 6.8k ohm resistor, 47k ohm resistor, 100k ohm variable resistor (VR), and LDR (Light-dependent Resistor) are shown in Fig. 17. Connect LDR circuit shown in Fig. 18, and put all the components on the breadboard as shown in Fig. 19, 20, and 21. You could refer to the video (video6-LDR_circuit.mp4) for demonstration.

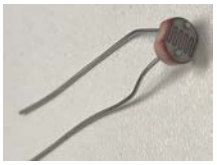
[Check point 4] Use screwdriver to turn VR1 to adjust voltage at node A to approximately equal to 2.5 V and turn VR2 to adjust voltage at node B to approximately equal to 2.5 V. Due to the light source in your place, you might not be able to tune to 2.5 V. In that case, you could tune it to any voltage between 1.2 Volt to 3.3 Volt. If you still could not tune it,

please try to remove the two 47k ohm from the circuit. You could refer to the video (video7-LDR-tunning.mp4) for demonstration.

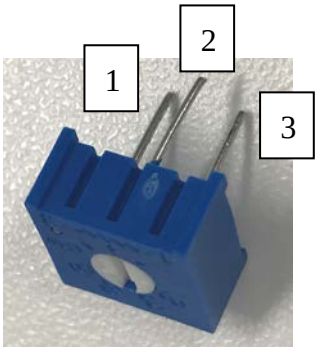


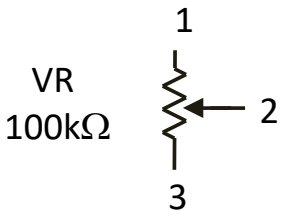
6.8k ohm resistor

47k ohm resistor



LDR
(light-dependent resistor)





100k ohm Variable resistor (VR)

Fig. 17

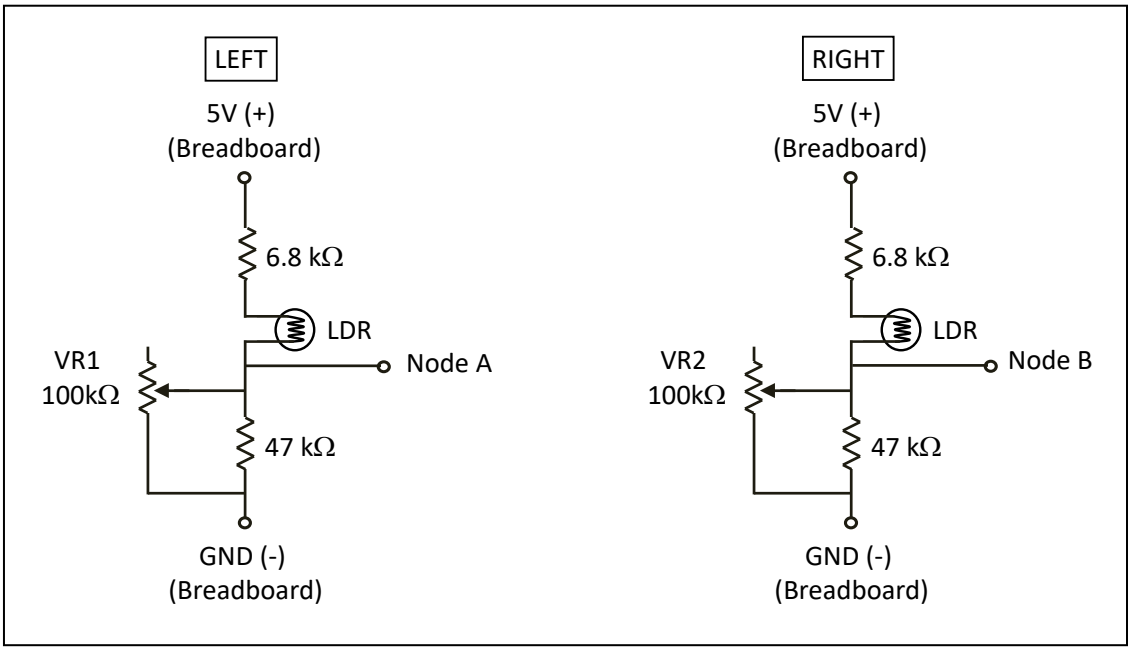


Fig. 18

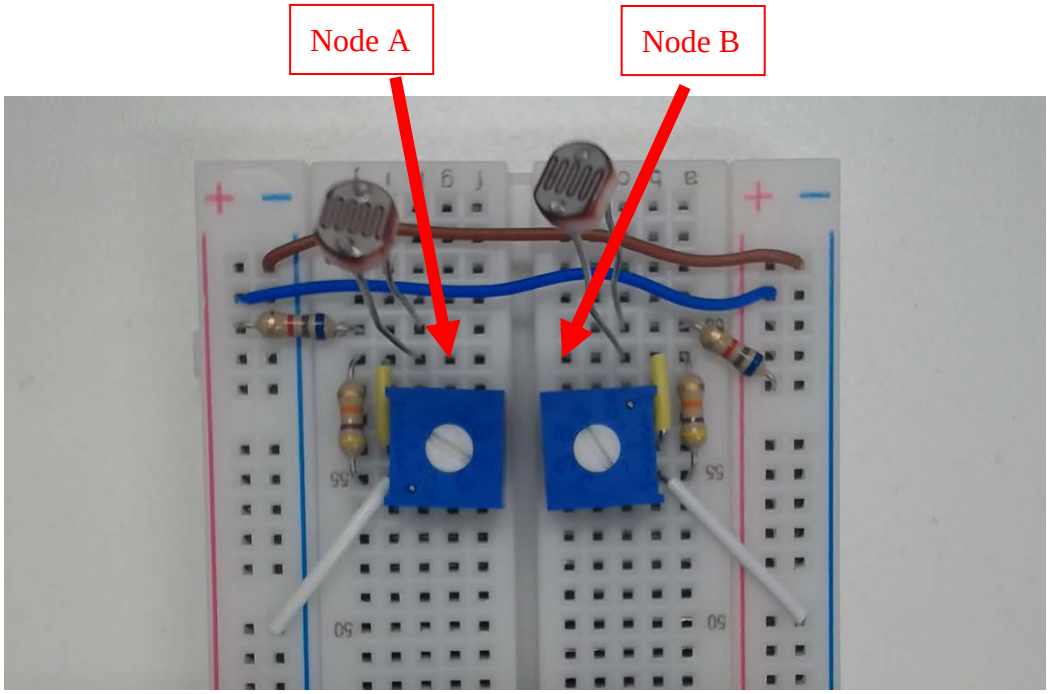


Fig. 19

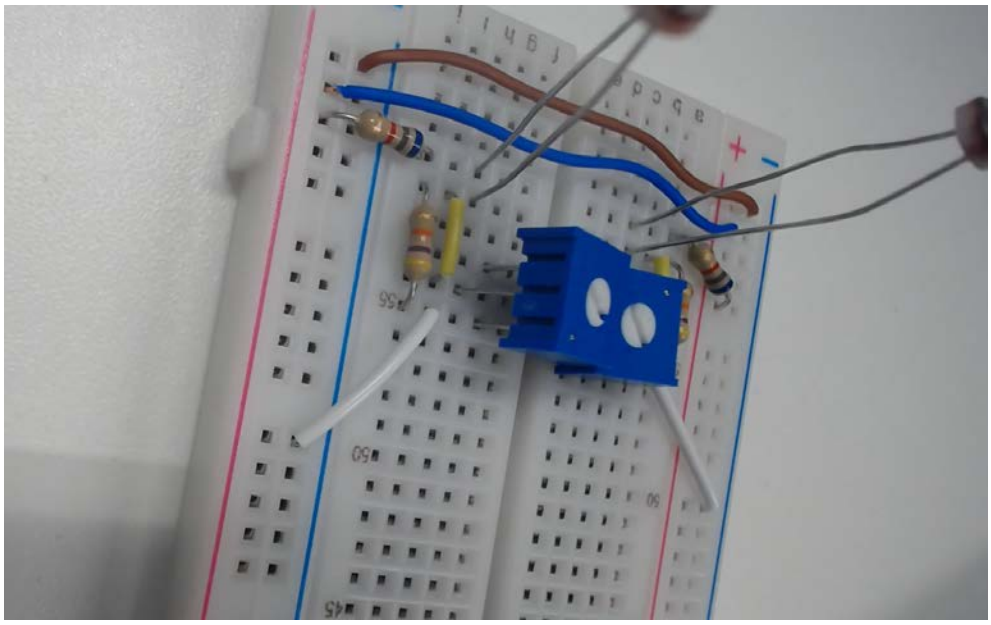


Fig. 20

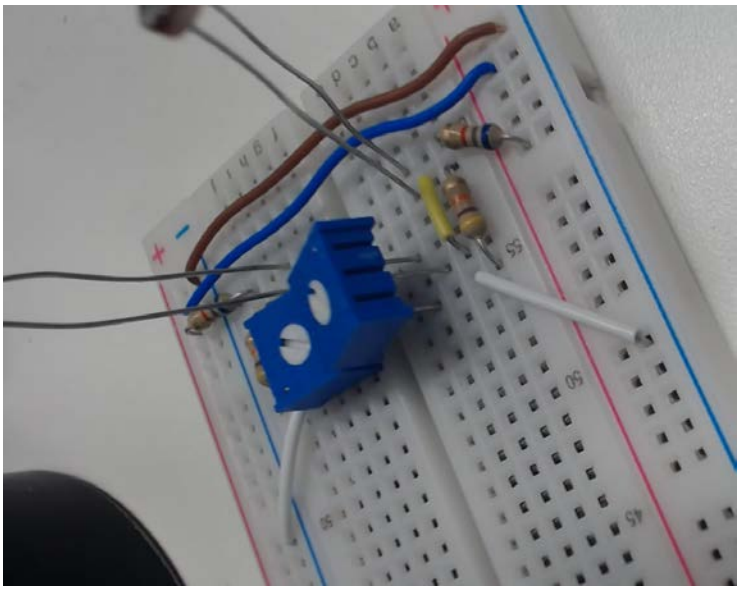


Fig. 21

5.1.5. Connect the Left and Right LED indicator circuit shown in Fig. 22, and put all the components on the breadboard as shown in Fig. 23. You could refer to the video (video8-LED_circuit.mp4) for demonstration.

[Check point 5] You use a wire to connect the Node C to 5 V (breadboard) to turn on the LED_Left, and connect the node D to 5 V (breadboard) to turn on the LED_Right. You could refer to the video (video9-Testing_LED.mp4) for demonstration.

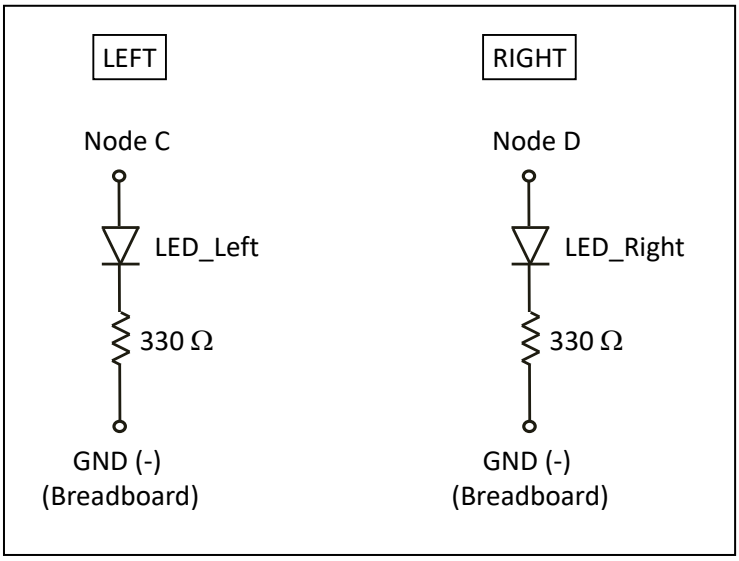


Fig. 22

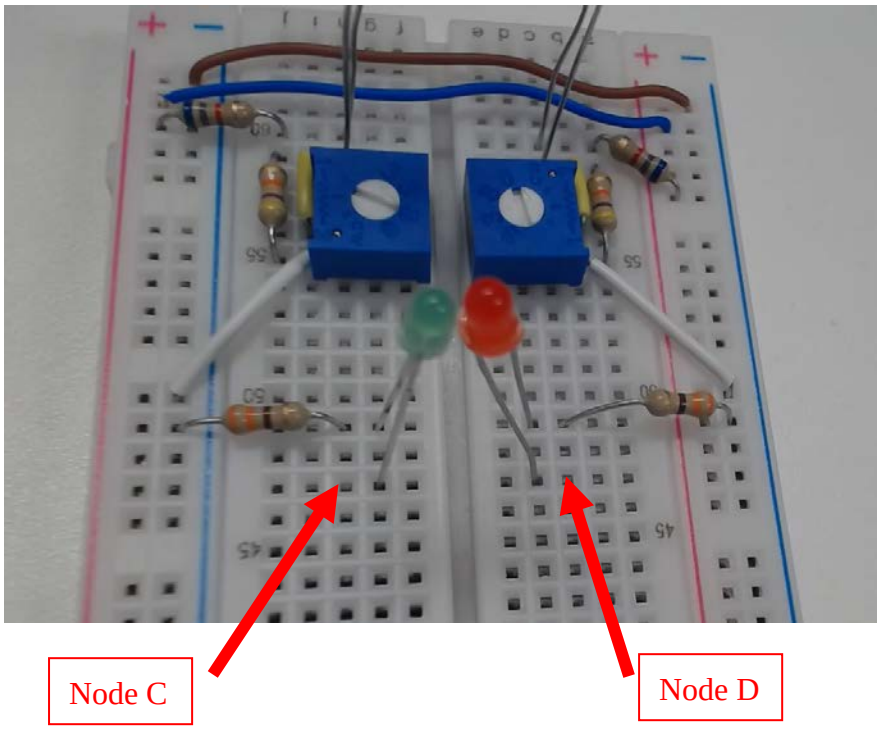
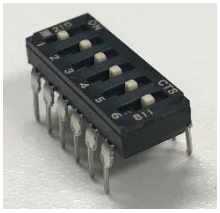


Fig. 23

5.6.6. The 47k ohm resistor, and DIP switch are shown in Fig. 24. Connect the DIP switch circuit shown in Fig. 25, and put all the components on the breadboard as shown in Fig. 26. You could refer to the video (video10-DIP_switch_circuit.mp4) for demonstration.

[Check point 6] You use a wire to connect the Node E in Fig. 25 to Node C in Fig. 22, to test the switch (ON and OFF setting). When the DIP switch is set to ON, the LED will be ON. You repeat doing that for Node F to Node J. You could refer to the video (video11-Testing_DIP_switch.mp4) for demonstration.

47k ohm



DIP switch

Fig. 24

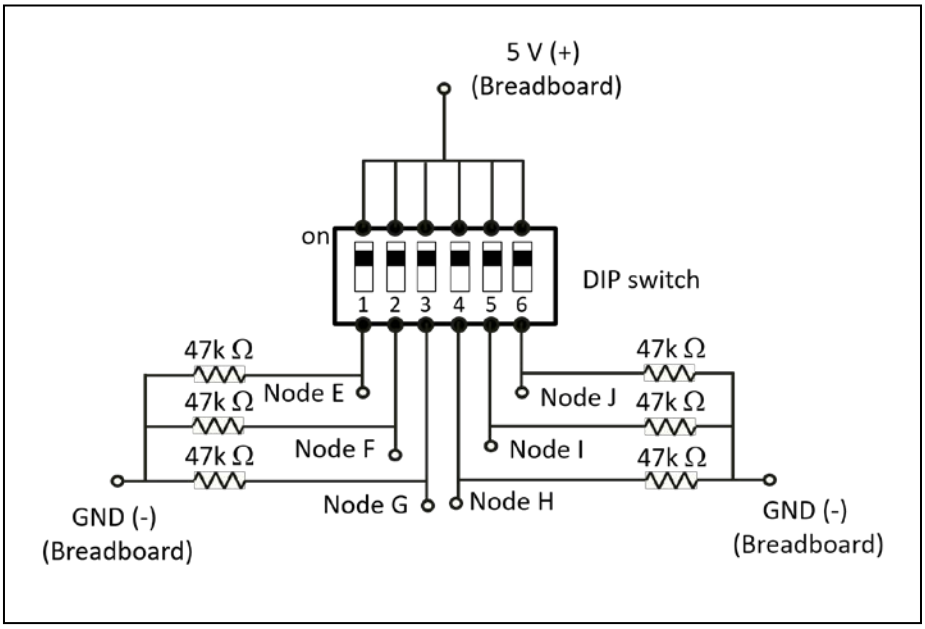

5 V (+)
(Breadboard)
on
DIP switch
1 2 3 4 5 6
47k Ω
47k Ω
47k Ω
Node E
Node F
Node G
Node H
Node I
Node J
47k Ω
47k Ω
47k Ω
GND (-)
(Breadboard)
GND (-)
(Breadboard)

Fig. 25

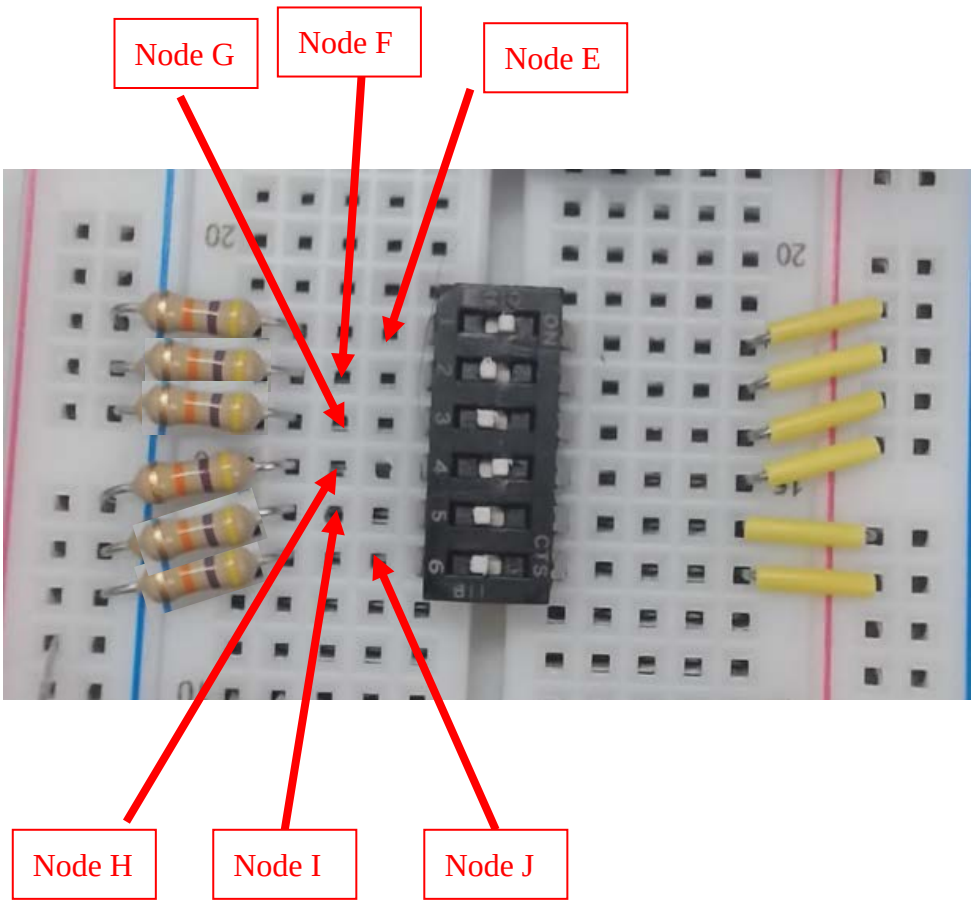

Node G
Node F
Node E
Node H
Node I
Node J

Fig. 26

5.6.7. The 2k ohm resistor and 2k Variable Resistor (VR) are shown in Fig. 27. Connect the threshold voltage circuit as shown in Fig. 28, and put all the components on the breadboard as shown in Fig. 29. You could refer to the video (video12-Threshold_voltage.mp4) for demonstration.

[Check point 7] Adjust the VR3 in Fig. 28 to obtain the voltage at Node K to around 0.4 Volt using the digital multimeter.
You could refer to the video (video13-Adjust_threshold_voltage.mp4) for demonstration.

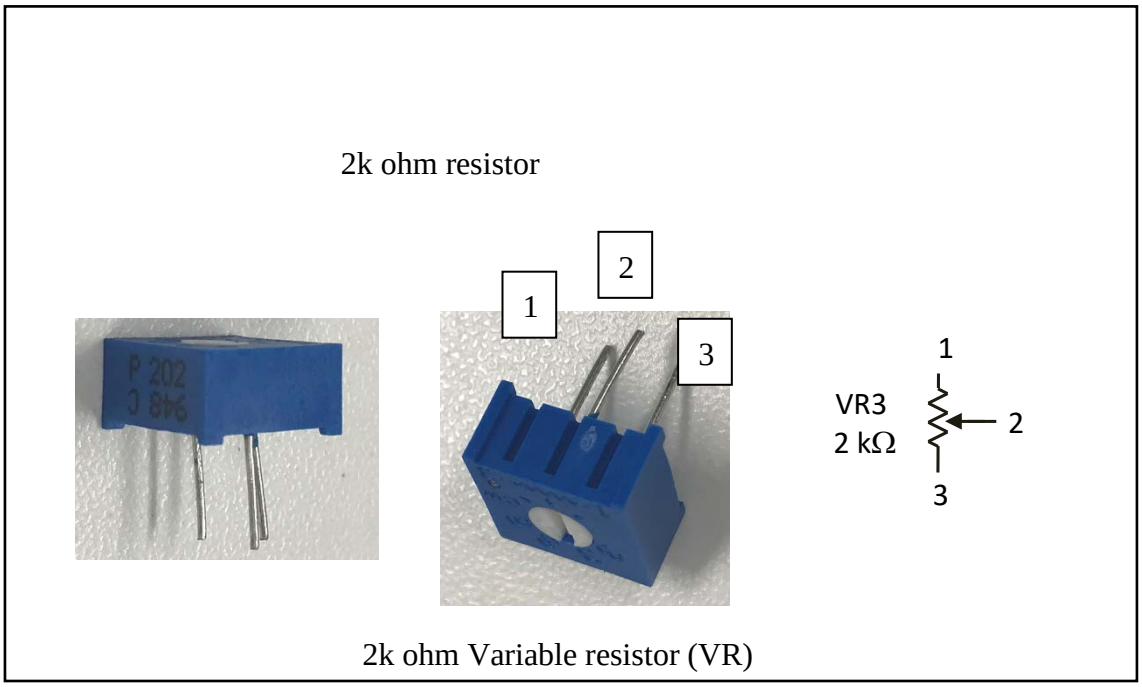


Fig. 27

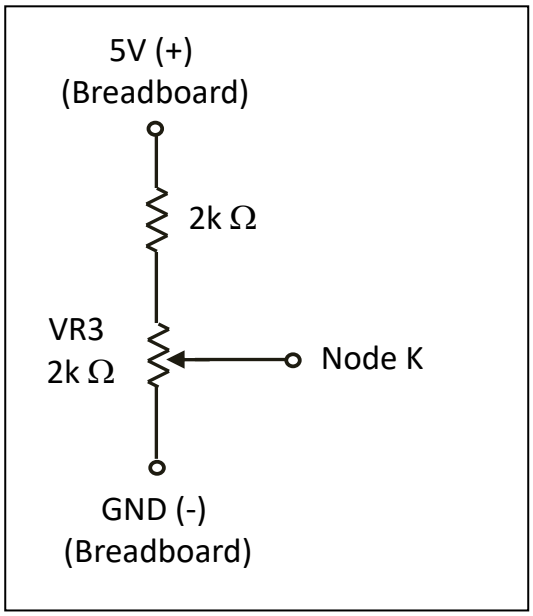


Fig. 28

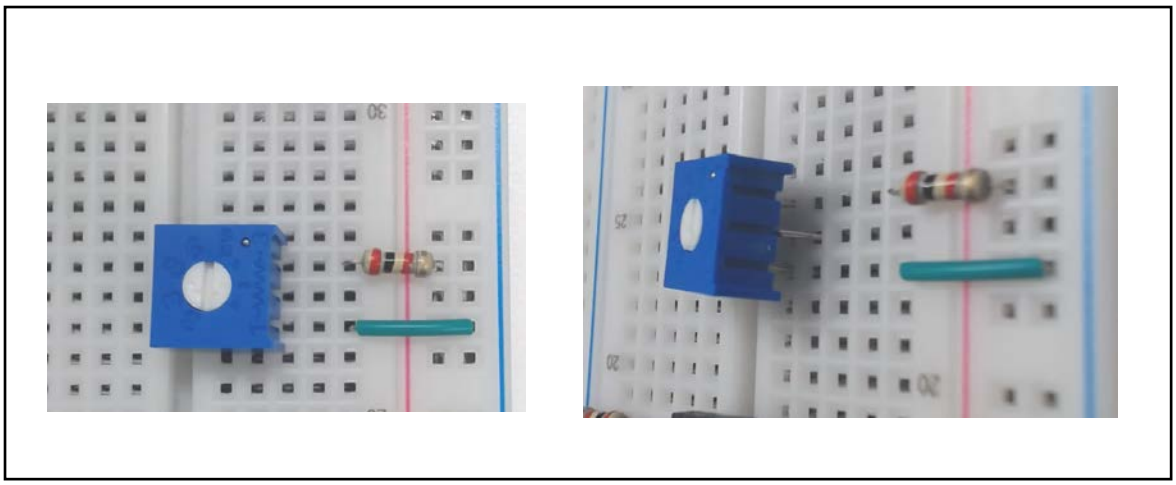


Fig. 29

5.6.8. The L293 motor driver IC is shown in Fig. 30. The motor wiring diagram is shown in Fig. 31. The AA battery compartment is shown in Fig. 32. Connect the motor diver circuit as shown in Fig. 33, and put all the components on the breadboard as shown in Fig. 34 and Fig. 35. You could refer to the video (video14-motor_driver_circuit.mp4) for demonstration.

[Check point 8] Put six AA battery into the battery compartment. Use a wire to connect the Node L in Fig. 33 to 5 V (breadboard), the left wheel will rotate. Use a wire a connect the Node M to 5 V (breadboard), the right wheel will rotate. You could refer to the video (video15-Testing_wheel_rotation.mp4) for demonstration. After finish checking, you should disconnect the battery (+) from the breadboard to save the battery power.

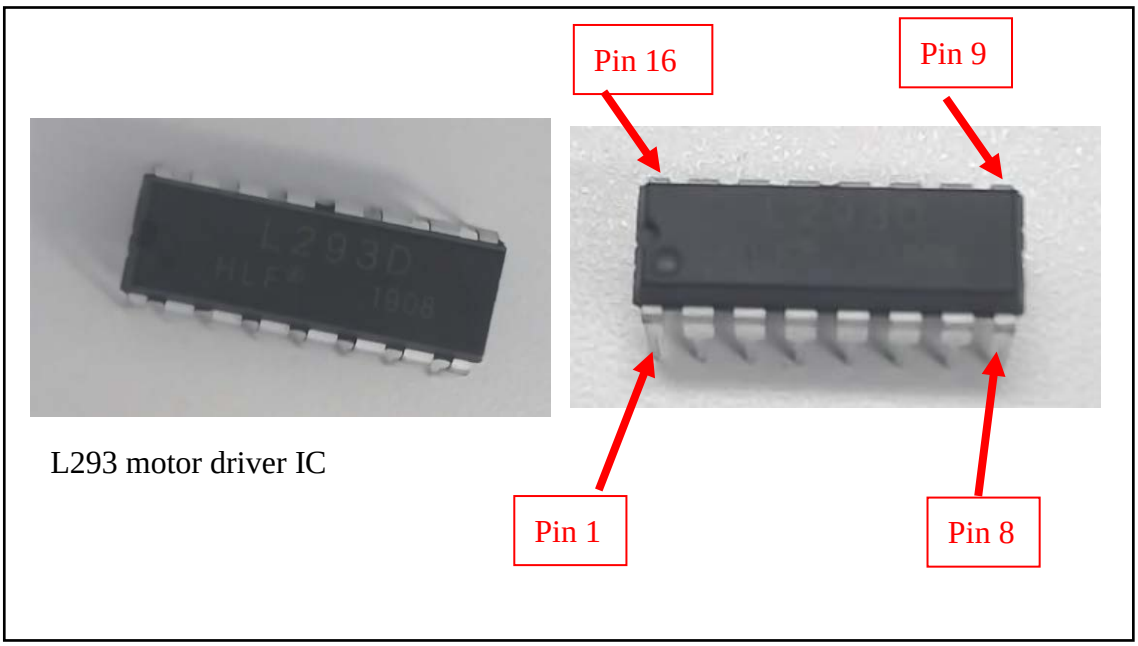


Fig. 30

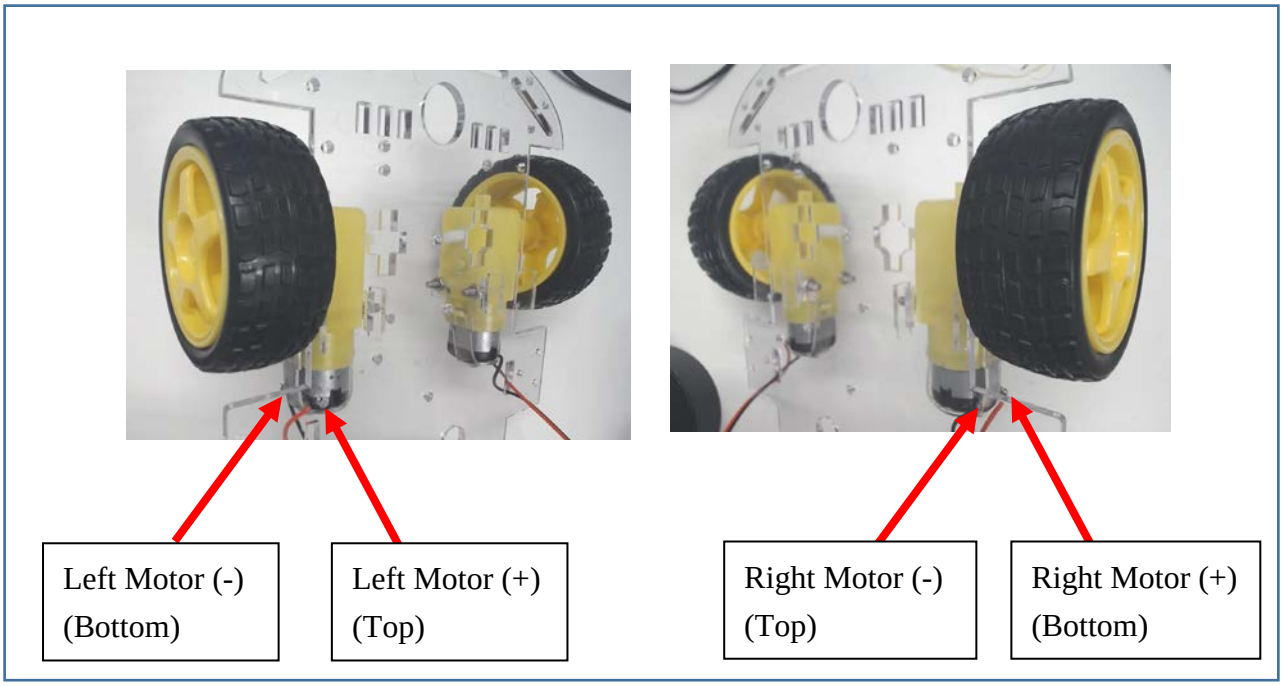

Left Motor (-)
(Bottom)
Left Motor (+)
(Top)
Right Motor (-)
(Top)
Right Motor (+)
(Bottom)

Fig. 31

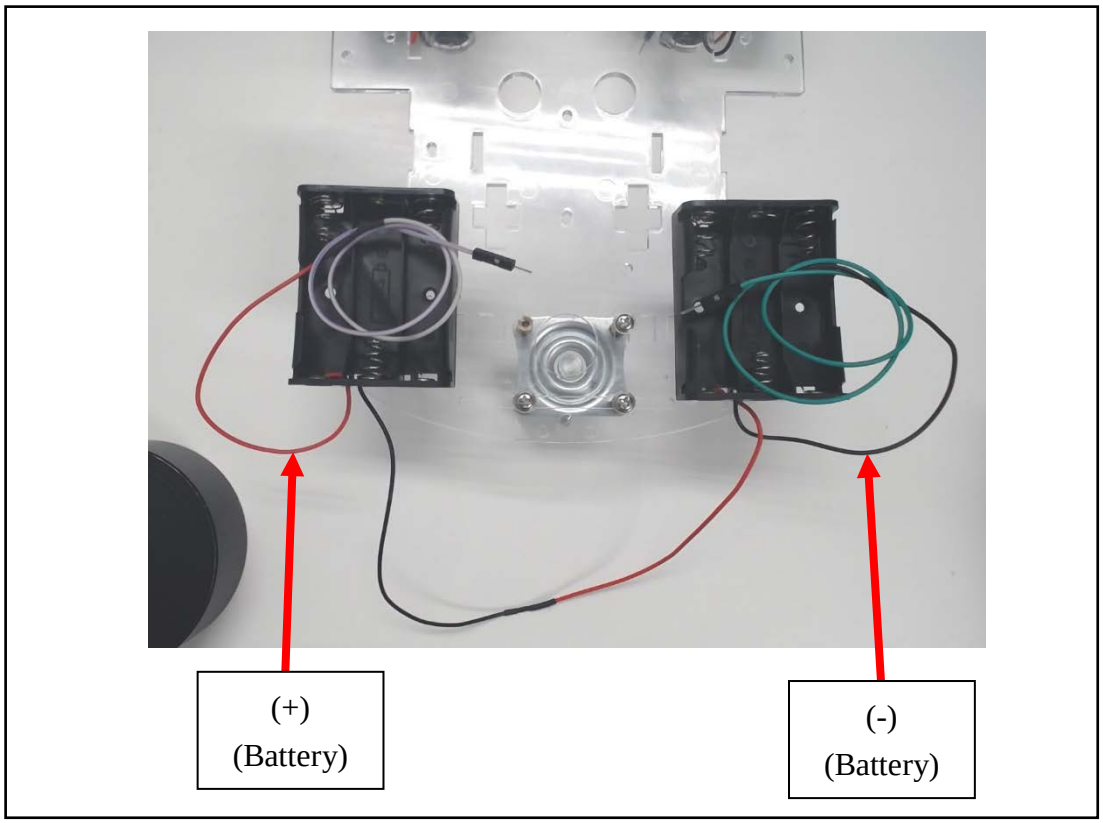

(+)
(Battery)
(-)
(Battery)

Fig. 32

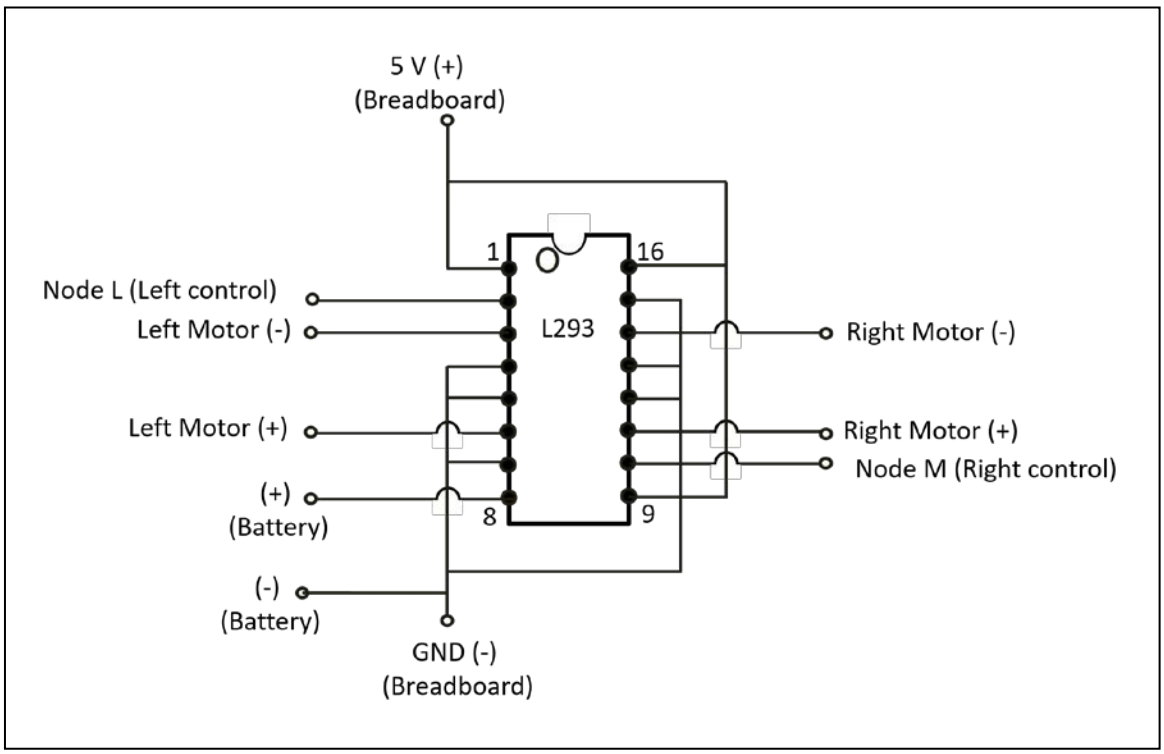

5 V (+)
(Breadboard)
1
16
Node L (Left control)
Left Motor (-)
L293
Right Motor (-)
Left Motor (+)
Right Motor (+)
Node M (Right control)
(+)
(Battery)
8
9
(-)
(Battery)
GND (-)
(Breadboard)

Fig. 33

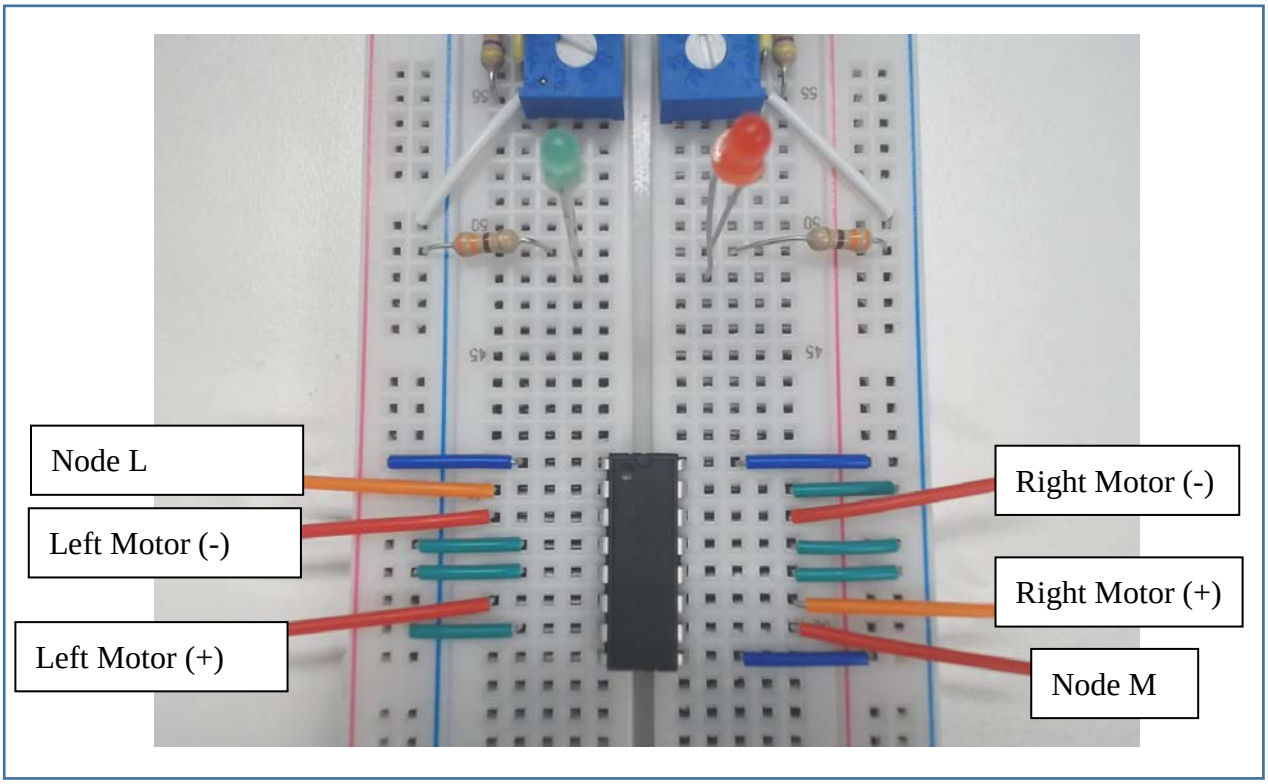

Node L
Left Motor (-)
Left Motor (+)
Right Motor (-)
Right Motor (+)
Node M

Fig. 34

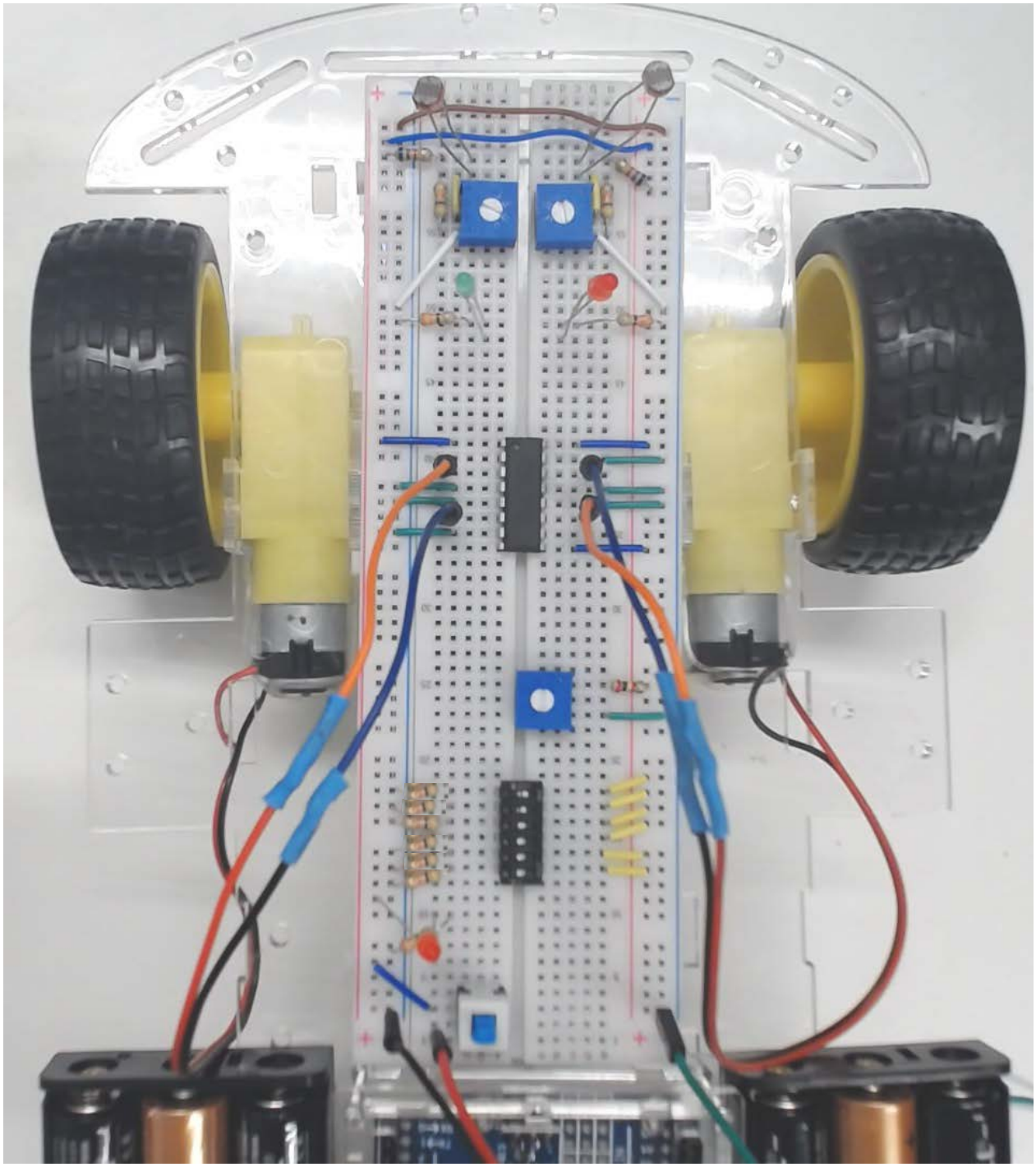


Fig. 35

5.6.9. Connect the LDR circuits to Arduino UNO board, as shown in Fig. 36. Connect the LED circuits to the Arduino UNO board, as shown in Fig. 37. Connect the threshold circuit to Arduino UNO board as shown in Fig. 38. You could refer to the video (video16-LDR_LED_Threshold.mp4) for demonstration.

[Check point 9] Use a flash light pointing at the LDR or use your finger covering the LDR surface to make the LED ON/OFF depending on the difference of the light intensity. You could refer to the video (video17-checking_LDR_LED_Threshold.mp4) for demonstration.

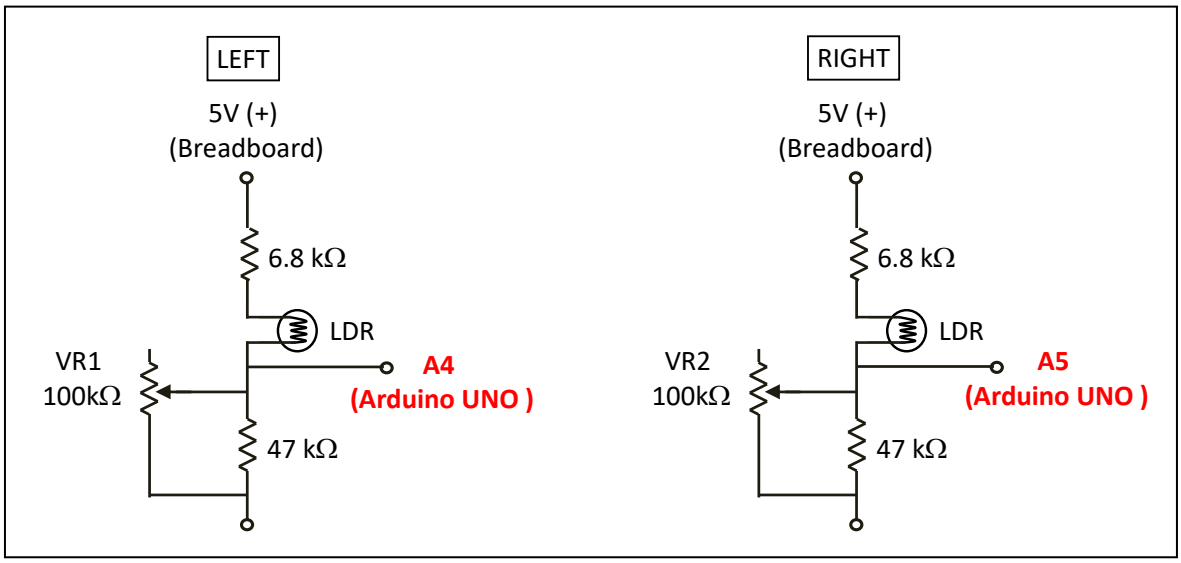


Fig. 36

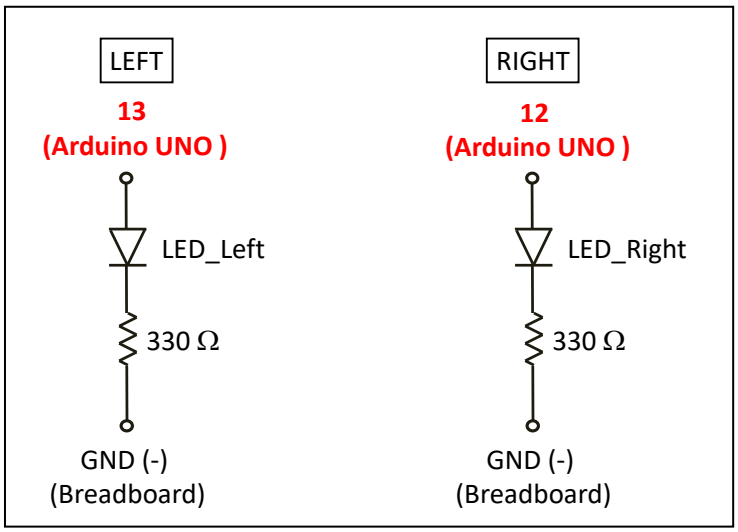


Fig. 37

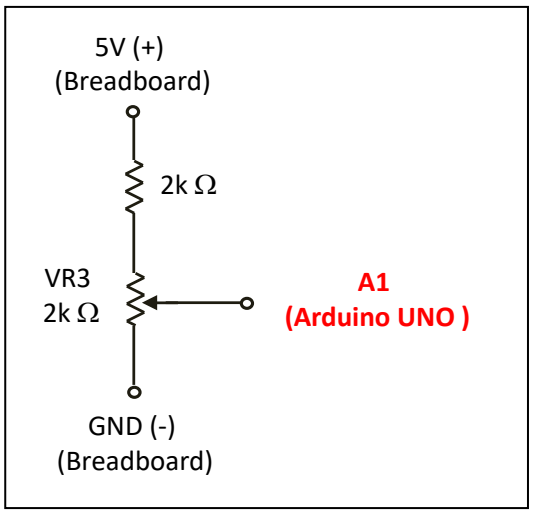


Fig. 38

5.6.10. Connect the DIP switch circuits to Arduino UNO board, as shown in Fig. 39. Connect the motor control circuit to Arduino UNO board, as shown in Fig. 40. You could refer to the video (video18-DIP_motor_control.mp4) for demonstration.

[Check point 10] Use a flash light pointing to the LDR or use your finger covering the LDR surface. If the light source were on the left side, and left side motor would turn slowly to make a left turn. If the light source were on the right side, and right side motor would turn slowly to make a right turn.
You could refer to the video (video19-checking_LDR_motor_control) for demonstration.

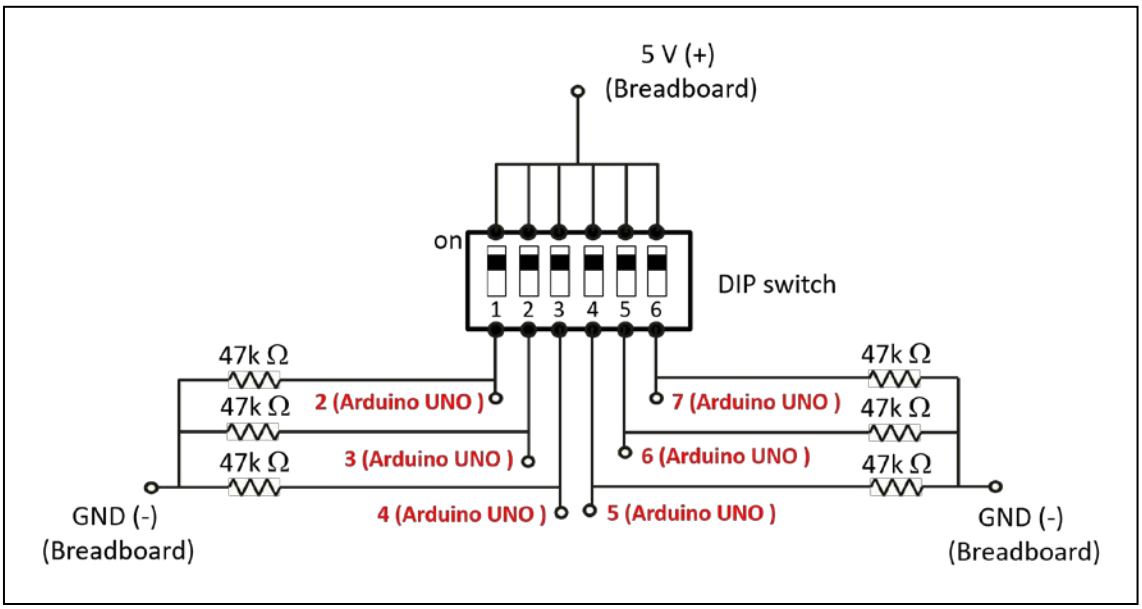


Fig. 39

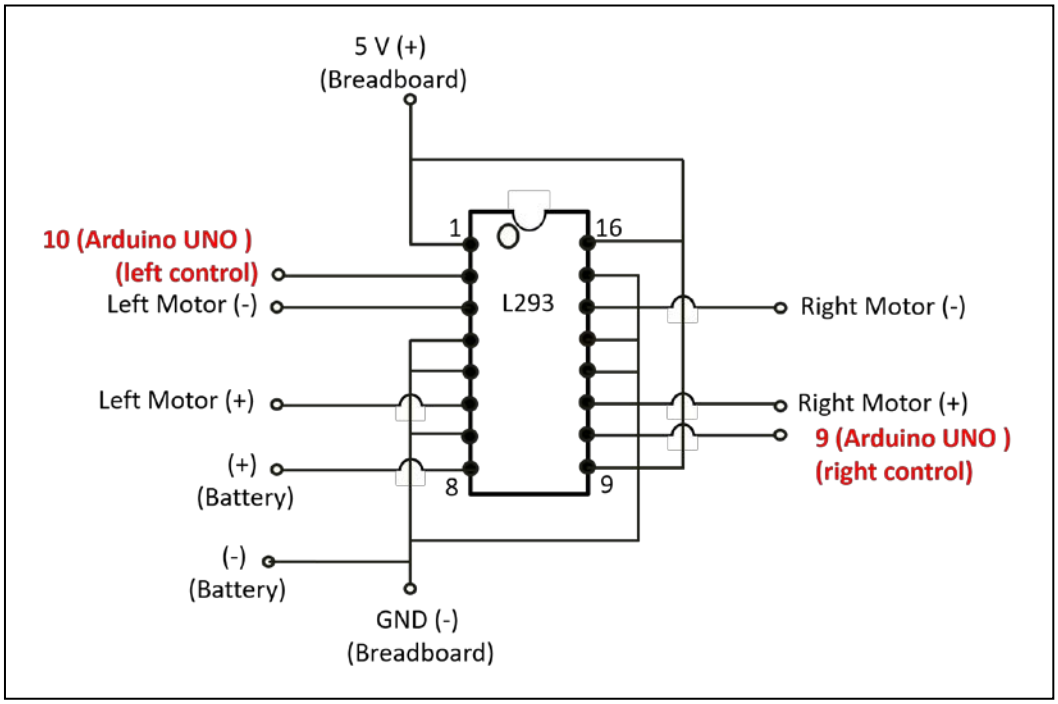


Fig. 40

Q1. Show the complete circuit.

TA Checked (if YES, write down TA's name): _____

Q2. Show the straight-forward movement with two different speed in which the speed can be adjusted by DIP switch.

TA Checked (if YES, write down TA's name): _____

Q3. Show the right-turn movement by adjusting the light intensity at the Light-dependent Resistor (LDR).

TA Checked (if YES, write down TA's name): _____

Q4. Show the left-turn movement by adjusting the light intensity at the Light-dependent Resistor (LDR).

TA Checked (if YES, write down TA's name): _____

--- END ---