LAB 4 – Light-Tracking Car (Analog Control)

1. Objective

This experiment is to design and assemble an analog-controlled light-tracking car. Same as the LAB 3, 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 the sensor circuit, the driver circuit and, in particular, the analog control 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 UNO Broad
g. Digital Multimeter

3. Background Information

The background information of the light-tracking car has been discussed in LAB 3. In this experiment, two Light-Dependent Resistors (LDRs) are also used to sense the light source and the light-tracking car will turn to the direction where guiding light source is located.

Same as the digital-control light-tracking car, the LDRs on the left and right are used to detect the incident light intensity from the left and 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. Similar to the digital-control light-tracking car, the car keeps detecting the incident light intensity from the left and right side of the car. When the difference of the light intensities between the left and right side of the car is small, the car keeps going straight. Otherwise, with large difference of light intensities between two LDRs, the car will turn to the direction with brighter light environment until the difference of the light intensities is returned to a small value. 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. Behavior of the motor under different situation

The rotating speed of the motors in the digital-control light-tracking car is fixed. They either switch ON or OFF to turn the car. However, the rotating speed of the motors in the analog-control light-tracking car is not a constant value. The rotating speed is determined by the light intensity sensed by the LDRs. The motors in the analog-control car are controlled by an analog circuit. The control signals are the two analog voltages: one for controlling left wheel and the other one for controlling right wheel. These two analog voltages are processed in the circuit on the breadboard, and sent to Arduino UNO board, as the inputs of the analog-to-digital converters (ADCs). Two signals from Arduino UNO board directly control the supply voltage of the left driver circuit and right driver circuit and accordingly control the rotating speed of

the left wheel and the right wheel. The operation of right-turn, left-turn and straight-ahead, are summarized in the following tables.

When the light intensity is uniform around the path,

	Light Intensity	Resistance of LDR	Input of ADC	Rotating speed of wheel	Operation of motor
Left	Uniform	Almost the same	Same	Same	Go straight ahead
Right					

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

	Light Intensity	Resistance of LDR	Input of ADC	Rotating speed of wheel	Operation of motor
Left	stronger	smaller	smaller	slower	Turn left
Right	weaker	larger	larger	faster	

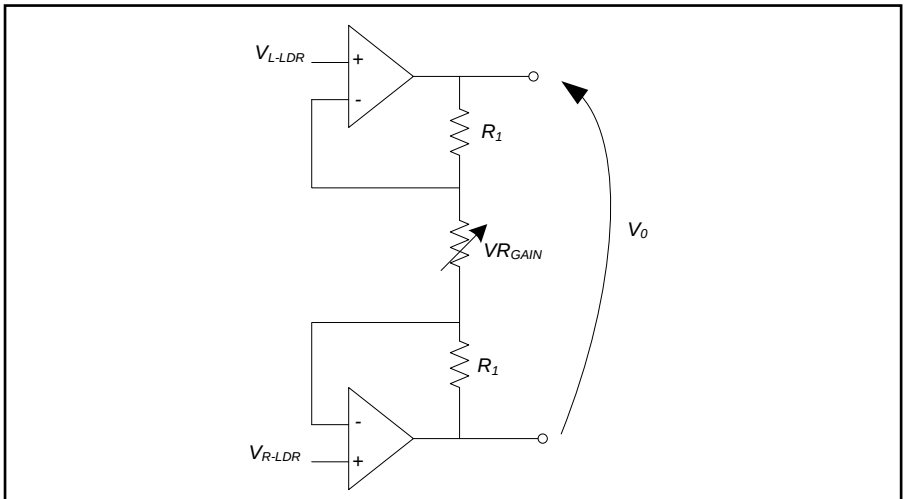
When the light source is on the right side of the path,

	Light Intensity	Resistance of LDR	Input of ADC	Rotating speed of wheel	Operation of motor
Left	weaker	larger	larger	faster	Turn right
Right	stronger	smaller	smaller	slower	

3.2. Sensitivity calibration

The sensitivity of the motor needs to be calibrated. If the control circuit is too sensitive to light, the difference of rotating speed will be too large even if the light intensity difference is actually small. The car will make sharp turns and proceed with a zigzag path. In contrast, if the motor is too insensitive to light, it always keeps moving straight ahead. Hence, we have to calibrate its sensitivity so that the motor reacts properly to light intensity difference.

The sensitivity can be calibrated by the gain of a differential amplifier. The differential amplifier used in our control circuit to control the gain is shown in Fig. 1. The resistor VR_{GAIN} decides the gain of the differential amplifier; hence it is directly related to the sensitivity. In our experiment, VR_{GAIN} is a variable resistor. You are required to adjust its value for calibration.

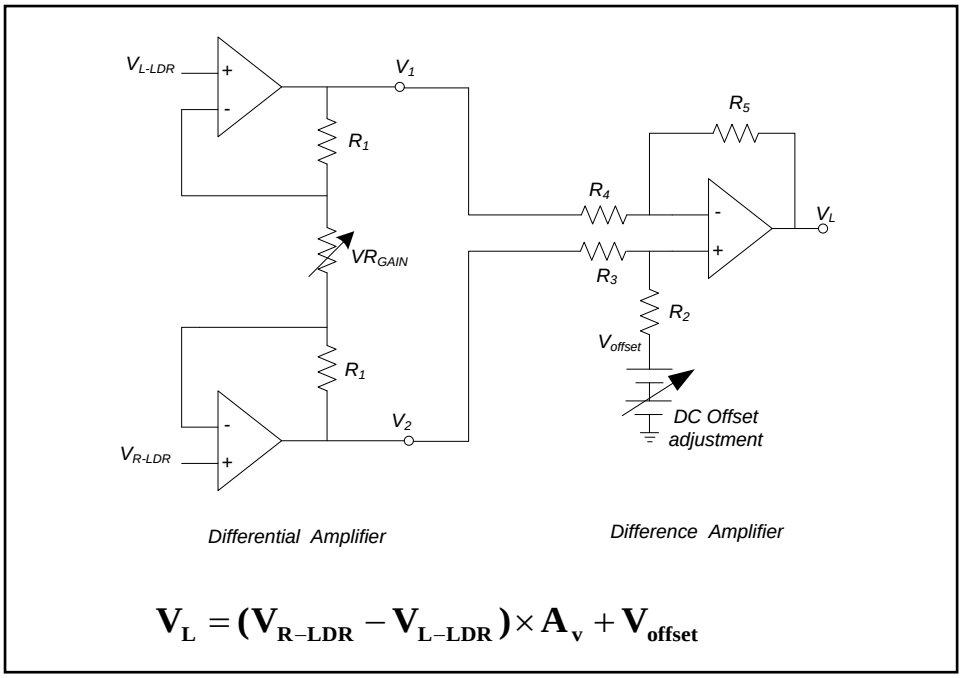


$$V_O = I \times (VR_{GAIN} + 2R_1) = (V_{R-LDR} - V_{L-LDR})(1 + \frac{2R_1}{VR_{GAIN}})$$

Fig. 1

3.3. Normal speed of the motor

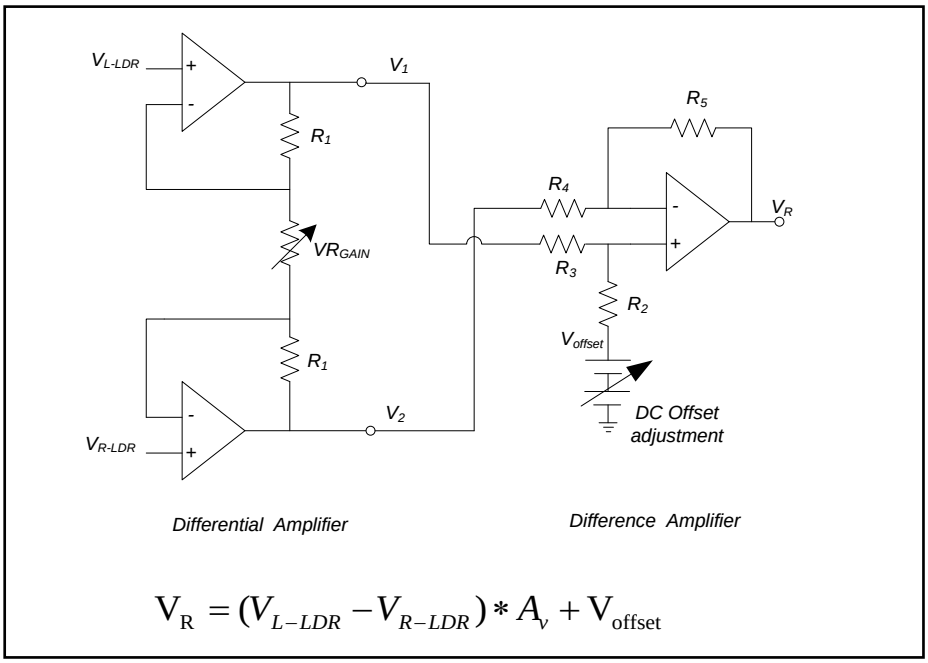
The rotating speed of wheels is controlled by their respective supply voltage, which is decided by the input signals of ADC - V_L for the left side and V_R for the right side. Fig. 2 shows the circuit that generates V_L.



$$\mathbf{V_L = (V_{R-LDR} - V_{L-LDR}) \times A_v + V_{offset}}$$

Fig. 2

As shown in Fig. 2, the left part of the circuit is exactly the same as the circuit in Fig. 1, which is a differential amplifier. The right part is a difference amplifier. V_1 is connected to the negative input of difference amplifier in the next stage and V_2 is connected to the positive input. The difference amplifier uses the differential output voltage generated by the left part to get the difference of the input voltages and also have adjustable voltage gain and adjustable DC Voltage offset. Fig. 3 shows the circuit that generates V_R.



$$V_R = (V_{L-LDR} - V_{R-LDR}) * A_v + V_{offset}$$

Fig. 3

The DC offset adjustment is implemented by a variable resistor (VR), as shown in Fig. 4.

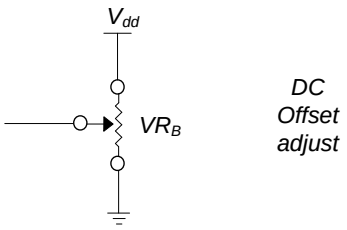


Fig. 4

Circuits in Fig. 2 and 3 shares the differential amplifier in the left part but have their own difference amplifiers. In Fig. 3, V_1 is sent to the positive input of difference amplifier in the next stage and V_2 is sent to the negative input.

$$A_v = \frac{2R_1 + VR_{gain}}{VR_{gain}} \times \frac{R_5}{R_4}$$

Adjustable gain is achieved by variable resistor VR_{gain}. V_{offset} is variable voltage to set the DC offset adjusted by VR_B. When $V_{L\text{-}LDR}$ equals to $V_{R\text{-}LDR}$, the output voltage is V_{offset}. Hence we can decide the normal speed of the car by adjusting VR_B. By increasing $V_{offset,}$ the normal speed is increased accordingly and vice versa.

4. Prelab

4.1 Read the background information carefully.
4.2 Complete session 5.1 to 5.6.
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 with the USB power bank (not provided) as shown in Fig. 5.

5.1.2 You should unplug the USB from the Arduino UNO board all the time as shown in Fig. 6. 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. 7. In the manual, it would mention to you, and marked on the top of the page, when you should put the battery into the battery compartment.

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 demonstration.

5.1.5 There is a power LED shown in Fig. 11, 12, 13 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/TO 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/TO immediately.

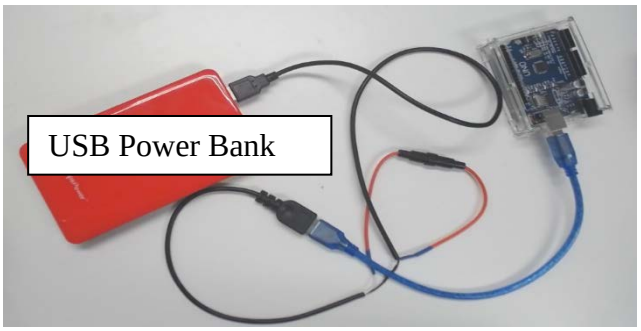


Fig. 5

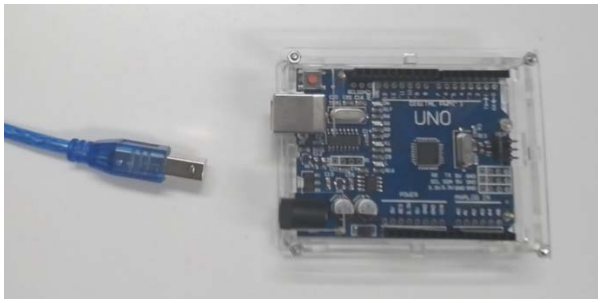


Fig. 6

Fig. 7

5.2 Construct the circuits

5.2.1. Put breadboard and the Arduino UNO labelled as "4" on the car board as shown in Fig. 8.

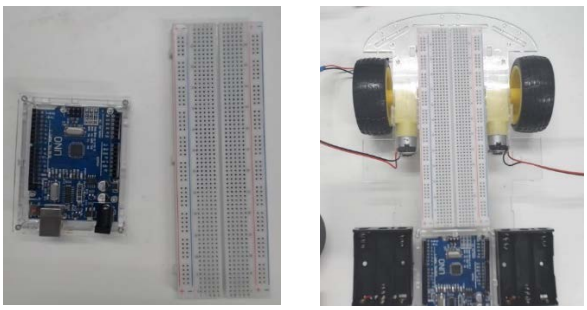


Fig. 8

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.

5.2.2. The power switch, LED, and 330 ohm resistor are shown in Fig. 9. The USB fuse extension cable is shown in Fig. 10(a). For safety, we have to use the USB fuse extension cable to power up the Arduino UNO board as shown in Fig. 10(b). You could cut down the resistor legs if you want as shown in Fig. 11. Connect power switch with the LED indication, the circuit shown in Fig. 12, and put all the components on the breadboard as shown in Fig. 13, Fig. 14, and Fig. 15. You could refer to the video (video3-power_switch.mp4) for demonstration.

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

[WARNING] You have to use the fuse USB shown in Fig. 10(b) for power up the Arduino UNO board. From now on, if the power switch is pressed, the LED is OFF at any time. You have to immediately switch off the power switch and check the circuit connection. You could also check whether the VDD and GND are shorted by using multimeter.

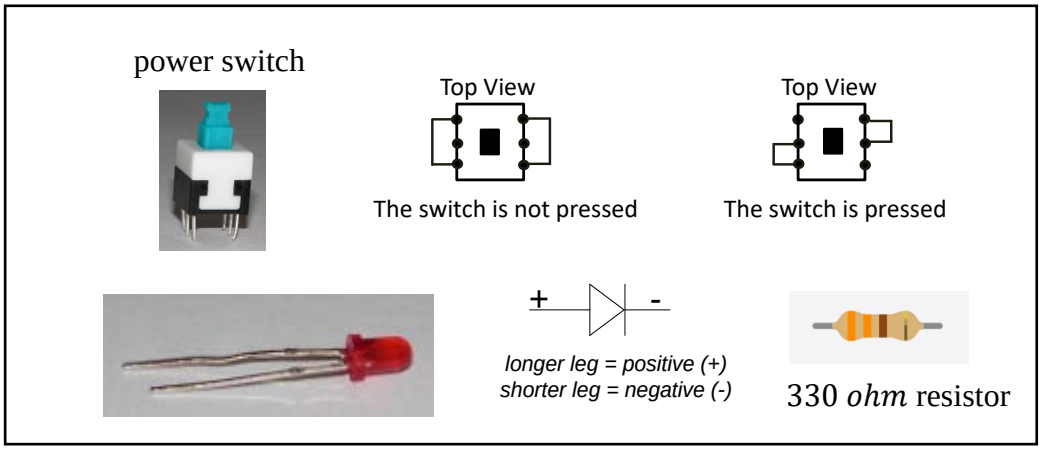
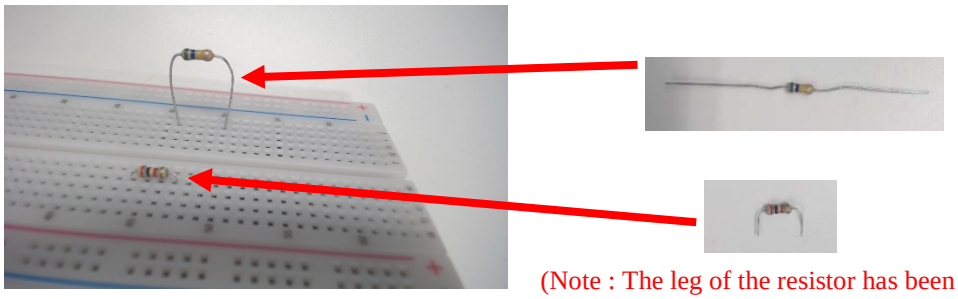


Fig. 9

(a) (b)

Fig. 10

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.



(Note : The leg of the resistor has been cut down.)

Fig. 11

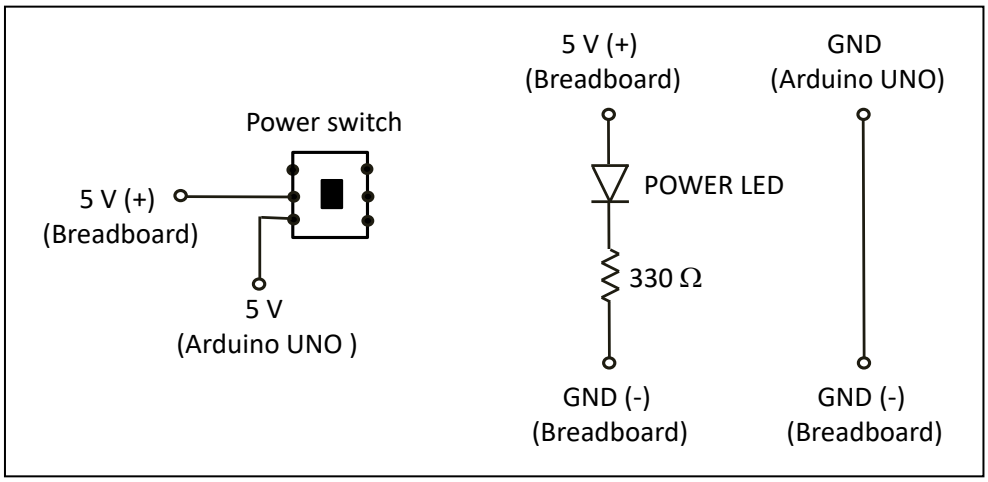
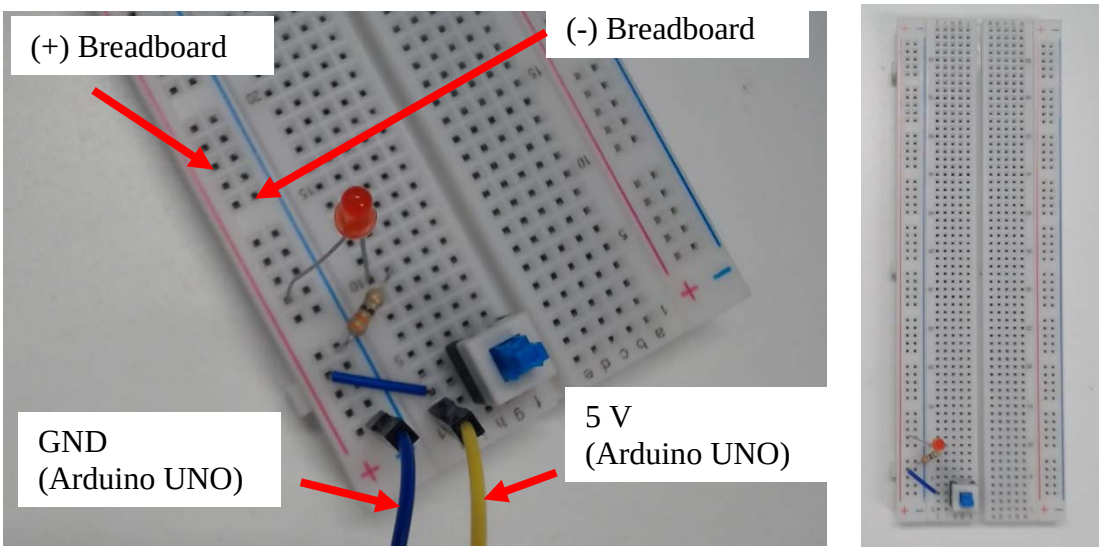


Fig. 12



(Note : The leg of the resistor has been cut down.)

Fig. 13

Note : **Disconnect / Connect** USB plug from Arduino UNO, **No battery** in battery compartment.

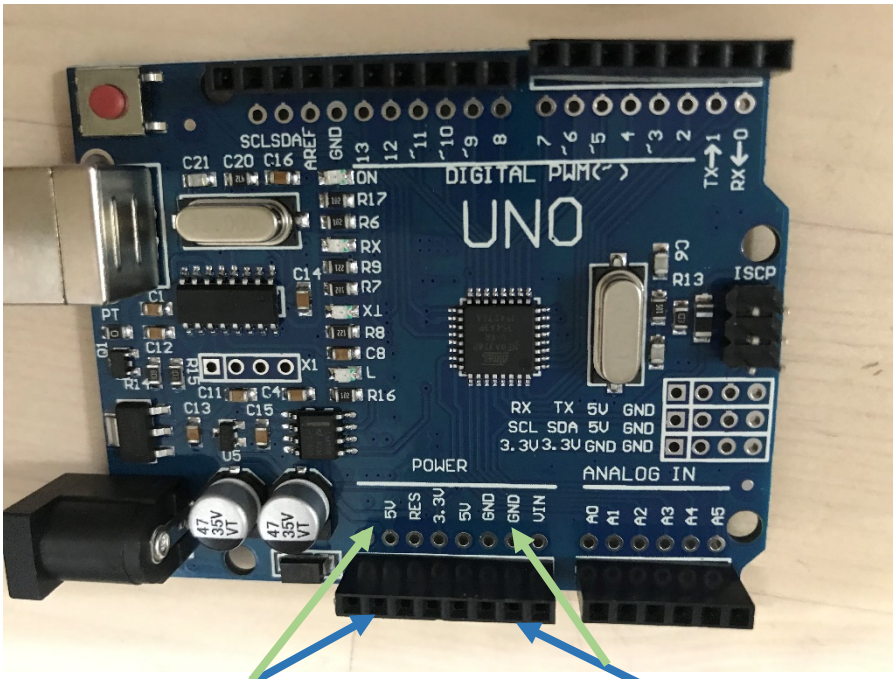


Fig. 14

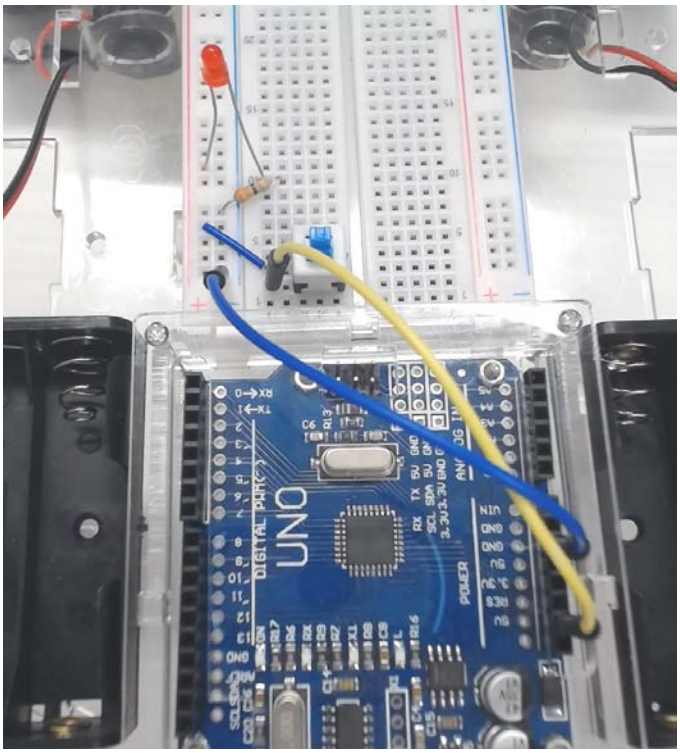


Fig. 15

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.

5.2.3. On the breadboard, connect both "+" columns together, and connect both "-" columns together as shown in Fig. 16 and Fig 17. As such, both "+" columns are connected to 5V, and both "-" columns are connected to ground (0 V), as shown in Fig. 18.

[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

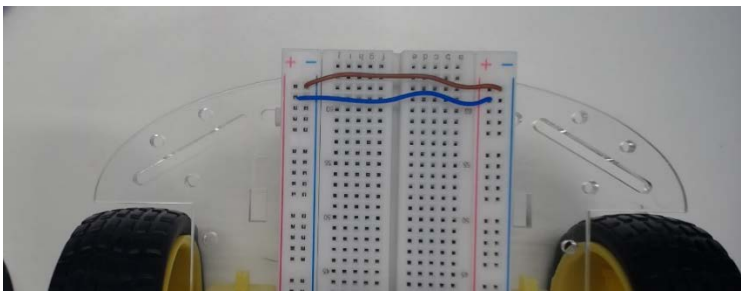


Fig. 16

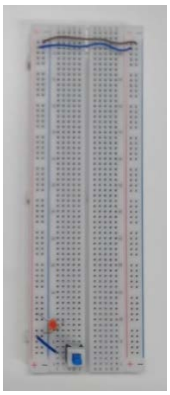


Fig. 17

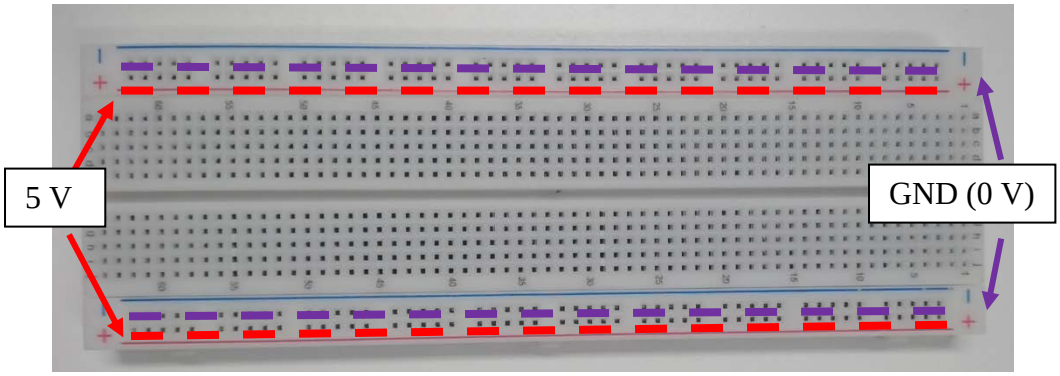


Fig. 18

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.

5.2.4. The 6.8k ohm resistor, 47k ohm resistor, 100k ohm variable resistor (VR), and LDR (Light-dependent Resistor) are shown in Fig. 19. Connect LDR circuit shown in Fig. 20, and put all the components on the breadboard as shown in Fig. 21, 22, and 23. 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 1.6 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.

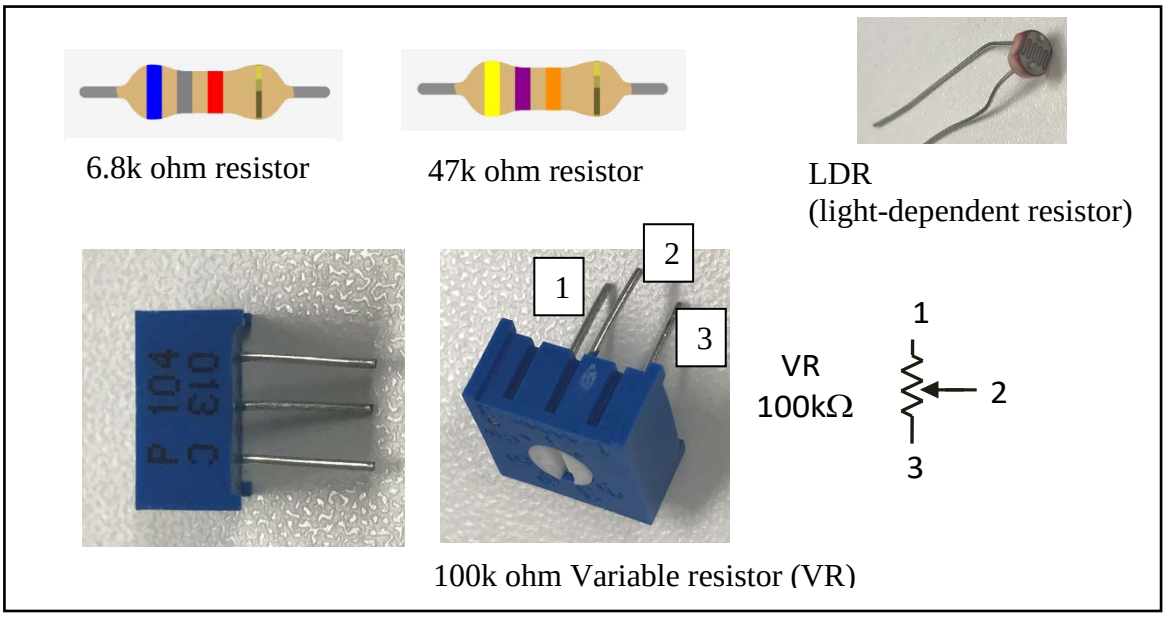


Fig. 19

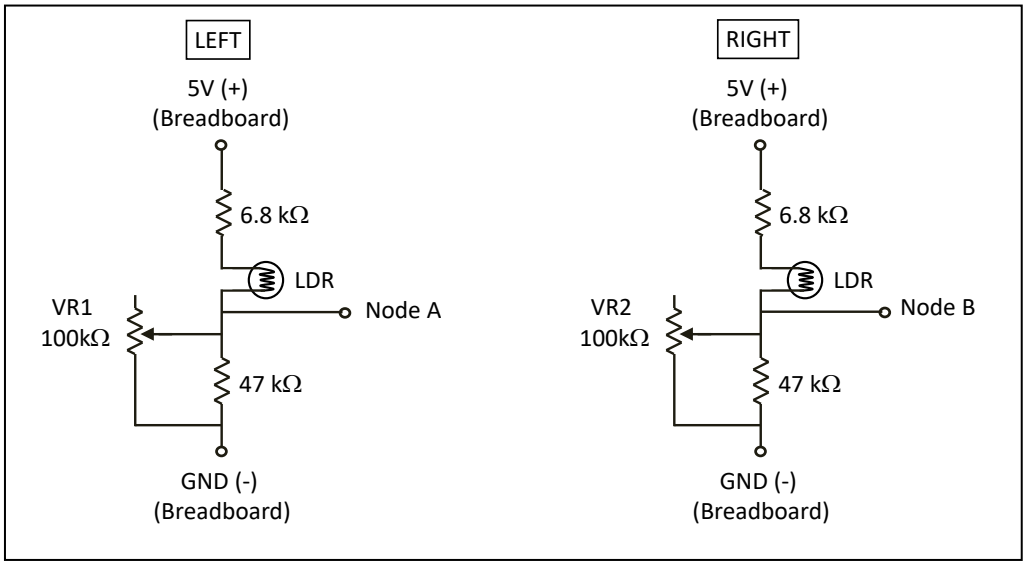
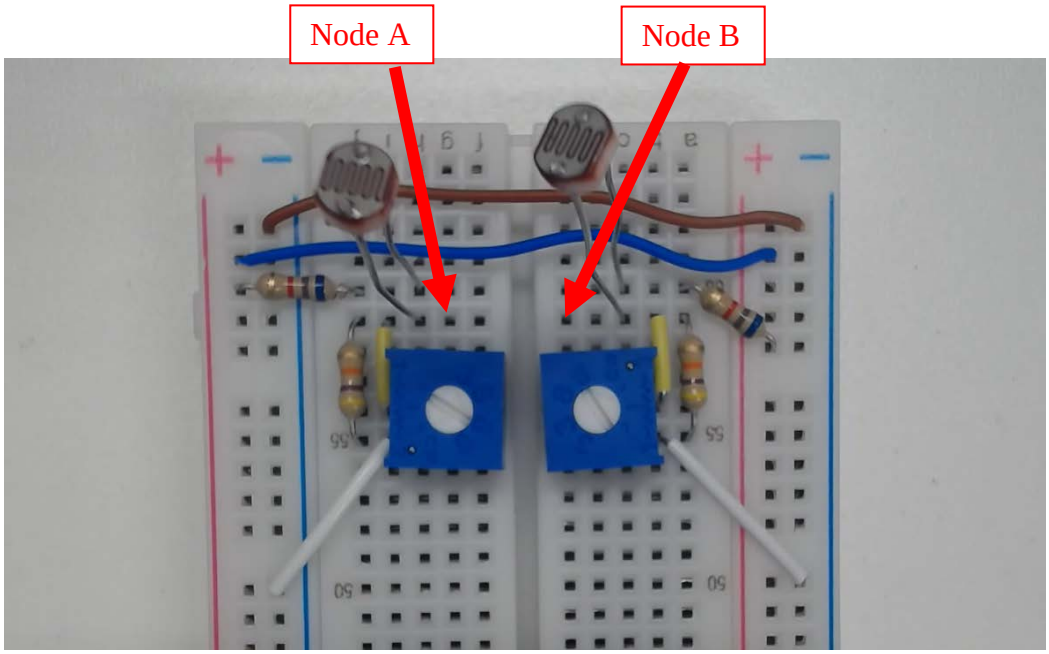


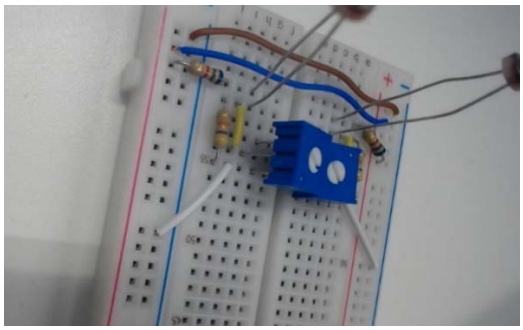
Fig. 20

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.



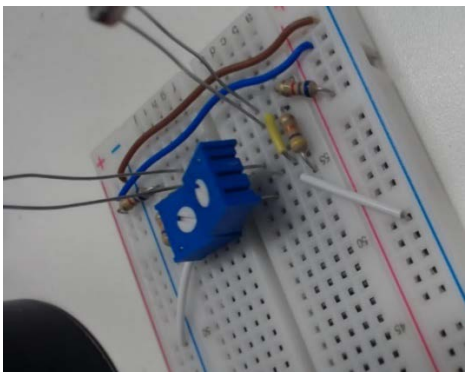
(Note : The leg of the resistor has been cut down.)

Fig. 21



(Note : The leg of the resistor has been cut down.)

Fig. 22



(Note : The leg of the resistor has been cut down.)

Fig. 23

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.

5.2.5. Connect the Left and Right LED indicator circuit shown in Fig. 24, and put all the components on the breadboard as shown in Fig. 25. 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.

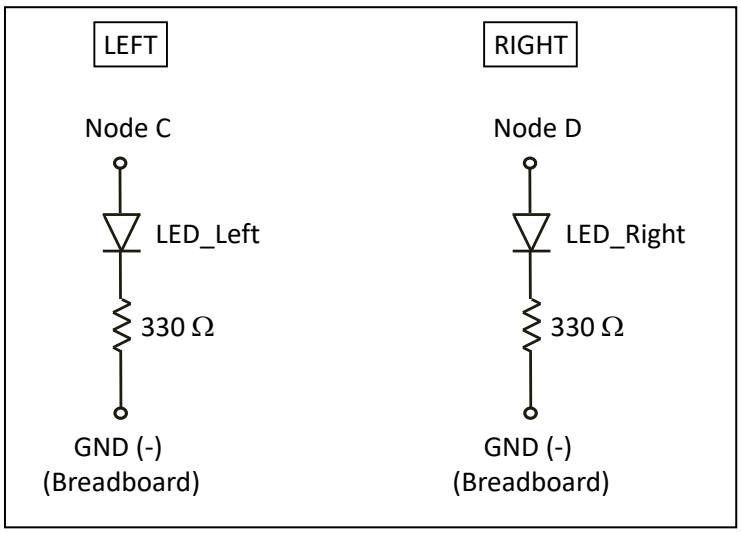
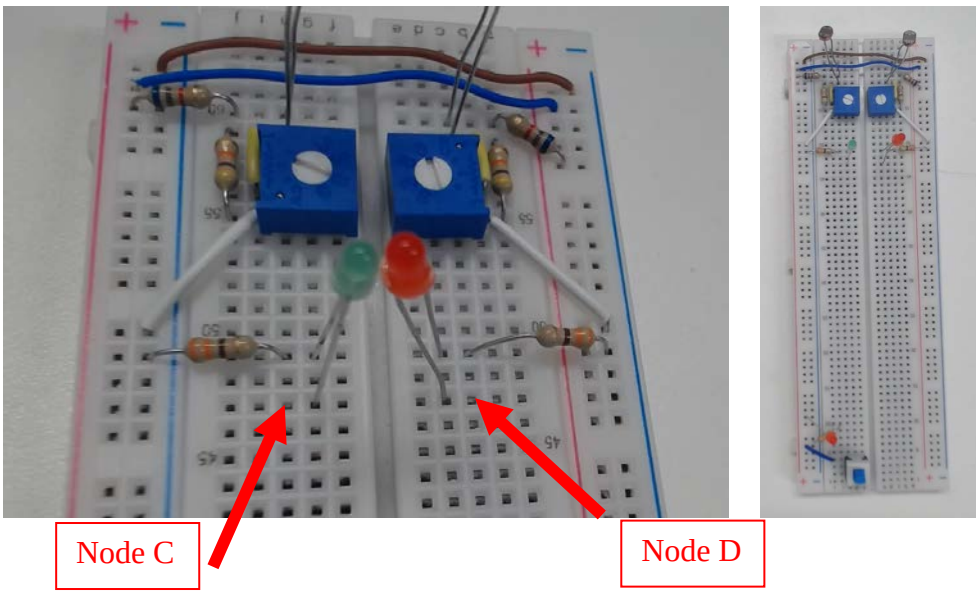


Fig. 24



(Note : The leg of the resistor has been cut down.)

Fig. 25

Note : Disconnect / Connect USB plug from Arduino UNO, **Keep Battery** in battery compartment.

5.2.8. The L293 motor driver IC is shown in Fig. 26. The motor wiring diagram is shown in Fig. 27. The AA battery compartment is shown in Fig. 28. Connect the motor diver circuit as shown in Fig. 29, and put all the components on the breadboard as shown in Fig. 30 and Fig. 31. You could refer to the video (video10-motor_driver_circuit.mp4) for demonstration.

[Check point 6] Put six AA battery into the battery compartment. Use a wire to connect the Node L in Fig. 29 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 (video11-Testing_wheel_rotation.mp4) for demonstration. After finish checking, you should disconnect the battery (+) from the breadboard, and take out the battery from battery compartment.

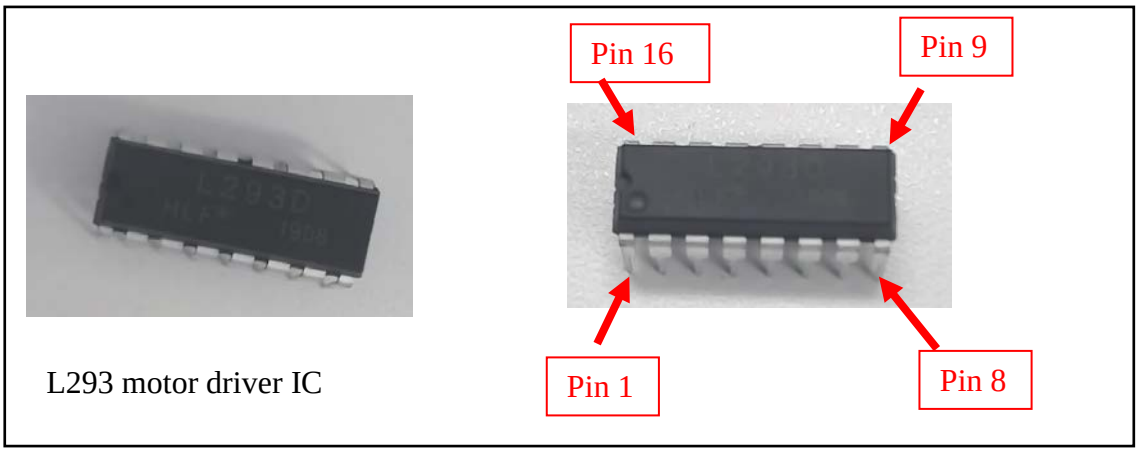


Fig. 26

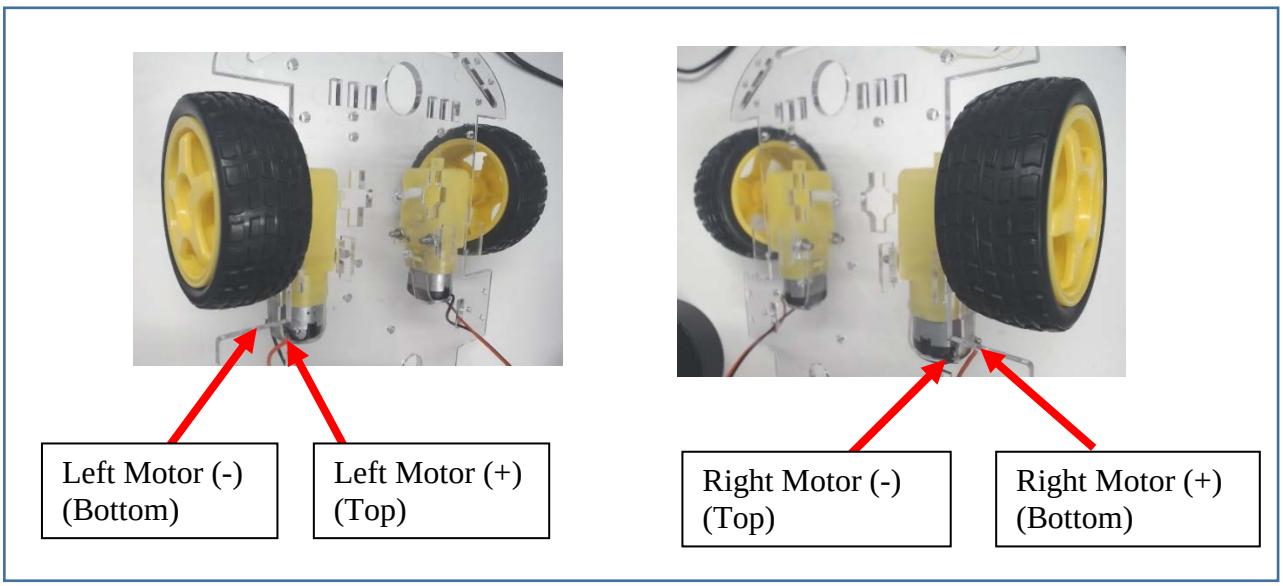


Fig. 27

Note : **Disconnect / Connect** USB plug from Arduino UNO, **Keep Battery** in battery compartment.

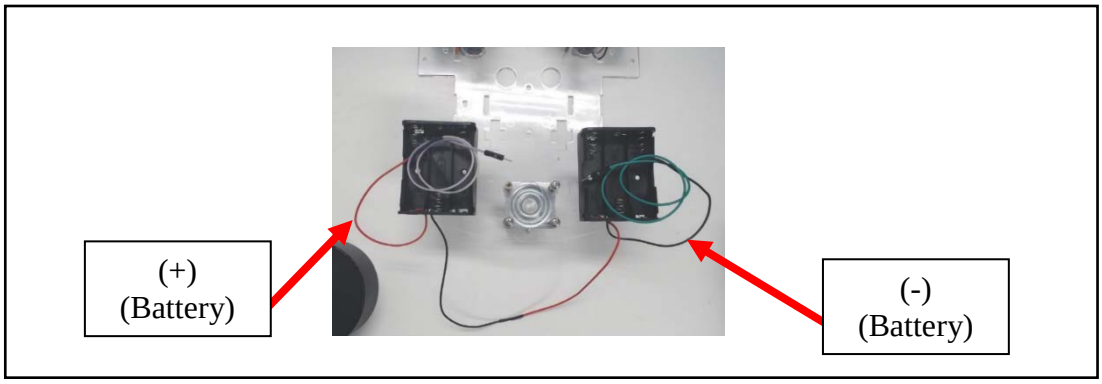


Fig. 28

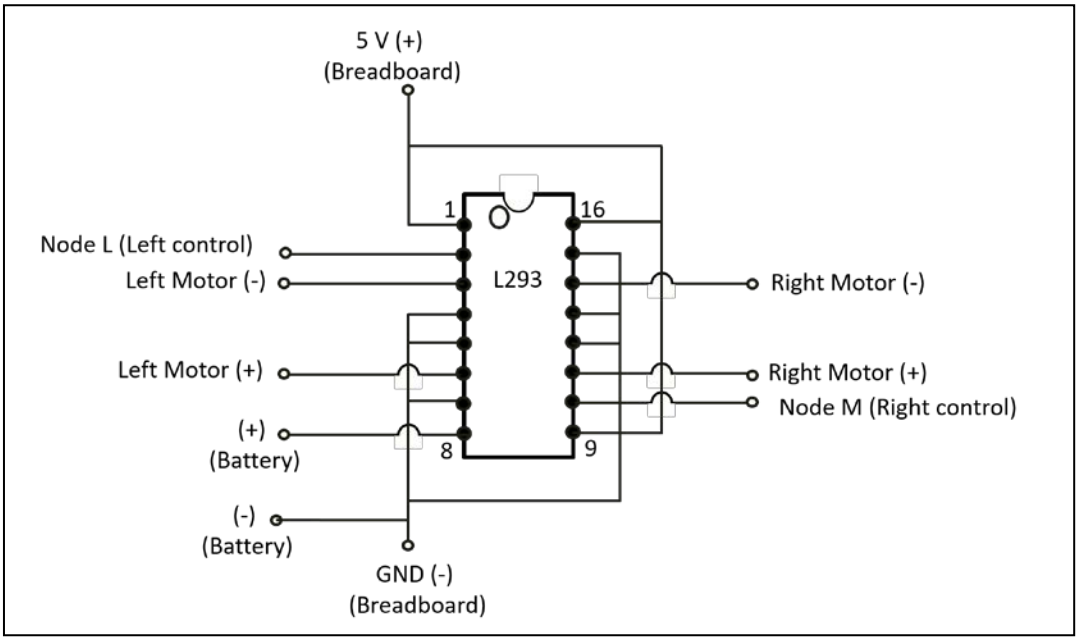
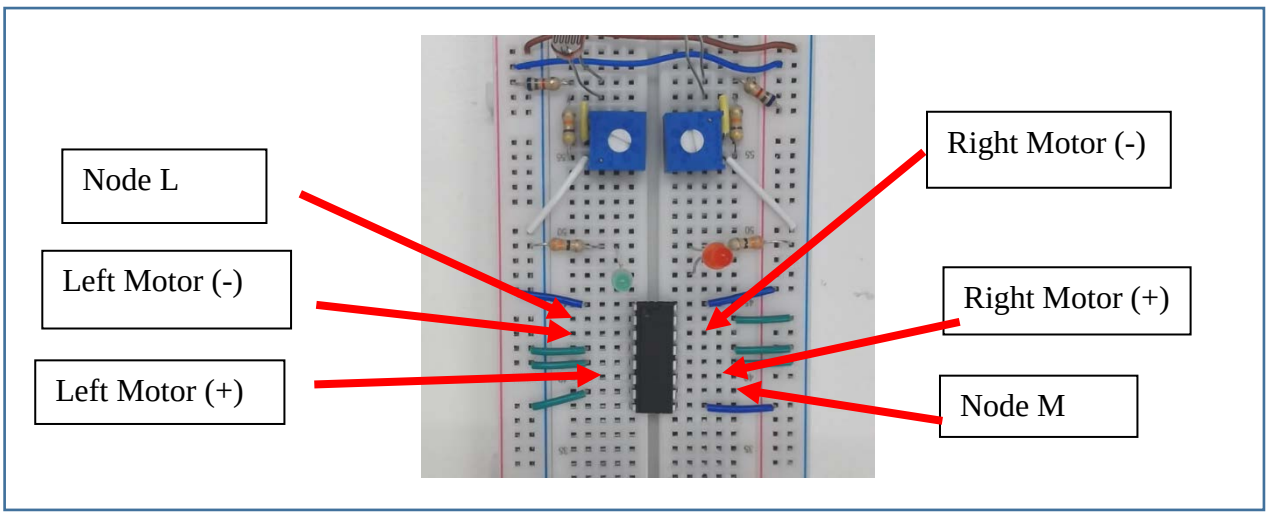


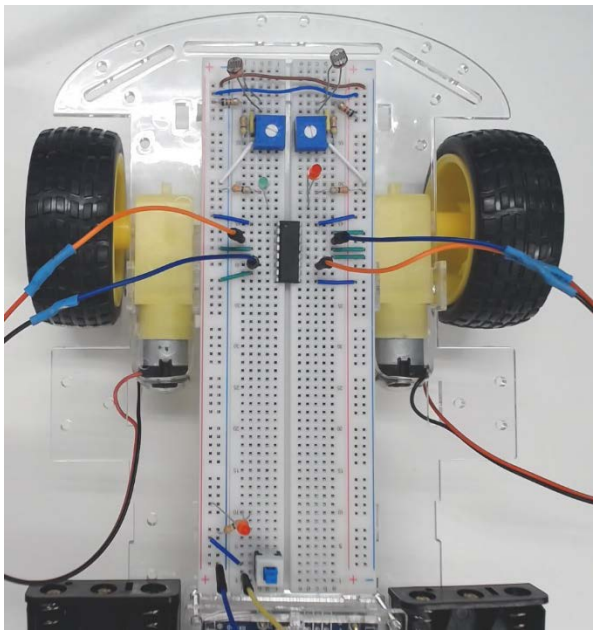
Fig. 29



(Note : The leg of the resistor has been cut down.)

Fig. 30

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.



(Note : The leg of the resistor has been cut down.)

Fig. 31

5.2.9. The LM324 (4 x op amps IC) is shown in Fig. 32. Connect the amplifier circuit 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 (video12-amplifier_circuit.mp4) for demonstration.

[Check point 7] Power up the Arduino UNO board with USB power bank. Turn the variable resistor VR_{gain} to the middle position. Adjust VR_{offset} to achieve Node K to be 2.5 V. You could refer to the video (video13-offset_voltage_tunning.mp4) for demonstration.

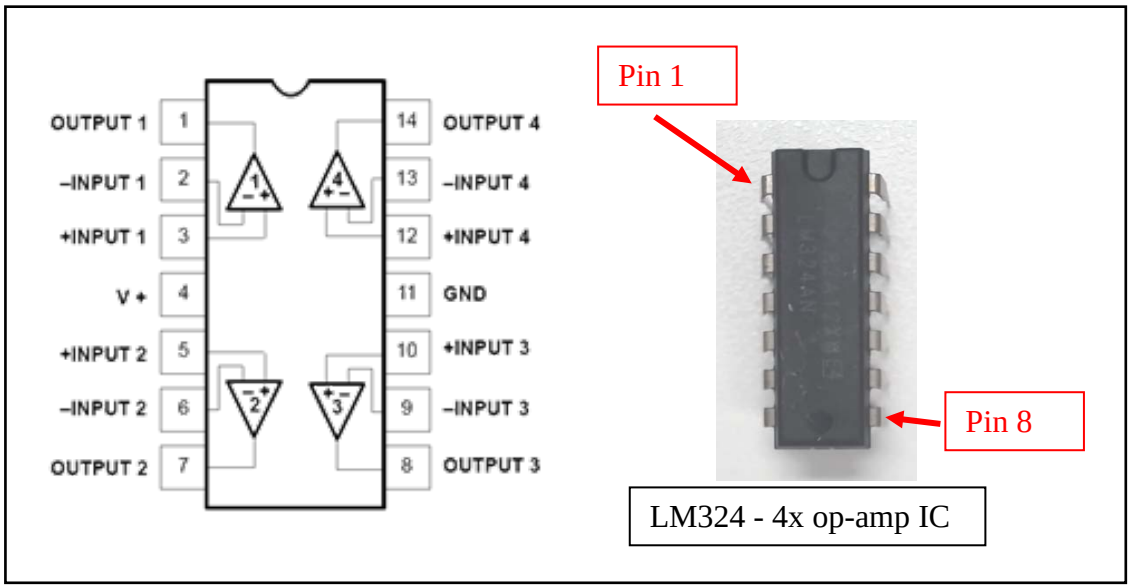
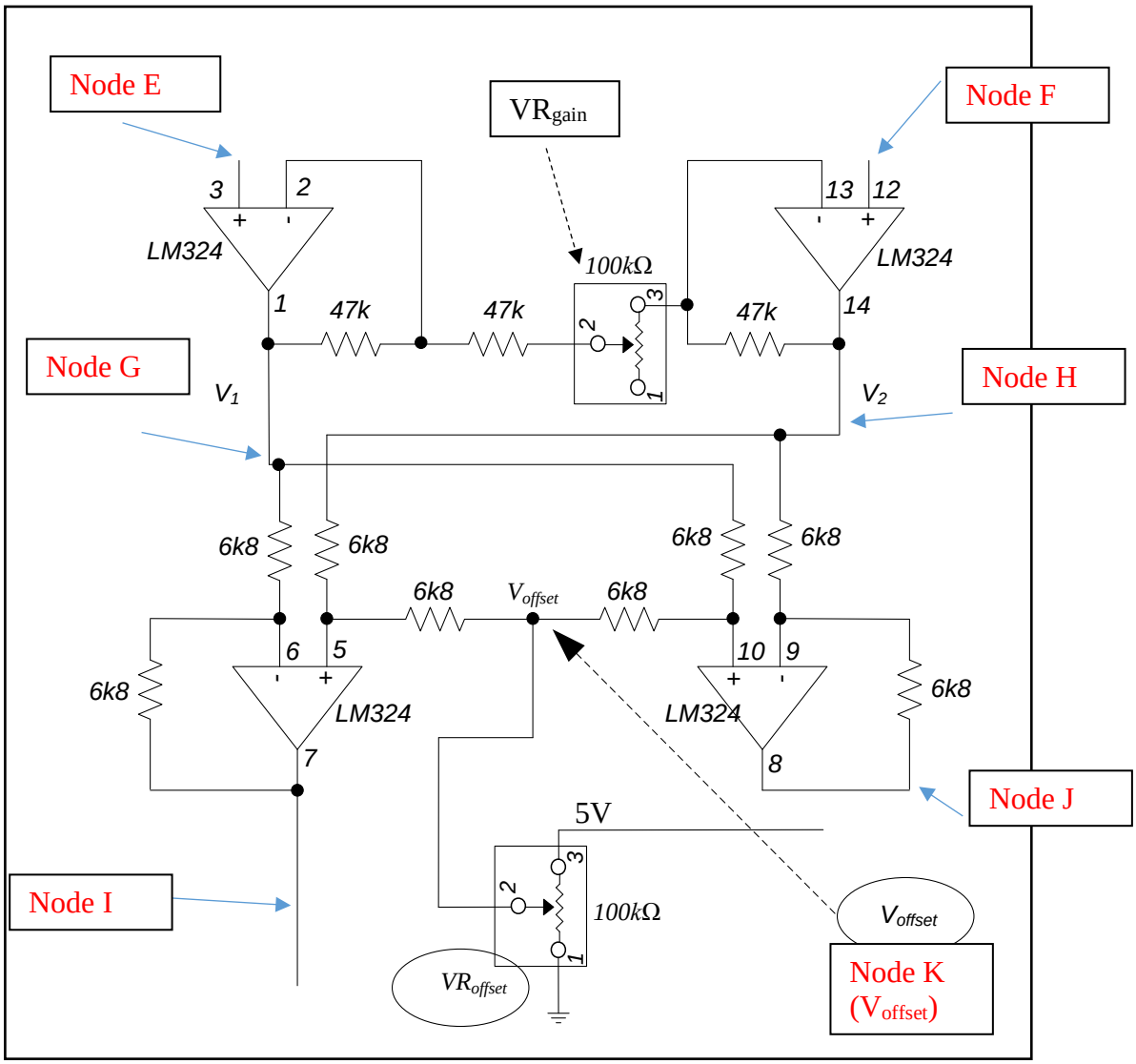


Fig. 32

Note : Disconnect / Connect USB plug from Arduino UNO, **No battery** in battery compartment.

Connect pin 4 (LM324) to 5V, connect pin 11 (LM324) to Gnd



Using LM324 (4 x opamp IC)

Fig. 33

Note : **Disconnect / Connect** USB plug from Arduino UNO, **No battery** in battery compartment.

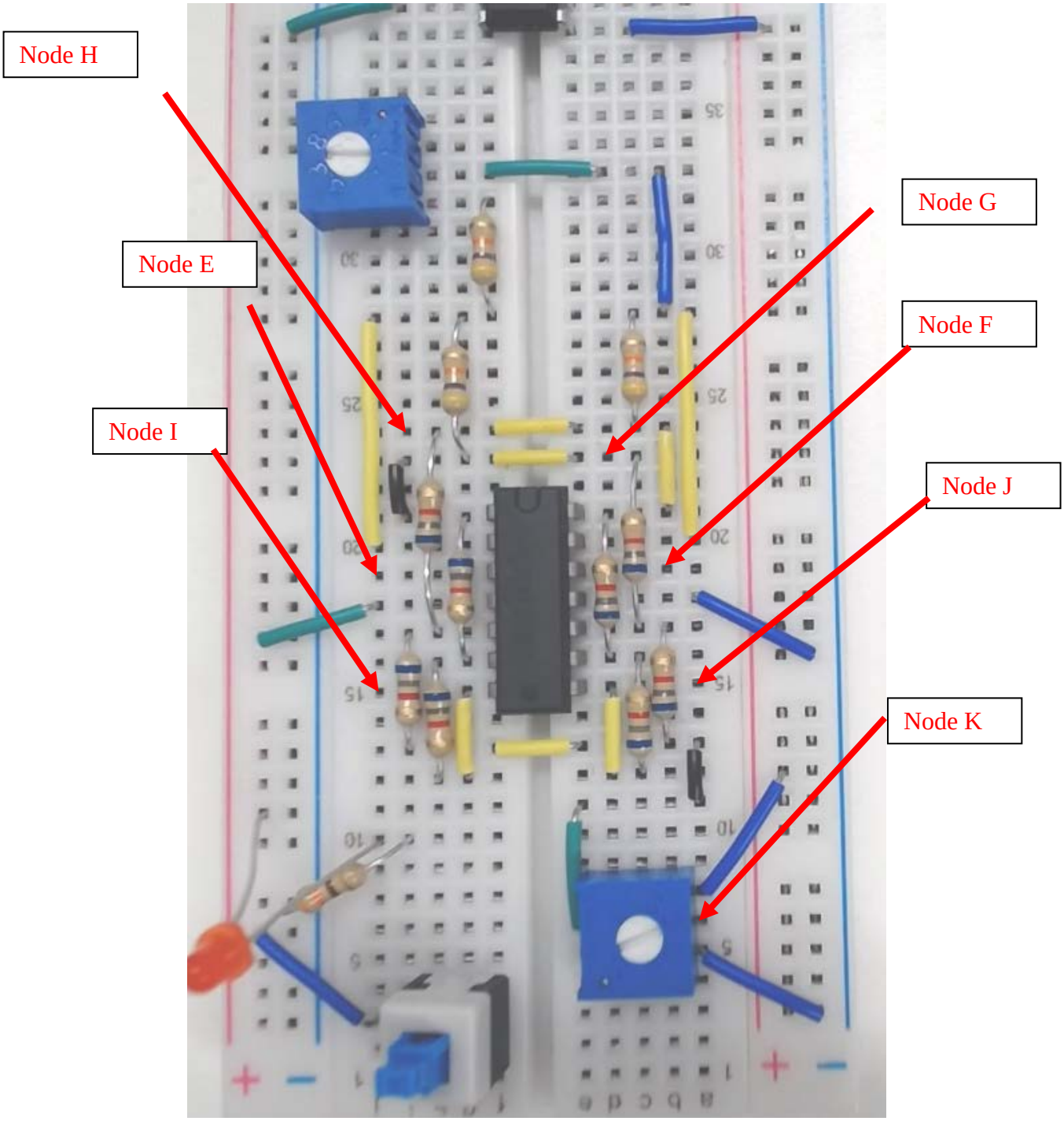
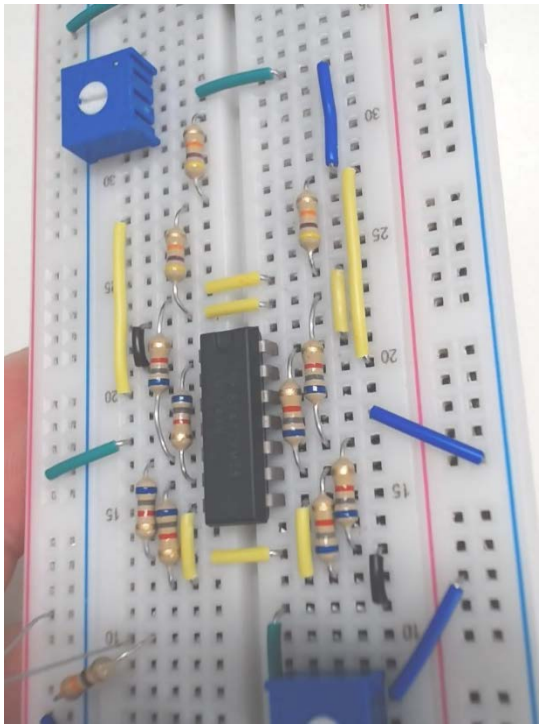
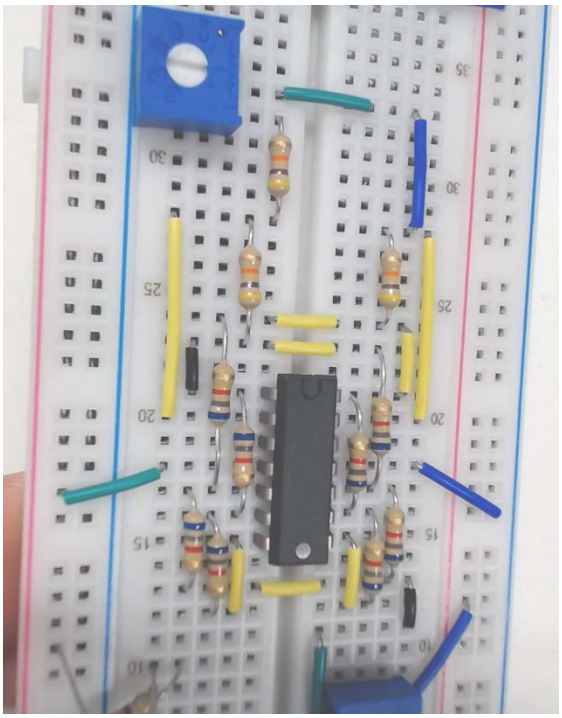
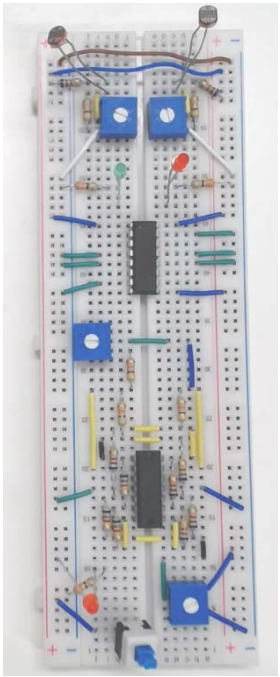


Fig. 34

Note : **Disconnect / Connect** USB plug from Arduino UNO, **No battery** in battery compartment.







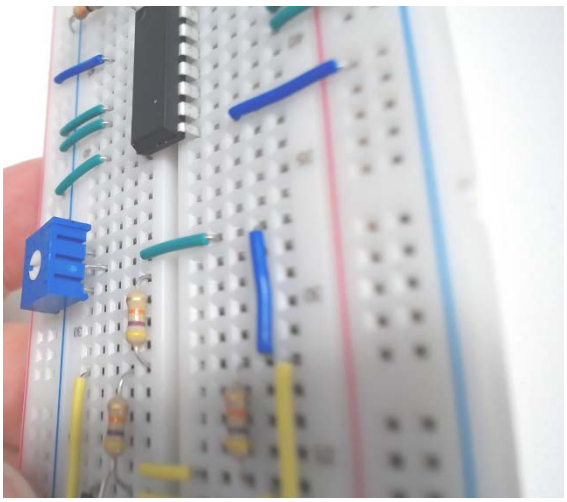


Fig. 35

Note : Disconnect / Connect USB plug from Arduino UNO, **Keep Battery** in battery compartment.

5.2.10. Connect the LED circuits to Arduino UNO board, as shown in Fig. 36. Connect the motor driver circuit to Arduino UNO board, as shown in Fig. 37. Connect the LDR circuit to amplifier and amplifier circuit to Arduino UNO board, as shown in Fig. 38. You could refer to the video (video14-LDR_motor_connection.mp4) for demonstration.

[Check point 8] Put the 6 AA battery in the battery compartment. 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 right side, and right side motor would turn slowly to make a right turn. You could refer to the video (video15-checking_LDR_motor.mp4) for demonstration.

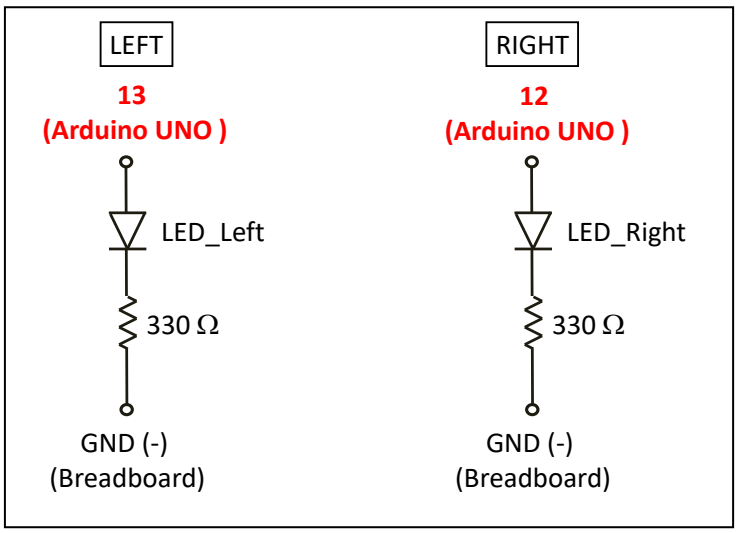


Fig. 36

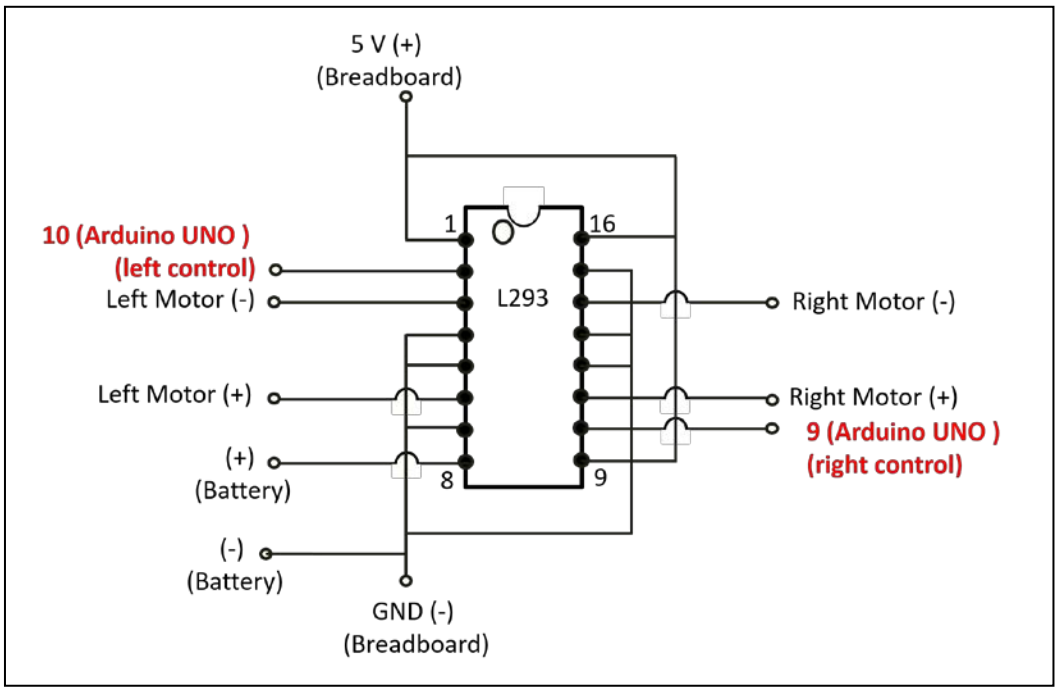
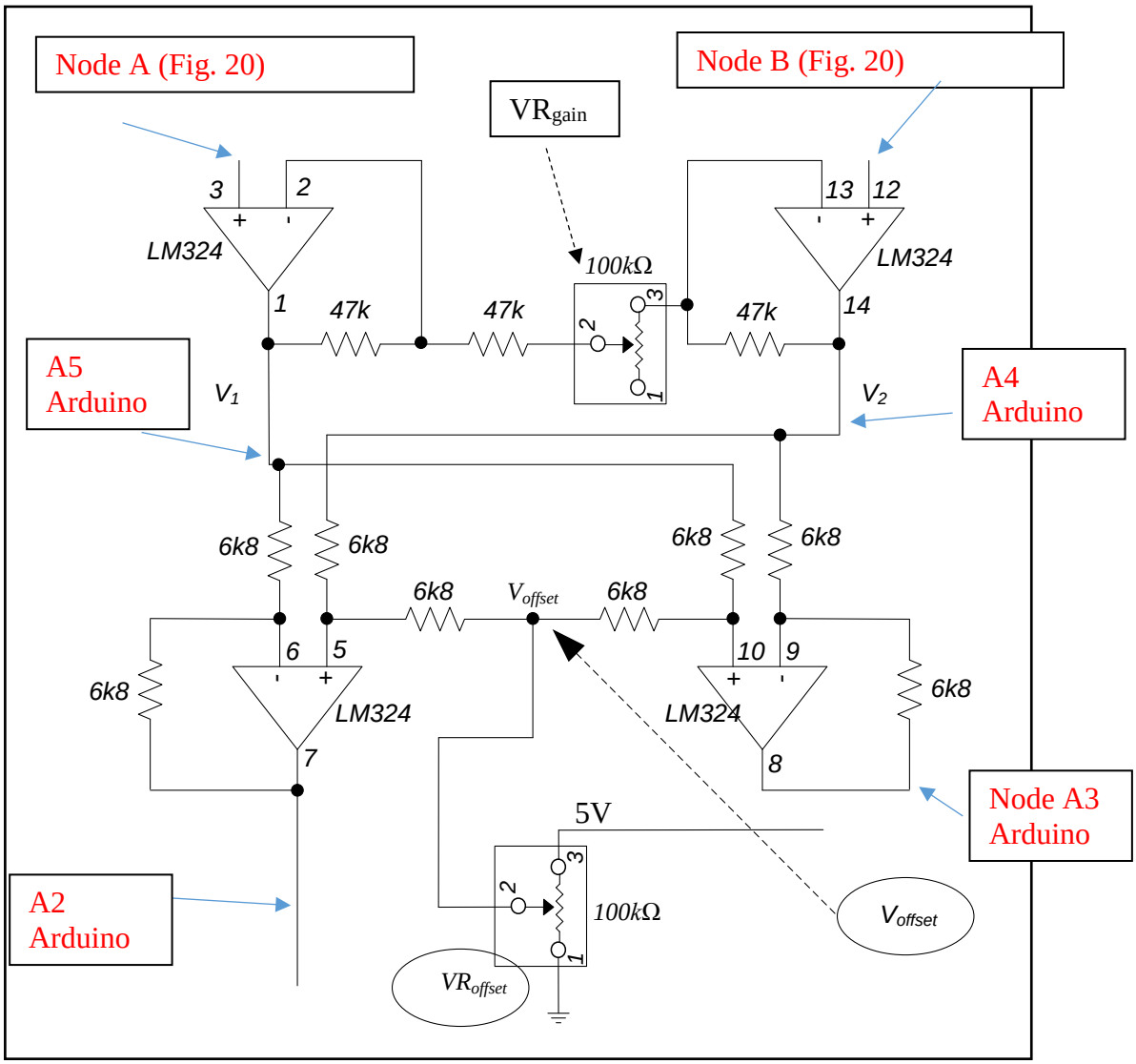


Fig. 37

Note : Disconnect / Connect USB plug from Arduino UNO, **Keep Battery** in battery compartment.

Connect pin 4 (LM324) to 5V, connect pin 11 (LM324) to Gnd



Using LM324 (4 x opamp IC)

Fig. 38

Q1. Show the complete circuit.

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

Q2. Show the straight-forward movement.

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 ---