National University of Singapore

Department of Electrical and Computer Engineering

CG1108 – Electrical Engineering

AY2010/2011 Semester 2

Project Manual: Line-tracking Autonomous Vehicle

1. INTRODUCTION

In this project, you will be designing and building an autonomous vehicle that has the ability to follow a black line on a white background by making use of the different reflectivity of dark and light surfaces.

1.1 PROJECT SPECIFICATIONS

The autonomous vehicle will be powered by a 7-9V battery pack containing 6 rechargeable batteries. The vehicle should be able to track a meandering black line on a white surface independently. It should also be able to climb up and down a ramp inclined at 18^o to the horizontal surface.

1.2 PROJECT ASSESSMENT

The project is assessed through vehicle demonstration during your lab session in Week 13. In addition, an individual learning journal and peer feedback are also required. The vehicle will be assessed on performance, circuit layout, vehicle design and extra features during the demonstration.

- ***Vehicle performance***
  - Moving speed
  - Turning capability
  - Up/Down the ramp
- ***Vehicle Design***
  - Structure
  - Decoration
- ***Circuit Layout***
  - Neatness
  - Color coding
- ***Additional Features***
  - Application
  - Creativity

1.3 PROJECT PLANNING

All the tasks that you need to complete have been compiled into this project manual with a recommended timeline included below.

As can be seen in the timeline below, you only have three lab sessions in Weeks 8 to 10 to construct all the electrical and mechanical blocks of the car. It is therefore extremely important that you complete your tasks on time or ahead of the recommended time line. Failure to do so will result in a lack of ability to complete the car.

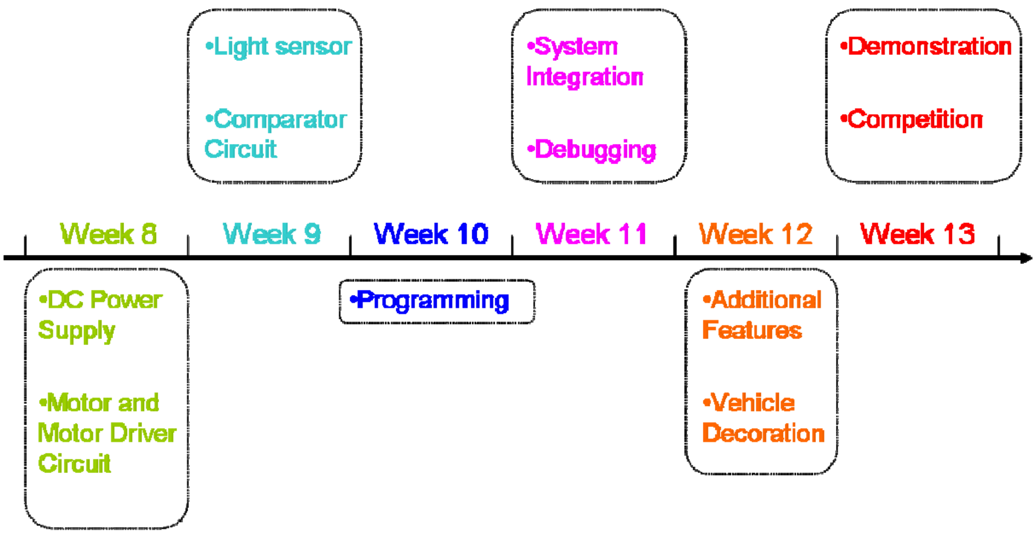


Fig. 1 Recommend timeline for project planning and progress.

2. VEHICLE CONSTRUCTION

Students may follow the step-by-step construction guide in this section to build the autonomous vehicle. The vehicle contains both a mechanical subsystem and an electrical subsystem. In Fig. 1 shown below, the conceptual diagram of the car and flow chart of the car's processing is shown.

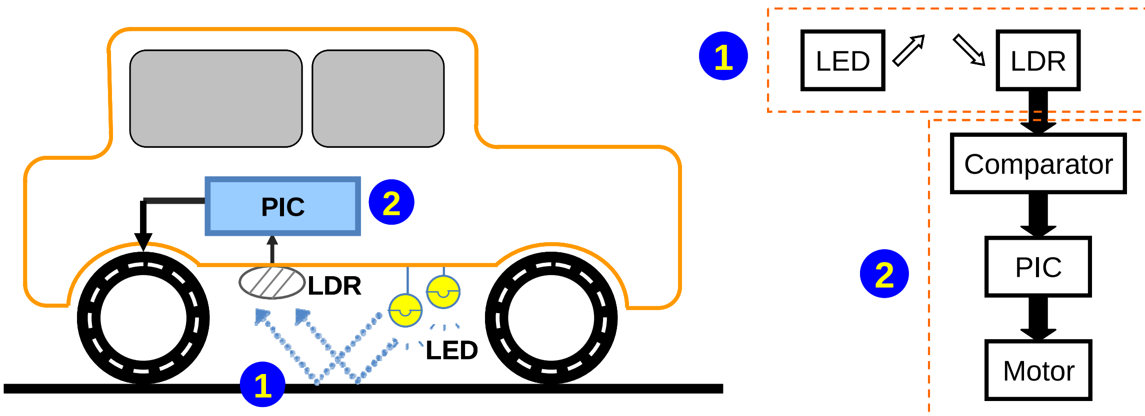


Fig. 2 Conceptual drawing and flow chart of operation of vehicle.

2.1 MECHANICAL SUBSYSTEM

The mechanical subsystem of the car consists of the following blocks – Wheels, Ball Castors, Gearbox, Motors and Base Plate. These parts have been provided to you in your Project Pack as follows.

(1) Wheels

a) Two side wheels driven by gearbox and motors.

b) Refer to detailed construction instructions provided within.

(2) Ball Castor

a) 360° rotary front wheel(s).

b) Refer to detailed construction instructions provided within.

(3) Gearbox and Motors

a) Mechanical system between wheels and motors that is used to increase torque while reducing speed of the motors.

b) **Gear Ratio C or D is recommended.**

There are 4 gear ratio options available for the construction of the Gearbox, each resulting in different Torque and Speed. Refer to Ratio and RPM table in the instruction set for more details.

(4) Base Plate

a) Refer to detailed construction instructions provided within.

Students shall design their mechanical subsystem such that the vehicle is robust and has good climbing and turning capabilities.

2.2 ELECTRICAL SUBSYSTEM

The electrical subsystem can be further divided into:

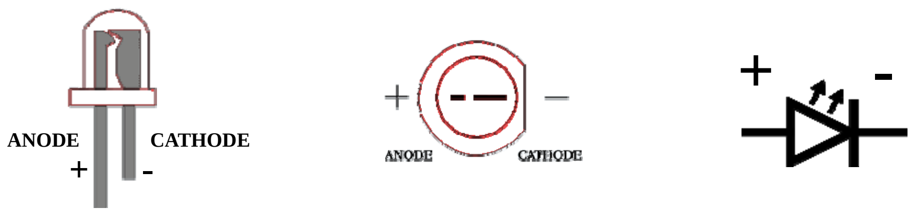
1) The line sensor
2) The motor driver
3) The vehicle controller

The line sensor (the 'eyes') provides feedback on the position of the vehicle. Based on this feedback, the vehicle controller (the 'brain') commands the motor (the 'limbs') to move either in forward/reverse direction or to turn left or right.

2.2.1 Light sensors using LDR

The line sensor consists of LED (Light Emitting Diode) which emit light and LDR (Light Dependent Resistor) whose resistance depends on the amount of light falling on them. The line sensor is mounted on the vehicle, facing the track. The light from the *LEDs* gets reflected from the ground to the LDRs as shown in Figure 1. The amount of light reflected from the black line will be less compared to that reflected from the white ground. The resistance of LDR will be different in these two cases and this is used by the LDR circuit to decide whether the vehicle is on the black line or white ground.

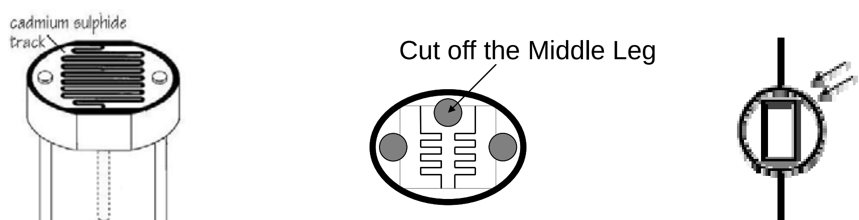
Brief Description



(a) Side View (b) Top View (c) Symbol

Fig. 3 (a) Side view of a LED. (b) Top view of a LED. (c) Electrical symbol of a LED.

The Light Emitting Diode (LED) is a specialized diode that emits light when the voltage difference across has the correct polarity (i.e. anode is made positive with respect to the cathode) and exceeds the threshold voltage. To avoid damaging the LED, a resistor is placed in series with the LED to limit the current to below 20-30 mA.



(a) Side View (b) Top View (c) Symbol

Fig. 4 (a) Side view of a LDR. (b) Top view of a LDR. (c) Electrical symbol of a LDR.

The Light Dependent Resistor (LDR) has a resistance that decreases with increasing levels of light that falls on it. Unfortunately, individual LDR's characteristics are slightly different from each other. Therefore, even under the same light conditions, the resistance values of each LDR may vary to a certain extent. The LDR does not have any polarity and can be connected both ways.

LED & LDR Circuit Schematic

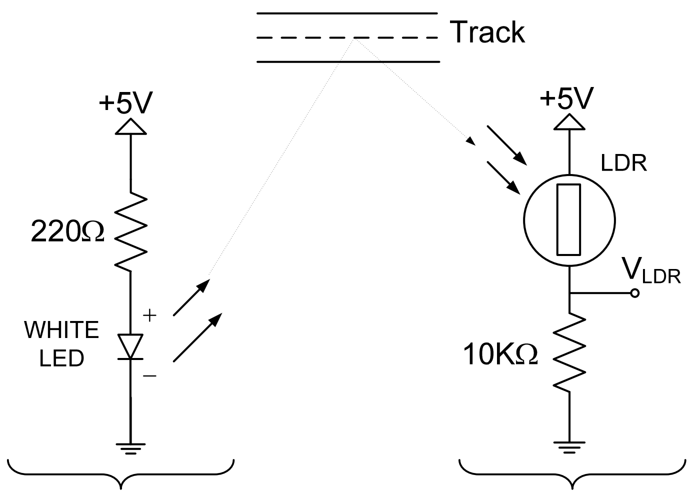


Fig. 5: Schematic of LED and LDR Circuit.

Please set up one set of LED circuit and LDR circuit on the breadboard. Change the value of the resistance in series with the LED and observe the variation of current and light intensity

The LDR circuit can be thought of as a voltage divider circuit and the V_{LDR} will be

$$V_{LDR} = 5 \times \frac{10000}{10000 + R_{LDR}}$$

When more light falls on the LDR, R_{LDR} will reduce which leads to V_{LDR} being higher. When less light falls on the LDR, R_{LDR} will reduce which leads to V_{LDR} being lower.

We need to have about 5 sets of LEDs in the sensor for sufficient illumination. The above circuit for LED is repeated for the 5 sets of the LED lighting.

Similarly, the vehicle may need at least 2 sets of LDR sensors to obtain more advanced control logic for the vehicle. The LDR circuit is to be repeated as needed.

Construct **2** sets of the LDR Circuit. As each LDR is slightly different, you will need to characterize the resistances of both LDRs at different light levels.

Measure and note down the values of V_{LDR} in each of the following instances. Using the voltage divider rule, calculate the corresponding R_{LDR}.

<u>Circuit 1</u>

At **LOW** levels of Light, $V_{LDR1,light}=$ $\therefore R_{LDR1,light} =$

At **HIGH** levels of Light, $V_{LDR1,dark}=$ $\therefore R_{LDR1,dark} =$

<u>Circuit 2</u>

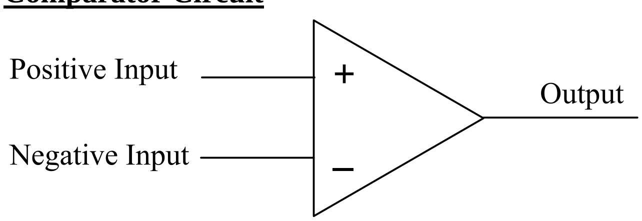
At **LOW** levels of Light, $V_{LDR2,light}=$ $\therefore R_{LDR2,light} =$

At **HIGH** levels of Light, $V_{LDR2,dark}=$ $\therefore R_{LDR2,dark} =$

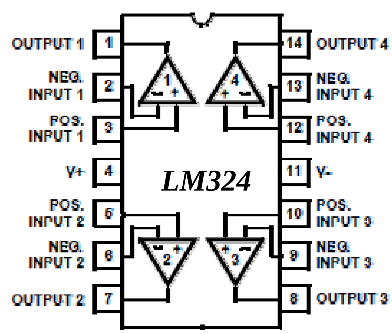
2.2.2 LM324 comparator circuit

The input from the ‘eyes’ (LDR sensors) is then sent for processing at the ‘brain’ (microcontroller). However, before the signals reach the ‘brain’, they must be converted to ‘brain’-compatible signals. The *Comparator Circuit* converts the LDR voltage output to ‘logic levels’ at the output $Sensor_{OUT}$.

<u>Comparator Circuit</u>



(a) Symbol



(b) Pin Diagram

Fig. 6(a) Electrical symbol of a comparator (b) Pin diagram of LM324, Quad Comparator Chip.

The comparator compares the voltages connected to the positive and negative input. If the voltage at the positive input is more than the voltage at the negative input, then the comparator output becomes 5V. If the positive input is less than the voltage at the negative input, then the comparator output becomes 0V.

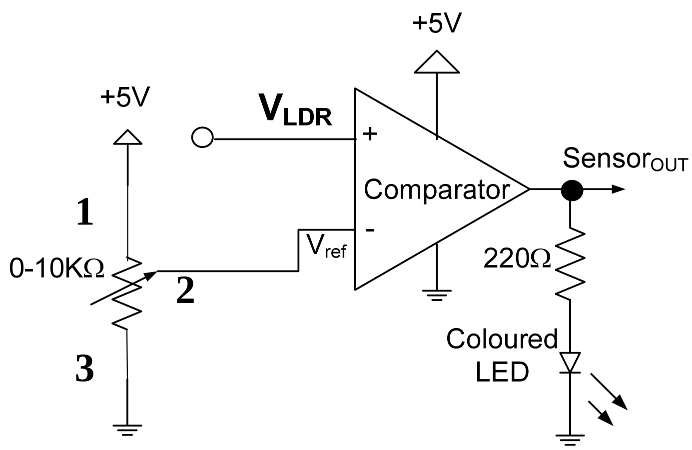
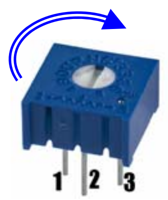
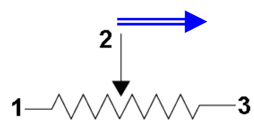


Fig. 7 Schematic of Comparator Circuit



(a) Pin Connection



(b) Symbol

Fig. 8(a) Pin connections of a Potentiometer. (b) Electrical symbol of a potentiometer with corresponding pin notations.

A potentiometer (trim-pot) is used to obtain a variable reference V_{ref} voltage between 0 and 5V. If V_{ref} is set between the LDR voltages for the white ground and the black line, then the sensor output will be 5V ('logic 1') when the sensor sees white surface and it will be 0V (logic '0') when the sensor sees the black line.

1) Construct the circuit as shown in Fig. 3.

   V_{LDR} is the LDR circuit output V_{LDR1} from Section (a).

2) By adjusting the trimmer and V_{REF1} to an appropriate value, achieve the following:

   - HIGH levels of light : $V_{LDR} = V_{LDR1,light}$ ➔ Coloured LED lights up
   - LOW levels of light : $V_{LDR} = V_{LDR1,dark}$ ➔ Coloured LED does not light up

3) Ensure that the behavior of the circuit is consistent by testing it several times.

4) Repeat the above steps for the second LDR circuit output voltage, V_{LDR2}.

GA VERIFICATION	DATE

2.2.3 DC Power supply using battery pack

The vehicle shall be powered by a 7-9V battery pack, which consists of 6 rechargeable batteries. To understand how the battery behaves as a non-ideal voltage source, we can compare the battery characteristics with that of an ideal voltage source.

Take one battery pack that is fully charged and record the battery's open circuit voltage. If the voltage of the battery is less than **7V** then inform the GA to replace the battery.

Now connect the battery output terminal to a set of variable resistances and note down the current through the resistance and the battery terminal voltage and complete Table-1.

Table - 1

Resistance in Ohms	Terminal voltage of battery	Current through the resistance
∞		
20Ω (2 x 10Ω, 10W in series)		
10Ω, 10W		
5Ω (2 x 10Ω, 10W in parallel)		

Plot a graph between battery terminal voltage and output current and comment on the shape of the graph. From the gradient of the graph in Figure 1, find out the internal resistance of the battery pack. What can you conclude about the effect of internal resistance?

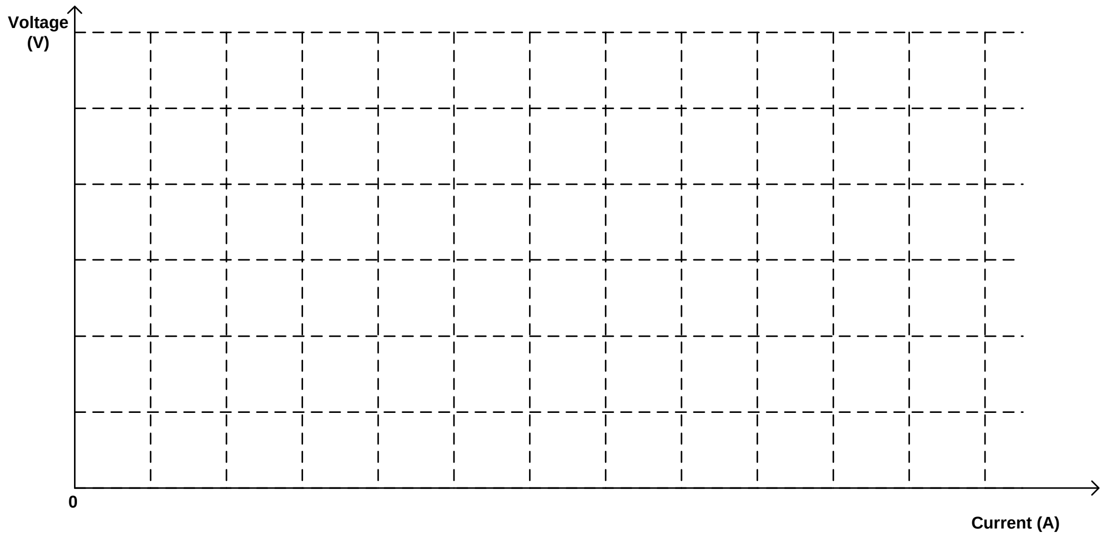


Fig. 9 Voltage/current characteristics of the battery pack

Connect the battery pack to the development board as shown in Figure 2. The indicator LED should light up, implying the development board is working properly. The voltage regulator IC 7805 takes in the battery voltage and outputs a regulated 5V. Test the voltage difference between the two pins pointed by the arrows, you should observe +5V. This 5V voltage shall be used to supply all the IC chips and components.

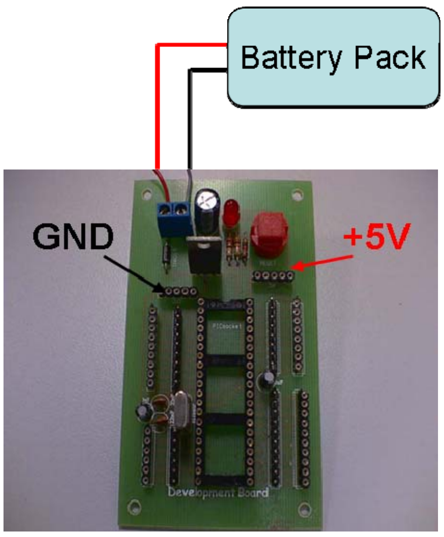


Fig. 10 Battery pack connected to the development board

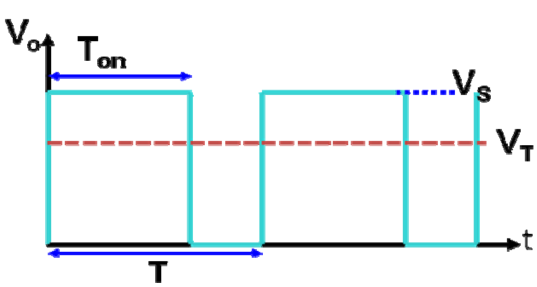
2.2.4 DC motor and L293D motor driver

In this section, you will be constructing and understanding the 'limbs' of the vehicle.

Connect a DC power supply directly to your DC motor. ***Be careful with the metal connections as they break easily.*** Make sure you set the current limit of the power supply below 1.0A. Vary the supply voltage from 0V to 5V and measure the motor speed using the Tachometer. Sketch a graph of speed against voltage. (Note: Do not make the DC voltage larger than 5V.)

Fig. 11 Plot of Speed of Motor against DC Input Voltage.

Instead of using a variable DC voltage, we will now explore an alternative method of controlling the speed of the motors called *Pulse Width Modulation (PWM)*.



$$V_T = V_S \cdot \frac{T_{ON}}{T_{Period}}$$

$$\frac{T_{ON}}{T_{Period}} = \text{Duty Cycle}$$

$$V_T = V_S \cdot \text{Duty Cycle}$$

Fig. 12 Pulse-Width-Modulation.

The voltage in Figure 12 is a pulse train, which alternates between zero and a DC value V_s. The time during each period for which the signal is at the DC value V_s is called the on-time (T_{on}). The **duty cycle (*D*)** of the pulse train is defined as fraction of time for which the voltage is at

V_s. The average value of the pulse train is proportional to the duty cycle. If the frequency of the pulse train is high (a few kHz), then the pulse train can be applied to DC motor in place of a variable DC supply and the motor speed will be proportional to the duty cycle.

The lab signal generator can output such a PWM pulse train from its CMOS/TTL output. However, it should be noted that the signal generator cannot supply the current demand of the DC motor. Hence, the PWM signal is used along with a motor driver (e.g. L293D) to supply a variable voltage to the DC motor.

You will be using this TTL signal to control the speed of the motor through the Motor Driver Chip – L293D. Next, connect the motor to the L293D motor driver according to the circuit diagram shown in Figure 13. **Take note that output diodes are internal in L293D, and therefore you do not need to connect any diodes**.

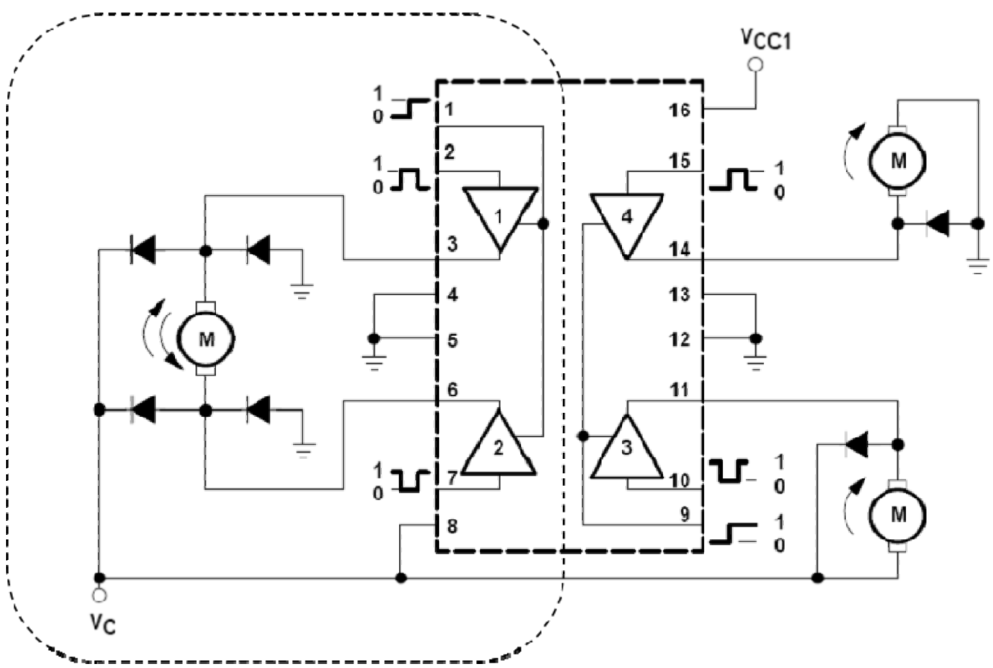


Fig. 13 Circuit schematic for Motor Driver Circuit.

Connect the left motor on the left side of the IC (pin1 – pin8) with the appropriate input signals to the chip. You may ignore the right side of the IC (pin9 – pin16) for the time being.

Please note the following pin connections:

- Pin 1: Enable pin, connect it to Vcc (+5V) for this practice.
- Pin 2: Input 1, connect it to a CMOS/TTL signal from the signal generator.
- Pin 3: Output 1, connect it to one terminal of the motor
- Pin 4: GND
- Pin 5: GND
- Pin 6: Output 2, connect it to the other terminal of the motor
- Pin 7: Input 2, connect it to GND.
- Pin 8: Vcc (+5V) (Vcc_1 at pin 16 is also +5V.)

Vary the duty cycle of the CMOS/TTL signal and observe the change in the motor speed. Measure the speed using the tachometer and sketch a graph of speed against duty cycle (in terms of percentage).

Fig. 14 Plot of Speed of Motor against Duty Cycle of Input PWM Signal.

Next, connect Pin 7 to Vcc (+5V) instead, and observe that the motor turns in the opposite direction. Thus, the voltage at Pin 7 decides the direction of rotation of the motor. This technique is used in the program to control the motor direction by changing it between logic 0 ('Low') and logic 1 ('High').

Repeat the same connections for the right motor and construct the same circuitry as the left side. Ignore the circuit provided in Fig. 13. Notice that due to the inherent characteristics of the motors, they will have different speed characterizations even when connected to the same inputs.

GA VERIFICATION	DATE

2.2.5 Programming Microcontroller

With the input from the ‘eyes’, the ‘brain’ decides to turn left or turn right, by controlling the ‘legs’.

Your program in the microcontroller is the brain of your vehicle. The quality of your program directly affects the vehicle’s performance. You will use C language to program the microcontroller. You may download the compiler (IAR Embedded Workbench) and the WinPIC800 programmer from IVLE to your laptop/desktop. Please note that WinPIC800 can only work in WinXP system. You can refer to the installation and user guide in IVLE workbin.

Now, please get familiar with microcontroller programming by doing the following practices.

Replace the corresponding part given in the mainsample.c file.

a)

```
int main()
{
 // initialization of the peripherals
 initialize_IO_ports();
 while(1)
 {
    //Port D is output
    //Port B is input
    //read port B and write it to port D
    RD0=RB0;
    RD1=RB1;
    RD2=RB2;
    RD3=RB3;
    RD4=RB4;
    RD5=RB5;
    RD6=RB6;
    RD7=RB7;
 }
}
```

To test the function of the program on the development board, you can connect the 0V or 5V at the port B pins and check the corresponding pins of port D, using multi-meter.

b)

```
int main()
{
 // initialization of the peripherals
 initialize_IO_ports();
 //initialize the ADC for analog inputs
 initialize_ADC();

 while(1)
 {
    //Port D is output
    //read ch0B and write it to port D
    PORTD=read_ADC(0);
 }
}
```

To test the function of the program on the development board, you can connect an analog voltage to channel 0. You can connect 8 LEDs (with resistor) to port D to see the digital value corresponding to the analog signal.

c)

```
int main()
{
 // initialization the PWM1
  PWM1_init();
 //initialize the ADC for analog inputs
 initialize_ADC();

  while(1)
  {
     //output PWM1, whose duty cycle is controlled by ch1

     PWM1_ChangeDutyCycle(read_ADC(1), 0x0F);
  }
}
```

To test the function of the program on the development board, you can connect an analog voltage (0V ~5V) to channel 1. You can see the PWM signal on an oscilloscope.

GA VERIFICATION	DATE

2.3 SYSTEM INTEGRATION

After the 'eyes', 'brain' and 'limbs' are constructed, it is time to integrate them together and build the complete electrical subsystem of the vehicle. It is always a good practice to test the sub-systems and ensure proper operation before building the complete system.

First, integrate the sensor and comparator circuitry on the breadboard. Connect the breadboard to the microcontroller on the development board, according to the following block diagram. Ensure that each part is functional before connecting to the next part.

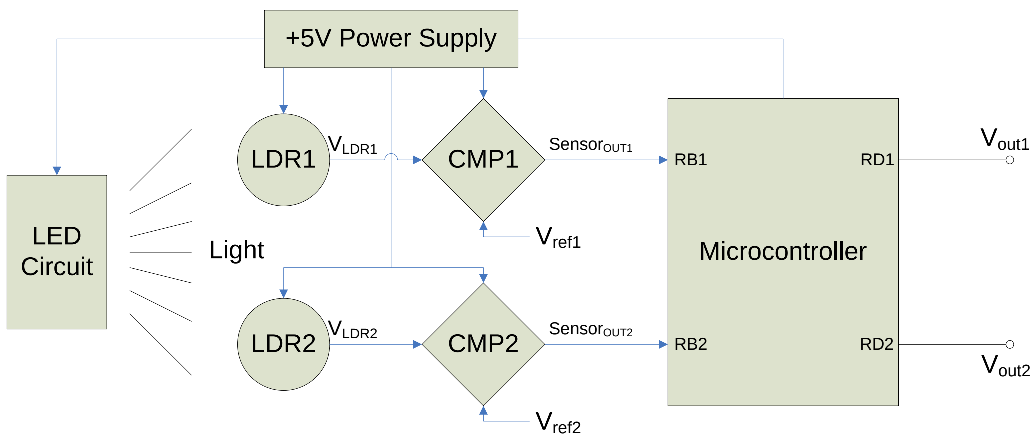


Fig. 15 Block diagram of sensor and microcontroller

This diagram only shows an example of 2 LDRs in the system. If you are using more than 2 LDRs, you should connect all of them. You may also use input pins other than RB1 and RB2.

Use the program in section 2.2.5 part (a) for your microcontroller. Measure the voltage V_{out1} and V_{out2} using the digital multi-meter. They should change according to the amount of light that LDR1 and LDR2 receives, respectively. Ensure that you understand each portion of the circuit and how it controls the subsequent part.

<u>You may now solder all LED and LDR circuits to PCB, which shall be located at the bottom of your vehicle. You need to decide the LDR positions before soldering. LDR positions will determine your programming logic and hence are very important!</u>

Next, disconnect $Sensor_{OUT1}$ and $Sensor_{OUT2}$ from the microcontroller, and connect the motor driver circuit with the 'brain', according to the following block diagram.

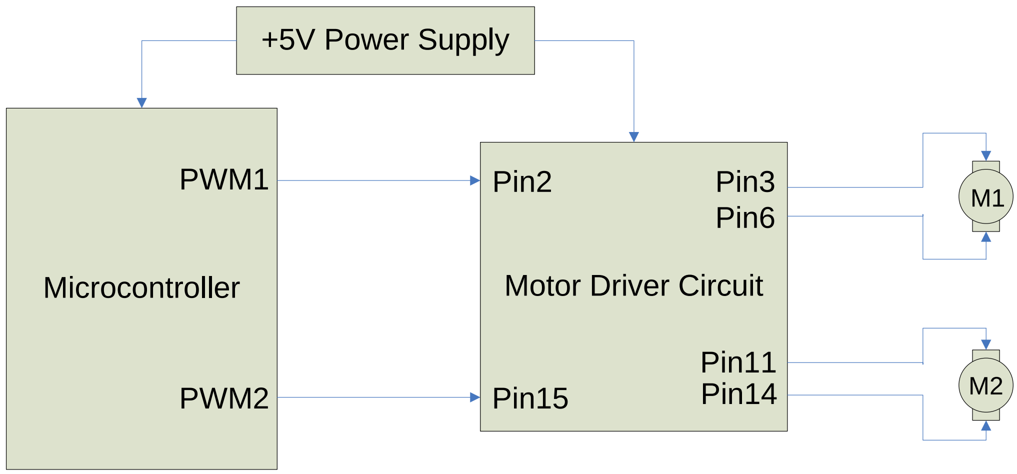


Fig. 16 Block diagram of microcontroller and motor driver circuit

Use the program in section 2.2.5 part (c) for your microcontroller. Connect an analog voltage (0V ~5V) to channel 1. You should observe motor M1 changing speed when the analog voltage is varied. You can then change the program for PWM2 and test the operation for motor M2.

Finally, you can integrate the sensor, microcontroller and the motor driver circuit together, as shown below. Pin connections in this diagram serve only an example, and you can design your own connections. Develop your own program algorithm and test the working condition of the entire system.

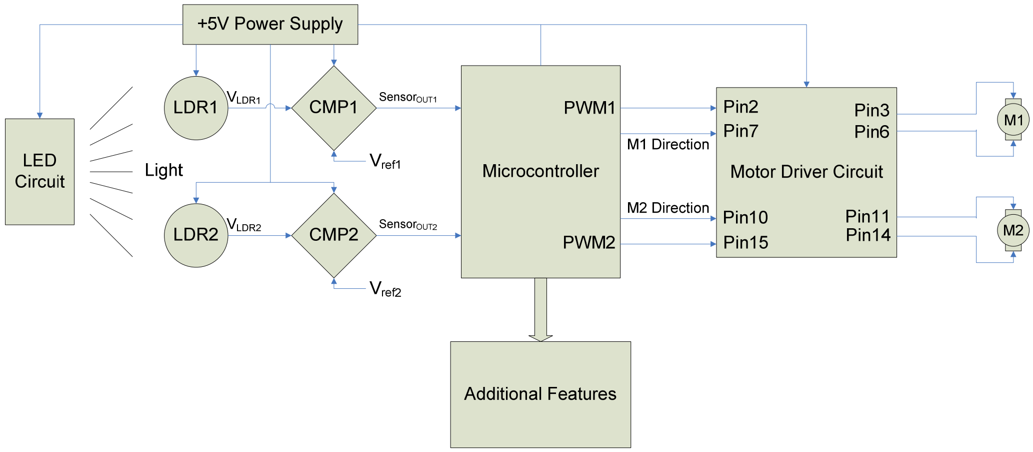


Fig. 17 Block diagram of the entire electrical subsystem

APPENDIX

PIC pin table: Show the connection of the input and output signals to the PIC

	MCLR/Vpp	1	PIC16F877(A)	40	RB7/PGD	
	RA0/AN0	2		39	RB6/PGC	
	RA1/AN1	3		38	RB5	
	RA2/AN2/Vref-	4		37	RB4	
	RA3/AN3/Vref+	5		36	RB3/PGM	
	RA4/T0CKI	6		35	RB2	
	RA5/AN4/SS	7		34	RB1	
	RE0/RD/AN5	8		33	RB0/INT	
	RE1/WR/AN6	9		32	Vdd	
	RE2/CS/AN7	10		31	Vss	
	Vdd	11		30	RD7/PSP7	
	Vss	12		29	RD6/PSP6	
	OSC1/CLKIN	13		28	RD5/PSP5	
	OSC2/CLKOUT	14		27	RD4/PSP4	
	RC0/T1OSO/T1CKI	15		26	RC7/RX/DT	
	RC1/T1OSI/CCP2	16		25	RC6/TX/CK	
	RC2/CCP1	17		24	RC5/SDO	
	RC3/SCK/SCL	18		23	RC4/SDI/SDA	
	RD0/PSP0	19		22	RD3/PSP3	
	RD1/PSP1	20		21	RD2/PSP2	