Line Following Robot

Mechatronics Project

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INTRODUCTION

NAVIGATION PRINCIPLES

Robots find extensive applications in space explorations, unmanned operations and usage in hazardous and difficult conditions without the presence of an operator. Such robots are required to move around on their own. These are usually self-guided or externally navigated.

External navigation includes laser guidance and GPS guidance. The principle of laser guidance is similar to the principle of Laser guided missiles. In this the target to be reached is marked by a laser and the Robot makes suitable navigation corrections to reach the target. On the other hand the GPS based robot estimates in own position and tried to reach the position of the target programmed to it. Self Guided robots use sensors like proximity sensors or CCD Camera to check their position.

All such guided vehicles usually have collision avoidance systems. These are usually executed by using a combination of sensors and path finding Techniques. These can either be preprogrammed (static) or adaptive (dynamic).

Line-following robots come under a certain kind of externally guided robots. These are extensively used in manufacturing to deliver parts between stations. It is also possible to use different colored lines to vary the part of the robot. Such robots are usually microprocessor controlled and can be programmed to handle different conditions.

Electronic Controlled robots on the other hand are hard wired. These are cheap and simple to make but require manual switching for handling different conditions. Hence these are usually used where there is not much change in the conditions of operation.

LINE FOLLOWING PRINCIPLES

SINGLE SENSOR

The single sensor line following principle uses a single sensor to follow a line. The robot usually detects the edge of a white line on a black background. A switching circuit directs power alternately to two motors. Hence the robot is powered by left motor once and then by the right motor which makes it stay on the line.

The main advantage of this method is that it uses only one sensor. It is much more suitable for sharp curves. But the robot has a jerky motion. Also if robot leaves path it turns 180' and moves in opposite direction.

DUAL SENSOR

This principle uses two sensors to control the robot. Two LDR's are used and each sensor controls one motor. The left sensor controls right motor and vice versa. Hence the robot moves in a straight line if the line is straight.

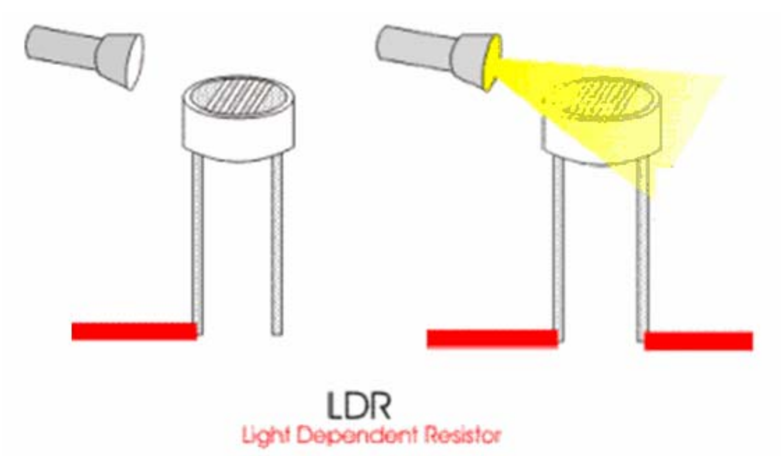
The advantages of this type include smooth motion on straight line and a non jerky motion. But it requires two sensors and hence two control circuits. Also the two motors should be synchronized to move in the same speed for the robot to move in a straight line.

COMPONENTS

CONTROL COMPONENTS

LIGHT DEPENDENT RESISTOR

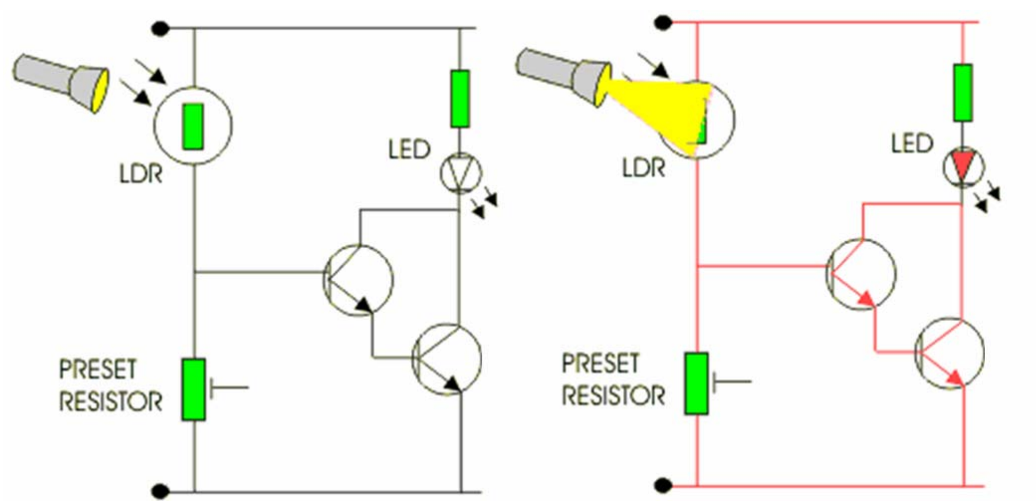
Light dependent resistors are electronic components where the resistance of the device decreases with increasing light intensity. They can also be called LDRs, photo resistors or photoconductors. Light Dependent Resistors are very useful especially in light/dark sensor circuits. Normally the resistance of an LDR is very high, sometimes as high as 1MΩ, but when they are illuminated with light resistance drops dramatically. In the picture shown, the resistance of the LDR falls when the torch is turned on, allowing current to pass through it.



LDRs are made of a high resistance semiconductor. If light falling on the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance.

In intrinsic devices, the only available electrons are in the valence band, and hence the photon must have enough energy to excite the electron across the entire band gap. Extrinsic devices have impurities added, which have a ground state energy closer to the conduction band - since the electrons don't have so far to jump, lower energy photons (i.e. longer wavelengths and lower frequencies) will suffice to trigger the device.

LDRs come in many different types. Inexpensive cadmium sulfide (CdS) LDRs can be found in many consumer items such as camera light meters, clock radios, security alarms and street lights. At the other end of the scale, GeCu photoconductors are among the best far-infrared detectors available, and are used for infrared astronomy and infrared spectroscopy.



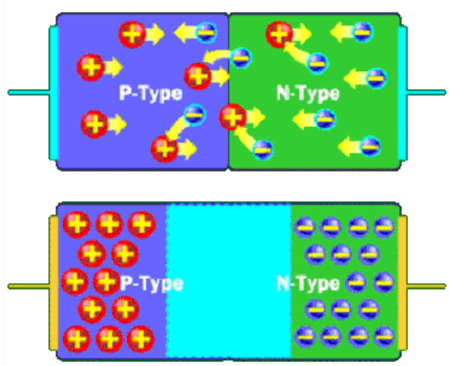
The figure shows an example of a light sensor circuit. When the light level is low the resistance of the LDR is high. This prevents current from flowing to the base of the transistors. Consequently the LED does not light. However, when light shines onto the LDR its resistance falls and current flows into the base of the first transistor and then the second transistor and the LED lights. The preset resistor can be turned up or down to increase or decrease resistance, in this way it can make the circuit more or less sensitive.

LIGHT EMITTING DIODE

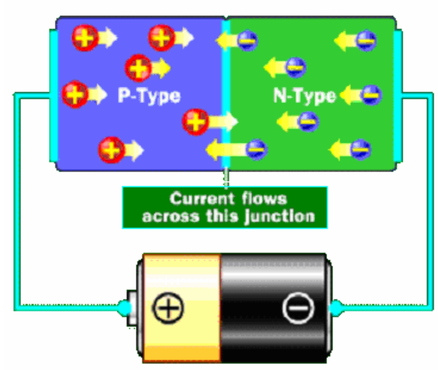
A diode is the simplest sort of semiconductor device. Broadly speaking, a semiconductor is a material with a varying ability to conduct electrical current. Most semiconductors are made of a poor conductor that has had impurities (atoms of another material) added to it. The process of adding impurities is called doping.

In the case of LEDs, the conductor material is typically aluminum-gallium-arsenide (AlGaAs). In pure aluminum-gallium-arsenide, all of the atoms bond perfectly to their neighbors, leaving no free electrons (negatively-charged particles) to conduct electric current. In doped material, additional atoms change the balance, either adding free electrons or creating holes where electrons can go. Either of these additions makes the material more conductive.

A semiconductor with extra electrons is called N-type material, since it has extra negatively-charged particles. In N-type material, free electrons move from a negatively-charged area to a positively charged area. A semiconductor with extra holes is called P-type material, since it effectively has extra positively-charged particles. Electrons can jump from hole to hole, moving from a negatively-charged area to a positively-charged area. As a result, the holes themselves appear to move from a positively-charged area to a negatively-charged area.



A diode comprises a section of N-type material bonded to a section of P-type material, with electrodes on each end. This arrangement conducts electricity in only one direction. When no voltage is applied to the diode, electrons from the N-type material fill holes from the P-type material along the junction between the layers, forming a depletion zone. In a depletion zone, the semiconductor material is returned to its original insulating state i.e. all of the holes are filled, so there are no free electrons or empty spaces for electrons, and charge can't flow.



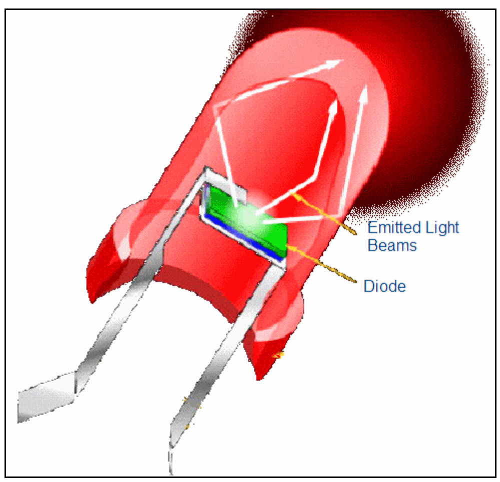
To get rid of the depletion zone, the electrons should start moving from the N-type area to the P-type area and holes should move in the reverse direction. To do this, the N-type side of the diode is connected to the negative end of a circuit and the P-type side to the positive end. The free electrons in the N-type material are repelled by the negative electrode and drawn to the positive electrode. The holes in the P-type material move the other way. When the voltage difference between the electrodes is high enough, the electrons in the depletion zone are boosted out of their holes and begin moving freely again. The depletion zone disappears, and charge moves across the diode. The interaction between electrons and holes in this setup generates light.

Light is made up of many small particle-like packets that have energy and momentum but no mass called photons. Photons are released as a result of moving electrons. In an atom, electrons move in orbitals around the nucleus. Electrons in different orbitals have different amounts of energy. Generally speaking, electrons with greater energy move in orbitals farther away from the nucleus. For an electron to jump from a lower orbital to a higher orbital, something has to boost its energy level. Conversely, an electron releases energy when it drops from a higher orbital to a lower one. This energy is released in the form of a photon. A greater energy drop releases a higher-energy photon, which is characterized by a higher frequency.

Free electrons moving across a diode can fall into empty holes from the P-type layer. This involves a drop from the conduction band to a lower orbital, so the electrons release energy in the form of photons. This happens in any diode, but you can only see the photons when the diode is composed of certain material. The atoms in a standard silicon diode, for example, are arranged in such a way that the electron drops a relatively short distance. As a result, the photon's frequency is so low that it is invisible to the human eye, i.e. it is in the infrared portion of the light spectrum.

Visible light-emitting diodes (VLEDs), such as the ones that light up numbers in a digital clock, are made of materials characterized by a wider gap between the conduction band and the lower orbitals. The size of the gap determines the frequency of the photon, in other words, it determines the color of the light.

While all diodes release light, most don't do it very effectively. In an ordinary diode, the semiconductor material itself ends up absorbing a lot of the light energy. LEDs are specially constructed to release a large number of photons outward. Additionally, they are housed in a plastic bulb that concentrates the light in a particular direction. As you can see in the diagram, most of the light from the diode bounces off the sides of the bulb, traveling on through the rounded end.

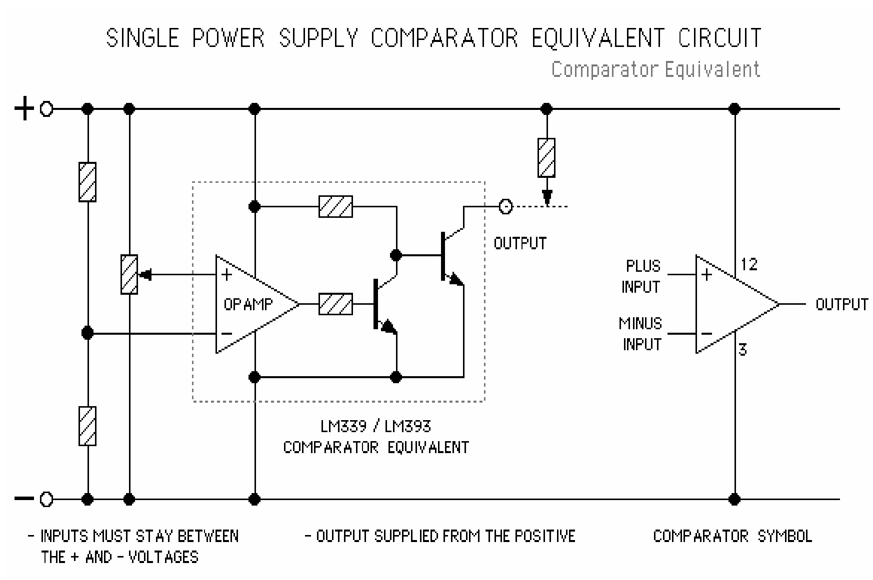


LEDs have several advantages over conventional incandescent lamps. They don't have a filament that will burn out, so they last much longer. Additionally, their small plastic bulb makes them a lot more durable. They also fit more easily into modern electronic circuits. The main advantage of LED is its efficiency. In conventional incandescent bulbs, the light-production process involves generating a lot of heat (the filament must be warmed). LEDs generate very little heat and much higher percentage of the electrical power is used to generate light.

VOLTAGE COMPARATOR

A comparator circuit compares two voltage signals and determines which one is greater. The result of this comparison is indicated by the output voltage: if the op-amp's output is saturated in the positive direction, the non-inverting input (+) is a greater, or more positive, voltage than the inverting input (-), all voltages measured with respect to ground. If the op-amp's voltage is near the negative supply voltage (in this case, 0 volts, or ground potential), it means the inverting input (-) has a greater voltage applied to it than the non-inverting input (+).

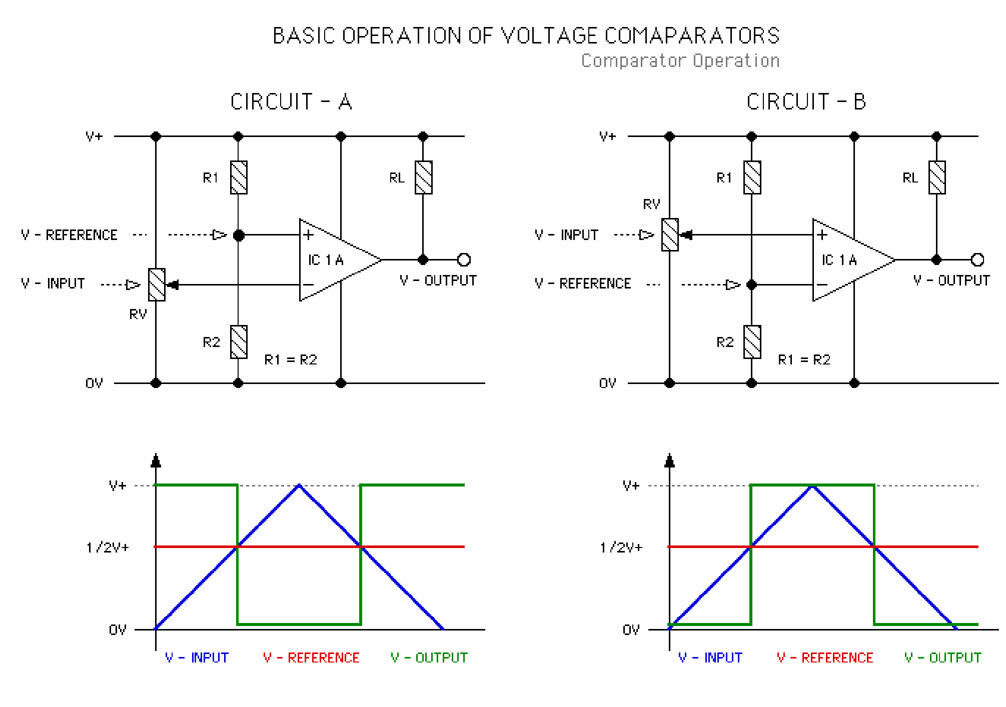
An integrated circuit "Voltage Comparator" is equivalent to an Operational Amplifier with two NPN transistors added to the output of each amplifier. This arrangement produces an "Open Collector" output for each of the four comparators in an LM339 chip. Each output can sink up to 20Ma and can withstand voltages of up to 50 Volts.



The output is switched ON or OFF depending on the relative voltages at the (+) and (-) inputs of the comparator, see the rules below. The inputs are quite sensitive and a difference of only a few milli-volts between the two will cause the output to turn on or off.

The LM339 comparator chip can operate from a single or dual power supply of up to 32 volts maximum. When operated from Dual or Split power supplies the basic operation of comparator chips is unchanged except that for most devices the emitter of the output transistor is connected to the negative supply rail and not the circuit common.

The following diagram shows the two simplest configurations for voltage comparators. The diagrams below the circuits give the output results in a graphical form. For these circuits the reference voltage is fixed at one-half of the supply voltage while the input voltage is variable from zero to the supply voltage.

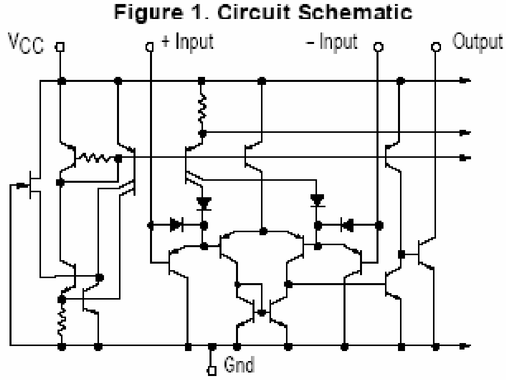


In theory the reference and input voltages can be anywhere between zero and the supply voltage but there are practical limitations on the actual range depending on the particular device used.

The LM339 series consists of four independent precision voltage comparators with an offset voltage specification as low as 2 mV max for all four comparators. These were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. These comparators also have a unique characteristic in that the input common-mode voltage range includes ground, even though operated from a single power supply voltage.

Applications of these comparators include limit comparators, simple analog to digital converters; pulse, square wave and time delay generators, MOS clock timers, multivibrators and high voltage digital logic gates. The LM339 series was designed to directly interface with TTL and CMOS. When operated from both plus and minus power supplies, they will directly interface with MOS logic where the low power drain of the LM339 is a distinct advantage over standard comparators.

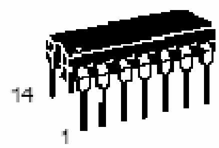
Figure 1. Circuit Schematic

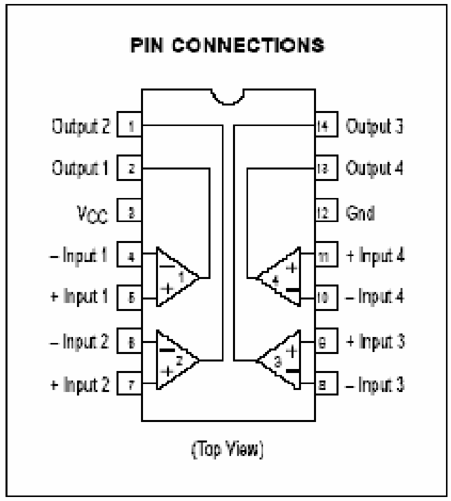


NOTE: Diagram shown is for 1 comparator.

The features of the LM339 integrated circuit includes

- Wide supply voltage range.
- Very low supply current drain (0.8 mA) independent of supply voltage.
- Offset voltage: ±3 mV.
- Input common-mode voltage range includes GND.
- Differential input voltage range equal to the power supply voltage.
- Low output saturation voltage: 250 mV at 4 mA.
- Output voltage compatible with TTL, DTL, ECL, MOS and CMOS logic systems.





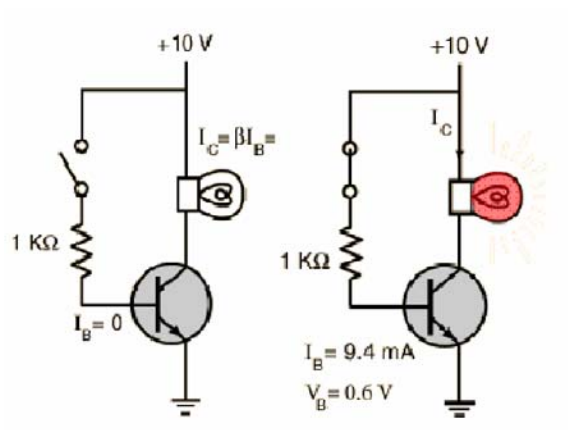
The main advantages of using the LM339 series comparators are listed as follows.

- High precision comparators.
- Reduced V_{OS} drift over temperature.
- Eliminates need for dual supplies.
- Allows sensing near GND.
- Compatible with all forms of logic.
- Power drain suitable for battery operation.

ELECTRICAL COMPONENTS

TRANSISTOR SWITCH

The transistor switch is used to control the load circuit. Even though the output voltage from the comparator is 9V, the current obtained from it is very less (in mA). The motor requires a current of 50mA. Hence a transistor switch is used to switch on and off the load circuit.



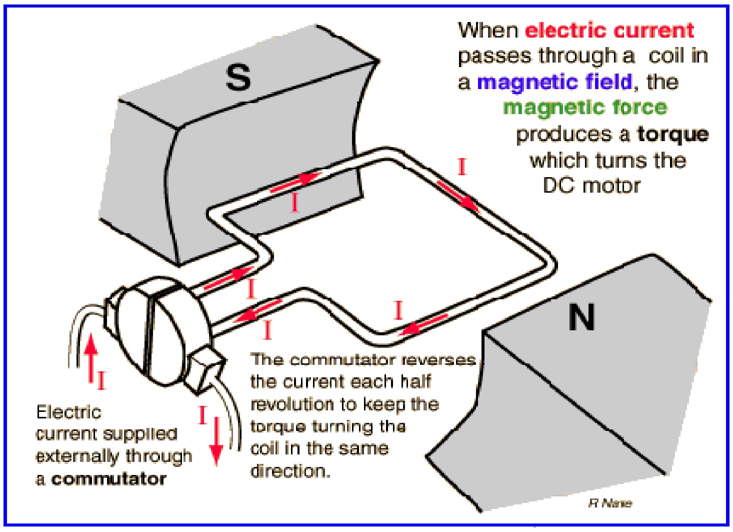
In the diagram shown, with the switch open, no base current flows, therefore no collector current can flow. The transistor is said to be cut-off state. With the switch closed the base current flows which cause the collector current to flow. The battery voltage is dropped across the lamp causing the collector voltage to fall to a very low value. The transistor is said to be in saturated state.

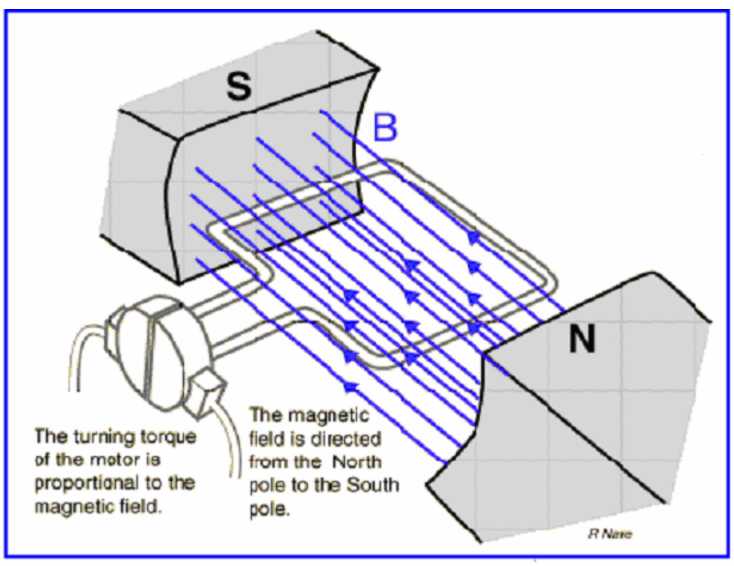
In this example the mechanical switch is used to produce the base current to close the transistor switch to show the principles. In practice, any voltage on the base sufficient to drive the transistor to saturation will close the switch and light the bulb. The base resistor is chosen small enough so that the base current drives the transistor into saturation.

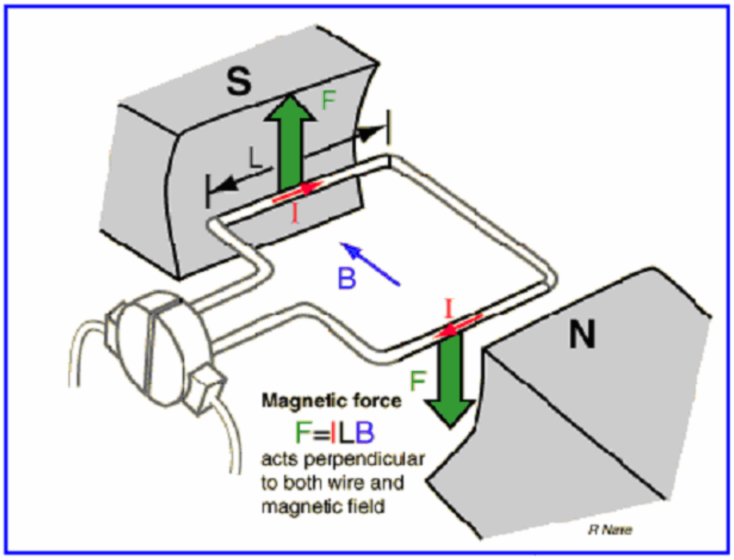
ELECTRO-MECHANICAL COMPONENTS

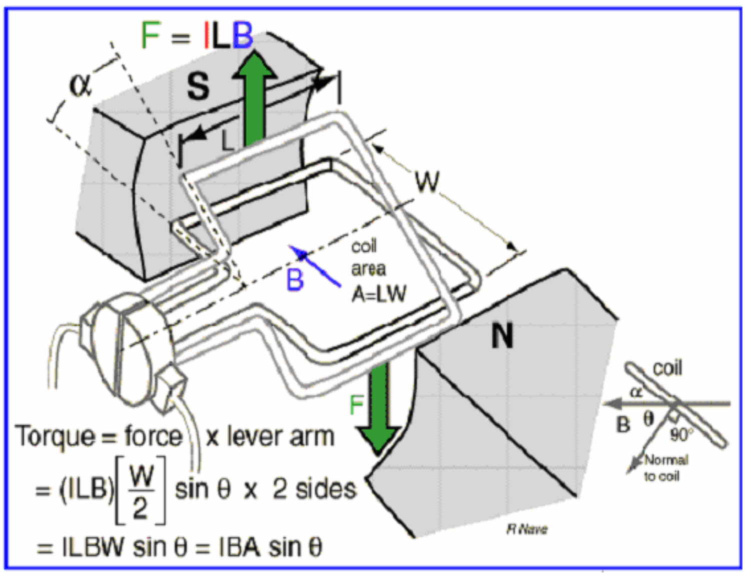
DC MOTOR

The DC Motor forms the electromechanical component of the system. The motor converts the electrical energy to mechanical energy. The following figures show the production of torque in a DC Motor.






S
F
L
I
B
I
N
F
Magnetic force
F=ILB
acts perpendicular
to both wire and
magnetic field
R Nave

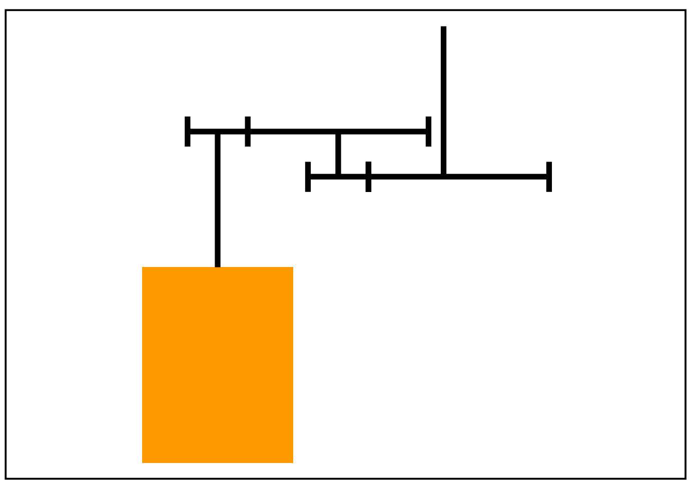

F = ILB
α
S
L
W
coil
area
A=LW
B
N
F
coil
α
B θ
90°
Normal
to coil
Torque = force x lever arm
= (ILB)[W/2] sin θ x 2 sides
= ILBW sin θ = IBA sin θ
R Nave

MECHANICAL COMPONENTS

GEAR ASSEMBLY

The gear assembly is used to improve the torque produced by the DC Motor. Also the speed of DC Motor gets reduced making it ideal for locomotion. If the output of the motor is directly coupled to the wheel, the speed will be high and also the torque will not be enough to move the robot.

A 1:36 gear reduction is used in the robot. This gear reduction is enough to power the robot for locomotion.



COMPLETE CIRCUIT

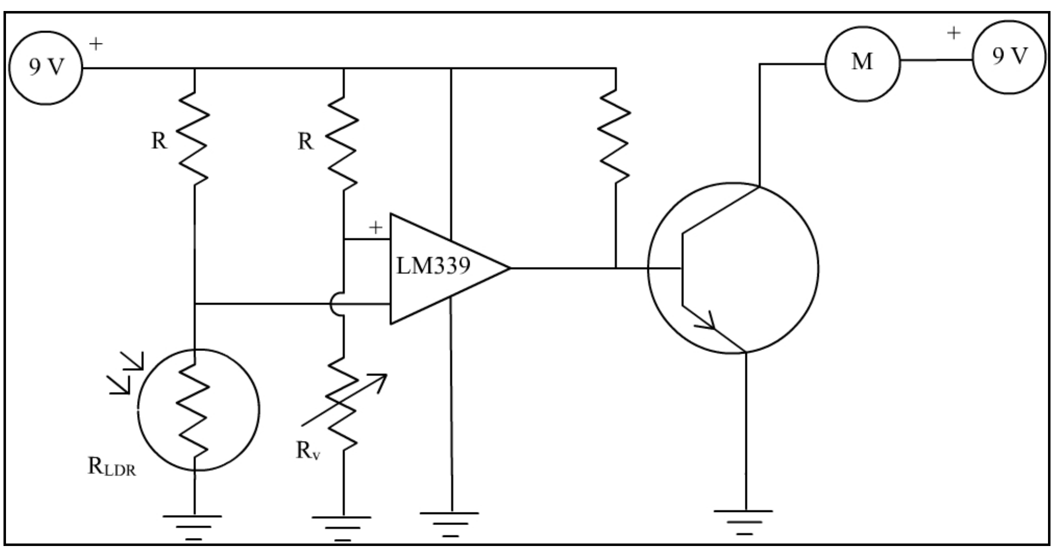
The figure below shows the complete circuit diagram of the line following robot. It shows one circuit which is connected to one of the motors. A similar circuit is connected to the second motor. The variable resistor R_v is tuned so that the reference voltage to the non-inverting input of the comparator is varied. The value is so kept such that the voltage in the inverting input crosses this value as the LDR gets light reflected from the white strip. When the LDR is over the black strip no light is reflected and the LDR value is high.

The equations are given by

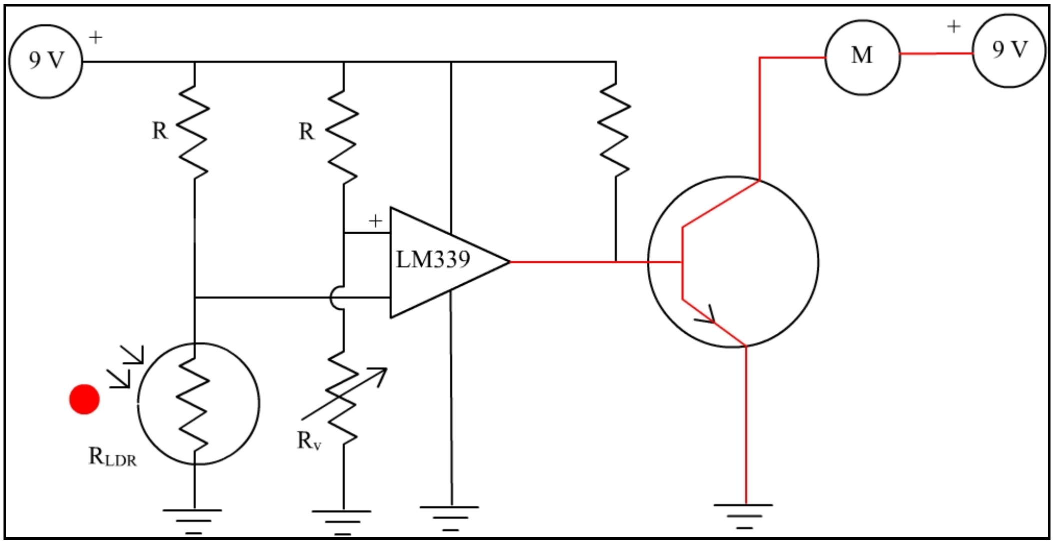
$$V_+ = \frac{R_v}{R_v + R} V_{cc}$$

$$V_- = \frac{R_{LDR}}{R_{LDR} + R} V_{cc}$$

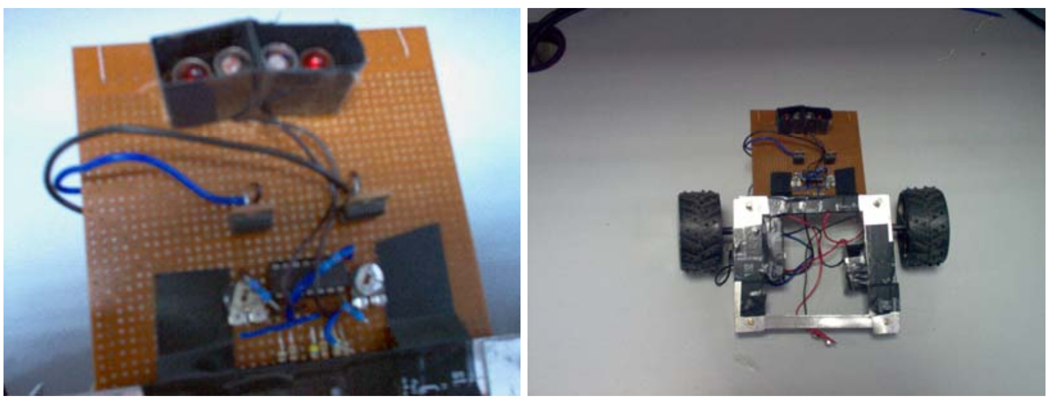
Thus, based on whether light is reflected to the LDR, the value of R_{LDR} changes and the output from the comparator is switched on or off. The figures show the circuit in the absence and presence of light.



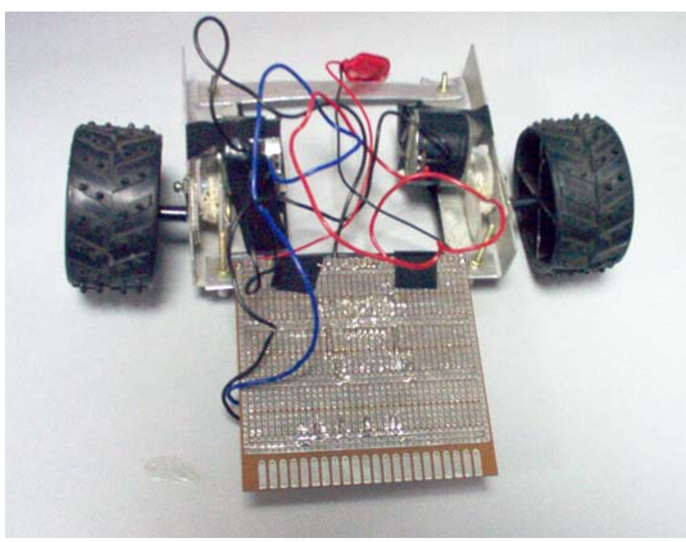
Circuit in off state



Circuit in on state



Circuit and Motors



The Final Robot

PRACTICAL PROBLEMS

ELECTRONIC PROBLEMS

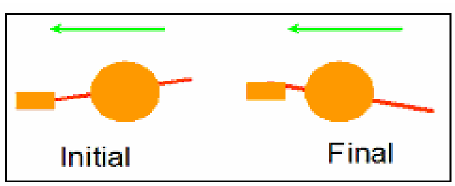
The LDR Initially used had a very high resistance (in MΩ range). Hence the reference voltage was not easily set by tuning the variable resistance. Another problem with the LDRs used was that they were not of the same resistance values. One of the LDR was around 3 KΩ, and the other was 10 KΩ. Hence the two circuits for the two motors were to be tuned differently.

The two LED's had different light intensity. Hence the amount of light reflected from the path was varying for the two LEDs. Also the two LEDs have to be separated physically. The light from one LED was to be prevented from reaching the other LDR. This was done by enclosing the LED and LDR pair in separate boxes.

There were also some problems with the transistors used. Initially transistor BC107 was used but its amperage rating was not high enough. Hence it got overheated and gave rise to heating problems. To prevent this it was replaced with BDX530 which has a heat sink to dissipate heat.

MECHANICAL PROBLEMS

One of the main mechanical problems faced was that of the gear assembly. It was not very rigid and the gears were constantly slipping. Using a worm gear or a thicker gear would have solved this problem.



Another problem faces was in the direction of motion. The power produced by the motors was not enough to push the robot. Hence the motor positions were changed to pull the Robot. Friction was also high due to lack of third wheel. A Teflon Tape was used and it helped in reducing friction to a certain extent.

REFERENCES

- Robot Room.
    - Line following Robots
- How Stuff Works Website.
- Sarjoun Skaffet. et. al., Inertial Navigation and Visual Line Following for a Dynamic Hexapod Robot. IEEE, 2003.