

# Sensor Based Autonomous Color Line Follower Robot with Obstacle Avoidance

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**Abstract**—This paper introduces the multiple source Multiple Destination Robot (MDR-1) having the ability to choose a desired line among multiple lines autonomously. Every line has different colors as their identities. The robot can differentiate among various colors and choose a desired one to find its target. Unlike any other simple line follower robot, this robot can be considered as a true autonomous line follower robot having the ability to detect presence of obstacle on its path. A powerful close loop control system is used in the robot. The robot senses a line and endeavors itself accordingly towards the desired target by correcting the wrong moves using a simple feedback mechanism but yet very effective closed loop system. The robot is capable of following very congested curves as it receives the continuous data from the sensors.

**Keywords**—Feedback, Sensors, Multiple sources multiple destinations, Color pass filter, Obstacle detection.

## I. INTRODUCTION

Line follower robots are one type of mobile robot having ability to follow a line very accurately which have an onboard hardwired control circuit [1] and [2]. Usage of line follower robot is also increasing day by day. Mostly in industrial areas where the automation is very much desired, a new kind of line follower robot can accelerate automatic transportation procedure. Airport can be another section to use this proposed robot technology. Though many researchers are studying regarding line follower robot but most of the concepts are concentrated on theoretical design. As a consequence a line follower robot is designed using artificial intelligence for autonomous driving and to stay on the line [3]. However, a group of robots whose are capable of target tracking is designed using fuzzy logic [4]. This robot team avoid collision among each other, moreover it is uncertain whether it can detect collision with obstacle or not. On the other hand, each member of this robot team capable of following ancestor robot rather than following line. A similar type of result oriented method is described in [5], where system performance is shown through simulation. Like previous method this design procedure is capable of tracking destination and avoids collision among each other through

sensors. A mobile robot controlling algorithm is developed having the ability of avoiding barriers [6]. Another algorithm for multiple controlling mobile robots are prescribed in [7] where performance is shown also through simulation results. Most researchers preferred to show their designed robot performance through simulation. Exception of these works is an efficient underground navigation mobile robot which is designed and tested experimentally [8]. Fuyi Xu et al. described the capability of following very narrow line. But the robot is unable to distinguish among different colored lines and also its expenses are relatively high. Another Practical approach to build graph follower robot is depicted in [9] although this group of robot is unable to track target. Person tracking mobile robot design procedure is introduced in [10] where they can only be used for only one way line follower actions. To meet the requirement of autonomous line based transportation, a new kind of line follower robot has to be designed. This paper provides an answer to that kind of requirements where there will be multiple destinations and the robot should have the ability to choose any of the desired destinations autonomously [11][12]. Moreover the robot should have another ability of avoiding collision which can be achieved either by ultrasound or by infra red (IR) radiation. Without the application of complex sensor like camera and processors, this requirement is very difficult to fulfill. Tremendous amount of calculations and logics are done to meet both cost effectiveness and complexities. Design model accuracy, artificial intelligence for decision making and steering mechanism are some important factors to design a stable and useful multiple source multiple destination line following robot. In this respect, Neural Network can be used to track the target efficiently in a very short time [13] and [14] though it is not contributed in this paper. For designing the model and improving performance, proper stability analysis is required [15]. The line sensors require high resolution and high robustness. Obstacle sensor needs to be accurate and sensitive enough to locate obstacle successfully. This robot is designed for practical applications which may include guidance system for industrial robots moving on shop floors,

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household applications or even at offices for transporting files from one room to any other room etc [16].

In this paper section II describes the basic block diagram of the systems, where section III gives some brief idea about the sensors. Color separation equation and threshold techniques are given in section IV. Section V deals with the algorithm used in the robot. This paper concludes with discussion about the electronics of the robot.

## II. BLOCK DIAGRAM

The block diagram of the MDR-1 robot is given in Fig. 1. LED and LDR based sensors are used here to sense the line. Four LEDs (Tx) and LDR sensors (Rx) facing the ground has been used in this setup. Two of them are used as line detectors and rest of them is used for detecting destination. The output of the sensors is analog in nature which depends on the amount of light reflected back. This analog signal is then processed to produce digital data containing information about the line and color. An IR obstacle sensor is used to gather information about nearby obstacle that may block the line. Processing all those data from installed sensors, the robot's brain generates control signals automatically to perform desired movements.

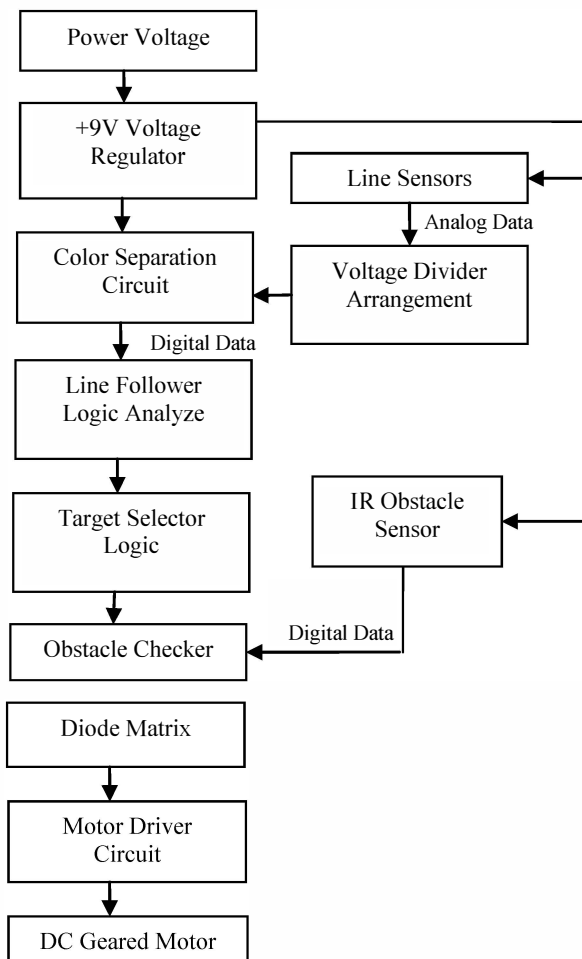


Figure 1. Block diagram of the line follower robot

## III. SENSORS

The robot uses two different types of sensors to gather all the necessary information. The sensors are line sensors and IR obstacle sensor.

### A. Line sensor

It has been observed that to attain efficient line following for any track not more than two sensors are needed on either sides of the line [1][17]. If the surface color is white, it reflects majority of the light and it will be sensed by the receiver. Similarly if we have black surface it absorbs majority of the light and the receiver sense relatively small amount of light. Different colors reflect different amount of light depending on their reflection properties. In this robot blue LED is used as light source and LDR is used as light sensor. When light falls in higher resistance, which means white color results in lowest voltage drop and black color results in highest voltage drop. on white surface, the resistance of the LDR is decreased while black surface results.

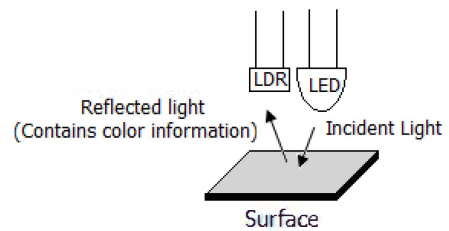


Figure 2. Line sensor arrangement and working principle.

All the other colors have voltage drops in between white and black color. A good sensor will be able to differentiate different colors even if the separation between two colors is very small. A powerful logical equation is developed to utilize this property to extract color information and build this line follower robot. To reduce the ambient light interference, the line sensors are placed in a bounded region where no ambient light can interfere in getting data.

### B. Obstacle sensor

An IR sensor is used for detecting presence of an obstacle. The sensor consists of an IR transmitter and receiver. There is an IR LED which emits IR light in front of the robot and if there is any obstacle nearby which blocks the line, the receiver of the IR sensor picks up the reflected IR light and produces a logic '1' which then forces the robot to stop. Otherwise the output of the IR sensor is logic '0'. The IR transmitter modulates the IR light to produce IR pulses at 38 KHz so that ambient light cannot create any interference in detecting presence of obstacle. The output of the modulated light is given Fig. 3.

## IV. COLOR SEPARATION EQUATION AND THRESHOLDING

Almost all the line follower robots, whose are previously implemented have a limitation that they can only follow either black line on a white surface and vice versa [1] and [18]. A color line follower robot is depicted in [20] which is

partially autonomous. As this robot is Human gesture based line follower robot is described in [19] for gaming systems.

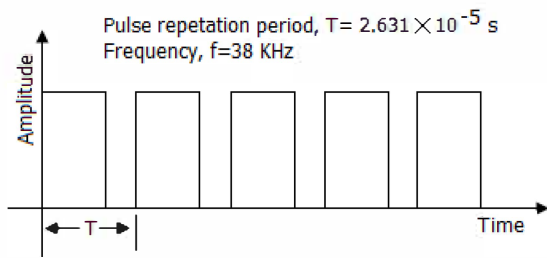


Figure 3. Modulated 38 KHz IR light waveform.

Experimental results of this type of robot also show that it is capable of following a line on the white surface. Another limitation is having no control over the color band. The problem is that all of them used very simple process for defining the line color. Fig. 4 shows simple line color selection process which was used by almost all the line follower robots previously implemented.

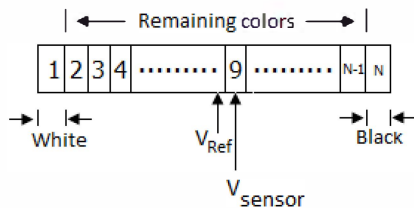


Figure 4. Color band having 'N' number of colors.

From the figure above let consider it to be the color band containing 'N' number of colors. Here first color is set to white and last is set to black. Previous line followers use only one reference point, suppose  $V_{ref}$ . If the voltage across line sensor, suppose  $V_{sensor}$  crosses  $V_{ref}$  it means that the robot is on the line, otherwise not. This process works well but it is a waste of color bandwidth as this process fails to select any particular color as it works as either high pass or low pass filter. For efficient utilization of multiple source multiple destination concept, the color band must be efficiently used. For this we need to have effective control over the color band. This simple process is pointless to do the task. So a more powerful and efficient equation is developed. The solution is to use two reference points instead of one. The figure below shows the upgrade color selection process which is used by this robot.

Now if we want to select any color suppose color '9' we have to take two reference points instead of one. Let  $V_{ref1}$  and

$V_{ref2}$  are the points which satisfies the conditions-

- $V_{ref1} < V_{sensor}$
- $V_{ref2} > V_{sensor}$

Here,  $V_{sensor}$  is the voltage against color no.'9'.

Now the logical equation for the color separator or color pass filter will be -

$$V_{Logical} = (V_{sensor} \sim V_{Ref1})(V_{Ref2} \sim V_{sensor})$$

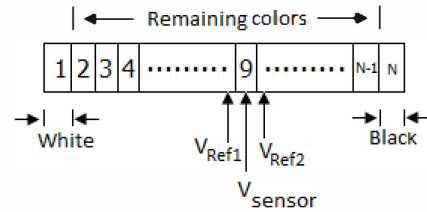


Figure 5. Two reference point method for color selection.

Here ' $V_{Logical}$ ' is binary output of line color selection process. When,  $V_{Logical} = 1$ , the particular color no.'9' is selected and when  $V_{Logical} = 0$ , color no. '9' is not selected.

This equation produces,  $V_{Logical} = 0$ , if  $V_{sensor}$  is outside the range  $V_{ref1}$  to  $V_{ref2}$ .

This equation is equivalent to a frequency band pass filter. It can be used for selecting a particular color as well as any particular range of colors. It forms the basis of control over the range of color band and it is the basic equation utilized for the MDR-1 robot.

If  $V_{ref} \ll V_{sensor}$  and  $V_{ref2} \gg V_{sensor}$ , a wide range of color will be selected and if the difference between  $V_{ref1}$  and  $V_{ref2}$  is small, a particular color will be selected.

Let consider the destination colors (line identity) have voltages,  $V = V_1, V_2, V_3, \dots, V_N$  across them, where  $V_1$  is the voltage against first destination color and  $V_N$  is the voltage against last destination color. The outer surface has voltage  $V_s$  and common line has voltage  $V_L$ .

Let separation between neighboring two colors is  $V_D$  which acts as a protector against inter-color interference. It can be considered as the bandwidth of a color.

$$V_D = V_{n+1} - V_n$$

Where,  $n=1, 2, 3, \dots, N-1$ .

Voltage across destination color satisfies one of the two conditions-

- (1)  $V < V_s$  if  $V_s > V_L$
- (2)  $V > V_s$  if  $V_s < V_L$

Each color requires two reference voltages to be tracked.

Reference voltages for  $V1$  will be-

$$V1_{Ref1} = V_1 - \frac{V_0}{2}, \text{ and } V1_{Ref2} = V_1 + \frac{V_0}{2},$$

For  $V2$  that will be-

$$V2_{Ref1} = V_2 - \frac{V_0}{2}, \text{ and } V2_{Ref2} = V_2 + \frac{V_0}{2}$$

and so on for rest of the destinations.

Voltage across common line color ( $V_L$ ) when  $V_s < V_1$  should be chosen such a way that common line voltage it satisfies one of the following conditions-

- $$\left. \begin{array}{l} (1) V_1 > V_L > V_s \\ (2) V_L > V_N \\ (3) V_1 < V_L < V_N \end{array} \right\} \text{When } V_s < V_1$$

But if  $V_s > V_N$ , conditions for  $V_L$  should satisfy one of the following conditions –

- $$\left. \begin{array}{l} (1) V_N < V_L < V_s \\ (2) V_1 < V_L < V_N \\ (3) V_L < V_1 \end{array} \right\} \text{When } V_s > V_N$$

All the colors must have minimum separation  $V_D$  from its neighboring color.

The common line should have one of the following reference voltages.

$$(1) V_{ref1} = V_L - \frac{V_0}{2}, V_{ref2} = V_N + \frac{V_0}{2}$$

If  $V_1 > V_L > V_s$ , or  $V_L < V_1$

$$(2) V_{ref1} = V_1 - \frac{V_0}{2}, V_{ref2} = V_L + \frac{V_0}{2}$$

If  $V_N < V_L < V_s$ , or  $V_L > V_N$ .

$$(3) V_{ref1} = V_1 - \frac{V_0}{2}, V_{ref2} = V_N + \frac{V_0}{2}, \text{ if } V_1 < V_L < V_N$$

$$V_1 < V_L < V_N$$

To calculate theoretical maximum number of colors that is available, let consider the sensor voltage for white color be  $V_w$  (lowest voltage against any color) and for black color it is  $V_s$  (highest voltage against any color).

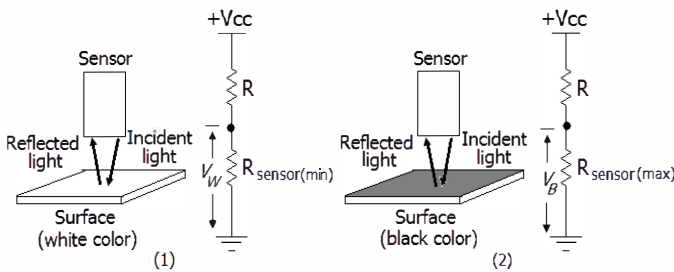


Figure 6. Voltages divider arrangement for calculating voltage drop across black and white color.

Applying voltage divider rule we find that-

$$V_w = \frac{V_{cc} \cdot R_{sensor(min)}}{R + R_{sensor(min)}} \text{ and } V_s = \frac{V_{cc} \cdot R_{sensor(max)}}{R + R_{sensor(max)}}$$

If we take separation between two neighboring colors as  $V_D$  voltage, then the maximum number of different colors that will be available is-

$$\text{No. of different colors available, } T = \frac{V_B - V_w}{V_D} + 1$$

But if  $V_s \neq V_w$  or  $V_s \neq V_B$ , then number of available colors will be reduced. Let the number of lost colors be  $L$ .  $L$  will have one of the following values-

$$(1) L = \frac{V_s - V_w}{V_D}, \text{ if } V_s < V_1$$

$$(2) L = \frac{V_B - V_s}{V_D}, \text{ if } V_s > V_N$$

So, the actual No. of available colors ( $T_c$ ) will be-

$$T_c = T - L$$

$$T_c = \left[ \frac{V_B - V_w}{V_D} + 1 \right] - \left[ \frac{V_s - V_w}{V_D} \right], \text{ if } V_s < V_1$$

$$\text{Or, } T_c = \left[ \frac{V_B - V_w}{V_D} + 1 \right] - \left[ \frac{V_B - V_s}{V_D} \right], \text{ if } V_s > V_N$$

If  $V_s = V_w$  or  $V_s = V_B$  then,  $L = 0$ . Then actual No. of available colors will be,  $T_c = T$ .

So, Total No. of possible destinations,

$$T_T = T_A - (\text{Outer surface color} + \text{Common line color})$$

So,  $T_T = T_A - 2$ .

Each destination will have different colors as their identity. From the above equation it is clear that the lower the value of  $V_D$ , the higher will be the number of available colors. But lower value of  $V_D$  may cause inter-color interference.

Optimum value of  $V_D = 0.03 V_{cc}$

## V. ALGORITHM

An efficient algorithm is developed to make the robot have the ability to find its destination from the source and follow it. If all calculations are properly done, the robot will never fail to track and follow a line from its source to the destination. Let's see the configuration of the line sensors of the robot.

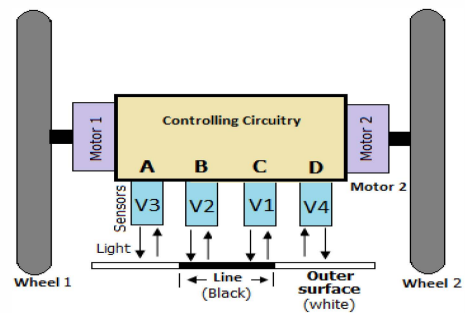


Figure 7. Line sensor arrangement of the robot.

The robot has four line sensors named 'A', 'B', 'C' and 'D' shown in Fig. 7. Sensor 'B' and 'C' act as common line sensors. Sensors 'A' and 'D' search the destination line. Let

voltages across the sensors be  $V_A, V_B, V_C$  and  $V_D$  respectively. The Table I shows functions of all the line sensors. Let logic level for sensor 'A', 'B', 'C' and 'D' are  $V1, V2, V3$  and  $V4$  respectively.  $V1, V2$  are common line logic levels and  $V3, V4$  are destination logic levels.

Table I. Functions of different line sensors

No.	Sensor name	Function
1.	A	Locate target if it is in left side of common line.
2.	B	Common line sensor to follow the line.
3.	C	Common line sensor to follow the line.
4.	D	Locate target if it is in right side of common line.

Applying the color separation equation-

$$V1 = (V_C \sim V_{Ref1}).(V_{Ref2} \sim V_C)$$

$$V2 = (V_B \sim V_{ref1}).(V_{Ref2} \sim V_B)$$

Where,  $V_{Ref1} < V_C, V_{Ref2} > V_C$

And  $V_{Ref1} < V_B, V_{Ref2} > V_B, V_{Ref2} > V_B$

Similarly,  $V3 = (V_A \sim V_{Ref3}).(V_{Ref4} \sim V_A)$

$$V4 = (V_D \sim V_{Ref3}).(V_{Ref4} \sim V_D)$$

Where,

$$V_{Ref3} < V_A, V_{Ref4} > V_A \text{ and } V_{Ref3} < V_D, V_{Ref4} > V_D$$

Every target line has its own identity. A particular color is assigned at the beginning of each destination as its identity. Sensor 'A' and 'D' searches this identity and compares it whether it is the desired destination or not. If it matches, then the robot performs necessary movements for following that line autonomously.

Here there are three destinations namely target1, target2 and target3. There are three different colors blue, red and yellow as their identity. Black is the common line color and outer surface color is white. The robot has the ability to go from one target to any other target autonomously based on the data analyzed by the mathematics and logic mentioned previously. The sensors 'B' and 'C' are used to follow the common line and 'A' and 'D' is used to find matching of the line identities.

The truth table below provides all the possible conditions and movements of the robot.

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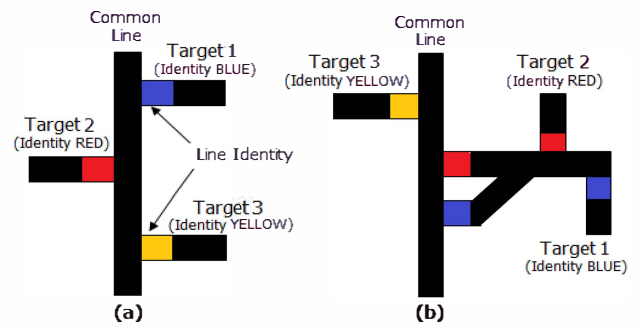


Figure 8. An exemplary of different line arrangement.

Simplified expressions for robot movements are-

$$Forward = (V1.V2.\bar{V3}.\bar{V4}).\bar{IR}$$

$$Right = [[(\bar{V1} + V2).V4] \oplus (V1.V2)].\bar{IR}$$

$$Left = [[(V1 + \bar{V2}).V3] \oplus (V2.\bar{V1})].\bar{IR}$$

The truth table shows that whenever  $V3 = V4 = 1$ , the robot will stop moving as it will be confusing for the robot to take decision whether to turn right or left.

Table II. Different conditions and corresponding movements

No.	IR (obstacle)	V1	V2	V3	V4	Command
1	0	0	0	0	0	Stop
2	0	0	0	0	1	Right
3	0	0	0	1	0	Right
4	0	0	0	1	1	Right
5	0	0	1	0	0	Left
6	0	0	1	0	1	Stop
7	0	0	1	1	0	Forward
8	0	0	1	1	1	Right
9	0	1	0	0	0	Left
10	0	1	0	0	1	Stop
11	0	1	0	1	0	Stop
12	0	1	0	1	1	Stop
13	0	1	1	0	0	Left
14	0	1	1	0	1	Stop
15	0	1	1	1	0	Left
16	0	1	1	1	1	Stop
17	1	x	x	x	x	Stop

## VI. MOTOR INTERFACE AND CONTROL CIRCUITRY

a) *Voltage Regulator*: The mathematics that is followed by this robot is very much dependent on voltage levels. Moreover, the brightness of the LED changes linearly with voltage change. So, to provide constant voltage, regulated voltage source is used in this robot. In this case +9V voltage regulator is used shown in Fig. 9.

b) *Comparators, Voltage Divider and Logic Gates*: Color separation equation requires comparators and logic gates for their implementation. Voltage divider networks provide necessary reference voltages. Instead of using microcontrollers basic digital electronics is used for designing the brain of the robot which makes it extremely cost effective and reduces complexity.

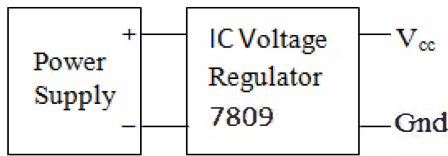


Figure 9. Voltage regulator arrangement.

c) *Diode Matrix and Motor Drivers:* The brain of the robot generates instructions of movement and a diode matrix distributes those data to the right and left wheel motor drivers, which drive the wheels of the robot. H-bridge motor drivers are used in this robot to drive wheel motors.



Figure 10. Different color sensing

d) *Driving and Steering Mechanism:* Steering mechanism has to be efficient for a line follower robot [1]. Two DC geared motors are used for driving. Those two motors are responsible for driving the robot backward and forward as well as steering in any required direction. A free running wheel is set in front of the robot. The robots steering mechanism is designed in such a way so that it can perform tight turns. The complete steering process is listed in the table III.

Table III. Different commands and corresponding wheel movements

No.	Command	Wheel 1	Wheel 2
1.	Forward	Forward	Forward
2.	Right	Forward	Backward
3.	Left	Backward	Forward
4.	Stop	Stop	Stop

## VII. CONCLUSION

The concept of the line follower robot is practically implemented in this paper based electronics logic circuit and sensors. Simultaneously, makes the use of instructions from sensors and on board logic circuits performs physical movements. The robot is succeeded to locate and follow target. This robot can follow not only black and white colors but also some other different colors. If the conditions are properly set and calculations are accurately done, then performance rate and accuracy will be more than ever. The algorithm guarantees its accuracy. Further modification of this robot includes application of shortest path algorithm and neural network so that it can find its target more efficiently in shortest amount of time.

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