DESIGN OF A LINE FOLLOWING SENSOR FOR VARIOUS LINE SPECIFICATIONS

Tushar Supe¹, Aishwarya Joy²

¹,²Department of Electronics and Telecommunication, Fr. C. Rodrigues Institute of Technology, Navi Mumbai, India.

ABSTRACT

A line follower is an autonomous robot which navigates by following a line present on the surface beneath the robot. The specifications of the line are in terms of its width and its color with respect to the color of the background. This paper describes a circuit to implement the sensor which can be designed to work with different line specifications and provide the output in a digital format making it much easier to utilize; and its results. It presents a comprehensive idea using which the threshold for the detection of the line from the background is decided and the circuit is designed to implement the same. It also describes the different frequency ranges that can be used for the same such as infrared and the basic colors of the visible spectrum, and their respective characteristics.

Keywords: Line following, Color detection, Line Specifications, Optical Sensor, Robotics, etc.

I. INTRODUCTION

The line following robot is a common autonomous robot which finds several applications in the field of robotics. It is essentially a bot which can navigate by itself to follow a line. The line maybe a predefined path for the bot follow depending upon the application. The working of the line follower can be broadly divided into two parts namely, the sensor used for the detection of the line and the microcontroller which takes the input from the sensor and accordingly decides which direction to move in. This paper proposes a design for the line following sensor to work with different line specifications and does not deal with the microcontroller aspect of the robot.

The specifications of the line are discussed mainly in terms of its width and its color in comparison to the color of the background. The width of the line however only influences the position of the sensors and whether isolation between two sensors is required. On the other hand, the color of the line greatly influences the requirements from the sensor. The most common configuration is that
of a white line placed on a black background or vice versa. However, this paper describes the design of a sensor for any given color for the line.

II. LITERATURE REVIEW

The previous work done based on this topic mainly focuses on the implementation of the line follower robot for the line specification of a white line on a black background. There exist papers which discuss the difficulties faced in implementing the same [2][3]. In other research, the line following mechanism has been tested on a helicopter to follow a multi-colored line on a white surface [4]. The positioning of the sensors and the performance of the bot for lines involving different curves and angles has been discussed [9].

Some other approaches to achieve the same are also possible such as with the use of image processing and a camera [1]. However the use of image processing makes the implementation a rather complex procedure. Also there are optimized algorithms for the line follower to adapt to its specific surroundings the first time the robot is run [5]. Similar work in the field of robotics has been done to implement photovore bots which navigate to areas with where the intensity of light is higher [6].

The line following robot has been utilized for various applications. Some of the innovative applications are in shopping centers [7] and cell phone detection [8].

III. WORKING

The color black is known to absorb all wavelengths falling onto it whereas the color white completely reflects back the wavelengths falling onto it. Therefore the difference between the two can be found by exposing it to a source of light or infrared and measuring the amount of reflected energy. An infrared LED is most commonly preferred as the source as the interference of ambient lighting is negligible. Colored LEDs can also be used as a source if proper isolation from the ambient light is provided. This can be easily achieved as the sensor has to be placed below the bot itself.

The color white is formed by the combination of all the primary colors and thus reflects wavelengths of all these colors. Therefore a red surface would reflect red light and absorb all other wavelengths. The same is applicable to all other colored surfaces. Likewise the infrared waves as well as white light can be used when only a difference in contrast is required to be detected. These statements were tested for their validity as described below.

IV. TEST SETUP

![Circuit Diagram of Test Circuit for LDR](image-url)
The circuit was developed as shown in figure 1. Two LEDs D1 and D2 are connected in series to illuminate the surface and the reflected light is allowed to fall onto LDR1. It should be noted that higher the current through these LEDs, more light will be emitted from the same. However, this current should not exceed the maximum current rating of the LED. The amount of current passing through them is controlled by the resistance R5 and is given by (1) which is valid for this circuit only.

\[
I_f = \frac{5 - 2V_f}{R5} \quad (1)
\]

Where, \( I_f \) = Forward biased LED Current  
\( V_f \) = Forward Voltage Drop of LED  

The resistance of LDR1 varies depending upon the amount of light falling onto it. The operational amplifier LM324 is used as a comparator. The voltage at the inverting terminal is kept at a constant value of about 6V using a potential divider. The voltage at the non-inverting terminal is dependent on the value of the resistance of the LDR. The threshold resistance is an intermediate value between the LDR resistance on the line and outside the line. Thus when the LDR is facing the brighter surface of the two, its resistance is lower than the threshold resistance and the value at the non-inverting terminal increases above 6V and the output is driven to saturation and vice versa. The output of the LM324 is run through the coil of a relay. The variable resistance RV1 has been used to adjust the threshold resistance.

\[\begin{array}{c}
\text{Fig. 2. Colour Strips for Testing}
\end{array}\]

The operational amplifier is connected to 12V supply to increase the voltage swing obtained at the non-inverting terminal as the resistance of the LDR is varied. This reduces the effects of noise and provides better accuracy. The 12V and 5V circuitry is isolated with the use of the relay.

For the purpose of testing, the color strips as shown in figure 2 were developed and printed with the following specifications. Strip 1 (Blue) starts at R0 G0 B0 and ends at R0 G0 B255 where R is Red, G is Green and B is Blue. Strip 2 (Green) begins with R0 G0 B0 and ends with R0 G255 R0. Strip 3 (Red) starts with R0 G0 B0 and ends with R255 B0 G0. The final strip (White) begins with R0 G0 B0 and ends with R255 G255 B255. The length of each strip is 24cm.
The phototransistor is another device which is sensitive to light and can be used for the purpose of line following. The circuit for the same is as shown above. It is to be noted that to reduce the computation for the microcontroller or in the lack of an ADC a comparator may also be used like in the previous case. However, the threshold voltage has to be manually calculated and then the comparator has to be accordingly designed. The simplicity of the threshold resistance as depicted in the previous case is not present.

V. TESTS AND RESULTS

5.1. Test 1

The sensor circuit shown above was developed for a 5mm red LED and the threshold resistance used was 470 (+100) ohm, by replacing R3 with a 470ohm resistor and RV1 is a 100ohm potentiometer. The forward voltage drop of the LED was found to be about 2.1V and the current through being about 17mA. The LDR used in this case is a small 5mm LDR with dark resistance of 1Mohm. This sensor was then assembled onto a bot ensuring the sensor height remains constant for all the readings taken. The sensor was placed to have a clearance distance of about 0.8cm from the ground. The strips which were developed were placed on the surface and the bot was programmed to keep moving straight along the direction of the strip till the threshold was crossed. The same was repeated 10 times to test the repeatability of the circuit and the distance travelled in each case was measured. The observations were as stated in Table 1.

<table>
<thead>
<tr>
<th>Strip Number</th>
<th>Minimum Distance Travelled</th>
<th>Maximum Distance Travelled</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strip 1 (Blue)</td>
<td>24cm</td>
<td>24cm</td>
<td>0cm</td>
</tr>
<tr>
<td>Strip 2 (Green)</td>
<td>24cm</td>
<td>24cm</td>
<td>0cm</td>
</tr>
<tr>
<td>Strip 3 (Red)</td>
<td>15.7cm</td>
<td>17.0cm</td>
<td>1.3cm</td>
</tr>
<tr>
<td>Strip 4 (White)</td>
<td>12.7cm</td>
<td>13.9cm</td>
<td>1.2cm</td>
</tr>
</tbody>
</table>
For the first two strips, the bot kept moving and did not stop till the end of the strip. For the third strip, the bot came to a halt in every case however the distance at which it did so varied by small amounts. The maximum and minimum values of the same were 17.0cm and 15.7cm which correspond to the colors R181 and R167 approximately. The corresponding readings for strip 4 are R148 G148 B148 and R135 G135 B135 approximately.

As the first two strips are formed purely of green and blue components and do not possess any red component, the red light emitted by the LEDs is not reflected back at all. Thus there are no variations in the resistance of the LDR and the bot does not come to a halt till the end of the strip. The third and fourth strip contained components of red and thus the threshold was crossed as the bot moved towards the end with higher red component. The bot is expected to come to a halt at the same distance for both the strips since the red component for both strips is the same. However it is observed that such is not the case. This may be attributed to ambient light (generally white) present in the surrounding which would be reflected onto the sensor in higher amounts by the white strip than the red strip. Another possible factor is the inaccuracy in the printing of the strips. The resolution in each case however is approximately the same which is 13 to 14 shades. This may even be improved further by improving the shielding of ambient light and surrounding sensors and with the use of high precision operational amplifier and resistors.

5.2.Test 2

In this test, the comparator circuitry was removed and only the resistance of the LDR was measured at specific distances on the strips. This was performed for different sets of LEDs emitting different frequencies. The observations were as stated in Table 2.

<table>
<thead>
<tr>
<th>LED and Strip</th>
<th>Resistance At (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23cm</td>
</tr>
<tr>
<td>Red LED on Blue Strip</td>
<td>607</td>
</tr>
<tr>
<td>Red LED on Green Strip</td>
<td>605</td>
</tr>
<tr>
<td>Red LED on Red Strip</td>
<td>351</td>
</tr>
<tr>
<td>Red LED on White Strip</td>
<td>332</td>
</tr>
<tr>
<td>White LED on Blue Strip</td>
<td>18.1K</td>
</tr>
<tr>
<td>White LED on Green Strip</td>
<td>18.1K</td>
</tr>
<tr>
<td>White LED on Red Strip</td>
<td>17.9K</td>
</tr>
<tr>
<td>White LED on White Strip</td>
<td>9.6K</td>
</tr>
<tr>
<td>IR LED on Blue Strip</td>
<td>82.9K</td>
</tr>
<tr>
<td>IR LED on Green Strip</td>
<td>83.4K</td>
</tr>
<tr>
<td>IR LED on Red Strip</td>
<td>82.1K</td>
</tr>
<tr>
<td>IR LED on White Strip</td>
<td>77.5K</td>
</tr>
</tbody>
</table>

It is observed that the strips’ containing red components (white and red strips) reflect back more red light than the other two strips. Thus the resistance for those strips is lower towards the nonblack areas. When white light was used, the responses obtained for the first three strips were similar to each other. Although, the resistance obtained from the white strip was lower than the other
strips as the white strip reflects back all the light falling onto it while the colored strips reflect only that respective color component from the white light. The same is also applicable for IR. However the LDR response for the IR frequency is much less sensitive as depicted from the readings.

This concept can also be used for the detection of colors in the following manner. Expose a completely white surface and obtain the reading of the LDR when it is exposed to red, green and blue light sequentially. Repeat the same process for a black surface. The readings obtained would be mapped to the 8bit color range i.e. 0 to 255. Now when any surface is brought next to the device, the corresponding readings on the LDR for each component of white light can be used to determine the shade of the surface next to it. However, one should bear in mind that for efficient functioning, all the surfaces to be tested have to at approximately equal distance from the LDR.

5.3. Test 3

This test utilizes a phototransistor as the receiver instead of the LDR. The circuit shown in figure 3 was developed for the LEDs being red and IR. The output from the circuit was provided to the 10bit ADC of a microcontroller and it was programmed to take the digital inputs continuously, 10 times every second, for 10 seconds while the sensor was placed either on a white or a black surface. The maximum and minimum values from the total recorded values were noted and are as shown in Table 3. The value of R1 in the circuit shown in figure 3 can be adjusted to provide higher resolution to the changes in current between the black level and white level. In this experiment, the value of R1 was chosen as 680K for the test with red LEDs and 1K for the test with IR LEDs.

<table>
<thead>
<tr>
<th>LED Color</th>
<th>Maximum value on white surface</th>
<th>Minimum value on white surface</th>
<th>Maximum value on black surface</th>
<th>Minimum value on black surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>551</td>
<td>477</td>
<td>943</td>
<td>903</td>
</tr>
<tr>
<td>IR</td>
<td>687</td>
<td>685</td>
<td>948</td>
<td>948</td>
</tr>
</tbody>
</table>

It can be seen that there is a clear distinction between the white and black levels in both the cases. For both cases a threshold of about 700 can be used to distinguish between the two. Also one may choose the value of R1 as required, to provide a greater difference between the white and black levels. But it can also be observed that the value of R1 required for red light is very high which is due to the low sensitivity of the phototransistor towards the red light. Also this causes the values obtained to possess lots of variations and not remain stable.

VI. ADVANTAGES AND DISADVANTAGES

The LDRs have a rise time typically around 5ms to 100ms and a fall time typically about 1ms to 50ms which make the LDR a slow device. If the application requires high speed operation, then the LDR fails to provide a reliable output. This is the major disadvantage of the same. Some other minor disadvantages are that its performance is affected by ambient light and also by the distance of the reflecting surface from it. The phototransistor however can work at high speeds and provide a reliable output at the same time. However, if a high resolution if expected from the phototransistor the speed of the ADC should be taken into account.

On the other hand, the phototransistor has the disadvantage of being less sensitive to the visible spectrum than the LDR and thus cannot be used for line following when the line or the background happen to be colored (different from black and white). Another disadvantage is that the phototransistor has lower range than the LDR and thus the position of the sensor has to be closer to the ground for accurate responses. It does however possess a greater sensitivity for the IR frequency
than the LDR. Although the problem of ambient light interfering with its performance is much lower for the phototransistor, coded or modulated signals of a specific frequency can be provided to the LED and the controller can be programmed to determine the response of that particular frequency only, to further reduce the effect of ambient light.

VII. DESIGN STEPS

To design a line follower therefore, one should firstly determine whether the application requires a LDR or a phototransistor based on the points discussed above. If one proceeds to use an LDR, he should determine the threshold resistance by testing the value of the resistance on and off the line and design the circuit and also the right frequency/color. For example, a white line placed on a blue background maybe easily distinguished by the response of the LDR under red light. In the case of the phototransistor, one may choose to place a potentiometer in place of R1 to determine the value at which optimum resolution is obtained.

VIII. CONCLUSION

The design of a line follower can be easily achieved using the proposed designs which are inexpensive and easy to implement. For all line specifications, this paper provides a design technique to implement the line follower with ease.

IX. REFERENCES


