Design Implementation of High-Performance Line Following Robot

Milan Shah, *L.D.College of Engineering*; Viraj Rawal, *Vishwakarma Government Engineering College*; and Jay Dalwadi, *L.D.College of Engineering*

***Abstract*—Nowadays, in hospitals, in medical centers, in farming, in the military, on factory floors, in each and every field application of robotics is increasing day by day. Line following robot is one of the widely used robots. Basically, line following robot is an autonomous mobile system which follows the line which has a different color from the background. So the performance of these line following robots heavily depends upon its efficiency in differentiating the line from the background. Many robotic events based on the line following robot are organized at college as well as industry level all across the world. In this paper, we have described various problems we faced while designing the line following system for the robot for ROBOCON 2016 (International robotics event), how we overcome them and how we designed the most optimized, efficient and high-performance line following system.**

***Index Terms*—Robotics, Line Following Robot, Control, Feedback, Autonomous System, Mobile System**

I. INTRODUCTION

Basically, line following robot achieves the objective of following the line through feedback. As shown in figure 1, sensors, placed over the line, send different signals, to the microcontroller, depending upon their position over the line.

Sensors consist of sender and receiver. The sender can be infrared LED (Light Emitting Diode), LED, LASER (Light Amplification by Stimulated Emission of Radiation) diode, etc. while the receiver can be photodiode, phototransistor, LDR (Light Dependent Resistor), etc. The sender sends a signal which gets reflected from the surface of the path to be followed and then incidents at the receiver. Now, different color has different absorptivity for the incident signal from the sender so the signal going towards the receiver, after the reflection, will have a different intensity. In this way sensors for line following robot work.

Microcontroller compares this signal to the ideal value, the value which sensors give when the robot is at the desired place on the line. Depending upon the difference between ideal value and actual value, the microcontroller generates a signal which is applied to the driver circuit.

So as shown in Figure 1, the performance of line following robot heavily depends upon sensors as they generate an input signal for microcontroller depending upon their position over the line to be followed.

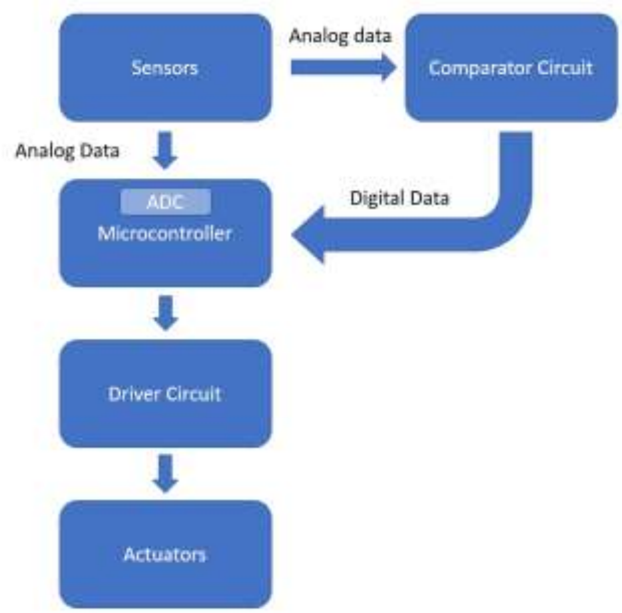

Fig. 1 – Schematic Block Diagram of Basic Line Following Robot

The paper outline is as follows: Section I describes about the basic concept of the line following robot and its main components. Section II describes about factors affecting the sensing in line follower robot. It is aimed at explaining in which situation which type of sensors is recommended. Section III expands the topic of when ADC should be used and when comparator. Section IV explains about how sensor arrangements play the crucial role and how sensors should be arranged depending upon the path. Section V concludes about the findings of our research.

II. FACTORS AFFECTING THE SENSING IN THE LINE FOLLOWING ROBOT

While designing the most optimized, efficient and high performance line following system for the robot for ROBOCON 2016, we faced many problems in sensing because, as shown in figure 2 and figure 3, in this competition the line to be followed had white color but the surrounding of that line was of various different colors at some interval. So here we have described different sensors we used, pros and cons of each of them and which sensor we finalized for our use and why.

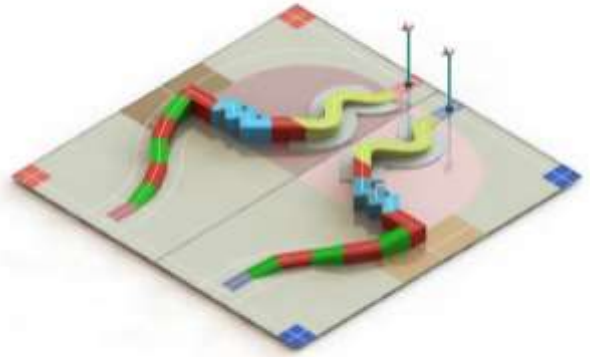

Fig. 2 – Isometric view of the actual game filed [1]

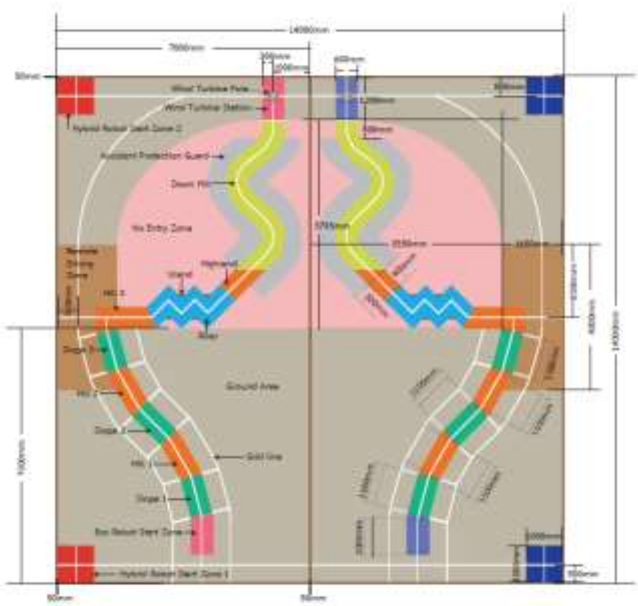

Fig. 3 – Top view of the actual game field [1]

We experimented with the following sensor combinations:

A. Infrared LED and Photodiode:

This duo works completely accurate when there is a white line to be followed in the black background or vice versa. But in our experiment, we could not use this duo efficiently because, as stated earlier, in the competition, the line to be followed had white color but the surrounding of that line was not black. So here photodiode was not able to discriminate between the signals getting reflected from white line and surrounding because, for the background of some colors, the difference was too small. Another demerit of this sensor combination is that they do not work properly when the game field is in open area because the sunlight also has an infrared light which interferes with the signals coming from the infrared LED.

B. LED and LDR:

In this case, for the sender, we had used normal LED and for the receiver, we had used LDR. This combination was better than the previous one because it was more reluctant to sunlight noise. In fact, the difference in the output voltage from the receiver was little high compared to the previous one but not high enough every time to be detected perfectly. For this, frequent calibration was required. Another drawback was that it was not able to discriminate between the surrounding colors which have very less color difference from white.

C. LASER Diode and LDR:

This time for sender we used LASER diode instead of normal LED. The main advantage of using LASER Diode is that it generates a highly dense light signal so the external sunlight has almost no effect on the LDR. So this duo gives quite an impressive result. But we faced the main issue when the surrounding has the same color as the LASER diode has e.g. we had used RED color LASER Diode as a sender and it worked really fine for all other color surroundings but it failed when we tested on the RED color surrounding. The reason was that pigments were used on the surface of the game field and they have the property of absorbing the light of the same color. Another important demerit of LASER Diode is their cost; they are very costly compared to normal LED. So when many LASER diodes are used, the overall cost of sensors becomes quite high.

D. White color LED with high Intensity and LDR:

Here we replaced the LASER diode with White color LED with high Intensity and it got the optimum result. It worked quite well for all the different color surroundings without any issue. In fact, as this LED has high intensity, there was no effect of sunlight. But, here, the distance between the surface of game field and sensors come into the picture. For this system, we had to keep the distance as low as possible for better color change detection, but it affected the speed of the robot because of the friction between sensors and the track.

E. White color LED with high Intensity and LDR having large surface Area:

Now, to overcome the robot speed issue of the previous case, we experimented with LDR. This time, we used the LDRs which had large surface area and the result was quite satisfactory. This duo was perfect because it was able to discriminate almost minute color difference at sufficient height without contributing any friction i.e. without hindering speed of the robot. Thus *White color LED with high Intensity* *and LDR having large surface Area* become the optimum choice for us.

III. ADC V/S COMPARATOR

ADC (Analog to Digital Converters) are among the most widely used devices for data acquisition. We need an ADC to translate the analog signals to digital numbers so that the microcontroller can read and process them. [3]

In most of the cases, the output of the basic sensing circuit of the line following robot is basically nothing but the voltage drop across the sensing element which can be photodiode, phototransistor, LDR, etc. As shown in figure 4, voltage drop across the LDR represents change in line color. Generally, in line following robot, the microcontroller is used to control the robot, and as the CPU of microcontroller works only on digital signals, output analog signal must be converted to digital before it's applied to the microcontroller.

There are many ways to convert this analog output signal, from the basic line following circuit, to digital, but following two are mainly used depending upon requirement(s):

- Using ADC (Analog to Digital Converter)
- Using Comparator

A. *Using (Analog to Digital Converter):*

Nowadays, most of the advanced microcontroller has inbuilt high-resolution ADC, so there is no need to use external ADC. In our experiment, we had used Arduino Mega development board which has Atmel's AVR ATmega 2560 microcontroller. This microcontroller has inbuilt ADC of 10-bit resolution and has 16 analog input pins and base value of 5 volts i.e. 16 different analog signals having value in between 0 volt and 5 volts can be applied to this microcontroller.

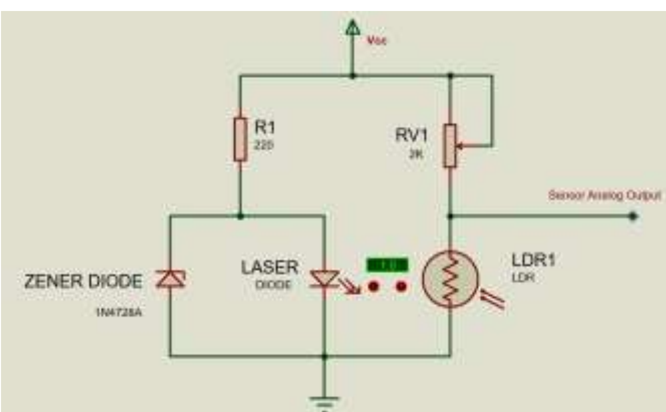

Fig. 4 – Basic line following circuit (using LASER diode and LDR)

So, after our research, we found when ADC is preferred over comparator:

1. When the speed of the line follower is not very critical, as processing the analog signal and translating it to digital signal requires more time compared to the comparator.

2. When the robot has to handle many other tasks, apart from following the line, and that requires many digital inputs/outputs and those are not very time critical.

3. When there are fewer sensors used in the robot. Because when ADCs, rather than comparators, are used, translated digital value changes when the sensor deviates from the line to be followed. So, using fewer sensors, the robot will be able to follow the line efficiently. While comparators require a number of sensors because the change in translate value may change to 0 or 1 at the digital pins.

4. When the size of the robot needs to be compact as comparators require extra hardware.

B. *Using Comparator:*

As the name suggests, the comparator compares two values and generates a binary output based on the comparison. So, in case of the line following robot, the analog output signal is applied to one input of the comparator while at another input, the analog reference signal is applied. For this reference, analog signal, simple voltage divider circuit using potentiometer is used. So before starting the robot, first, these reference values are set on the actual field.

As shown in the below figure, analog signal is applied to positive (non-negative) terminal of the comparator and reference signal is applied to negative (inverting) terminal of the comparator. They can also be interchanged.

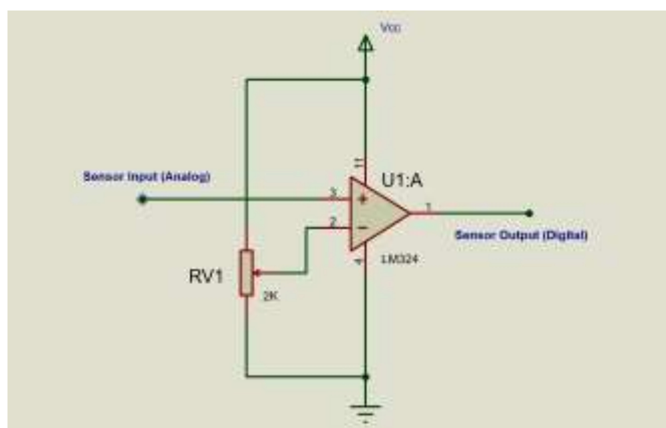

Fig. 5 – Basic internal circuit of comparator [2]

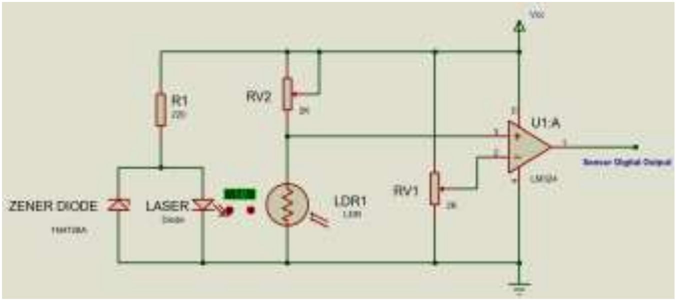

Fig. 6 – Implementation of comparator in basic line following circuit

So, after our research, we found when the comparator is preferred over ADC:

1. When the speed of the robot is a very crucial factor and it also has to perform many other tasks. Because comparators are an external circuit and they just compare two analog signals rather than translating one analog signal to digital one, it requires very less time compared to ADC. Moreover, here the digital output of the comparator is applied to the microcontroller so it has to read digital signals rather than analog, which again results in fast performance because microcontroller's reading time for a digital signal is far less than that of for analog signal.

2. In case of the complex line following robot, which has to perform many other tasks apart from following the line, can have many different analog sensors e.g. a pressure sensor, a current sensor, temperature sensor, etc. For such sensors, translated digital value from the analog signal is more important. So in such cases, analog pins of the microcontroller can be used for these sensors while for sensors which are used for following the line, digital pins can be used with the help of comparator.

3. When the value of the analog sensor is changing at a very high rate compared to the sampling frequency of ADC of the microcontroller.

IV. SENSOR ARRANGEMENT

In section II, we discussed what factors are important to design line following system which can detect even small color variation and can focus on the line to be followed (generally has white color). But considering only these factors are not enough, because in many line following robot competition, for making the competition even more challenging, very complicated paths are made. So here, the arrangement of multiple sensors also plays a pivotal role in the design of optimized and efficient line following robot.[4]

Generally, if the line to be followed is straight or at least has no sharp turns then in that situation, robot, even with simple sensor design, works fine. But the problems appear when there is a 90-degree turn or sharp turn.

Here, we have described about the final sensor arrangement which we had implemented in our robot, to give throat cut competition to other fellow teams in ROBOCON 2016.

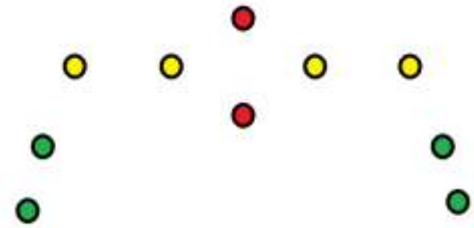

Fig. 7 – Sensors arrangement which we had implemented in our robot

As shown in figure 2, figure 3 and figure 4, in ROBOCON 2016, the path had many complicated turns.

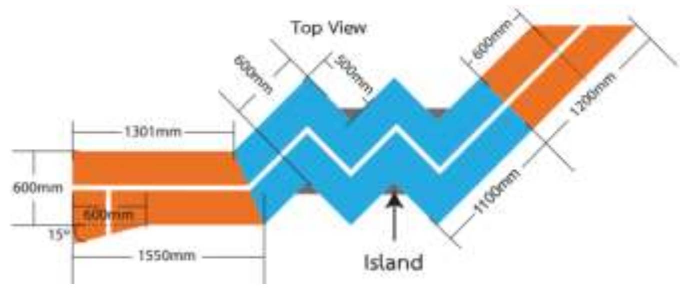

Fig. 8 – Complicated turn-1 in the Path of ROBOCON 2016[1]

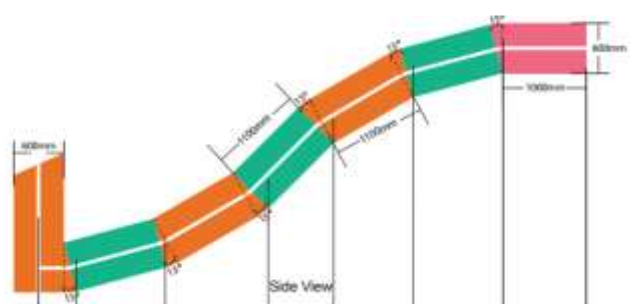

Fig. 9 – Complicated turn-2 in the Path of ROBOCON 2016[1]

As shown in the figures below, there will be particular sensor(s), here, on the white line, at different parts of the path. So, when the robot will be on the path, a fixed set of values of sensors output will take place. By identifying this set, we implemented that logic in the controller by programming accordingly.

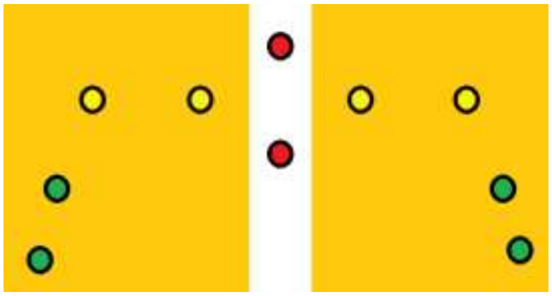

Fig. 10 – Sensors positions when robot the line is straight

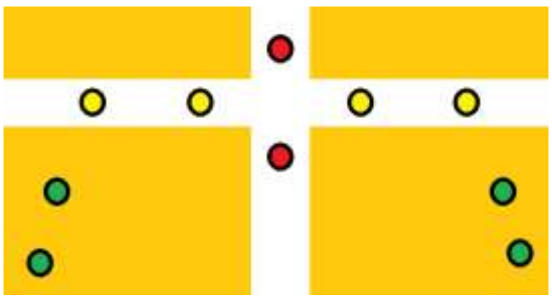

Fig. 11 – Sensors positions when there is 90-degree turn

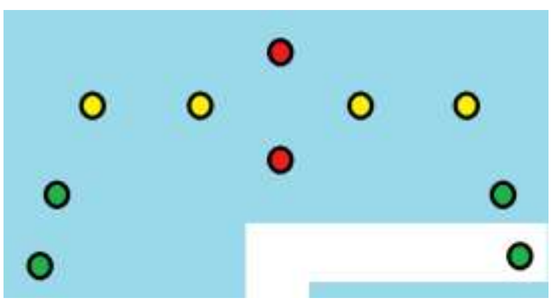

Fig. 12 – Sensors positions when there is complicated 90-degree turn

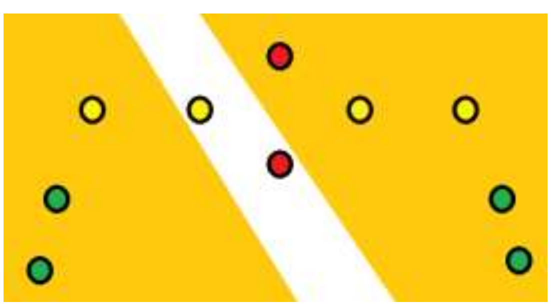

Fig. 13 – Sensors position when there is 25 degree left turn

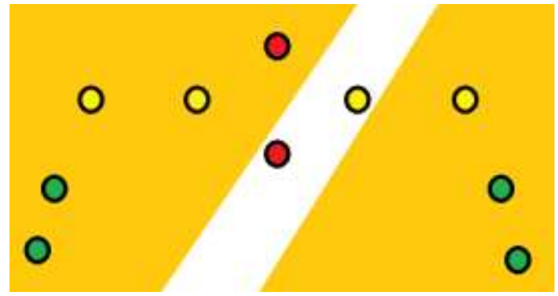

Fig. 14 – Sensors position when there is 25 degree right turn

So based on the path of the track on which line following robot has to follow the line, arrangement of sensors may vary.

V. CONCLUSION

The basic circuit of the line following robot is not very complex but the selection of proper sensors combination results in very high efficient line following system which will be able to discriminate even small color variation of surrounding from the color of the line to be followed. Selecting ADC or comparator also depends upon various requirements. Sensor arrangements also play a pivotal role depending upon the track complexity. Proper balance and augmentation of all these factors result in the optimized, efficient and high-performance line following system. In fact, in engineering colleges, if students were taught in such way and they do research in this way then it can result in significant improvement in their knowledge.

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