Analysis of Line Sensor Configuration for the Advanced Line Follower Robot

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ABSTRACT

Navigation is important to many envisioned applications of mobile robots. The variety of navigation tools may vary from expensive high accuracy tools to cheap low accuracy tools. The complexity of these tools would be dependent upon the navigation requirements. The more complex the navigation requirements, the more expensive the tools required. A cheap and simple navigation tool would be the line following sensor. However, the challenge posed in this navigation technique may be complex. A straight or wavy line would be simple to navigate whereas a T-junction, 90 degree bends and a grid junction would be difficult to navigate. This is due to the physical kinematics constraints which is limited to the motor response, position and the turning radius of the robot. This paper presents a proposed line sensor configuration to improve the navigation reliability of the differential drive line following robot.

Keywords: LDR sensors, wheeled mobile robot, adaptive programming

1. INTRODUCTION

A line follower robot is basically a robot designed to follow a 'line' or path already predetermined by the user. This line or path may be as simple as a physical white line on the floor or as complex path marking schemes e.g. embedded lines, magnetic markers and laser guide markers. In order to detect these specific markers or 'lines', various sensing schemes can be employed [1]. These schemes may vary from simple low cost line sensing circuit to expansive vision systems. The choice of these schemes would be dependent upon the sensing accuracy and flexibility required. From the industrial point of view, line following robot has been implemented in semi to fully autonomous plants. In this environment, these robots functions as materials carrier to deliver products from one manufacturing point to another where rail, conveyor and gantry solutions are not possible[1].

Apart from line following capabilities, these robots should also have the capability to navigate junctions and decide on which junction to turn and which junction ignore. This would require the robot to have 90 degree turn and also junction counting capabilities. To add on to the complexity of the problem, sensor positioning also plays a role in optimizing the robots performance for the tasks mentioned earlier[2].

This paper attempts to present a simple set of experiments on sensor positioning and also controlling strategy to enable junction counting and also 90 degree turn accuracy. These strategies are tested on a basic test robot base (refer to figure 1) system on a test pitch based upon ROBOCON 2006 [3]requirement as shown in figure 2.

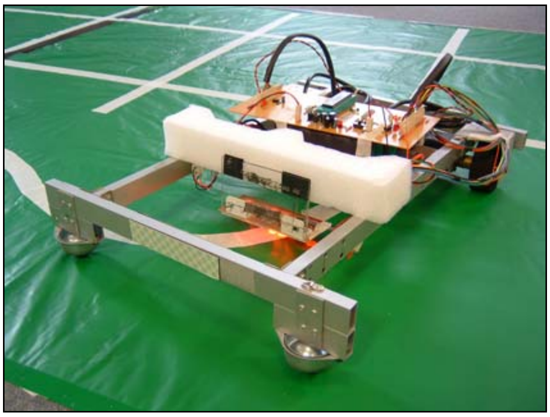

Figure 1: Advanced Line Follower (ALF) Robot

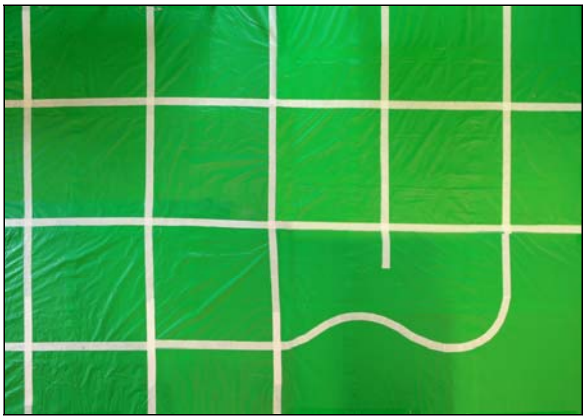

Figure 2: ROBOCON 2006 pitch requirement

2. TEST PITCH REQUIREMENT

A test pitch was built in accordance with the ROBOCON 2006 Rules and Regulations [3]. Referring to Figure 2, each square box is 50cm × 50cm and the white lines are 3cm wide made using modified masking tape on a green plastic sheet. A curved line section on the lower right portion of the test pitch was made to test line following capability of the robot. It is also assumed that the robot will only encounter cross-junctions and no T-junctions.

3. ADVANCE LINE FOLLOWER ROBOT TEST BASE

All experiments were made using a test base that was custom made to suit the purpose of this research. The test base will be a two-wheeled mobile robot with motors and sensors all mounted on top of it. The Advanced Line Follower (ALF) robot would consist of the following electronic components:

3.1 Motors

The motor selected for the ALF is the VEXTA 15W DC Motors with motor driver cards. This motor operates at 24V DC, with an operating torque from 0.4lb/inch to an excess of 260 lb/inch, depending upon the sizes of the motor.

The supplied motor card has the ability to control the basic movements of the motor via logic signals which makes it very versatile for microcontroller control applications. The controller card is also equipped with a speed feedback and speed control facilities which rely on voltage signals given to the motor card. Apart from that, the motor card would also have a built in manually controlled speed selector.

3.2 Master Controller

The Master controller functions as the main controller which oversees the general function of the robot. By having a master controller instead of a conventional single controller would increase the master controller availability to cater for any robot functionalities. For ALF applications, the microcontroller chosen is the PIC16F877a manufactured by Microchip Inc. The rational behind this is simply because that the PIC is easily obtainable with a reasonable cost incurred.

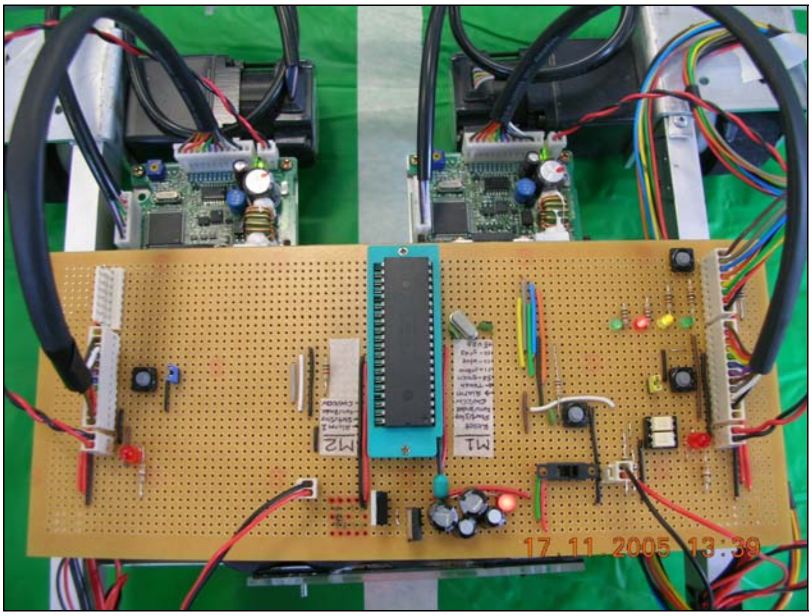

Figure 3: The Master controller with the DC motor card connected

3.3 Sensors with Slave controller

The sensors used for the slave controller consist of the ultra bright red LED combined with a light dependent resistor (LDR). Although there are other sensors that can be used which would give higher flexibility and dependability such as machine vision system, but these sensors are expansive. Therefore, a low cost but popular alternative choice would be the LED-LDR combination sensors.

In terms of the colours chosen for the LED, based upon literature done [4], it can be seen that red would be the best choice due to its high spectral intensity as compared to other colours. The basic line sensor circuit would be as shown in figure 4.

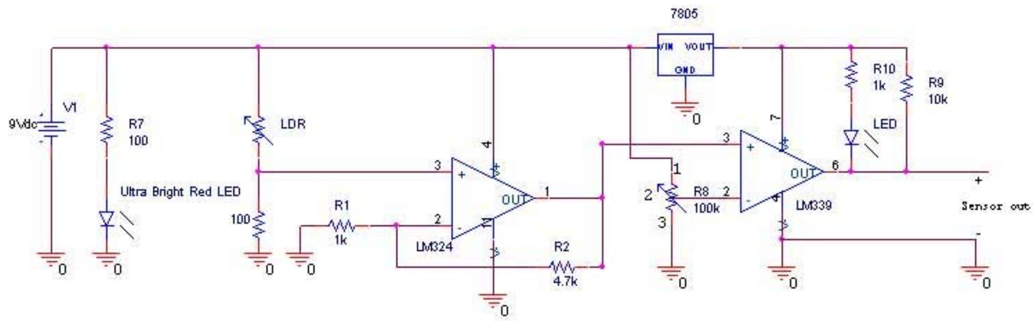

Figure 4: Basic line sensor circuit [5]

Based upon figure 4, the output of sensor circuit could either be logic high or logic low depending upon the condition whether the sensor senses a line or not. However, the circuit shown in figure 4 would require the user to repeatedly tune the circuit when there is a different ambient light condition. Apart from that the threshold level between line and no line is very fine as such that different ambient light condition would affect its performance[2].

However, for the ALF robot, a new breed of tune-able sensors were introduced which is based upon direct sensor reading. This type of sensors would require the use a microcontroller (PIC16F688) to do onboard processing after which the result of it is conveyed to the master controller. The advantage of having this facility would improve the flexibility of the sensor if applied to a different controller in the future. Apart from that it would reduce computing burden onto the master controller. Figure 3 shows the actual circuit used for the ALF robot.

4. ALF NAVIGATION STRATEGY

Assuming that the sensor array design is already completed, an analysis on the navigational strategies is presented. These strategies are based upon an assumption that the line sensor will give logic HIGH to the master controller when it detects a line and vice versa. The general overview of the navigation strategy is illustrated in figure 5.

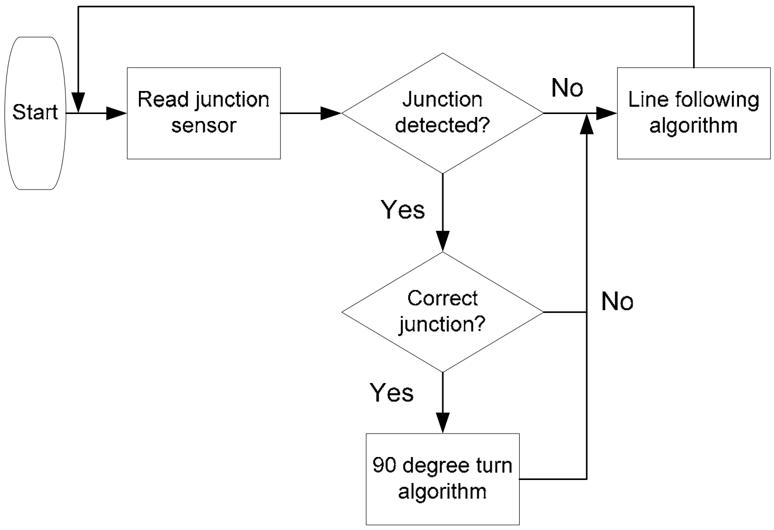

Figure 5: ALF navigational strategy flow chart

Based upon figure 5, the navigational strategy can be divided into several blocks which are: the line following algorithm, junction detection – junction counting algorithm and 90 degree turn algorithm. Each of these blocks was designed in modular form in order to optimize the memory utilisation. The following will outline the details of the blocks shown in figure 5.

4.1 Line follower algorithm

In order for achieve line following capabilities in ALF a line follower algorithm is designed. This algorithm will only utilize the middle 2 sensors (S_L and S_R) located at the sensor array for navigation. In order to compensate for possible robot overshoot which would result in no line detected by the navigational sensors, another set of algorithm is included to search for the line. The line follower algorithm is as shown in figure 6.

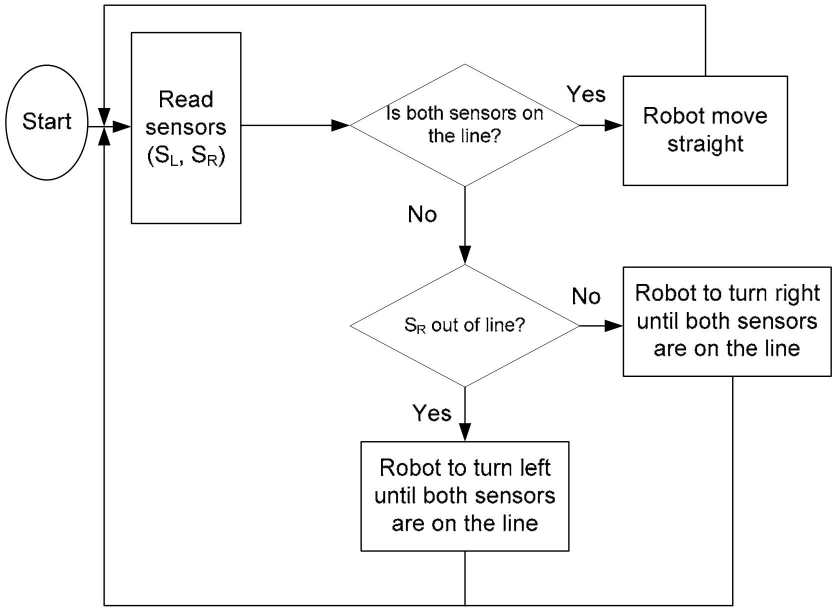

Figure 6: Line following algorithm flow chart

Referring to figure 6, the direction of the robot will be determined by the status of the sensors mentioned earlier. Based upon which sensors that did not detect the line, a corresponding corrective action signal is sent to the motor card. This corrective action will continue until both sensors detect the line again. The corresponding corrective action signals are as shown in figure 6.

In an event that both sensors did not detect a line, the robot will stop and reverse until either one of the sensor detects a line after which the line following algorithm is activated again. By incorporating this idea into the line following algorithm, ALF will never miss a line.

4.2 Junction detection - Junction counting algorithm

In order for ALF to decide which junctions to turn and which junctions to ignore, there is a need to incorporate a junction detection-junction counting algorithm. The overview of this algorithm is as shown in figure 7 and figure 8.

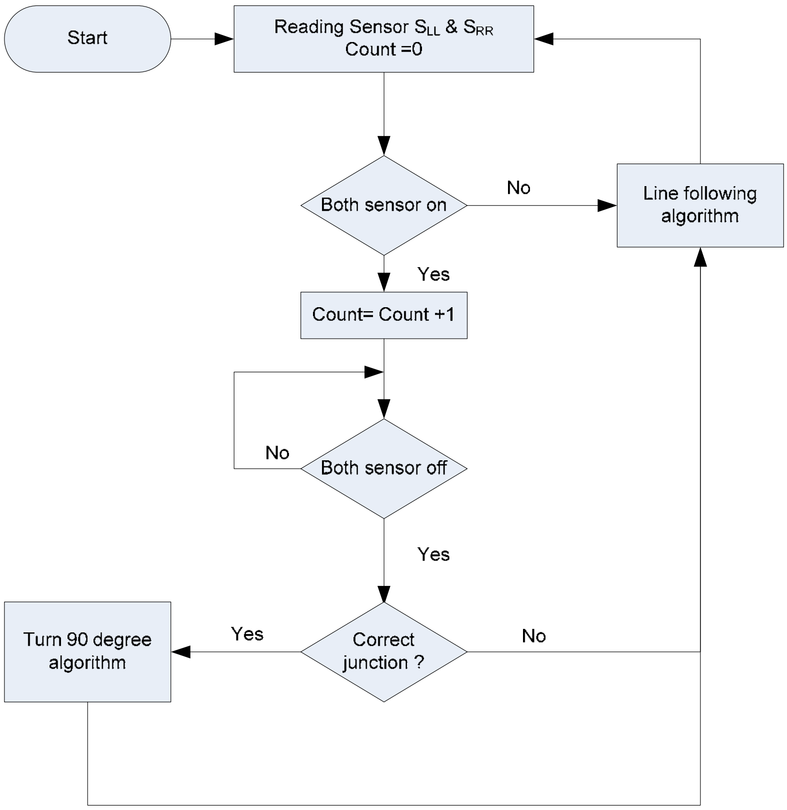

Figure 7: Junction detection Algorithm

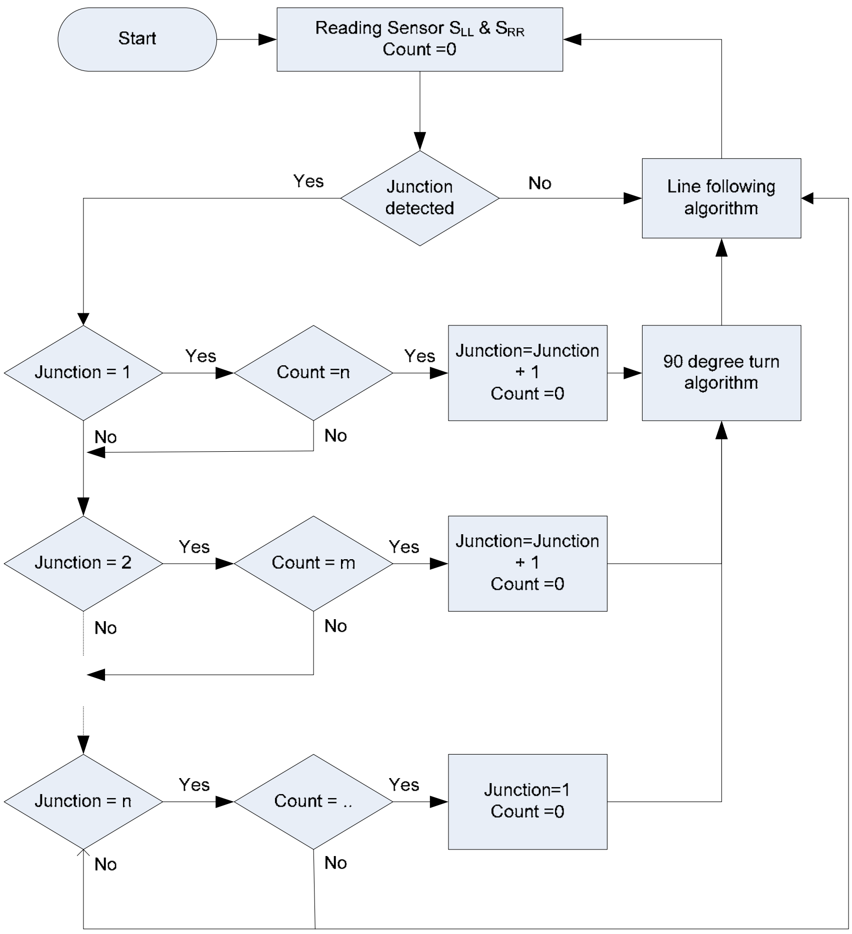

Figure 8: Junction Count Algorithm

Based upon both figure 7 and figure 8, ALF would require 2 sensors, which are S_{LL} and S_{RR} to detect and count the junctions. It is also worth noting that the junction count and junction detection would require both of these sensors to see the junction at the same time. If only either one of these sensors sees the junction, controller would register it as a junction. Hence placements for both of these sensors are very critical. This issue will be elaborated in Section 5.2 of this paper.

4.3 90 degree turning algorithm

Once ALF has reached to the correct junction, the robot would have to execute a 90-degree turn. The algorithm for the 90-degree turn is as illustrated in figure 9.

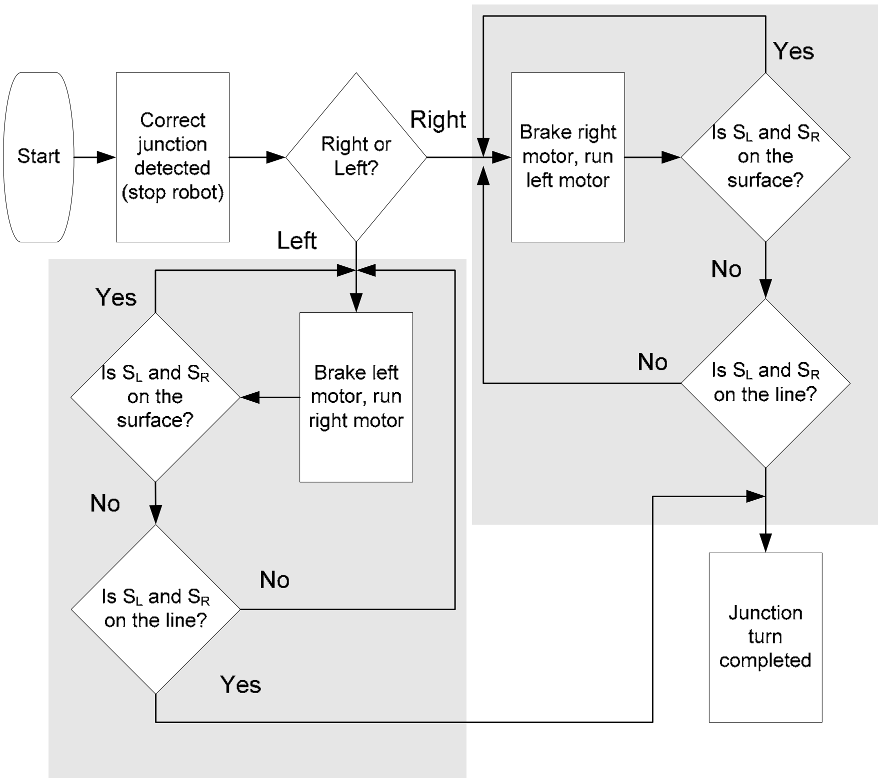

Figure 9: 90 Degree turn Algorithm

Referring to figure 9, the success of this algorithm will be dependent upon sensor placement and also the response of the sensors when detecting the last junction. To avoid any overshoot, the robot will stop first before executing the 90-degree algorithm. Based upon experimental observation, this strategy would yield an accurate turning sequence with less post turn line correction. The details of the sensor placement will be elaborated in Section 5.3 of this paper.

5. EXPERIMENTAL RESULTS AND DISCUSSION

Based upon the pitch requirement, a basic two-wheeled mobile robot with advance line follower (ALF) capabilities is constructed as shown in figure 10. This robot is equipped with a line sensing array with an embedded microcontroller to enable auto tuning and line-surface differentiation facility.

5.1 Auto tuning of sensor array

Figure 11 illustrates the line sensor array used in ALF. The auto tuning function flow chart of the sensor array is as shown in figure 10.

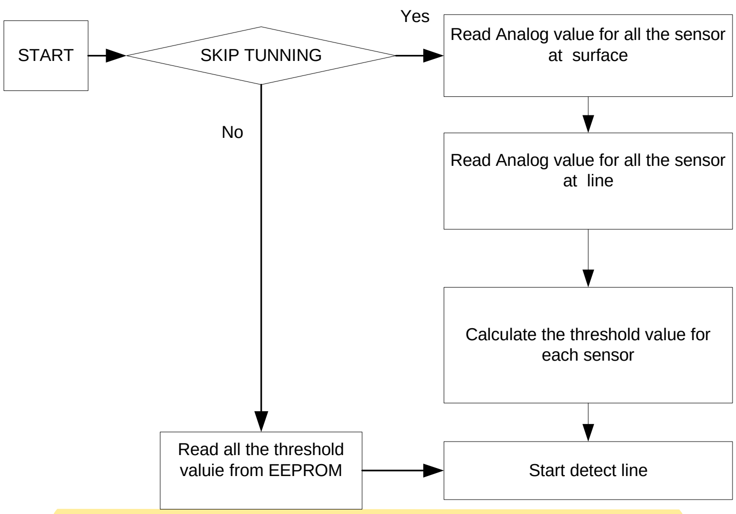

Figure 10: Auto tuning sensor array flow chart.

ALF basic controlling strategy is based upon a hierarchical control concept where the robot would have a master controller which functions as the main coordinator for the robot [6]. This master controller would require the services of slave controllers to do detailed functions for specific requirements, e.g. line sensing function and motor control functions. The advantage of this method is that distributed processing is possible which would reduce computational burden of the master controller. The modules used for ALF are the line sensor array and the motor control as shown in figure 11 and figure 12 respectively.

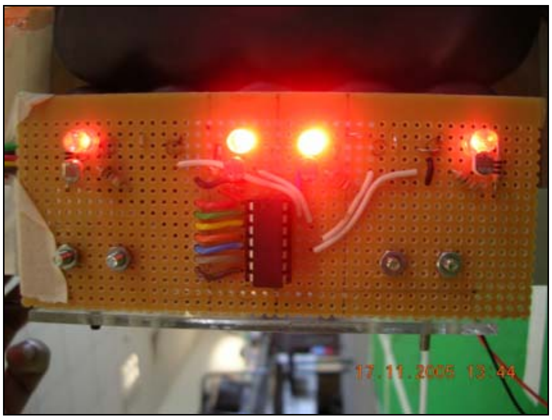

Figure 11: Auto tuning sensor array

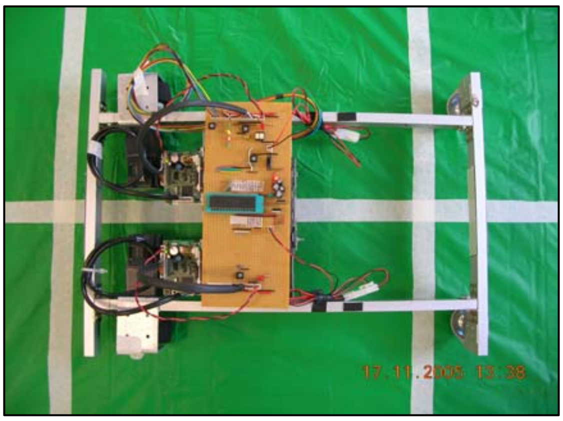

Figure 12: Top view of ALF

5.2 Sensor Array Design

In order to achieve successful navigation, the amount of sensors used and the location of these sensors play an important role. Inadequate number of sensors would result in a reduction of sensor resolution and could even prevent the robot from following a line. Based upon the test pitch requirement discussed earlier, it was deduced that the sensor array would require more than 2 sensors. To enable efficient line following capabilities, a minimum of 2 sensors is required (refer to figure 13(c)). However, 2 sensors are not enough to distinguish a single line from a junction; hence various possible arrangements were looked into. This is shown in figure 13.

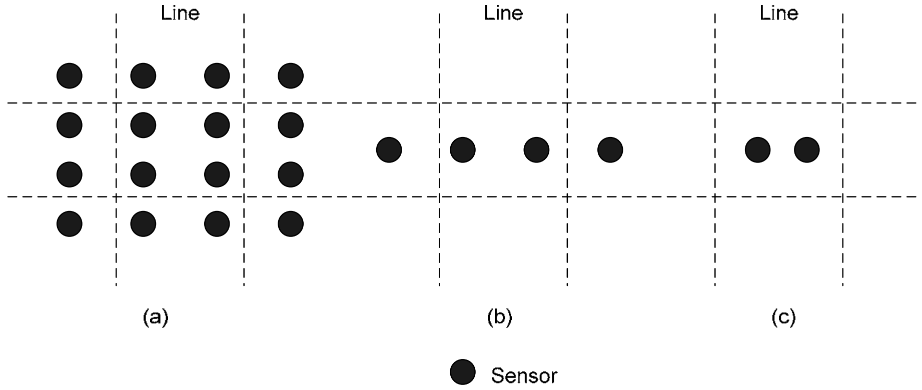

Figure 13: Different types of sensor array (a) Matrix type sensor array, (b) Single line sensor array, (c) Basic two-sensor configuration

Referring figure 13(a) and 13(b), the matrix and line configuration would be possible solutions to achieve junction detection. However, looking into the matrix configuration and relate it back to the ALF movement on the test pitch, this configuration uses too much sensors. For example, there are 8 sensors located on top of the vertical line which is superfluous for line navigation purposes. In addition to that, there are also 4 sensors located in a vertical fashion on the extreme left and right of the sensor array which in this is suppose to function as junction detection. This also is considered to be too much for junction detection.

Looking into the single line sensor array (figure 13(b) and figure 15), it utilizes two middle sensors for line navigation; sensors S_R and S_L; and the other two outer sensors for junction detection; sensors S_{RR} and S_{LL}. Comparing between the matrix and the single line sensor array, the single line sensor array can be seen to be suitable because it uses less sensors but it would still be able to perform line navigation and junction detection.

In terms of the 2 outer sensors, care must be taken not to place these sensors too far or too near to the line navigation sensors. If these sensors are placed too far from the navigational sensors, there may be sensor inaccuracy to differentiate junction if it enters the junction at an awkward angle. If the sensors are placed too near, the junction sensors may accidentally detect the line self rather than the junction. This is illustrated in figure 14.

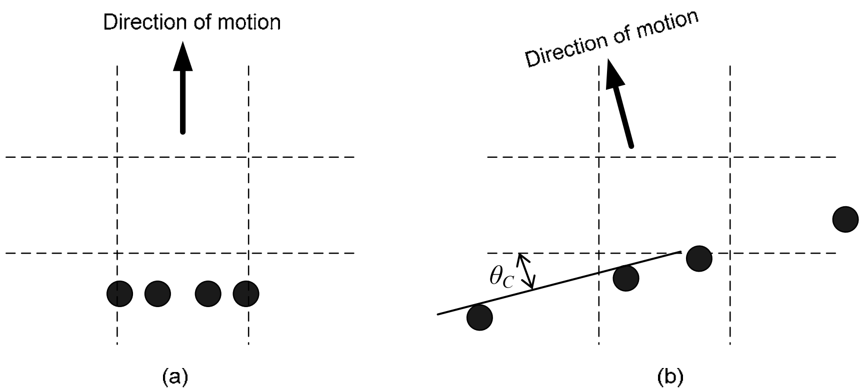

Figure 14: Junction sensor positional scenarios:
(a) sensors placed too near, (b) sensors placed too far.

In order to avoid the dilemma of sensor positioning mentioned earlier, equation (1) may be utilised to determine the exact distance between the sensors.

$$w < |S_{RR} - S_{LL}| < \frac{w}{\tan\theta_C} \tag{1}$$

Where:

$|S_{RR} - S_{LL}|$ is the distance between the left most and right most sensors in mm, w is the width of the line being detected in mm and θ_C is the critical entry angle of the robot. Please refer to figure 14 (b) for the angle θ_C.

The width of the line has been determined by the ROBOCON pitch requirements [3] to be 30mm. Setting the distance between the outermost sensors to be 85mm, and rearranging inequality (1) to calculate the critical entry angle:

$$\theta_C < \tan^{-1}\left(\frac{w}{|S_{RR} - S_{LL}|}\right) \tag{2}$$

This yields θ_C to be 19.44 degrees. If the robot attempts to enter the line at an angle above this value, it will not be able to detect the junction.

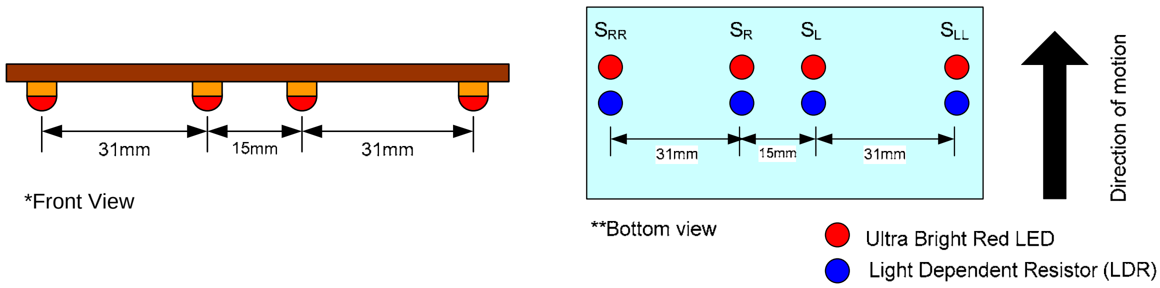

Figure 15: Front and bottom view of sensor array used in this study

5.3 Sensor placement for turning

Just as a driver needs to know when to turn into a junction, the robot also needs to know when to turn when it reaches a junction point. Exact placement of the sensor will ensure a smooth transition when turning into a junction. A robot will know when to turn depending on the location of the sensors. Thus it is very important that the placement of the sensors correspond to the method of turning.

There are two turning methods that were tested on as explained in the following subsection:

5.3.1 One motor moving forward and the other motor stationary (Method I)

Referring to figure 16, this method requires the sensors be placed at half the length of the distance between the left and right wheel. At this point, when the robot turns into the junction it will enter the line exactly on the line. Hence the sensor array will be perpendicular with respect to the line after the 90-degree turn is completed. This will ensure smooth transition from one line to another when turning junctions as illustrated in figure 17.

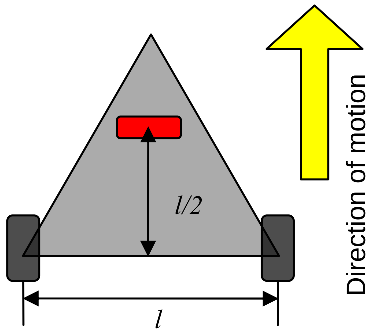

Figure 16: Location of sensors for 90 degree turns

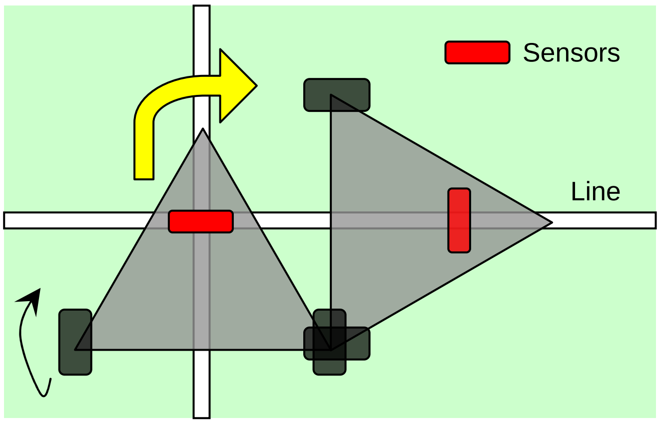

Figure 17: Sensor Placement for 90 degrees turning by Method I

5.3.2 Both motors moving in opposite directions (Method II)

For Method II, the robot will have the best turning point if its sensors detect the junction exactly in between its two wheels. Figure 18 shows how the robot will turn for Method II, also called a point-turn.

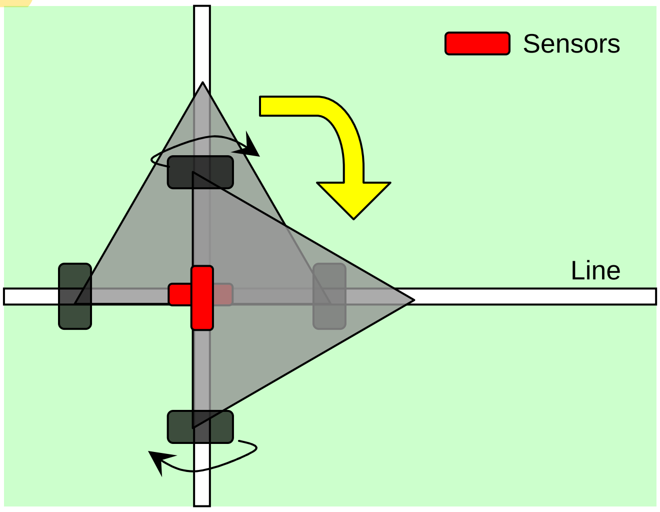

Figure 18: Sensor Placement for 90 degrees turning by Method II

5.3.3 Overall experiment observation

In general, ALF was tested employing all the navigational strategies discussed in this paper. Observation made for every proposed strategy show that the robot is capable of navigating the line with no difficulties at all. Introducing ambient lighting to the test pitch does not affect ALF's line following capability. The same can be said in terms of junction navigation algorithms.

However, if the same strategies were employed to the same robot base but at a much higher robot velocity, the robot would have difficulties in line and junction navigation. This is due to a compound problem which consists of sensor position and the speed control during navigational correction. Observing the current configuration, any navigational correction will cause the sensor to overshoot the sensors from the desired position. This problem may be solved by implementing a few optional strategies. One of these strategies would include speed control implementation in the navigational algorithm. Apart from that, a much finer navigation can be achieved if the sensor is placed further away from the sensor. Both of these options must be implemented together to improve line following capabilities at high robot velocities.

6. CONCLUSION

This paper has discussed and suggested standard methods to place sensors for junction tracking and junction turning. The proposed methods were tested on a test pitch with a test robot base. Test results yields that the proposed strategy implemented for ALF navigation is successful. However some navigational problem will occur at higher velocities. These problems can be solved by introducing a second sensor array for minute changes and speed control in the final navigational strategy. These options will be looked into and implemented for future development of ALF.

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