DEVELOPMENT OF WAREHOUSE ROBOT WITH ADVANCED LINE FOLLOWING AND BACKGROUND COLOR SENSORS

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ABSTRACT: Warehouse robot uses normal line following sensor to move and deliver inventory around the warehouse. The main disadvantage of the sensor is its inaccuracy in sensing due to different lighting conditions. Therefore, an autonomous robot with advanced line following sensor that is capable of detecting any line color with different brightness and background color is developed. In addition, the color sensor is integrated into the robot to detect the background color to determine the speed of the robot. The objectives are achieved by investigating the characteristics of the sensors to establish the relationship between the input and output of both sensors, design circuit connection, develop the code for the robot using Arduino Uno controller, and test run the performance of the developed robot with output observation. Results show that, the robot with advanced line following sensor was able to move and follow correctly black line with different background colors, where the robot had changed its speed accordingly when enter different zones. Findings from the project can be used to increase performance of warehouse robot in industry at different zones with different conditions.

KEYWORDS: *Autonomous Robot; Arduino Uno; Advanced Line Following Sensor; Color Sensor*

1.0 INTRODUCTION

Warehouse robot is an autonomous, portable robot used on the warehouse floor. It is capable of carrying loads, towing object, moving stock, navigating up and down the aisles without the need of an on-board operator, and others. [1] highlighted the need for shelf-moving robot and automated guided vehicles in the future for warehousing in the e-commerce and the Fourth Industrial Revolution era. Such automation is high in demand for reducing labor costs and workplace injuries, improving efficiency safety, and increasing the capability of performing tedious tasks a round the clock.

In the literature, many researchers have worked on improving the performance of warehouse robot [2-11]. There are studies done on the search for the shortest distance for a robot to travel around the warehouse [2-4], to increase the speed of delivery [5], and avoid collision [6], whereas Tatsumoto et al. [7] proposed an online supervisory control to model and control multiple warehouse robots. Task grouping, scheduling, and balanced allocation problems for warehouse robot have been discussed in detail in [8], where the authors have proposed an algorithm for each problem. Safety and efficiency management of warehouse robot had also been discussed thoroughly in [9-10]. Meanwhile, a study in [11] proposed image-based technology which can be attached to a robot to perform automatic inspection and analysis for electrode drilling machine.

There are different methods that can be used to navigate warehouse robot between various zones, such as laser guided [9], magnetic guided [12], and the most widely used is the automated guided, which is a basic line follower [13-15]. Previous works in [13-14] only presented the control algorithm used in controlling the robot, where [13] used finite state machine, whereas [14] used artificial neural network in controlling the robot without focusing on types of sensor used in navigating the robot. Instead of using infrared (IR) sensor in normal line following sensor, which is only capable to detect black lines in white background and vice versa, authors in [15] used blue sensors which transmit blue light with an appropriate receiver and is capable of detecting different colors in different lighting conditions. However, the computer vision line following robot in [15] with an on board camera can only move in a short distance, as it is attached to the computer. In addition, the blue color LED used in [15] has a low sensitivity, as mentioned in [16]. The performance of use of IR line following sensor is poorer in actual application, as light intensity is not constant all the time.

Hence, the main focus of this project is to develop a warehouse robot using an advanced line following sensor (LSA08) with green LED, which is more sensitive to spectral color compared to blue LED. It can follow any color of line with different colors on the background. Then, the color sensor is used to detect color of the background and determine the speed of the robot at different color area. The idea is that, at certain zone in the warehouse where the robot can speed up, the speed is high; whereas the other zone where the robot needs to slow down, the speed is low. It is important to change speed at different zone areas to increase the efficiency of the robot.

2.0 METHODOLOGY

There are six components required to complete the circuit of the robot, which are advanced line following sensor LSA08, Grove I2C color sensor, Arduino Uno microcontroller, motor driver, DC motors, and wheels. Figure 1 shows the typical line follower block diagram.

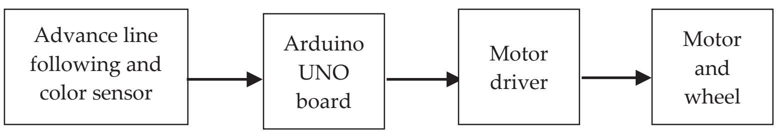


Figure 1: Block diagram of the line follower robot

2.1 Advanced Line Following Sensor (LSA08)

LSA08 is an advanced line following sensor with eight sensors pair, green LEDs and photodiodes, to detect the line path for the robot, as shown in Figure 2. LSA08 must be connected to a power supply in the range of 7.5V – 20V to operate and protected by power polarity protection to avoid damage by reverse voltage. The sensing distance is in the range of 1 to 5 cm, while the minimum width of line path is 1.5 cm. The detailed specification of the sensor can be obtained from [17]. The special feature of the sensor is its capability of detecting junction using Junction Pulse pin.

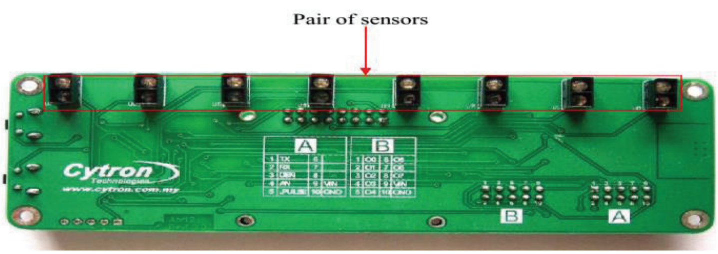
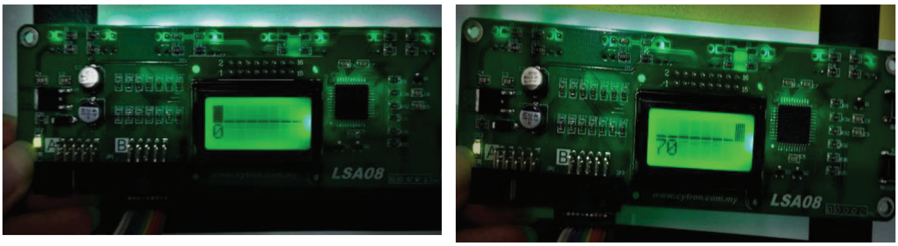


Figure 2: Advance line following sensor – LSA08 [17]

When the sensor is connected to a power supply, a value with eight bars will be shown on the LCD screen of the sensor. The relationship between the values shown on LCD increase linearly with the location of the sensor sensing the line. From the most left sensor (S0) to the most right sensor (S7), each sensor adds a value of 10 when it detects the line starting from 0 for S0 until 70 for S7, as shown in Figure 3. If two sensors detect the line, for example S3 and S4, the value of 35 is displayed.



(a) (b)

Figure 3: LCD displays values representing the location of the sensors: (a) S0 and (b) S7 detects the line

2.2 Grove I2C Color Sensor

Grove I2C color sensor is a color sensor made by TCS3414CS color sensor with digital output I2C. It has 16 photodiodes, in which four of them have red filters, four of them has green filters, four of them have blue filters and the other four have no filter to give higher accuracy and sensitivity. The operating voltage for this sensor is in the range of 3.3V to 6.0V, which can be provided by a microcontroller. It uses the I2C communication, which provides simple connection method to microcontroller. The connection of the color sensor and Arduino Uno is shown in Table 1.

Table 1: Connection pins of Grove I2C color sensor and Arduino UNO

Color sensor pins	Arduino UNO pins
VCC	3.3V / 5V
GND	GND
SDA	SDA
SCL	SCL

2.3 Circuit of Robot

The circuit of robot was completed by combining two circuits of two sensors together with an Arduino Uno board, a motor driver, two motors, and an 11.1 V battery. The circuit diagram is shown in Figure 4 and the actual circuit of robot is shown in Figure 5.

2.4 Robot Assemble

By screwing all the components to the base, except the battery and the motor driver, the robot is deemed to be half assembled. The 11.1 V battery will be put on the top of the base and the motor driver will be placed on to the base by using a hot glue gun. The robot was completed by attaching the wheels to the motors and adding a metal ball castor in front of the robot base. The complete robot is shown in Figure 6.

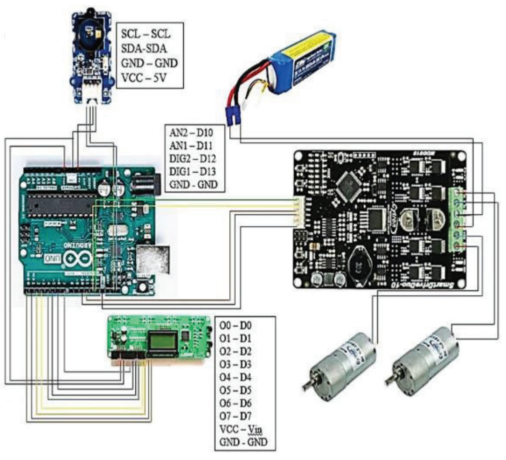


Figure 4: Circuit diagram of the complete circuit

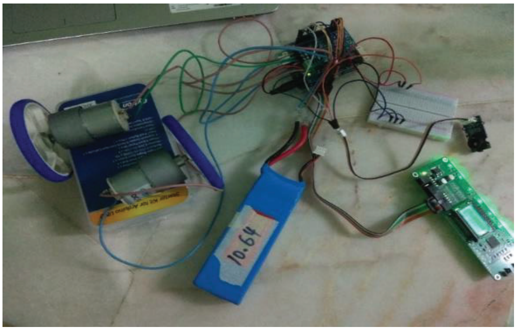


Figure 5: Complete circuit of robot

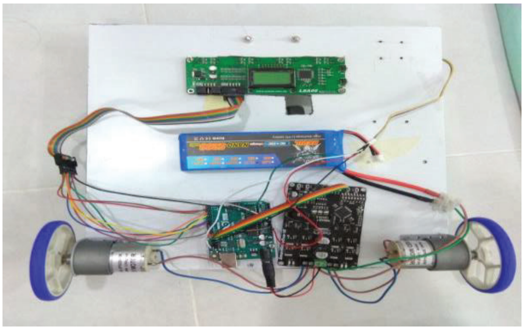


Figure 6: Complete assembled robot

2.5 Test Field of Robot

An A3 size of field was constructed to perform the output observation. The image of test field is shown in Figure 7. The figure shows five different zones with four different colors. The starting point is at Zone 1. Using the test field, the robot will be tested and should change the speed based on the different background colors.

Figure 7: A3 size test field for the robot

2.6 Flowchart of the Code

By combining both codes for LSA08 and color sensor, the complete code for the robot was developed. When the robot is ON and placed on the floor, it will auto calibrate to detect the line path that it will followed after. If the line path is detected, it will move in a normal speed follow the line. If the background floor color is green, it will move faster, whereas if the floor is yellow, it will slow down. The robot will stop when it detects the red color. The flowchart of the complete code is shown in Figure 8. Based on the algorithm in Figure 8, the code is written in C language using Arduino IDE and uploaded in Arduino Uno.

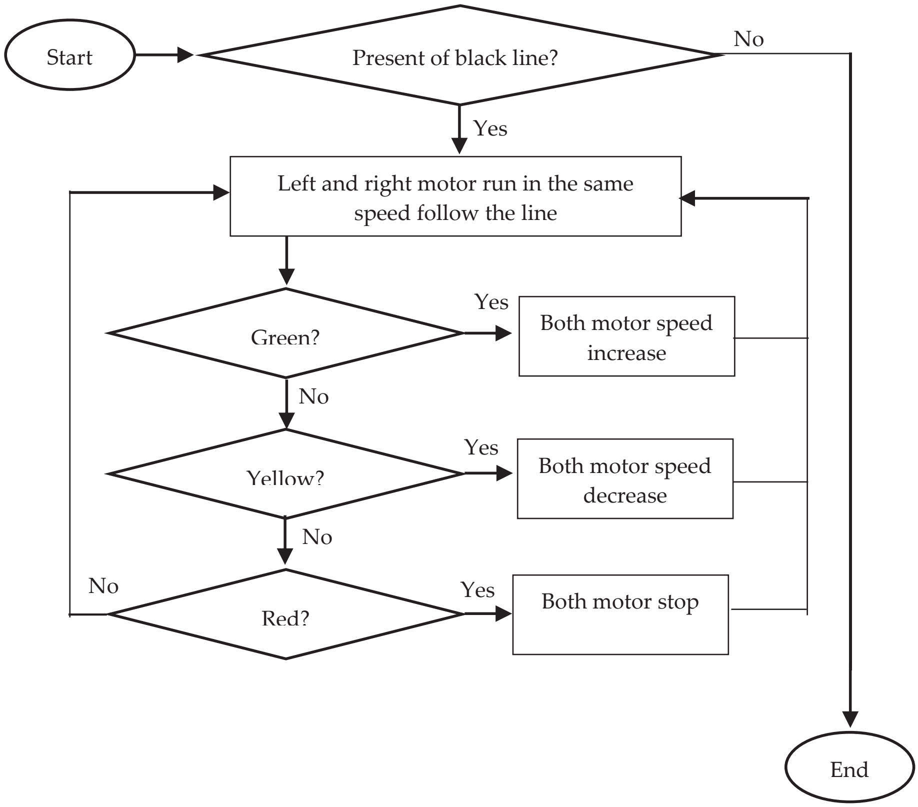


Figure 8: Flowchart of the code of robot

3.0 RESULTS AND DISCUSSION

The LSA08 had performed well, as expected. It showed high accuracy on sensing the line path. The photodiode which sensed the line path portrayed bar display on the LCD. Even when the sensor was moving at a higher speed, the sensing performance was still very accurate and precise, illustrating immediate changing of bar display and sensor value as in Figure 3. The test of LSA08 with connection to motors was observed after the test of LSA08 on sensing line path. Evidently, the motors work correctly with LSA08.

The output of background color sensor is in the form of combination 16-bit red, green and blue (RGB) code value. An example of the RGB value of an object in a serial monitor is shown in Table 2.

Table 2: Example of the RGB value shown in serial monitor

R value	G value	B value
R: 268	G: 273	B: 243
R: 267	G: 273	B: 243
R: 262	G: 264	B: 234
R: 262	G: 266	B: 237
R: 248	G: 245	B: 217
R: 239	G: 231	B: 204
R: 247	G: 242	B: 214
R: 245	G: 236	B: 209
R: 183	G: 201	B: 188
R: 107	G: 136	B: 139

From a simple experiment of exposing the color sensor to red, yellow, and green background, it is shown that the color sensor is very sensitive to the sensing distance due to the bright white color light on the receiver of the sensor. The result of the average RGB value for red, yellow and green color according to several different sensing distance is shown in Table 3.

From Table 3, the actual value representing red, yellow, and green color in the programming stage is determined from the sensing distance set after the robot has been assembled. To determine the speed of the robot, different value of pulse width modulator (PWM) is used for both side of wheels for different background color as in Table 4.

After the robot is tested, the results show that the robot was able to work correctly, following the black line path with several colors of background and changing the speed according to different color of background with some delay. Figure 9 shows how the robot was tested through the test field. From Figure 9, the time taken by the robot to cross the line for different background color was recorded and the distance of the background color was measured, then the speed of the robot was calculated and shown in Table 5.

Table 3: Average RGB value for different color for different sensing distance

Sensing distance (cm)	Red (R-G-B)	Yellow (R-G-B)	Green (R-G-B)
< 1	1540-640-710	2700-2400-1330	820-1540-1380
1	1390-560-600	2590-2340-1259	550-960-875
2	620-375-420	921-925-600	341-581-551
3	530-350-390	800-830-555	304-500-469
4	479-356-391	701-740-510	300-485-450

Table 4: PWM value for different background color

Background color	PWM
Red	0
Green	90
Yellow	20
Others	50

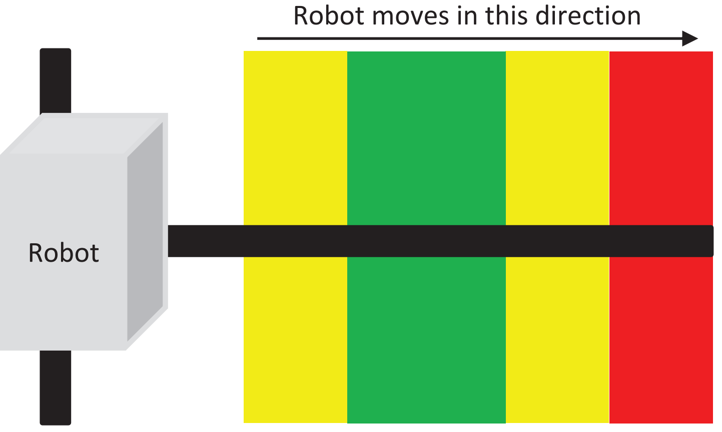


Figure 9: Top view of the robot tested through the test field

Table 5: Speed measurement for different color background

Background color	Distance (cm)	Time (s)	Speed (cm/s)
Zone 1: White	6	1.2	5
Zone 2: Yellow	6.5	3.2	2
Zone 3: Green	12.5	1.4	8.9
Zone 4: Yellow	8	4.1	1.9
Zone 5: Red	4.5	1 s then stop	0

Based on the result, the robot experienced some delay when reacting to the background color change and for the red zone, it can be clearly seen that the robot took almost 1 second to stop. In addition, the experiment also observed the highest speed that can be set for the robot, in which it cannot exceed a PWM of 120. During the experiment, it was also found that the motor driver with L298P chip that was originally used was not suitable for warehouse robot development because the chip lost at least 2 V when the circuit was running, and it consumed more voltage up to around 4 V at a higher current. With L298 motor driver, the robot cannot work with low PWM of less than 150. However, due to the small field for testing of the robot, a MDDS10 motor driver has taken place of the previous motor driver's job to provide better performance similar in [18]. This affected the original arrangement that was set for the components to be arranged on the robot base, since

MDDS10 motor driver is larger than L298P. Furthermore, it was found that the base of the robot was too big for this robot, resulting in the robot unable to make a sharp turn at high speed. The loads on the robot base were also another issue that had limited the performance of the robot, similar to in [19]. Due to heavy loads such as battery and motors with no bearing, the motor shaft needed to support the whole weight of the robot. The motors will be damaged over time when this situation remains unchanged.

This was also due to the field made for the robot, which was merely an A3-sized paper. After some experiments were done, it was found that the motors react immediately on a bigger field. Therefore, it was assumed that the robot can work perfectly in a field such as a real warehouse or industry. Lastly, the component used in this project resulted in better performance compared with robot with normal line following sensor and ultrasonic sensor due to its ability to detect different background colors. Although the efficiency increases, the cost of the components in this project was relatively high compared with the components that was previously mentioned. Hence, for high-risky environment that requires efficiency, this type of robot is deemed better than the conventional ones.

4.0 CONCLUSION

The robot equipped with LSA08 and color sensor is developed successfully. It was observed that the robot had followed the black line with different background color and changed the speed of the wheel for different zone correctly.

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