# AUTONOMOUS DELIVERY ROBOT

By

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## Abstract

Our project is about an autonomous delivery robot in coffee shop. As a delivery robot, it is able to navigate to the destination as well as avoid obstacles that are blocking its way. We successfully finished the main functionalities of the delivery robot and it is working in the following procedure. As it gets loaded and initiated, the robot turns around to find the direction of destination. Then it navigates to the destination and reacts to obstacles properly. Though there are some flaws in the design of navigation, the robot is able to work as expected in most cases.

## Contents

# 1. Introduction

## 1.1 Background & Problem

Robot is so called the next generation technology and indeed has been brought to our life in many aspects such as education, military and so on. With the occurrence of robots in varieties of areas, a new revolution is happening in real life since robots have their own advantages – low labor cost and stable working performance. In a word, robots have been part of the society in a deep level but there is still a lot of improvements needed to enhance the performance. For example, in the coffee shop in the future, not only does the robot make coffee, but also delivers safely by itself. An autopilot robot that is able to deliver food will save a lot labor cost, but the way to its destination is not always smooth and safe, therefore, a solution is needed to deal with different kinds of special situations and potential obstacles. It is difficult for robots to recognize the surrounding objects and react as it supposed to but failure of avoiding obstacles raises the concern of safety. High performance detection, analysis and controlling systems are capable of decreasing the failure rate. However, it would cost too much to be afford for industrial applications. Due to this reason, delivery robot is still far away to daily life.

## 1.2 Solution

Our goal is to find a low-cost solution so that delivery robots becomes applicable in the real life. We use a combination of 2D LiDar and ultrasonic sensors to lower the cost but keep the functionalities of detecting obstacles. The microprocessor collects data from sensor system and then gives instructions to motor to avoid the obstacles. The robot is also be able to navigate to the destination, after equipped with an infrared detector as a guide for direction.

## 1.3 Subsystem Overview

Overall, there are three subsystems in our project, power supply, sensor system, control unit and navigation system. Power supply contains a 9-Volts battery and 2 voltage regulators of 3.3 Volts and 5 Volts, and it supplies required voltage to modules. The detailed numbers of input voltage of each module are listed on the graph. Sensor system contains an infrared receiver, ultrasonic sensors and a 2D LiDar. The infrared receiver is used to pair with the infrared transmitter at the destination to guide the robot to find the correct direction. The combination of ultrasonic sensors and 2D LiDar works to detect obstacles in front and on two sides. Control unit works as the brain of robot, as the microcontroller collects data from sensor systems, analyzes current direction and surroundings, and instructs the navigation system to react correspondingly. There are two components in the driving and navigation system, motor controller and motors. Motor controller receives and translates instructions from microcontroller, and then set the parameter of motors such that the robot in different driving method - going straight, turning around or turning in one direction. The integration of subsystems works well on the robot, so that it can avoid obstacles as well as navigate to the destination.

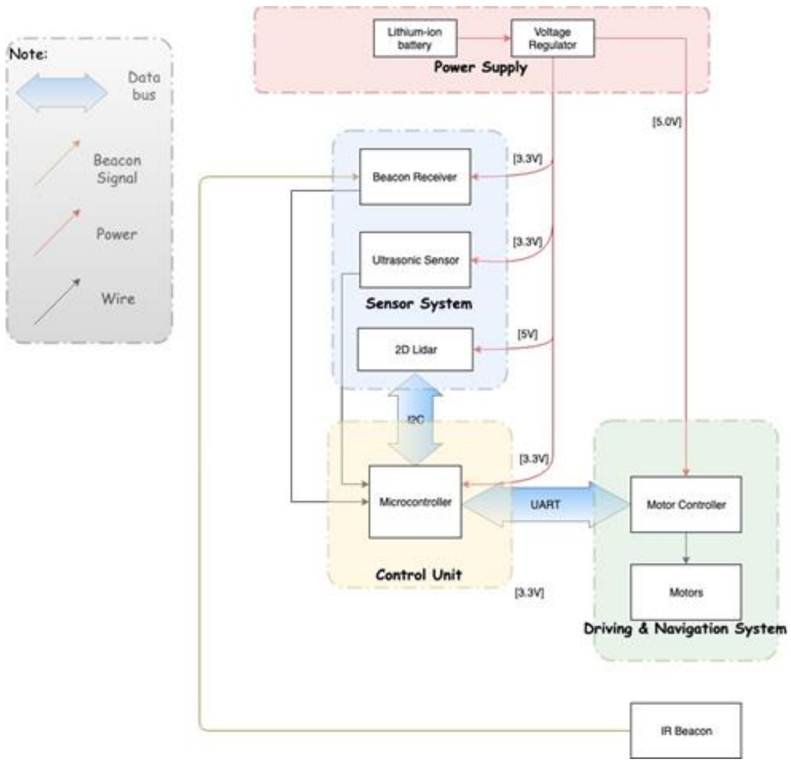
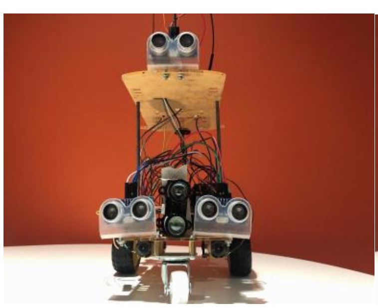
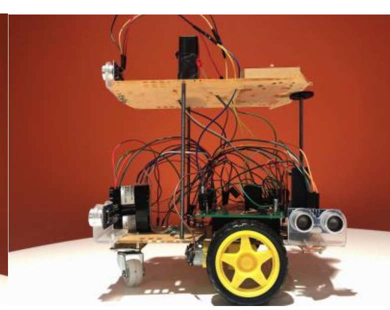



**Figure 1.1 Block diagram for the delivery robot**

# 2. Design

## 2.1 Physical Design





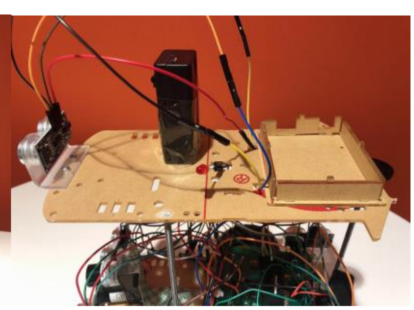


**Figure 2.1 Front view** **Figure 2.2 Side view** **Figure 2.3 Top view**

The figures shown above display the physical design of our robot, which has two levels with all components mounted on it. The top level consists of a single ultrasonic sensor, an IR sensor, a LED and a food holder. The ultrasonic sensor is used for detecting the customers(moving obstacles) in the restaurant, because we assume that all the still obstacles are below the top level, and there is also a LED to alarm the customers if the robot is blocked by them. Additionally, the IR sensor is able to locate the destination by searching for the IR signal transmitted by the IR beacon, so that the robot can move in the right direction. On the bottom side, there are four ultrasonic sensors and a LiDar. The two ultrasonic sensors with a Lidar in the middle of them are responsible for detecting the obstacle in the front, and other two ultrasonic sensors can detect the obstacle on each side to determine the correct turning direction.

## 2.2 Subsystems

In our block diagram (Figure 1.1), we have four subsystems with distinct functionalities work together to accomplish our goal.

### 2.2.1 Power System

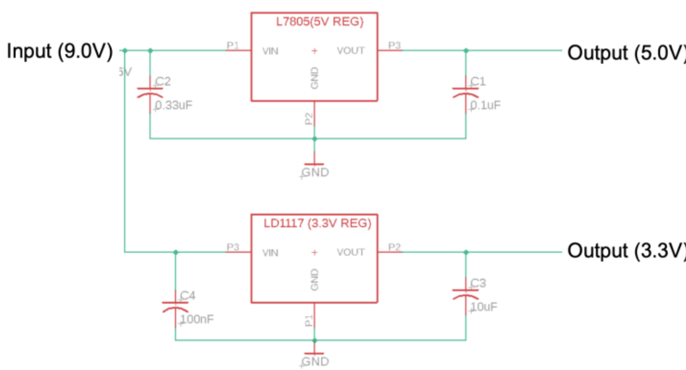



**Figure 2.4 Schematic of power supply**

#### 2.2.1.1 9V Lithium-ion battery

The Lithium-ion battery is the overall electric energy source of the entire project, providing steady 9 Volts DC voltage.

#### 2.2.1.2 Voltage Regulators LD1117 (3.3V) & L7805 (5.0V)

Based on the power requirements of all the other electronic parts in our project, we chose two kinds of voltage regulators to provide the corresponding input voltages. The LD1117 is able to convert the DC voltage from battery to a steady DC voltage of 3.3V. And L7805 is capable of convert the battery voltage to a steady DC voltage of 5.0V.

### 2.2.2 Sensor System

#### 2.2.2.1 Ultrasonic sensor


**Figure 2.5 Ultrasonic Sensor and its pin out**

We choose HC-SR04 (Figure 2.2) to serve as the major distance detection part in our sensor system, unlike other kinds of sensors used for range detection, ultrasonic sensor is cheap and can produce ultrasonic signal which is not easily interfered. We can also take advantage of the characteristic that the ultrasonic signal will bounce back after hitting the obstacle to calculate the distance.

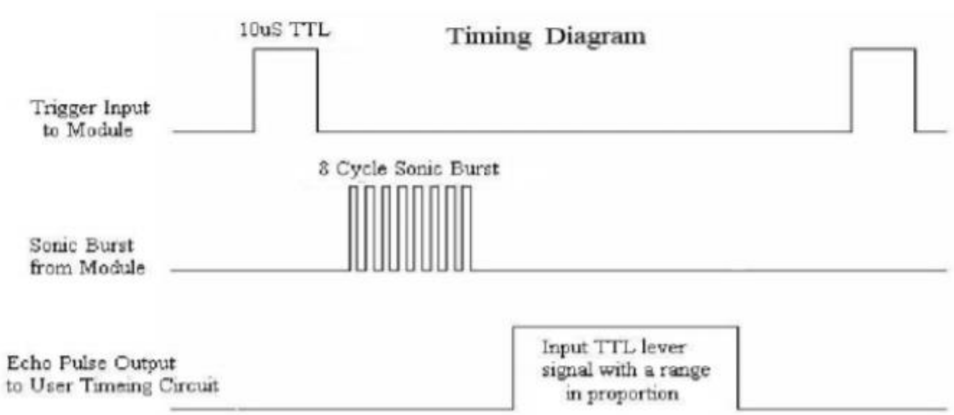



**Figure 2.6 Working principle of ultrasonic sensor (HC-SR04)**

Figure 2.3 shows how our ultrasonic sensor works. First, we need to generate a pulse into its trigger pin, then the sensor will produce a sonic burst and the sonic burst will bounce back after hitting obstacle. As long as the sensor receives the bounce back signal, the echo pin will produce another pulse that has the same duration as the travelling time. To calculate the distance, we use the time we got to multiply the speed of sound $0.034\text{cm}/\mu\text{s}$, and divide the result by 2, since the signal travels forward and bounce backward, the distance is doubled.

$$s(\text{distance in cm}) = t(time\ in\ \mu s) * 0.034\left(\frac{cm}{\mu s}\right)/2 \qquad \text{(Eq.2.1)}$$

**2.2.2.2 IR sensor & IR transmitter**

**Figure 2.7 IR sensor (TSOP4838)**

The main usage of IR sensor in our project is to find the right direction to the destination and realize the functionality of navigation. We also think about using Bluetooth to accomplish this goal, but then we find that almost all the Bluetooth navigations depend on certain Apps and have to be controlled by phone, which is not suitable for our design, because our robot must do navigation by itself. The pair of IR transmitter and IR receiver fits our design perfectly, because we can put a IR receiver in the front of the robot and let it go straight only when it faces right to the IR transmitter installed in the destination. TSOP4838 will not be interfered by all visible lights because it only detects light in wavelength of 870 nm to 970 nm, and it has a detecting range of 15m, which is enough for our indoor navigation. There is an alternative plan using GP2Y0A21YK0F sharp sensor, but this plan is abandoned by us. Although this type of sensor can detect intensity of IR signal to estimate the range, the test results show that the relative error are too high, and we are not going to take risk of it.

**Figure 2.8 970 nm IR transmitter** **Figure 2.9 IR illuminator** **Figure 2.10 iPhone X**

As for the IR transmitter, there are many available choices. Figure 2.5 is a regular 970 nm IR transmitter, this kind of transmitter is very common in small robot projects using IR signal communication, it's cheap and easy to install because of its small size, but the problem is this transmitter only generate a weak IR signal. Since we have to find an IR transmitter with longer range, alternative we try is the IR illuminator, it always work with security camera to provide night vision in our daily life, and the IR signal it produce will cover a large degree. A large coverage is unnecessary in our project, because our robot is a cart and will not approach destination in all directions, and this trait also causes the signal to scatter a lot- the signal will become weak and too unstable to be detected by our IR sensor. Our final choice is iPhone X, actually any electronic devices with the same face recognition functionality will work, it can generate a strong IR signal to help front the camera scan user's face. We consider this kind of device to be customer-friendly, because it's possible for customer to guide the robot by their own phones or we can even install devices on each table and let customers order food on them. The only flaw of this choice is the high cost.

**2.2.2.3 LiDar**

**Figure 2.11 LiDar Lite v3**

One of main functions in our project is to detect and avoid potential collision with obstacles. We Chose Lite v3, a 2D LiDar that is able to provide an accurate measurement in the range of 0-100cm to work together with the ultrasonic sensors to cover all possible detecting angles at the front of the robot.

### 2.2.3 Driving & Navigation System

**2.2.3.1 Motor Driver**

**Figure 2.12 Motor Driver Microchip L298N**

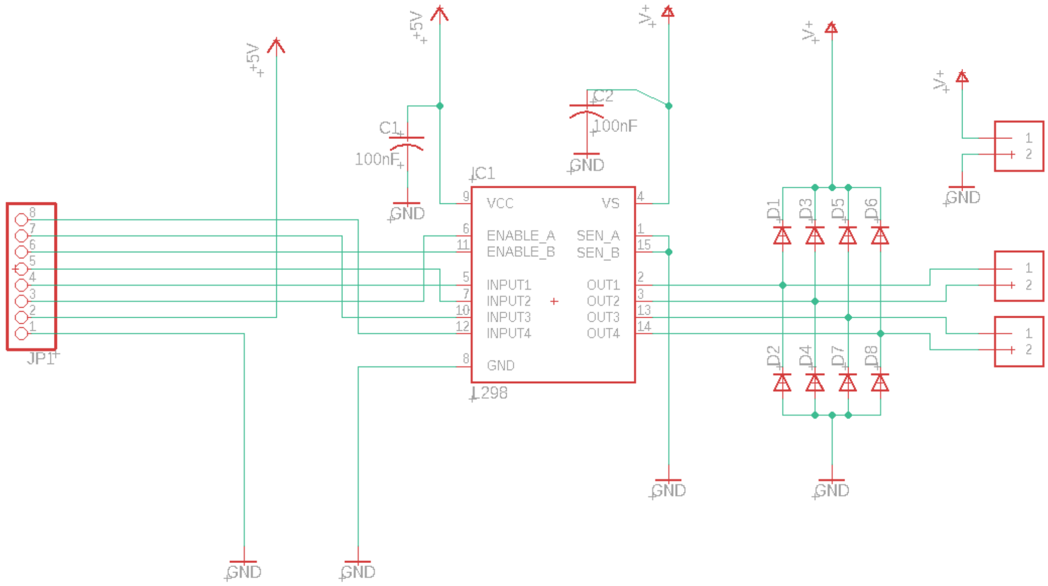




**Figure 2.13 Schematic for motor control circuit**

A fairly important function of our project is to let the vehicle to find the correct orientation of final destination while circumvent the obstacles. Then the robot should be able to achieve different movements such as going straight, turning left/right or turning around. The microchip L298N contains a H-bridge design, which is an electronic circuit design that is capable of switch the voltage polarity, which met our requirement.  This motor driver controls all the motor's operations. It takes the signals from our center processor ATMEGA328P and sent output signals as the instructions for motors to take corresponding actions.

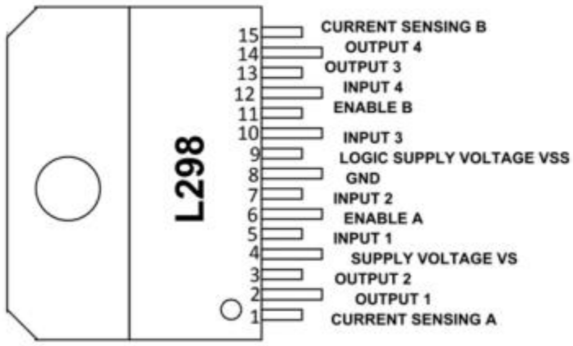




**Figure 2.14 L298N pinout**

One enable and two INPUT signals determine the two OUTPUT signals for a single motor. The truth table of the actual implementation of single motor is attached below:

| ENA | IN1 | IN2 | Motor Operation |
|---|---|---|---|
| 1 | 0 | 0 | HALT |
| 1 | 1 | 0 | GOING FORWARDS |
| 1 | 1 | 1 | HALT |
| 1 | 0 | 1 | GOING BACKWARDS |

**Table 2.1 Motor Operations with different input signals**

The enable pin takes the digital signal (PWM) and the two INPUT pins take the regular digital signals generated by ATMEGA328P. And the value of ENA controls the rotation speed of the motor.

**2.2.3.2 DC Motor**

**Figure 2.15 Dual Shaft DC Motor**

We used two DC motors to control two wheels on the vehicle. Each motor accepts the voltage from 5V-12V. And the maximum rotation speed for each motor is 75 rpm, we adjust the value of ENA pin in L298N microchip to change the rotating speed.

### 2.2.4 Control Unit

The control unit contains the microprocessor, which works as the brain of our robot, as it collects the data from sensor systems and then gives instructions to the motors. We chose to use ATMEGA328p as our microcontroller, since it is one of the most common choice for microcontroller and it has all the functionalities we need. Since we have a lot of sensors in our design, the number of pins will be an issue, we considered about using ATMEGA 2560 that has much more pins. However, unlike ATMEGA328p that can be took off from the socket on Arduino, ATMEGA 2580 is complicated to program.

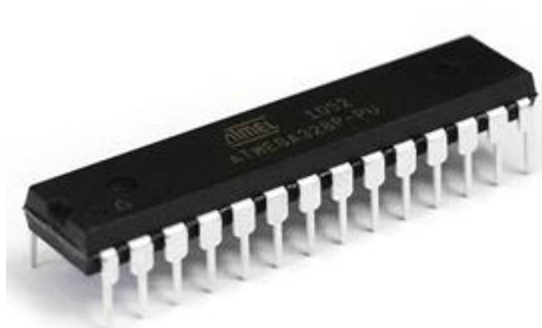


**Figure 2.16 ATMEGA328p**

## 2.3 Algorithm

The algorithm is drawn in the flowcharts below.

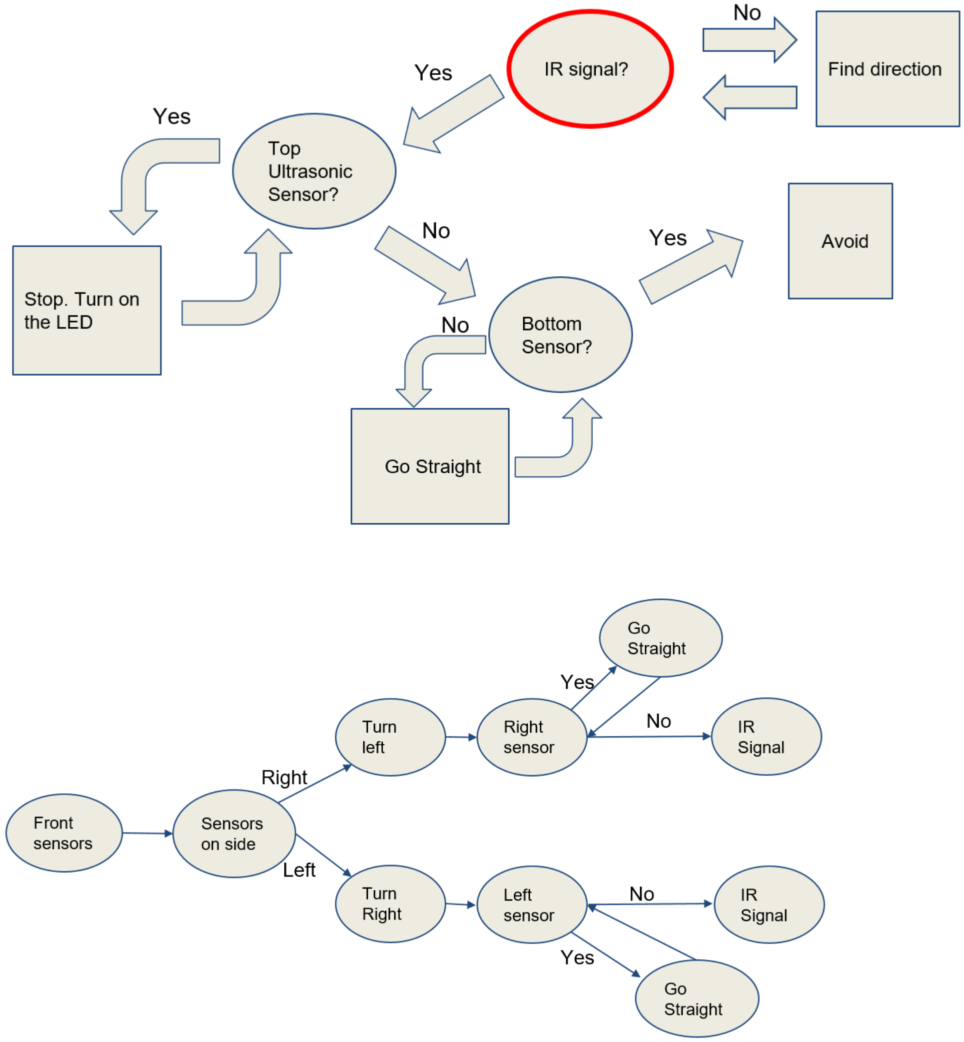



**Figure 2.17 Flow chart**

# 3. Design Verification

## 3.1 Power System

Initially the power source we were using was 6V DC battery, but we found that sometimes the voltages on some certain parts were not high enough for regular work. And we replaced it with a 9V DC battery and it worked as what we expected. In order to get the most accurate desired voltages, we did modular testing on six different regulators for each type.

### 3.1.1 Voltage Regulator

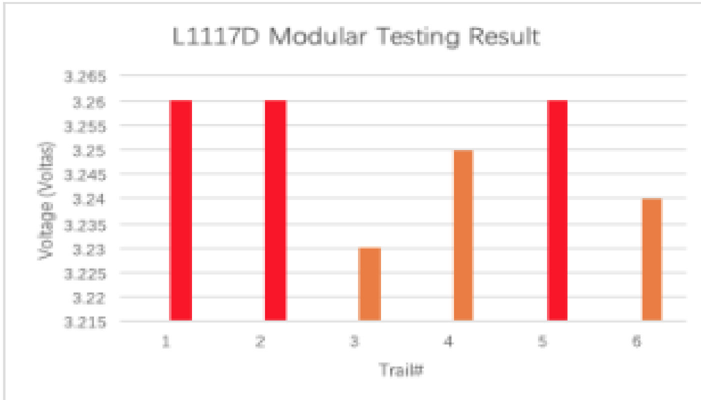



**Figure 3.1 L1117D modular testing result**

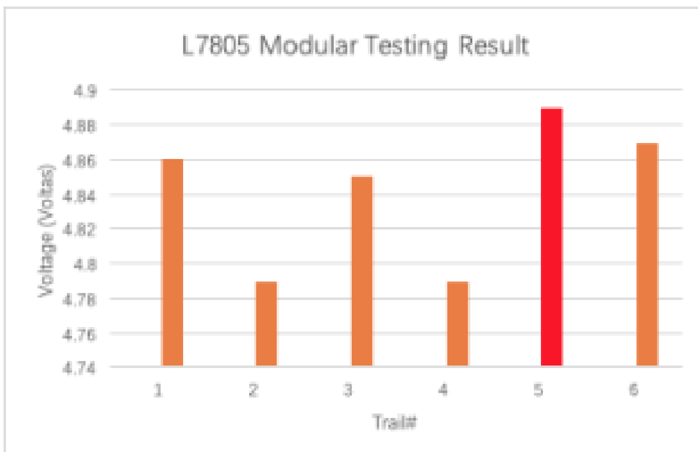



**Figure 3.2 L7805 modular testing result**

According to this testing result graph, we picked the regulators which are colored in red. And the calculated relative error is attached below:

LD1117:

Expected Value of $V_{out}$: 3.3 Volts

Relative error: $\frac{|3.26-3.3|}{3.3} = 1.21\%$

L7805:

Expected Value of $V_{out}$: 5.0 Volts

Relative error: $\frac{|4.89-5|}{5} = 2.2\%$

## 3.2 Sensor System

### 3.2.1 Ultrasonic Sensor

The robot is expected to detect and avoid an obstacle if the distance between them is less than 40 cm, so we require the ultrasonic sensor to be accurate in the range of 2 - 70 cm, since 2 cm is the minimum detecting range of ultrasonic sensor and 70 cm gives a buffer for robot to react properly.

To verify the requirement, we connect the ultrasonic sensor to a power supply of 3.3 Volts and Arduino board to collect and analyze data. Then obstacles are placed from distance of 2 cm to 200 cm. Measured results were printed out in the screen and compared with the actual distance. A testing graph is generated for the verification.

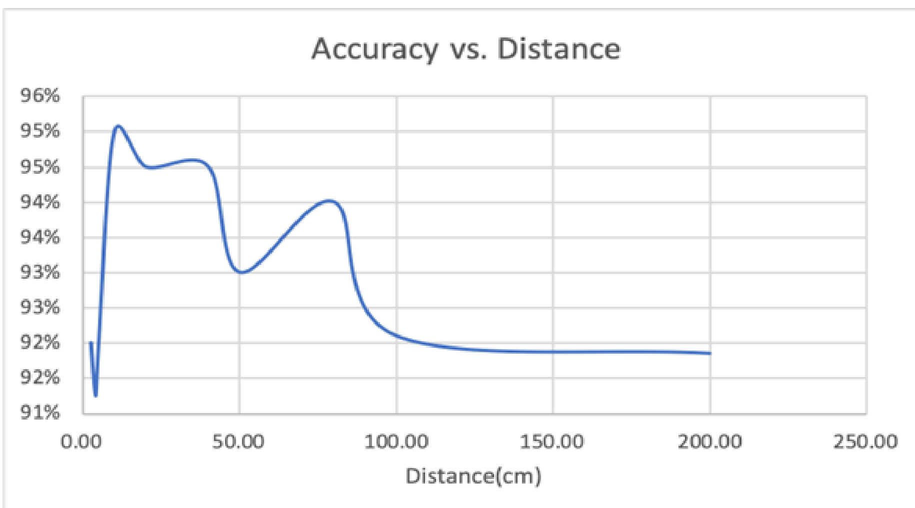



**Figure 3.3 Ultrasonic sensor testing result**

From the graph, we can tell that the ultrasonic sensor reaches an accuracy of 95% when the distance is in the range of 2.5 cm to 50cm, and the accuracy is also acceptable when the obstacle is around 50 - 100 cm away.

### 3.2.2 IR Sensor & IR transmitter

We connect TSOP4838 to the Arduino and put different types of IR transmitter in the range we set to see if the IR sensor can detect signal. Since the IR sensor is active low, we write test code on our PC to make sure Arduino interface can print out "detected" once the signal is successfully detected. These "Yes, but unstable" results in the Table 3.1 below mean the signal can still be detected but we cannot guarantee it will be detected every time.

| Transmitter type | Distance(m) | Can be detected? | Availability |
|---|---|---|---|
| 970 nm IR transmitter | 0.1 | Yes | Not available. Signal of this kind of transmitter is too weak and has very small angle |
| | 0.5 | Yes, but unstable | |
| | 1 | Yes, but unstable | |
| | 1.5 | No | |
| Tendelux 80ft IR Illuminator \| AI4 | 0.5 | Yes | Not available. This IR illuminator has large angle but still cannot be detected with distance larger than 3m |
| | 1 | Yes | |
| | 2.5 | Yes, but unstable | |
| | 3 | No | |
| IR signal from iPhone X faceID | 1 | Yes | Available. The 10 m range is enough for indoor navigation design. |
| | 3 | Yes | |
| | 10 | Yes | |
| | 15 | Yes, but unstable | |

**Table 3.1 Test of three different types of IR transmitters**

### 3.2.3 LiDar

We used LiDar lite v3 to detect several obstacles and measure the distances, and we compared the measured distances with the actual distances to check its accuracy.

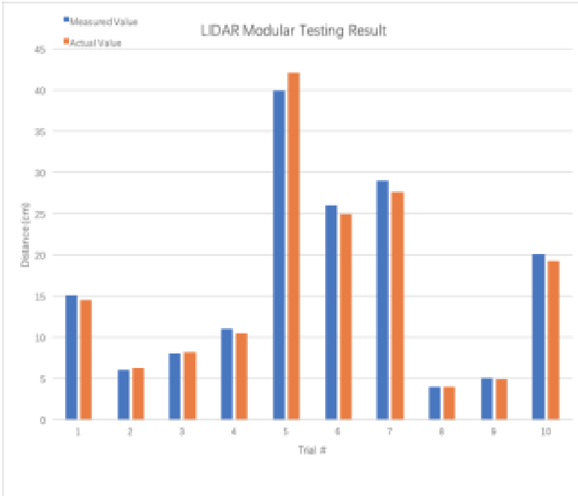



**Figure 3.4 Measured distance vs. Actual distance**

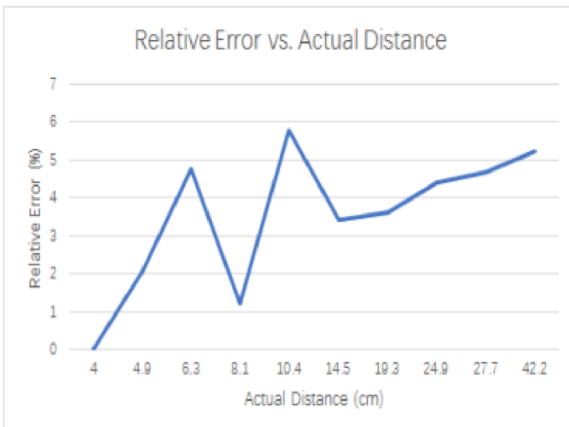



**Figure 3.5 Relative Error vs. Actual Distance**

According to our test results, we found that the relative error within the range of 50 cm was mostly below 5%, which met our accuracy requirement.

## 3.3 Driving & Navigation System

### 3.3.1 Motor & Motor Controller

We tried different logic combinations of the INPUT signals on the L298N microchip to manipulate the vehicle's movements.

| IN1 | IN2 | IN3 | IN4 | Operation |
|---|---|---|---|---|
| 1 | 0 | 0 | 1 | Turning around |
| 1 | 0 | 1 | 0 | Going straight |
| 1 | 0 | 0 | 0 | Turning Left |
| 0 | 0 | 1 | 0 | Turning Right |

**Table 3.2 Vehicle operations**

From this table, the vehicle satisfied all the requirement movements that we need in the software algorithm.

# 4. Cost

## 4.1 Parts

| Part | Manufacturer | Retail Cost ($) | Bulk Purchase Cost ($) | Actual Cost ($) |
|---|---|---|---|---|
| DMW-BCM13 Lithium-Ion Battery | Panasonic | 32.00 | 8.00 | 32.00 |
| IR Beacon and receiver (SKU 902111-IR) | Phoenix Junior | 30.00 | 5.00 | 5.00 |
| Microcontroller (Atmega328p) | Microchip Technology | 40.00 | 1.62 | 1.62 |
| Chassis and Motor | Sandy's SHOP | 17.99 | 7.99 | 17.99 |
| Resistors, capacitors, ICs, LEDs, sockets | TT Electronics | 9.99 | 0.99 | 9.99 |
| 2D LiDar (LIDAR-Lite v3) | Star Lite International, LLC | 129.99 | 8.99 | 129.99 |
| Ultrasonic Sensor (HC-SR04) | OSEPP Electronics | 3.95 | 0.50 | 3.95 |
| Voltage regulator (LD1117, L7805) | STMicroelectronics | 3.00 | 0.10 | 3.00 |
| PCB | PCB Way | 5.00 | 0.10 | 5.00 |
| **Total** | | **270.92** | **33.29** | **208.84** |

**Table 3.3 Parts Cost with Manufacturer, retail cost, bulk cost and actual cost.**

## 4.2 Labor

The estimated labor cost is about $20/hour, 8 hours/week for three team members. We spent 12 weeks on finishing this project, the total labor cost is:

$$3 * \frac{\$20}{\text{hour}} * \frac{8\text{hours}}{\text{week}} * 12\text{weeks} * 2.5 = \$14400 \qquad \text{(Eq 4.1)}$$

## 5. Schedule

| Week | Ningyuan Du | Jue Ni | Wuwen Wang |
|---|---|---|---|
| 02/25 | Schematic design | Sensor design | Schematic design |
| 03/04 | Finish the schematic design | Continue sensor design | Initiate microcontroller design |
| 03/11 | Version 1 PCB design | Unit test and bug fix on sensor design | Continue microcontroller design |
| 03/18 | Initiate navigation design | Version 1 PCB design | Version 1 PCB design |
| 03/25 | Unit test and bug fix on navigation design | Version 2 PCB design | Unit test and bug fix on microcontroller design |
| 04/01 | Version 2 PCB design | Version 2 PCB design | Version 2 PCB design |
| 04/08 | Prototype case and mechanical design | Complete design of sensors | Complete design of microcontroller |
| 04/15 | Bug fix on navigation | Bug fix on sensors | Bug fix on microcontroller |
| 04/22 | Test in real environment | Test in real environment | Test in real environment |
| 04/29 | begin final report and prepare presentation | begin final report and prepare presentation | begin final report and prepare presentation |

**Table 5.1 Schedule for our project**

# 6. Conclusion

## 6.1 Accomplishments

Overall, all individual modules worked well, and we successfully integrated them together. The robot can detect the obstacles in its surroundings and reacts correspondingly. If there is a customer blocking the way, the robot can stop instantly and turn on the LED to alarm. If there are still obstacles in the way, the robot would detect the obstacles on two sides and make correct decisions about directions to turn. The robot succeeded to avoid two obstacles during the final demonstration.

## 6.2 Uncertainties

The robot can roughly find the correct direction for navigation, but sometimes it failed to navigation to this direction. The accuracy of finding the correct direction is only 60%. The main reason behind this issue is the inertia of motion and high turning speed. We set the speed of turning around to be 60 RPM, which is relatively fast in this condition. Because of the inertia of motion, the robot cannot stop instantly after it received IR signal from destination.

## 6.3 Ethical considerations

The most common ethics issue of robotics is that robots may hurt people's health and property because of its failure of reacting properly. It is possible that a delivery robot navigates at a high speed and hit people or their property. This goes against #9 of the IEEE code of Ethics, "to avoid injuring others, their property, reputation, or employment by false or malicious action." [10]. During the process of designing our robot, we have carefully examined the design and make sure the ethics codes are followed. There is no harmful parts such as piercing parts in the structure of our robot, which prevents the potential hazard. In this way, the action of robot is more human-friendly.

## 6.4 Future work

In the future, we are going to modify the navigation system, such as lowering the turning speed or using a step motor instead. In this way, the robot should be able to find the correct direction and stop instantly. When navigating in straight line, the robot should also check the direction continuously to ensure that the direction is correct. The functionality of LiDar can also be optimized. Instead of fixing it in the front, we are going to swing it continuously to detect the surroundings. A camera and a more powerful microcontroller can be used to add additional features such as mapping and image recognition.

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