



(REVIEW ARTICLE)



Delivery line tracking robot

Md Rakibul Karim Akanda *, Jason Lazo, Quintwon Carter and Haineef Roberts

Department of Engineering Technology, Savannah State University, Savannah, GA 31404, United States of America.

International Journal of Science and Research Archive, 2024, 11(01), 627–638

Publication history: Received on 09 December 2023; revised on 20 January 2024; accepted on 23 January 2024

Article DOI: <https://doi.org/10.30574/ijrsra.2024.11.1.0099>

Abstract

The project we embarked on is making an electronic robot that can deliver a package along a set route through infrared sensors. It uses the infrared sensors to determine if the path it is following is correct or if it is off course. This is determined by sending off a photon to reflect off the path and determines if it is on a light surface by the amount of light emitted back or if it is a dark surface by the amount of light that is not present. In addition to following a line, the user can stop and start the robot at any interval through the infrared remote control. The project is a combination of the practical parts of machinery with the software part of coding in Arduino which is a coding subset of C++. This can lead to endless possibilities that could help a wide variety of people from all ranges of life, especially with those that live with disabilities.

Keywords: Arduino; Microcontroller; Robot; Sensor

1. Introduction

Automation in daily life can be something that allows such difficult tasks to become a wanton action that anybody can do. There are a wide range of purposes that the robot delivery system can fill in practical daily life. This is a combination of compassion and forward thinking towards the future. As people age their mobility tends to decrease with time because of injuries due to falling [1]. Falling is an issue that can be problematic to even the point of deadly as a person progresses in age. It is shown that throughout the years, coming up to the age of a typical senior citizen, means that a person is more likely to suffered death instead of just an injury.

The automation of robots for delivering packages could greatly aid senior citizens and those with disabilities as it relates to physical mobility. These individuals may face difficulties leaving their homes to run errands or receive deliveries due to limitations in their physical ability, which can impact their independence and quality of life. With the use of robots for package delivery, these individuals can receive their packages without having to leave their homes, making their lives easier and more comfortable.

One of the benefits of using robots for package delivery is that they can navigate obstacles and uneven surfaces that might pose a challenge for individuals with mobility issues. This means that the robot can deliver packages directly to the doorstep of the recipient, regardless of the challenges presented by stairs or steep inclines. About 36 million falls are reported among older adults each year—resulting in more than 32,000 deaths [2]. Additionally, the use of robots for package delivery eliminates the need for individuals with mobility issues to carry heavy packages, which can be especially challenging for those with physical limitations.

Moreover, the automation of robots for package delivery could provide an extra layer of safety and security for senior citizens and those with disabilities. These individuals may be at a higher risk of theft or harm when out in public, particularly if they are carrying valuable items or are visibly struggling with mobility issues. With the use of robots for

* Corresponding author: Md Rakibul Karim Akanda

package delivery, the individual can receive their package without leaving their home, reducing the risk of exposure to potential harm or theft.

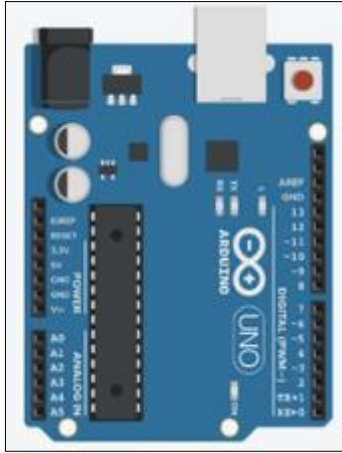

Overall, the automation of robots for package delivery could greatly improve the quality of life for senior citizens and those with disabilities as it relates to physical mobility. By providing a safe, secure, and convenient means of package delivery, individuals with mobility issues can receive the items they need without having to leave their homes or face physical challenges associated with package delivery.


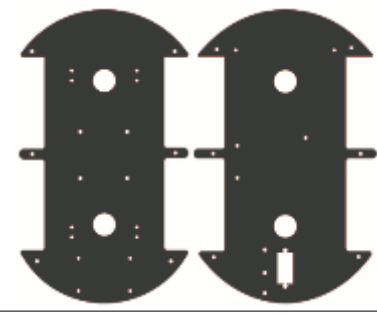
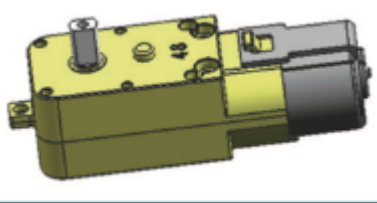






























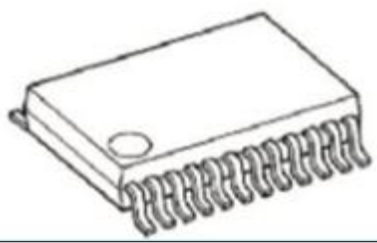
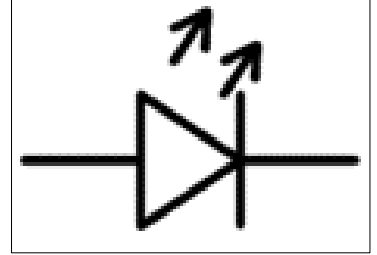
This is not only an issue facing the older generation but for a large swath of people across the country. As stated by the Center of Disease Control 11% of all adults in the United States face an issue with mobility, such as walking or climbing stairs. This problem is only getting more exasperated as the general age of the population increases over time. The issue of how society maintains normalcy as aging becomes the norm, but people need to be as they once were. To put the how much of a tidal wave of that this issue is something that needs to be concerned about it is estimated that more than one out of every six, including children and younger, is 65 or older and only continues to get bigger as time goes forward [3].

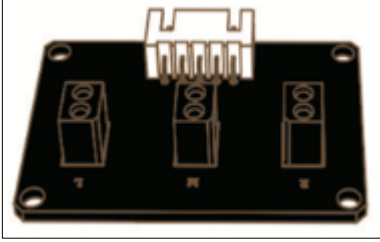
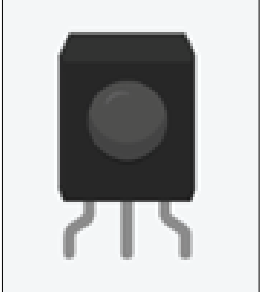
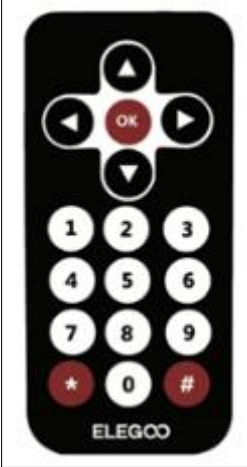
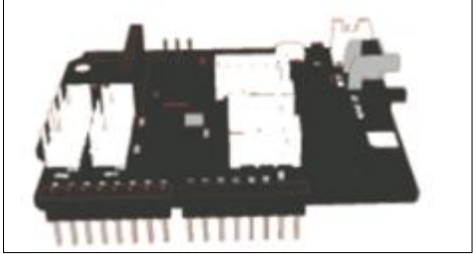

2. Equipment


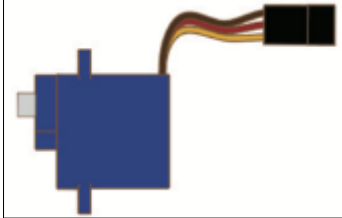

The project revolves around the programmable circuit board, also referred to as a microcontroller, the Arduino UNO. The flexibility of a microcontroller enables the user to assign inputs and outputs and control with a few lines of code. The equipment list is given in Table 1.

Table 1 List of components and their images

Component	Image
Arduino UNO (x1)	
Battery 9 Volt (x1)	

<p>Black Tape</p>											
<p>Chassis</p>											
<p>DC Motor (x4)</p>											
<p>Hardware (Assorted)</p>	<table border="0"> <tr> <td> M3*30 Hexagon Socket Screw*24PCS</td> <td> ML6 Nut*6PCS</td> </tr> <tr> <td> M3*12 Hexagon Socket Screw*3PCS</td> <td> M2 Nut*3PCS</td> </tr> <tr> <td> M3*14 Hexagon Socket Screw*8PCS</td> <td> M3 Nut*21PCS</td> </tr> <tr> <td> M3*30 Hexagon Socket Screw*9PCS</td> <td> M2*6 Copper Pillar*5PCS</td> </tr> <tr> <td> ML6*8 Cross Screw*3PCS</td> <td> M3*11 Copper Pillar*1PC</td> </tr> </table>	 M3*30 Hexagon Socket Screw*24PCS	 ML6 Nut*6PCS	 M3*12 Hexagon Socket Screw*3PCS	 M2 Nut*3PCS	 M3*14 Hexagon Socket Screw*8PCS	 M3 Nut*21PCS	 M3*30 Hexagon Socket Screw*9PCS	 M2*6 Copper Pillar*5PCS	 ML6*8 Cross Screw*3PCS	 M3*11 Copper Pillar*1PC
 M3*30 Hexagon Socket Screw*24PCS	 ML6 Nut*6PCS										
 M3*12 Hexagon Socket Screw*3PCS	 M2 Nut*3PCS										
 M3*14 Hexagon Socket Screw*8PCS	 M3 Nut*21PCS										
 M3*30 Hexagon Socket Screw*9PCS	 M2*6 Copper Pillar*5PCS										
 ML6*8 Cross Screw*3PCS	 M3*11 Copper Pillar*1PC										
<p>H-Bridge (TB6612 x1)</p>											
<p>LED (Delivery x1)</p>											

<p>Line Tracking Sensor (ITR20001 x3)</p>	 A black printed circuit board (PCB) with a central five-pin connector and three pairs of infrared sensors on either side.
<p>Infrared Receiver (x1)</p>	 A small, black, rectangular component with three pins extending from the bottom.
<p>Infrared Remote (x1)</p>	 A black remote control with a directional pad, an 'OK' button, and a numeric keypad. The brand name 'ELEGOO' is visible at the bottom.
<p>IO Expansion Board (x1)</p>	 A black PCB with various connectors, including a USB port and a header, used for expanding the capabilities of a microcontroller.
<p>Package Mechanism</p>	 A photograph showing a pink cylindrical component, likely a sensor or actuator, mounted on a mechanical assembly.

Resistor	
Servo Motor (x1)	
Wheels (x4)	

2.1.1. Arduino UNO

Research on a variety of materials and tools that aid in the creation of tiny chips utilized in a variety of applications has been conducted during the past few decades [4-17]. Here we use a low-cost microcontroller board that can be programmed based on the C++ computer language. Arduino is an open-sourced accessible solution for a wide range of electronics, robotics, and programming projects.

2.1.2. DC Motor

Direct current motors have a large use base, anything from large industrial equipment to small toys. A typical DC motor has a pair of permanent magnets in the stator creating an electromagnetic field when current passes through the coil an electromagnetic current is induced causing the coil to rotate. The direction of the current will determine the direction of the armature to rotate. With many use cases, the application for a servo motor can be used at a vast scale.

2.1.3. H-Bridge (TB6612)

The TB6612 H-Bridge is used to drive higher amperage than capable with the Arduino microcontroller board. In so requiring a greater external power source. The H-Bridge consists of four switches that control voltage which allows the ability to apply voltage across the DC motors in different directions to rotate in either clockwise (CW) or counterclockwise (CWW) configurations.

2.1.4. Line Tracking Sensor (ITR20001 x3)

The line tracking module is composed of three ITR20001 photoelectric sensors, each perspective component is aligned for a Right, Center and Left sensor. A photoelectric sensor is a device useful to detect the presence or absence of an object using light. Each sensor consists of a phototransistor and an infrared light-emitting diode (LED). Detecting the light reflected from the LED sensor can detect the difference between light and dark lines.

2.1.5. Infrared Receiver and Remote

The IR receiver is sensitive to infrared light which detects the supplied infrared light from the IR remote at a certain frequency. The IR receiver is a photodiode that converts the IR signal light to an electrical signal. The IR remote is a transmitter with an IR LED that emits IR light. The encoded light signal from the remote is received to by the IR receiver and converted to binary for the Arduino microcontroller to intake. The binary signal is converted to hexadecimal and is viewable with the serial communication dialogue. Each button input from the IR remote has a unique code which can be assigned to a specific command. Buttons 1 and 2 were chosen to stop and resume all functions of the line tracking car.

2.1.6. Servo Motor

A simple servo motor consists of a DC motor combined with a potentiometer and a set of gears that can position the output shaft to a certain angle. Servo motors have angle limitations along with certain torque limits. Regardless of the limitations the reliability of a servo motor permanently established the popularity in robotics and other electronic applications.

3. Theory

The line following car displays a very simplified introduction to how real-world applications such as automated guided vehicles (AGV) and autonomous transportation work. Autonomous transportation technology navigates through various environments, including responding to obstacles, navigating on roads with different types of lines (or no lines at all), and encountering constantly evolving conditions. While automated guided vehicles follow along marked long lines or wires on the floor, or use radio waves, vision cameras, magnets, or lasers for navigation. The line following car is comprised of 4 key parts IR sensors, motor driver, an Arduino, and a power source. IR sensors are placed on both right and left side of the car, the car is situated over a black line such that both sensors are outside of the line. When the black line is detected by one of the sensors a signal is sent to the Arduino and the corresponding motor rotates backwards while the other motor rotates forward to turn the car to that side. This is theoretically comparable (but not identical) to how a real autonomous car might monitor lane lines to make sure the car does not drift out of its lane. There are many applications that display similar technology in this project such as automated guided vehicles in warehouse environments and autonomous transportation to name a few.

Automated guided vehicles are load carrying vehicles that navigate along the floor of a facility without guidance from personnel. Their movement is controlled by a mixture of software and sensor-based guidance systems. Since they move on a predetermined path along with accurately controlled acceleration and deceleration, and include automatic obstacle detection bumpers, AGVs provide safe movement of loads. AGV applications are used mainly in warehouses and manufacturing facilities with pallet trucks, forklifts, and transportation of light loads to name a few. There are various methods used to control AGV navigation, but for the sake of simplicity the 3 that will be covered are laser guided, guide tape, and wired (radio frequency). The guided tape navigation method is the method that closely relates to the method used in this project. The two styles of tape are colored and magnetic, with colored tape sensors sense the contrast between the tape and the background/floor to navigate and with magnetic tape there are inductive sensors that sense utilized to navigate.

AGV's provide many benefits such as safety, efficiency, and cost effectiveness. Safety is always the most important thing to any business AGVs can increase safety for personnel by performing tasks that could potentially dangers for humans along with the fact that they always follow their guide path and stop if they encounter an obstruction. Repetitive tasks can be completed with AGV's high volumes accuracy enabling employees to have more time to complete complicated tasks. High efficiency helps reduce unnecessary cost along with the reduced labor needs helps AGV's become a cost-effective solution.

3.1. Circuit

Additionally, a replica circuit of the project was created using 'Tinker Cad' online software simulator. The circuit was made as close as possible with the available components from the simulation program.

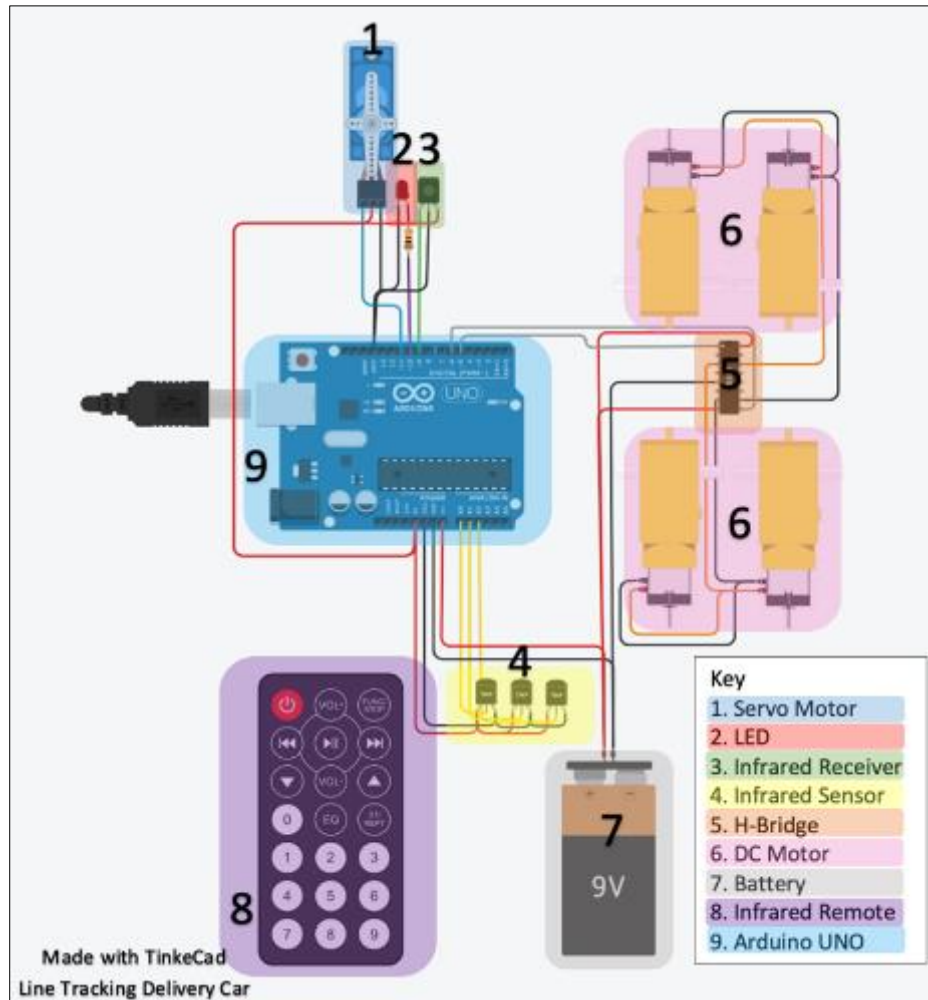


Figure 1 Connection diagram of Arduino with sensors and motors.

(Please note the three ITR20001 infrared sensors used for the line tracking functions were substituted by the famous TMP36 sensors in Figure 1, wiring is the same for both mentioned components).

The project relies heavily on the input from the line tracking system, as previously mentioned it is composed of three ITR20001 infrared sensors (Figure 2). This sensor, similar to the Servo (Figure 3) and Infrared Receiver (Figure 4) are utilizing a traditional three pin configuration made up of the 5 Volts supply, ground and their perspective signal wire.

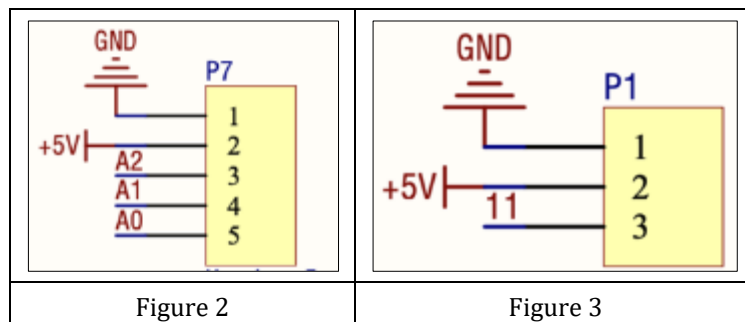


Figure 2, 3 Infrared sensor pin configuration is shown in left figure, and servo pin configuration is shown in right figure.

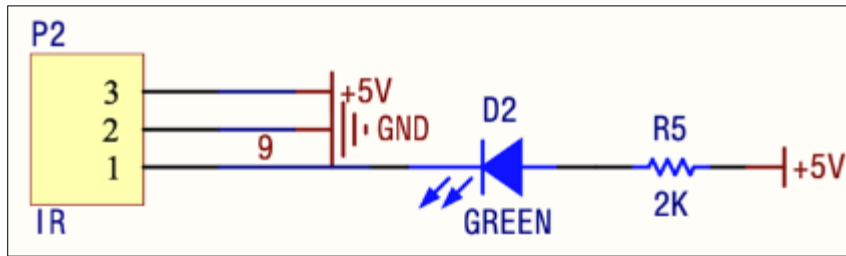


Figure 4 Infrared receiver pin configuration.

The IR receiver Figure 4 is connected to PIN 9 on the Arduino UNO, an LED is connected in series with the input signal to illuminate a green LED when signal is received from the IR remote. A 2 kohm resistor is used as the small green LED does not require a vast amount of current. The expansion board supplied with the project kit does not specify the green LED current ratings but we can assume by using the supplied resistor with the following equation:

$$R = V / I \rightarrow R = 5V - V_f / I_f \rightarrow 2k = 5 - 2 / I_f \rightarrow I_f = 3 / 2k = 1.5 \text{ mA}$$

In similar fashion, we can calculate the current limiting resistor on the red Delivery LED that was added to the project. The red Delivery LED is connected to PIN 10. The current limiting resistor was found using the following equation:

$$R = V / I \rightarrow R = 5V - V_f / I_f \rightarrow R = 5V - 2V / 20\text{mA} \rightarrow R = 3V / 20 \text{ mA} = 150 \text{ ohms}$$

The decision was made to round up to a more common resistor value of 220 ohm. It is critical to round upwards to a greater robust resistor rating than to round down to prevent component failure from supply current.

Transitioning to the DC motors that propel the delivery car, the TB6612 H-Bridge is used to drive the load. The right-side motors are wired in series, and the left side are paired as well. The H-Bridge is critical to the operation of the delivery car as it grants us the ability to reverse the current in thus changing the direction of the wheels. The CW and CWW motion can be seen by reviewing the control function chart Figure 6.

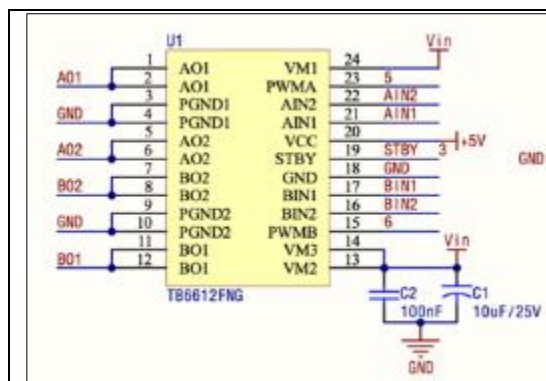


Figure 5

Input				Output		
IN1	IN2	PWM	STBY	OUT1	OUT2	Mode
H	H	H/L	H	L	L	Short brake
L	H	H	H	L	H	CCW
		L	H	L	L	Short brake
H	L	H	H	H	L	CW
		L	H	L	L	Short brake
L	L	H	H	OFF (High impedance)		Stop
H/L	H/L	H/L	L	OFF (High impedance)		Standby

Figure 6

Figure 5 and 6 H-bridge pin configuration is shown in left figure; control function of H-bridge is shown in right figure.

The TB6612 is shown in Figure 5, it is important to highlight the wiring function for this H-Bridge. For PIN 5, the right-side motors, are connected to PWMA which ultimately functions and an enable pin for the right side. The AIN1 signal is connected to PIN 7 which is our phase pin. AIN1 allows the motor to function forward/reverse (CW and CWW) depending on the 1/0 assignment in the code. The phase assignment was influential during turning movements as discussed in the Code section of this literature. The left-side motors also have the same structure with a PWMB in PIN 6 and a BIN1 phase in PIN 8.

3.2. Code

The code for this project is written in C++ language for the Arduino UNO microcontroller. See Figure 7 for the initial portion of the code. In this program we are utilizing two external libraries for the Servo Motor and the Infrared Remote and Receiver functions.


```

1  /* Arduino Line Follower Robot Code
2  by Jason Lazo, Quinton Carter, and Haineef Roberts */
3  #include <Servo.h>           // Include the Servo Library
4  #include <IRremote.h>       // Include the IRremote library
5
6  #define IRReceiver 9        // Define the pin for the IR receiver module
7  IRrecv irrecv(IRReceiver); // Create an IR receiver object
8  decode_results results;     // Create a variable to store the decoded results
9
10 #define Button1 0xFF6897    // Assigning IR HEX value to Button1
11 #define Button2 0xFF9867    // Assigning IR HEX value to Button2
12
13 //Line Tracker Module
14 #define L_S A2              // Right Sensor
15 #define M_S A1              // Middle Sensor
16 #define R_S A0              // Left Sensor
17
18 #define DeliveryLED 10      // Delivery Alert LED
19
20 Servo DeliveryServo;       // Create servo object to control a servo
21
22 // H-Bridge Pins
23 #define ENABLE_RIGHT 5      // Right side motors (PWMA)
24 #define ENABLE_LEFT 6      // Left side motors (PWAB)
25 #define R_Direction 8      // Forward or Reverse (AIN1 : Phase Pin)
26 #define L_Direction 7      // Forward or Reverse (BIN2 : Phase Pin)
27 #define Master_Enable 3     // H-Bridge Enable (STBY)
28
29 #define speed 100           // Motor speed is 100 (0-255)
30 #define tspeed 120          // Motor turning speed is 120 (0-255)

```

Figure 7 Assignment of variables and pins.

3.3. Initial assignment of variables and pins.

Each button key pressed on the IR Remote generates a unique hexadecimal code. The hexadecimal code may vary with different remotes. Utilizing the `Serial.begin(9600)` command line to initialize serial communication along with the `irrecv.enableIRIn()` line to start the IR receiver in Figure 8, the ability to review the unique hexadecimal codes by our specific IR Remote. The baud rate of 9600 bits per second is more than enough to receive sufficient data to gather the button inputs. As shown in Figure 7, hexadecimal `0xFF6897` and `0xFF9867` were gathered from Button 1 and 2 respectively. A switch statement was used to specify which case was received for both Button 1 and Button 2 of the IR Remote.

Two different variables were created for the speed of DC Motors. Taking advantage of the PWM capabilities, a motor speed (0 to 255) was assigned for straight line motion and a different duty cycle for turning speed as the need for adjustment was found during testing. Ultimately the speed assignment is called upon the 'analogWrite' commands see Figure 10 and Figure 11.

```

31
32 void setup(){
33
34 Serial.begin(9600);           // Initialize serial communication
35 Irrecv.enableIRIn();         // Start the IR receiver
36
37 //Line Tracker Module (ITR20001)
38 pinMode(R_S, INPUT);        // Right IR diode
39 pinMode(M_S, INPUT);        // Middle IR diode
40 pinMode(L_S, INPUT);        // Left IR diode
41
42 //Delivery LED Alert
43 pinMode(DeliveryLED,OUTPUT); // Assigning Delivery LED as output
44
45 //Motor Pin Setup
46 pinMode(ENABLE_RIGHT, OUTPUT); // Right Motors (PWMA)
47 pinMode(ENABLE_LEFT, OUTPUT); // Left Motors. (PWMB)
48 pinMode(R_Direction, OUTPUT); // Right Motors Direction, high moves forwards
49 pinMode(L_Direction, OUTPUT); // Left Motors Direction, low moves backwards
50 pinMode(Master_Enable, OUTPUT); // H-Bridge Enable
51
52 //Presets with Master Enable
53 digitalWrite(Master_Enable, HIGH); // Enabling H-Bridge
54 digitalWrite(R_Direction, HIGH); // Right Motors Direction, high moves forwards
55 digitalWrite(L_Direction, HIGH); // Left Motors Direction, low moves backwards
56
57 //Servo setup
58 DeliveryServo.attach(11);    // Attaches the servo on pin 11
59 }

```

Figure 8 Using setup function to select the mode of different pins.

The main void loop of the code is mainly comprised of situations encountered by the line tracking module. Since this project is primarily dependent on the black line for output movements, the decision was made to create and call upon a function for each scenario the design may encounter (Figure 9).

```

61 void loop(){
62
63 DeliveryServo.write(0);      // Set the Delivery Servo to 0 degree
64
65 if (Irrecv.decode(&results){ // If IR signal is received
66 {
67   Serial.println(results.value, HEX); // Print the received signal value
68   switch (results.value)           // Map the signal to the LED
69   {
70     case Button1:                  // Button1
71       IRGo();                      // IR Go function
72       break;
73     case Button2:                  // Button2
74       IRStop();                    // IR Stop function
75       break;
76   }
77   Irrecv.resume();               // Receive the next signal
78 }
79 // Line Tracking : 1 = black line : 0 = white background
80 // Forward Movement
81 // If Right Sensor and Left Sensor are at White color then it will call forward function
82 if ((digitalRead(R_S) == 0)&&(digitalRead(L_S) == 0)&&(digitalRead(M_S) == 1)){forward();} \
83
84 // Right turn
85 // If Right Sensor is Black and Left Sensor is White then it will call turn Right function
86 if ((digitalRead(L_S) == 0)&&(digitalRead(M_S) == 0)&&(digitalRead(R_S) == 1)){turnRight();delay(10);forward();}
87 if ((digitalRead(L_S) == 0)&&(digitalRead(M_S) == 1)&&(digitalRead(R_S) == 1)){turnRight();delay(10);forward();}
88
89 // Left turn
90 // If Right Sensor is White and Left Sensor is Black then it will call turn Left function
91 if ((digitalRead(L_S) == 1)&&(digitalRead(M_S) == 0)&&(digitalRead(R_S) == 0)){turnLeft();delay(10);forward();}
92 if ((digitalRead(L_S) == 1)&&(digitalRead(M_S) == 1)&&(digitalRead(R_S) == 0)){turnLeft();delay(10);forward();}
93
94 // Delivery Stop
95 if((digitalRead(R_S) == 1)&&(digitalRead(M_S) == 1)&&(digitalRead(L_S)==1){Deliver();}
96
97 // Stopping at all white background
98 if ((digitalRead(R_S) == 0)&&(digitalRead(M_S) == 0)&&(digitalRead(L_S) == 0){Stop();}
99 }

```

Figure 9 Decision criteria to move on different directions.

```

100 void IRStop() //IR function to Stop
101 {
102     digitalWrite(DeliveryLED,HIGH); // Turn Delivery LED on
103     digitalWrite(Master_Enable , LOW); // Disable H-Bridge
104 }
105
106
107 void IRGo() // IR function to Go
108 {
109     digitalWrite(DeliveryLED,LOW); // Turn Delivery LED off
110     digitalWrite(Master_Enable , HIGH); // Enable H-Bridge
111 }
112
113 void forward() { //forward
114     analogWrite(ENABLE_RIGHT, speed); // Motor speed is 100 (0-255)
115     analogWrite(ENABLE_LEFT, speed); // Motor speed is 100 (0-255)
116     digitalWrite(R_Direction, HIGH); // Right Motor, high moves forwards
117     digitalWrite(L_Direction, HIGH); // Left Motor, low is moves backwards
118 }
119
120 void Stop() { //stop
121     digitalWrite(ENABLE_RIGHT, LOW); // Disabling Right Motors
122     digitalWrite(ENABLE_LEFT, LOW); // Disabling Left Motors
123 }
124
125 void turnRight() { //turnRight
126     analogWrite(ENABLE_RIGHT, tspeed); // Motor turning speed is 120 (0-255)
127     analogWrite(ENABLE_LEFT, tspeed); // Motor turning speed is 120 (0-255)
128     digitalWrite(R_Direction, HIGH); // Right Motor, high moves forwards
129     digitalWrite(L_Direction, LOW); // Left Motor, low is moves backwards
130     //delay(10);
131 }

```

Figure 10

```

132
133 void turnLeft() { //turnLeft
134     analogWrite(ENABLE_RIGHT, tspeed); // Motor turning speed is 120 (0-255)
135     analogWrite(ENABLE_LEFT, tspeed); // Motor turning speed is 120 (0-255)
136     digitalWrite(R_Direction, LOW); // Right Motor, low is moves backwards
137     digitalWrite(L_Direction, HIGH); // Left Motor, high moves forwards
138     //delay(10);
139 }
140
141 void Deliver() { // Deliver
142     digitalWrite(Master_Enable, LOW); // H-Bridge in standby
143     DeliveryServo.write(0); // Setting servo to 0 degrees
144
145     for (int t = 0; t < 5;t++) // Delivery LED blinking for delivery
146     {
147         digitalWrite(DeliveryLED, HIGH);
148         delay(200);
149         digitalWrite(DeliveryLED, LOW);
150         delay(200);
151     }
152
153     DeliveryServo.write(160); // Setting servo to 160 degrees
154     delay (1000);
155
156     digitalWrite(Master_Enable, HIGH); // Enabling H-Bridge
157     digitalWrite(R_Direction, HIGH); // Right Motor, high moves forwards
158     digitalWrite(L_Direction, HIGH); // Left Motor, low moves backwards
159 }
160

```

Figure 11

Figure 10 and 11 First five functions are shown in left figure; last two functions are shown in right figure.

As shown in Figure 10 and 11, seven different functions were created to orchestrate the movements of the delivery car. The functions are as follows: Infrared Go and Infrared Stop to be executed via the inputs of the IR Remote. The remaining five functions are situational based from the black line path in front of the car. It needs to be mentioned that since the functions command movement the car will constantly be breaking in and out of the function statements as it travels the delivery path. This allows for the functions to be kept simple without the need for a complicated code structure to constantly break out of the current movement function. Although the system is not perfect, we are aware that the occasional requirement of human intervention is to physically reset the car back on delivery path.

4. Conclusion

This design is the meshing of two elements, hardware, and software, that are critical to the completion of real-world assignments where software and hardware developers work hand in hand together. In this project we replicated autonomous robotics used in industrial applications to perform repetitive delivery tasks with the line following car. During prototyping and the implementation of this project valuable troubleshooting skills and programming techniques were further developed. One of the major challenges during the prototyping was designing a mechanism that was sturdy enough for holding an item while being light enough to be within the torque range for the servo motor to actuate it, but success was achieved through dedicated group work. When designing any system there is a fair amount of troubleshooting involved to verify the correct operation of the system. Coding presented more troubleshooting opportunities followed by the electronic devices; this is nothing short of the activities that ensue the installation of the corresponding practical applications for this project. Throughout the course of this project the complete understanding of the line following car helps us gain insight into how closely the conceptualization of this project aligns with AGV's and AMR's (automated mobile robots). A complete understanding of these technologies helps us visualize the benefits that these solutions offer.

Compliance with ethical standards

Acknowledgments

This work was supported as part of Modeling and Simulation Program (MSP) grant funded by the US Department of Education under Award No. P116S210002 and Improving Access to Cyber Security Education for Underrepresented Minorities grant funded by the US Department of Education under Award No. P116Z230007.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

- [1] Centers for Disease Control and Prevention. (2023, March 24). Keep on your feet-preventing older Adult Falls. Centers for Disease Control and Prevention. Retrieved April 21, 2023, from <https://www.cdc.gov/injury/features/older-adult-falls/index.html>
- [2] Ylitalo, K. R., & Karvonen-Gutierrez, C. A. (2016). Body mass index, Falls, and injurious falls among U.S. adults: Findings from the 2014 behavioral risk factor surveillance system. *Preventive Medicine*, 91, 217–223. <https://doi.org/10.1016/j.ypmed.2016.08.044>
- [3] Searing, L. (2023, February 10). More than 1 in 6 Americans now 65 or older as U.S. continues graying. *The Washington Post*. Retrieved April 14, 2023, from <https://www.washingtonpost.com/wellness/2023/02/14/aging-boomers-more-older-americans/>
- [4] M. R. K. Akanda, Catalogue of Potential Magnetic Topological Insulators from Materials Database, *IOSR Journal of Applied Physics (IOSR-JAP)* 15 (3), 22-28 (2023)
- [5] M. R. K. Akanda, Scaling of voltage controlled magnetic anisotropy based skyrmion memory and its neuromorphic application, *Nano Express* 10, 2 (2022). <https://iopscience.iop.org/article/10.1088/2632-959X/ac6bb5/pdf>
- [6] Md. Rakibul Karim Akanda and Roger K. Lake, Magnetic properties of nbsi2n4, vsi2n4, and vsi2p4 monolayers, *Applied Physics Letters* 119, 052402 (2021). <https://doi.org/10.1063/5.0055878>
- [7] Md. Rakibul Karim Akanda, In Jun Park, and Roger K. Lake, Interfacial dzyaloshinskii-moriya interaction of antiferromagnetic materials, *Phys. Rev. B* 102, 224414 (2020). <https://journals.aps.org/prb/abstract/10.1103/PhysRevB.102.224414>
- [8] M. R. K. Akanda, Catalog of magnetic topological semimetals, *AIP Advances* 10, 095222 (2020). <https://doi.org/10.1063/5.0020096>
- [9] M. R. K. Akanda and Q. D. M. Khosru, Fem model of wraparound cntfet with multi-cnt and its capacitance modeling, *IEEE Transactions on Electron Devices* 60, 97–102 (2013). <https://ieeexplore.ieee.org/abstract/document/6375797>
- [10] Yousuf, A., & Akanda, M. R. K. (2023, June), Ping Pong Robot with Dynamic Tracking Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland. <https://peer.asee.org/43897>
- [11] M. R. K. Akanda and Q. D. M. Khosru, Analysis of output transconductance of finfets incorporating quantum mechanical and temperature effects with 3d temperature distribution, *ISDRS*, 1–2 (2011), <https://ieeexplore.ieee.org/abstract/document/6135292>
- [12] M. R. K. Akanda, R. Islam, and Q. D. M. Khosru, A physically based compact model for finfets on-resistance incorporating quantum mechanical effects, *ICECE* 2010, 203–205 (2010). <https://ieeexplore.ieee.org/abstract/document/5700663>
- [13] M. S. Islam and M. R. K. Akanda, 3d temperature distribution of sic mesfet using green's function, *ICECE* 2010, 13–16 (2010). <https://ieeexplore.ieee.org/abstract/document/5700541>
- [14] M. S. Islam, M. R. K. Akanda, S. Anwar, and A. Shahriar, Analysis of resistances and transconductance of sic mesfet considering fabrication parameters and mobility as a function of temperature, *ICECE* 2010, 5–8 (2010). <https://ieeexplore.ieee.org/abstract/document/5700539>
- [15] Md. Rakibul Karim Akanda, In Jun Park, and Roger K. Lake, Interfacial dzyaloshinskii-moriya interaction of collinear antiferromagnets mnpt and nio on w, re, and au, *APS March Meeting* (2021). <https://ui.adsabs.harvard.edu/abs/2021APS..MARE40004A/abstract>
- [16] Rakibul Karim Akanda, 3-D model of wrap around CNTEFT with multiple CNT channel and analytical modeling of its capacitances, *Department of Electrical and Electronic Engineering (EEE)* 2013.
- [17] Akanda, Md. Rakibul Karim, *Magnetic Properties of Ferromagnetic and Antiferromagnetic Materials and Low-Dimensional Materials*, University of California, Riverside ProQuest Dissertations Publishing, 2021, 28651079.