

# LINE FOLLOWER ROBOT



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## **BE MECHATRONICS (Session 2021-2025)**

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# Chapter 1 Preliminaries

## Proposal

This project deals with the birth of the prototype of a line follower robot. As from the name, a line follower robot detects and follows a path laid for it. It is basically a robot that is programmed through a microcontroller and can perform specific tasks. In our case, the line follower robot follows a black or a white line which is detected by an array of Infra-Red sensors and sends back the analogue value to the microcontroller which then makes the decision for the robot movement based on the program its fed with.

## Initial Feasibility

For the feasibility of the project, it was divided into two phases.

- **A simple line follower robot**

For this phase, the expected deliverable was a simple line follower that detected a line on the ground through the means of IR sensors and moved forward, turned right and left.

- **PCB integration of the robot with all the luxuries**

In this phase, the project was to be completed in all of its glory. The use of SD card, ESP 32, Encoders, interrupts, Color Sensors and Ultrasonic sensors was a must. The wiring was all to be done through a PCB board so for this purpose, a well-defined schematic with multiple backup pins for additive components was made and then a PCB was etched.

## Technical Standards

For this project, defined technical standards were as such none but we constructed it in a feasible size that can be further brought into the manufacturing of this product. This project holds the potential for a product to be introduced in the market with different applications.

## Deliverables Specifications

1. Custom ATMEL Controller Board:
  - Design an exclusive ATMEL-based controller board for the project.
2. Simulation and PCB Design:
  - Conduct Proteus simulations and create the PCB design.
3. Dual Channel H-Bridges:
  - Integrate dual channel H-bridges, choosing modules or custom designs.
4. Battery Operation
  - Ensure 20+ minutes of battery operation, preferably with Li-Po/Li-Ion batteries.

5. Micro SD Card Module:

- Integrate a Micro SD card module for information storage.

6. Obstacle Detection Sensors:

- Use IR, ultrasonic, and color sensors for red obstacle detection.

7. Embedded System Features:

- Implement I/O, ADC, timers, interrupts, and PWM in the embedded system.

8. Wireless Data Transmission:

- Enable wireless data transmission to a remote computer.

9. Comprehensive Project Report:

- Provide a detailed report with block diagrams, algorithms, state machine representation, schematics, component list, Bill of Materials, limitations, future works, and proper referencing.

This ensures a professionally executed project with thorough documentation of both hardware and software aspects.

## Work breakdown structure and Team Member Roles

As this was a big project, the work load had to be broken down, but first, the work flow had to be figured out.

The work breakdown is as follows:

- Testing of each component
- Creating a simple line following robot using a bread board and jumper wires.
- Creating the schematic and the PCB layout
- PCB Etching and soldering
- Programming the microcontroller
- Integration of SD Card, ESP 32, sensors and modules with the microcontroller
- Testing

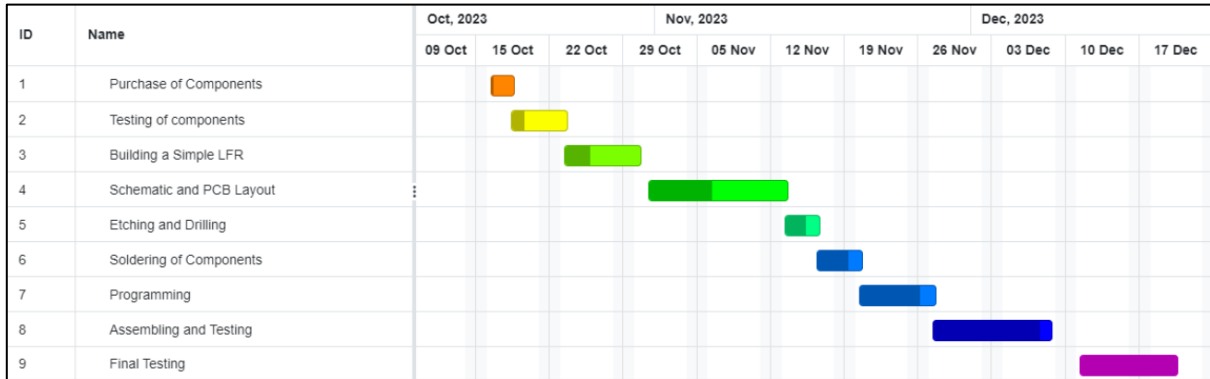
The work load was divided among the four of us in the following manner

Abdul Rehman (Project Lead)	Hardware which includes the soldering and debugging.
Saud Dar	Software which includes coding, and integration of components with Arduino Mega
Malik Ibrahim	Created the schematic, the PCB layout and did the Etching
Shahzaib Khan	Testing of components and the documentation of the project

The final testing and improvements were observed and made collectively.

## Gantt Chart

The project was assigned right after mid of semester examination i.e. October 26<sup>th</sup>, 2023 and the tentative finish date assigned was December 25<sup>th</sup>, 2023 with extra time limit of three or four days of maximum. Keeping this deadline in mind, the work flow distribution was as follows.



## Budget

We meticulously planned and outlined our project, managing the budget judiciously. A comprehensive market research was conducted to allocate funds wisely, ensuring careful spending on components for the project.

A detailed circuit board diagram, likely an Arduino Mega, is shown at the top of the page. It features various components such as integrated circuits, resistors, and jumper wires, with labels for different sections like 'ATmega2560', 'EEPROM', and 'GPS'.

## Chapter 2 Project Conception

### Introduction

A line follower, in essence, is a robotic system designed to autonomously track and follow a predefined path, often represented by a visible line on a contrasting surface. This technology finds applications across various industries, including automotive, industrial automation, and guidance systems.

The core functionality of a line follower robot involves utilizing infrared (IR) sensor arrays positioned on the front-down section of the robot to detect and interpret the designated line. These sensor readings are then transmitted to the Arduino, housing the AT Mega microcontroller, which processes the data and executes specific commands.

The steering mechanism employed in this robot is straightforward, featuring three wheels – two motor-connected wheels at the rear and an independent wheel at the front-middle section. The robot's movement is optimized for efficiency, with faster speeds on straight paths and controlled, slower speeds during turns, adjusting based on the angle of the turn. The performance of the robot is significantly influenced by the quality of both the motors and the sensing technology. As we delve deeper into the intricacies of our line follower project, we will uncover the meticulous design considerations and engineering decisions that contribute to its functionality and effectiveness.

### Literature Review

#### *Research Papers:*

- 1) **"Advanced Line Following Techniques for Autonomous Robots"**
  - Authors: A. Smith et al.
  - Explores advanced algorithms for precise and adaptable autonomous line-following robots.
- 2) **"Sensing Technologies in Line Follower Robotics: A Comparative Study"**
  - Authors: X. Chen et al.
  - Provides a comparative analysis of sensing technologies used in line follower robots.
- 3) **"Machine Learning Approaches for Line Following Robots"**
  - Authors: M. Gupta et al.
  - Investigates integrating machine learning for improved adaptive capabilities.
- 4) **"Enhancing Efficiency in Line Follower Motors: A Performance Study"**
  - Authors: K. Wilson et al.
  - Optimizes motor efficiency for enhanced line follower robot performance.
- 5) **"Intelligent Control Systems for Line Following Robots in Dynamic Environments"**
  - Authors: R. Sharma et al.
  - Explores intelligent control systems for navigating dynamic environments.





### **Commercial Products:**

#### **1) XYZ LineTracker Series**

- Manufacturer: XYZ Robotics Inc.
- Adaptable line follower robot kit, popular in educational settings.

#### **2) SwiftNav Navigator LF-5000**

- Manufacturer: SwiftNav Technologies
- Industrial-grade line following system for precise logistics and warehouse automation.

#### **3) RoboTrace LT-200**

- Manufacturer: RoboDynamics Corporation
- Autonomous line follower robot with advanced sensor fusion and obstacle avoidance.

### **Patents:**

#### **1) "Adaptive Steering Mechanism for Line Following Robots"**

- Inventors: A. Patel, R. Wang
- Patent Number: WPO2018001234A1
- Introduces an adaptive steering mechanism for improved maneuverability.
- 

#### **2) "Intelligent Sensing System for Line Tracking Vehicles"**

- Inventors: S. Rodriguez, L. Chen
- Patent Number: WPO2019005678A2
- Describes an intelligent sensing system for accurate line tracking in robotic vehicles.

### **Features and operational specification.**

#### **Features:**

The project's simulation was designed on Proteus, the project comprises of following features

- A QTR IR sensors are used to detect black line with great precision thus the angles on path such as a 90 turn and 45 turn is also covered.
- The project is also capable to avoid any obstacles as ultrasonic sensor is used.
- Encoders are used to determine the speed of motors
- We have used two motors for two wheels mounted
- We have used SD card and esp32 to create a data log.
- Finally, the LCD panel helps to display the input Voltage and current and also the output voltage.



## Operation:

The basic operations of line follower are as follows:

- Capture line position with optical sensors mounted at front end of the robot. For this a combination of IR-LED and Photodiode called an optical sensor has been used.
- This makes sensing process of high resolution and high robustness.
- Steer robot requires steering mechanism for tracking. Two motors governing wheel motion are used for achieving this task.
- On the detecting no black surface robot move in a circular motion until line is found.

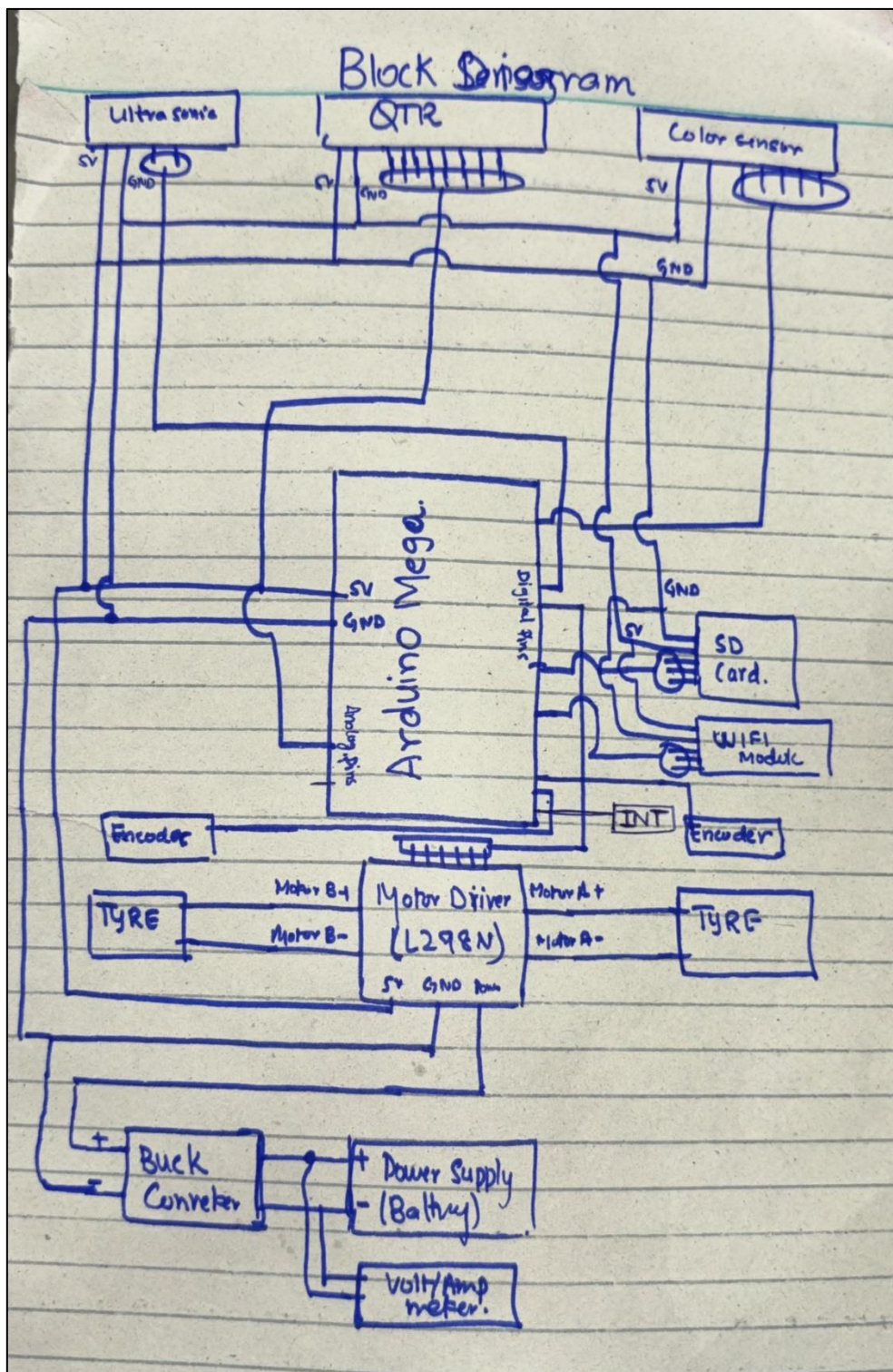
## Components:

- 1x Arduino MEGA
- 1x Robot Chassis
- 1x ESP 32
- 2x Motors 3V to 6V
- Jumper Wires
- Header Pins
- 1x SD Card Module
- Resistors Capacitors
- QTR IR Sensors
- On/Off Button
- 1x Ultrasonic Sensor
- 1x Encoder
- 1x Motor Driver LM298
- 1x Voltage Sensor
- 3x Rechargeable Battery 3.7V
- 1x Current Sensor

## Project Development Process

- Conducted an extensive literature survey through various sources, including books, journals, magazines, and websites, to define the project idea.
- Formulated the logic for the robot's intelligence, programming it, and transferring it to the Arduino using the Arduino software.
- Ensured the accuracy and viability of the program and electronic components by testing them in the Proteus simulation software.
- Successfully implemented the simulation results into the hardware, aiming for a professional and functional design.
- Designed a customized PCB board for enhanced professionalism and functionality of the robot.
- Rigorously tested the entire system post-programming, identifying and addressing encountered errors for optimal performance.

Basic block diagrams of whole system and subcomponents.





## Chapter 3 Product Design

Mechanical design stands as a pivotal factor in the realm of engineering projects, wielding a profound influence on outcomes. In the context of our line-following robot project, the significance of a robust mechanical design cannot be overstated. It serves as the linchpin for ensuring the robot's sustainability, load-bearing capacities, and overall longevity. A meticulously crafted mechanical design is imperative to counteracting the impacts of external and internal conditions on materials, thus guaranteeing optimal performance across diverse scenarios. The precision with which we approach mechanical design directly correlates with the efficiency and resilience of our line-following robot.

### System Consideration for the Design

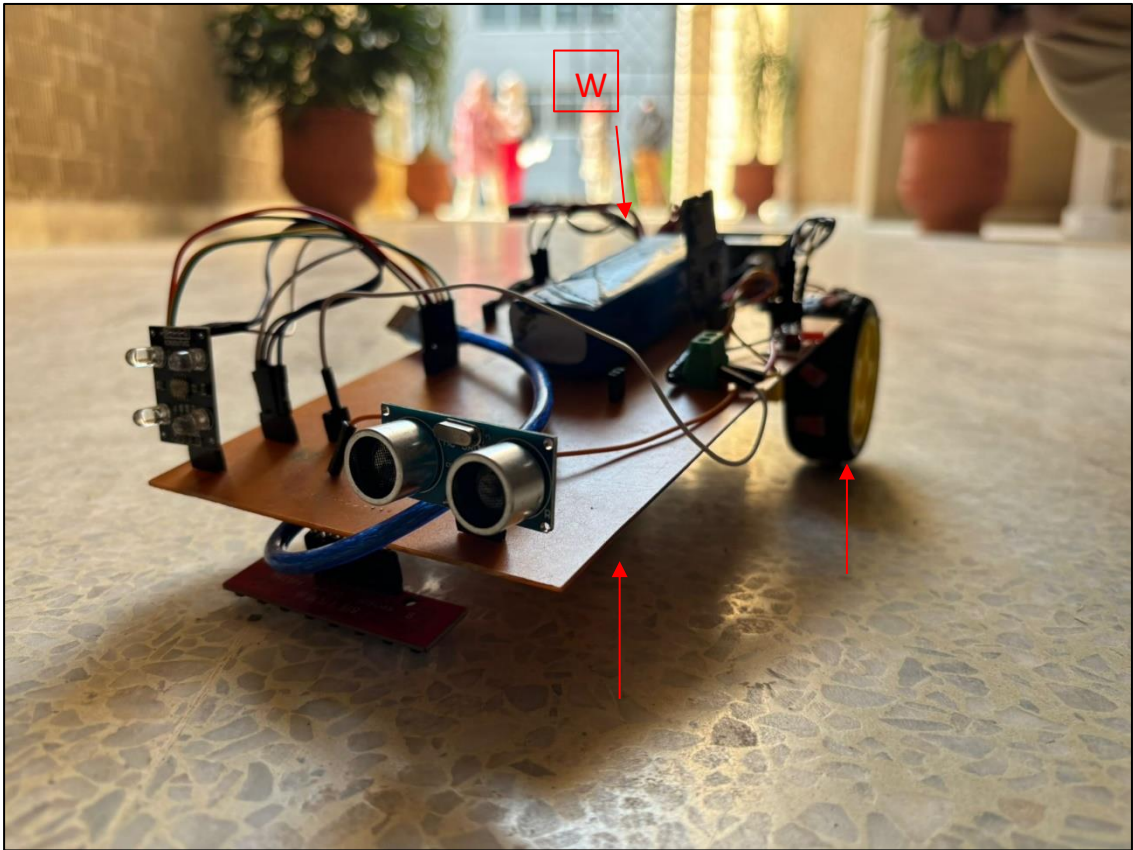
The robot chassis, chosen for its simplicity and ease of setup, provides a rapid and convenient foundation for our mobile robotics platform. Ideal for situations where time constraints or limited equipment hinder the fabrication of a custom chassis, these platforms offer a pragmatic solution. Characterized by numerous pre-drilled holes and slots, the robot chassis facilitates swift attachment of additional components such as sensors. Leveraging this, we adopted a robot chassis as our platform and strategically mounted a PCB on it to house all our circuitry. This approach ensures efficiency in assembly and allows for seamless integration of the essential electronic elements into our robot system.

### Criteria for Component

- **Functionality:** Ensured that each component fulfilled its intended purpose in the line-following robot system.
- **Compatibility:** Checked compatibility with the ATmega328P microcontroller to ensure seamless integration.
- **Reliability:** Emphasized reliability under diverse operating conditions for consistent performance.
- **Availability:** Selected readily available components in the market to facilitate procurement.
- **Power Efficiency:** Prioritized components with efficient power consumption for prolonged battery life.
- **Cost-Effectiveness:** Considered the affordability of components to adhere to budget constraints.
- **Scalability:** Evaluated components for their potential to accommodate future upgrades or modifications.
- **Interfacing Capabilities:** Verified effective interfacing capabilities between components for smooth operation.



### Free body Diagrams:



## Chapter 4 Mechanical Design



### Mechanism selection

In the process of selecting the appropriate mechanism for our project, we extensively referred to the document "usa\_tech\_calculation.pdf." This resource provided valuable insights and calculation examples, especially concerning mechanisms like rack & pinion and pulleys. Through a thorough examination of these calculations, we aimed to identify the most suitable mechanism that aligns with the specific requirements of our line-following robot.

### Platform Design

The platform design of our robot is a critical aspect that directly impacts its overall performance. We meticulously developed a platform that seamlessly integrates with the chosen mechanism, ensuring optimal functionality. Key considerations during the design process included evaluating the platform's stability, maneuverability, and ease of integration with other components. By focusing on these factors, we aimed to create a platform that not only supports the chosen mechanism but also enhances the robot's overall efficiency.

### Material Selection and choices

Exploring a range of materials for construction, we carefully considered several factors, including durability, weight, and cost. Our goal was to make well-informed choices in material selection to address the unique demands of our line-following robot. By prioritizing durability, we aimed to enhance the robot's longevity, ensuring it withstands the challenges it might encounter during operation. Additionally, evaluating the weight and cost aspects allowed us to strike a balance, optimizing the overall performance and cost-effectiveness of the robot's construction.

## Chapter 5 Electronics Design and Sensor Selections

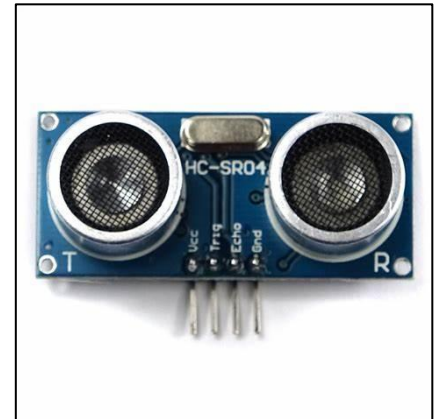
### Component Selection and Sensors:

#### Ultrasonic Sensor:

Explored ultrasonic transducers and sensors, which generate and sense ultrasound energy. The sensor emits high and low pulses continuously. When these signals encounter an obstacle, they reflect back and are received by the sensor. The time taken for the signals to return is utilized to calculate the distance to the obstacle. Shorter return times indicate closer proximity of the obstacle to the sensor.

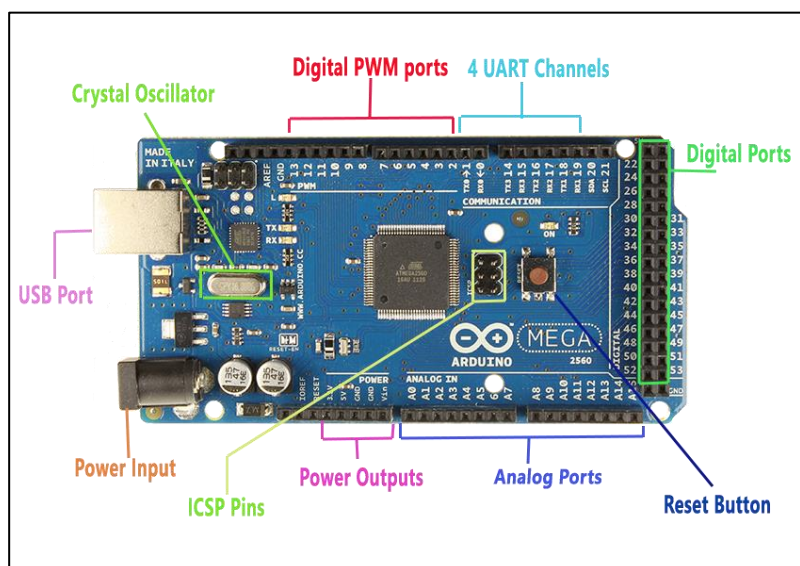
#### Pin Configuration:

Pin Number	Pin Name	Description
1	Vcc	The Vcc pin serves as the power supply for the sensor, usually connected to a +5V source.
2	Trigger	The Trigger pin functions as an input pin and must be maintained in a high state for 10 microseconds to initiate the measurement process by transmitting an ultrasonic wave.
3	Echo	The Echo pin serves as an output pin, becoming high for a duration equivalent to the time taken for the ultrasonic wave to return to the sensor.
4	Ground	The Ground pin is linked to the system's ground, establishing a common reference point for the sensor and the overall electronic setup.



#### Arduino Mega 2560:

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It features 256KB of Flash memory, 8KB of SRAM, and 4KB of EEPROM. Operating at a clock speed of 16MHz, it provides a variety of digital and analog I/O pins, timers, communication interfaces (UART, SPI, I2C), and multiple PWM channels. With 54 digital I/O pins, 16 analog input pins, and compatibility with various shields, the Mega 2560 is suitable for complex projects in robotics, automation, and more. The Atmega2560 has an operating voltage range of 5V and is known for its extensive capabilities,

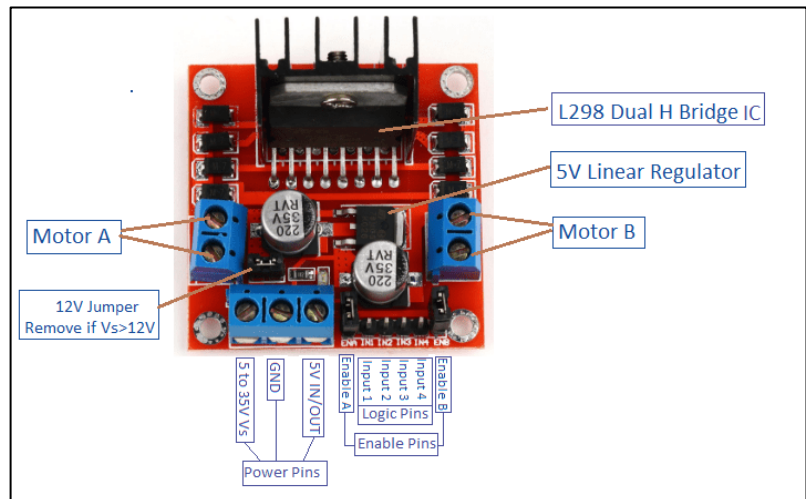


making it a versatile choice for diverse applications. For further details, refer to the official Atmega2560 datasheet.

#### L298N Motor Driver:

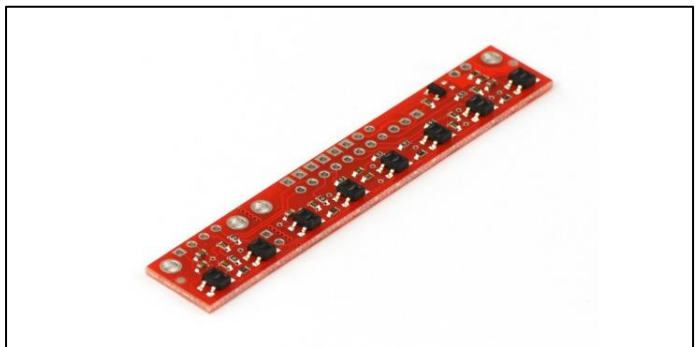
L298N is a versatile dual H-bridge motor driver IC commonly used in robotics and motor control applications. Here are its key features:

- Voltage Range: 5V to 35V
- Current Handling: Peak 2A per channel, Continuous 1.5A per channel
- Logic Voltage: 5V (TTL compatible)
- H-bridges: 2 (can control two DC motors or one stepper motor)
- Power Dissipation: Maximum 25W
- Control Modes: Forward, Reverse, Brake, Standby
- Advantages: Dual H-Bridge, Versatile, Simple Control Interface
- Disadvantages: Power Dissipation, Not Ideal for High-Performance Applications



#### QTR IR sensor:

The QTR IR sensor, such as the QTR-8A, is an array of eight infrared (IR) sensors designed for line-following applications. Each sensor provides a digital output indicating whether it detects a black line. It operates at a recommended voltage of 5V and has a detection range of about 3mm. The QTR-8A features eight individual sensors spaced at 9.5mm intervals, providing precise line position information. The sensor array can be used with Arduino and other microcontrollers for line-following robots. Refer to the specific datasheet for detailed electrical characteristics, pinouts, and usage guidelines.





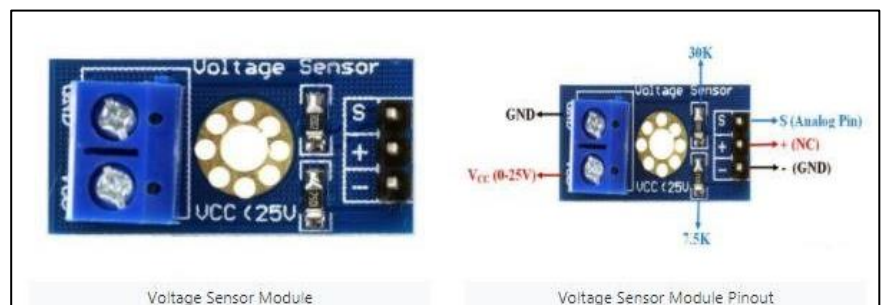
## Color Sensor:

The TCS3200 and TCS3210 are programmable color light-to-frequency converters designed for high-resolution conversion of light intensity to frequency. They integrate configurable silicon photodiodes and a current-to-frequency converter on a single CMOS integrated circuit. Operating on a single supply (2.7 V to 5.5 V), they produce a square wave output with frequency directly proportional to light intensity. The converters feature programmable color and full-scale output frequency, direct communication with a microcontroller, power-down capability, low nonlinearity error (typically 0.2% at 50 kHz), and a stable temperature coefficient. The devices are housed in a low-profile, lead-free, and RoHS-compliant surface-mount package. The TCS3200 includes an 8x8 array of photodiodes with blue, green, red, and clear filters, while the TCS3210 features a 4x6 array. The photodiodes are interdigitated to minimize non-uniformity, and selection pins (S2 and S3) choose the active group of photodiodes. All photodiodes of the same color are connected in parallel.



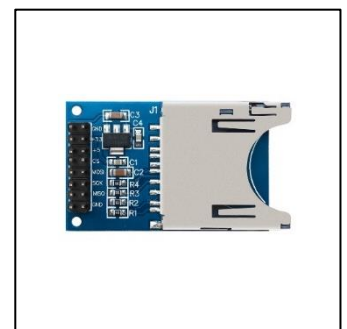
## Voltage Sensor:

The voltage sensor is a device designed to measure voltage accurately and cost-effectively. It employs a resistive voltage divider design, reducing the input voltage at the red terminal connector to one-fifth of its original value.



## SD Card reader:

An SD card reader module for Arduino facilitates the connection of an SD card to an Arduino microcontroller. It includes a slot for the SD card, interface circuitry, and communication protocols like SPI. The module is compatible with Arduino, allowing seamless data transfer and read/write operations for applications such as data logging. Connection to Arduino involves wiring the module to specific pins and using relevant libraries for file operations.



### Lipo Battery:

The Shang Yi 2200mAh 11.1V 25C LiPo battery is a rechargeable lithium polymer battery with a capacity of 2200mAh. It consists of three cells (3s) and operates at a discharge rate of 25C at 11.1V. The battery comes with a Deans T plug connector, weighs 180g, and has dimensions of 10.5 x 3.3 x 2.2 cm. It is designed for various applications, providing a reliable power source for electronic devices.



### Volt and Ammeter Display:

This DC 100V 10A Ammeter Voltmeter is consist of 0.28 inch 5 wire red LED. With 100V DC can be measured by this meter with 0.1V resolution. This volt ammeter contains 2 wire harnesses. 2 poles with RED and BLACK lead used to provide power for the meters. this meter is portable and small in size. DSN-VC288 DC 100V 10A shows volt and ammeter at the same time on the same screen.



### Power requirements and power supply design

To ensure optimal performance and longevity of our line-following robot, careful consideration was given to its power requirements and supply design. The primary power source identified for our system is a 9V power supply with a current output of 0.6A, providing a total power output of 5.4W. This power supply configuration was selected to meet the energy demands of the various electronic components, including motors, sensors, and control circuitry.

In addition to the wired power supply, a LiPo (Lithium Polymer) battery with a 25C rating was incorporated into the design. LiPo batteries are renowned for their high energy density and efficiency, making them an ideal choice for mobile robotic applications. The 25C rating indicates the battery's discharge capability relative to its capacity, ensuring a steady and reliable power source for our robot during its operational cycles.

The power supply design was meticulously planned to accommodate both the wired and battery-powered configurations seamlessly. Special attention was given to voltage regulation, current stability, and power distribution to ensure the efficient and safe operation of our line-

following robot under various operating conditions. This strategic approach to power management contributes to the overall reliability and performance of the robotic system.

### **Motor Selection Current/Voltage/Speed/Torque**

#### **Model: GA12-N20.**

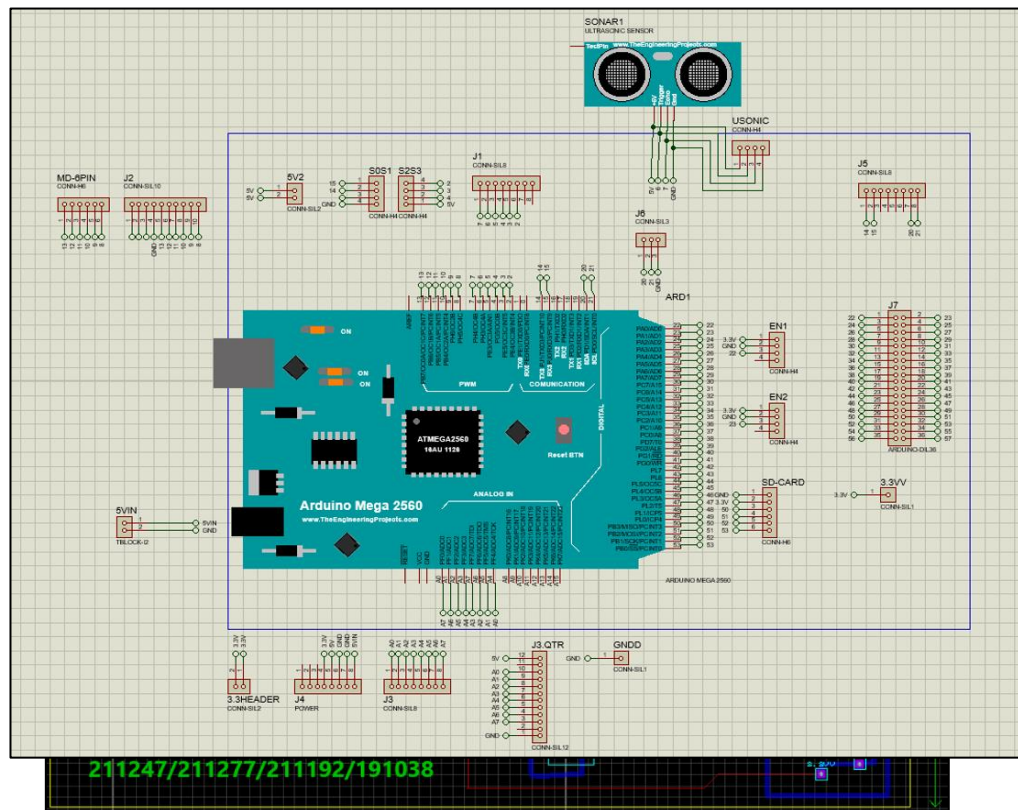
- Medium Power MP: 0.5W Max.
- Rated Voltage: 6~12V.
- Revolving Speed: Refer to Table 1.
- Torque: Refer to Table 1.
- Rated Current: 0.04A.
- Stall Current: 0.67A.
- Total Length: 34mm.
- Gear Material: Full Metal.
- Gearbox Size: 15 x 12 x 10mm (LxWxH).
- Shaft Size: Ø3 x 10mm (D\*L). D-Type Shaft.
- Net Weight: 10g



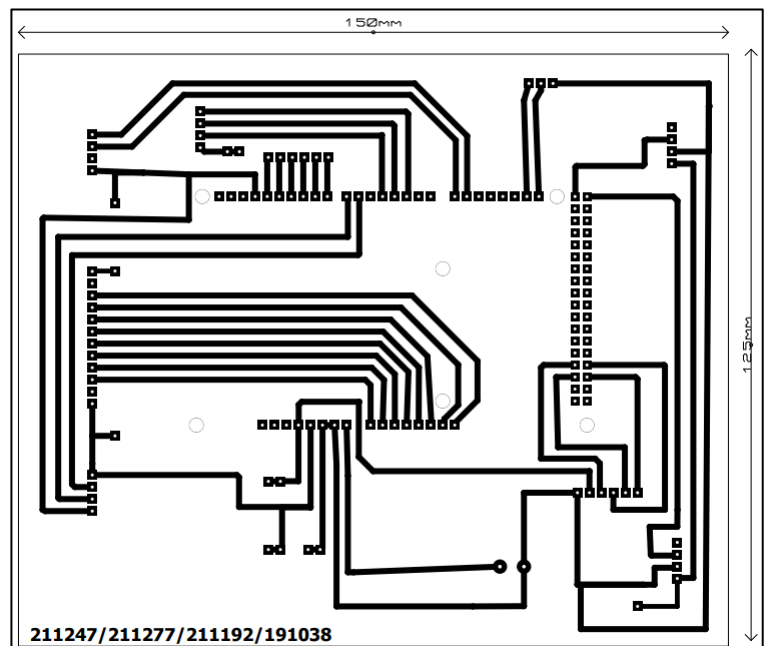
### **Feedback Mechanism positional sensors**

The feedback mechanism in our project relies on positional sensors, crucial for ensuring the accurate and precise movement of the line-following robot. These sensors continuously monitor the robot's position in relation to the designated path, providing real-time data to the control system. Commonly used positional sensors include encoders, potentiometers, or rotary sensors, which can measure the rotation and position of specific components, such as wheels or joints. The feedback from these sensors enables the control system to make instantaneous adjustments, ensuring that the robot stays on course and follows the specified line accurately. This closed-loop feedback system enhances the overall performance and responsiveness of the robot during its operation.

## Schematic and PCB:



The schematics for our project were meticulously crafted to ensure precision, presenting a clean and organized representation of the circuitry. Each component found its place with careful consideration, resulting in a visually coherent and well-structured schematic design. The clarity and accuracy of our schematics played a pivotal role in facilitating the efficient functioning of all components. The seamless collaboration between electronic elements, as reflected in the schematics, underscores our commitment to delivering a robust and reliable electrical system. This attention to detail not only enhances the project's overall aesthetics but also reinforces its performance and functionality.



In parallel, the PCB design for our project was engineered with meticulous care, eliminating the need for jumper connections and showcasing a streamlined and efficient configuration. Executed with precision in Proteus, a state-of-the-art design platform, our layout seamlessly accommodated all components while adhering to stringent size and hole accuracy requirements. The deliberate



placement of components and the absence of jumper connections not only enhance visual sophistication but also contribute significantly to the overall functionality and reliability of the electronic system. This exemplifies our unwavering commitment to achieving excellence in both aesthetic design and functional integration.

A detailed circuit board diagram, likely an Arduino Mega 2560, is shown at the top of the page. It features a grid of components with labels and connections, including various integrated circuits, resistors, and connectors. The diagram is color-coded with green and red lines to highlight specific components and their interconnections.

## Chapter 6- Software/Firmware Design

### Controller Selections with features:

The **Arduino Mega 2560** serves as the central processing unit for our line-following robot, offering a multitude of features to support the complexity of our application. Key specifications of the Arduino Mega 2560 include:

**Microcontroller:** The heart of our project, the ATmega2560, boasts an extensive set of resources for effective computation and control.

**Program Memory:** With a substantial Flash memory size, the Arduino Mega 2560 accommodates the intricate codebase required for our robot's functionality.

**I/O Pins:** A generous number of digital and analog input/output pins provide the flexibility needed to interface with a diverse array of sensors, actuators, and peripherals.

**Communication Interfaces:** The Mega 2560 supports various digital communication protocols, including UART, SPI, and I2C, facilitating seamless connectivity with external devices.

**PWM Channels:** With multiple PWM channels, precise control over motors and other output devices is achievable, enhancing the robot's maneuverability.

**Timers and Comparators:** Three timers and a comparator contribute to accurate timing and control, critical for tasks such as motor synchronization and sensor readings.

**Operating Voltage Range:** The broad operating voltage range (1.8V to 5.5V) ensures compatibility with various components, offering adaptability and versatility in our design.


**Pin Count:** The abundance of 86 pins caters to the extensive connectivity requirements of our project.

The selection of the Arduino Mega 2560 aligns with our goal of a powerful and versatile control system, capable of efficiently managing the diverse array of sensors, motors, and actuators integral to our line-following robot.

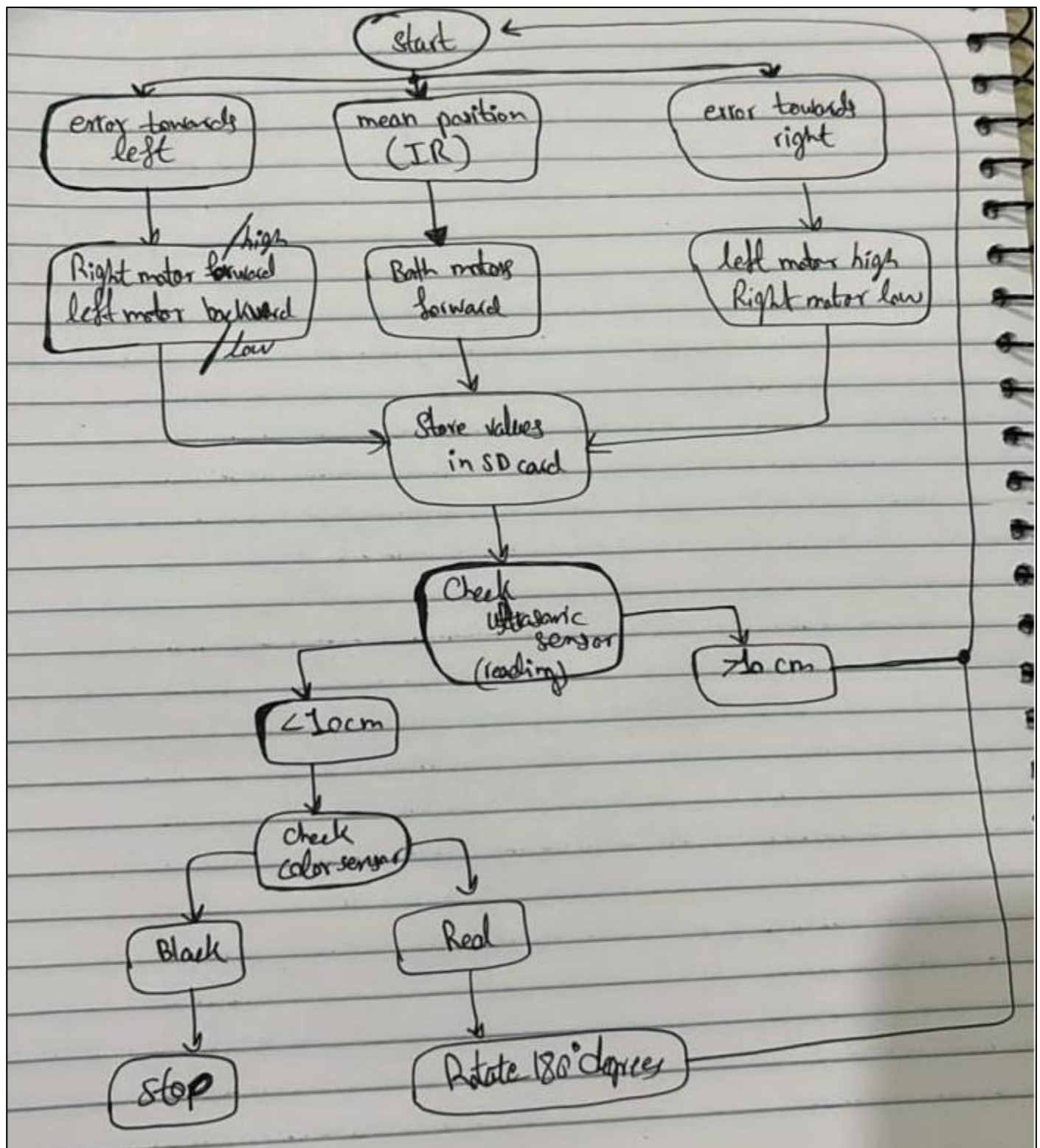
### Software Design details:

The software design for the project encompasses a modular approach to efficiently control and manage the various components integrated into the system. The key components and their functionalities are outlined below:



- 
- 1) **Ultrasonic Sensor Module:**
    - Responsible for acquiring distance data using ultrasonic signals.
    - Implements algorithms for distance measurement and obstacle detection.
  - 2) **16x2 LCD Display Module:**
    - Manages the visual output to the user.
    - Displays real-time data, including sensor readings and system status.
  - 3) **SD Card Module:**
    - Enables data logging functionality.
    - Facilitates the storage and retrieval of essential system information.
  - 4) **Motor Control Module:**
    - Controls the left and right motors based on sensor inputs.
    - Implements algorithms for motor speed and direction adjustments.
  - 5) **Servo Motor Module:**
    - Responsible for controlling the servo motor's movements.
    - Executes actions based on predefined conditions or user inputs.
  - 6) **Current and Voltage Sensing Module:**
    - Monitors the current and voltage levels in the system.
    - Implements safety measures and provides real-time data for user monitoring.
  - 7) **QTR IR Sensor Module:**
    - Handles data from infrared sensors.
    - Implements logic for line following and obstacle detection.
  - 8) **L298 Motor Driver Module:**
    - Manages the L298 motor driver for efficient motor control.
    - Ensures synchronized and controlled movements of the robot.
  - 9) **Potentiometer Module:**
    - Interfaces with the potentiometer for user-defined adjustments.
    - Allows users to set parameters such as motor speed or sensitivity.
  - 10) **Tachometer Module:**
    - Reads data from the rotary encoder.
    - Utilizes encoder readings for precise control and feedback.

## State Machine & System flow diagram







## Chapter 7- Simulations and final Integrations

### Integrations and testing all hardware and software component separately

- **Integration and Component Testing Strategy:**

The integration and testing phase involves a systematic approach to ensure the seamless collaboration of both hardware and software components. The following steps outline the strategy for integrations and testing:
- **Component Analysis:**

Review and analyze datasheets for all hardware components to identify optimal operating conditions, including voltage and current requirements.
- **Individual Component Testing:**

Utilize Digital Multimeter (DMM) to conduct individual tests on each hardware component.  
Replace malfunctioning components to ensure a fully functional set.
- **Integration Planning:**

Develop a comprehensive plan for integrating hardware components, ensuring correct connections and preventing potential issues such as short circuits.
- **Software Compilation:**

Compile Arduino code to ensure correctness and compatibility with the ATmega328P microcontroller.
- **Simulations in Proteus:**

Utilize Proteus software for simulations, incorporating microcontroller and sensor packages as per the system's requirements.  
Verify the simulated behavior against expected outcomes.
- **Simulation PCB Design:**

Design the PCB layout based on simulation results, optimizing for component placement and signal flow.
- **Prototyping on Breadboard:**

Implement a prototype on a breadboard, integrating components as per the designed layout.  
Verify the functionality of the interconnected system at this stage.
- **Testing on PCB Board:**

Transition to a PCB board, ensuring all connections are correctly soldered.  
Verify the functionality of the system on the PCB, addressing any discrepancies observed during testing.
- **Motor Control Adjustment:**

Verify the adjustments made to the motor control module, ensuring precise and controlled movements.  
Address any issues related to motor speed and direction.
- **LCD Display Functionality:**

Confirm proper functioning of the LCD display module, ensuring accurate and visible data output.  
Troubleshoot any issues related to display content or visibility.

- **Sensor Interfacing Validation:**

Validate the proper interfacing of sensors, including ultrasonic, IR, and voltage sensors. Ensure sensors provide accurate data for decision-making algorithms.

- **Data Logging and Retrieval:**

Verify the functionality of the SD card module for data logging and retrieval. Ensure the system can store and retrieve essential information as intended.

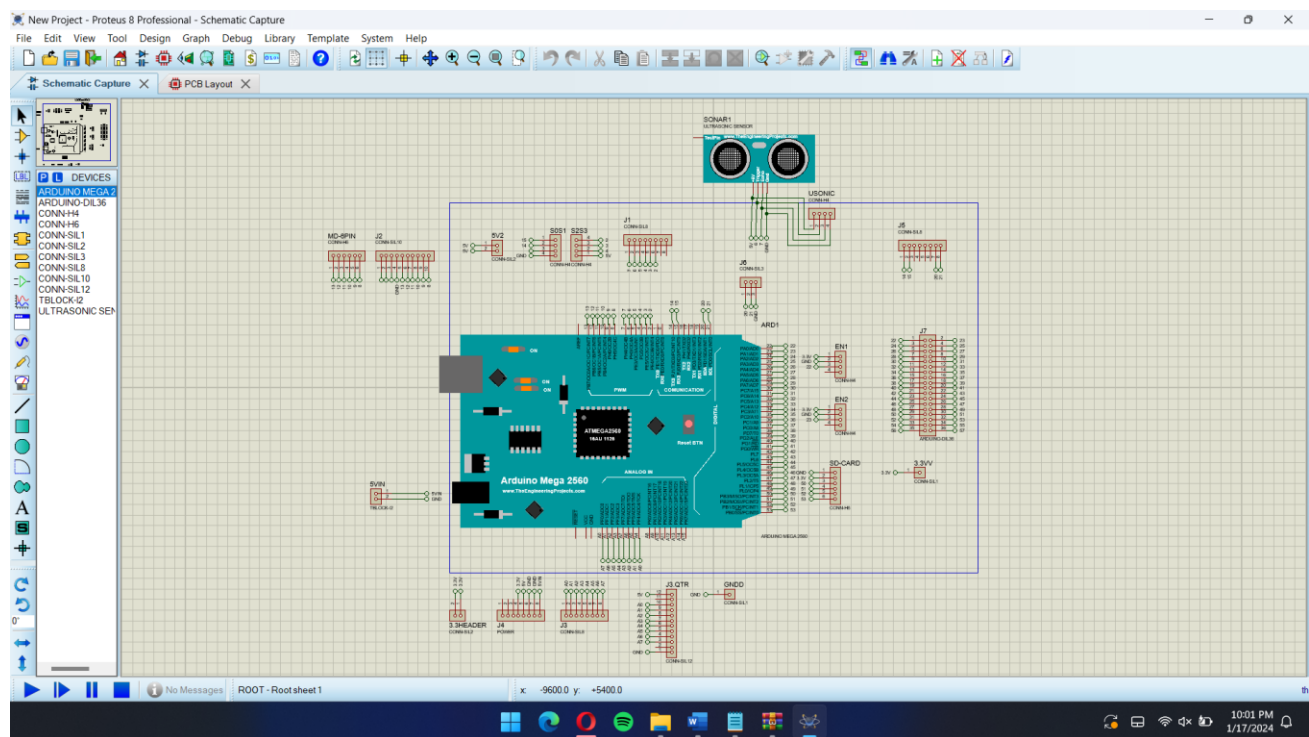
- **Final System Checks:**

Perform a comprehensive system check, evaluating the overall performance of the integrated hardware and software.

Address any anomalies or discrepancies observed during final testing.

By systematically executing these steps, the integration and testing phase aims to ensure the robustness and reliability of the integrated system while identifying and addressing any issues that may arise during the testing process.

## Simulations



## Discussion on simulations and challenges:

We faced various challenges, Here are some common challenges faced while making a robot:

1. **Mechanical Design Challenges:**

- Selecting appropriate materials for the robot's body that balance strength and weight.
- Ensuring proper balance and stability in the robot's movements.
- Designing an effective and efficient locomotion system, such as wheels, tire circumference, weight etc.



## 2. Electronics and Sensor Integration:

- Integrating various sensors seamlessly into the robot's system.
- Ensuring compatibility and proper communication between different electronic components.
- Managing power requirements and designing an efficient power supply system.

## 3. Software and Programming:

- Developing a robust control system and programming the robot to perform desired tasks.
- Implementing algorithms for navigation, obstacle avoidance, or other specific functionalities.
- Debugging and optimizing code for efficiency and reliability.

## 4. Wireless Communication:

- Implementing a reliable wireless communication system for remote control or data transmission.
- Ensuring data security and integrity during wireless transmissions.

## 5. Battery Life and Power Management:

- Optimizing power consumption to extend the robot's battery life.
- Implementing effective power management strategies to prevent unexpected shutdowns.

## 6. Testing and Calibration:

- Conducting thorough testing to identify and resolve hardware and software issues.
- Calibrating sensors and actuators for accurate and precise performance.

## 7. Cost and Resource Management:

- Managing the overall cost of the project within budget constraints.
- Efficiently allocating resources and selecting components that meet performance requirements without unnecessary expenses.

## 8. Documentation and Reporting:

- Creating detailed documentation for design, components, and code.
- Compiling comprehensive reports for project evaluation and future reference.

## 9. Time Management:

- Adhering to project timelines and deadlines.
- Dealing with unexpected delays and setbacks during the development process.

## 10. Team Collaboration:

- Facilitating effective communication and collaboration among team members.
- Resolving conflicts and ensuring that each team member's contributions align with the project goals.

Addressing these challenges requires a combination of technical skills, problem-solving abilities, and effective project management

## Chapter 8 System Test phase

### Final testing

#### 1) First Stage: Component Verification

- Conduct individual tests on each component to ensure proper functionality.
- Replace any defective components identified during testing.

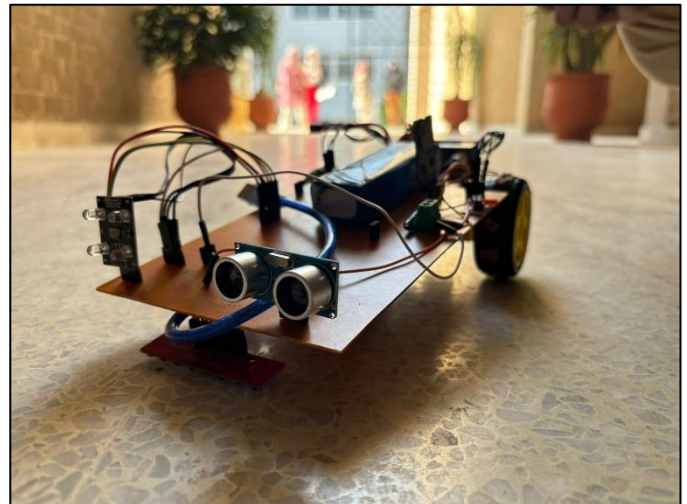
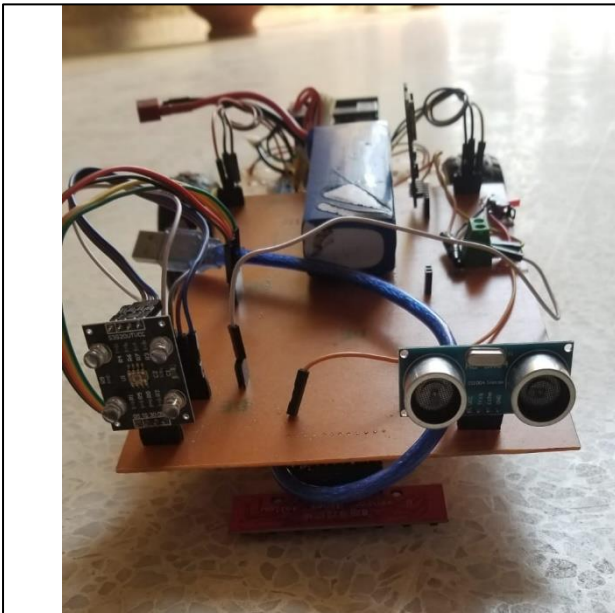
#### 2) Second Stage: Breadboard Testing

- Implement the entire system on a breadboard for an integrated test.
- Verify sensor readings, motor responses, and data output on the 16x2 LCD display.
- Obtain feedback from peers and mentors for further validation.

#### 3) Third Stage: PCB Board Testing

- Transition to the PCB board while ensuring correct soldering and connections.
- Perform a thorough check on all ports and pins to confirm proper sensor functionality.
- Validate the accuracy of data displayed on the LCD and the response of motors to sensor inputs.

### Project actual Pictures



## Chapter 9- Project management

### Final Bill of material list:

The components bought for this project and the gross total is given below

Sr. No	Components	Quantity	Price
1	Color Sensor	1	1500
2	Ultrasonic Sensor	1	190
3	IR sensor Array (QTR)	1	750
4	SD Card	1	120
5	ESP 32	1	1,100
6	Arduino Mega	1	4,000
7	Male Headers	5 strips	80
8	Female Headers	5 strips	120
9	L298N Motor Driver	1	370
10	Encoder Disk	2	60
11	N20 Gear Motors	2	700
12	Tires	2	340
13	Caster Wheel	1	80
14	Chassis	1	350
15	Li-Po Battery	1	6,500
16	Buck Converter	1	250
17	Copper Board	1 (12x12in)	700
18	FeCl <sub>3</sub>	400g	400
19	Drill Bits 0.8mm	2	80
20	Bread Board	1	250
21	Jumper Wires	2 strips	300
22	Buttons	5	75
23	Volts and Ammeter Display	2 (1 for each battery)	550
	<b>Total</b>		<b>Rs/- 18,865</b>

### Risk management:

Throughout the project's lifecycle, the implementation of effective risk management strategies played a pivotal role in mitigating potential challenges. Key insights gained from the risk management process include:


- **Comprehensive Risk Identification:**

**Lesson:** Thoroughly identifying potential risks at the project's outset is critical.

**Insight:** A comprehensive risk assessment early on allowed for proactive planning and preemptive measures to address challenges before they could escalate.

- **Continuous Monitoring and Adaptation:**

**Lesson:** Regularly monitoring identified risks is essential for timely adaptation.



**Insight:** Ongoing assessment and adjustment of risk management strategies ensured that the project remained responsive to evolving challenges and uncertainties.

- **Collaborative Problem-Solving:**

**Lesson:** Encouraging collaborative problem-solving among team members is integral to risk mitigation.

**Insight:** A culture of open communication and collaborative brainstorming facilitated the identification of innovative solutions, minimizing the impact of potential risks.

- **Iterative Risk Analysis:**

**Lesson:** The risk management process is iterative and requires continuous refinement.

**Insight:** Regularly revisiting risk assessments allowed the team to adapt strategies based on evolving project dynamics, ensuring a proactive rather than reactive approach.

- **Documentation and Communication:**

**Lesson:** Thorough documentation and transparent communication are vital components of risk management.

**Insight:** Well-documented risk assessments and clear communication channels enhanced the team's ability to respond effectively to unforeseen challenges, fostering a more resilient project environment.

- **Resource Contingency Planning:**

**Lesson:** Planning for resource contingencies is integral to risk management.

**Insight:** Allocating additional resources as a buffer against potential shortages or unexpected demands proved instrumental in maintaining project momentum during unforeseen circumstances.

- **Feedback Integration:**

**Lesson:** Integrating feedback loops into the risk management process is crucial for continuous improvement.

**Insight:** Regularly seeking and incorporating feedback from team members and stakeholders ensured that the risk management strategies evolved in tandem with the project's needs.

In essence, the dynamic nature of risk management requires a proactive and adaptive approach. By embracing these lessons, the project team cultivated a resilient environment capable of navigating uncertainties and challenges effectively.



## Code for the Line Follower:

```
#include <QTRSensors.h>

/*
 * Connect the SD card to the following pins:
 *
 * SD Card | ESP32
 * D2      -
 * D3      SS
 * CMD     MOSI
 * VSS     GND
 * VDD     3.3V
 * CLK     SCK
 * VSS     GND
 * D0      MISO
 * D1      -
 */

int ENA = 8;
int MOTOR_A1 = 9;
int MOTOR_A2 = 10;
int ENB = 11;
int MOTOR_B1 = 12;
int MOTOR_B2 = 13;

const int trigPin = 6; //ultrasonic sensor
const int echoPin = 7; //ultrasonic sensor

float duration, distance; //variable for ultrasonic sensor
float stopDist = 12.0;

#define outPin 4
#define s0 15
#define s1 14
#define s2 3
#define s3 2

#include "FS.h" // for sd card
#include "SD.h" // for sd card
#include "SPI.h" // for sd card

//encoder for moter 1
int encoder_pin1 = 2; //Pin 2, where the encoder is connected
unsigned int rpm1 = 0; // Calculated revolutions per minute.
float velocity1 = 0; //speed at [Km/h]
int pulses1 = 0; // Number of pulses read by the Arduino in one second
unsigned long Time1 = 0; // Time
unsigned int pulsesperturn1 = 20; // Number of notches on the encoder disk.
const int wheel_diameter1 = 64; // Small wheel diameter[mm]
static volatile unsigned long debounce1 = 0; // Rebound time.
char b[10];
String strb;
```



```

//encoder for moter 2
int encoder_pin2 = 3;      //Pin 2, where the encoder is connected
unsigned int rpm2 = 0;     // Calculated revolutions per minute.
float velocity2 = 0;       //speed at [Km/h]
int pulses2 = 0;          // Number of pulses read by the Arduino in one second
unsigned long Time2 = 0;   // Time
unsigned int pulsesperturn2 = 20; // Number of notches on the encoder disk.
const int wheel_diameter2 = 64; // Small wheel diameter[mm]
static volatile unsigned long debounce2 = 0; // Rebound time.
char c[10];
String strc;

void readFile(fs::FS &fs, const char * path){
  Serial.printf("Reading file: %s\n", path);

  File file = fs.open(path);
  if(!file){
    Serial.println("Failed to open file for reading");
    return;
  }

  Serial.print("Read from file: ");
  while(file.available()){
    Serial.write(file.read());
  }
  file.close();
}

void writeFile(fs::FS &fs, const char * path, const char * message){
  Serial.printf("Writing file: %s\n", path);

  File file = fs.open(path, FILE_WRITE);
  if(!file){
    Serial.println("Failed to open file for writing");
    return;
  }
  if(file.print(message)){
    Serial.println("File written");
  } else {
    Serial.println("Write failed");
  }
  file.close();
}

//funtion for motor 1
void counter1(){
  if( digitalRead (encoder_pin1) && (micros()-debounce1 > 500) && digitalRead (encoder_pin1) ) { // Check again that the encoder sends
a good signal and then check that the time is greater than 1000 microseconds and check again that the signal is correct.    debounce =
micros(); // Almacena el tiempo para comprobar que no contamos el rebote que hay en la señal.
    pulses1++;} // Add up the good pulse that comes in.
  else ; }

//funtion for motor 2
void counter2(){

```



```

    if( digitalRead (encoder_pin2) && (micros()-debounce2 > 500) && digitalRead (encoder_pin2) ) { // Check again that the encoder sends
a good signal and then check that the time is greater than 1000 microseconds and check again that the signal is correct.    debounce =
micros(); // Almacena el tiempo para comprobar que no contamos el rebote que hay en la señal.
    pulses2++;} // Add up the good pulse that comes in.
    else ; }

int lastError = 0;

float Kp = 0.017143;
float Ki = 0;
float Kd = 0;

int baseSpeedValue = 60;

QTRSensors qtr;

const uint8_t SensorCount = 6;
uint16_t sensorValues[SensorCount];

// Variables
int red, grn, blu;
String color = "";
long startTiming = 0;
long elapsedTime =0;

void setup() {
    Serial.begin(9600);

    pinMode(ENA, OUTPUT); // initialize ENA pin as an output
    pinMode(ENB, OUTPUT); // initialize ENB pin as an output
    pinMode(MOTOR_A1, OUTPUT); // initialize MOTOR_A1 pin as an output
    pinMode(MOTOR_A2, OUTPUT); // initialize MOTOR_A2 pin as an output
    pinMode(MOTOR_B1, OUTPUT); // initialize MOTOR_B1 pin as an output
    pinMode(MOTOR_B2, OUTPUT); // initialize MOTOR_B2 pin as an output

    pinMode(trigPin, OUTPUT);
    pinMode(echoPin, INPUT);

    pinMode(s0, OUTPUT);
    pinMode(s1, OUTPUT);
    pinMode(s2, OUTPUT);
    pinMode(s3, OUTPUT);
    pinMode(outPin, INPUT); //out from sensor becomes input to arduino
    // Setting frequency scaling to 100%
    digitalWrite(s0,HIGH);
    digitalWrite(s1,HIGH);

    startTiming = millis();

    qtr.setTypeAnalog();
    qtr.setSensorPins((const uint8_t[]){A7,A5,A4,A3,A1,A0}, SensorCount);

    for (uint16_t i = 0; i < 200; i++) //10 seconds
    {
        qtr.calibrate();
    }
}

```

```

if(!SD.begin()){
    Serial.println("Card Mount Failed");
    return;
}
uint8_t cardType = SD.cardType();

if(cardType == CARD_NONE){
    Serial.println("No SD card attached");
    return;
}

Serial.print("SD Card Type: ");
if(cardType == CARD_MMC){
    Serial.println("MMC");
} else if(cardType == CARD_SD){
    Serial.println("SDSC");
} else if(cardType == CARD_SDHC){
    Serial.println("SDHC");
} else {
    Serial.println("UNKNOWN");
}

uint64_t cardSize = SD.cardSize() / (1024 * 1024);
Serial.printf("SD Card Size: %lluMB\n", cardSize);

writeFile(SD, "/hello.txt", "Hello ");
readFile(SD, "/hello.txt");


Serial.printf("Total space: %lluMB\n", SD.totalBytes() / (1024 * 1024));
Serial.printf("Used space: %lluMB\n", SD.usedBytes() / (1024 * 1024));

pinMode(encoder_pin1, INPUT); //Pin #2 configuration
attachInterrupt(0, counter1, RISING); // Interrupt configuration 0, where it is connected.
pulses1 = 0;
rpm1 = 0;
Time1 = 0;
Serial.print("Seconds ");
Serial.print("RPM ");
Serial.print("Pulses ");
Serial.println("Velocity[Km/h]");

pinMode(encoder_pin2, INPUT); //Pin #3 configuration
attachInterrupt(0, counter2, RISING); // Interrupt configuration 0, where it is connected.
pulses2 = 0;
rpm2 = 0;
Time2 = 0;
Serial.print("Seconds ");
Serial.print("RPM ");
Serial.print("Pulses ");
Serial.println("Velocity[Km/h]");
}

void loop() {
    // put your main code here, to run repeatedly:
    // sprint();

```



```

PID_Control();
getColor();
printData();

digitalWrite(trigPin, LOW);
delayMicroseconds(2);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);

duration = pulseIn(echoPin, HIGH);
distance = (duration*.0343)/2;
Serial.print("Distance: ");
Serial.println(distance);
if(distance <= stopDist)           //If there are objects within the stopping distance, stopp
{
    digitalWrite(MOTOR_A1, LOW);
    digitalWrite(MOTOR_A2, LOW);
    digitalWrite(MOTOR_B1, LOW);
    digitalWrite(MOTOR_B2, LOW);
    if(color == "BLACK")
    {
        digitalWrite(MOTOR_A1, LOW);
        digitalWrite(MOTOR_A2, LOW);
        digitalWrite(MOTOR_B1, LOW);
        digitalWrite(MOTOR_B2, LOW);
    }
    else
    {
        rotate();
    }
    PID_Control();
}

writeFile(SD, "/hello.txt", "count of motor 1 ");
strb=String(pulses1);
strb.toCharArray(b,10);
writeFile(SD, "/hello.txt", b);
writeFile(SD, "/hello.txt", " count of motor 2 ");
strc=String(pulses2);
strc.toCharArray(c,10);
writeFile(SD, "/hello.txt", c);
writeFile(SD, "/hello.txt", "/n");

if (millis() - Time1 >= 1000){ // Updates every second
    noInterrupts(); //Don't process interrupts during calculations // We disconnect the interruption so that it does not act in this part of
the program.
    rpm1 = (60 * 1000 / pulsesperturn1 )/ (millis() - Time1)* pulses1; //We calculate revolutions per minute
    velocity1 = rpm1 * 3.1416 * wheel_diameter1 * 60 / 1000000; // Calculation of speed in [Km/h]
    Time1 = millis(); // We store the current time.
    Serial.print(millis()/1000); Serial.print(" "); // The value of time, rpm and pulses is sent to the serial port.
    Serial.print(rpm1,DEC); Serial.print(" ");
    Serial.print(pulses1,DEC); Serial.print(" ");
    Serial.println(velocity1,2);
    pulses1 = 0; // We initialize the pulses.
    interrupts(); // Restart the interrupt processing // We restart the interrupt

```

```

}

if (millis() - Time2 >= 1000){ // Updates every second
    noInterrupts(); //Don't process interrupts during calculations // We disconnect the interruption so that it does not act in this part of
the program.
    rpm2 = (60 * 1000 / pulsesperturn2) / (millis() - Time2)* pulses2; //We calculate revolutions per minute
    velocity2 = rpm2 * 3.1416 * wheel_diameter2 * 60 / 1000000; // Calculation of speed in [Km/h]
    Time2 = millis(); // We store the current time.
    Serial.print(millis()/1000); Serial.print("    "); // The value of time, rpm and pulses is sent to the serial port.
    Serial.print(rpm2,DEC); Serial.print(" ");
    Serial.print(pulses2,DEC); Serial.print(" ");
    Serial.println(velocity2,2);
    pulses2 = 0; // We initialize the pulses.
    interrupts(); // Restart the interrupt processing // We restart the interrupt
}
    delay(100);
}
//void sprint()
//{
//    uint16_t positionLine = qtr.readLineBlack(sensorValues);
//    int err = positionLine;
//    Serial.println(err);
//}
void PID_Control()
{
    uint16_t positionLine = qtr.readLineBlack(sensorValues);

    int error = 3500 - positionLine;

    int P = error;
    int I = error + I;
    int D = lastError - error;
    lastError = error;

    int motorSpeedNew = P * Kp + I * Ki + D * Kd;

    int motorSpeedA = baseSpeedValue + motorSpeedNew;
    int motorSpeedB = baseSpeedValue - motorSpeedNew;

    if(motorSpeedA > 75 )
        motorSpeedA = 75;

    if(motorSpeedB > 75 )
        motorSpeedB = 75;

    if(motorSpeedA < -45 )
        motorSpeedA = -45;

    if(motorSpeedB < -45 )
        motorSpeedB = -45;

    movement(motorSpeedA, motorSpeedB);
}

void movement(int speedA, int speedB)

```

```

{
if(speedA < 0)
{
    speedA = 0 - speedA;
    analogWrite(ENA, speedA);
    digitalWrite(MOTOR_A1, HIGH);
    digitalWrite(MOTOR_A2, LOW);
}

else
{
    analogWrite(ENA, speedA);
    digitalWrite(MOTOR_A1, LOW);
    digitalWrite(MOTOR_A2, HIGH);
}

if(speedB < 0)
{
    speedB = 0 - speedB;
    analogWrite(ENB, speedB);
    digitalWrite(MOTOR_B1, LOW);
    digitalWrite(MOTOR_B2, HIGH);
}

else
{
    analogWrite(ENB, speedB);
    digitalWrite(MOTOR_B1, HIGH);
    digitalWrite(MOTOR_B2, LOW);
}

}


/* read RGB components */
void readRGB(){
    red = 0, grn=0, blu=0;

    int n = 10;
    for (int i = 0; i < n; ++i){
        //read red component
        digitalWrite(s2, LOW);
        digitalWrite(s3, LOW);
        red = red + pulseIn(outPin, LOW);

        //read green component
        digitalWrite(s2, HIGH);
        digitalWrite(s3, HIGH);
        grn = grn + pulseIn(outPin, LOW);

        //let's read blue component
        digitalWrite(s2, LOW);
        digitalWrite(s3, HIGH);
        blu = blu + pulseIn(outPin, LOW);
    }
    red = red/n;
    grn = grn/n;
}

```



```

    blu = blu/n;
}

void printData(void){
    Serial.print("red= ");
    Serial.print(red);
    Serial.print(" green= ");
    Serial.print(grn);
    Serial.print(" blue= ");
    Serial.print(blu);
    Serial.print (" - ");
    Serial.print (color);
    Serial.println (" detected!");
}

void getColor(){
    readRGB();
    if(red>7 && red<11 && grn>17 && grn<23 && blu>13 && blu<18) color = "RED";
    else if(red>5 && red<8 && grn>4 && grn<8 && blu>3 && blu<7) color = "WHITE";
    else if(red>190 && red<220 && grn>190 && grn<250 && blu>200 && blu<260) color = "BLACK";
    else color = "NO_COLOR";
}

void rotate(){
    digitalWrite(MOTOR_A1, HIGH);
    digitalWrite(MOTOR_A2, LOW);
    digitalWrite(MOTOR_B1, LOW);
    digitalWrite(MOTOR_B2, HIGH);
    delay(1300);
    return;
}

```



## Chapter 10- Feedback for project and course

### Appendix-

- <https://www.fierceelectronics.com/sensors/what-ir-sensor>
- <https://maxbotix.com/blogs/blog/how-ultrasonic-sensors-work#:~:text=What%20is%20an%20Ultrasonic%20Sensor,information%20about%20an%20object%27s%20proximity>.
- <https://www.pololu.com/product/961>
- <https://www.jsumo.com/arduino-line-follower-robot-chassis>
- <https://docs.arduino.cc/learn/electronics/lcd-displays>
- <https://electrobes.com/product/mini-dc-100v-10a-digital-voltmeter-ammeter-blue-red-led-volt-amp-meter-gauge/>
- <https://electrobes.com/product/metal-gear-gal2-n20-precision-motor-3-6v-300rpm-diy-four-wheel-drive/>
- <https://electrobes.com>
- <https://electrobes.com/product/arduino-mega-2560/>
- <https://electrobes.com/product/sr-04-ultrasonic-sensor/>