Department of Electronic & Telecommunication Engineering
University of Moratuwa

EN2160 - Electronic Design Realization

Final Report-Application of the Cambridge EDC Inclusive Design Methodology

Obstacle Avoidance System for Warehouse AMR and AGV

Group H

210212N - Herath B.H.M.K.S.B.
210325M - Kuruppu M.P.
210349N - Madhushan I.D.
210454G - Peiris D.L.C.J.

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Chapter 1

Obstacle Avoidance System for Warehouse AMR and AGV

1.1 Introduction

In the ever-evolving landscape of warehouse management, the integration of advanced technologies has become imperative for efficiency, safety, and productivity. Among these technologies, the development of obstacle avoidance systems for Autonomous Mobile Robots (AMRs) and Automated Guided Vehicles (AGVs) stands out as a critical frontier. This report delves into the progress made in the implementation of such a system, examining achievements, challenges encountered, and the roadmap for future endeavors.

1.2 Review Progress

A comprehensive assessment of existing technologies in the field of obstacle avoidance systems for warehouse automation, particularly focusing on Autonomous Mobile Robots (AMR) and Automated Guided Vehicles (AGV), has been conducted. This review aims to elucidate the current methodologies, advancements, and technological landscape to serve as a foundational understanding for proposed projects in this domain.Primary sources utilized for this review encompass YouTube videos, product literature from pertinent manufacturers, and scholarly research articles.

Please visit `https://en.wikipedia.org/wiki/Automated_guided_vehicle`

Please visit `https://www.agvnetwork.com/agv-technology/agv-components`

1.2.1 Obstacle detection methods:

We have been researching what are object detection methods that we can use . we found out there are many ways used in the industrial robots to detect obstacles. By observing industrial obstacle avoidance systems we found out obstacle detection methods that we can use to build our system.

1. **AMR Obstacle Avoidance Robot Sensing Ultrasonic Sensor:**
   This is specially made for obstacle detection in Obstacle avoidance systems. Typical ultrasonic sensors have a small measuring angle, long response time, poor installation adaptability and many more problems which make them not suitable for industrial applications. But with contrast to those ultrasonic sensors, these have a larger measuring angle, shorter response time, filtering interference, high installation adaptability, dust and waterproofing, high reliability, and many more.
   Please Visit `https://youtu.be/kEQeu6ObSx0`

Figure 1.1: AMR Obstacle Avoidance Robot Sensing Ultrasonic Sensor

2. **LiDAR Sensor:**
   360 Degree LiDAR (Light Detection and Ranging) systems are the most commonly used obstacle avoidance systems in the industry. These lidars use laser pulses to measure distances to surrounding objects with high precision and accuracy. In obstacle avoidance applications, LiDAR scanners generate detailed three-dimensional maps of the environment by rapidly sweeping laser beams in a horizontal and vertical plane. These maps provide information about the surroundings, including the location, size, and shape of obstacles. By continuously scanning the surroundings and analyzing the acquired data in real-time, obstacle avoidance systems can detect objects in warehouse environments. This allows autonomous vehicles or robots to navigate safely by planning trajectories that avoid collisions. Key features of these LiDAR systems include their ability to operate in various lighting conditions, their high scanning speed, and their capability to detect objects at long ranges.

   How Lidar works `https://www.yellowscan.com/knowledge/how-does-lidar-work/`

   Lidar Technologies `https://youtu.be/3EehCU3csJQ`

   Data sheet: `https://www.ydlidar.com/Public/upload/files/2024-02-01/YDLIDAR%20X4%20Data%20sheet%20V1.2(240125).pdf`

Figure 1.2: Lidar Sensor

3. **TF Mini LiDAR:**
   This also uses LiDAR technology to operate. But it cannot dynamically rotate as 360 Degree LiDAR. Hence it cannot be used to make a 3D map in the environment. But these LiDARs are much more accurate than other static obstacle avoidance sensors like ultrasonic and TOF sensors. But the problem with these LiDARs is their narrow scope. So, it can only detect objects in front of the robot which may limit its effectiveness in certain applications.

   Data sheet:`https://cdn.sparkfun.com/assets/5/e/4/7/b/benewake-tfmini-datasheet.pdf`

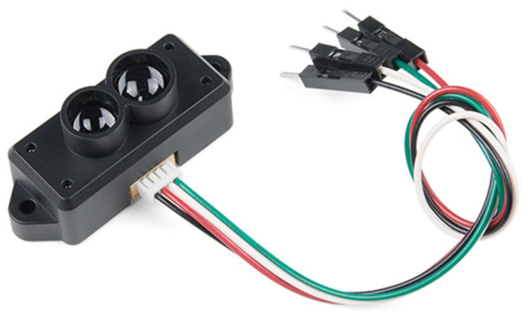


Figure 1.3: bert

4. **Vision-based systems:**
   In industrial warehouses, computer vision-based systems also can be used in obstacle avoidance and plan safe trajectories to avoid collisions. They can be useful when in environments where traditional sensors like LiDAR may struggle due to factors like varying lighting conditions and reflective surfaces. These computer vision systems enhance safety, efficiency, and productivity in warehouse operations by enabling these robots to navigate effectively in dynamic industrial settings. So in such cases, computer vision-based systems can be more useful.

   Machine vision systems utilize cameras and image processing algorithms to perceive and interpret visual information. Convolutional Neural Networks (CNNs) and other deep learning models are employed for object detection, classification, and tracking. Machine vision enables AMRs and AGVs to recognize obstacles, navigate through cluttered environments, and interpret signage or symbols for localization.

5. **TOF sensor:** Time-of-flight (ToF) sensors for obstacle avoidance utilize the principle of measuring the time it takes for light to travel to and from objects in their field of view. These sensors emit infrared light pulses and measure the time it takes for the light to bounce back, providing accurate distance measurements to nearby objects. ToF sensors offer advantages such as high accuracy, fast response times, and the ability to operate in various lighting conditions. In industrial warehouses, ToF sensors can be mounted on robots and automated vehicles to detect obstacles and navigate safely through the environment.
   Please Visit:`https://www.pololu.com/product/2490`

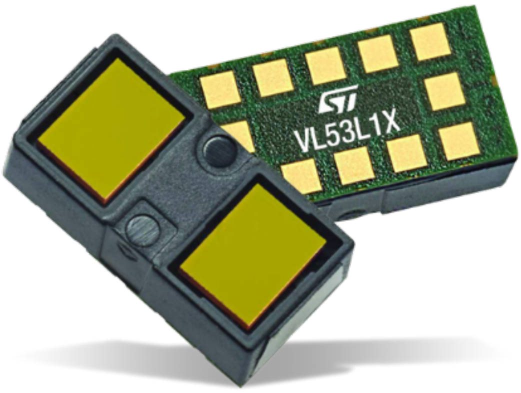


Figure 1.4: TOF Sensor

1.2.2 Calculating Motor Torque for a Mobile Robot

When it comes to a mobile robot, having sufficient power to perform tasks is crucial. We are planning to design our robot that's intended for warehouse use with a chassis measuring 400mm by 200mm. It's designed to achieve a speed of 0.5 m/s, carry a payload of 2.5 kg, and have two direct-drive wheels along with two other wheels.The robot will operate on surfaces such as marble, wooden floors, or concrete.

Calculation of System Parameters

Firstly, we need to calculate the force required for the mobile robot. Under the robot's operating conditions, we need to overcome friction and acceleration forces. Assuming the robot is moving on a flat surface, we can calculate the frictional force using the formula $F_{\text{friction}} = \mu N$, where μ is the coefficient of friction and N is the weight of the robot.

We have found that the coefficient of friction for marble is $\mu_{\text{marble}} = 0.5$, $\mu_{\text{wood}} = 0.4$, $\mu_{\text{concrete}} = 0.8$. We will use the maximum coefficient of friction for the design, which is (mu = 0.8). Additionally, the mass of the robot is 2 kg, and the acceleration due to gravity is approximately 9.8 m/s^2.$Therefore, wecancalculatethefrictionalforceasfollows$:

$$N = 2.5\,\text{kg} \times 9.8\,\text{m/s}^2 = 24.5\,\text{N}$$
$$F_{\text{friction}} = 0.8 \times 24.5\,\text{N} = 19.6\,\text{N}$$

We can calculate the acceleration force using the formula $F_{\text{acceleration}} = ma$, where m is the mass of the robot and a is the acceleration of the robot. Assuming that we want the robot to achieve its design speed of 1.0 m/s within 2 s, we can calculate the acceleration force as follows:

$$a = \frac{0.5\,\text{m/s}}{2\,\text{s}} = 0.25\,\text{m/s}^2$$
$$F_{\text{acceleration}} = 2.5\,\text{kg} \times 0.25\,\text{m/s}^2 = 0.625\,\text{N}$$

Hence, summing up the frictional force and the acceleration force gives the total force required for the robot to move:

$$F = F_{\text{friction}} + F_{\text{acceleration}} = 19.6\,\text{N} + 0.625\,\text{N} = 20.225\,\text{N}$$

Selection of Wheel Type

The wheels should be designed to provide good traction on all surfaces. Soft rubber material would be a good choice since it provides good grip on both smooth surfaces like marble and wood, and rough surfaces like concrete. The wheel diameter should be large enough to provide good ground clearance but not too large to avoid insufficient torque or unstable movement of the robot. A wheel with a radius of $r = 0.065$ m is a reasonable compromise.

Design of Motor Parameters

We need to select a motor that can provide the required force. The torque τ provided by the motor can be calculated using the formula $\tau = Fr$, where F is the force required by the mobile robot, and r is the radius of the wheel. Since our design is a direct-drive system with two wheels, each motor only needs to provide a half of the total torque. We are using wheels with a radius of $r = 0.065$ m, so we need the motor to provide a torque of:

$$\tau = \frac{(20.225\,\mathrm{N} \times 0.065\,\mathrm{m})}{2} = 0.6573\,\mathrm{Nm}$$

Then, with a design speed of $1.0\,\mathrm{m/s}$ and wheel radius of $r = 0.065\,\mathrm{m}$, we can calculate the required rated speed of the motor:

$$n = \frac{(0.5\,\mathrm{m/s} \times 60\,\mathrm{s})}{2\pi \times 0.065\,\mathrm{m}} \approx 73.4467\,\mathrm{rpm}$$

In addition, a safety factor of usually $1.0 \sim 1.5$ is adopted to ensure that the robot can move reliably under all conditions. Here, we adopt a safety factor of 1.5. Therefore, we need to select a motor with a rated torque $\tau = 0.9860\,\mathrm{Nm}$.

Power Design

Based on the calculations above, assuming we select a brushed motor with a rated voltage of $U = 12$ V, rated torque of $\tau = 1.1$ Nm (11 kgcm) and rated speed of $n = 300$ rpm, the required power of the motor can be calculated using the formula $P = \tau\omega$, where τ is the torque provided by the motor and ω is the angular velocity of the motor.

$$\omega = \left(\frac{300 \text{ rpm} \times 2\pi}{60}\right) \approx 31.42 \text{ rad/s}$$

$$P = 0.9860 \text{ Nm} \times 31.42 \text{ rad/s} \approx 30.9761 \text{ W}$$

The total power required for two motors is $P_{\text{total}} = 2 \times 30.9761 \text{ W} = 61.9522 \text{ W}$, and the rated voltage of the selected motors is $U = 12$ V, we can calculate the required current:

$$I = \frac{P_{\text{total}}}{U} = \frac{61.9522}{12} = 5.1627 \text{ A}$$

Therefore, the minimum capacity of the power battery should be 5.1627 Ah in order to power the robot for 1 hour of operation.

1.2.3 Motors:

We need to have a brushed motor with encoders to control the AMR and AGV robot. Since the toque we required for the 0.9860 Nm (with the safety factor of 1.5) we have to choose a motor which have a toque more than 0.9860 Nm. Also the required rated speed of the motor is approximately 74.45 rpm.

1.2.4 Why Encoders?

For Autonomous Mobile Robots (AMRs) and Autonomous Guided Vehicles (AGVs), encoders play a crucial role in providing feedback for precise control of position and velocity. Here are the requirements and the importance of encoders for PID controllers in both position and velocity control

Figure 1.5: Encoders

1. Position PID Controllers:

- Encoders should have high resolution to accurately measure the position of the wheels or motors. This ensures precise localization and navigation of the robot.
- Encoders should provide quadrature output to determine both the direction and magnitude of movement, enabling the robot to track its position accurately.

Importance:

- **Localization:** Encoders provide feedback on the position of the wheels or motors, allowing the robot to determine its position relative to its environment. This is essential for tasks such as mapping, navigation, and path planning.
- **Precision Control:** Position PID controllers use encoder feedback to regulate the position of the robot's wheels or motors, ensuring accurate movement and positioning.
- **Error Correction:** Encoders help the PID controller correct any deviations from the desired position, allowing the robot to follow predefined paths or reach specific waypoints accurately.

2. Velocity PID Controllers:

- **High Accuracy:** Encoders should provide accurate measurements of motor speed or wheel velocity to ensure precise control.
- **Fast Response Time:** Encoders should have a fast response time to provide real-time feedback to the velocity PID controller, enabling rapid adjustments to changes in speed.
- **Low Noise:** Encoders should have low noise levels to minimize measurement errors and ensure smooth velocity control.

Importance:

- **Speed Regulation:** Encoders allow the velocity PID controller to regulate the speed of the robot's motors or wheels accurately, ensuring consistent and stable movement.
- **Dynamic Response:** Real-time feedback from encoders enables the velocity PID controller to respond quickly to changes in speed commands or external disturbances, maintaining the desired velocity profile.
- **Energy Efficiency:** By accurately controlling the speed of the motors, encoders help optimize the energy efficiency of the robot, prolonging battery life and reducing operating costs.

Encoders are essential components for both position and velocity control in AMRs and AGVs. They provide vital feedback to PID controllers, enabling precise and reliable operation for various applications, including navigation, localization, and velocity control.

Metal Gearmotor 25Dx67L mm HP 12V with 48 CPR Encoder

This gearmotor is cylindrical in shape and provides high-power output suitable for various applications. The gear ratio allows for increased torque at the expense of speed, making it versatile for tasks requiring both power and precision. The integrated encoder provides feedback for accurate position and speed control. It can be easily swapped with other versions of the same series, facilitating adaptability to changing design requirements.

Please Visit `https://www.pololu.com/product/4844`

Figure 1.6: Metal Gearmotor

- Voltage: 12 V
- No-load Performance: 300 RPM, 300 mA
- Stall Torque: 11 kg·cm (150 oz·in)
- Stall Current: 5.0 A
- Gear Ratio: 34.014:1
- Encoder: 48 CPR (counts per revolution)
- Output Shaft: D-shaped, 4 mm diameter, extends 12.5 mm from the face plate of the gearbox

- Diameter: Approximately 25 mm
- Motor Type: Brushed DC

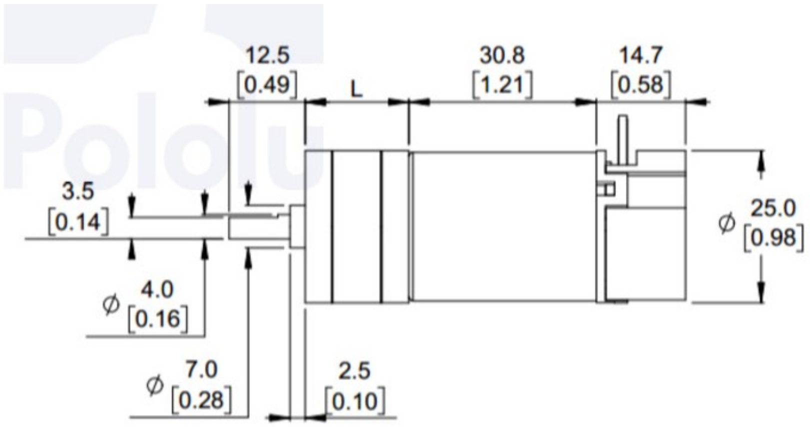


Figure 1.7: Dimensions of metal gearmotors with encoders. Units are mm

1.2.5 Motor Control System and Motor Driver:

Please Visit `https://www.researchgate.net/publication/303806333_Control_Systems_in_Robotics_A_Review`

Since existing motor driver modules are not suitable for industrial Obstacle avoidance systems we are going to make our own motor driver with the ability to control motor position, current, and voltage more precisely. Here we are going to make a separate PCB for the motor driver with a suitable motor-driving IC that suits our mobile robots' requirements.

Figure 1.5 shows the motor control system we are going to implement. This motor control system operates by using sensors to measure the motor's position, current, and voltage, more precisely encoders to measure position, current sensor to measure current, and voltage sensor to measure voltage, then fed into a controller which is with a PID control. This controller compares the measured values to desired setpoints for position, velocity, and current, calculates the error, and generates control signals accordingly. These signals are sent to the motor driver, which translates them into power to adjust the motor's behavior. The sensors continuously provide feedback to the controller, enabling it to fine-tune the control signals in real time, ensuring the motor operates as close to the desired setpoints as possible. This closed-loop system allows for precise control over the motor's performance.

Through research we have found motor driver ICs that can be suitable to our Obstacle avoidance robot. But we haven't still decided what specific IC to use in our Circuit. Let's go through some of our findings.

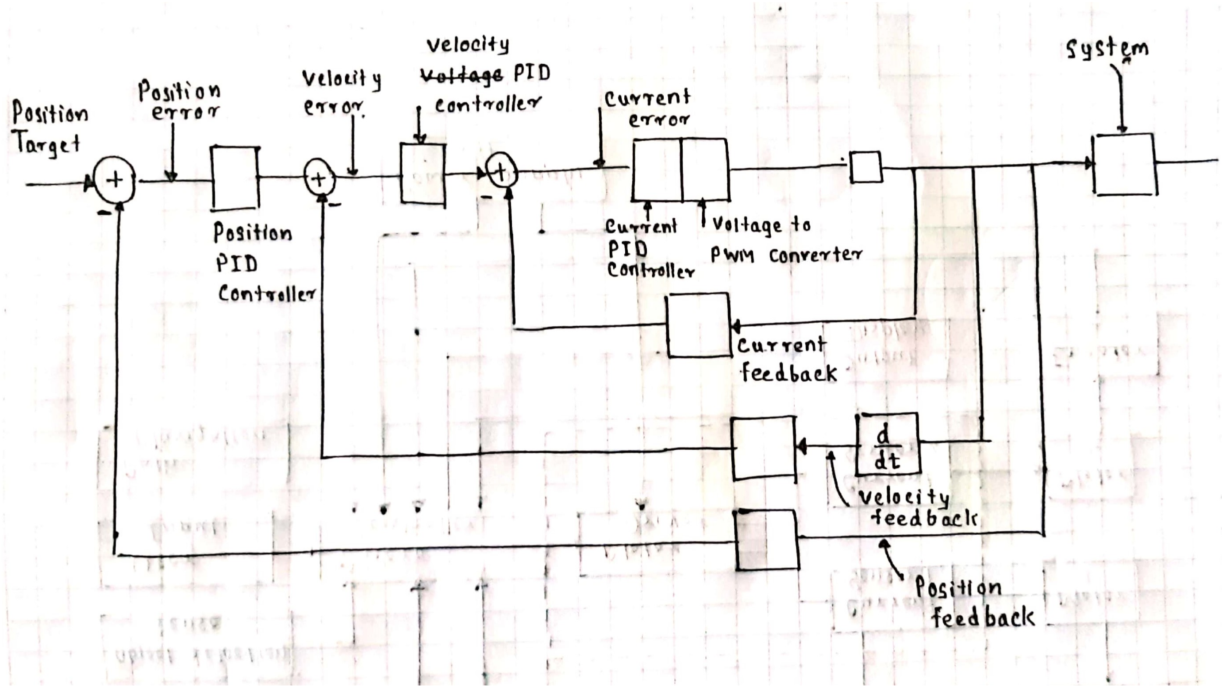


Figure 1.8: Motor Control System

BTS7960 motor driver IC:

The BTS7960 is a dual H-bridge motor driver IC designed for controlling the speed and direction of DC motors. With its capability to handle high currents, up to 43A per channel, it's suitable for applications requiring better motor control. Operating within a voltage range of 5V to 27V.It has features like overcurrent protection and overtemperature protection. BTS7960 motor driver IC is a popular choice for projects demanding high-power motor control. Making it ideal for applications ranging from industrial mobile robots.

Data Sheet : `https://image.dfrobot.com/image/data/DRI0018/BTS7960.pdf`

L298 Motor Driver IC

The L298N is a dual full-bridge driver IC, designed for high current and voltage applications. It can control the speed and direction of two DC motors or one bipolar stepper motor. With a maximum operating voltage of 46V and a peak current of 4A per channel.

Data Sheet: `https://www.sparkfun.com/datasheets/Robotics/L298_H_Bridge.pdf`

DRV8701: Motor Driver IC

The DRV8701 is a high-current H-bridge motor driver IC designed for driving brushed DC motors. It can handle peak currents up to 7A and operates over a wide voltage range. It features integrated protection and diagnostic features, making it suitable for industrial and automotive applications.

Data Sheet: `https://www.ti.com/lit/ds/symlink/drv8701.pdf?ts=1711198150410&ref_url=https%253A%252F%252Fwww.google.com%252F`

LMD18245 Motor Driver IC

The LMD18245 is a high-voltage, high-current H-bridge motor driver IC capable of driving large DC motors. It can handle peak currents up to 6A and operates over a wide voltage range. It's commonly used in applications requiring high-power motor control, such as robotics and CNC machines.

Data Sheet: `https://www.ti.com/lit/ds/symlink/lmd18245.pdf?ts=1711150772639`

1.2.6 Microcontroller

We have researched what are the microcontrollers used in these obstacle-avoidance robots. We found that Atmega 328P, STM 32, and Jetson Nano are the most used microcontrollers in obstacle avoidance robot systems.

- **Atmega2560**:

  Data Sheet: `https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrol`
  `Datasheet.pdf`

  The Atmega is 2560 a microcontroller chip manufactured by Microchip Technology, commonly used in various embedded systems and robotics projects. It belongs to the AVR family of microcontrollers and is widely known for its use in the Arduino Uno board. The Atmega2560 features a high-performance 8-bit AVR RISC-based CPU, flash memory for program storage, EEPROM for data storage, SRAM for data manipulation, and various peripherals such as timers, USARTs, SPI, and I2C interfaces. It operates at relatively low power.

  - **Pros:** Easy to use, Cost-effective, Low Power consumption
  - **Cons:** Limited processing power, Limited Memory, Limited real-time capabilities

Figure 1.9: Atmega2560

- **STM 32**:

  Data Sheet: `https://www.mouser.com/datasheet/2/389/stm32g071c8-1826604.pdf`

  The STM32 is a series of microcontrollers manufactured by STMicroelectronics. These microcontrollers are based on the ARM Cortex-M processor cores and are widely used in a variety of applications ranging from industrial automation to consumer electronics. The STM32 family offers a broad range of performance, memory, and peripheral options to suit different application requirements. They are known for their high performance, low power consumption, rich peripheral set including GPIOs, timers, ADCs, DACs, communication interfaces (such as UART, SPI, I2C, USB), and advanced features like DMA controllers and hardware encryption. STM32 microcontrollers are commonly used in robotics, IoT devices, and embedded systems.

- **Pros:** Higher processing power compared to ATmega328P,More memory for program storage and data. , Enhanced real-time capabilities., Low Power consumption
- **Cons:** compatibility issues, Lack of good firmware libraries, Complexity of minimal usage

Figure 1.10: STM 32

- **Jetson Nano**:

  Data Sheet: `https://components101.com/sites/default/files/component_datasheet/Jetson-Nano-DataSheet.pdf`

  The Jetson Nano is a small, powerful computer module designed by NVIDIA specifically for AI and robotics applications. It features a system-on-module (SoM) design, integrating a quad-core ARM Cortex-A57 CPU, NVIDIA Maxwell GPU with 128 CUDA cores, and 4 GB of LPDDR4 RAM. The Jetson Nano is capable of running various AI frameworks and libraries, making it suitable for tasks such as image classification, object detection, and speech recognition. It also provides interfaces for connecting cameras, displays, sensors, and other peripherals, making it a popular choice for developers and researchers working on AI-powered edge computing applications, autonomous robots, and drones.

  - **Pros:** Very high performance, GPU Acceleration, Low Power consumption
  - **Cons:** High cost, High complexity, High Power consumption

Figure 1.11: Jetson Nano

1.2.7 Selecting the suitable obstacle avoidance sensor for the obstacle avoidance System

There were many choices on what the best option is to be used as the obstacle avoidance sensor. By considering the above facts we discussed earlier about those sensors, we decided that the suitable obstacle avoidance sensor would be the industrial ultrasonic sensors for our case. Cost was a major concern when selecting a suitable sensor. In most industrial obstacle avoidance systems, Lidar systems were used. But the problem involved in that was the high cost of those sensors. Compared to that, Industrial ultrasonic sensors and TOF sensors seem a bit more cost-effective than this. Similarly, we had to consider other parameters like reliability, accuracy, feasibility, and many more factors when selecting the proper obstacle avoidance sensor for this system.

1.2.8 Implementation of suitable Motor Driver for the obstacle avoidance System

We have done research on what the requirements are for our motor driver. To meet our requirements, we have made a suitable motor controller system. Our next step is to test this motor controller with actual elements. So for that, we had to decide on a suitable motor driver IC. We decided to use BTS7960 H brigde motor IC in designing the motor driver

1.2.9 Designing the main PCB of the Obstacle Avoidance System

1.2.10 Designing a suitable enclosure and material selection for the obstacle avoidance system

We did some preliminary designs on how our enclosure design should be. As the main design, we chose one of those designs that we have done. And based on the additional requirements and the better ideas in the rejected designs were added to the selected design. We need to choose an enclosure that is spacious enough. Also, it should be durable and should provide adequate protection against dynamic warehouse conditions.

1.2.11 Experimental Setup and Methodology

We simulated the current sensor and voltage sensor, which are used in the motor controller for the PID controllers. Then we implemented a simple circuit on the breadboard before printing the PCB for the motor driver.

1.2.12 Evaluation Criteria and Performance Metrics

- As the evaluation criteria for assessing the effectiveness of the obstacle avoidance system, including accuracy, reaction time, and adaptability to dynamic environments are used.
- We have planned to study performance metrics such as obstacle detection rate, false positive rate, and collision avoidance success rate.

1.3 Planing Next Steps

1. Pilot Testing and Feedback Collection Pilot Deployments: We have planned to conduct real-world testing for the obstacle avoidance system. User Feedback: Gather detailed feedback from warehouse operators to identify any issues and areas for improvement. Performance Metrics: Measure key performance indicators such as accuracy of obstacle detection, response time, reliability, and overall impact on warehouse efficiency. 2. Optimization and Fine-Tuning Software Updates: Based on feedback and performance metrics, update the software to enhance the system's capabilities and address any identified issues, mainly the PID tuning.

Hardware Adjustments: Make necessary adjustments to the hardware components to improve durability, installation adaptability, and overall performance.

3. Cost Optimization: Identify cost-saving measures in the production process to lower unit costs without compromising quality.

Technical Support: Getting support with troubleshooting and maintenance.

5. Marketing and Sales Strategy Marketing Campaigns: Launch targeted marketing campaigns to raise awareness of the new obstacle avoidance systems among potential customers. Customer Demonstrations: Organize demonstrations to showcase the system's capabilities and benefits.

6. Continuous Improvement and Innovation New Features: Explore the addition of new features such as advanced AI algorithms for predictive obstacle avoidance and machine learning for continuous improvement. Sustainability Initiatives: Focus on developing eco-friendly technologies and sustainable production practices.

1.4 Stakeholder Map

1.4.1 Stakeholder Map Description

The stakeholder map is a visual representation that categorizes stakeholders based on their levels of interest and influence over the project. It helps in identifying key players and understanding their potential impact on the project's success.

1.4.2 Stakeholder Categories

- High Influence, High Interest: These stakeholders have significant power to affect the project and a vested interest in its success. They typically include team members, supervisors, and clients.
- High Influence, Low Interest: Stakeholders in this category can impact the project but may not have a strong interest in its daily operations. Examples are regulatory bodies and investors.
- Low Influence, High Interest: These stakeholders are interested in the project but have little power to influence its outcomes, such as the academic community and media.
- Low Influence, Low Interest: Stakeholders with minimal interest and influence, such as competitors, might be monitored but not actively engaged.

1.4.3 Identification of Stake Holders

- Design team :They are directly responsible for designing the AMRs and AGVs, ensuring they meet the functional requirements of the project while considering factors such as usability, reliability, and safety.
- End Users (Warehouse workers) : They will interact with the AMRs and AGVs on a daily basis within the warehouse environment. Their feedback and satisfaction with the technology will directly impact its effectiveness and acceptance. They are directly impacted by the introduction of AMRs and AGVs, as it may affect their job roles, responsibilities, and working conditions. Involving them in the process can help address concerns and ensure a smoother transition.
- Warehouse Owners: Warehouse owners are directly impacted by the adoption of AMRs and AGVs in their facilities. These technologies offer the potential to enhance operational efficiency, reduce labor costs, and improve overall productivity. Warehouse owners have a vested interest in leveraging such advancements to optimize their operations, stay competitive in the market, and maximize profitability. They are responsible for making strategic decisions regarding the investment in and implementation of AMRs and AGVs, as well as ensuring the successful integration and management of these technologies within their warehouses.
- University of Moratuwa : The project is being conducted under the guidance of a staff member from the university. The university has a vested interest in the success and outcomes of the project, which could contribute to its research endeavors or reputation.
- Suppliers : Suppliers of hardware components, such as sensors, motors, batteries, and other essential parts for AMRs and AGVs, play a crucial role in the successful implementation of the project. Their ability to provide high-quality, reliable components on time directly impacts the development, performance, and maintenance of the robotic systems. Close collaboration and communication with these suppliers are essential to ensure that the selected components meet the project's requirements, specifications, and quality standards. Any issues or delays in the supply chain can potentially disrupt the project timeline and increase costs. Therefore, suppliers are important stakeholders whose cooperation and support are necessary for the seamless integration and operation of AMRs and AGVs in the warehouse environment.
- Worker's Unions: Unions represent the collective interests of warehouse workers and may have concerns regarding job security, working conditions, and potential job displacement due to automation. Their involvement is essential for addressing labor-related issues and ensuring fair treatment of workers. Worker's unions are concerned about the potential impact of automation, such as AMRs and AGVs, on job security for warehouse workers. Automation could lead to job displacement or changes in job roles, which unions seek to mitigate through negotiation, advocacy, and potentially retraining or redeployment programs. Unions advocate for safe and fair working conditions for their members. They may want assurances that the introduction of AMRs and AGVs does not compromise workplace safety standards and that adequate measures are in place to prevent accidents or injuries involving automated equipment.
- Manpower Companies: Manpower companies provide labor and workforce solutions to warehouse owners. The implementation of AMRs and AGVs may impact the demand for certain types of labor, such as manual material handling and repetitive tasks traditionally performed by warehouse workers. As a result, manpower companies need to adapt their recruitment, training, and staffing strategies to meet the evolving needs of warehouse owners deploying automation technologies. They may need to provide specialized training programs for workers to transition into roles that complement or support the operation of AMRs and AGVs, such as maintenance technicians, system operators, or logistics coordinators. Additionally, manpower companies may need to collaborate closely with warehouse owners to address any workforce adjustments, ensure a smooth transition, and minimize disruptions to operations. Therefore, manpower companies have a vested interest in the successful implementation of AMRs and

AGVs, as it directly impacts their business model, service offerings, and relationship with warehouse clients.

- 8. Competitors : Competitors in the same industry may be affected by the adoption of AMRs and AGVs by a rival warehouse. Understanding their reactions and strategies can help anticipate market dynamics and potential competitive responses to the project.

1.4.4 Stakeholder Map

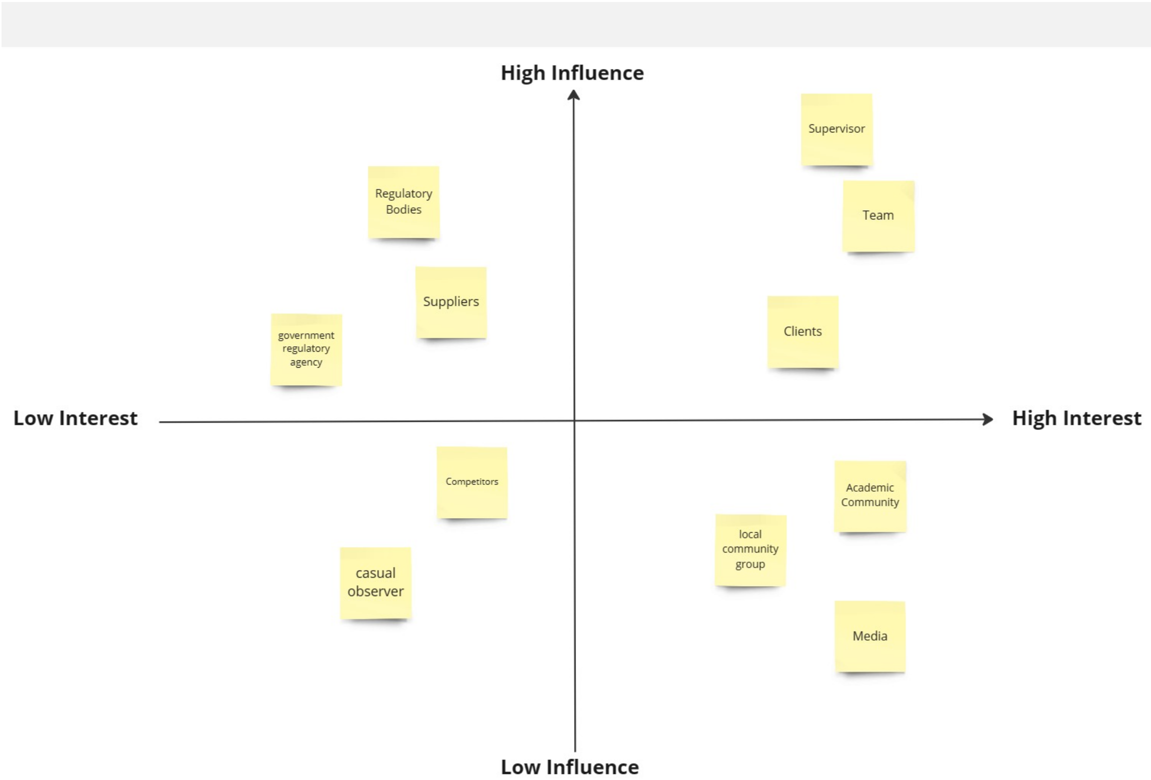


Figure 1.12: Stake Holder Map

1.5 Observe Users

We have identified the industrial users of Obstacle avoidance systems. These are mainly large warehouses. The obstacle avoidance systems used in these warehouses are mainly used as AMR or AGV. We have observed such users who have larger warehouses. As examples, we can give Amazon, FedEx, Tesla, etc. These automated warehouse robots increase the efficiency of the factory by automating material handling and transporting. Using these automated robots will reduce the labor cost by a significant amount. For such a system, it is necessary to have a robust obstacle avoidance system. In this section, we are going to discuss use Cases and scenarios of such Obstacle avoidance systems for warehouses.

1.5.1 Autonomous mobile robotics by KUKA

These robots are designed to operate autonomously, navigating through environments without the need for constant human supervision. KUKA's AMRs typically utilize a combination of sensors, including Lidar, cameras, and other proximity sensors, to perceive their surroundings and navigate safely. They are equipped with onboard computing systems and software algorithms that enable them to make real-time decisions about path planning, obstacle avoidance, and task execution.
In industrial settings, KUKA's AMRs are used for tasks such as material handling, logistics, and assembly. They can transport goods between different locations within a facility, follow predefined routes, and adapt to dynamic environments by avoiding obstacles and optimizing their paths.

- **Autonomous mobile robotics by KUKA-** https://youtu.be/DUrKvPSOL8U
- **Smart AMR platform KMP 1500P maximizes efficiency in production halls-** https://youtu.be/LfVk2qFgPks
- **KUKA omniMove-** https://youtu.be/2O8Cj0XiRIM
- **Website-**https://www.kuka.com/en-us/products/amr-autonomous-mobile-robotics

Figure 1.13

Figure 1.14

1.5.2 Amazon Warehouse

Amazon utilizes a diverse array of Automated Guided Vehicles (AGVs) and robots within its warehouses to optimize operations and boost efficiency. These include Kiva, Hercules, Pegasus, Pegasus X-Sort Drive, Xanthus, Bert, Ernie, and Cardinal. These robots perform various tasks such as goods-to-person retrieval, lifting heavy loads, navigating the warehouse, sorting items, and picking and placing boxes accurately.

- **Please Visit** `https://www.youtube.com/watch?v=IMPbKVb8y8s`

1.5.3 KIVA Robots

Kiva Systems, now known as Amazon Robotics, revolutionized warehouse logistics with their autonomous mobile robots. These robots are designed to efficiently move and transport goods within warehouse environments, reducing the need for human labor in certain tasks. Kiva robots operate by navigating through the warehouse space, locating items on shelves, and transporting them to designated areas for packing, shipping, or further processing. They can communicate with each other and with the central warehouse management system to optimize their routes and tasks, ensuring smooth operations. Amazon acquired Kiva Systems in 2012, and since then, these robots have become a major part of Amazon's vast network of fulfillment centers, enabling the company to handle large volumes of orders quickly and efficiently.

- **A Day in the Life of a Kiva Robot** `https://youtu.be/6KRjuuEVEZs`
- **CNET News - Meet the robots making Amazon even faster** `https://youtu.be/UtBa9yVZBJM`
- **Kiva robots in Amazon** `https://youtu.be/ter-qR-7qSk`

Figure 1.15: KUKA Robot figure 1

Figure 1.16: KUKA Robot figure 2

1.5.4 Proteus Robot

This is the Amazon's first fully Autonomous Mobile Robot. Amazon's Proteus robot is designed to autonomously navigate its warehouses while carrying carts filled with packages. Equipped with advanced safety, perception, and navigation technology, Proteus aims to automate the movement of package carts, reducing the need for manual labor and enhancing workplace safety. It emits a green beam to detect obstacles and stops when a human worker steps in its path. This innovation aligns with Amazon's vision of integrating technology and human workers to deliver efficient and safe operations in their fulfillment centers

- **Amazon Reveals First Fully Autonomous Mobile Robot** `https://youtu.be/yKuK_MeXDck`
- **Meet Proteus, Amazon's New Autonomous Robot** `https://youtu.be/lyYpcKM-fWg`

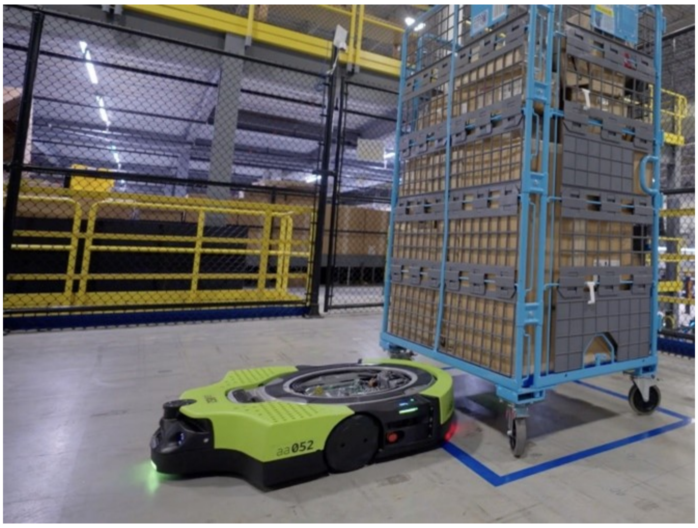


Figure 1.17

Figure 1.18

1.5.5 Mecalux's Autonomous Mobile Robots

Mecalux, a leading provider of warehouse storage solutions and automation technology, has also developed its own line of Autonomous Mobile Robots (AMRs). These robots are designed to automate various tasks within warehouse environments, such as material transportation, inventory management, and order fulfillment. Mecalux's AMRs are equipped with advanced navigation systems, sensors, and software algorithms that allow them to navigate through warehouse spaces safely and efficiently. Similar to Kiva robots, Mecalux's AMRs can communicate with each other and with the warehouse management system to optimize their routes and tasks in real-time. These robots can be easily integrated into existing warehouse operations and adapted to different workflows and environments.

- **Mecalux's Autonomous Mobile Robots (AMRs)** `https://youtu.be/yKuK_MeXDck`

Figure 1.19

Figure 1.20

1.5.6 FedEx Warehouses

FedEx employs Automated Guided Vehicles (AGVs) in its warehouses to enhance efficiency and streamline logistics operations.

- https://s21.q4cdn.com/665674268/files/doc_financials/oar/2018/AnnualReport2018/automation.html

1.6 Conceptual Design Details

1.6.1 Conceptual design 01

Enclosure design 01

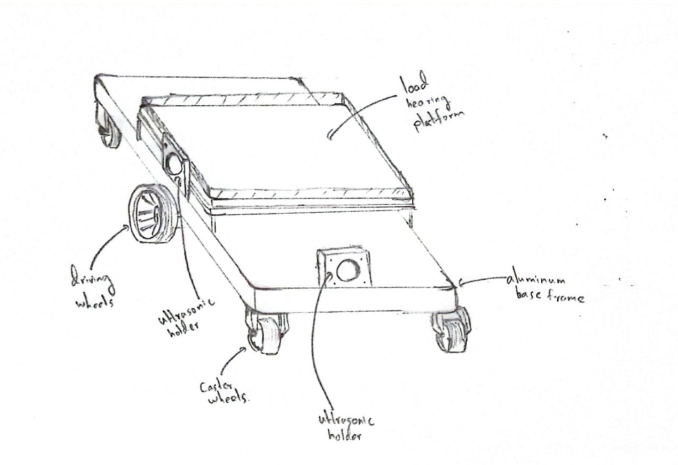


Figure 1.21: Conceptual Design I

Functional Block Diagram 01

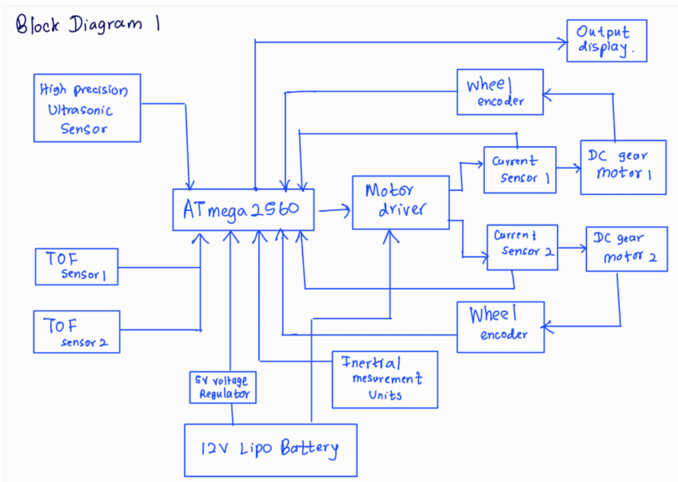


Figure 1.22: Functional Block Diagram I

1.6.2 Conceptual design 02

Enclosure design 02

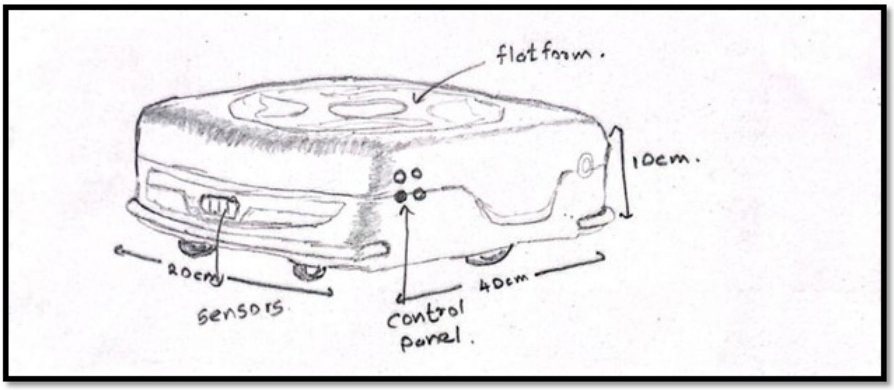


Figure 1.23: Conceptual Design II

Functional Block Diagram 02

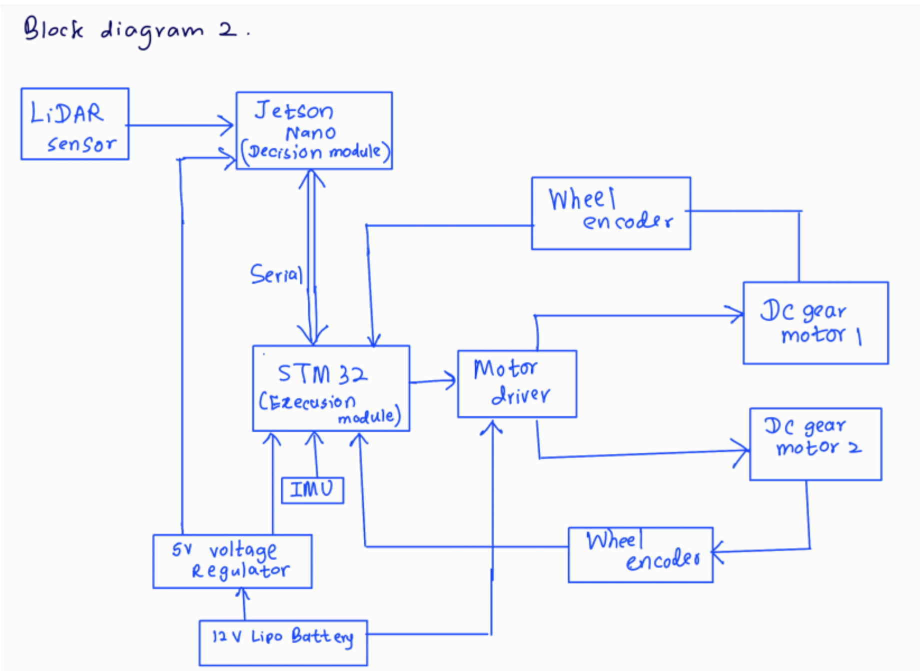


Figure 1.24: Functional Block Diagram II

1.6.3 Conceptual design 03

Enclosure design 03

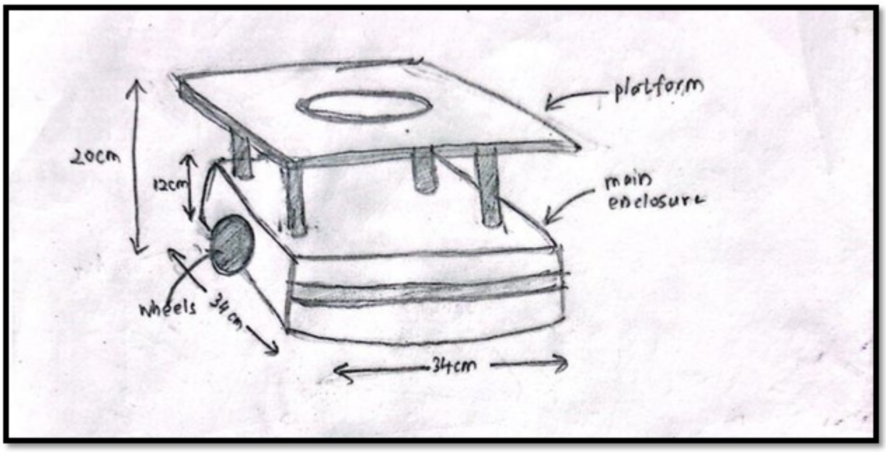


Figure 1.25: Conceptual Design III

Functional Block Diagram 03

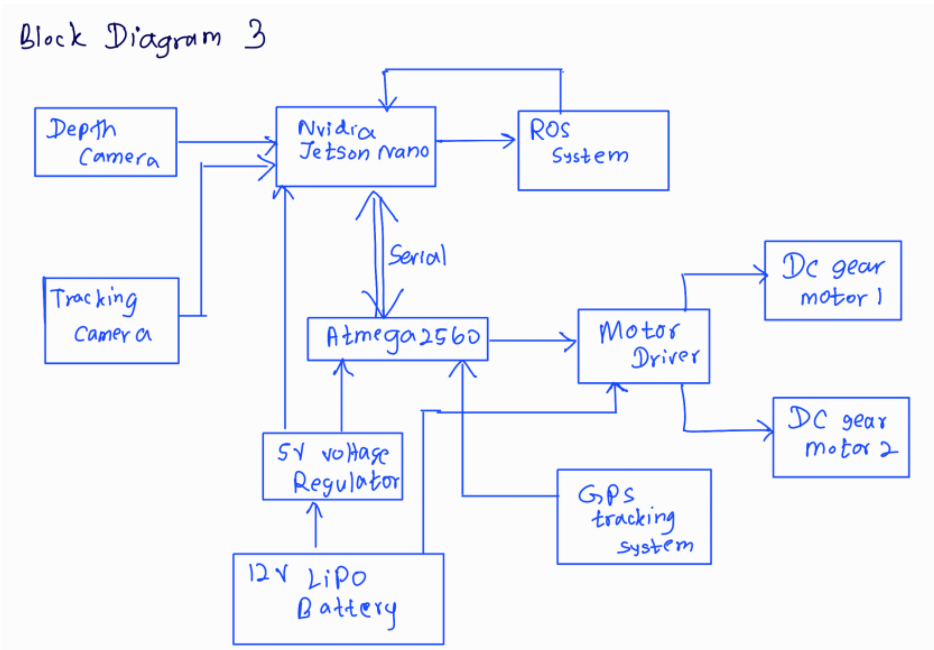


Figure 1.26: Functional Block Diagram III

1.6.4 Conceptual design 04

Enclosure design 04

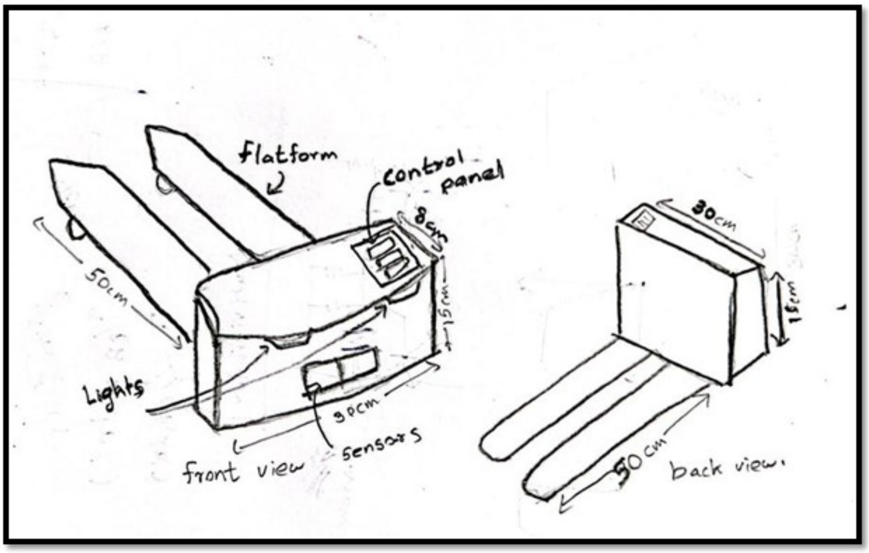


Figure 1.27: Conceptual Design IV

Functional Block Diagram 04

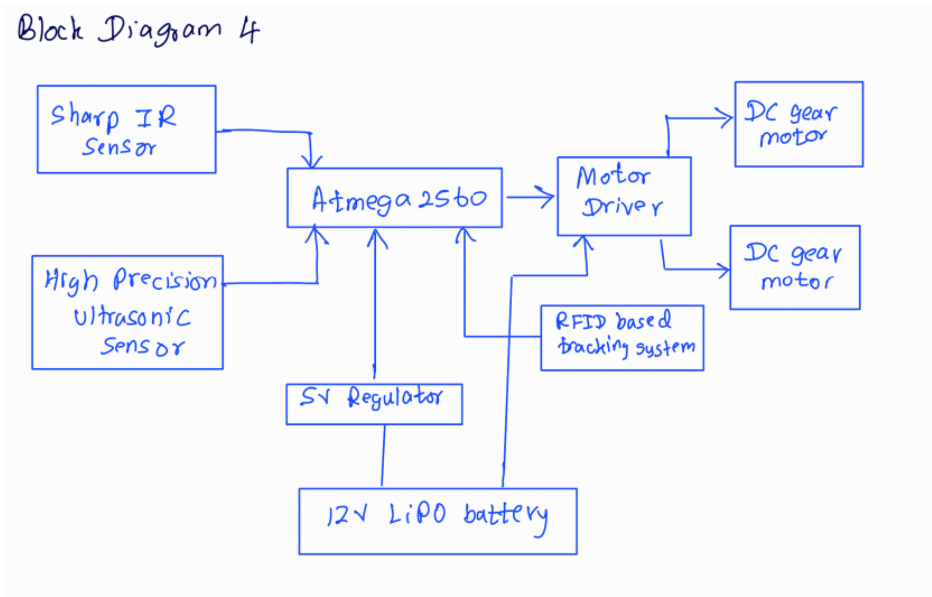


Figure 1.28: Functional Block Diagram IV

1.6.5 Motor Controller Design

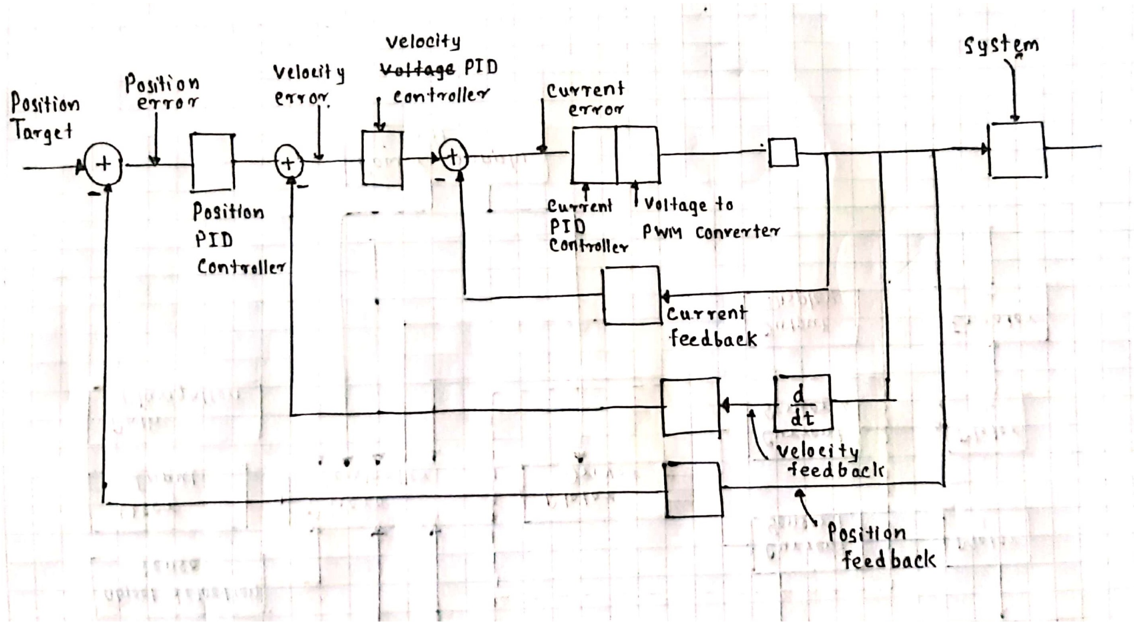


Figure 1.29: Motor Control Design

1.6.6 Comparison of the models

Table 1.1: Conceptual Design Evaluation

Enclosure design criteria	**Conceptual Design**			
	Design 1	**Design 2**	**Design 3**	**Design 4**
Functionality	8	6	7	7
Mobility	8	8	7	5
Heat Dissipation	7	8	7	6
Integration	6	8	7	6
Feasibility	8	6	7	8
Simplicity	6	8	7	6
Durability	8	6	7	7
Total	51	50	49	45

Table 1.2: Functional Block Diagram Evaluation

Functional block design criteria	**Functional Block Design**			
	Design 1	**Design 2**	**Design 3**	**Design 4**
Functionality	8	6	7	8
User Experience	9	7	8	8
Manufacturing feasibility	8	6	7	7
Cost	6	9	6	5
Performance	9	6	7	7
Future proofing	9	6	7	6
Power	7	9	6	6
Total	56	49	48	47

1.6.7 Evaluation Criteria

Enclosure Design Criteria

1. Functionality: The functionality criterion assesses how effectively the enclosure design supports the main functionalities of the device it houses. This includes factors such as component placement, accessibility to ports and interfaces, and integration of features that enhance usability and performance.

2. Aesthetics: Aesthetics evaluate the visual appeal and attractiveness of the enclosure design to users. This criterion considers factors such as form factor, color scheme, texture, and overall design coherence, aiming to create a visually pleasing and engaging product.

3. Heat Dissipation: Heat dissipation measures the effectiveness of the enclosure design in managing thermal energy generated by internal components. It encompasses considerations such as ventilation, heat sinks, material selection, and thermal insulation to ensure optimal operating temperatures and prevent overheating.

4. Assembly and Serviceability: Assembly and serviceability evaluate how easily the enclosure can be assembled, disassembled, and serviced. This includes factors such as modular design, accessibility of internal components, use of tool-less assembly techniques, and provision of service access points for maintenance tasks.

5. Ergonomics: Ergonomics assesses how well the enclosure design fits in the user's hand and facilitates comfortable interaction. This criterion considers factors such as grip ergonomics, button placement, tactile feedback, and overall user comfort to enhance usability and minimize user fatigue.

6. Durability: Durability evaluates the ability of the enclosure design to withstand impacts, environmental conditions, and long-term use. This includes material durability, structural integrity, resistance to scratches and abrasions, and compliance with relevant durability standards to ensure product longevity and reliability.

7. Simplicity: Simplicity measures the simplicity of the enclosure design in terms of its form, function, and user interface. This criterion assesses the clarity of design intent, elimination of unnecessary complexity, and intuitive user interaction to enhance usability and user satisfaction.

Functional Block Diagram Criteria

1. Functionality: The functionality criterion evaluates how effectively the circuit design meets the functional requirements of the system. This includes assessing the completeness of functional blocks, adherence to specifications, and robustness of the overall design to ensure reliable performance.

2. User Experience: User experience assesses the intuitiveness and user-friendliness of the interaction with the functional block diagram. This criterion considers factors such as ease of operation, clarity of feedback, and consistency of user interface design to enhance user satisfaction and efficiency.

3. Manufacturing Feasibility: Manufacturing feasibility evaluates the practicality and efficiency of manufacturing the functional block diagram design. This includes considerations such as component availability, assembly complexity, manufacturing cost, and scalability to ensure smooth production processes.

4. Cost: Cost evaluates the overall cost-effectiveness of the functional block diagram design in relation to its provided functionality. This criterion considers factors such as component costs, manufacturing expenses, and lifecycle costs to optimize cost-efficiency without compromising performance or quality.

5. Performance: Performance assesses the signal quality, resolution, and bandwidth range achieved by the functional block diagram. This criterion includes quantitative measures such as signal-to-noise ratio, dynamic range, and frequency response to ensure optimal performance and fidelity in signal processing.

6. Future Proofing: Future proofing evaluates the extent to which the functional block diagram design allows for easy replacement or upgrade of individual components. This criterion considers factors such as modularity, compatibility with future technologies, and provision for expansion to ensure long-term viability and adaptability.

7. Power Efficiency: Power efficiency measures how effectively the functional block diagram manages power consumption. This includes optimizing power distribution, minimizing standby power, and implementing power-saving features to enhance energy efficiency and extend battery life.

1.6.8 Added Features and Removed Features

According to the evaluation criteria conceptual design 1 was selected.

Originally designed with six wheels, our configuration was subsequently streamlined to just three, comprising a single caster wheel at the front and two main wheels positioned at the rear. This adjustment was made based on the determination that this setup adequately meets our stability requirements while simplifying the overall design.

Initially, the design included a single distance measuring sensor. However, it was later decided to enhance obstacle detection accuracy by incorporating three ultrasonic sensors: one at the front and two on the sides of the robot.

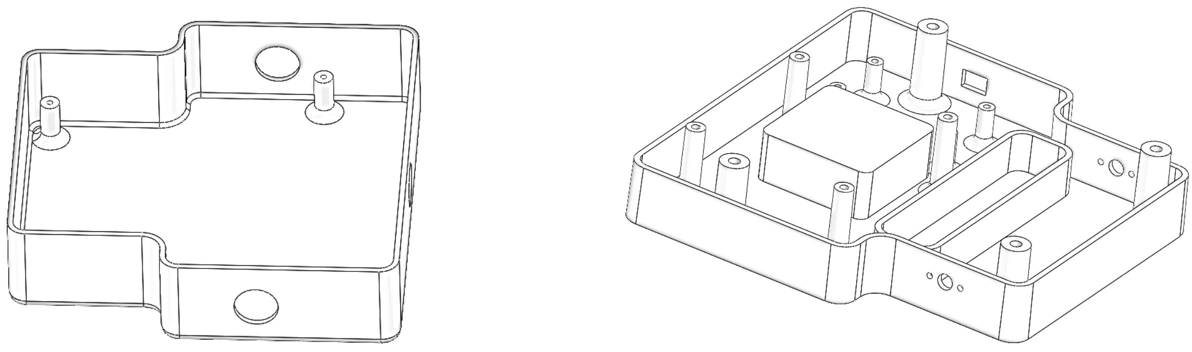


Figure 1.30: Top and Bottom parts

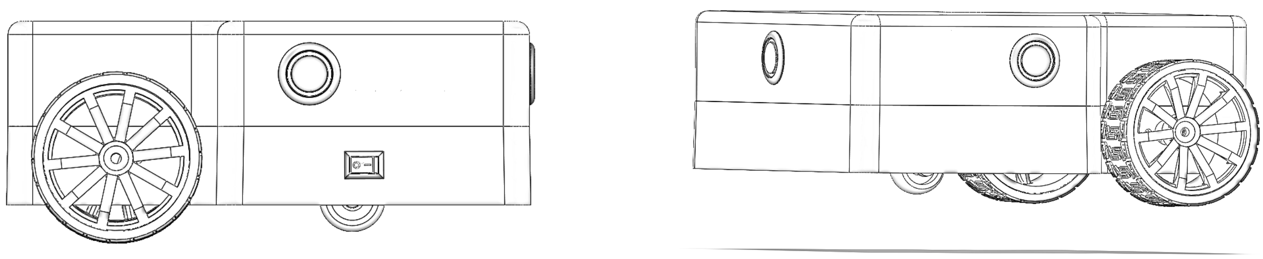


Figure 1.32: Final Design

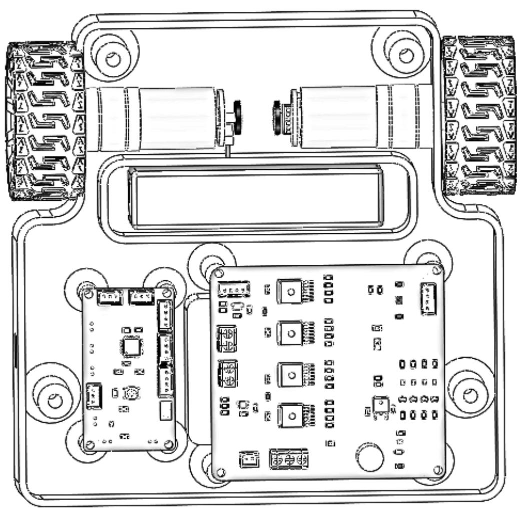


Figure 1.31: Inside

1.7 Dimensions

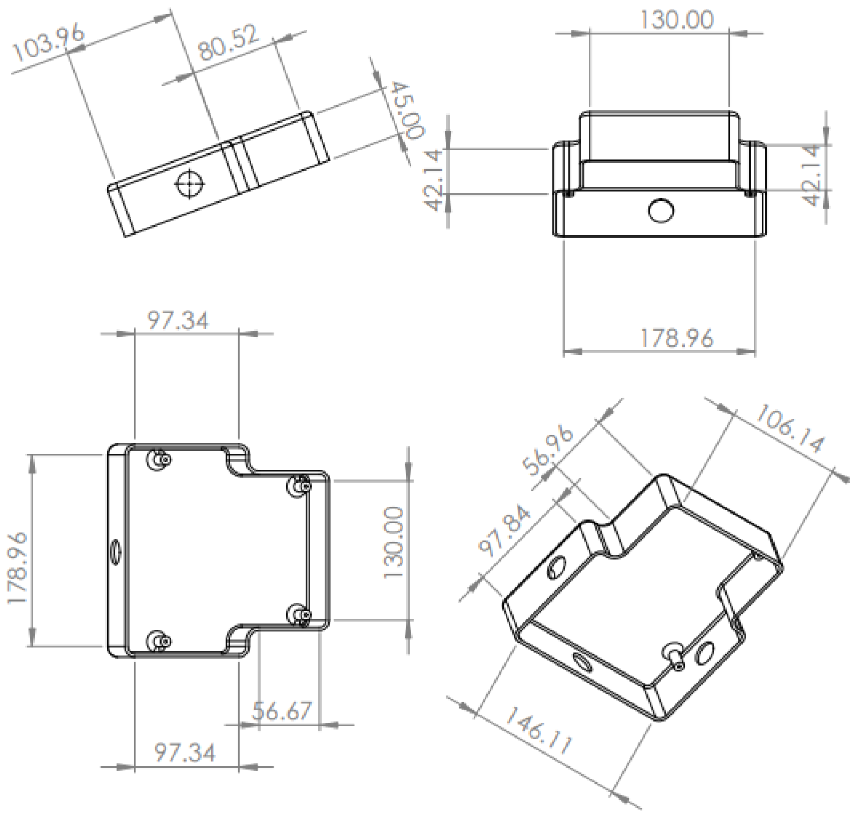


Figure 1.33: Top part dimensions

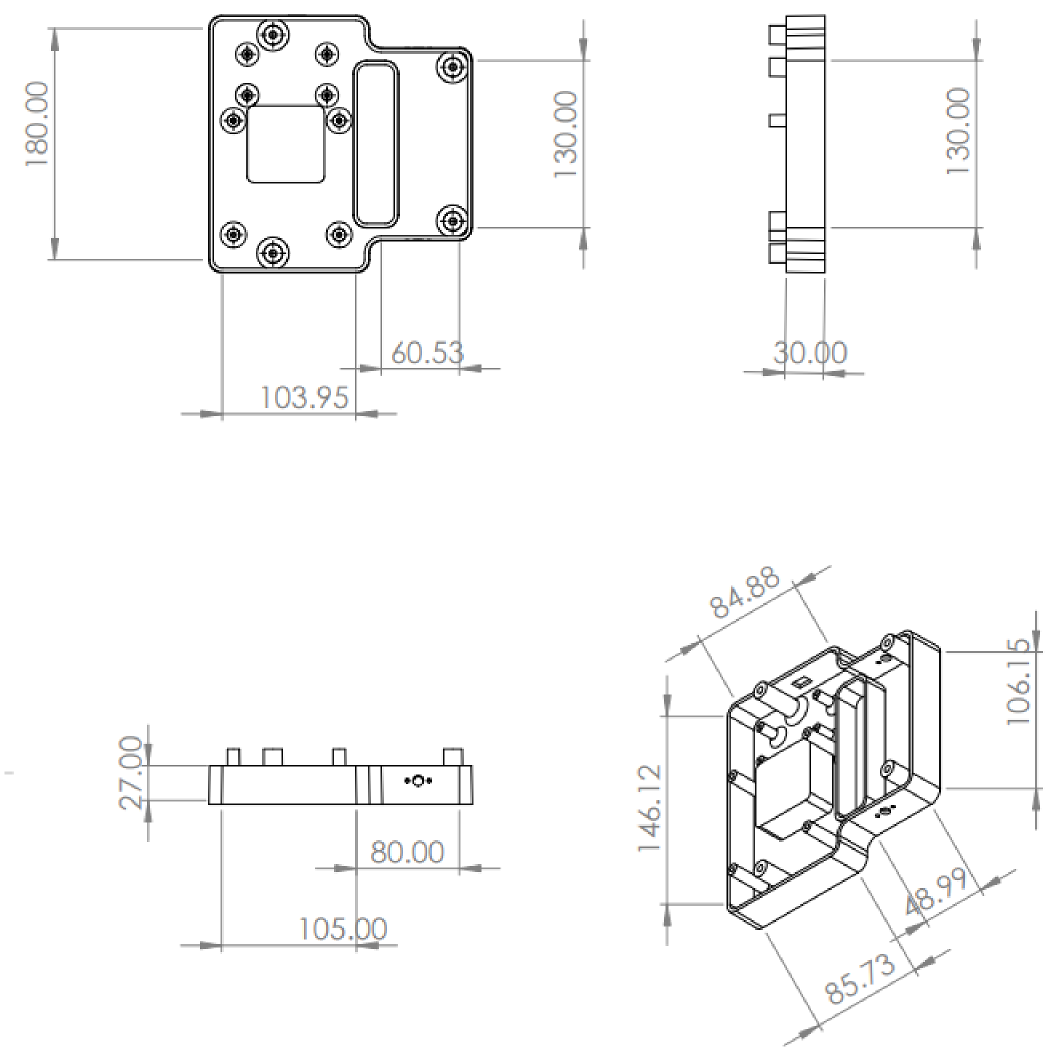


Figure 1.34: Bottom part dimensions

1.8 Need List

1.8.1 Need List for Main PCB

Need List	Quantity
ATMEGA328P-AU	1
22 pF capacitor	2
10 nF Capacitor	2
L78M05ACDT-TR, Linear Voltage Regulator	1
16.000MHz crystal oscillator	1
B2B-XH-A(LF)(SN) Connector Header	5
B3B-XH-A(LF)(SN), Connector Header	3
B4B-XH-A(LF)(SN), Connector Header	3
TS-1187A-B-A-B, Switch	1
10k resistor 500 mW	1
0.1uF Capacitor	3
0.33uF Capacitor	1
Standard LED (Red)	1

Figure 1.35: Need List 1

1.8.2 Need List for Motor Controller PCB

18	Need List	Quantity
19		
20	Logic Gates 74HC00BQ	1
21	100 Kohm Resitors	2
22	B4B-XH-A(LF)(SN) Connector Header	2
23	SPD50P03L G Power Transistor	1
24	3 Position Wire to Board Terminal Block	1
25	10 Kohm Resistor	20
26	Standard LEDs (Red)	1
27	Zener Diodes	1
28	470uf Capacitor	1
29	0.47uF Capacitor	1
30	Linear Voltage Regulators 5.0V	1
31	0.33uF Capacitor	1
32	0.1uF Capacitor	3
33	1.0Kohm Resistor	8
34	Standard LEDs(Blue)	2
35	Standard LEDs (White)	2
36	IC HALF BRIDGE BST7960P	4
37	5.1 kohm Resistor	8
38	100pF Capacitors	4
39	2 Position Wire to Board Terminal Block	2
40	B2B-XH-A(LF)(SN) Connector Header	1
41	INA226 Current IC	2
42	0.015ohms 1W Current Sense Resistors	2
43	1uF Capacitors	1
44	74HC244BQQ100 Line Driver	1

Figure 1.36: Need List 2

1.9 Stimulate Ideas

In our exploration of automated guided vehicles (AGVs) and autonomous mobile robots (AMRs) for warehouse applications in Sri Lanka, we delved into a diverse landscape of technological innovations and emerging trends. Our comprehensive market research encompassed a wide array of existing products and solutions, revealing a dynamic market driven by the need for efficiency, flexibility, and adaptability in logistics operations. From our analysis, it became evident that successful implementations often hinge on robust obstacle avoidance algorithms, sophisticated sensor integrations including ultrasonics, and advanced navigation strategies tailored to complex warehouse environments. These insights informed our conceptual designs, emphasizing modularity, scalability, and the seamless integration of cutting-edge technologies to enhance operational performance. Crucially, our project recognizes the unique logistical challenges specific to Sri Lanka, such as infrastructure limitations and diverse warehouse layouts, necessitating solutions that are not only innovative but also practical and cost-effective. By leveraging these insights and focusing on interdisciplinary collaboration, our goal is to develop a next-generation AGV/AMR system that not only meets but exceeds industry standards, setting a new benchmark for warehouse automation in the region.

1.10 Schematic

We need to design two separate PCBs: one for the motor controller and another for the main controller.

1.10.1 Main PCB Schematic

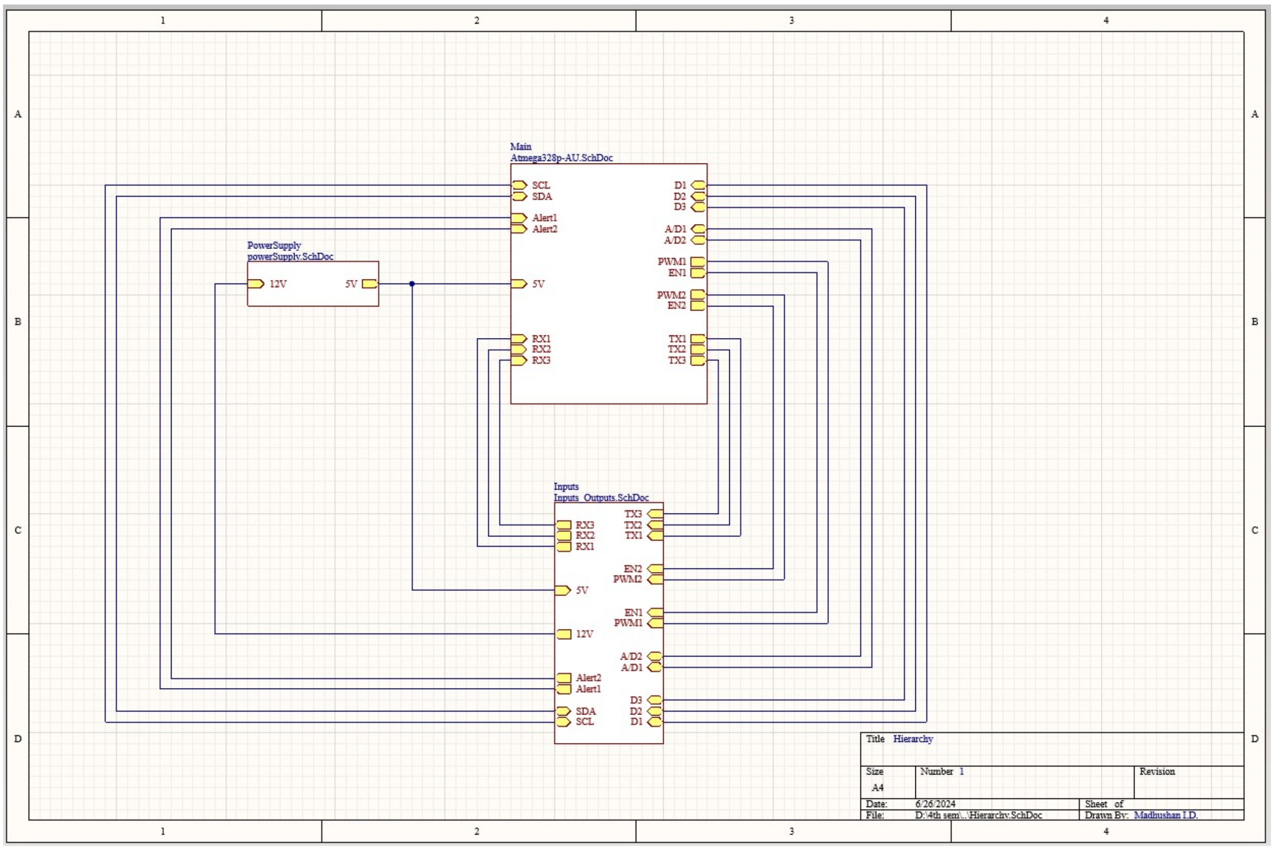
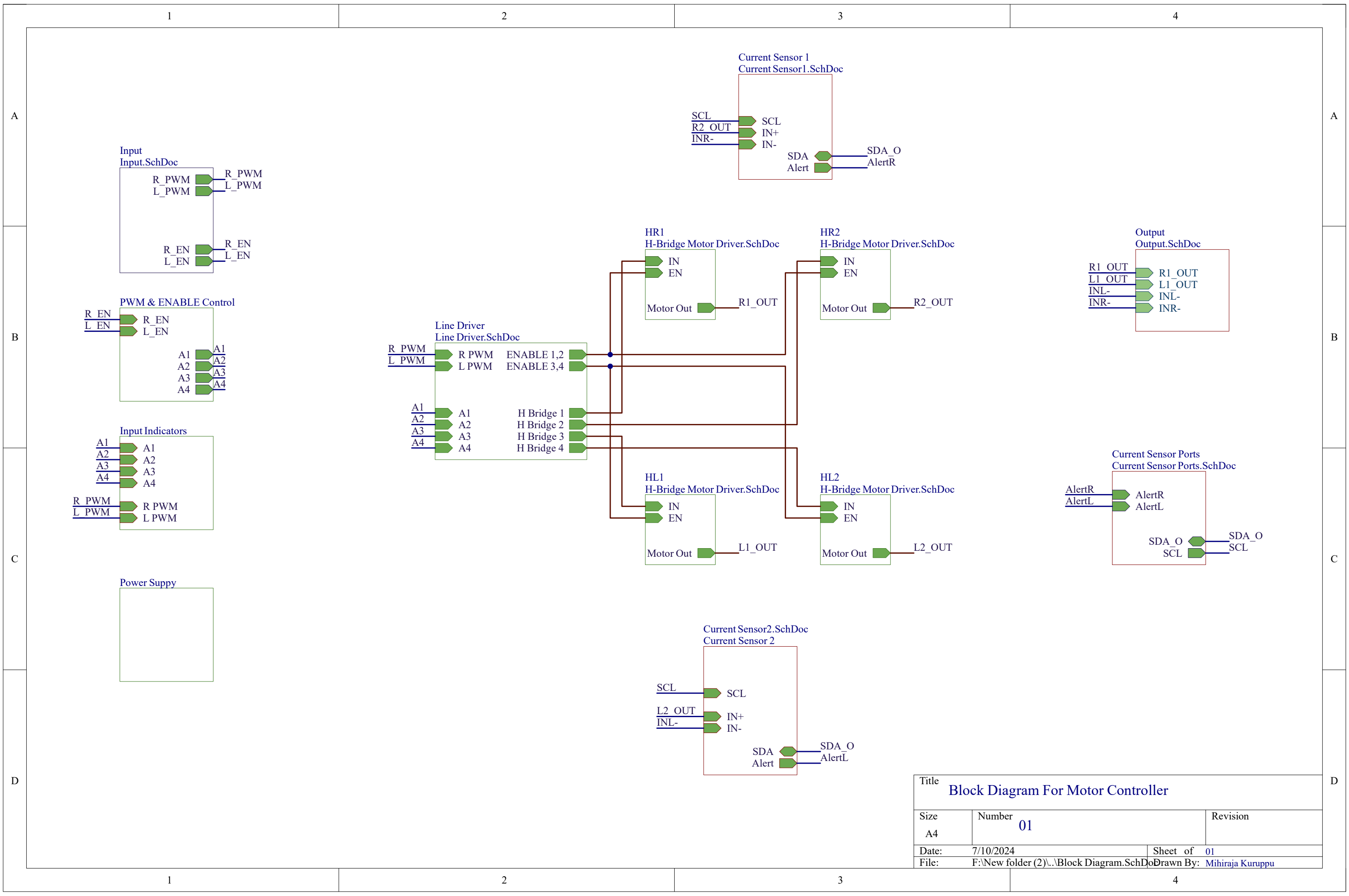


Figure 1.37: Hierarchy

1.10.2 Motor controller PCB Schematic


Current Sensor 1
Current Sensor1.SchDoc
SCL
R2_OUT
INR-
IN+
IN-
SDA
Alert
SDA_O
AlertR
Input
Input.SchDoc
R_PWM
L_PWM
R_EN
L_EN
PWM & ENABLE Control
A1
A2
A3
A4
Input Indicators
R PWM
L PWM
Power Suppy
Line Driver
Line Driver.SchDoc
ENABLE 1,2
ENABLE 3,4
H Bridge 1
H Bridge 2
H Bridge 3
H Bridge 4
HR1
H-Bridge Motor Driver.SchDoc
IN
EN
Motor Out
R1_OUT
HR2
H-Bridge Motor Driver.SchDoc
R2_OUT
HL1
H-Bridge Motor Driver.SchDoc
L1_OUT
HL2
H-Bridge Motor Driver.SchDoc
L2_OUT
Output
Output.SchDoc
R1_OUT
L1_OUT
INL-
INR-
Current Sensor Ports
Current Sensor Ports.SchDoc
AlertR
AlertL
SDA_O
SCL
Current Sensor2.SchDoc
Current Sensor 2
L2_OUT
INL-
AlertL
Title
Block Diagram For Motor Controller
Size
A4
Number
01
Revision
Date: 7/10/2024
Sheet of 01
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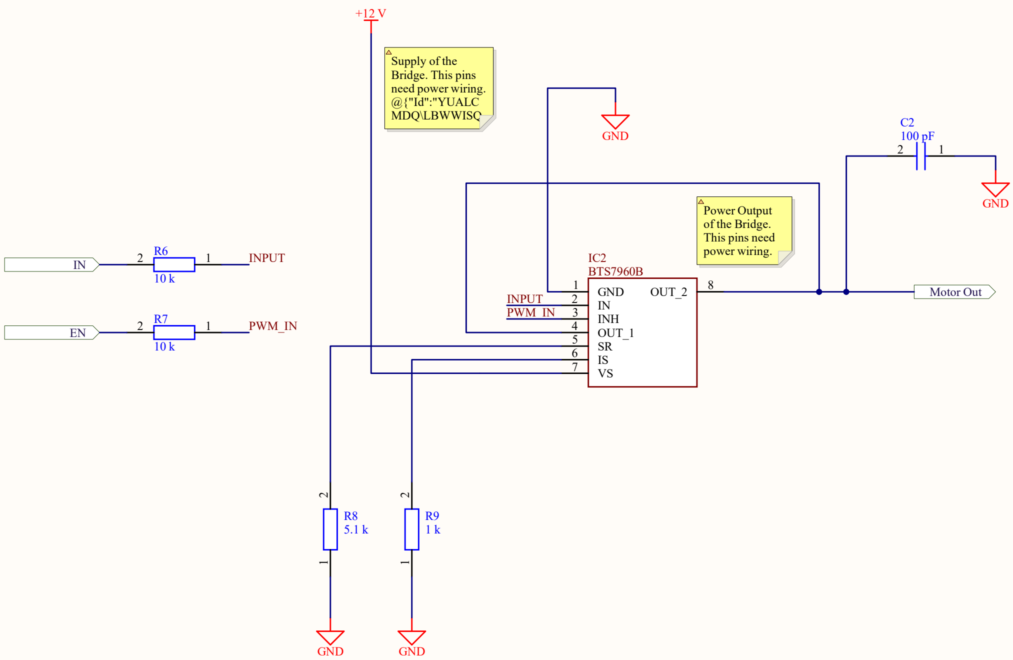
Drawn By: Mihiraja Kuruppu



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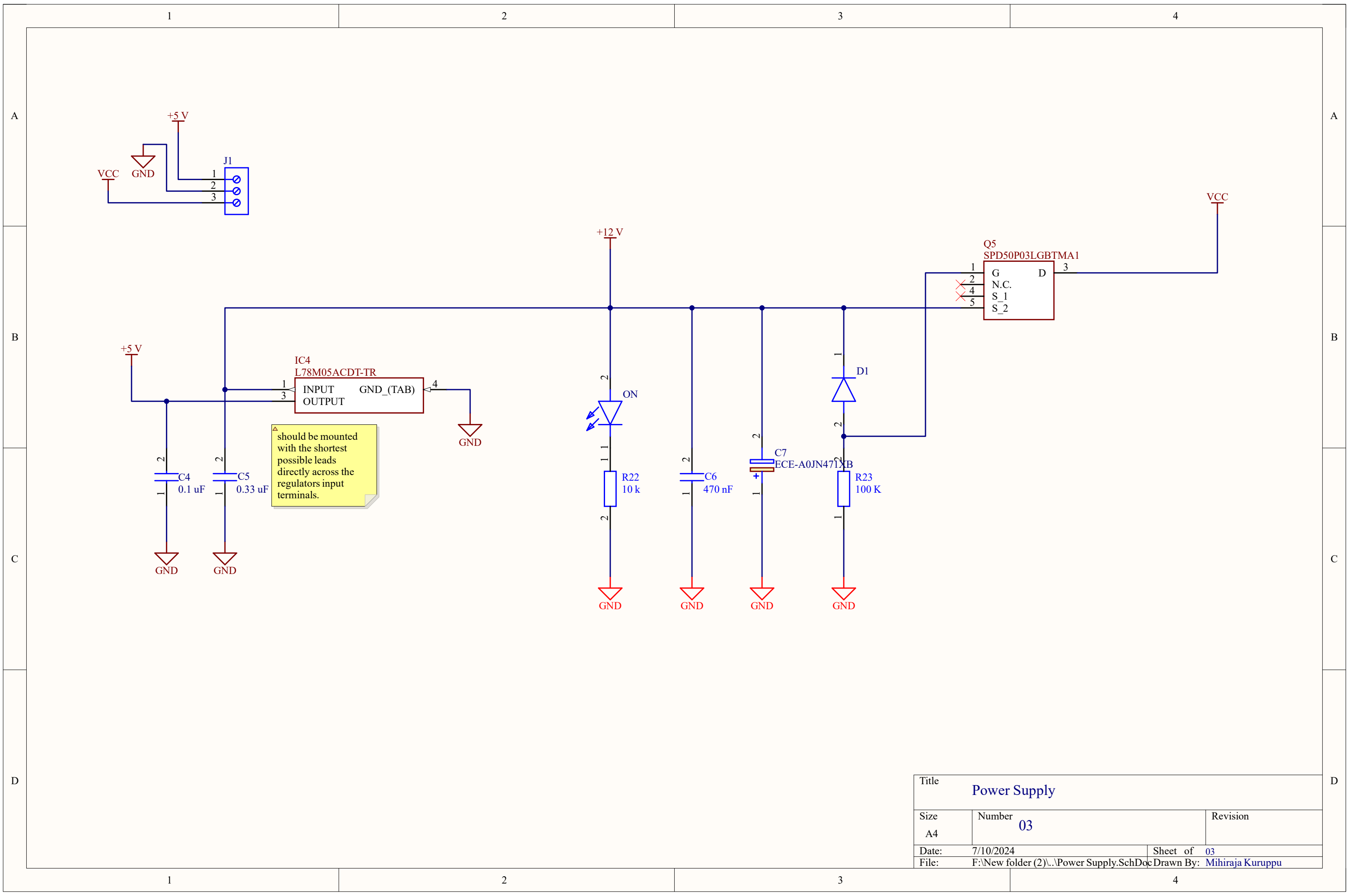
+5 V
GND
VCC
J1
1
2
3
+12 V
VCC
Q5
SPD50P03LGBTMA1
G
N.C.
S_1
S_2
D
+5 V
IC4
L78M05ACDT-TR
INPUT
OUTPUT
GND_(TAB)
GND
should be mounted with the shortest possible leads directly across the regulators input terminals.
C4
0.1 uF
C5
0.33 uF
GND
GND
ON
R22
10 k
C6
470 nF
C7
ECE-A0JN471XB
D1
R23
100 K
GND
GND
GND
GND
Title
Power Supply
Size
A4
Number
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Date:
7/10/2024
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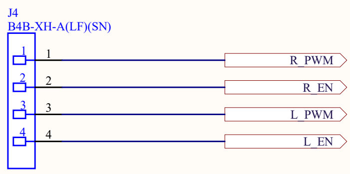
Drawn By:
Mihiraja Kuruppu



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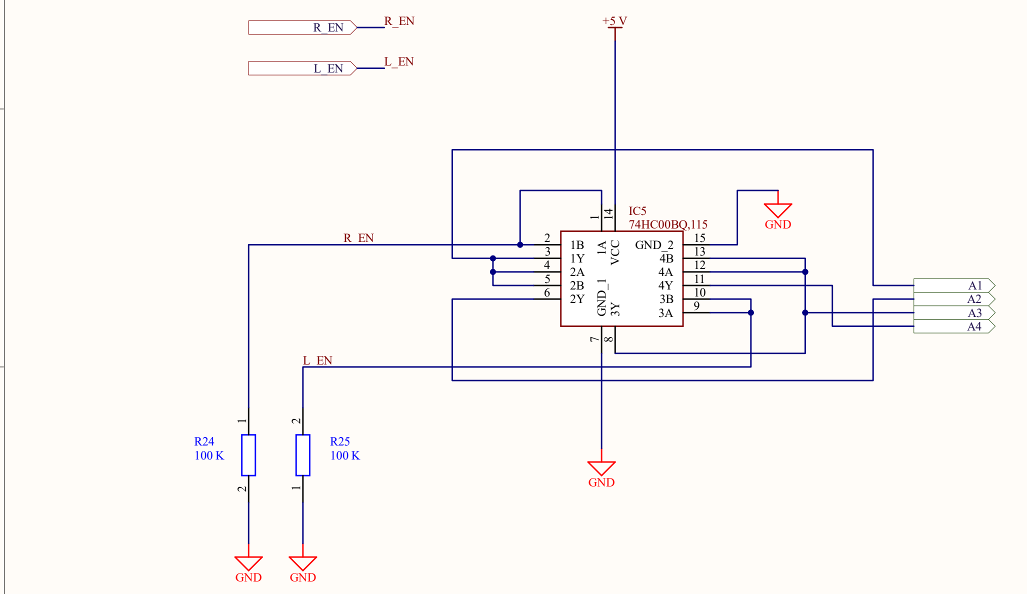

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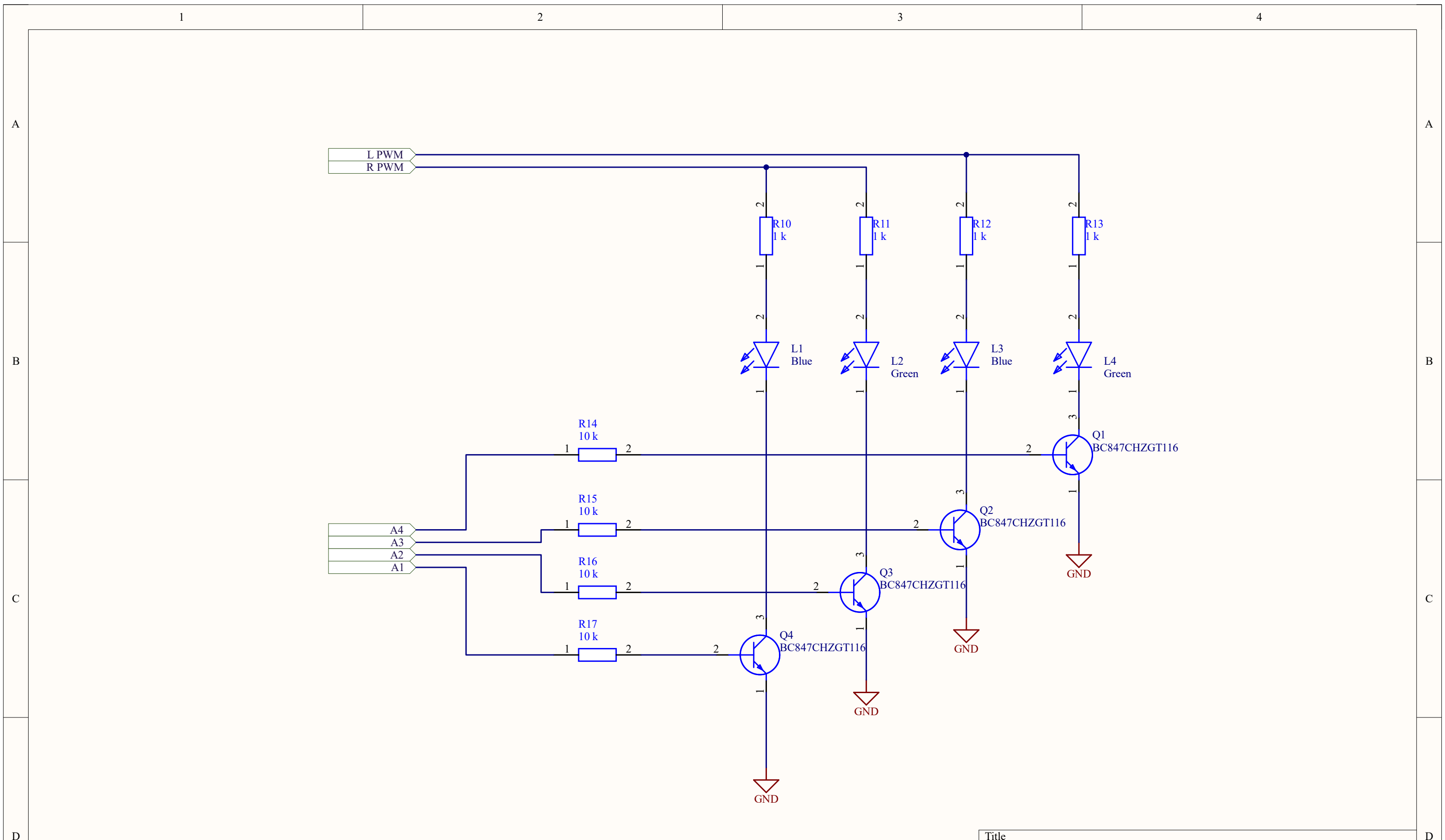

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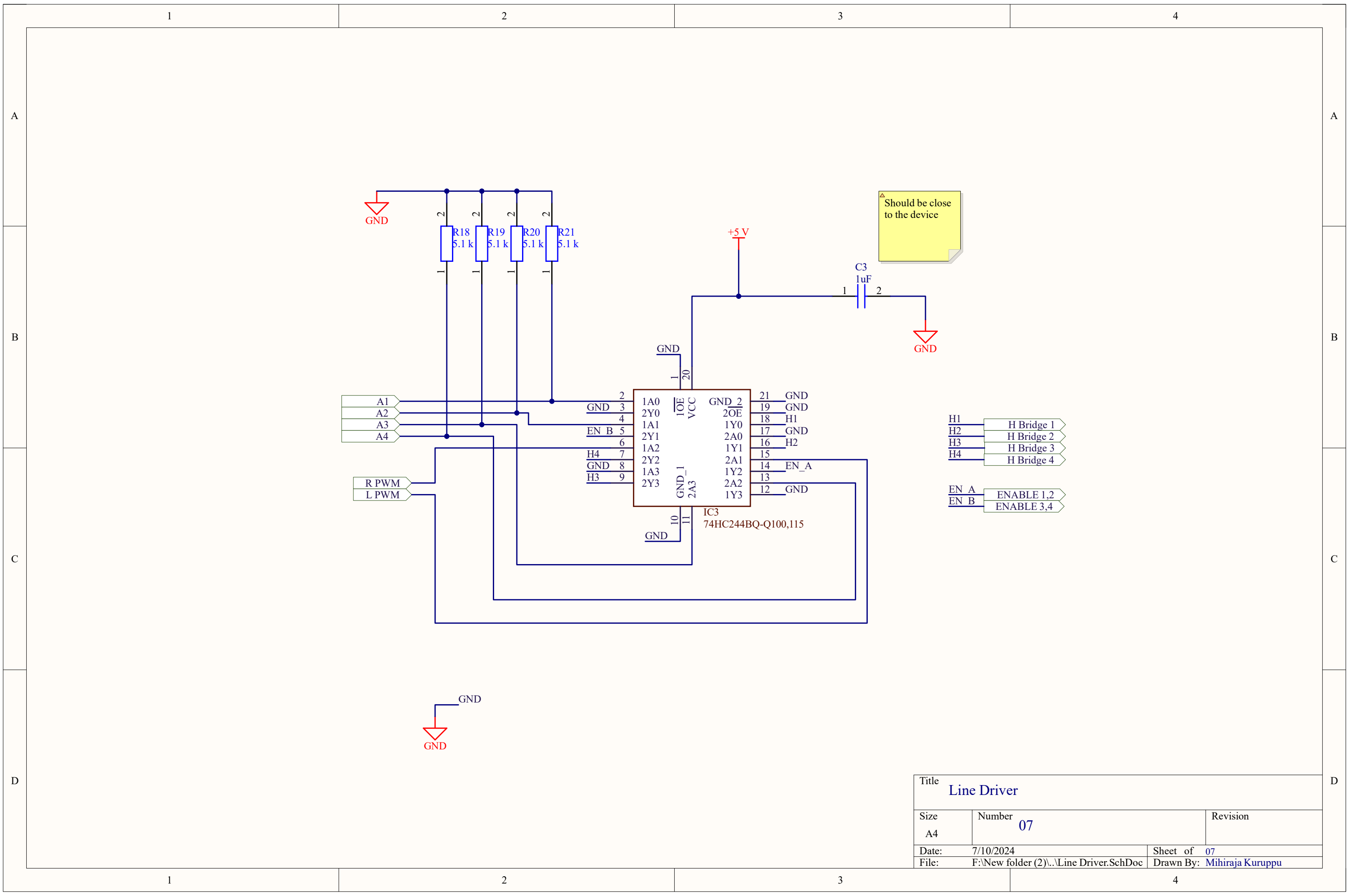

GND
R18
5.1 k
R19
5.1 k
R20
5.1 k
R21
5.1 k
+5 V
Should be close to the device
C3
1uF
GND
GND
A1
A2
A3
A4
R PWM
L PWM
GND
EN_B
H4
GND
H3
1A0
2Y0
1A1
2Y1
1A2
2Y2
1A3
2Y3
1OE
VCC
GND_2
2OE
1Y0
2A0
1Y1
2A1
1Y2
2A2
1Y3
GND_1
2A3
GND
H1
GND
H2
EN_A
GND
IC3
74HC244BQ-Q100,115
GND
H1
H2
H3
H4
H Bridge 1
H Bridge 2
H Bridge 3
H Bridge 4
EN_A
EN_B
ENABLE 1,2
ENABLE 3,4
GND
GND
Title
Line Driver
Size
A4
Number
07
Revision
Date:
7/10/2024
Sheet of
07
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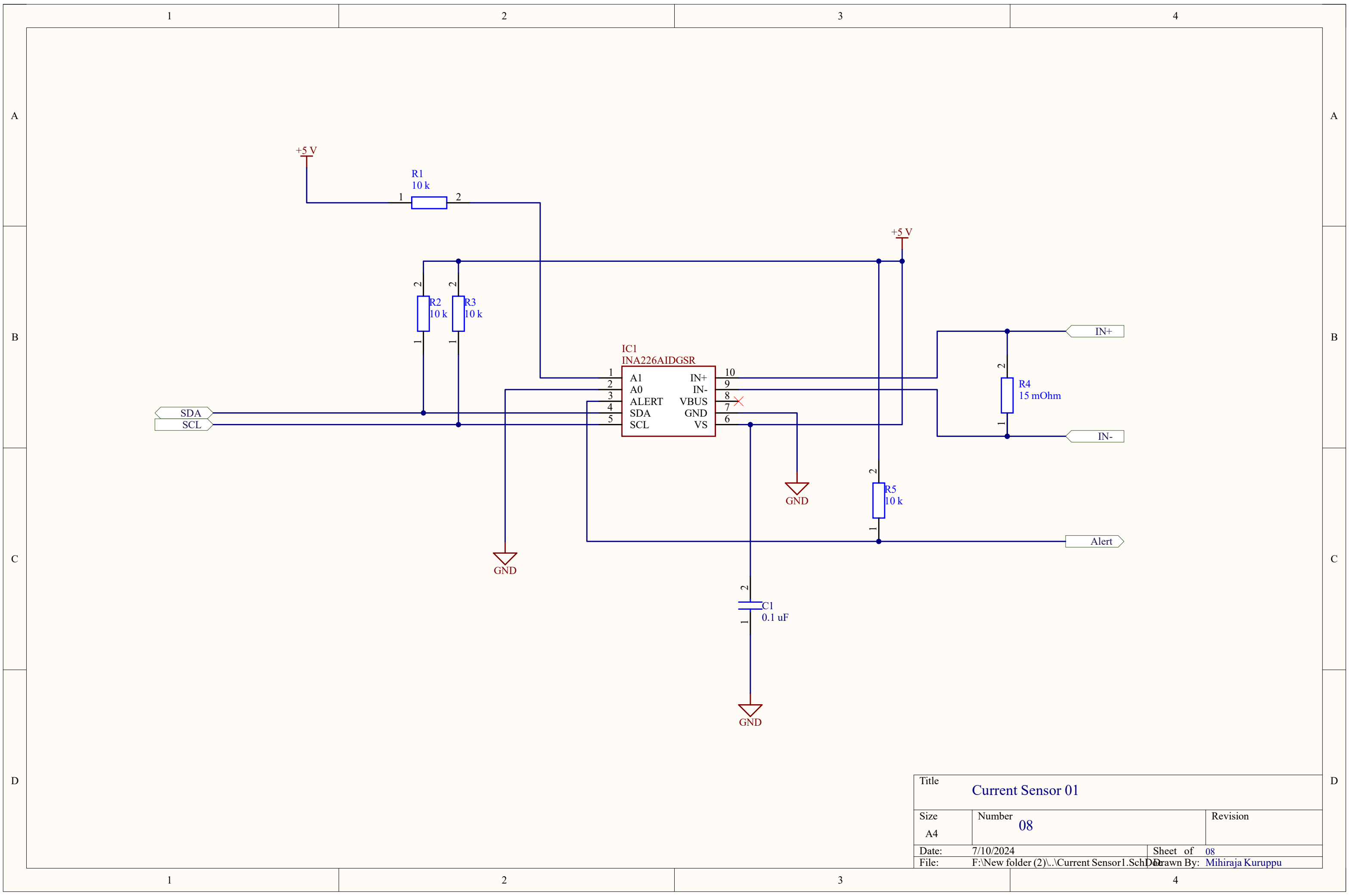
Drawn By:
Mihiraja Kuruppu


+5 V
R1
10 k
+5 V
R2
10 k
R3
10 k
IC1
INA226AIDGSR
A1
A0
ALERT
SDA
SCL
IN+
IN-
VBUS
GND
VS
SDA
SCL
IN+
IN-
R4
15 mOhm
R5
10 k
Alert
GND
GND
C1
0.1 uF
GND
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Current Sensor 01
Size
A4
Number
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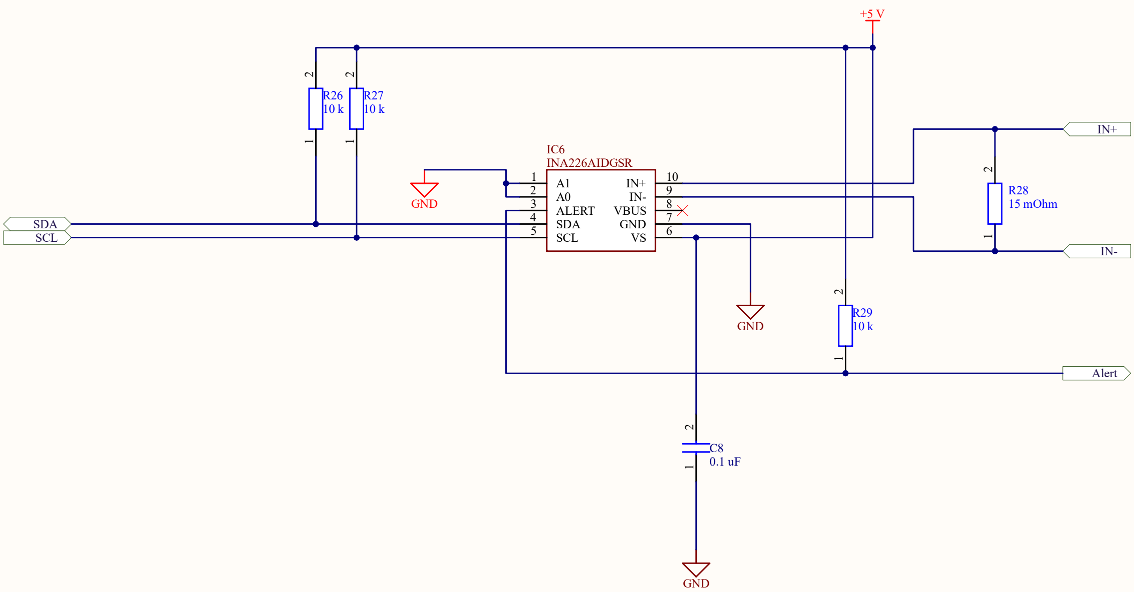
Mihiraja Kuruppu



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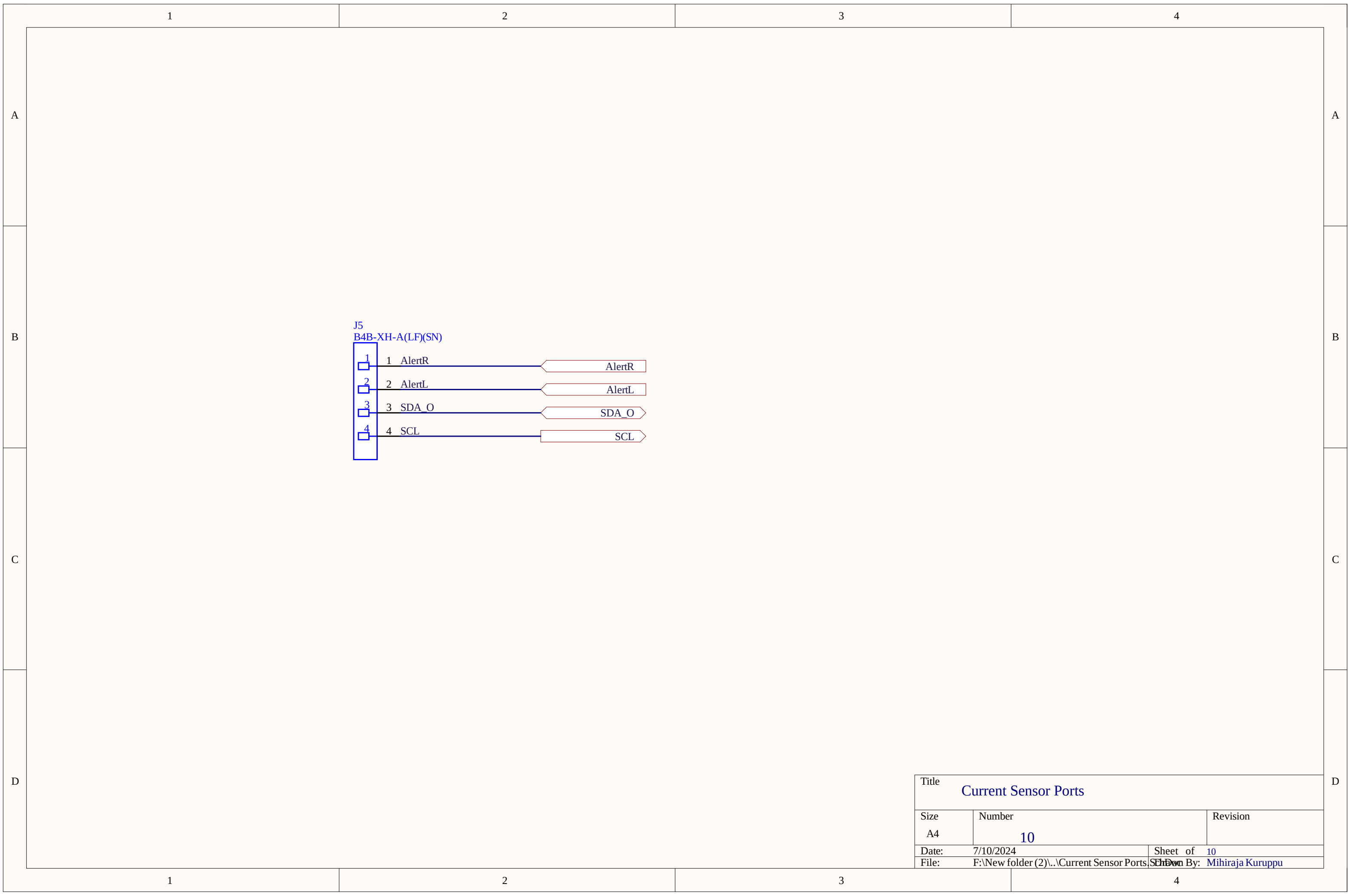
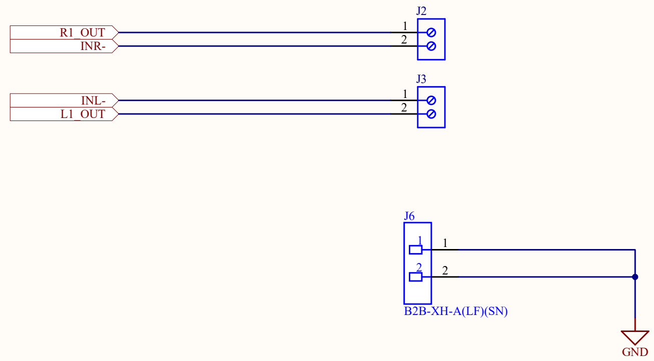

J5
B4B-XH-A(LF)(SN)
1 AlertR
2 AlertL
3 SDA_O
4 SCL
AlertR
AlertL
SDA_O
SCL
Title
Current Sensor Ports
Size
A4
Number
10
Revision
Date: 7/10/2024
Sheet of 10
File: F:\New folder (2)\..\Current Sensor Ports.SchDoc
Drawn By: Mihiraja Kuruppu



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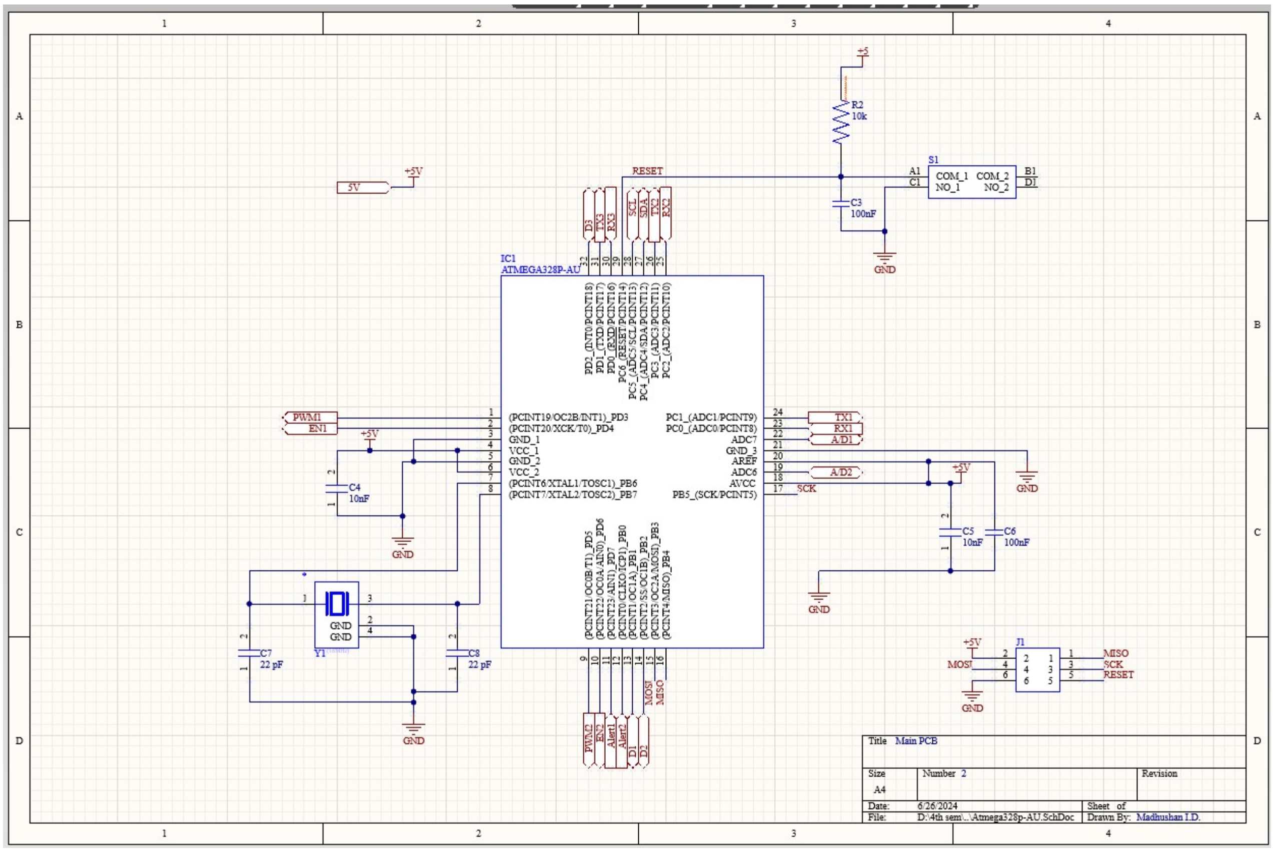


Figure 1.38: Micro Controller

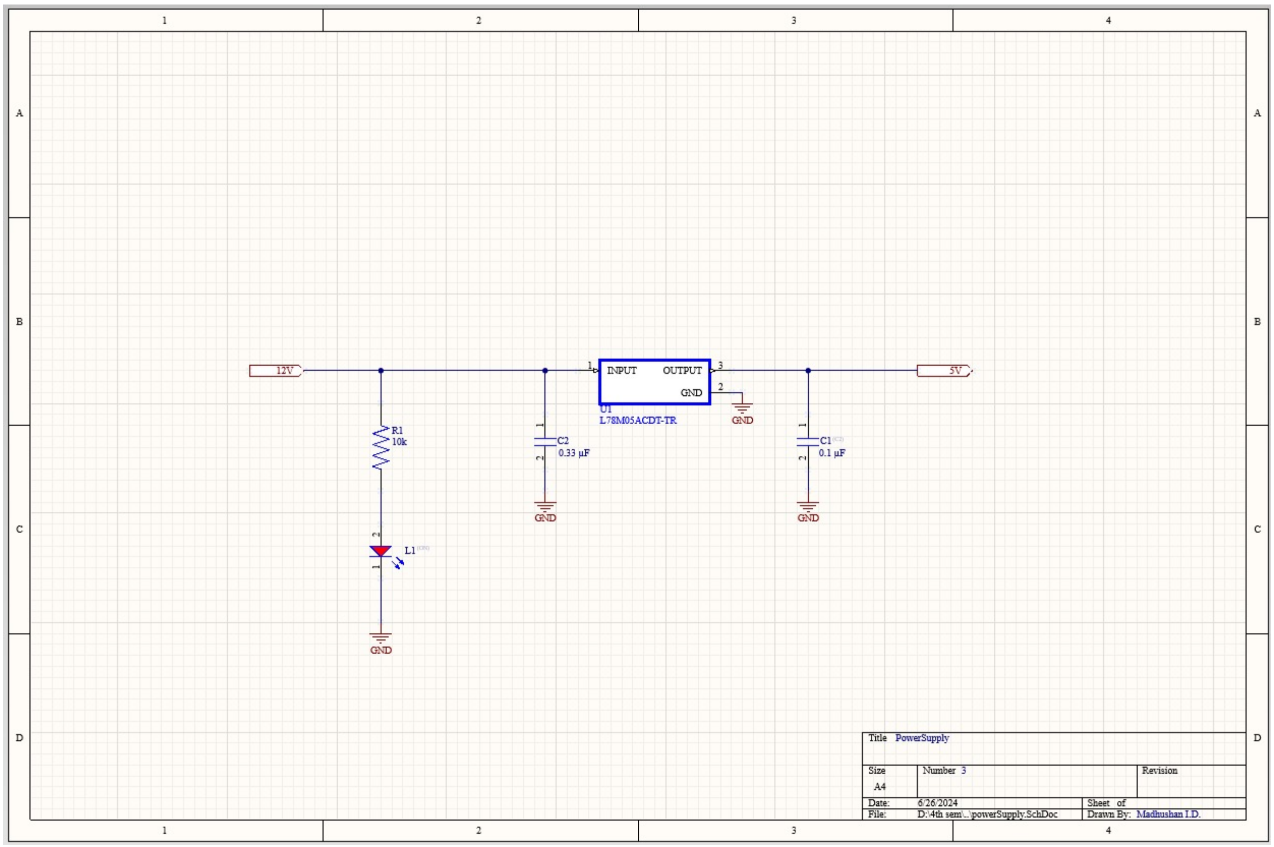


Figure 1.39: Power Supply

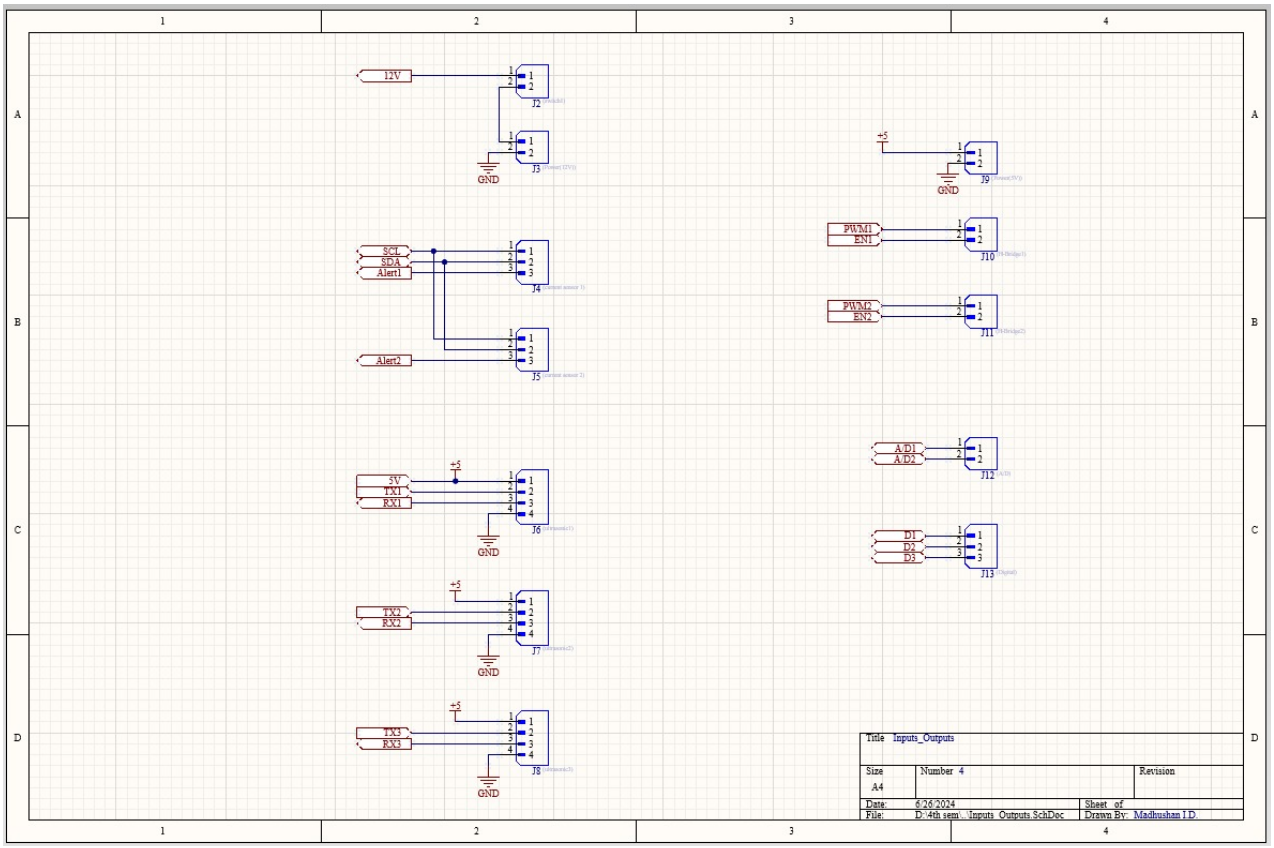


Figure 1.40: Inputs / Outputs

1.11 PCB Design

1.11.1 Main PCB

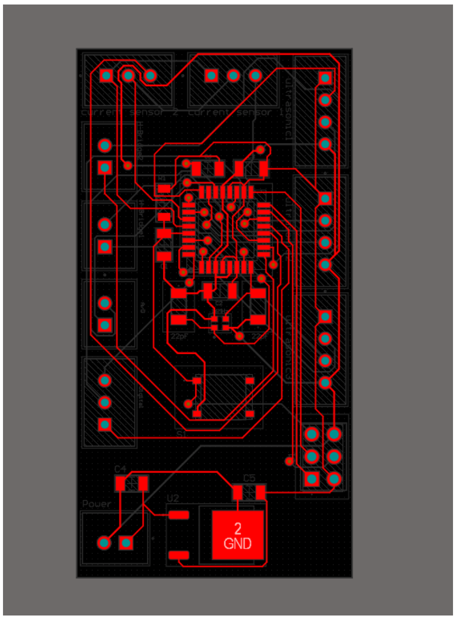


Figure 1.41: Main PCB Top layer

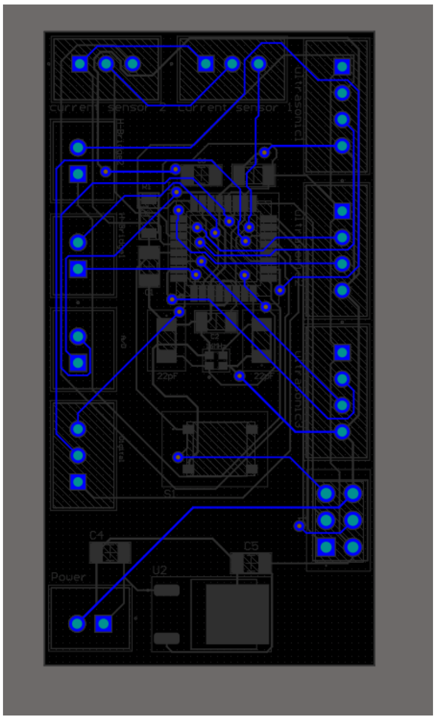


Figure 1.42: Main PCB Bottom layer

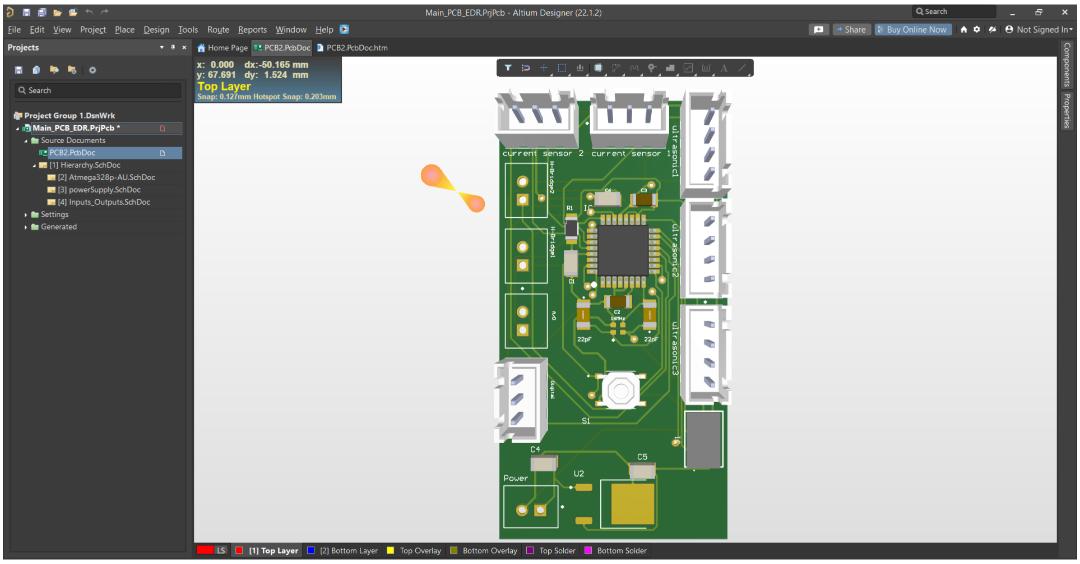


Figure 1.43: Main PCB 3D view

1.11.2 Motor controller PCB Design

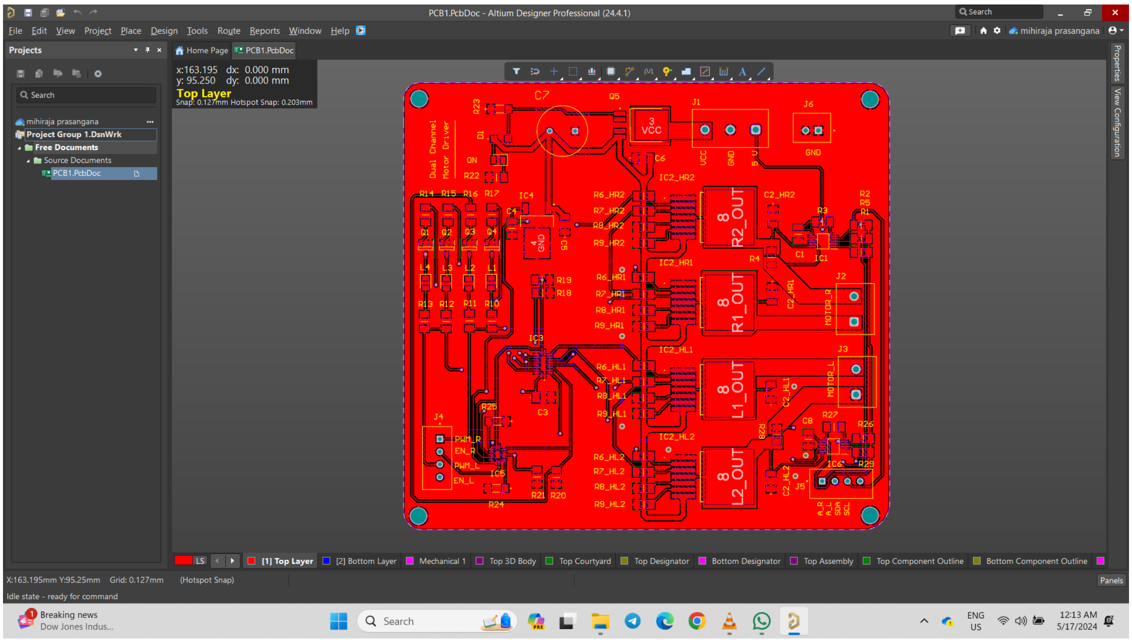


Figure 1.44: Motor control PCB Top layer

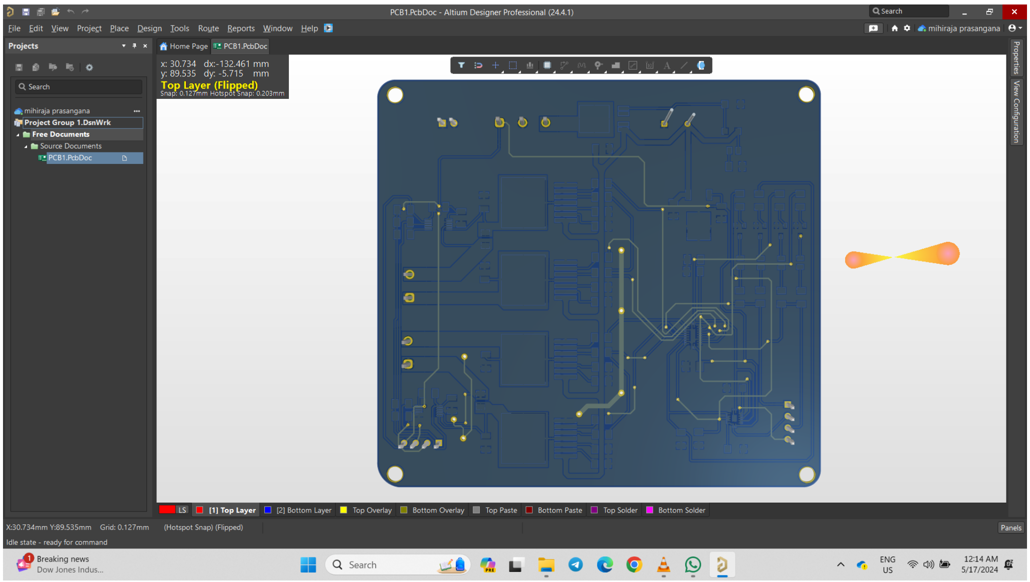


Figure 1.45: Motor control PCB Bottom layer

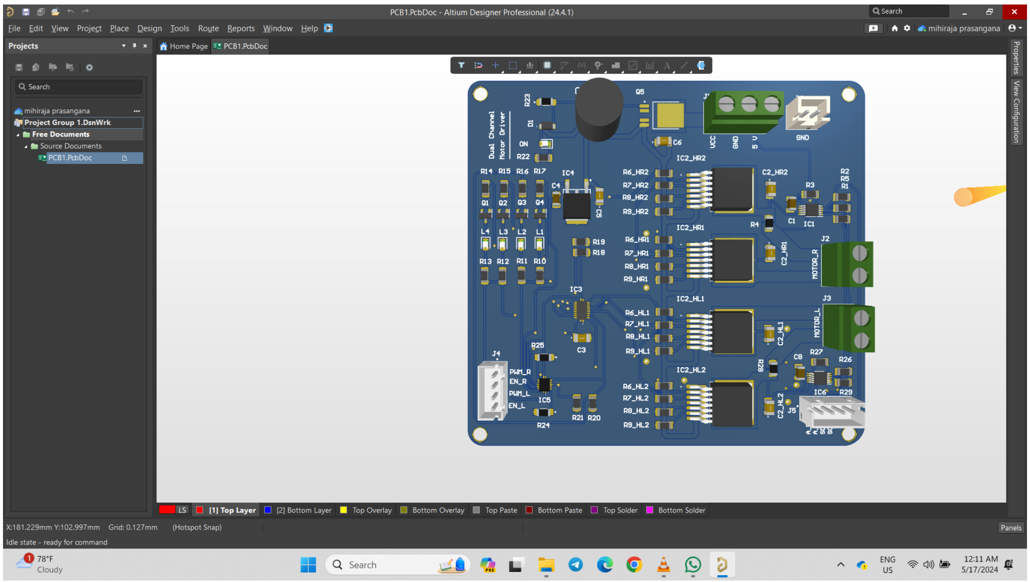


Figure 1.46: Motor control PCB 3D view

1.12 Solidworks Design

Our enclosure design comprises two main sections. the top and bottom parts. The top part is designed with three openings to accommodate ultrasonic sensors, to detect objects in the robot's environment. The bottom part consits of two PCBs which are main PCB, the motor driver PCB, and the battery.

There are two PCBs in our design. So placing those two PCBs appropriately within the enclosure is very important. Motor controller PCB is placed to minimize wire lengths, particularly critical for connections to the motors, where higher currents are drawn. This arrangement not only reduces potential electrical interference, but it also enhances the overall efficiency of the robot's motor control system. The orientation of the two PCBs is also crucial. Both the main PCB and motor controller PCB are oriented within the enclosure to minimize the length of connections and ensure integration with external inputs and outputs. Also, we have taken space considerations into account when orienting the PCBs. Also, we used mounting bosses to Mount the PCBs. It helps in dissipating heat generated during operation and helps maintain electrical isolation to prevent interference and ensure reliable performance in different operating conditions.

Wheel placement in the enclosure is also a main concern when designing the enclosure. We are using two main wheels and one caster wheel in our design. The stability of our design mainly relies on how we place those wheels in the enclosure. We have placed the main wheels at the rear end of the enclosure. And we have allocated space in the front of our design to place the caster wheel. We have placed caster wheels in such a way that the it level perfectly with two main wheels. For that, we made a special arrangement in our enclosure.

The stability of autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) is a major concern in our design. To Achieve optimal stability we placed the robot's center of gravity as low as possible to minimize its gravitational potential energy during movement. Since the battery of the robot contributes a significant portion of the robot's total weight, we have given special attention to how to place the battery to balance torque effectively with other components, to enhance the robot's overall stability. To achieve that we have placed the battery horizontally and near to the center of our design.

Achieving maximum compactness was a main concern while designing the enclosure. The orientation of the battery within the bottom section of the enclosure is carefully planned to optimize spatial efficiency. This not only conserves valuable space but also contributes to the overall compactness and the appearance of the robot. To secure the battery firmly in place and ensure it remains stable during operation, a frame has been incorporated into the enclosure's design. We also have placed the PCBs in such a way that it uses minimum space within our design. So we have designed the enclosure to place the two PCBs near each other to improve the compactness of the design. When placing the two PCBs near to each other we also have taken the other concerns when placing the two PCBs nearby.

These are some other design aspects we focused during the enclosure design:

- **Moldability**: The enclosure is crafted with manufacturing in mind, ensuring it can be efficiently produced using common molding techniques. This consideration helps in achieving a robust and uniform structure, which is critical for the reliability of the robot.
- **Draft Angles Consideration**: Special attention was given to draft angles in the design process. Proper draft angles were implemented to facilitate smooth ejection of the molded parts from the molds, optimizing manufacturing efficiency.
- **Industrial Standards Compliance**: The design adheres to relevant industrial standards, ensuring compatibility with various industrial environments. This compliance guarantees that

the enclosure can withstand rigorous operational conditions, including exposure to dust, moisture, and mechanical impacts.

- **Load Accommodation**: Sufficient internal space has been allocated within the enclosure to accommodate the necessary payload and internal components. This includes designated areas for batteries, sensors, and other electronic components, ensuring that the load is securely housed and easy to access for maintenance.
- **Accessibility and Maintenance**: The design includes strategically placed access points and removable panels to facilitate easy maintenance and upgrades. This ensures that technicians can quickly perform repairs and replacements, minimizing downtime.
- **Ventilation and Heat Dissipation**: Adequate ventilation is incorporated into the design to manage heat dissipation effectively, ensuring that the internal components operate within safe temperature ranges.
- **Aesthetic and Ergonomic Considerations**: The enclosure not only meets functional requirements but also features an ergonomic design that enhances the robot's aesthetic appeal and ease of handling.

1.12.1 Bottom Part

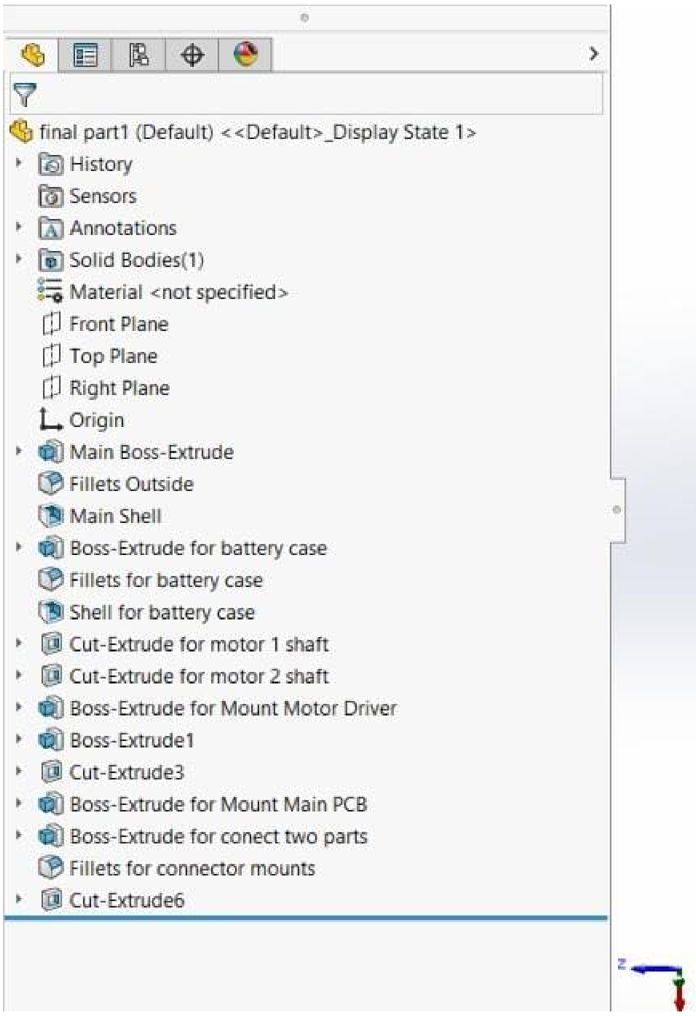
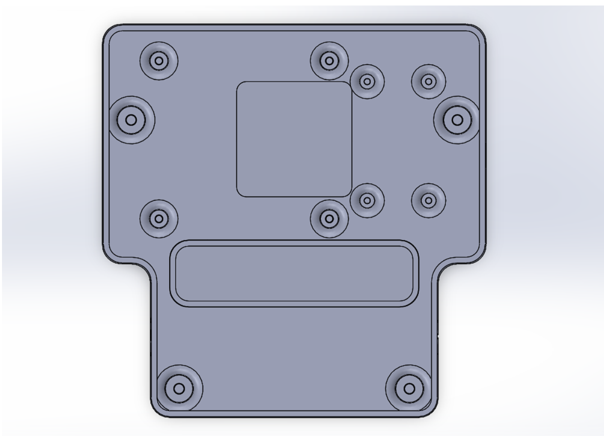
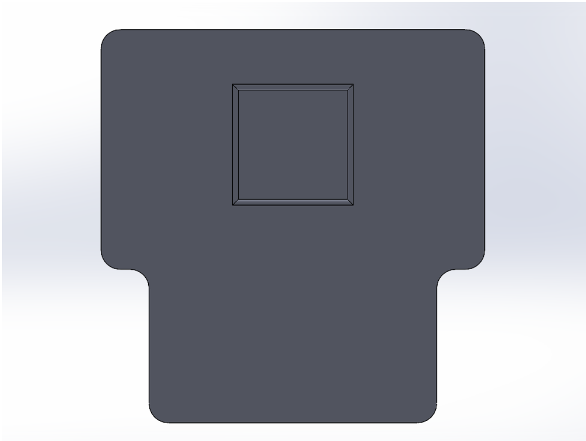
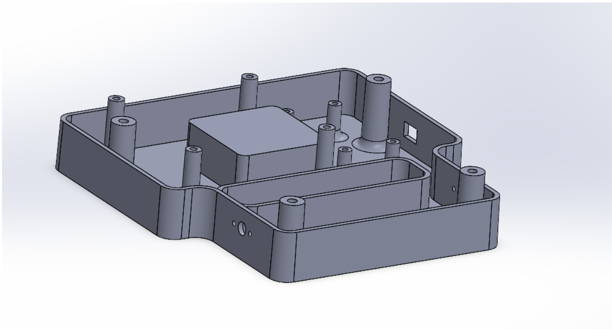
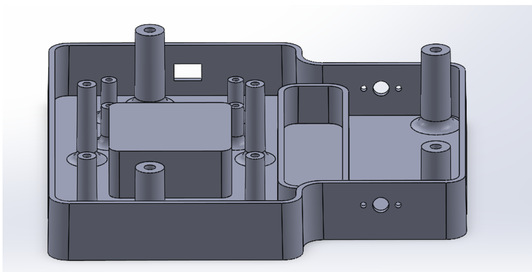


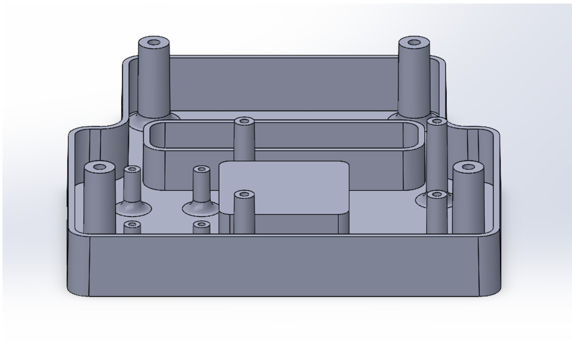
Figure 1.47: Bottom part desgin tree











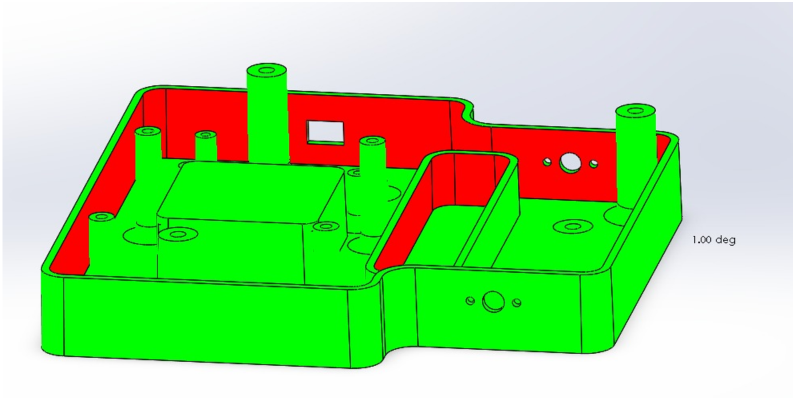


Figure 1.48: bottom part draft analsyis

1.12.2 Top Part

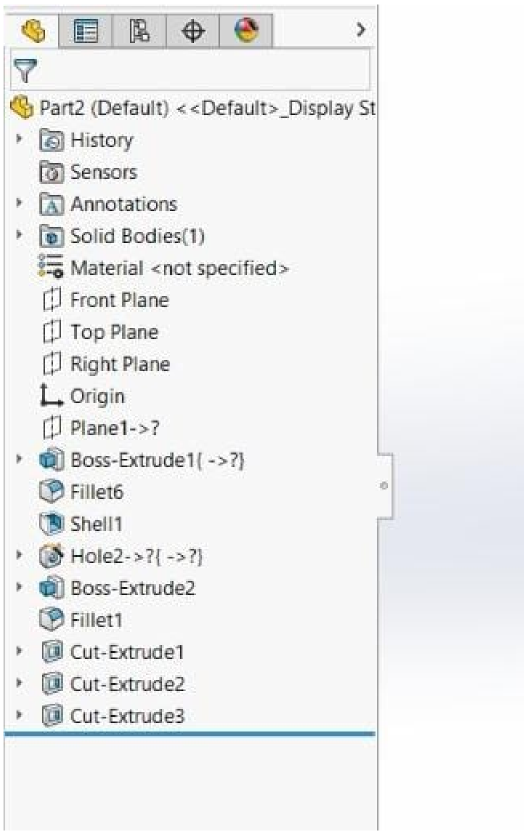
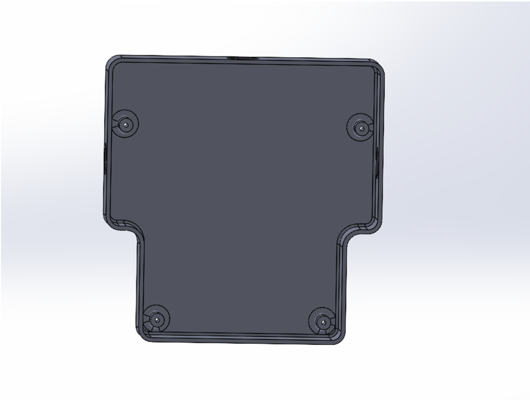
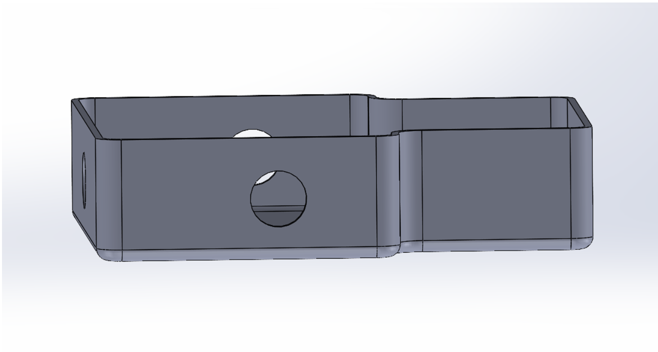
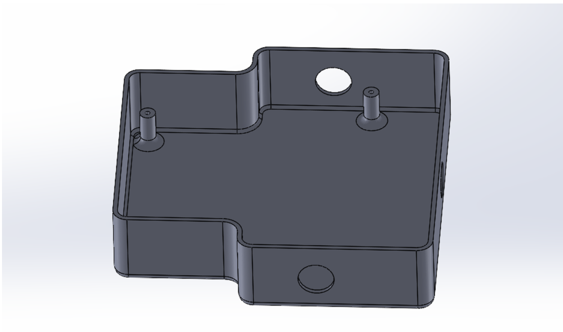
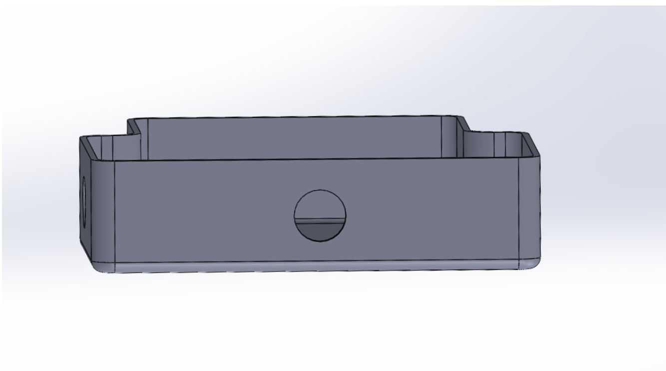


Figure 1.49: top part desgin tree









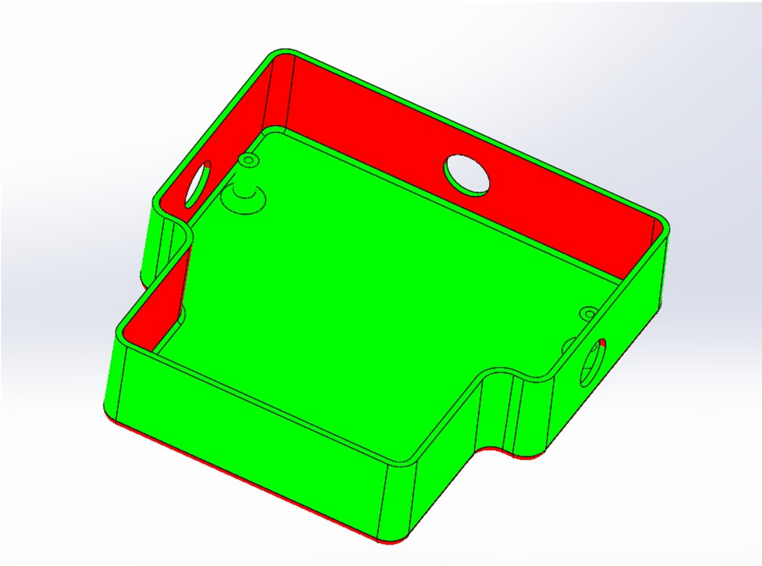
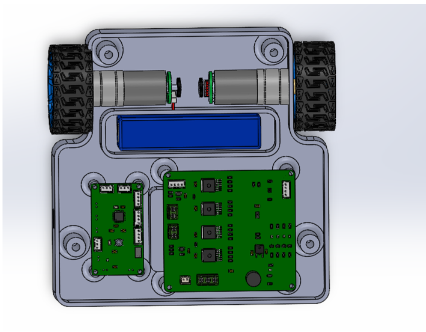
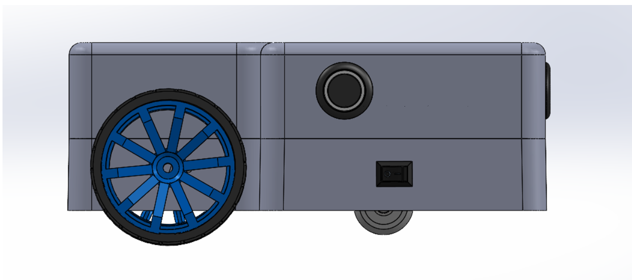
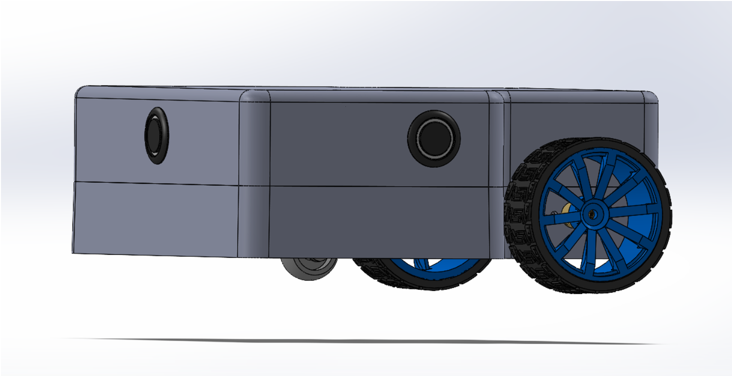


Figure 1.50: top part draft analysis

1.12.3 Assembled Enclosure







1.12.4 3D Printed Enclosure

Changes made to the Enclosure Design

Our new enclosure design is made to address the limitations of our previous design, particularly the previous design was not able to carry heavier weights because it is made from plastic. So by taking that into consideration we have designed a new enclosure from aluminum material to carry higher weights. Here are some of the enhancements and features of our new enclosure design:

1. Higher Structural Stability with Aluminum Extrusion Bars
The structure of the new enclosure is constructed using aluminum extrusion bars. Aluminum is chosen for its strength and lightweight. These extrusion bars form a rigid and stable framework, which significantly increases the enclosure's ability to support heavier loads compared to the previous design which was made from plastic.

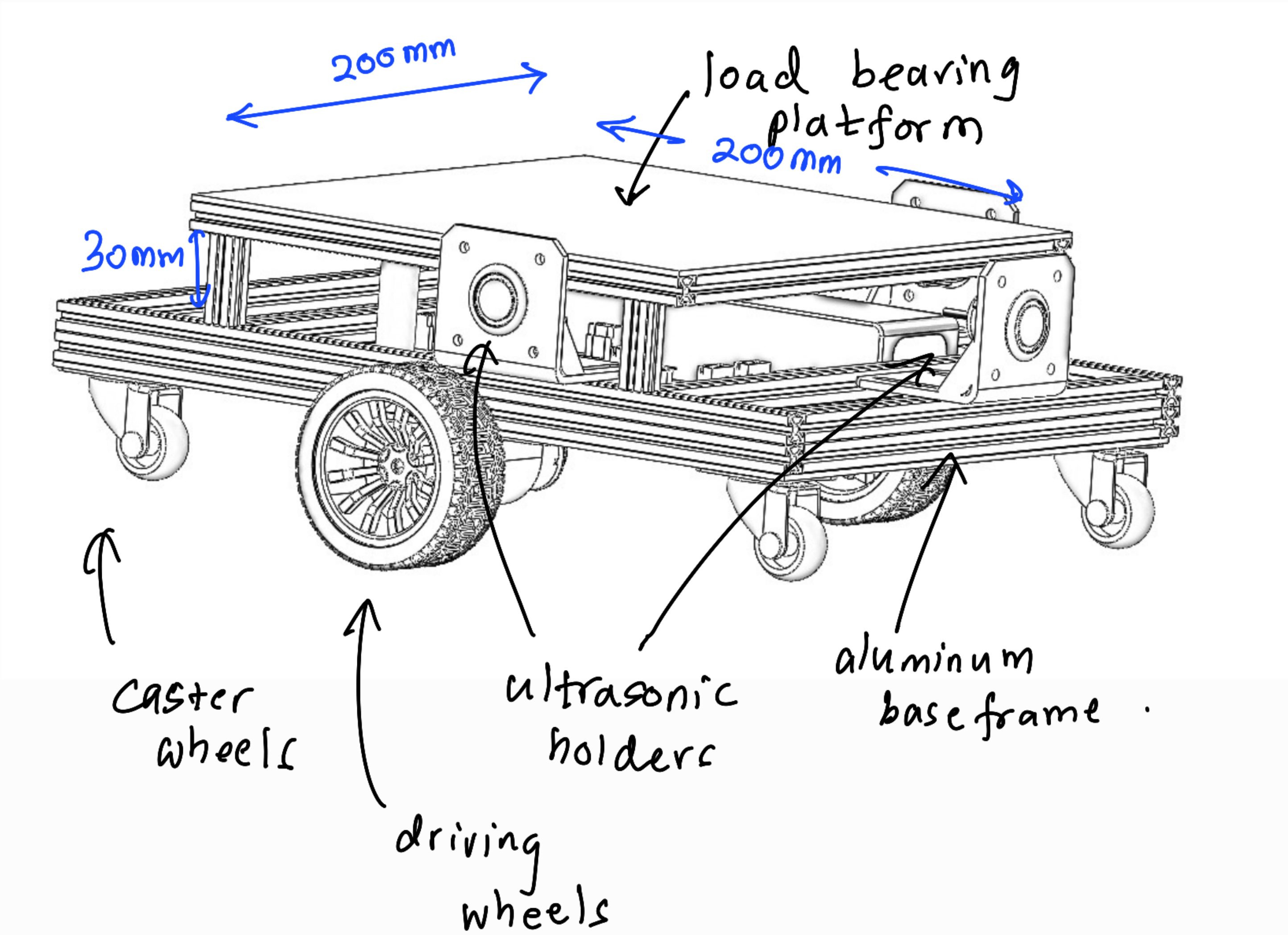
2. Aluminum Platform which is capable of carrying higher weight
The platform used to carry weights is made from a 3mm thick aluminum sheet. This thickness ensures that the platform is strong enough to support substantial loads without bending or warping. The platform's placement on top of the frame allows for an even distribution of weight, contributing to the overall stability of the enclosure.

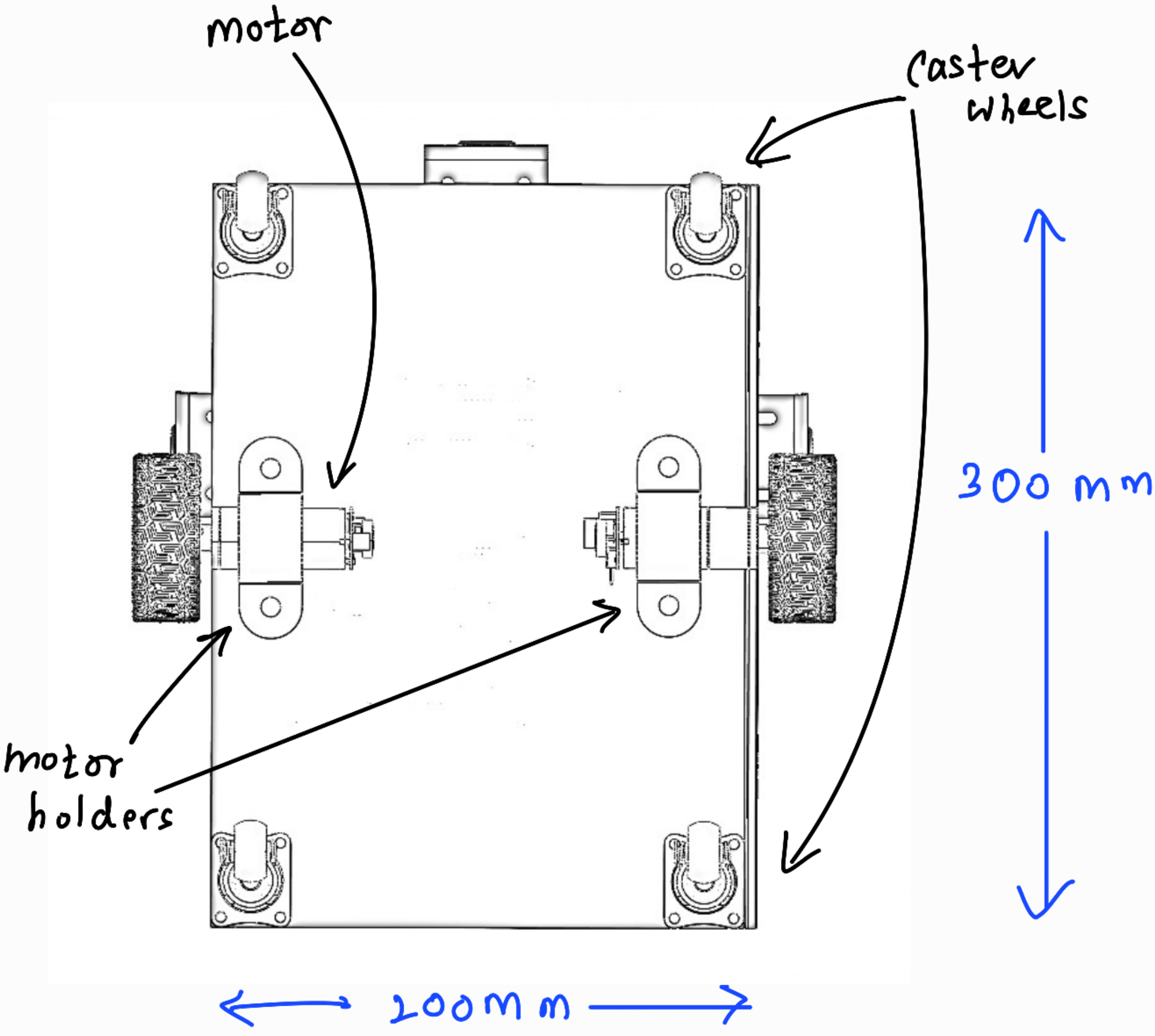
3. Aluminum Base platform to place Components
The base platform is constructed from 2mm thick aluminum sheets, it holds two PCBs (Main PCB and Motor Controller PCB) and the battery. Here we have chosen a 2mm thickness aluminum sheet to ensure the base platform avoid adding unnecessary weight. This base platform prevents the main components to make any movement or damage during operation.

4. Placement of Ultrasonic Sensors:
In our design, we have three ultrasonic sensors. We have placed the three ultrasonic sensors in such a way that it covers the maximum area as possible. So we have placed ultrasonic sensors in the front, left side, and right side of the enclosure. Here We have used Holed L bars to hold the ultrasonic sensors. These L bars are mounted on Aluminium extrusion bars. The placement and mounting of these sensors are done to ensure they function accurately and more reliably.

5. Improved Mobility and Stability with Wheel Configuration:
Our design has two driving wheels and four caster wheels to enhance both mobility and stability. In the prevous design we had the two driving wheels along with only one caster wheel. But in this design we have increased the number of caster wheels to 4 to increase the stability of the design. In this way our design is able to carry more weight than the previous design. Here the two main driving wheels are placed in the middle of the enclosure to proivde propulsion necessary to move the enclosure much more easier. These wheels are positioned centrally to provide better driving power and control. The four caster wheels, placed at the corners which improves maneuverability and stability of the design. These caster wheels enable the enclosure to turn smoothly and maintain balance, even on uneven surfaces.

6. Material Selection and Thickness Considerations:
The materials and their thicknesses are carefully selected to balance strength and weight. 3mm aluminum sheet for the load-bearing platform and 2mm sheets for the base frame which holds components are more than enough to carry the intended loads. By using aluminum extrusion bars and aluminum sheets, the new enclosure design provides a significant improvement in weight-bearing capacity and structural stability. The combination of a strong platform, and a strong base frame increases the overall stability of our design.


200 mm
load bearing platform
200mm
30mm
caster wheels
driving wheels
ultrasonic holders
aluminum base frame


motor
caster wheels
300 mm
motor holders
200mm

Screeshots of the New Assembled Solidworks Design

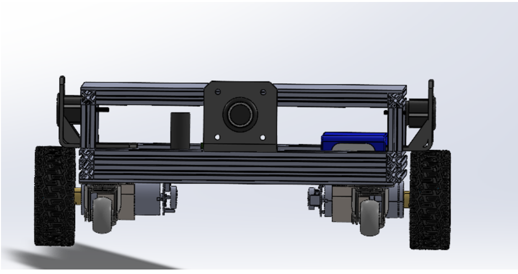


Figure 1.51: Enclosure Front View

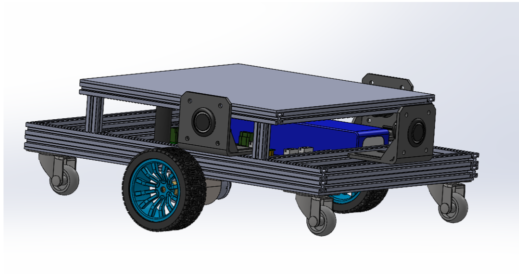


Figure 1.52: Enclosure Side View 1

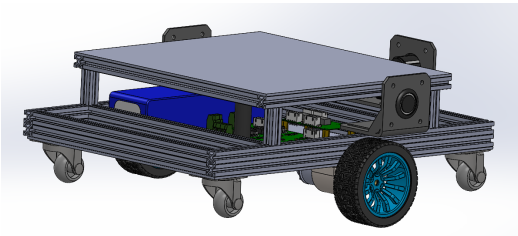


Figure 1.53: Enclosure Side View 2

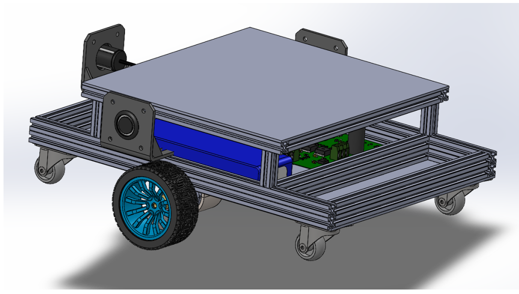


Figure 1.54: Enclosure Side View 3

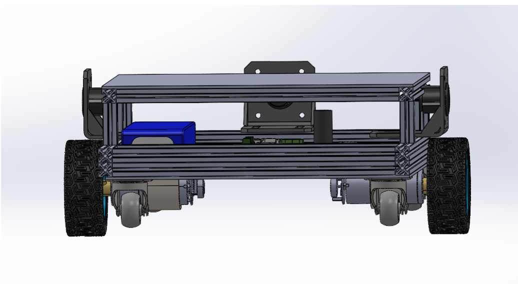


Figure 1.55: Rear View

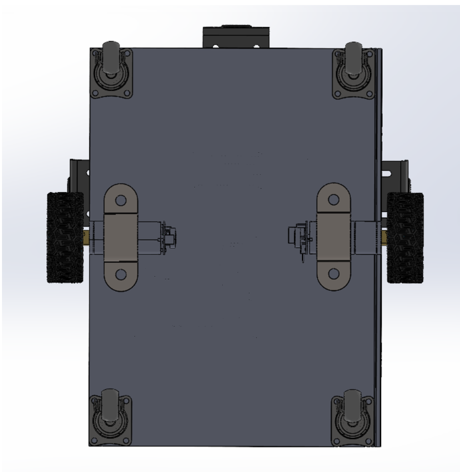


Figure 1.56: Bottom View

1.13 Component Selection and Schematic Diagram

1.13.1 Motor Controller Part

BTS7960B P-TO-263-7 IC

THE BTS 7960B is a fully integrated high current half bridge for motor drive applications. It is part of the NovalithICTM family containing one p-channel highside MOSFET and one n-channel lowside MOSFET with an integrated driver IC in one package

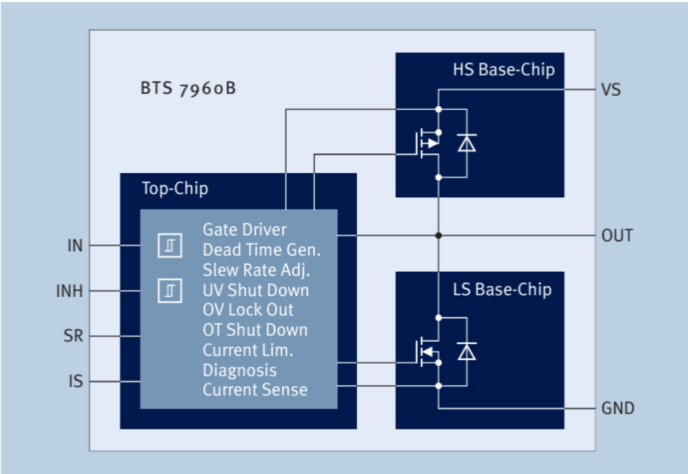


Figure 1.57: BTS7960B Block Diagram

Features

- High peak current capability of minimum 33 A
- Path resistance of typical 16 mOhm at 25°C
- Low quiescent current of typical 7 µA at 25°C
- PWM capability of up to 25 kHz with active freewheeling
- Switched mode current limitation for reduced power dissipation in overcurrent
- Status flag diagnosis with current sense capability
- Overtemperature shutdown with latch behavior
- Overvoltage and undervoltage shutdown
- Driver circuit with logic level inputs
- Adjustable slew rates for optimized EMI

`https://drive.google.com/file/d/1dMO3JEmmCqmN1aDXzng5d-XnPcxtUffN/view?usp=drive_link`

When right PWM set to low INH pin of the BTS7960B ICs connected to right side of the motor goes in sleep mode. When the right PWM (R PWM) signal is set to high the INH pin of the BTS7960B ICs connected to the right side motor becomes high. Setting the INH pin to high enables the device. In this condition one of the two power switches is switched on depending on the status of the IN pin. To deactivate both switches, the INH pin has to be set to low. Same principal is applied to the left ICs.

We have chosen R_{SR} to be 5.1 kΩ. According to the data sheet it will give the following values,

- Rise-time of HS - 2 μs
- Slew rate HS on - 6 V/μs
- Switch on delay time HS - 4.4 μs
- Fall-time of HS - 2 μs
- Slew rate HS off - 6 V/μs
- Switch off delay time HS - 3.4 μs
- Rise-time of LS - 2 μs
- Slew rate LS on - 6 V/μs
- Switch on delay time LS - 2.2 μs
- Fall-time of LS - 2 μs
- Slew rate LS off - 6 V/μs
- Switch off delay time LS - 5.6 μs

The BTS 7960 has no separate pin for power ground and logic ground. Therefore it is recommended to assure that the offset between the ground connection of the slew rate resistor, the current sense resistor and ground pin of the device (GND / pin 1) is minimized.

A ceramic capacitor from VS to GND close to each device is recommended to provide current for the switching phase via a low inductance path and therefore reducing noise and ground bounce. A reasonable value for this capacitor would be about 470 nF.

Adding a capacitor between the output of the BTS7960 and ground before connecting it to the DC motor primarily serves the purposes such as noise filtering, voltage stability, and protection.
In the context of a DC motor control circuit, AC signals are typically not a concern since DC motors operate on direct current. The BTS7960 is designed to handle DC signals for controlling the motor direction and speed. However, if there are any residual AC components or electrical noise present in the circuit due to factors like electromagnetic interference (EMI) or switching transients, the capacitor can help to filter out some of these unwanted AC signals, contributing to overall circuit stability and performance. So while the capacitor can indirectly assist in grounding AC signals by providing a low-impedance path to ground for noise and interference, its primary function is related to DC motor control and circuit stability.

The digital inputs need to be protected from excess currents (e.g. caused by induced voltage spikes) by series resistors in the range of 10 kΩ.

74HC244BQ-Q100,115

Line Driver provide isolation between input and output circuits, preventing loading effects. This is particularly useful when connecting multiple devices to a single input source without affecting signal integrity.

- Reference of Data sheet : `https://drive.google.com/file/d/1RP3Lotkrh9-QXtmySPuVobINfrRY_k0O/view?usp=drive_link`

Figure 1.58: Line Driver 74HC244BQ-Q100,115

L78M05ACDT-TR

The L78M05ACDT-TR is a voltage regulator IC manufactured by STMicroelectronics.The L78M05ACDT-TR is a linear voltage regulator that provides a fixed output voltage of +5 volts (5V). It belongs to the L78xx series of voltage regulators, where "xx" represents the output voltage. In this case, "M05" indicates a +5V output.

It is recommended that the regulator input be bypassed with a capacitor if the regulator is connected to the power supply filter with long wire lengths, or if the output load capacitance is large. An input bypass capacitor should be selected to provide good high-frequency characteristics to insure stable operation under all load conditions. A 0.33 F or larger tantalum, mylar, or other capacitor having low internal impedance at high frequencies should be chosen. The bypass capacitor should be mounted with the shortest possible leads directly across the regulators input terminals. Normally good construction techniques should be used to minimize ground loops and lead resistance drops since the regulator has no external sense lead.

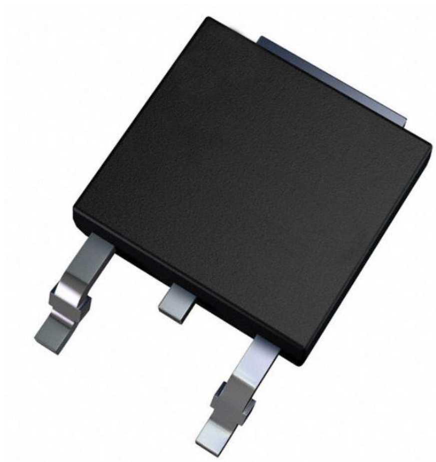


Figure 1.59: Voltage Regulator L78M05ACDT-TR

- Reference of Data sheet : `https://drive.google.com/file/d/1m67dCa51ut69hYTwb8qPmmC_Bun6vvzD/view?usp=drive_link`

Current Measurement Using INA226AIDGSR

To accurately measure the current through the motors, we have employed the **INA226AIDGSR**, a high-precision current shunt and power monitor. This device operates from a single 2.7V to 5.5V supply and draws a typical supply current of 330 μA. The INA226 provides digital readings of current, voltage, and power, which are crucial for precise decision-making in controlled systems.

Key Features of INA226AIDGSR:

- **Wide Supply Voltage Range:** Operates from 2.7V to 5.5V, making it compatible with a variety of systems.
- **Low Power Consumption:** With a typical supply current of only 330 μA, it is highly efficient.
- **Digital Output:** Provides digital readings via I^2C or SMBus-compatible interface, enabling easy integration with microcontrollers and other digital systems.

Application in Motor Current Measurement: In our setup, a precision shunt resistor of 15 milliohms (mΩ) is connected across the terminals of the motor. The INA226AIDGSR measures the voltage drop across this shunt resistor. Using Ohm's Law (V = IR), the current through the motor can be accurately calculated. The digital output from the INA226 allows for real-time monitoring and control of the motor current, enhancing the performance and safety of the system.

Advantages:

- **High Precision:** The INA226 offers high-accuracy current measurements, essential for fine-tuned motor control.
- **Real-time Monitoring:** Digital readings of current, voltage, and power facilitate real-time system monitoring and adjustments.
- **Versatility:** Suitable for a wide range of applications due to its broad supply voltage range and low power consumption.

By integrating the INA226AIDGSR into our motor control system, we ensure precise and reliable current measurement, which is critical for maintaining optimal performance and protecting the motors from overcurrent conditions. This integration exemplifies the importance of accurate current sensing in modern electronically controlled systems.

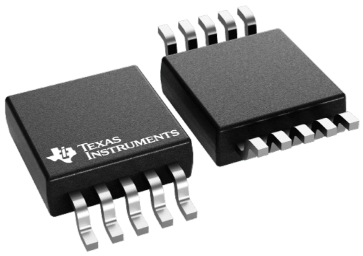


Figure 1.60: INA226AIDGSR

- Reference of Data sheet : `https://drive.google.com/file/d/1nxFOuBpqzkl-vuOSdjNEv78ri7r-sjzS/view?usp=sharing`

1.13.2 Main Controller Part

ATmega328P-AU as the Main Controller

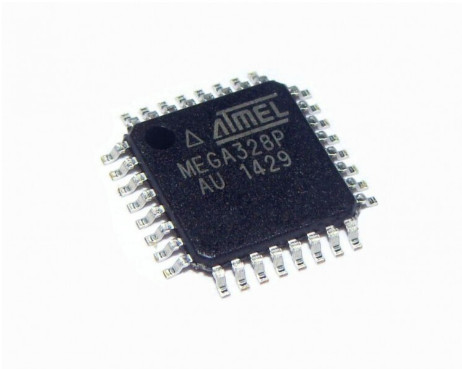


Figure 1.61: Atmega 328P-AU

The ATmega328P-AU is an excellent choice for the main controller in our project, offering a balance of performance, low power consumption, and ease of use. Here are the key reasons why the ATmega328P-AU is an ideal selection:

1. **Performance and Efficiency**:
    - The ATmega328P operates at up to 20 MHz, providing sufficient processing power for a wide range of applications while maintaining low power consumption. This makes it suitable for battery-powered devices where energy efficiency is critical.
2. **Rich Set of Features**:
    - The microcontroller features 32 KB of Flash memory for program storage, 2 KB of SRAM, and 1 KB of EEPROM for data retention. This ample memory space ensures that complex programs and data can be handled efficiently.
    - It includes a versatile set of peripherals such as timers, counters, PWM outputs, ADC (Analog-to-Digital Converter), and communication interfaces (UART, I2C, SPI), allowing it to interface with various sensors, actuators, and communication modules.
3. **Wide Community Support and Documentation**:
    - The ATmega328P is widely used in the hobbyist and professional electronics communities, most notably as the microcontroller in the popular Arduino Uno. This widespread use translates into a wealth of community support, tutorials, and extensive documentation, making development and troubleshooting more straightforward.
4. **Ease of Programming and Development**:
    - The microcontroller is compatible with the Arduino IDE, which simplifies programming and prototyping. This compatibility allows for rapid development and iteration, reducing the time from concept to functional prototype.
5. **Robustness and Reliability**:
    - The ATmega328P is designed for robustness with features like brown-out detection, watchdog timers, and multiple sleep modes, ensuring reliable operation in various conditions. Its reliability is proven in numerous applications, from consumer electronics to industrial systems.

6. **Cost-Effectiveness**:

    - The ATmega328P offers a competitive price point, providing excellent value for its feature set. This makes it a cost-effective solution for projects with budget constraints without sacrificing performance or functionality.

- Reference of Data sheet : `https://drive.google.com/file/d/1J_3y-_kFbGCJjyrPH6wMYKS2Xd-ZQdWR/view?usp=drive_open`

L78M05ACDT-TR as the Linear Voltage Regulator

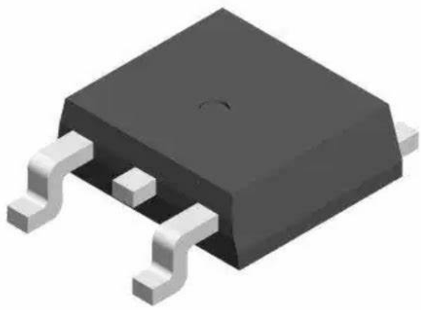


Figure 1.62: L78M05ACDT-TR

The L78M05ACDT-TR is chosen as the linear voltage regulator for our project due to several key advantages:

1. **Regulation and Stability**:

    - The L78M05ACDT-TR provides a stable 5V output voltage, essential for powering sensitive electronic components and ensuring consistent performance across varying loads and input voltages.

2. **Low Dropout Voltage**:

    - With a low dropout voltage characteristic, the regulator can maintain a steady output voltage even when the input voltage approaches the output voltage, maximizing efficiency and minimizing power dissipation.

3. **Wide Input Voltage Range**:

    - It operates over a wide input voltage range, typically from 7V to 35V, making it versatile for various power supply configurations and applications.

4. **Current Capability**:

    - The L78M05ACDT-TR can supply a continuous output current of up to 500mA, sufficient for powering microcontrollers, sensors, and other peripherals commonly used in our project.

5. **Thermal Overload Protection**:

    - It incorporates thermal shutdown and current limiting features to protect itself from overheating and current spikes, enhancing reliability and longevity.

6. **Compact and Cost-Effective**:
   - The regulator is available in a compact TO-252-3 package, facilitating easy integration into our PCB layout while keeping manufacturing costs low.

- Reference of Data sheet : https://drive.google.com/file/d/1m67dCa51ut69hYTwb8qPmmC_Bun6vvzD/view?usp=drive_link

Conclusion

This project Obstacle Avoidance System for Warehouse Automation (AMR, AGV) is done based on industrial standards. This system aims to enhance safety and efficiency within warehouse environments by navigating autonomously while avoiding obstacles. When considering the review progress of our project, We have conducted thorough research and found suitable solutions to use as our microcontroller, and object avoidance sensor according to industrial standards. We have also calculated the torque and the current required for our motor. Based in that we have decided on a suitable motor for our obstacle avoidance system. We also have done research on what motor controller we are going to use, and based on that we are going to design the motor driver. As next steps of our project include selecting the suitable obstacle avoidance sensor, implementing a suitable motor driver, and Implementing the main PCB and enclosure design and material selection. Furthermore, our stakeholder analysis underscores the importance of engaging and managing various stakeholders, including supervisors, team members, investors, and potential end-users such as warehouse operators and logistics companies. In the observe users part of our project we have conducted research in industrial obstacle avoidance systems. We have found out there are many users of obstacle avoidance systems in the industry. Many warehouse robots use these obstacle avoidance systems to navigate safely navigate through the warehouse environment. By addressing their needs and concerns, our project holds the potential to significantly improve efficiency, accuracy, and cost-effectiveness across diverse industries, marking it as a promising and impactful initiative in the field of warehouse automation.

Acknowledgement

We would like to extend our heartfelt gratitude to Prof. J.A.K.S. Jayasinghe and Dr. S. Thayaparan for their invaluable guidance, expertise, and unwavering support throughout this project. Their insightful feedback and encouragement have been instrumental in shaping the direction and outcomes of our project.

Special thanks are also due to all the members of our group who contributed tirelessly to various aspects of this project. Their dedication, collaboration, and diverse skills have significantly enriched our work.

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Individual Contribution to the Obstacle Avoidance System for Warehouse AMR and AGV Project

Index : 210212N
Name : B.H.M.K.S.B.Herath

Throughout the development of the Obstacle Avoidance System for Warehouse AMR (Autonomous Mobile Robot) and AGV (Automated Guided Vehicle), I played a significant role in several key aspects of the project. My contributions spanned research, design, implementation, documentation, and project management.

- Research Phase
  At the outset of the project, I dedicated more than two weeks to researching various methods for obstacle detection. This involved an extensive review of existing technologies, including their pros and cons. I collaborated closely with my team members during this phase to identify the optimal solution for our specific application. After thorough analysis and discussions, we collectively decided to use ultrasonic sensors for obstacle detection. This choice was based on factors such as accuracy, cost-effectiveness, and ease of integration.

- Sensor Selection
  Once we settled on ultrasonic sensors, I took the lead in researching various models available in the market. I meticulously reviewed datasheets and technical specifications to ensure we selected the most suitable sensors for our project. This involved evaluating parameters such as range, sensitivity, response time, and reliability under different operating conditions. My careful selection process ensured that the sensors met all our requirements and could be seamlessly integrated into our system.

- PCB Design and Component Selection
  In collaboration with Dinuka, I designed the schematic for the main PCB. This task required a deep understanding of the circuit requirements and the ability to translate those into a functional design. I also conducted an extensive search for suitable components, ensuring they were both high-quality and compatible with our design. Our efforts culminated in the creation of a robust and reliable PCB design, which was then sent to JLCPCB for manufacturing.

- Soldering and Assembly
  Receiving the PCBs marked the beginning of the assembly phase. It was my first experience with SMD soldering, and I quickly adapted to the precision and technique required for this task. Despite the initial learning curve, I successfully soldered the components onto the PCB, gaining valuable hands-on experience in the process.

- Coding
  I undertook the AVR coding for our project with the guidance of my team. As my first experience with AVR, it was initially challenging, but with the support of my colleagues, I successfully managed to overcome obstacles and deliver effective solutions.

- Documentation and Project Management
  Beyond technical tasks, I was responsible for preparing the project proposal, Progress Review Report and design documentation. These documents were crucial for outlining our objectives, methodologies, and expected outcomes. Additionally, I maintained a daily work log, which I updated weekly.

Individual Contribution to the Obstacle Avoidance System for Warehouse AMR and AGV Project

Index : 210349N
Name : Madhushan I.D.

As a dedicated team member in our project to design an Autonomous Mobile Robot (AMR) for industrial applications, I made significant contributions in various aspects of the development process. My efforts were crucial in designing of our AMR. Below are the key contributions I made to the project:

- PCB Design:
  I designed the fully functional main Printed Circuit Board (PCB) for the AMR. This involved creating a detailed layout that integrated all necessary components, ensuring optimal performance and reliability.

- Schematic Drawing:
  I collaborated with my team to draw the schematics for both the motor driver and main PCBs. This required precise attention to detail and a thorough understanding of circuit design principles, resulting in accurate and efficient schematics.

- Soldering:
  I was actively involved in soldering the components onto the PCBs. This hands-on work was essential to ensure that all connections were secure and that the PCBs functioned as intended.

- Connectivity Testing:
  I conducted thorough testing of the connectivity on the PCBs. This involved identifying and resolving any issues occurred during soldering process, ensuring the reliability and functionality of the final product.

- Research on Sensors:
  I conducted detailed research on various sensors that could be integrated into our AMR. This included evaluating sensor specifications, performance, and compatibility with our design requirements.

- Design Suggestions:
  I proposed different types of designs for our product. This involved evaluating various design options and suggesting innovative ideas to improve the overall functionality and efficiency of the AMR.

Through these contributions, I played a key role in the development of our Autonomous Mobile Robot, ensuring its functionality, reliability, and efficiency for industrial applications.

Individual Contribution to the Obstacle Avoidance System for Warehouse AMR and AGV Project

Index : 210325M
Name : Kuruppu M.P.

- Market Research
  I conducted extensive market research to identify the project requirements and suitable technologies for implementation in Sri Lanka. I reviewed numerous websites, research papers, and case studies to gather comprehensive insights into the current landscape of AGVs and AMRs in Sri Lanka and globally.

- Conceptual Design and Enclosure Design
  I was actively involved in the creation of conceptual designs for our project. Through collaborative discussions with team members, we developed three robust conceptual models. My role included brainstorming design ideas, sketching initial concepts, and contributing to the refinement of these designs to ensure they met our project goals and specifications.I actively participated in discussions and contributed ideas for the enclosure design based on our conceptual designs and requirements.

- Motor Driver Circuit Design
  Working alongside Chandeepa, I played a critical role in designing the motor driver circuit. This was a complex task that required us to delve into various research papers and technical resources to understand the nuances of motor control. We consulted with lecturers to ensure our design was both innovative and functional. The process involved multiple iterations of testing and debugging to refine the circuit design. Our persistence paid off, and we successfully designed a reliable motor driver circuit.

- PCB Design
  Designing the PCB for the motor driver was a crucial part of our project. I was in charge of designing the motor driver PCB with Altium Designer Software, ensuring that all components were correctly placed and that the design adhered to our specifications. This involved creating detailed schematics, routing the PCB layout, and performing connectivity tests to ensure all connections were accurate and functional. The PCB design process was iterative, with several rounds of testing and adjustments to achieve a reliable and efficient design.

- Soldering
  The soldering of the main PCB and the motor controller PCB was a collaborative effort. I, along with the other three team members, learned and applied surface mount soldering techniques.

- Coding
  The coding phase of our project is ongoing, and I am actively involved in programming the motor driver components. This involves writing and testing code to ensure seamless operation of the motors, implementing control algorithms, and integrating sensor feedback for navigation and obstacle avoidance.

- Documentation
  I took a leading role in the documentation process. This involved drafting the project report and design documentation, ensuring all aspects of the project were thoroughly and clearly documented.

Individual Contribution to the Obstacle Avoidance System for Warehouse AMR and AGV Project

Index : 210454G
Name : Peiris D.L.C.J.

- Market research about the project
  Along with other members I involved researching about existing similar products in the market and how they have implemented such designs. We had to go through many websites and sources to acquire the necessary knowledge about the project.

- Conceptual design
  Along with other members of the group I also involved designing the conceptual designs for our design. Through effective discussions we were able to build three conceptual designs for our project.

- Schematic Design for Motor Controller PCB
  Mihiraja and myself designed the motor controller circuit. Since this is a new design, finding proper resources was challenging. We had to go through many research papers and articles about motor controllers and also consulted with lecturers to acquire the necessary knowledge for the circuit design. After extensive reading and research, we successfully designed the motor controller circuit. Before implementing the design directly into the PCB, we conducted multiple rounds of testing and debugging. Due to the unavailability of proper components in the market, we had to find suitable alternatives. After several attempts, we were able to make the design work successfully.

- Enclosure design and SolidWorks
  Based on discussions about the enclosure design requirements with the group members and the conceptual designs we developed I took the responsibility to design the enclosure for our obstacle avoidance robot. To ensure the design was suitable for an industrial obstacle avoidance system, I researched on various industrial websites to make the design more industry suitable way. After thorough research, I had to make some improvements to the conceptual designs that we made. Then we had a group discussion to gather suggestions for improvements of this new design. Incorporating feedback from the team, we finalized the enclosure design. Then I used SolidWorks software to model the enclosure. This is designed in two parts: the top part and the bottom part. I applied the design techniques taught by our sir in class and made additional adjustments to enhance the modularity of the design. Finally, the design was deigned successfully and sent for 3D print.

- Soldering
  Along with other members of the group I also involved in soldering the main PCB and Motor controller PCB. Since we are using surface mount components in the PCB, we had to learn how to solder those components. We used online learning materials and YouTube tutorials on how to solder these SMD components.

- Documentation
  I also involved in documentation of the Project Report and the design documentation along with other members of our team.

This documentation has been reviewed by Group H - Multi Turn Absolute Magnetic Encoder

Name	Signature
1. Epa Y. L. A.	
2. Epa Y. R. A.	