0.1 ELECTRICAL DESIGN

0.1.1 Electrical system design

At the core of an AGV's electrical system are power management, motor control, and communication networks, all of which must be carefully designed to meet performance and safety requirements. The power system typically consists of a rechargeable battery, often lithium-ion or lead-acid, along with a Battery Management System (BMS) to monitor voltage, current, and temperature for optimal energy efficiency and longevity. Motor controllers regulate the movement of the drive and steering motors, ensuring smooth acceleration, precise navigation, and effective braking. Additionally, AGVs rely on a network of embedded controllers, sensors, and communication modules to process data in real time, enabling obstacle detection, localization, and coordination a central control system.

0.1.2 Power supply and distribution system

At the heart of the AGV's electrical design lies the power supply and distribution system, which serves as the backbone for all onboard functionalities. This system is responsible for storing, managing, and delivering electrical energy to various components, including motors, sensors, control systems, and communication modules. Given that AGVs must operate continuously for extended periods, the selection of battery technology, capacity, and management strategies plays a critical role in determining performance, efficiency, and reliability. The AGV must be able to complete all assigned tasks without running out of power, making energy efficiency and power optimization essential in the design.

To ensure safe and efficient energy usage, the AGV's battery system must integrate a Battery Management System (BMS). This system continuously monitors key parameters such as voltage, current, temperature, and state of charge, ensuring that the battery operates within safe limits while optimizing power delivery.

Equally important is the power distribution architecture, which ensures reliable and efficient energy delivery to all AGV subsystems. This involves designing robust wiring harnesses, fuses, circuit breakers, and connectors capable of handling dynamic load requirements during various operational phases.

The following section explores the key components of the AGV's power supply and distribution system, their functions, and how they contribute to the overall efficiency and reliability of the vehicle.

0.1.2.0.1 Power distribution architecture (System architecture)

A well-structured power distribution network minimizes voltage drops and energy losses, directly contributing to longer operating times and reduced downtime for recharging. Furthermore, if the expected task duration exceeds the battery capacity, solutions such as hot-swappable batteries or rapid charging stations should be considered to maintain uninterrupted operations.

Figure 1 illustrates an efficient power distribution system [**?**]for an AGV. The architecture includes key components such as the battery, power management system, motor controllers, sensors, microcontroller, and embedded computer. The power supply must ensure reliable and continuous energy delivery while optimizing efficiency and minimizing losses. The power requirements of an AGV are primarily determined by the embedded-PC, microcontroller, sensors, and motors. The microcontroller is responsible for low-level control, including direct motor actuation and sensor data acquisition. Additionally, it provides a programming interface for the embedded-PC, which has higher computational capabilities and is used for high-level tasks, such as motion planning and coordination.

Since the battery supplies direct current (DC), different power conversion techniques are required to meet the voltage demands of various components. The high-voltage DC motors require DC-DC boosters to step up the supplied voltage to the necessary operating level. Meanwhile, low-voltage components such as sensors, the microcontroller, and embedded-PC rely on DC voltage regulators to ensure stable power delivery. This architecture enables precise control over motor speed through pulse width modulation (PWM), allowing for efficient and adaptive movement of the AGV.

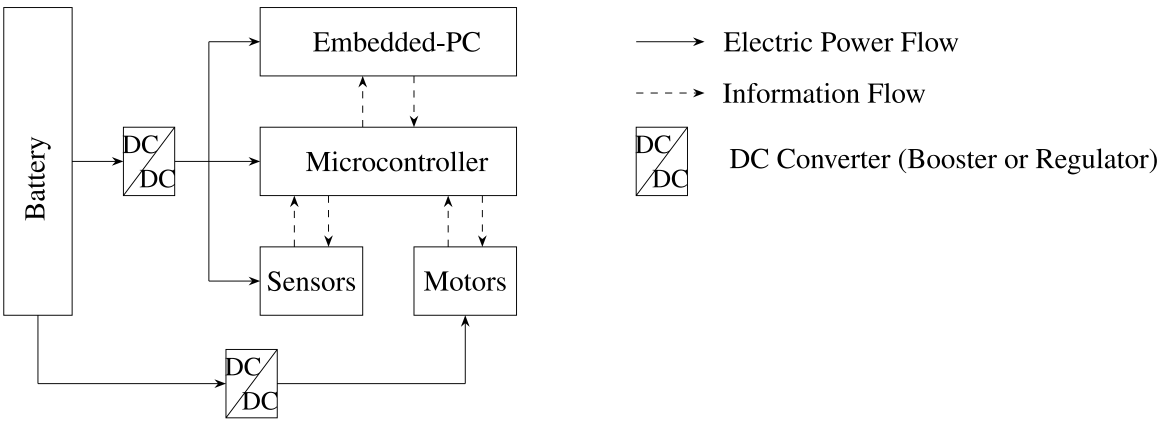

Figure 1: Typical architecture of an automated guided vehicle in terms of the electrical power distribution.

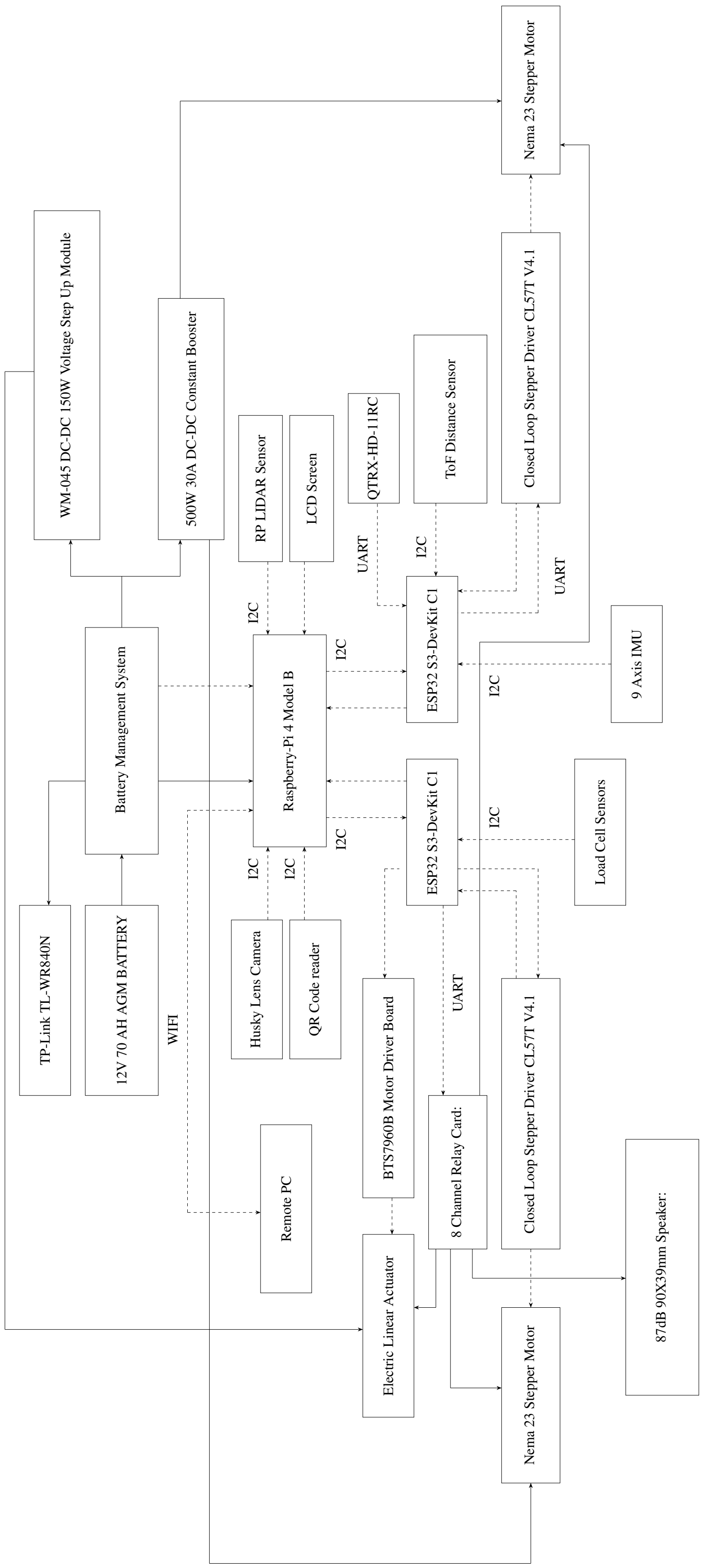

Figure 2: Actual system architecture

The CIU_Fox robot features a sophisticated electrical and control system integrating multiple embedded components, sensors, and power management units to ensure efficient operation. At the core of its control system are two ESP32 S3-DevKit C1 microcontrollers, responsible for handling various sensor inputs and executing real-time processing. These microcontrollers communicate with a Raspberry Pi 4 Model B, which serves as the main computational unit, facilitating high-level processing and decision-making. The Raspberry Pi is interconnected with several peripherals through I2C and UART communication protocols, ensuring seamless data transmission between components such as the Husky Lens camera, QR code reader, and RP LIDAR sensor, which contribute to the robot's vision and navigation capabilities. Additionally, an LCD screen displays real-time feedback (Sensors output,error message,...), while a 9-axis IMU enhances motion sensing for precise movement adjustments.

For actuation, the robot relies on Nema 23 stepper motors, which are powered and controlled by Closed Loop Stepper Driver CL57T V4.1 modules, ensuring precise rotational movements. These motors work in conjunction with an electric linear actuator (Lifting mechanism) controlled via a BTS7960B motor driver board. To manage additional mechanical operations and ensure safety, an 8-channel relay card is integrated into the system. This relay card not only coordinates multiple control signals for precise operation but also serves as a critical safety feature by isolating power components, such as motors and brakes, from the main circuit in case of an emergency. This dual functionality ensures both reliable control and robust fail-safe protection during operation. The CIU_Fox robot is also equipped with load cell sensors, allowing it to measure forces applied to its lifting mechanism.

Distance sensing and obstacle avoidance are managed by a Time-of-Flight (ToF) sensor and a LiDAR system, which together provide precise environmental awareness for navigation and object detection. Complementing these systems, the QTRX-HD-11RC modules work alongside the camera to deliver robust line-following capabilities, ensuring accurate path tracking and reliable navigation in structured environments.

A 12V 70AH AGM battery serves as the primary power source, delivering energy to various subsystems. A Battery Management System (BMS) regulates power flow, preventing overcharging and ensuring optimal energy usage. Voltage regulation is achieved using a combination of modules, including a WM-045 DC-DC 150W step-up converter, a 500W 30A DC-DC constant booster, and LM2576 buck converters for 3.3V, 5V, and 9V outputs, ensuring stable and precise voltage levels for all components. To enhance system functionality, an 87dB speaker is integrated, providing auditory alerts or notifications as needed. Wireless connectivity is established through a TP-Link TL-WR840N router, enabling remote access and control via a connected PC, which facilitates real-time monitoring and decision-making.

0.1.2.0.2 Battery Management System (BMS)

The **BMS** is integrated to monitor and manage the battery's health, ensuring safe and reliable operation. It oversees critical parameters such as voltage, current, and temperature, preventing issues like overcharging, over-discharging, and overheating. Having a BMS typically optimizes battery performance, extending battery life by up to 30% and supporting over 3500 charge-discharge cycles at 90% Depth of Discharge (DOD). It also ensures safe operations with features like overcurrent protection, overvoltage protection, and temperature monitoring. Additionally, the BMS in this system includes a charging system that complies with the competition specifications, which supports an **AGM Battery** with a nominal voltage of **12VDC** and a charging current of **10A**.

0.1.2.1 Battery System

Battery selection is a key factor in the efficiency and reliability of an AGV system. Among the available options, Absorbent Glass Mat (AGM) and Gel (GEL) batteries, both types of Sealed Lead-Acid (SLA) or Valve-Regulated Lead-Acid (VRLA) batteries, stand out for their maintenance-free, leak-proof design and low self-discharge rate. While both are deep-cycle batteries capable of discharging up to 80% of their capacity, GEL batteries emphasize durability and stable power delivery, whereas AGM batteries support higher discharge rates and slightly faster charging. However, neither is well-suited for opportunity charging, as frequent partial recharges reduce their lifespan.

For AGVs operating in controlled, single-shift environments, GEL batteries provide a strong balance between safety, longevity, and consistent performance, making them an optimal choice. They typically last 8–16 hours per charge, depending on the AGV type, and require a full recharge when reaching 40–50% depth of discharge (DOD). While their charging time is slower (e.g., a 100Ah battery takes about 3 hours at 0.3C), their deep-cycle capability ensures steady, long-term operation, minimizing the need for frequent replacements.

Considering the AGV's operational demands and the competition's specified battery requirements, AGM batteries are selected for this application. The competition specifies the following parameters: *Battery Type: AGM Battery, Battery Voltage (Nominal): 12VDC, Battery Charging Current: 10A*.

Figure 3: AGM battery

0.1.2.2 Voltage Regulation

The AGV's electrical system contains various components operating at different voltage levels, making voltage regulation and distribution critical for stable operation. The majority of sensors operate at 3.3V to 5V, while components like the Raspberry Pi and ESP32 require 5V and others like the Wi-Fi router operates at 9V. To accommodate these diverse requirements, multiple voltage regulators are incorporated to step down the 12V battery supply to the appropriate levels, ensuring consistent performance across all subsystems.

The **LM2596** in Figure 6 voltage regulator will be used to step down the 12V battery supply to the required voltage levels for various components. Different versions of the LM2596 are available, including fixed output versions (9V, 5V, and 3.3V) as well as an adjustable version, allowing flexibility to meet the specific voltage requirements of each subsystem. For example, the 5V version will power the Raspberry Pi and ESP32, while the 3.3V version will support sensors operating at lower voltages. In cases where multiple components require the same voltage and draw significant current, multiple LM2596 regulators are placed in parallel to increase the current supply capacity(Table1).

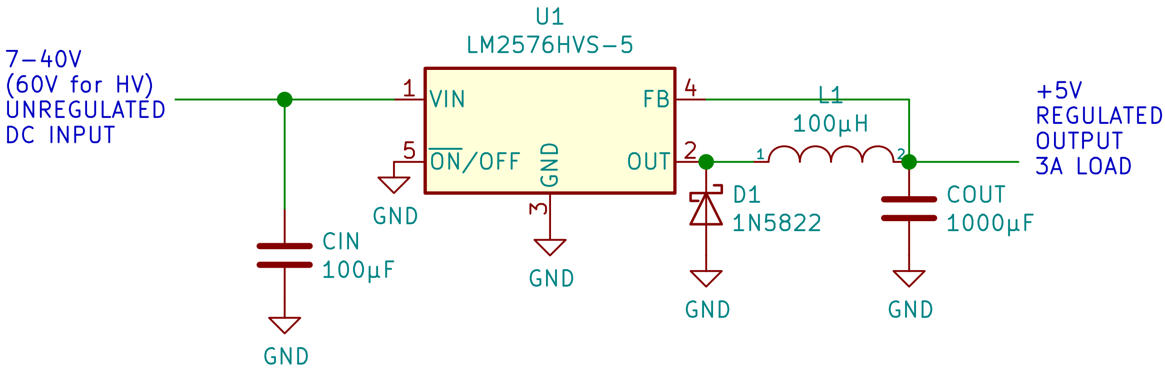

Figure 4: Fixed Output Voltage Version Typical Application Diagram

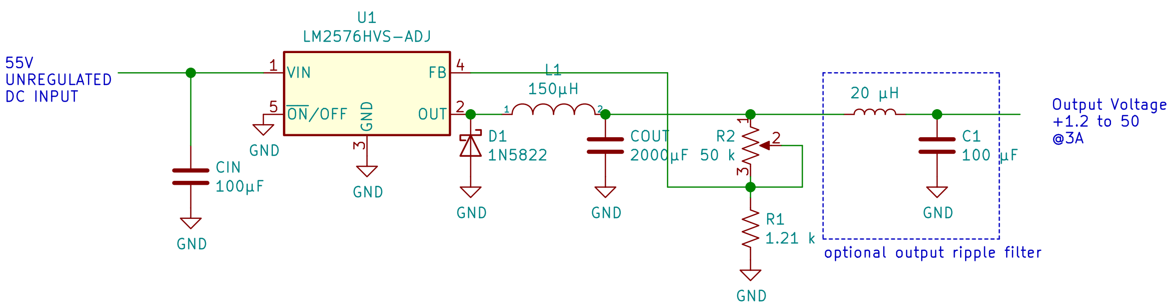

Figure 5: 1.2-V to 55-V Adjustable 3-A Power Supply With Low Output Ripple

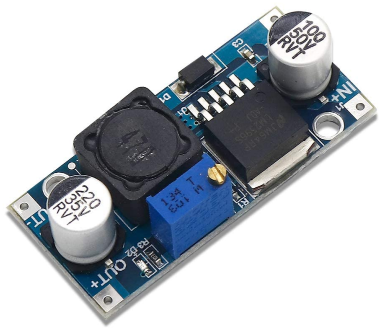

Figure 6: LM2596 Voltage Regulator

Parameter	Value
Input Voltage Range	`Up to 40V`
Output Current	`Up to 3A`
Switching Frequency	`150 kHz`
Output Voltage Options	`Fixed: 3.3V, 5V, 9V` `Adjustable: 1.2V--37V`
Efficiency	90%
Protection Features	`Thermal shutdown, current limiting`
Package Type	`TO-220, TO-263`
Operating Temperature	`-40°C to +125°C`

Table 1: LM2596 Voltage Regulator Specifications

Furthermore, subsystems, such as the traction unit (composed of two stepper motors) and the lifting system (powered by linear actuators), require voltages higher than the battery's output. To address this, boost converters(fig. 7 and fig. 8) are used to step up the voltage to the necessary levels.

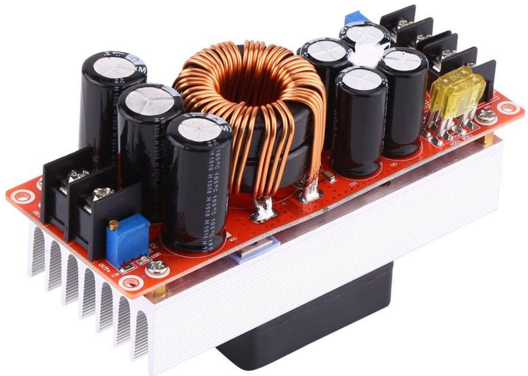

Figure 7: 1500W 30A DC-DC Constant Current Boost Converter Step-up Power Supply Module 10-60V to 12-90V

Features:	Flexible DC input voltage range from 10V to 60V; Adjustable output voltage from 12V to 90V for versatile applications; Maximum output current of 20A for reliable power supply; Built with high-power 100V/210A low resistance MOS for efficiency; Reverse input protection with MOS for added safety; Low voltage protection to prevent damage from over-discharge; Thickened heat sink and intelligent cooling fan for optimal heat dissipation.
Specifications:	Power: 1500W; Current: 30A; Input Voltage Range: 10V - 60V; Output Voltage Range: 12V - 90V; Maximum Output Current: 20A.
Package Includes:	1 × Boost Converter Step-up Power Supply Module.

Table 2: DC-DC Constant Current Boost Converter Specifications and Features

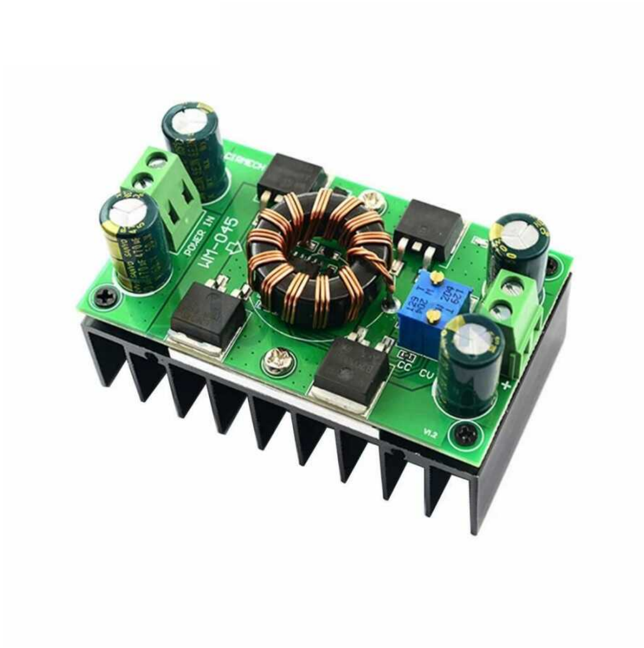

Figure 8: WM-045 DC-DC 150W Voltage Step Up and Step Down Regulator Module

Features:	Input Voltage: 5Vdc 30Vdc; Buck-Boost (automatic boost/lower); Output Voltage: 1.25Vdc -- 30Vdc (Adjustable); Output Current: 10A (MAX).
Specifications:	Output Power: 150W; Conversion Efficiency: 90% Max; Ripple and Noise: 200mVp-p; No-Load Current: 6mA typical.
Performance Metrics:	Voltage Regulation: ± 0.5%; Load Regulation: ± 0.5%; Dynamic Response Rate: 300uS.

Table 3: Buck-Boost Converter Specifications

The power distribution circuits are designed to efficiently deliver power to all subsystems, including motors, sensors, controllers, and communication modules, while minimizing power losses and ensuring reliable operation. Protection circuits and fuses are also integrated to safeguard sensitive components from voltage spikes, short circuits, and other electrical faults, enhancing the overall safety and durability of the AGV.

0.1.3 Motor control system

The performance and reliability of automated guided vehicles (AGVs) are deeply rooted in the precision and efficiency of their motor control systems [?]. At the heart of these systems lies the electrical design, which governs the interaction between power supply, control devices, and the physical dynamics of the motors. Direct current (DC) motors [?], Stepper motors [?] and Servo motors [?], widely used in AGVs due to their high torque, excellent speed regulation, and robust performance, require sophisticated electrical architectures to ensure optimal operation.

From an electrical perspective, motor control involves not only the precise regulation of voltage and current but also the implementation of efficient drivers and motor controllers, which are critical for achieving smooth acceleration, stable speed control, and efficient energy utilization. Furthermore, the motor control system must address challenges such as minimizing power losses, managing heat dissipation, and ensuring reliable operation under varying load conditions.

A motor control system comprises two fundamental components: the motors themselves and the motor drivers or controllers. The motor alone cannot achieve optimal operation without the integration of a sophisticated motor driver or controller. The motor driver acts as the intermediary between the power supply and the motor, regulating voltage and current to ensure smooth and efficient operation. It interprets control signals and translates them into precise commands.

0.1.3.1 Motors and actuators

The choice of motor depends on several factors, including torque requirements, speed, wheel size, load capacity, operating voltage, and environmental conditions. Below, we discuss the key considerations for motor selection in AGV applications.

0.1.3.1.0.1 Torque and Speed Requirements

The motor must generate sufficient torque to move the AGV and its payload efficiently, overcoming rolling resistance and any potential obstacles. Simultaneously, it should achieve the desired speed without compromising torque. For instance, AGVs operating in environments with frequent stops and starts may require motors with high torque at low speeds, while those used in long-distance transportation may prioritize higher speed capabilities.

0.1.3.1.0.2 Wheel Size and Load Capacity

The size and weight of the AGV wheels directly influence motor selection. Larger wheels and heavier payloads demand motors with higher torque and power ratings. Additionally, the motor must be capable of handling the AGV's maximum load capacity without overheating or losing efficiency.

0.1.3.1.0.3 Operating Voltage

The motor's operating voltage must align with the AGV's power supply system. Common voltage options include 12V, 24V, and 48V. It is essential to choose a voltage that is both compatible with the AGV's design and readily available for the intended application.

0.1.3.1.0.4 Motor Types

The two most common motor types for AGVs are DC motors and brushless DC (BLDC) motors. DC motors are cost-effective and straightforward, making them suitable for simpler applications. On the other hand, BLDC motors offer superior efficiency, longer lifespan, and smoother operation, making them ideal for more demanding AGV tasks. The choice between these motor types depends on the specific requirements of the AGV, such as precision, durability, and control complexity.

0.1.3.1.0.5 Control System Compatibility

The selected motor must integrate seamlessly with the AGV's control system. This includes compatibility with communication protocols and interfaces, such as PWM (Pulse Width Modulation) for speed control or CAN bus for advanced communication. Ensuring compatibility is crucial for achieving precise control and coordination with other AGV subsystems.

0.1.3.1.0.6 Encoders and Feedback Mechanisms

For AGVs requiring high precision and accurate path correction, motors equipped with encoders or feedback mechanisms are highly recommended. Encoders provide real-time data on the motor's position and speed, enabling closed-loop control and improved navigation accuracy. This feature is particularly important for AGVs operating in dynamic or complex environments.

0.1.3.1.0.7 Environmental Considerations

The operating environment plays a significant role in motor selection. AGVs operating in harsh conditions, such as dusty or moist environments, require motors with appropriate protection ratings (e.g., IP65 or higher). Additionally, motors should be selected based on their ability to withstand temperature variations and mechanical stress.

0.1.3.1.0.8 Energy Efficiency

Energy efficiency is a critical factor, especially for AGVs that operate for extended periods or rely on battery power. Motors with high efficiency reduce power consumption, extend battery life, and lower operational costs. BLDC motors, for example, are known for their energy-efficient performance compared to traditional DC motors.

0.1.3.1.0.9 Cost and Availability

While selecting a motor, it is essential to balance performance requirements with budget constraints. Consider not only the initial cost of the motor but also its availability, maintenance requirements, and long-term reliability. Consulting with manufacturers and industry experts can help identify cost-effective solutions without compromising performance.

0.1.3.1.1 Traction unit motors and linear actuator

0.1.3.1.1.1 P Series Nema 23 Closed Loop Stepper Motor with Electromagnetic Brake (2Nm):

The traction system of the automated guided vehicle (AGV) is driven by two NEMA 23 P-Series stepper motors shown Figure 9, each delivering a holding torque of 2.0 Nm to ensure reliable and precise motion. These motors are selected for their high torque-to-size ratio, making them well-suited for the dynamic demands of AGV operations.

Both motors are equipped with incremental encoders, which provide real-time feedback on motor speed and position. This closed-loop system enhances the AGV's ability to maintain smooth and synchronized motion, ensuring stability and precision during navigation.

Additionally, each motor is integrated with an electromagnetic brake, enabling rapid deceleration and enhancing safety by halting motion instantly when required.

Figure 9: Nema 23 stepper motor 2 Nm torque

Electrical Specification	
Manufacturer Part Number	23E1KBK20-20
Number of Phases	2
Step Angle	1.8deg
Holding Torque	2Nm (283.28oz.in)
Rated Current/Phase	5.0A
Phase Resistance	0.4ohms
Inductance	1.8mH ± 20% (1KHz)
Insulation Class	B 130°C [266°F]
Physical Specification	
Frame Size	57 x 57mm
Body Length	76.5mm
Shaft Diameter	8mm
Shaft Length	21mm
D-Cut Shaft Length	15mm
Lead Length	270mm
Weight	1.06kg
Encoder Specification	
Output Circuit Type	Differential type
Encoder Type	Incremental
Output Signal Channels	2 channels
Supply Voltage Min	5V
Supply Voltage Max	5V
Output High Voltage	<4V
Output Low Voltage	<1V
Brake Connections	
Red–24V+	Red--24V-
Brake Torque	2.0Nm

Table 4: Stepper Motor Specifications (Model: 23E1KBK20-20)

paragraphDC 12V Electric Linear Actuator (Maximum Force 6000N):

The lifting mechanism of the automated guided vehicle (AGV) utilizes a high-performance linear actuator to achieve precise vertical motion. The actuator includes an overload protection feature, preventing excessive force application and minimizing mechanical wear.

Figure 10: Linear actuator with a maximum stoke of 6000N

Model	JS-TGZ-U3
Material	Metal
Voltage	DC 12V
Maximum Push/Pull Force	Approx. 6000N/6000N
Stroke	450mm
No-Load Speed	Maximum 5mm/s
Rated Load Rate	5mm/s (600kg)
Environment Temperature	-26°C to +65°C
Standard Protection Level	IP54
Built-in Stroke Switch	Yes
Color	Silver

Table 5: Specifications of the linear actuator model JS-TGZ-U3

0.1.3.1.2 Motor Drivers and Controllers

0.1.3.1.2.1 Closed Loop Stepper Driver V4.1 CL57T:

The **Closed Loop Stepper Driver V4.1 CL57T** has been selected to complement the **Nema 23 Closed Loop Stepper Motor**, ensuring precise and reliable control over the AGV's propulsion and mechanical functions.

From an electrical perspective, the CL57T driver leverages advanced closed-loop technology to guarantee accurate motor positioning, even in dynamic environments or when encountering external resistance. Fully compatible with software tools like **CLseries** and **Motion Studio**, the driver enables fine-tuning of critical motor parameters, optimizing performance for specific operational requirements.

Additionally, its extensive diagnostic and monitoring ports provide real-time tracking of key electrical and operational metrics, such as **temperature**, **current**, **torque**, **RPM**, and overall motor state during operation. These capabilities not only enhance operational visibility but also streamline troubleshooting and diagnostics, minimizing downtime and ensuring swift resolution of issues.

Key Features	
RS232 debugging interface	
Do not need a high torque margin	
Broader operating speed range	
Reduced motor heating and more efficient	
Smooth motion and super-low motor noise	
5V/24V logic voltage selector, default setting 24V	
Closed-loop, eliminates loss of synchronization	
Protections for over-voltage,over-current,and position following error	
By default, supports an encoder with a resolution of 1000PPR; customizable between 0-5000PPR	
Electrical Specifications	
Output Peak Current	0 8A
Input Voltage	+24 48VDC (Typical 36VDC)
Logic Signal Current	7 16mA (Typical 10mA)
Pulse Input Frequency	0 200kHz
Isolation Resistance	500Mohm
Operating Environment and Other Specifications (Tj = 25°C/77°F)	
Cooling	Natural Cooling or Forced Cooling
Environment	Avoid dust, oil mist, and corrosive gases
Ambient Temperature	0°C - 65°C
Humidity	40%RH - 90%RH
Operating Temperature	0°C - 50°C
Vibration	10-50Hz / 0.15mm
Storage Temperature	-20°C - 65°C
Weight	Approx. 280g (9.9oz)

Table 6: Specifications of the Closed-Loop Stepper Driver

Figure 11: Closed Loop Stepper Driver CL57T V4.1

0.1.3.1.2.2 BTS7960B 40 Amp Motor Driver Board

The BTS7960B 40A Motor Driver Board is selected for its capability to control high-power motors, making it ideal for the AGV's linear actuator. Supporting currents up to 40A, it ensures reliable performance in demanding applications.

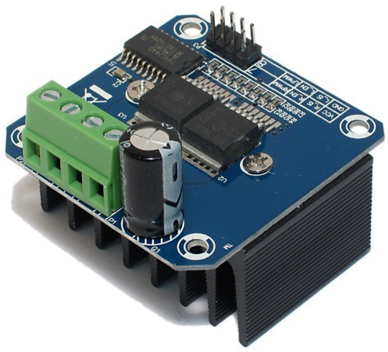

Figure 12: DC-MOTOR DRIVER MODULE 24V 43A (2x BTS7960B)

Features	
Double BTS7960 large current (43A) H-bridge driver	
5V isolation with MCU, effectively protecting the MCU	
5V power indicator on board	
Voltage indication of motor driver output end	
Can solder heat sink for improved thermal management	
Requires only four lines from MCU to driver module (GND, 5V, PWM1, PWM2)	
Isolation chip 5V power supply (can share with MCU 5V)	
Supports motor forward and reverse control; two PWM input frequencies up to 25kHz	
Two heat flow passing through an error signal output	
On-board 5V supply can be used or shared with MCU 5V	
Specifications	
Model	IBT-2
Input Voltage	6V - 27V
Maximum Current	43A
Input Level	3.3V - 5V
Control Method	PWM or level
Duty Cycle	0% - 100%
Size	4 x 5 x 1.2 cm / 1.6 x 2.0 x 0.5 inch

Table 7: Features and Specifications of the IBT-2 Motor Driver Module

0.1.3.1.3 Motor Feedback and Braking Systems

For precise control and safety, the AGV's motors are equipped with encoders and brakes. The two primary motors feature optical incremental encoders and power-off brakes, ensuring accurate feedback and reliable stopping mechanisms.

0.1.3.1.3.1 Encoder Specifications

The motors utilize optical incremental encoders with the following specifications:

Encoder Specifications	
Encoder Type	Optical Incremental
Resolution	1000 PPR (Pulses Per Revolution)
Output Circuit Type	Differential
Output Signal Channels	2

Table 8: Encoder Specifications

These encoders provide high-resolution feedback on motor position and speed, enabling precise control and navigation for the AGV.

0.1.3.1.3.2 Brake Specifications

The motors are equipped with power-off brakes, which engage automatically in the event of a power failure, ensuring the AGV remains stationary. The brake specifications are as follows:

Brake Specifications	
Brake Type	Power Off Brake
Holding Torque	200 Ncm
Brake Rated Voltage	24V
Brake Current	0.16A
Brake Power	4W
Response Time	50ms

Table 9: Electromagnetic Brake Specifications

The brakes shown in Figure 13 provide a holding torque of 200 Ncm, ensuring the AGV remains stable even under load. he fast response time of 50ms guarantees quick engagement, enhancing safety during operation.

Figure 13: Electromagnetic Brake for Nema 23

The encoder feedback is integrated into the AGV's control system, enabling real-time monitoring and adjustment of motor performance. The brakes are designed to work seamlessly with the power supply, ensuring immediate activation during emergencies or power loss.

0.1.4 Sensors

Various sensors, such as LiDAR, cameras, and infrared sensors, are utilized for navigation, obstacle detection, and localization.

The AGV is equipped with a variety of sensors to ensure accurate navigation, obstacle detection, weight measurement, and environmental perception. These sensors work together to enhance the robot's autonomy, safety, and efficiency. The following sensors are integrated into the system:

0.1.4.1 VL53L0X (Time-of-Flight Distance Sensor)

The VL53L0X time-of-flight (ToF) distance sensors play an important role in enhancing the AGV's perception of its immediate surrounding in an operational perspective. hese sensors are strategically integrated into the AGV design by deploying eight ToF sensors—two at each corner of the robot insuring a comprehensive coverage. The ToF sensors are especially important in scenarios where traditional sensing methods, such as LiDAR, may be limited or rendered ineffective. For instance, when the AGV carries a lifted platform that obstructs the LiDAR's field of view, the ToF sensors take over to provide reliable distance measurements within a range of 0.5m to 12m .

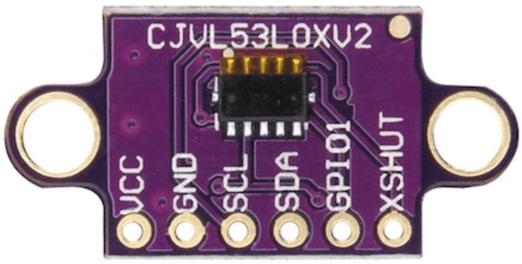

Figure 14: VL53L0X time-of-flight (ToF) distance sensor

0.1.4.2 Weight Sensor - Load Sensor 50Kg

This sensor provides accurate and continuous monitoring of the load on the AGV.

Figure 15: Load cell

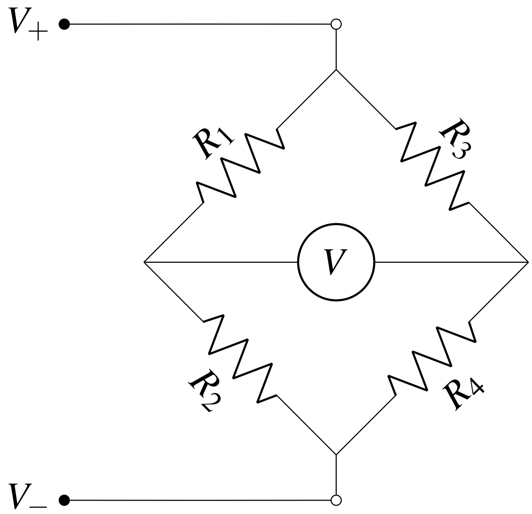

Figure 16: Load Cell Circuit with Wheatstone Bridge and Amplifier

The idea behind the load cell is to use the Wheatstone bridge (fig. 16). In a Wheatstone bridge, $R_1 = R_2 = R_3 = R_4$, and the output voltage is zero when no force is applied. When weight is applied, it bends the material, which changes the resistivity of the material. This change disrupts the equality of the resistances, causing a difference in voltage across V. By experimenting and calibrating with different weights and tracking the changes in voltage, we can measure the weight.

It is also worth noting that the signal produced depends on the material properties. If the bending factor is linear, the output will be proportional to the applied weight. However, if the bending becomes exponential (which would be a limitation of the material), the relationship between the applied weight and the output signal may no longer be accurate. Additionally, the placement of the load affects the measurement. The voltage difference across V is used to measure the output of the bridge.

In theory, we could use the microcontroller's analog input to read the voltage differences. However, the changes are too small to provide an accurate reading. For this reason, the **HX711** amplifier is used to amplify the signal and convert it into a digital signal.

The HX711 in fig. 17 is specifically designed to enhance the weak output signals from the load cellin fig. 15, ensuring accurate and reliable weight measurements.

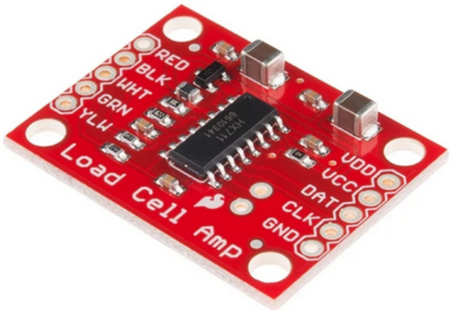

Figure 17: HX711 Load cell amplifier

0.1.4.3 RPLIDAR - 360

The RPLIDAR sensor provides comprehensive environmental mapping, making it indispensable for AGV navigation from an electrical control perspective. With its ability to deliver high-accuracy, real-time 360-degree scanning, the RPLIDAR enables the AGV to perceive its surroundings with exceptional precision.

Figure 18: RPLIDAR - 360

0.1.4.4 Camera HUSKYLENS

The **HUSKYLENS** vision sensor enhances the AGV's performance used for **object detection and line following**. It provides accurate real-time visual feedback, allowing dynamic adjustments to motor speed, direction, and trajectory.

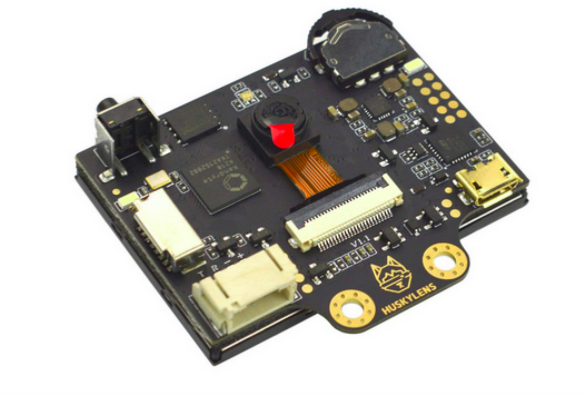

Figure 19: Huskylens camera

0.1.4.5 IMU Sensor

The Inertial Measurement Unit (IMU) is used for achieving precise positioning and movement control in automated guided vehicles (AGVs) The MPU9255 integrates a 3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer, providing comprehensive data on angular velocity, linear acceleration, and magnetic field orientation. The MPU9255 communicates with the AGV's control system via I2C or SPI interfaces, ensuring low-latency data transmission while minimizing power consumption—a key consideration for energy-efficient operation.

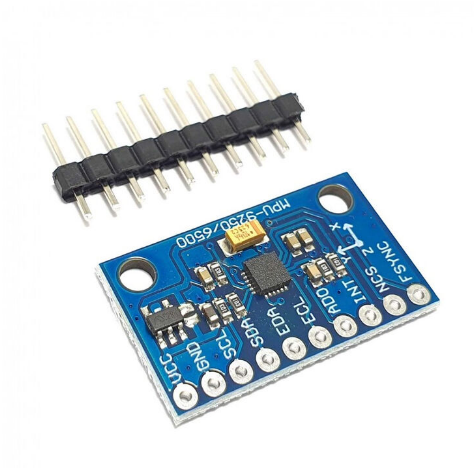

Figure 20: Inertia measurement unit 9 axis

0.1.4.6 Barcode Scanner GM65

Figure 21: Qr code scanner

0.1.4.7 QTRX-HD-11RC

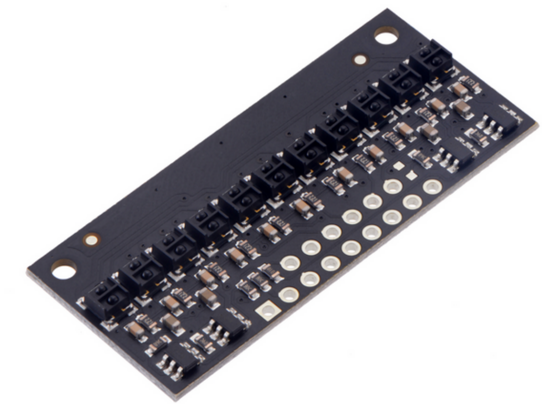

Figure 22: QTRX-HD-11RC Reflectance Sensor Array: 11-Channel

0.1.5 Microcontroller and communication

When selecting a microcontroller (MCU), several key factors must be considered to ensure it meets the demands of the system. One of the most critical criteria is processing power. The system design requires an embedded computer capable of running Linux, which is essential for implementing the Robot Operating System (ROS).

ROS provides a robust framework for handling robotic applications, including sensor fusion, navigation, and communication between various components. Running ROS efficiently requires an embedded system with sufficient computational capabilities, including a high-performance CPU and adequate RAM.

Another crucial factor is the number of available I/O pins. The system involves interfacing with multiple sensors and actuators, necessitating a microcontroller with a high pin count to accommodate all necessary connections. Many of these devices operate using different communication protocols, such as I2C, SPI, and UART.

0.1.5.1 Microcontroller and Embedded computer integration

The AGV's microcontroller and communication system form the backbone of its control and data exchange capabilities, ensuring efficient processing, seamless communication, and real-time control of the robot's operations.

In this design, the **Raspberry Pi 4** shown in Figure fig. 23 serves as the primary computational unit, acting as the "brain" of the system. Equipped with a Linux operating system, it hosts all necessary **ROS (Robot Operating System)** packages, enabling high-level decision-making, sensor data processing, and trajectory planning.

0.1.5.1.1 Raspberry Pi 4

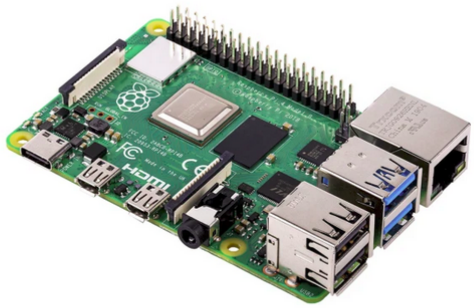

Figure 23: Raspberry Pi 4

Complementing the Raspberry Pi, the **ESP32 microcontroller** in fig. 24 supports it by managing low-level tasks such as motor control and real-time sensor interfacing. The ESP32 directly interfaces with motor drivers to regulate speed, and direction, ensuring precise actuation of the AGV's propulsion system.

Communication between the Raspberry Pi 4 and the ESP32 is achieved through a **serial communication protocol**, which ensures reliable and efficient data exchange. This division of responsibilities – high-level computation on the Raspberry Pi and low-level control on the ESP32 – optimizes the system's performance and reliability.

Additionally, the sensors are shared between both components, with the ESP32 handling time-sensitive data acquisition and the Raspberry Pi performing higher-level processing and integration into the ROS framework.

0.1.5.1.2 ESP32-S3-DevKitC-1

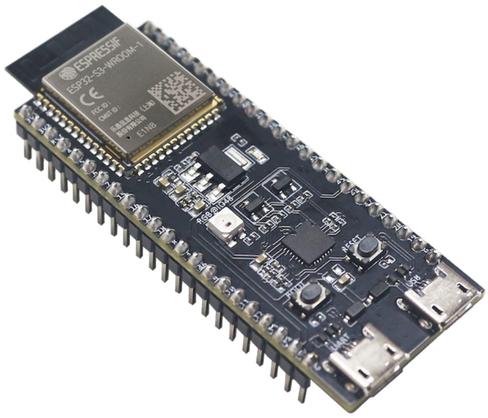

Figure 24: ESP32-S3-DevKitC-1

0.1.5.1.3 RS232 to Bluetooth Series Adapter

RS232 to Bluetooth Series Adapter

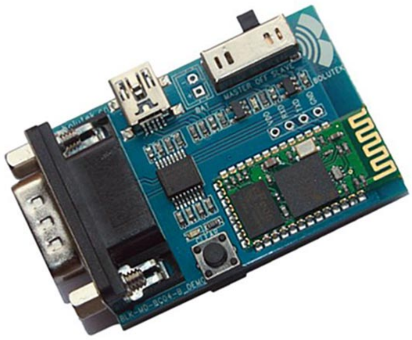

Figure 25: RS232 to Bluetooth Series Adapter

0.1.5.1.4 TP-Link TL-WR840N

- The **TP-Link TL-WR840N** is utilized as an access point to facilitate communication between the control unit (PC) and the robot's microcontrollers (Raspberry Pi and ESP32 modules).

- By configuring the TL-WR840N as an access point, it creates a wireless network that enables seamless data and command exchange between the PC, Raspberry Pi, and ESP32 modules.

- This setup allows for remote control and monitoring of the AGV's operations, enhancing its usability and adaptability.

All **sensors, microcontrollers, and motor drivers** in the AGV are selected to work in a **cohesive and well-integrated system**, ensuring seamless communication and efficient operation. **Protocols such as I2C and UART** enable reliable data exchange between components, allowing real-time monitoring and control. This structured communication enhances **precision, synchronization, and responsiveness**, optimizing the AGV's navigation, lifting, and traction systems while maintaining operational efficiency and safety.