DESIGN AND ANALYSIS OF AUTONOMOUS MOBILE ROBOT FOR MATERIAL HANDLING APPLICATION

Karpaga Ganesh V (18R220)
Thiyanayugi M (18R256)
Umashankar S (18R257)
Jai Gowtham S (19R432)

Dissertation submitted in partial fulfillment of the requirements for the degree of

BACHELOR OF ENGINEERING

Branch: ROBOTICS AND AUTOMATION

of Anna University

May 2022

DEPARTMENT OF ROBOTICS AND AUTOMATION ENGINEERING

PSG COLLEGE OF TECHNOLOGY

(Autonomous Institution)

COIMBATORE – 641 004

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..………………………	..…………………………
Dr. B. Vinod	**Dr. B. Vinod**
Faculty Guide	Head of the Department

Certified that the candidate was examined in the viva-voce examination held on ………………...

……………………………	…………………………...
(Internal Examiner)	(External Examiner)

PRICOL *LIMITED*
Passion to Excel

Plant 1,
132 Mettupalayam Road
Perianaickenpalayam
Coimbatore 641020, India.

REGISTERED OFFICE
109, Race Course,
Coimbatore 641018, India.

CIN L34200TZ2011PLC022194

+91 422 4331100
+91 422 4331122
factory@pricol.co.in
pricol.com

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Department	: Manufacturing Engineering
Period	: 23.12.2021 to 13.05.2022
Performance	: Good

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Ramkumar R R
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132 Mettupalayam Road
Perianaickenpalayam
Coimbatore 641020, India.

+91 422 4331100
+91 422 4331122
factory@pricol.co.in
pricol.com

REGISTERED OFFICE
109, Race Course,
Coimbatore 641018, India.

CIN: L34200TZ2011PLC022194

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This is to certify that **Mr. Thiyanayugi M,** student from PSG College of Technology, Coimbatore, has undergone his Internship at Pricol Limited.

Department	: Manufacturing Engineering
Period	: 23.12.2021 to 13.05.2022
Performance	: Good

We wish him all success in his future endeavors.

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Ramkumar R R

Ramkumar R R
Deputy Manager - Human Resources

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Plant 1,
132 Mettupalayam Road
Perianaickenpalayam
Coimbatore 641020, India

REGISTERED OFFICE
109, Race Course,
Coimbatore 641018, India

CIN: L34200TZ2011PLC022194

+91 422 4331100
+91 422 4331122
factory@pricol.co.in
pricol.com

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This is to certify that **Mr. Umashankar S,** student from PSG College of Technology, Coimbatore, has undergone his Internship at Pricol Limited.

Department	: Manufacturing Engineering
Period	: 23.12.2021 to 13.05.2022
Performance	: Good

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Ramkumar R.R

Ramkumar R R
Deputy Manager - Human Resources

M.Raj

pricol

PRICOL LIMITED
Passion to Excel

Plant 1,
132 Mettupalayam Road
Perianaickenpalayam
Coimbatore 641020, India.

+91 422 4331100
+91 422 4331122
factory@pricol.co.in
pricol.com

REGISTERED OFFICE
109, Race Course,
Coimbatore 641018, India.

CIN: L34200TZ2011PLC022194

CUSTOMERS EMPLOYEES SHAREHOLDERS SUPPLIERS

PL/TRG/INT/42/2022

May 13th, 2022

TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Mr. Jai Gowtham S,** student from PSG College of Technology, Coimbatore, has undergone his Internship at Pricol Limited.

Department	: Manufacturing Engineering
Period	: 23.12.2021 to 13.05.2022
Performance	: Good

We wish him all success in his future endeavors.

For Pricol Limited,

Ramkumar. R.R.

Ramkumar R R
Deputy Manager - Human Resources

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SYNOPSIS

Autonomous material handling robots are poised to provide a more efficient, zero-touch environment that will extend beyond the shop floor to both ends of the storage operation, and eventually into the logistics supply chain. AMRs perform better because of their dynamism and efficiency in sharing responsibilities. Furthermore, autonomous mobile robots have far more advanced software and hardware, allowing them to do jobs more quickly.

At a warehouse, AMR must transport items weighing about 250 kg with caution. In a warehouse and distribution centre environment, advanced technologies are linked with warehouse management systems to improve the efficiency and productivity of processes and workflows above Human Labourers, giving AMRs more freedom to establish their own routes between sites within a warehouse or facility. By Implementing, an AMR within the plant and scheduling jobs that are currently done manually can be automated to some extent, according to the issue statement. AMR must deliver raw materials in a methodical and consistent manner without requiring human intervention, ensuring that manufacturing lines receive the materials they need without interruption. Because the layout map is the only item that needs to be updated, the AMR can be used in any industrial context. The project highlights all of the important aspects, including cycle time calculation for the necessary PCB to be delivered at each assembly lines, AMR run time calculation, and AMR mechanical design. The scope of work comprises of 3D modelling as well as electrical and mechanical component selection.

The internship was undertaken at Pricol Limited, Coimbatore, which is a well-established company engaged in the manufacture and export of a complete range of automotive components starting from instrument clusters, dashboard meters to fuel cut off valve and dynamo. They intend to also become a leading provider of creative robotic solutions that exceed customer expectations.

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CHAPTER 1

INTRODUCTION

The Autonomous Mobile Robot (AMR) project is described in this chapter, along with its issue description. The AMR's goal is determined according to the issue description. An Autonomous Mobile Robot is any robot that can understand and navigate around its surroundings without direct supervision from a human. This is often accomplished using a slew of sophisticated on-board sensors, processors, and maps that allow AMRs to comprehend and interpret their surroundings in order to serve as a kind of asynchronous transportation.

Autonomous material handling robots are ready to deliver a more efficient, zero-touch environment that extends beyond the shop floor to both ends of the warehousing operation and, eventually, into the logistics supply chain. Because of their dynamism and efficiency in sharing duties, AMRs perform better. Furthermore, autonomous mobile robots have considerably more advanced software and hardware, allowing them to perform more efficient tasks.

1.1 OBJECTIVES

The objectives of this project are:

- To design an Autonomous Mobile Robot (AMR) for material handling application.
- The AMR must be capable of carrying a maximum payload of 250 kg.
- To select components for an AMR that should have a work time 5 – 6 hours, maximum speed of 1.5 m/s.
- As per the requirement of Pricol Plant 1, the AMR design must be capable of loading dual trays upon it.
- To select and analyse the compatibility of each module of the AMR, and prepare bill of materials of those components with target cost Rs. 15,00,000/-.

1.2 SCOPE OF THE PROJECT

The scope comprises 3D modelling of the AMR, the selection of electrical and mechanical components. AMR is used for material handling and it needs to delivers raw materials methodically and faithfully without requiring human involvement, ensuring that manufacturing lines receive the materials they need without interruption. The AMR can be relocated to any industrial environment since the only thing to change is the map of the layout it operates.

1.3 ORGANISATION OF THE REPORT

- In chapter 1, an overview, objective and the scope of the project are discussed.
- In chapter 2, the existing techniques are summed up based on literature survey.
- In chapter 3, the detailed methodology of the project is discussed.
- In chapter 4, the target specification was established.
- In chapter 5, the architecture and operational modes of the AMR were discussed.
- In chapter 6, controller comparison and selection were done.
- In chapter 7, the selection and study of navigation software was done.
- In chapter 8, selection of components was discussed
- In chapter 9, a final mechanical design was illustrated.
- In chapter 10, a conclusion and future work were specified.

CHAPTER 2

LITERATURE SURVEY

This chapter lists information obtained from the study of different journals on autonomous mobile robots. Some currently existing patents and the outcome of the literature survey is also mentioned.

2.1 LITERATURE REVIEW

2.1.1 A Review on Challenges of Autonomous Mobile Robot and Sensor Fusion Methods

Mary B. Alatise, et al [1], has done complete research on devices/sensors, and popular sensor fusion approaches created for addressing difficulties such as localization, estimation, and navigation in mobile robots are also discussed, and are categorized according to relevance, strengths, and shortcomings. Their study focuses on autonomous mobile robots' capacity to travel in an environment without the need of physical or electro-mechanical guiding systems.

2.1.2 A Review of Mobile Robots: Concepts, Methods, Theoretical framework, and Applications

Francisco Rubio, et al [2], presented the influence of new trends such as artificial intelligence, network communication, cooperative work, nanorobotics, friendly human–robot interfaces, safe human–robot interaction, and emotion expression and perception in the field of autonomous robots. They also pointed out the current and future influence of the autonomous robots in medicine, industry, agriculture, health care, underwater exploration, domestic service, and so on.

2.1.3 Integrated Mechanical Design and Modelling of a New Mobile Robot

Ollero, et al [3], have summarized the mechanical design of VAM new wheeled robotic vehicle capable of navigating 10 door and paved floor unstructured environments. This design is the result of several issues related with control, planning and perception requirements for navigation and operation in several conditions. VAM-I has a simple and inexpensive dual locomotion system for trajectory following and maneuvering in cluttered areas.

2.1.4 Design and Analysis of a Mobile Robot for Storage and Retrieval System

E. Vijayaragavan and colleagues [4] developed and tested a mobile robot for a storage and retrieval system. The robot's purpose is to convert lengthy racks in storage houses to other locations rather than transporting individual components in the racks. The lead screw mechanism will be utilized to raise the racks, and a differential drive will be employed as the main drive. The primary problems were spreading the load distribution evenly throughout the chassis to provide optimum stability and restricting the weight ratio of the robot to the racks to an ideal amount. CATIA and ANSYS were used to design and analyses the robot, respectively.

2.1.5 Mobile Robot Structure Design, Modeling and Simulation for Confined Space Application

A. A. A. Razak et al [5], showed how to build, develop, and simulate a mobile robot structure for restricted area application. The mobile robot is built with a four-wheel skid-steering drive system that allows for quick and sharp turns. A static kinematic model represents the mathematical description of the robot. The robot's rectangular frame is built of hollow rectangular mild steel bars. Simulation is used to examine the structure's stress and displacement. The data analysis reveals that the structure is suitable for use in small areas.

2.2 PATENT SEARCH

2.2.1 Autonomous Mobile Robot (US20080294288A1)

A mobile robot is outfitted with a range finder and a stereo vision system. The mobile robot is capable of independently travelling through urban terrain, constructing a map based on data from the range finder, and sending the map to the operator as part of a variety of reconnaissance operations requested by the operator. The mobile robot uses a Hough transform technique to identify linear features in its environment, then aligns itself with those features to navigate through the urban terrain; at the same time, a scaled vector field histogram technique is applied to the combination of range finder and stereo vision data to detect and avoid obstacles, the mobile robot encounters when navigating autonomously. To guarantee that the autonomous activities are completed, the tasks conducted by the mobile robot may incorporate limiting parameters depending on distance or time elapsed.

2.2.2 Autonomous Guided Vehicle (US7008164B2)

Multiple conveyors for transporting items are installed on a self-propelling dolly and juxtaposed in a transverse direction on an autonomous guided vehicle. Each conveyor has many component conveyors that may be operated separately and organized in a transferred direction in tandem. In the direction of the vehicle width, one, three-, or more-part conveyors may be positioned or organized in tandem. In the transverse direction, one, three-, or more-part conveyors may be placed or opposed.

2.3 OUTCOME OF THE LITERATURE REVIEW

The literature survey has bought effective results and has helped in understanding the requirements clearly. The outcome includes

- Identification of different modules of an AMR
- Current technologies in designing and analysing an AMR
- Kinematics study about each component of an AMR
- Study on localization and navigation methods
- Compatibility of camera and range finder fusion technology

CHAPTER 3

METHODOLOGY

This chapter begins by listing out the methodology as per our requirements. By keenly surveying the plant layout, material shuttling frequency, product dimensions, production rate, and three different conceptual designs have been formulated. Among them, third design is selected as the optimal AMR design for our requirement.

3.1 PROCESS FLOWCHART

As per the desired load carrying capacity, the motors and the appropriate driver were selected. The methodology flowchart is shown in Fig 3.1.

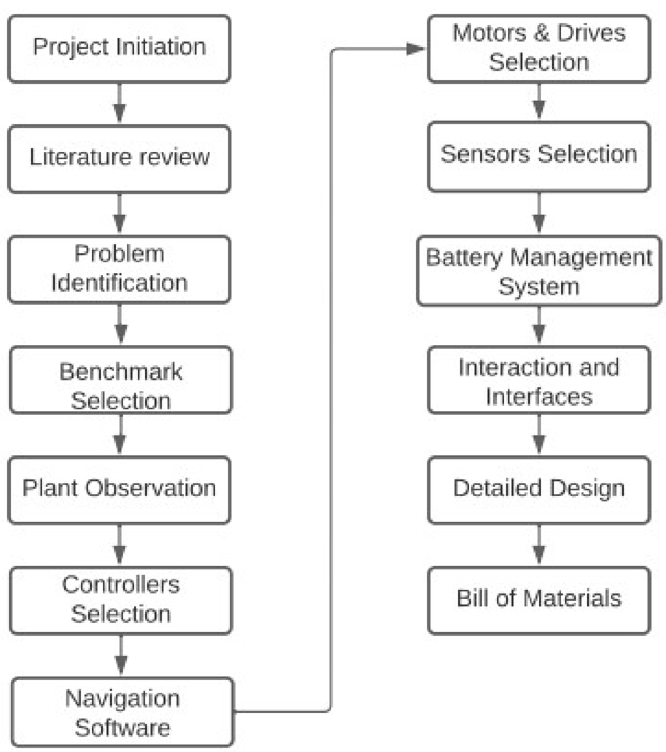

Fig 3.1 Methodology Flowchart

The first and foremost step in this project is project initiation. It involves the processes like deciding the project title, finding the motivation for the project and acquiring project approval. Next step involves the literary survey. The literature survey includes the process of finding different research journals and patterns associated to the project and thoroughly understanding them. It helps in proposal of the different approaches, error handling. The next step followed is problem identification. Literature survey gives the clear-cut picture of what to follow. This made the problem identification possible. Every project needs an ideal project to compete with which results in a better outcome. Thus, the next step in methodology is benchmark selection. Since this project is mainly based on work environment, the study of that environment and an existing solution is important.

The next process in methodology is plant observation. This helps in finding the distance of the AMR travel path, calculation of operating time, cycle time, and fixing the target specification. The next steps of the methodology are the selection of the individual components. The controller is selected as primary followed by navigation software selection. The next components for selection are motors and drivers followed by sensors. The power source battery and its management system are selected next. It is followed by the selection of the interaction and interfaces components such as HMI, LED lights, etc.

The ultimate step is the detailed design. It includes the selection of mechanical components It involves the organization of all the selected mechanical and electronic components into a single design. The final step is the compilation of the Bill of Material (BOM) of each and every component in this project.

CHAPTER 4

TARGET SPECIFICATION

This chapter explains the factors considered before fixing the target specification for the autonomous mobile robot. It also consists of the target specifications of the different elements of the autonomous mobile robot.

4.1 MOTIVATION FOR TARGET SPECIFICATION

Establishing target specification is the most important process in designing any product. Target specifications must be accurate because the success of the product depends on the solidarity of it. Target specifications is a collection of the general specifications of the autonomous mobile robot which are required for proper functioning. Target specification for the AMR is established by analyzing the different criteria such as operating time, observations from the environment the AMR has to be operated.

4.2 STUDY OF AMR WORKING ENVIROMENT

The environment in which the AMR plays an important role in establishing the target specifications. The observations from the industrial layout are

- AMR has to deliver the raw material from the storage area to the 10 assembly lines
- The dimensions of the pathway that the AMR has to travel is around 2.4 m.
- In a single day, AMR must work all shifts. Each day consists of three shifts.
- The loading and the unloading of the tray which contains raw material is done manually.
- The dimensions of the tray and the number of raw materials in each tray for each specific model is collected.
- The frequency of the requirement of products is collected.
- The layout of the entire industrial plant is collected which will be useful in the calculation of the operating time.

4.3 CYCLE CALCULATION

The maximum possible cycles travelled by the AMR in a shift is formulated. A cycle refers to the single back and forth travel from storage area to any assembly line. The number of trays carried per cycle by the AMR is 2. The AMR can also travel only to the respective assembly i.e.; only carrying the tray of a single assembly line at time. The Cycle time represents the assembly time of a single product. With the help of that output per hour and shift is calculated.

Table 4.1 Cycle Calculation

Line Number	Cycle Time per piece (sec)	Output per Hour	Output pieces per Shift	PCB Capacity per Tray	No. of Trays Required per Shift	No. of Cycle Required per Shift
1	135.4	27	203	33	7	4
2	71	51	389	40	10	5
3	37.6	96	734	33	23	12
4	58.1	62	475	40	12	6
5	61.7	58	447	40	12	6
6	**LINE NOT IN USE**					
7	61.7	58	447	40	12	6
8	35	103	788	44	18	9
9	129.3	28	213	10	22	11
10	76.7	47	360	16	23	12
11	76.7	47	360	16	23	12
AMR Cycle per Shift (Required)						**83**

The table 4.1 depicts the calculation of number of cycles. As a result, the AMR has to do a maximum of 83 cycles in a shift.

4.4 OPERATING TIME CALCULATION

Operating time of the AMR per shift is calculated per cycle and per shift based on the distance travelled and time taken by the AMR in that particular time period. The longest distance, AMR has to travel is 27 meters which is the distance from the storage area to furthest assembly line. The speed of the AMR is chosen as 0.5 m/s. The speed is chosen lowest to calculate the longest operating time.

Table 4.2 Operating Time Calculation

Line Number	Travel Distance from Storage (m)	Travel Time for AMR from Storage to Assembly Line and vice versa (sec)	Loading, Unloading Time and Lag Time (sec)	Total Time taken for AMR to pick, deliver and return (sec)	Total Time Required for a Shift (sec)	Takt Time (min)	Priority
1	27	108	60	168	588	74	4
2	23	92	60	152	760	95	8
3	18	72	60	132	1518	62	2
4	15	60	60	120	720	78	3
5	12	48	60	108	648	82	7
6	**LINE NOT IN USE**						
7	5	20	60	80	480	82	7
8	7	28	60	88	792	77	5
9	13	52	60	112	1232	65	6
10	19	76	60	136	1564	61	1
11	25	100	60	160	1840	61	1
Total Time Required for AMR (sec)				**1256**	**10142**		
Total Time Required for AMR (min)				**20.93**	**169.03**		
Total Time Required for AMR (min)				**21 Minutes**	**2 hrs. 49 minutes**		

The Takt time is the time interval between the requirements of the raw material. The priority is set for the next AMR cycle based on the shortest Takt time. The entire representation of the operating time is shown in table 4.2.

4.5 AUTOMATED DELIVERY CYCLE

The AMR is going to be operated primarily based on the requirement from the assembly line using the DPMS (Digital Production Monitoring System). It also can operate in different modes that will be discussed later.

Table 4.3 Automated Delivery Cycle

Cycle Number	Sequence of Delivery Line Number (Number of Trays)
1	1 (1) and 3 (1)
2	2 (1) and 4 (1)
3	5 (2)
4	2 (1) and 4 (1)
5	3 (2)
6	7 (1) and 8 (1)
7	9 (1) and 10 (1)
8	11 (2)
9	8 (2)
10	9 (2)
11	10 (2)
12	7 (1) and 11 (1)

As an alternative to this method, the raw material delivery can be automated based on the Takt time, cycle time of each assembly line. This automated cycle shown in table 4.3 can reduce the cycle time of the AMR in a shift even further. The values in the bracket represents the number of trays. The significant improvement in this method is that the AMR always carries two trays. For example, in the first cycle, assembly line 1 only required 1 tray but the AMR carriers another and deliver it to assembly line 3. Thus, keeping the efficiency of the AMR in mind, the automated cycle is formulated.

4.6 ESTABLISHING TARGET SPECIFICATIONS

The initial step in the establishment of target specification is studying the customer needs. As mentioned above, a detailed analysis on the needs of the customer is done.

Table 4.4 Target Specifications

Description	Values
Payload	250 kg
Type of Load	Top Load
Type of Material to be Transferred	Trays (bin)
Speed	0.5 – 1.5 m/s
Dimensions (L X W X H)	1000 x 600 x 1000 mm
Operating Time	5 hrs.
Battery Capacity	200 Ah
Chassis Material	Aluminum
Turning Radius	1.2 m
Positioning Accuracy	x, y axis: +/- 10 mm,
	Yaw: +/- 1 degree
Operational Mode	Manual / Autonomous
Nominal Voltage	48 V – Motors
	24 V – Other Electronic Components
Communication	Wi-Fi 2.4 / 5 GHz
AMR Vehicle Mass	150 kg
Other Sensors	Ultrasonic, Mechanical Bumper Sensors
Environmental Temperature	0 – 60 degrees Celsius
Emergency stop and lights	Two emergency stop buttons, Perspective 360-degree lighting

With the help of the above studies, metrics and required specification for general components of the AMR is fixed. It is shown in table 4.4.

CHAPTER 5

ARCHITECTURE

The AMR has a number of sub modules on board, including a controller, 2D LiDAR, driver, motor, and battery management system module, Human Machine Interface (HMI), Programmable Logic Controller (PLC), ultrasonic sensors, bumper sensors, emergency stop button, and ambient lights. The architecture is designed to comprehend the whole data and power flow between these units. The design aids in the visualisation of numerous communications between each module contained inside the AMR.

5.1 AMR ARCHITECTURE

The AMR architecture is only framed for on-board components since the modules inside the AMR have significantly more intricate connections and communications than the AMR's exterior modules. The AMR's architecture is seen in the Fig 5.1.

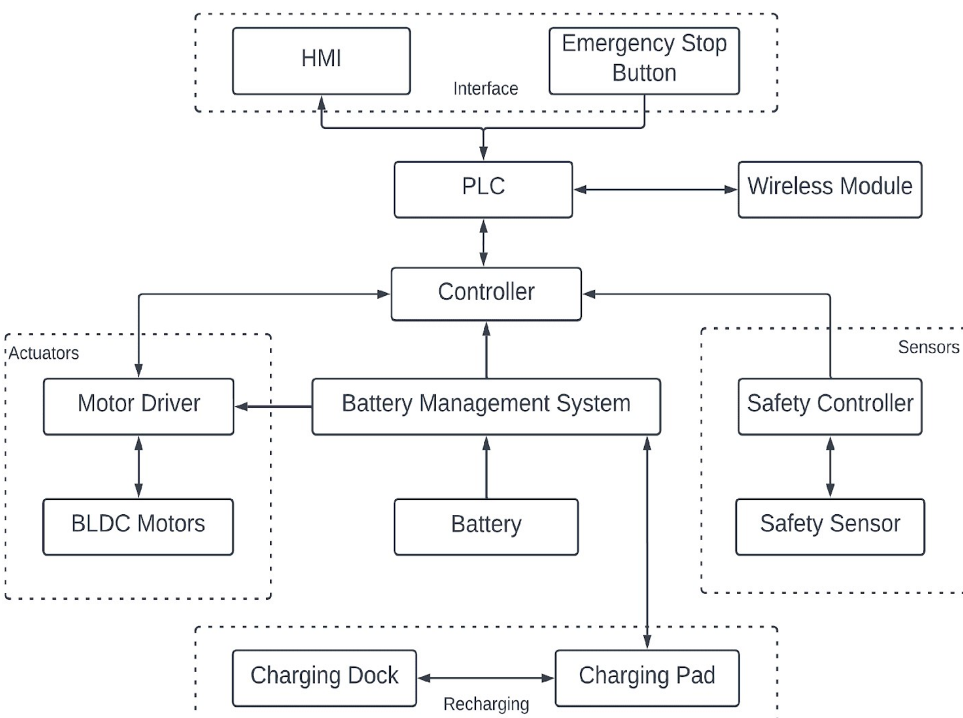

Fig 5.1 AMR Architecture

According to the power flow, the source is the battery, which is directly connected to the Battery Management System, which constantly monitors the voltage, current, state of charge that is flowing into every component from it. If the battery is about to die or falls below a predetermined threshold, an indication is sent to the controller. Between the BMS and the other components is a Switch Mode Power Supply (SMPS). The SMPS converts 48 V DC to 24 V DC, 12 V DC and 5 V DC and powers all electronic components except the driver. The 48 V DC supply is sent directly to the driver by the BMS.

Whereas the data flow, there are two sources, one is from the wireless module connected to the controller. The wireless module receives the information from the database of the plant. And the other source of data is from the operator from the HMI. The PLC process these data and acts according to the logic written in it. The controller takes input from the sensor and acts upon it.

5.2 OPERATIONAL MODES OF AMR

The AMR can be operated in either one of the 2 modes, namely the online mode and offline mode. The online mode has different software and hardware architecture when compared with offline mode, external to the AMR. In either mode the operational mode of the AMR comes under 3 kinds,

- Fully - autonomous mode
- Semi - autonomous mode
- Manual mode

In order to automate the plant entirely, fully autonomous mode is planned, in which there is no intervention of human takes place for deciding the sequence of tasks. At some times the AMR would need to be under control of an operator, the delivery station is known by that person and he instructs the AMR by giving tasks directly to the AMR, semi - autonomous mode have been planned for this application. The final mode, manual mode is used in emergency cases and in case of shifting the vehicle for a new location.

5.3 FULLY – AUTONOMOUS MODE

Autonomous mode is the most efficient and futuristic where no human intervention takes place in taking decision for the sequence of delivery of materials. In online mode, the data from the database is transferred to the server PC which must be installed for online mode. The intermediate software developed by the Guidance Automation will constantly look into the database of the Pricol plant 1 and act as a bridge to the system manager software of Guidance Automation, Monitrav and the database of the Pricol. The Monitrav takes input from the intermediate software and controls sequence of task that have to be carried out by the AMR. The control data, assembly line number and the material to be loaded are transferred via a wireless communication. The line number and the material to be loaded are displayed in the HMI. The operator loads the dual rack accordingly. The AMR can be lively tracked of its location on the map using the Monitrav Software. The Fig 5.2 depicts the architecture of the fully autonomous mode when operated under online.

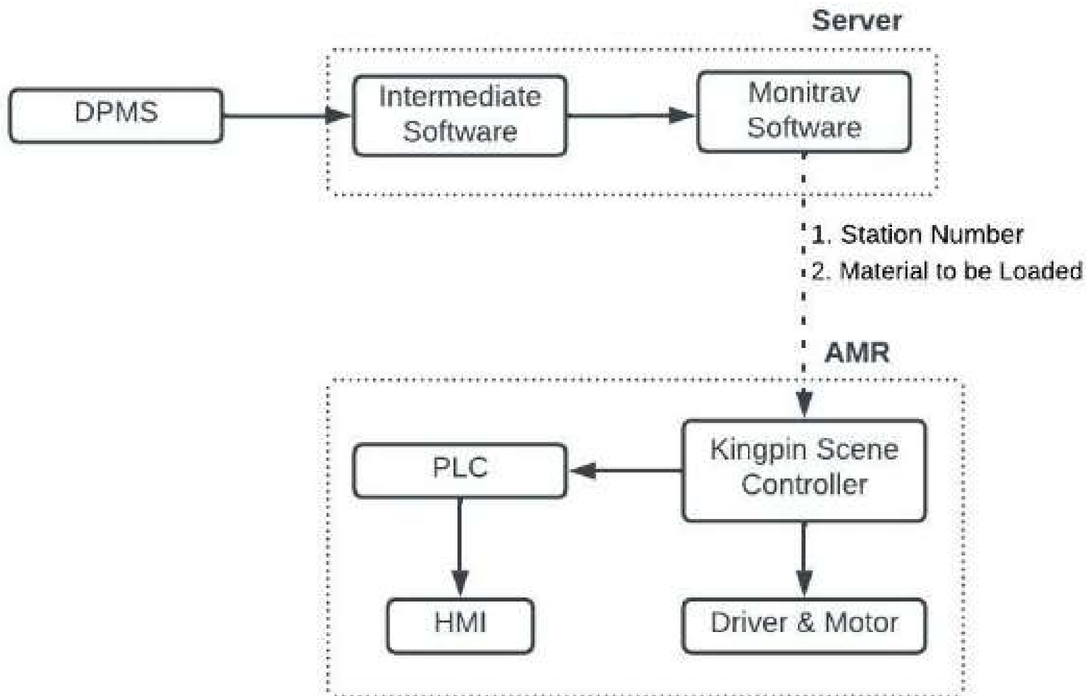

Fig 5.2 Fully Autonomous Mode - Online

The PLC takes the two information namely, assembly line number and material to be loaded and displays on the HMI. The fully autonomous mode can be operated even when the AMR is in offline mode, the required information for the AMR to navigate to the delivery points are assembly line number and the material to be loaded. This two information's are sent via a wireless communication directly to the PLC. The control of the vehicle is done by the Transitrak Software which is installed in the Kingpin Scene Controller. This software is only for an individual AMR, where there is no fleet management or traffic control is necessary.

The Fig 5.3 depicts the data flow between each module of the AMR for offline mode. The AMR can be tracked lively if necessary, using a laptop or a PC enabled with wireless communication (Wi-Fi), by installing the Transitrak software. The controls can be given via the laptop or PC through the Transitrak software.

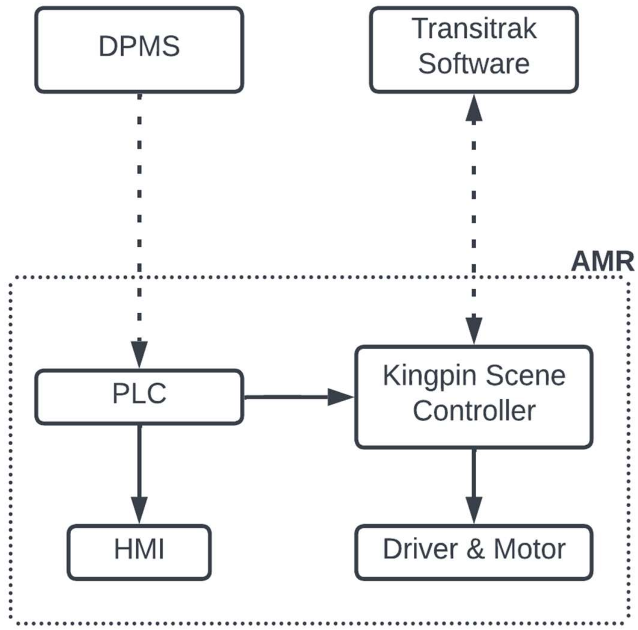

Fig 5.3 Fully Autonomous Mode - Offline

5.4 SEMI – AUTONOMOUS MODE

The Semi – Autonomous mode, when operated in online mode, basically have two sources of information. One from the Monitrav Software, the operator who monitors the AMR's location can give the delivery line number as per his wish via the software. Whereas the other source is from the HMI.

The operator must know the line number and the material to be loaded by some other means and select the data's directly in to the HMI. The AMR receives the next task from reaching each checkpoint. The Actuation is based on the control signals provided by the Kingpin Scene controller. The Fig 5.4 depicts the architecture of semi-autonomous mode when run online.

The offline mode has the similar architecture of the online mode, but the data from the external server is neglected here. But the compatibility of scheduling tasks from an external PC or Laptop is possible. The live location of the AMR can also be seen using the Transitrak Software. But the software architecture is same as the online mode. The Fig 5.5 depicts the offline mode.

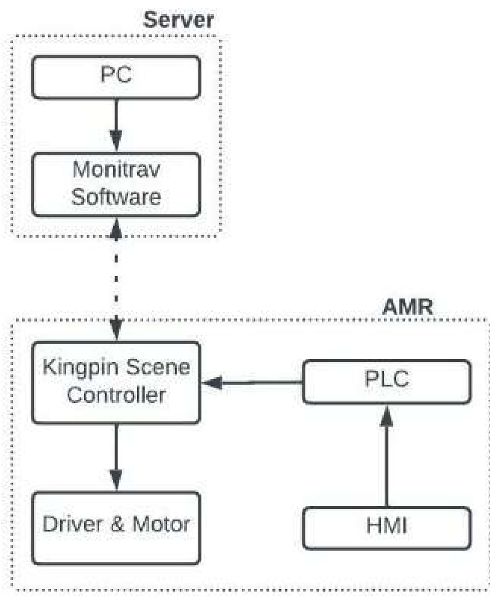

Fig 5.4 Semi Autonomous Mode – Online

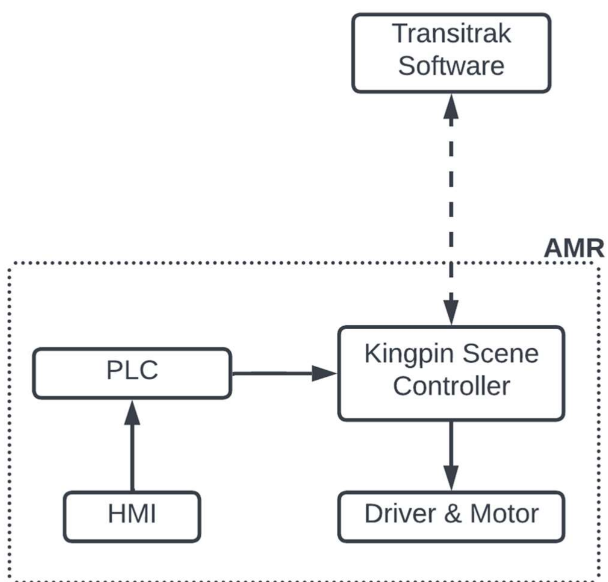

Fig 5.5 Semi Autonomous Mode – Offline

5.5 MANUAL MODE

The software and hardware architecture are same for both online and offline mode of AMR. The person who has the joystick completely takes control of the AMR. The wireless communication between the two devices help to control the vehicle. Even using the joystick to control the vehicle, the sensors and indicating systems are active and will always looks for the collision safety with any kind of the obstacles. The AMR's live location can be seen using the Monitrav Software for online mode and Transitrak software for offline mode. The Fig 5.6 depicts the architecture for the Manual Mode – Online and Fig 5.7 shows the architecture for the Manual Mode - Offline

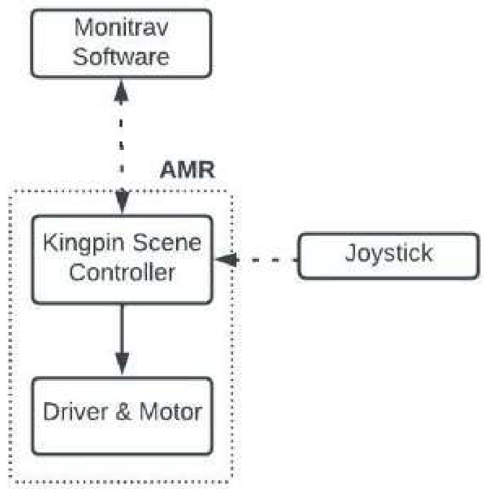

Fig 5.6 Manual Mode – Online

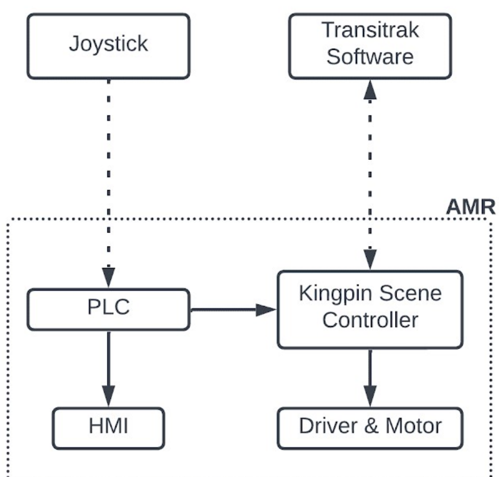

Fig 5.7 Manual Mode – Offline

CHAPTER 6

CONTROLLER SELECTION

In this chapter, the controller selection is discussed. The controller is the heart of the AMR, and its selection must take into account a variety of factors like as rated voltage, power consumption, available communication ports, and compatible software. According to the AMR architecture, the controller processes data from multiple sensors, including 2D LiDAR, where the input is in the form of point clouds, where the controller analyses the data and updates the local map before sending the signal to the driver through RS485 connection. In addition, data from ultrasonic sensors is evaluated and suitable functions are sent to the motor driver. Likewise, data from the bumper sensor is analysed within the controller and a control signal is sent to the motor driver.

6.1 MINIMUM REQUIRED SPECIFICATIONS

A controller should have an operating voltage of less than 48 V and a maximum power consumption of 15 W. To connect with the PLC, sensors, and other components, basic communication interfaces like as USB, RS-232, and RS-485 are required. According to the general structure of the AMR, the controller's allotted dimensions are about 200 mm in length, 200 mm in width, and 80 mm in height.

Table 6.1 Minimum Required Specifications

Description	Values
Rated Voltage	24 V
Rated Power	15 W
Communication Ports	USB, RS-242/485, Ethernet
Operating Software	Compatible with the Controller

Furthermore, the operating environment for the AMR Controller, according to the enclosure, is between - 25 and 70 degrees Celsius. Finally, the controller must reach an accuracy of roughly 10 mm. Table 6.1 shows minimum required specification of controller.

6.2 CONTROLLERS COMPARISON

After extensive research of numerous firms worldwide, two organisations named Guidance Automation and Kollmorgen were chosen for the comparison because their technological specifications closely fit the demand. Because data is collected from the DPMS through a Wireless Module in Fully Autonomous Mode, the controller must have an Ethernet connection in order to receive the data. Similarly, in Manual Mode, the joystick controls the AMR wirelessly, therefore the controller must be flexible enough to regulate the speed and radius of curvature at the bends. Fig 6.1 and Fig 6.2 shows the Kingpin Scene Controller and Kollmorgen CVC 700 respectively.

Fig 6.1 Kingpin Scene Controller

Fig 6.2 Kollmorgen CVC 700

Table 6.2 Controllers Comparison

Make	Guidance Automation	Kollmorgen
Model Name	Scene Controller	CVC 700
Differential	Up to 4 wheels	Up to 4 wheels
Communication & I/O Interface	DVI-I Connector (Up to 1920 x 1080) – 1 RS-232/422/485 – 4 RJ45 – 1 USB 3.0 – 1 USB 2.0 – 3 CAN bus / CAN open Connection – 9 W D-Sub Male Connector – 2	Wi-Fi Bluetooth CAN - 3 LAN - 2 RS232/422/485 - 1
Operating Voltage	24 to 48 V DC	24 to 48 V DC
Power Consumption	8.3 W	6 W
Navigations Compatible	Natural Feature Reflector Navigation Spot Navigation	Natural Feature
2D/3D Laser Scanning	Pepperl & Fuchs R2000 Sick S300/S3000	Kollmorgen Safety Scanner
Weight	860 g	940 g
Dimensions (LxWxH) mm	150 x 105 x 56	195 x 125 x 50
Protection	IP65 Over voltage protection (up to 51V) Over Current Protection (120V/20A) Reverse polarity protection	IP65 Over voltage protection (up to 51V) Over Current Protection (120V/20A) Reverse polarity protection
Operating Environment	-25 to +70 °C	-30 to +55 °C
Software Used	Scene Software	NDS Solutions

Table 6.2 depicts the detailed technical comparison between the two controllers, it is clear that the controller made by Guidance Automation have many advantages over the Kollmorgen. Hence, considering all the factors starting from the Kingpin Scene controller is chosen for the AMR.

CHAPTER 7

NAVIGATION SOFTWARE

In this chapter, various Navigation Softwares are discussed. The Navigation Software controls the movement of the vehicles between the home position, loading stations, and dropping stations. The navigation software systemizes, controls, and navigates the vehicle in accordance with the requirements in the assembly lines. There are two types of navigation software, each designed for a certain mode. AMR's online and offline modes use various types of architecture. Because the software module is only compatible with their own Controllers, the firms who sell AMR Controllers also sell navigation software.

Guidance Automation and Kollmorgen are two firms that provide navigation software. They also supply system manager software, which essentially handles fleet administration, as well as auxiliary tools to build and improve maps for upload to the controller.

7.1 ADOPT SCENE SOFTWARE

This software is provided by Guidance Automation, the purpose of this software is to refine the map generated initially with the help of 2D LiDAR. The initial map contains many irregularities and been roughly generated. The rough map will be uploaded to the Adopt Scene Software and refined with the tools provided by the software. This map will be uploaded to the Kingpin Scene Controller for its reference while driving the AMR. The Fig 7.1 shows the Adopt Scene Software.

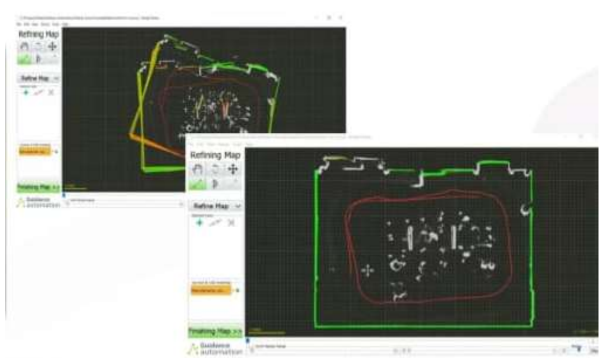

Fig 7.1 Scene Software

7.2 MONITRAV SOFTWARE

Guidance Automation also provides the Monitrav Software. This software is used when the AMR is in online mode, and it allows you to control up to 10 vehicles at the same time. It's the system manager software that pulls data from the database and sends it to the AMR controller via wireless communication. It does the traffic management job within the 10 vehicles as per its task and routings. As the software is only compatible when the AMR is connected to the server, a separate centralised server must be deployed within the facility. Monitrav runs on that server, obtaining data from the database and managing the fleet of ten vehicles in accordance with the previously mapped path. The Fig 7.2 shows the Monitrav Software.

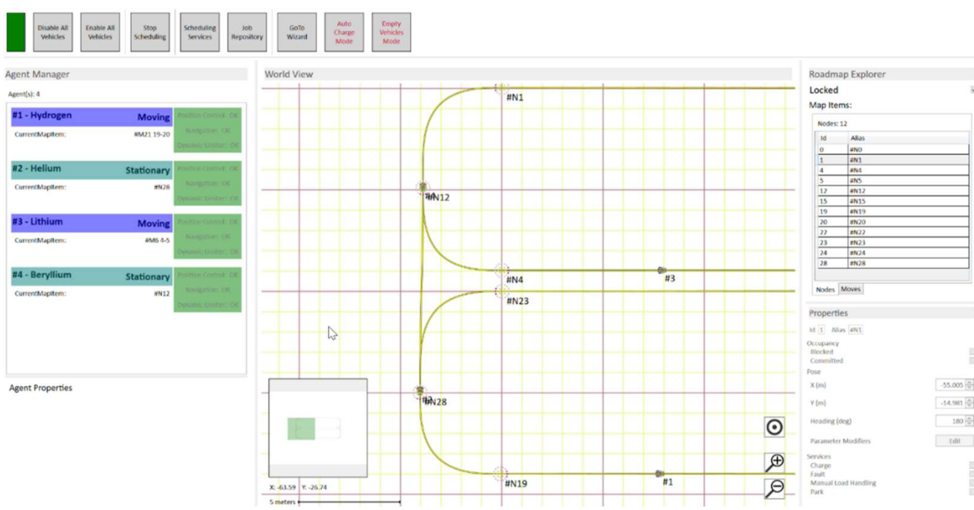

Fig 7.2 Monitrav Software

The Monitrav can transfer data from the database, especially the line number and the material to be loaded, to the AMR Controller, where it may be retrieved using a PLC and shown on the HMI. Monitrav is rather pricey because to its multiple capabilities and compatibility with up to ten AMR's.

7.3 TRANSITRAK SOFTWARE

The Transitrak Software is mainly developed for offline mode AMR, the AMR will have the HMI to take command from the operator. The data from the HMI is processed by the Transitrak software which runs on the AMR controller. Except for the fully autonomous mode, the AMR runs completely in offline as there won't be any transfer of data from external agent. Although it is possible to monitor the AMR's location on the map with the help of a PC or

Laptop with a Wi-Fi connection as the Transitrak software's extension can be installed on a windows-based system. The Fig 7.3 shows the Transitrak Software.

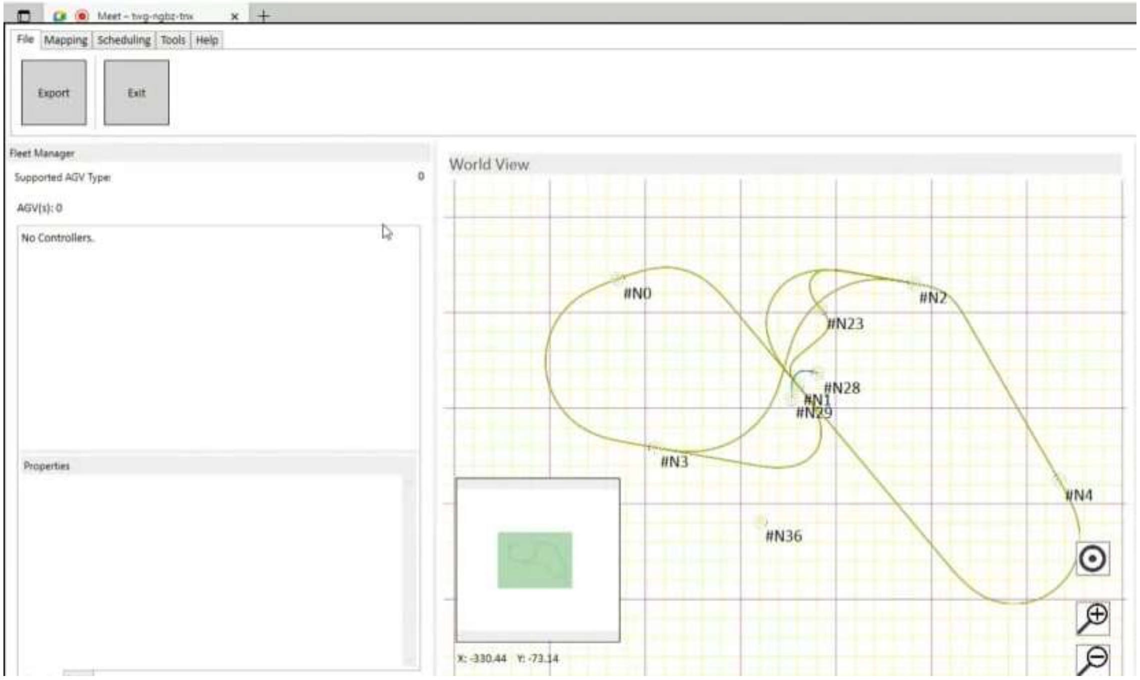

Fig 7.3 Transitrak Software

7.4 NDC SOFTWARE

This software is provided by Kollmorgen. The objective of this software is to act as a fleet manager and take control of AMR motion. Initially a 3D CAD model of the entire plant have to feed into the NDC software, it takes the following data and layout the map, to navigate the vehicle. The Fig 7.4 shows the NDC software provided by Kollmorgen.

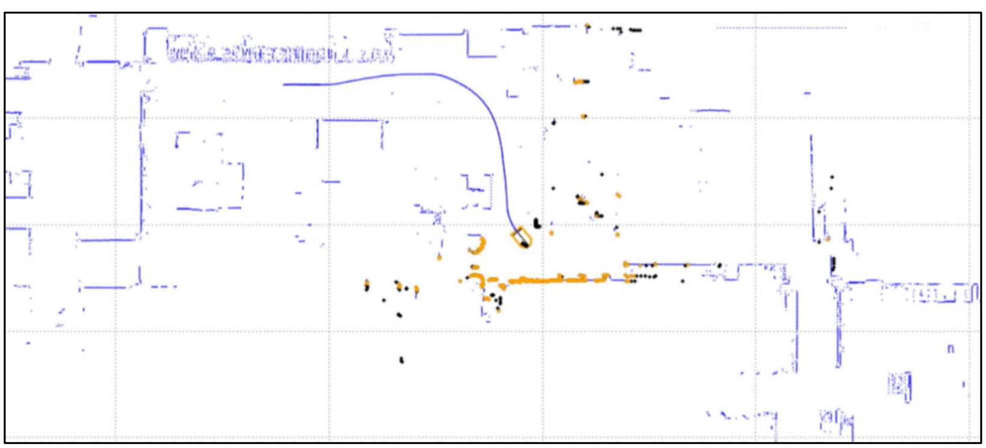

Fig 7.4 NDC Software

The pathway of the AMR should be drawn with the reference from the map. The next step is to set out destination points at which the AMR delivers the materials. The list of operations is drawn from the database for the fully autonomous mode, whereas for the semi – autonomous mode, the commands are provided via HMI by an operator. In case of numerous vehicles, by the help of all this information NDC software does traffic management and take control of individual AMR.

CHAPTER 8

SELECTION OF COMPONENTS

In this chapter, components like sensors, motors, drivers, battery and its management systems, interaction and interfaces are selected and their specifications are listed.

8.1 SENSORS IDENTIFIED

An AMR's sensors are similar to its eyes. Sensors, when paired with sensing software algorithms, enable an AMR to comprehend and navigate its surroundings, detect and avoid collisions with objects, and offer information about the robot's location.

Cameras, lasers, and LiDAR, radar, sonar, infrared, touch detectors like whiskers or bump sensors, GPS, and proximity sensors are examples of exteroceptive sensors. Accelerometers, gyroscopes, magnetometers, compass, wheel encoders, and temperature sensors are examples of proprioceptive sensors that interact with the robot itself. Sensors can be classified into a variety of categories, including active and passive sensors. It's also worth noting that the lines among exteroceptive & proprioceptive perception can occasionally blur.

It's a difficult task to choose the proper sensors when there are so many available. Type of application, definition of navigation and localization characteristics, environment in which the AMR will function, available computing capacity to perform sensing algorithms, choice of different algorithms, such as sensor fusion, energy consumption, and prices are all factors that influence the decisions. When balancing across all selection factors, a compromise is invariably made.

Table 8.1 Sensors Identified

Sensor	Quantity
LiDAR	1
Ultrasonic Sensor	10
Bumper sensor	2

Sensor quality is determined by a variety of factors like dynamic range, precision, resolution, linearity, field of view, and many more. Sensors for defence applications are quite costly and can fulfil very high specifications. However, in most non-defence applications, when sensor specification, faults, and biases are poor, the choice of algorithms that execute the software is critical. Sensors required for the AMR are listed in the table 8.1.

8.2 LIDAR

LiDAR is a remote sensing technique that uses a laser to illuminate a target and then analyses the reflected light to determine its distance. As a result, the sensor is able to compute the proper distances between objects. Only one laser beam is required for a 2D LiDAR sensor. To capture data on the X and Y axes, 2D sensors frequently employ a spin movement. 2D sensors are well-suited to detection and range activities.

Table 8.2 LiDAR Minimum Requirements

Specification	Values
Measurement range	30 m
Scanning angle	360°
Angular resolution	Below 0.1 °
Resolution	Below 1 mm
Weight	Below 1 kg
Enclosure rating	IP65
Communication Interfaces	Ethernet

The majority of modern AMRs have two LiDAR’s to provide 360-degree coverage. Because the load creates the obstruction, it has one in the front and one in the back. However, by positioning the load tray one story above the LiDAR surface, a single LiDAR can be used while also covering the whole angle. Four Aluminum rods are positioned at the corners to raise the payload significantly. Only these four rods are blind areas for the LiDAR, which is positioned perfectly in the middle. The minimum required specifications are listed in the table 8.2.

These specifications must be satisfied when choosing a LiDAR sensor for our AMR. After evaluating the plant layout and consulting with the plant supervisors, they were developed. Following the requirements research, key suppliers across the country were identified, and two large manufacturers were found. Pepperl + Fuchs (P & F) and Sick are their names. The Fig 8.1 and Fig 8.2 shows the LiDAR sensors of P & F and Sick respectively.

Fig 8.1 P & F LiDAR

Fig 8.2 Sick LiDAR

Table 8.3 LiDARs Comparison

Make	P & F	SICK
Measurement range	30 m	30 m
Scanning angle	360°	270°
Angular resolution	0.014 °	0.5°
Resolution	1 mm	30 mm
Communication Interfaces	Ethernet	Ethernet
Dimensions	Housing width - 106 mm Housing height - 116.5 mm	Housing width - 152 mm Housing height - 106 mm
Weight	0.8 kg	1.2 kg
Housing material	ABS + PC + Aluminum	Aluminum die cast
Ambient operating temperature	–10 °C to +50 °C	–10 °C to +50 °C
Storage temperature	–20 °C to +70 °C	–25 °C to +50 °C
Type of light	laser diode	laser diode

The specifications of these two manufacturers were discovered and compared in table 8.3 after contacting their vendors through our organisation. Comparing these two LiDAR's manufactured by P & F and Sick, only P & F's OMD30M-R2000-B23-V1V1D-1L has the coverage angle of 360 degree.

Also, the angular and linear resolutions are better in it compared to Sick's S300 MODEL NO: S30B-3011GB. The weight is also much lower and is highly compatible for our requirement. So, P & F's LiDAR is selected and is to be mounted exactly at the center of the body of the AMR.

8.3 ULTRASONIC SENSOR

Ultrasonic sensors are needed all around the AMR for Safety. Any object detected within the range of the sensor is considered an obstacle and the vehicle should apply brakes. Here, as our AMR is preloaded with the Map of the workplace, it has the knowledge of existing walls and blockages.

Table 8.4 HC – SR04 Specifications

Specification	Values
Operating Voltage	5 V
Sensing Range	2 - 400 cm
Max. Sensing Range	450 cm
Measuring Angle	15 degrees
Frequency	40 kHz

To detect any immediate changes or temporary objects such as humans, these sensors come into play. So, the required range of the ultrasonic sensors is 1 meter minimum. Ultrasonic sensors compatible with Arduino can be used here with PLC. The Fig 8.3 shows the Ultrasonic Sensor. The Specification of HC-SR04 module can be found in table 8.4.

Fig 8.3 HC – SR04 Ultrasonic Sensor

8.4 BUMPER SENSOR

The Mechanical Bumper sensor for the AMR is a set of simple switches that allows us to detect a collision before it occurs. The sensor functions as an SPST switch. When the "whisker" collides with a foreign item, it makes contact with a nut close to it, sealing the connection and shutting off the motor by default. The Fig 8.4 shows the mechanical bumper sensor. The whisker will hit anything before the robot smashes into it if we install these mechanical bumpers to the AMR.

Fig 8.4 Mechanical Bumper Sensor

8.5 MOTOR REQUIREMENTS

Building a mobile robot is a simple endeavour, and choosing the proper motor is an important step in the process. The AMR is directed in the desired direction by the controller and the physical linear is done by motor. The decision is made based on the AMR's payload capacity that consumers require, and the Vehicle motion is decided after all characteristics are taken into account. Furthermore, the motor's power consumption is crucial for battery selection. Although the motor is appropriate for most common industrial AMR applications, actual motor, gearbox, and wheel dimensioning is a complicated calculation that depends on various factors:

- Robot's total weight when loaded
- Acceleration and deceleration to the maximum desired levels
- Inclination of the floor
- The floor harness creates rolling resistance
- Tire stiffness
- System friction

By considering all the factors, and observing the application area, the minimum requirements of the motors are derived.

Table 8.5 Motor Minimum Requirements

Description	**Representation**	**Values**
Vehicle mass	m_1	400 kg
Wheel outer diameter	D_1	156 mm
Wheel mass	m_{D1}	2 kg/pc
Number of wheels	n_1	2 pc
Rolling friction coefficient between wheel and floor	μ_1	0.01
System efficiency Drive mechanism efficiency	η	85 %
Floor slope Maximum angle of floor slope	α	0 °
Variable Operating speed	V_1	30 m/min
	V_2	90 m/min
Acceleration / deceleration time	t_1	7 s
Stopping accuracy	Δl	10 mm
Safety factor	S. F	1.5

The table 8.5 lists the motor's minimum requirements for AMR. From this table, the motor calculation is made.

8.5.1 Torque Calculation

The resistance of any physical object to any change in speed from the perspective of the rotational axis is known as load inertia, or moment of inertia as shown in equation 8.1. For a rotational load, it is the product of its mass and the square of the mass's perpendicular distance from the axis.

JL = (m1 + (1/2) mD1 × n1) × (D1 × 10-3 / 2)2 (8.1)

= (400 + (1/2) × 2 × 2) × (156 ×10-3 / 2)2

= 2.446 [kg·m2]

The distance divided by the time is used to calculate speed as per the equation 8.2. Acceleration time must be taken into account when using stepper or servo motors.

Required Speed (Vm)

$$Vm1 = (V1) / (\pi\ D1 \times 10\text{-}3)\ (30) / (3.14 \times 156 \times 10\text{-}3) \qquad (8.2)$$

$$= 61.24\ [r/min]$$

$$Vm2 = (V2) / (\pi\ D1 \times 10\text{-}3)\ (90) / (3.14 \times 156 \times 10\text{-}3)$$

$$= 183.7\ [r/min]$$

Acceleration torque is made up of inertia and acceleration rate, as shown in equation 8.3. If the values are known, this is used to determine the acceleration torque.

Acceleration Torque (Ta)

$$Ta = JL\ (Vm / (9.55 \times t1)) \qquad (8.3)$$

$$= (183.7 / (9.55 \times 10))$$

$$= 4.705\ [N\cdot m]$$

The acceleration torque or deceleration torque must always be specified whenever the motor speed is changed. By multiplying the total of load torque and acceleration torque by the safety factor, the needed torque is computed as per the equation 8.4.

Required Torque (T)

$$T = (Ta + TL)\ (\text{Safety Factor}) \qquad (8.4)$$

$$= (4.705 + 3.633) \times 1.5$$

$$= 12.51\ [N\cdot m]$$

The product of force and the distance between the centre of rotation and the acting is defined as Torque. This is shown in equation 8.5. In order to calculate load torque as per the equation 8.6, firstly identify the force in the system as well as the logical distance between the motor shaft and the location where the force is acting. The stopping accuracy of the motor also calculated using the wheel diameter as shown in equation 8.7.

Load Torque (F)

$$F = 9.8\ ((m1 + n1 \times m\ D1) \times (\sin\alpha + \mu 1 \cos\alpha) + (m2 + n2 \times mD2) \times N \times (\sin\alpha + \mu 2 \cos\alpha)) \qquad (8.5)$$

$$= 9.8\ ((400 + 2 \times 2) \times (\sin 0 + 0.01 \times \cos 0) \times (\sin 0 + \times \cos 0))$$

= 39.59 [N]

TL = (F × D1 ×10-3) / (2 η × 0.01) (8.6)

= (39.59 × 156 ×10-3) / (2 × 85 × 0.01)

= 3.633 [N·m]

Required Stopping Accuracy

θ = Δl (360° / π D1) (8.7)

= 10 × (360 / (3.14 × 156))

= 7.349 [deg]

Other requirement(s) – Electro-Magnetic Brake

Hence, the required torque is 12.51 Nm, calculated with 1.5 times safety factor and 85 % efficiency.

8.5.2 Motor Comparison

As per the requirement and results from the calculation, the motor selection is made between the RoboteQ and Electro craft.

Table 8.6 Motors Comparison

Make	RoboteQ	Electro Craft
Model Name	RoboteQ 060LDB300	RP34-313V48
Operating Voltage (Vdc)	48 V	48 V
Nominal Current	10 A	11.4 A
Rated Torque	1.28 Nm	1.59 Nm
Torque at Wheel	11.52 Nm	14.31 Nm
Speed	3000 RPM	2600 RPM
Rated Power	480 W	547 W
Weight	15 kg	4.1 kg

Frame Size	60 mm	86 mm
Dimensions (WxHxL)	60 x 60 x 102 mm	86 x 86 x 139.7 mm
Gear Box attached	Yes	External Gearbox Required
Driver available from the same make	Yes	Yes

The table 8.6 lists the comparison between the two motors. The Nidec CTD 089LDA30XROB Motors/Gearbox/Brake and wheel assemblies are suitable for the application and providing the necessary drivers to connect with the controllers. The motor is fitted inside a slim 160 mm long, 89 frames, and it can produce 29 Nm of continuous torque at the output of its precise, ultra-silent 9:1 Shimpo gearbox. The 48 V motor spins at 3000 RPM max, giving the robot a top speed of 2.7 m/s on the ground with its 156mm wheel. A mechanical brake is included in this motor variant. The Nidec also provides a wheel with a diameter of 156 mm and ESD-resistant layers, which is ideal for our use inside our plant.

8.6 MOTOR DRIVER SELECTION

Nidec Company provides also provides the motor with the BLDC motor driver. As a result, no separate driver search is required. There are two channels in this Nidec SBLM2360T driver, each of which gives 30 A of power to the motor from a variable battery source ranging from 48 V to 60 V.

Table 8.7 Motor Driver Specifications

Description	Values
Max Voltage	60 V
Number of Channels	2
Max Amps per Channel	30
Continuous Amps per Channel	20
Communication	RS485, RS435, USB, CAN bus
Rotor sensor	Encoder

Max Analog Inputs	8
Max Digital Inputs	10
Max Digital Outputs	4
Max Pulse Inputs	8

Additionally, it has cooled coils and a heat sink. Nidec also supplies the appropriate cables and wires for connecting the various components. The detailed specification of the motor driver is listed in table 8.7.

8.7 BATTERY

Battery acts as a source of electric power for an autonomous mobile robot. It drives the entire system. Battery must provide power for autonomous mobile robot is expected to work around clock. So, the selection of battery and its associated system is an important step in design of autonomous mobile robot. The factors considered for selecting a battery for autonomous mobile robot are operating time, power consumption of the components, battery chemistry.

8.7.1 Operating Time

Operating time of the AMR places a major role in the selection of the battery. Battery drains proportional to the operating time. If the operating time of the AMR is higher, the battery has to be selected with relatively high capacity. The operating time of the AMR for this application is calculated and explained in chapter 4.

8.7.2 Battery Chemistry

The two primary battery chemistries that are in use today are lead-based and lithium-based chemistry. The former is intended to be depleted until they are nearly dead, then recharged without causing any harm to the battery. Lithium-ion batteries have a substantially higher energy capacity than lead-ion batteries of the same weight. Another disadvantage is that lithium-ion batteries cannot be depleted as deeply as other battery chemistries. However, a type of lithium-ion battery known as a lithium iron phosphate battery (LiFePO4) outperforms lithium ion in terms of cycle life (it lasts 4-5 times longer) and safety. This is a significant benefit since lithium-ion batteries can overheat and even catch fire, but LiFePO4 does not. So LiFePO4 is chosen for this application.

8.7.3 Power Consumption of Each Component

The overall capacity of the battery is calculated with considering the power consumption of each component. All the components even the necessary sensors and miscellaneous components like LEDs depends on battery for their proper functioning. So, care has been taken for the selection of the battery.

Table 8.8 Power Consumption of Each Component

Component	Voltage (V)	Current (A)	Total Current (For Each Device) (A)	Power Consumption (W)	Duration (hrs.)	Energy (Wh)
Motor	48	10	20	960	4	3840
Controller	24	0.6	0.6	14.4	8	115.2
LiDAR	24	0.4	0.4	9.6	4	38.4
Ultrasonic Sensor	5	0.15	1.5	7.5	4	30
HMI	24	0.23	0.23	5.52	8	44.16
PLC	24	0.5	0.5	12	8	96
Driver	48	0.3	0.3	14.4	4	57.6
BMS	48	0.3	0.3	14.4	8	115.2
Ambient Light	5	0.4	0.4	2	8	16
Mechanical Bumper Sensor	5	0.4	0.8	4	8	32
Total		13.28	25.03			4384.56

The overall capacity needed for operation of the AMR including safety factor is 200 Ah. Table 8.8 lists the total power consumption.

8.7.4 Battery Selection

Considering the above-discussed factors, the battery with desired capacity, cycle time, and energy is selected from Pinnacle batteries.

Table 8.9 Battery Specifications

Description	Values
Nominal Voltage	48 V
Nominal Capacity	200 Ah, 9600 Wh
Battery Type	Prismatic LiFePO4
Energy	7200 Wh
Cycle Life	≥ 2000 cycles @ 80 % DOD
Standard Charge Current	≤ 40 A
Max Charge Current	≤ 100 A
Continuous discharge current	≤ 100 A
Pulse discharge current	≤ 200 A
Over-discharge protection cut-off voltage	37.5 V
Discharge Temperature	- 4 to 140 ºF (-20 to 60 ºC)
Charge Temperature	32 to 113 ºF (0 to 45 ºC)
Storage Temperature	77 ± 3 ºF (25 ± 3 ºC)

The table 8.9 depicts detailed specification of the selected Pinnacle batteries.

8.8 BATTERY MANAGEMENT SYSTEM

A Battery Management System (BMS) is a piece of technology that is dedicated to the supervision of a battery pack, which is an assembly of battery cells electrically organized in a row x column matrix configuration to enable delivery of a targeted range of voltage and current for a period of time against expected load scenarios. It is used of monitoring the battery, providing battery protection, estimating the battery’s operational state etc., Overall BMS acts a safety bridge and filter between battery and other components. Roboteq's BMS10x0 model BMS, shown in Fig 8.5 is suitable for our application. It can manage batteries within the range of 12V to 60V and 10 to 1000Ah capacity. It has built-in Precision voltage sensors and current sensors and supports USB, CAN bus, and RS485, PWM or Bluetooth communication.

Fig 8.5 Battery Management System

8.9 ROBOPADS CHARGE SYSTEM

A Robopads charge system, shown in Fig 8.6 is made up of a charge contacts base that is usually attached to the floor and a collector unit with extensible contacts that is put on the robot. Unlike typical spring-loaded contact, Robopads uses high intensity magnets to autonomously regulate the connection and separation operation, requiring no additional power from the mobile system's batteries.

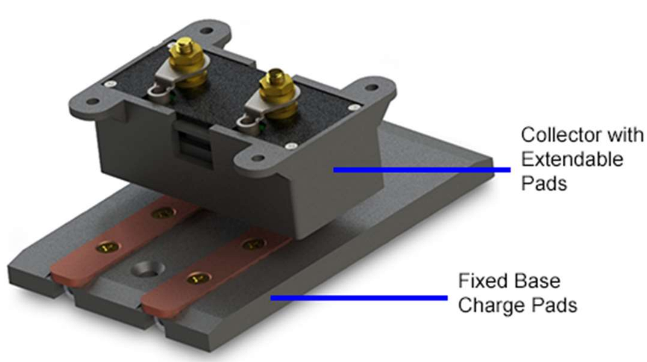

Fig 8.6 Robopads Charge System

Table 8.10 Robopads Specifications

Dimensions Base	140 x 90 x 10 mm
Dimensions Collector Extended	90 x 56 x 42 mm
Dimensions Collector Retracted	90 x 56 x 32 mm
Extension range	10 mm
Current	100 A max, 70 A continuous
Voltage	200 V max
Extension/Retraction speed	20 ms typical
Contact Pressure	1.5 kg typical
Left/Right alignment tolerance	+/-5 mm
Hall sensor voltage	4.5 to 24 V, open collector output
Max up/down cycles	>100,000

The powerful attracting effect of the magnet results in a high pressure, high quality electrical contact. As the robot advances away, the magnet's repelling function actively causes the pads retractions. Roboteq’s RPKIT90100 Robopads is selected which specification has shown in table 8.10.

8.10 CHARGING STATION

The charging station has one of the contacts of the Robopads and helps it connect to the power supply. The charging station is fully automatic, thus eliminating any manual errors. The charging station can be kept anywhere in the industry but ideally it is kept in the home position of the mobile robot.

Table 8.11 Charging Station Specifications

Description	Values
Output Voltage Nominal	48 V
Output Current Nominal [A]	100 A
Mains Phase	3 Phase
Power Consumption	6315 W
IP Enclosure	IP20
Charging Times (8 Hours cap. ah/5h)	833
Cooling	Yes

The specification of the selected charging station from micro power group is shown in table 8.11.

8.11 HMI

In the industrial design field of human–computer interaction, a User Interface (UI) is the point at which humans and machines interact. The goal of this interaction is for the human to be able to properly run and manage the machine, while the machine provides back data that aids the operators' decision-making process. One type of User Interface is Human Machine Interface (HMI). Siemens Simatic HMI (7.0 inch) can be used on the front and can be seen in Fig 8.7.

Fig 8.7 HMI

Our AMR needs a large HMI at its front for displaying instructions to the operator in fully autonomous mode. It receives commands from the operator in semi-autonomous mode. So, minimum 7-inch HMI that is compatible with our PLC can be used in our AMR.

Table 8.12 Siemens HMI Specifications

Description	Values
Display width	154.1 mm
Display height	85.9 mm
Horizontal image resolution	800 pixels
Vertical image resolution	480 pixels
Number of function keys	8
Keyboard	Onscreen Keyboard
Processor type	ARM
Communication Protocols	PROFINET, Ethernet/IP

The specifications of the selected HMI are shown in Table 8.12

8.12 PLC

A PLC is made up of a central processing unit (CPU) and input/output (I/O) modules. The majority of PLC designs are modular, which implies that numerous I/O modules may be stacked in a single PLC. The I/O modules can be installed in various physical places and linked together via data cables. PLC is required in our AMR for interfacing with external devices like as HMI, emergency stop buttons, and indicators. Fig 8.8 depicts a Siemens Simatic S7-1200 PLC.

Fig 8.8 Siemens Simatic S7-1200 PLC

Table 8.13 Siemens PLC Specifications

Description	Values
Programming package	STEP 7 V17 or higher
Rated Voltage	24 V DC
Rated Current	500 mA; CPU only
Number of digital inputs	14
Number of digital outputs	10
Number of analog inputs	2
Number of analog outputs	0
Communication Protocol	PROFINET

The primary responsibility of the PLC includes, importing data from the database to the programme operating within the controller through a wireless module. After reviewing the essential criteria, Siemens Simatic S7-1200 is chosen. The specifications of the chosen PLC are shown in table 8.13.

8.13 E-STOP BUTTONS

Another, interaction module which is necessary in all mobile robots are emergency stop buttons. These buttons have the most priority over any other modules in applying brakes to the motors. Generally, it is present in the robot to avoid any harm made by it. It is provided in many numbers around the robot, and must be easier to press. So, in the AMR the emergency stop button is placed one near the HMI, which can be activated by a standing man using his hands. Another button is placed in the backside bottom for pressing with legs. Schneider's XALD328 Button can be used in both sides for our AMR. The emergency stop button is shown in Fig 8.9.

Fig 8.9 E-Stop Button

8.14 VISUAL AND AUDIBLE INDICATORS

Light strips and other visual indicators must be utilised all around the robot, particularly for interaction while turning and halting. When the AMR intends to stop, the RGB lights in the strips are configured to glow red. When the operation mode changes, the pattern of the lights changes as well. There are signalling lights on all four corners. Ambient lighting should be used so that the operator in the workplace is not disturbed. Also, a couple of speakers are used in the AMR for audible indication. The Fig 8.10 shows LED strips that is used in the AMR.

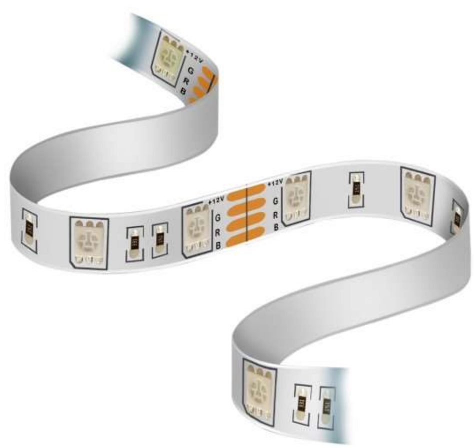

Fig 8.10 LED Strips

8.15 JOYSTICK

In the Manual mode the AMR is controlled directly by the operator with the help of joystick. The joystick is connected to the PLC, inside the robot through wireless module. The switches on the joystick are mapped to each direction of the AMR. Brakes can also be applied manually. Eleven digital buttons, two analogue triggers, two analogue sticks, and a digital D-pad are included in a typical Xbox 360 controller. Four digital action buttons are located on the controller's right face: a green A button, a red B button, a blue X button, and a yellow Y button. The right analogue stick is in the lower right, the digital Dpad is in the lower left, and the left analogue stick is on the left face. The Fig 8.11 shows joystick that is used for the AMR.

Fig 8.11 Joystick

8.16 WI-FI MODULE

The data from the DPMS must be provided to the PLC in fully autonomous mode in order to locate the shortage. Since the PLC will be installed within the robot, this transmission must be wireless. As a result, a wireless module must be interfaced with the PLC in order to retrieve data from the database. This wireless module can also retrieve data from a joystick in manual mode. The antennas are left outside the AMR for receiving and sending the signals. The server PC’s Wi-Fi is extended up to the working range of the AMR so that the communication is constant. The Wi-Fi module can be seen in Fig 8.12.

Fig 8.12 Wi-Fi Module

8.17 BARCODE SCANNER

The AMR is equipped with a barcode scanner for authentication purpose. After loading the trays into the slots, the operator must scan the barcode on each tray. The AMR receives acknowledgement and proceeds through with delivery only once the code fits the requirement. This is done to avoid squandering time due to human mistake. If the tray code does not match, the HMI shows "wrong product" and alerts the operator, and it does not move until the trays are properly placed. The Fig 8.13 shows the barcode scanner that is used in the AMR

Fig 8.13 Barcode Scanner

8.18 SERVER PC

A PC must be placed near the storage area for Fleet management (Online mode). The main software runs on the PC, while an extension runs on the robot's controller. The Wi-Fi module allows for entirely wireless connection. The PC can also be utilised in semi-autonomous mode to select the assembly line or reorder the queue for our convenience. The Industrial PC and monitor can be seen in Fig 8.14 and 8.15 respectively.

Fig 8.14 Industrial PC

Fig 8.15 Monitor

Using a specific software on the server PC, the AMR may be tracked in all three modes. A keyboard and mouse, as well as a CPU and monitor, are required for this configuration.

CHAPTER 9

MECHANICAL DESIGN

In this chapter, the design of all components and its assembly is illustrated. The design is made completely with Solid works Software. SolidWorks is a solid modeller that creates models and assemblies using a parametric feature-based method developed by PTC.

The AMR chassis is built primarily of standard 25x25 mm special profile aluminum, which is commonly accessible. The AMR is supported by six wheels with two drive wheels attached with motor coupled gearbox in the middle and casters at each corner. The chassis is made up of two basic rectangular frames that are joined by a pivot to form a cantilever that distributes the AMR's weight and load evenly across all six wheels. Even on uneven conditions, the articulated chassis guarantees that all wheels remain in contact with the ground.

9.1 TOP FRAME

Top frame functions as a big surface for mounting or carrying weights. Almost no components are carried by the top, bigger frame. Two casters and a pivot that connects to the bottom frame make up this frame. The frame is entirely built of special profiles that have been machined to size. The top frame is shown in Fig 9.1.

Fig 9.1 Top Frame

9.2 BOTTOM FRAME

The chassis incorporates cantilevered wheels to transfer the load weight evenly across its six wheels. The cantilever permits wheel pairs to move up and down in relation to one another, allowing them to follow the slope of the floor, even if it is not exactly level. The entire carrying capacity, provided it is uniformly distributed, is equal to the lowest carrying capacity of the weakest element divided by the weight ratio, according to this concept. The motor mount was built and installed on the bottom frame in accordance with the manufacturer's motor design. As a result, the procedure is merely mounting the motors in the available area. The motor will drive the AMR and carry the full load in this case. It also includes needed component mounting slots and mounting locations, as well as easy installation and removal provisions in the AMR's bottom frame. The bottom frame is shown in Fig 9.2.

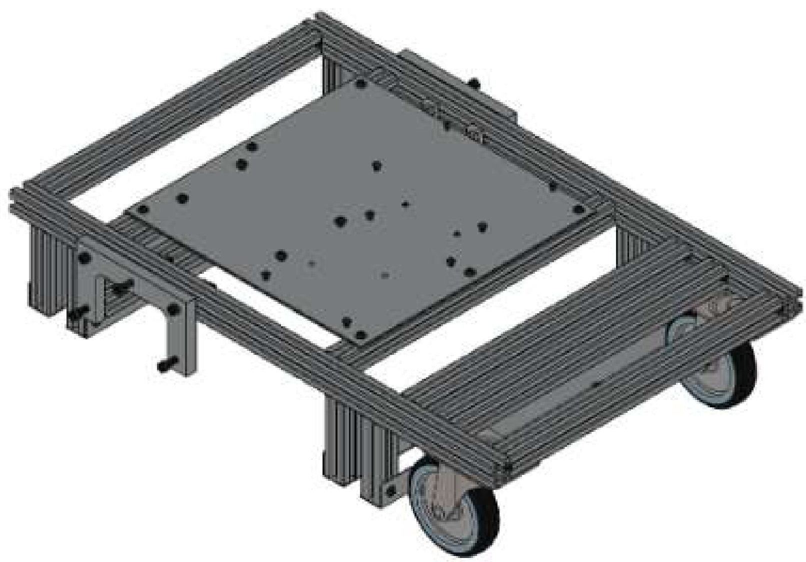

Fig 9.2 Bottom Frame

9.3 PIVOT GROUP

The pivot group serves as an AMR's suspension system, distributing load evenly across all six wheels. Also, in rare situations, the ground surface may be uneven. In this situation, the pivot group will produce some twisting force between each frame, increasing ground clearance but simultaneously requiring tyre contact on all four wheels to move the AMR. The pivot group is shown in Fig 9.3. Also, the combined assemblies are shown in Fig 9.4.

Fig 9.3 Pivot Group

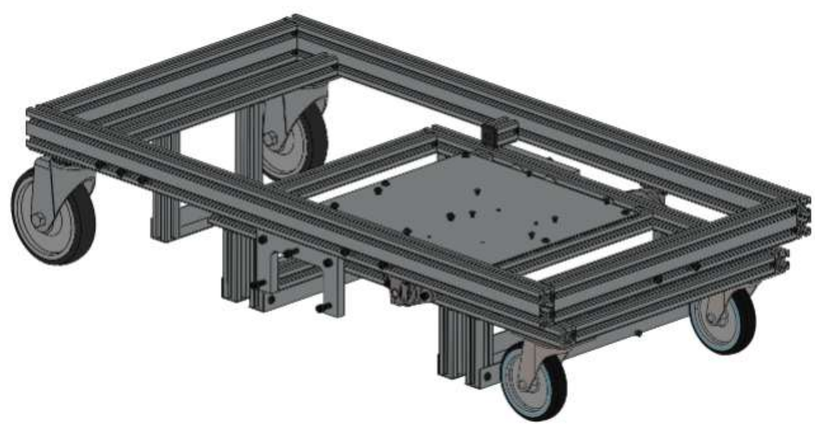

Fig 9.4 Combined Assemblies

9.4 OUTER BODY

The exterior body protects the internal components from touch with external objects while also preventing dust from entering the AMR. Misuse of the AMR will be shielded from intervention. While the outside body is composed of sheet metal, it will be lighter and require less machining. A door is provided in the top of the AMR to access the interior components, allowing for the maintenance or replacement of AMR components.

9.5 MOUNTING STANDS

The whole AMR has been elevated to some extent in order to allow individuals to easily lift things from the AMR. In this example, ergonomics research was conducted to raise the table to a particular height, and another reason for the elevation is to position the LiDAR at the centre of the AMR to observe the 360-degree range of detection, which eliminates the need for two LiDAR. This allows for the easy installation of the HMI at the table, as well as HMI accessibility.

9.6 TABLE

Trays must be placed on the table using guide ways to direct and hold the tray as it is being placed on the AMR's table. The table is built of 6 mm plate and is additionally supported by a cross member to prevent bending. The two tables put on top of the AMR-like rack structure are shown in Fig 9.5. Mounting stands raise the table, and an HMI sits in front of an AMR on the middle table.

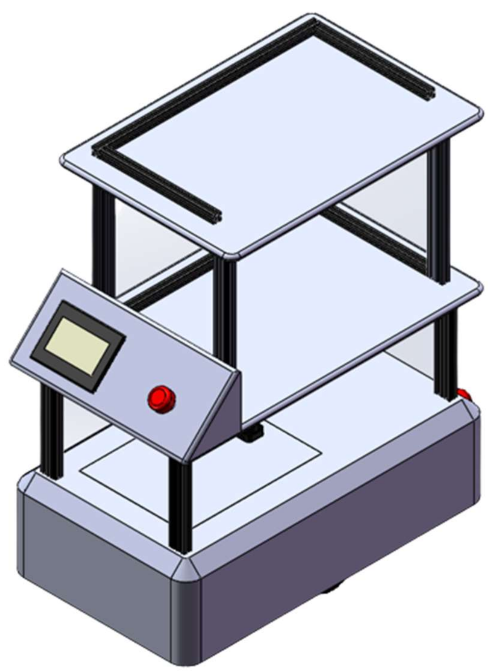

Fig 9.5 Assembly of mounting stand and tables

9.7 MOUNTING MOTORS

The drive kit includes a set of motors, gearbox, and wheels that can be readily attached to the bottom frame using bolts. The motor kit includes a motor driver and connecting wires, as well as a combination of motors. So, it's a simple plug-and-play module which can be seen in Fig 9.6.

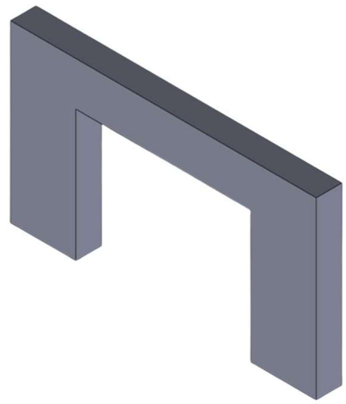

Fig 9.6 Motor's Mount Bracket

9.8 CHARGING PADS MOUNTING

The charging dock mechanism is beneficial in automated charging applications when manual involvement is limited. The charging dock is installed at the bottom of the AMR, allowing the AMR to travel close to the charging station. There are charging pads underneath, and when the AMR needs to be charged, the charging pad in the charging station and the dock in the AMR are magnetically attracted and wait for the signal from the controller. The charging will be completed after the controller passes the signal, and the charging pad will demagnetize and the charging dock will automatically disconnect.

9.9 FINAL MECHANICAL DESIGN

Table 9.1 Dimensions of the AMR

Description	Values
Length	1000 mm
Breadth	535 mm
Height	1068 mm
Height Including Tray	1468 mm

Ground Clearance	30 mm
Diagonal	1150 mm

The Fig 9.7 shows the final mechanical design of the AMR. The dimensions of the AMR are listed in the table 9.1.

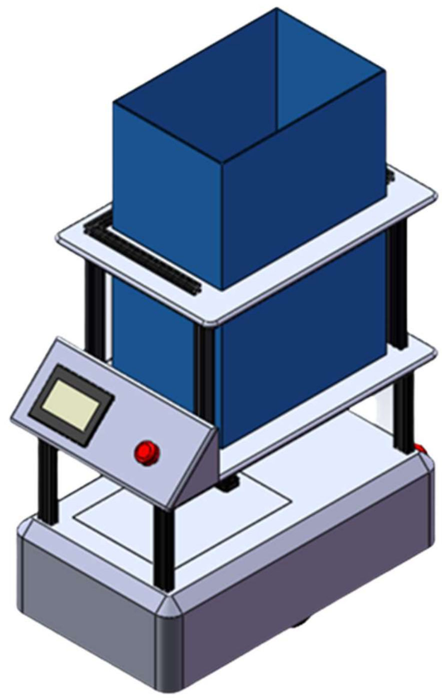

Fig 9.7 Final Mechanical Design

The design has been validated and verified. And this can be used as a reference for Simulation, Fabrication and Assembly.

CHAPTER 10

CONCLUSION

This chapter lists out the comparison of the different aspects of Pricol AMR 250 with the benchmarked Omron LD 250.

10.1 BENCHMARK COMPARISON

Various AMRs produced by different manufacturers has been studied. Omron LD 250 is chosen to be the benchmark because it correlates mostly with the target specifications and it one of the best AMRs available in the market.

Table 10.1 Benchmark Comparison

Factors	Requirement	Omron LD 250	Pricol AMR 250
Physical Characteristics			
Material	Aluminum	Aluminum	Aluminum
Dimensions (L x W x H)	1000 x 600 x 1000 mm	963 × 718 × 383 mm	1000 x 585 x 800 mm
Weight of the AMR (with Battery)	150 kg	150 kg	150 kg
Payload	250 kg	250 kg	250 kg
Mobility			
Maximum Speed	2000 mm/s	1350 mm/s	2000 mm/s
Maximum Rotation Speed	180°/s	180°/s	180°/s
Position Accuracy	X, Y axis: (+/-) 10 mm	X, Y axis: (+/-) 75 mm	X, Y axis: (+/-) 10 mm

	Yaw: (+/-) 1 deg	Yaw: (+/-) 2 deg	Yaw: (+/-) 1 deg
Wheels	2 Drive Wheels 4 Casters	2 Drive Wheels 4 Casters	2 Drive Wheels 4 Casters
Battery			
Output Voltage	48V DC	30V DC	48V DC
Capacity	180 Ah	72 Ah	200 Ah
Operating Time	5 hours	6 hours	8 hours
Recharge Time	6 hours	5 hours	6 hours
Battery Life Cycles	More than 2,000 recharge cycles (battery cell nominal)	2,000 recharge cycles (battery cell nominal)	2,000 recharge cycles (battery cell nominal)
Charging Method	Automatic	Automatic or Manual	Automatic or Manual
Operator Interface			
Screen / Touch Panel	7.0 In. HMI	3.5 in HMI	7.0 In. HMI
Button	On button Off button Brake-release button	On button: green Off button: red Brake-release button: orange	On button: green Off button: red Brake-release button: orange
Connectivity			
Wireless	IEEE 802.11 a/b/g	IEEE 802.11 a/b/g	IEEE 802.11 a/b/g
Ports	USB Audio Jack LAN	2 LAN	4 USB 1 Audio Jack 3 LAN

The comparison of the various characteristics of both AMRs are shown in table 10.1. The requirement is specified for reference.

10.2 CONCLUSION

In this project, an entire modelling of an Autonomous Mobile Robot, complete study of plant 1, and selection of components to build the AMR have been done. Many problems were encountered in the modelling and study. Manual transfer of materials requires a lot of time and energy to do it perfectly. To solve this problem, many solutions were provided and came up with one final concept. Compared to other commercial process in the market, our product seems to be less cost and more efficient. All the target specifications were added to the machine which meets the requirement of the application. Final model of the AMR was developed and all the motion constraints were specified. All the design and study were completely analysed and verified. This study can be used for further process such as Fabrication and Implementation.

10.3 SCOPE FOR FUTURE WORK

The future works includes, analysis of the above study, validating the 3D model, purchasing the required components, and fabrication. Then assembling each module of the AMR, testing and validating the performance and finally, implementation on the plant 1. For further development the AMR can be integrated with internet and can be used as IoT for Industry 4.0, also systemize the Pricol plant 1 and bring in an advanced material transportation system using several AMRs.

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ANNEXURE - I

BILL OF MATERIALS

In this chapter, the prices of all the components and accessories are listed after contacting the vendors. The prices are converted to Rupees in case of foreign vendors and listed. There are three categories in costing. Namely,

- Mechanical Parts
- Navigation Software
- Electronic Components

1.1 MECHANICAL PARTS

The major mechanical parts and its fasteners are aluminum profile, bracket, bearings, bolts and nuts.

Table 1.1 Mechanical BOM

SL No.	Part Name	Make	Qty	Cost/Unit	Cost (Rs.)
1	20 mm x 40 mm x 4000 mm Aluminum Profile	Misumi	3	3128.53	9,385.59
2	25 mm x 25 mm x 4000 mm Aluminum Profile	Misumi	3	1814.46	5,443.38
3	5 Series (Groove Width 6 mm), Low Profile Bracket	Misumi	200	42.14	8,428
4	25 series End cap Plug	Misumi	30	288	8,640
5	20 series End cap Plug	Misumi	30	114.44	3,433.2
6	Sealing Strip 1 meter	Misumi	5	50	250

7	M5 Insertion Nuts	Misumi	250	28	7,000
8	12 mm M5 Buttonhead Bolt	Misumi	250	26.3	6575
9	10 mm M5 Buttonhead Bolt	Misumi	100	3	300
10	35 mm M5 Buttonhead Bolt	Misumi	5	42	210
11	45 mm M5 Buttonhead Bolt	Misumi	5	42	210
12	50 mm M5 Buttonhead Bolt	Misumi	5	45	225
13	55 mm M5 Buttonhead Bolt	Misumi	7	45	315
14	65 mm M5 Buttonhead Bolt	Misumi	5	50	250
15	M5 Nylon Lock Nut	McMaster-Carr	2	160	320
16	Oversized Washer	McMaster-Carr	3	218.66	655.98
17	M5 Washer	McMaster-Carr	30	15.4	462
18	M4 8mm Buttonhead Screw	McMaster-Carr	1	11.24	11.24
19	4 in Shepherd Regent Caster	Shepherd Casters	2	2,211.4	4,422.8
20	6.25-inch Cardinal Caster	McMaster-Carr	2	211.4	4,422.8
21	12 mm Shaft Support	McMaster-Carr	2	1,713.34	3,426.68
22	Side Mounted Pillow Bearing	McMaster-Carr	2	1,150.14	2,300.28
23	12 mm Diameter Shaft 200 mm	McMaster-Carr	2	703.42	1,406.84

24	Imperial Bolt Bushing	McMaster-Carr	4	688.09	2,752.36
25	1 mm Bearing Shim	McMaster-Carr	2	500.36	1,000.72
26	26 mm x 26 mm x 305 mm Aluminum Corner Brace (1ft)	McMaster-Carr	1	209.19	209.19
27	26 mm x 26 mm x 610 mm Aluminum Corner Brace (2ft)	McMaster-Carr	4	366.27	1,465.08
28	610 mm x 610 mm x 4 mm Aluminum Plate		1	300	300
29	1000 mm x 600 mm x 4 mm SS Plate		2	245	490
30	Sheet Metal 1000 mm x 3000 mm x 3 mm		1	1,000	1,000
Total Cost					**75,311.14**

The table 1.1 shows the list of mechanical parts and their respective cost in Rupees.

1.2 NAVIGATION SOFTWARE

The Guidance Automation provides two kinds of software. Either of the software can be used according to the requirement. Currently, as the plant needs a single AMR, Transitrak Software is enough. The data from DPMS is alone transferred to PLC using external Wi-Fi.

Table 1.2 Software BOM

Software	**Cost (Rs.)**
Monitrav (Online mode)	15,57,520.00
Transitrak (Offline mode)	1,94,839.92

The quotes are received for the software from Guidance Automation and listed in table 1.2.

1.3 ELECTRONIC COMPONENTS

Controller and LiDAR contributes to the major part of the total cost as it is the key components of the AMR.

Table 1.3 Electronic BOM

Component	Vendor	Cost (Rs.)
Controller	Guidance Automation	3,48,498.50
LiDAR	Guidance Automation	2,48,797.50
Motors and Wheels	RoboteQ	1,90,000.00
Driver	RoboteQ	62,000.00
BMS	RoboteQ	39,000.00
PLC	Siemens	22,732.70
HMI	Siemens	25,507.09
Battery	Pinnacle Batteries	1,85,000.00
Emergency Stop Button	Schneider	400.00
Charging Dock and Charging Pad	RoboteQ	41,000.00
Joystick	Xbox	2,200.00
Ultrasonic Sensor	Robu	750.00
SMPS	Electronicscomp	720.00
Wireless Module	TP-Link	2,500.00
Barcode Scanner	Honeywell	12,000.00
Mechanical Bumper Sensor	Spark Fun	1,130.00
Ambient Lights	Hobby King	700.00
Total Cost (Offline mode)		**11,82,935.79**
Server PC	Lan ware Infotech	62,150.00
Monitor	ViewSonic	11,411.00
Total Cost (Online mode)		**12,56,496.79**

The table 1.3 shows the list of electronic components and their respective cost in Rupees.

1.4 TOTAL BILL OF MATERIALS

Table 1.4 Total BOM

	Online mode	**Offline mode**
Mechanical Parts	75,311.14	75,311.14
Navigation Software	15,57,520	1,94,839.92
Electronic Components	12,56,496.79	11,82,935.79
Total Cost (Rs.)	**28,15,766.93**	**14,53,086.85**

The table 1.4 shows the total bill of materials for both online mode and offline mode separately.