



AGV (automated guided vehicle) robot: Mission and obstacles in design and performance

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Abstract

The AGV (automated guided vehicle) was introduced in UK in 1953 for transporting. But nowadays, due to their high efficiency, flexibility, reliability, safety and system scalability, they are used in various applications in industries. In brief, the AGV robot is a system which typically made up of vehicle chassis, embedded controller, motors, drivers, navigation and collision avoidance sensors, communication device and battery, some of which have load transfer device. In this review paper, based on existing systems, the AGV structures are studied and compared from various points of view and analysis of the AGV structure is done for designer.

Keywords: AGV, automated guided vehicle, Robotics, automated guided vehicle

1- Introduction

Today's industries activity have merged with the robotic and automation world and day by day having the precise and better-quality product make the sense of using new technology. Between all types of robot, the AGV (automated guided vehicle) robot has the special place between others and improvement in technology helps this design to grow and become more helpful in various applications. The AGV robot is a programmable mobile robot integrated sensor device that can automatically perceive and move along the planned path[1] This system consists of various parts like guidance facilities, central

control system, charge system and communication system[2]. The initial used and Invention AGV is not clear exactly and was mentioned in different articles and reference for many times but the earliest time of using this system in industries is mentioned in 1950s [3] (Figure 1) and even mentioned in some reference that the first AGV in the world was introduced in UK in 1953 for transporting which was modified from a towing tractor and can be guided by an overhead wire [4].

AGVs are widely applied in various kinds of industries including manufacturing factories and repositories for material-handling. After decades of development, it has a wide application due to its high

efficiency, flexibility, reliability, safety and system scalability in various task and missions.



Figure 1: one of the Oldest AGV picture [5]

AGV operates all day long continuously that cannot be achieved by human workers. Therefore, the efficiency of material handling can be boosted by having the collaborating task with number of AGV [5]. In this case, administrator can enable more AGVs as the system is extensible. AGV has capability of collision avoidance and emergency braking, and generally the running status is monitored by control system so that reliability and safety are ensured. Generally, a group of AGVs are monitored and scheduled by a central control system. AGVs, ground navigation system, charge system, safety system, communication system and console make up an AGV system. [6]. In this Paper the design aspect and consideration for this type of robot reviewed and tried to give the reader critical hint about existing used technology in this domain. This paper was organized as bellow: the AGV Application is presented in section II. The AGV systems type and design shown in section III. Finally, the paper has concluded in section IV with the AGV systems overview.

2- AGV applications:

As flexible manufacturing system and logistics automatic transportation system rapidly developing and widely applying, a

huge demand for the transport equipment with flexibility, reliability and efficiency is created [7]. AGV system (Figure2) significantly reduced labor intensity, improved productivity and safety comparing with human workers.



Figure 2: The old AGV with wire mesh as the bumper sensor [7]

Consequently, it has an extensive popularity in the fields of industry manufacture, such as: warehousing, logistics, factory and hazardous locations which are mentioned as following:

2-1 Warehousing and logistics

Warehousing and logistics industry are the earliest application of AGV [8]. Traditional logistics industry mainly relies on manual labor (Figure 3).



Figure 3: MIR AGV robots [9]

With the rapid rise of e-commerce enterprises, some of the companies invested a lot to develop automated logistics systems. Some post offices introduced AGV in 1980s for transportation of packages [9] (Figure4).



Figure 4: Tzbot Warehouse Logistics AGV [10]

As a famous AGV client, some of the important one are mentioned below: Amazon (Figure 5), the biggest online retailer, has implemented tens of thousands of AGVs called Kiva across 10 U.S. warehouses for material-handling that normally completed by human workers (Figure 6), [11].



Figure 5: Kiva Warehouse AGV [12]



Figure 6: Amazon rolls out Kiva robots [11]

Another big logistics enterprise called Cainiao built the biggest robot distribution center of China in 2018. 350 AGVs work all day long in a 2000 square meter warehouse, distribute more than 500,000 packages every day [13].

2-2 Manufacturing

As a part of flexible manufacture system, AGV is one of the driving forces of growth

in manufacture lines. In order to improve the flexibility of the transport system, VOLVO deployed an assembly system that used 280 computers controlled AGVs as carriers. As a result, assembly failure and investment recovery time both had a significantly decline. Recently, AGVs not only have been widely used in assembly lines of automobile factories including GM, Toyota, Chrysler, and Volkswagen, but also used in many other industries for clean and safe transportation operation [8].

2-3 public service establishments

Flexibility is the most important feature in these fields such as library (Figure 7), hospital and airport because the form of the load is dynamic.



Figure 7: AGV Picker robot from inVia robotics [14]

AGVs are serving in hospital for medical service such as delivering food and drugs and collecting medical and biological waste and serving in airport for baggage transport.

2-4 Hazardous locations and special industries

AGV is also used in some places that dangerous for human to reach. AGVs are used in nuclear plants for radioactive material and nuclear waste handling. (Figure 8), Ontario nuclear power plants introduced AGVs to transport nuclear waste like spent rods in order to disposal them safely and accurately [8].



Figure 8: AGV operating in nuclear power plants **Error! Reference source not found.**

They are also used in pharmaceutical industries to handle hazardous products.

3- AGV TYPE

AGV has a variety of mechanical structures and navigation approaches. According to mechanical structures, it can be divided into 3 categories of: **Unit load AGV**, **Automated pallet truck** and **Tugger AGV** which are described as following [16].

3-1 Unit load AGV

Unit load AGV (Figure 9) typically equipped with a deck or container on it to carry pallets, shelves, rolls or many other forms of load. Some of the decks have power to lift and lower, while some of them have rollers in order to unload easily [17].

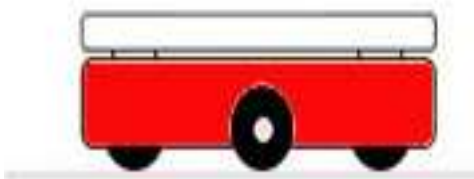


Figure 9: Unit load AGV

3-2 Automated pallet truck

Automated pallet truck (Figure 10) is specialized for transporting palletized loads. Some of them are forklifts that have power to lift up the load, while others can only carry loads on floor level [17].



Figure 10: Automated pallet truck

3-3 Tugger AGV

The Tugger AGV (Figure 11) is a towing vehicle that can pull a train of trailers, generally have a large capacity [17].

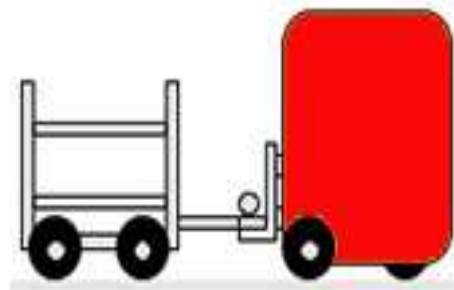


Figure 11: Tugger AG

3-4 Hybrid AGV

Hybrid AGV is a vehicle that can either be operated manually like a general forklift or automatically perform the mission (Figure 12) [17].



Figure 12: Hybrid AGV[18]

4- AGV parts and design

An AGV vehicle is typically made up of vehicle chassis, embedded controller,

motors, drivers, navigation and collision avoidance sensors, communication device and battery, some of them have load transfer device. Various design of AGV vehicles have been done by research institutions and corporations. But mainly all AGVs are consist of parts which shown in Figure13.

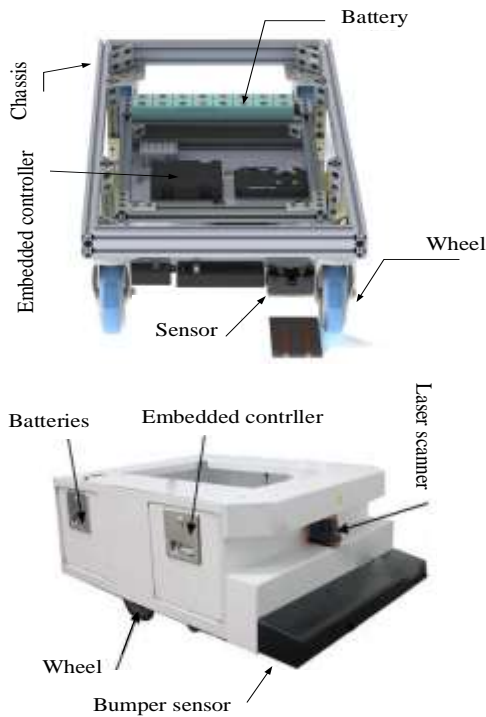


Figure 13 : typical AGV parts[19]

Ajay M Patel et al. designed a simple model of optical guidance AGV based on Arduino. Infrared sensors array is used to detect the track made of black strip, while ultrasonic sensor is used to detect obstacle in front of the AGV [20]. Jeisung Lee et al. installed an AGV prototype with Pioneer3DX robot and a Microsoft webcam. They developed an OpenCV program for Marker Recognition running on-board. The robot calculates rotation angle and distance by processing the captured image of triangle sign [21]. Hongpeng Chi et al. developed an AGV in the shape of scraper equipped with laser-based navigation system. Two 180° laser scanners are installed in front and at the

back of the vehicle respectively. After recognizing featured beacon and a bunch of calculation AGV can get location coordinates in the laneway [22]. Zoran Miljković et al. assembled an AGV model that equipped with a 2MP web camera and applied extended Kalman filter for state estimation in monocular SLAM framework. The algorithm is running in MATLAB environment on a desktop computer connected with the AGV through cables [23]. Amazon Kiva is equipped with Lattice LFXP6C FPGA for logic control and Freescale MPC5123 as the main controller, and ADI ADSP-BF548 multimedia processor for bar code recognition, a Winstrom NeWeb CM9 wireless module with dual-antenna for communication [24]. But mainly AGV parts are Splitted into the sections shows in Figure 14 and described as following:

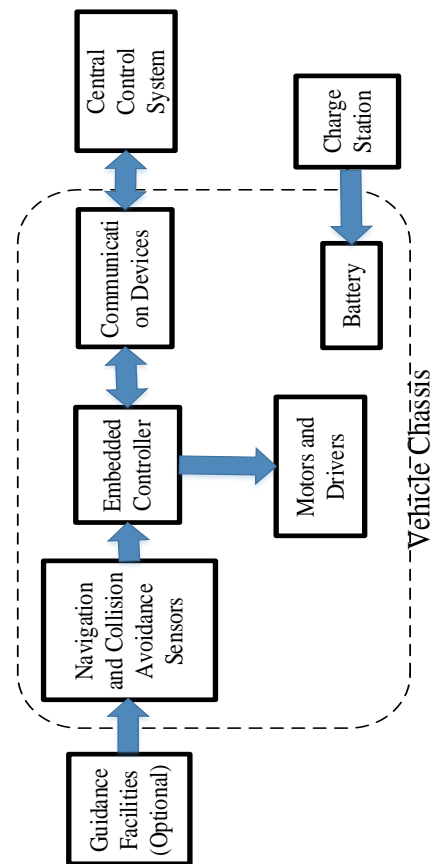


Figure 14 : Structure of AGV

4-1 vehicle chassis

Chassis is the container of all the devices of AGV. Wheels, motors and drivers are mounted under the chassis, while the embedded controller, sensors and communication device are equipped on the chassis. It should have the ability of anti-electromagnetic interference, especially for those schemes which use magnetic tape or RFID for guidance sign [20] [7].

4-2 Embedded controller

The level of intelligence of AGV relatively depends on the performance of embedded controller [20]. AGV Basic scheme use microcontroller or PLC to handle the tasks of capturing data from sensors, communicating with central control system and controlling the movement of the vehicle. Some advanced schemes use a powerful ARM chip running Robot Operating System (ROS) to handle these tasks [7].

4-3 Sensors and guidance facilities

The types of sensors which equipped on AGV depend on navigation approach. **Ultrasonic sensors** can be used to detect nearby obstacles. Infrared sensors can be used to detect guidance line. **Electromagnetic sensors** can be used to detect electricity wires. Cameras can be used to capture QR code tags.

RFID modules can be used to read RFID tags. **Laser scanner** can be used to detect surrounding obstacles and find reflective tags. Some intelligent schemes that use laser scanner or depth camera for navigation are independent of any guidance facilities [7].

4-4 Communication device

Unlike, other industrial automation equipment's which generally communicate on wired bus, AGV requires wireless communication. Recently, to ensure the reliability, the products typically use WLAN with MIMO antenna and have a high standard of electromagnetic compatibility design. 5G technology is applied on AGV produced by Ericsson and China Mobile this year, provided higher reliability and security [25]. In addition, some products also provide a remote controller which has an emergency stop button.

4-5 The load transfer device

A powered device that used for loading and unloading, generally shaped like a fork, but it has other form that specialized for some kinds of goods [26] (Figure 15).



Figure 15: AGV load transfer device[26]

4-6 Battery

There are various types of batteries can be used in AGVs including flooded lead acid, NiCad, lithium ion, sealed, inductive power and fuel cells. But lithium ion type is mainly used due to size and performance. But to compare the battery types Lead-acid battery is the most cost-effective rechargeable battery. It's quite heavy that can be a counterweight of forklift. The drawback is that it creates gas

while charging, and it's relatively slow for charging. Lead gel battery and lithium-ion battery charges are faster and is more environment-friendly which have no gas emissions, but maintenance is needed [27].

4-7 Motors

The motor of AGV generally is mounted with an encoder in order to measure the distance of path. The motor type which are used in AGV are named as Geared DC motor, brushless DC motor, servo motor. these motors are selected based on their impacts on flexibility and accuracy of AGV movement. Drive mode is divided into single wheel drive, differential drive and omnidirectional drive. **Single wheel drive** means a driving wheel have the function of walking and steering and two driven wheels are fixed. **Differential drive** has two drive wheels that use the speed difference to realize rotation. **Omnidirectional drive** is much more flexible. With two driving and rotatable wheels, both parallel movement and differential drive function are available [28].

4-8 Central control system

Central control system is responsible for AGV task scheduling, traffic management, path planning, automatic charging and some other functions. It has human interface for workers to monitor and manage AGV tasks. It keeps on communicating with AGVs, receive the operating status and send commands. Status data typically including position, velocity, battery remaining capacity and some other sensor data [29]. It analyzes all these data to assign the AGVs with new work tasks, generates the most reasonable path and sequence for AGVs, avoids

collision accidents, instruct AGVs which lack power to move to charge station in order to ensure safety and accuracy and finish the planned task in the most efficient way.

4-9 Charge station

There are two ways for design of the charge station, replace the exhausted battery with a fully charged battery, or arrange the AGV whose battery is low to suspend at the charge station. In some other reference it's noted four 4 approaches for AGV charging: manual battery swap, automatic battery swap, automatic charging and opportunity charging [30]. Battery swap method requires less idle time but require extra quantity of batteries for exchange. Automatic battery swap is more cost-effective than manually exchanging if the amount of AGV is large. For charging, automatic charging requires large capacity battery because battery won't be charged before AGV finish the duties of the whole day. Nevertheless, charging in idle short idle time is permitted for opportunity charging [7].

5- AGV control types and navigation

In order to improve the transportation efficiency, the controller devices of AGV system are distributed into two parts: stationary control system and peripheral control system [1]. All the super-ordinated controller devices are integrated in the stationary control system. The duty of it is managing transportation order, optimizing the schedule and communicating with other systems. In addition, it has graphic display interface and statistical analysis for workshop administrator. Meanwhile, peripheral control system is in charge of management of various on-board devices

on the vehicle including forklift and charging device [1]. Navigation techniques consist of 3 key points: positioning, environmental perception and path planning. Positioning is to determine the current location and direction of the vehicle in the workspace, as the fundamental technique of navigation. Variety kinds of sensors can support for achieving autonomous movement by providing environmental information including position of road boundary and obstacle. With this technique AGV can determine the reachable area and unreachable area which is useful for path planning [31]. Path planning includes two categories, global path planning that based on known environmental information, Local path planning based on simultaneous sensor data. Numerous of navigation methodologies can be divided into two main categories. Traditional AGV systems use fixed paths such as underground metal wires, for navigation, however, modern AGVs rarely require fixed guidance infrastructure. They either depend on flexible guidance facility that can be adjusted relatively easily or navigate by perceiving surrounding nature environment that free from any artificial markers. Flexibility and efficiency performance are highly required by flexible manufacturing system. Using the free-ranging AGVs [32] non-fixed guidance AGV a modification of layout can be done by a change of software configuration and a distribution of markers which requires smaller amount of time and cost comparing to AGVs guided by fixed path. At present, the mainstream navigation approaches are:

5-1 Wire guidance navigation

Electromagnetic navigation is one of the traditional navigation methods and still

popular today. Some electric wires carrying low-frequency current were buried in the floor which can be detected by the electromagnetic sensor mounted on the AGV. (Figure 17)

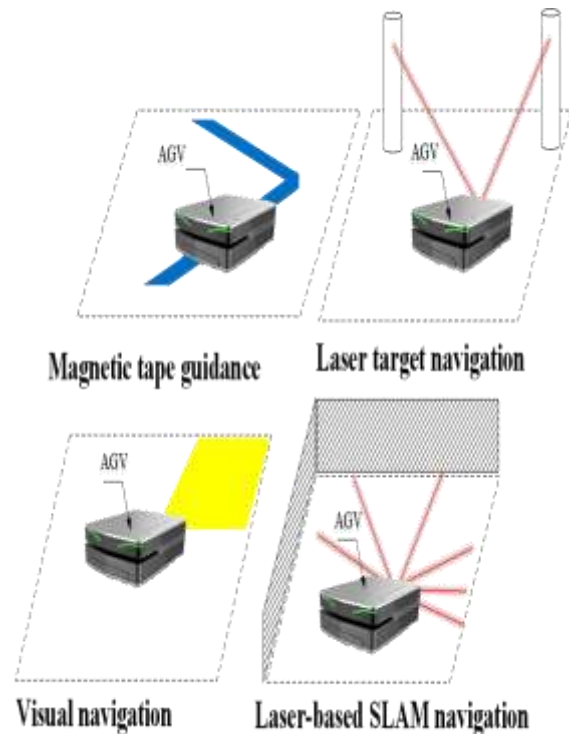


Figure 5 : Major navigation approaches[32].



Figure 6: Wire guidance navigation [33]

The covert wires are quite durable and free from interference of dirt and light. Consequently, it's a reliable approach for AGV navigation [34]. But it's sensible for electromagnetic interference and costly to modify or extend the route.

5-2 Magnetic tape guidance navigation

Guide AGVs by magnetic tape (Figure 18) (Figure 19) placed on the floor surface. It has a similar principle with wire guidance,

but it's much easier and more cost-effective for construction. But it requires a cost of maintenance because it's easy to damage. [34].



Figure 18: Magnetic tape guidance AGV [35]

5-3 Magnetic Marker Guidance and Inertial Navigation

Magnetic nails are embedded in the floor as reference points that can be detected by electromagnetic sensor. It is generally matched with inertial navigation. AGV use the encoders mounted on motors and gyroscope to navigate from one point to another. It's quite suitable for almost all kinds of environments except metal floor [34].

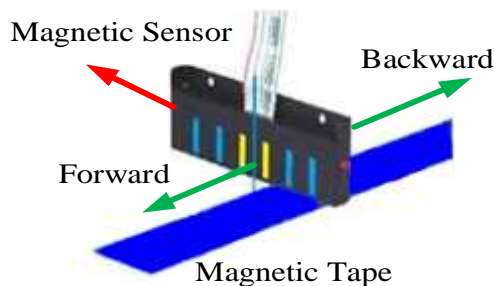


Figure 19: magnetic sensor [36]

5-4 QR code guidance Stick

QR code tags on the floor or shelves that can be captured by cameras equipped on AGVs for guidance. AGV use the feedback of QR code, encoder and gyroscope to determine its location [34]. But, QR code tag is also fragile that needs maintenance.

5-5 Optical track guidance navigation

It resembles magnetic tape guidance that guide AGVs by the colored lines on the

ground. Cameras and image processing function are required for track recognition. Maintenance is needed as well, but it is of high adaptability of electromagnetic interference [34] (Figure 20).



Figure 20: Optical track guidance [36]

5-6 GPS Navigation

The GPS (Global Positioning System) method is based on Communicate with satellite to follow the track. GPS navigation is not adopted for indoor use because blocking, jamming and multi pathing of satellite signals reduce the accuracy of location. Currently, it is used for some outdoor long-distance transportation. Its flexibility is higher than those approaches which require guidance equipment [38].

5-7 Laser target navigation

Reflective targets are mounted around the workspace of AGV. The laser scanner on the AGV emits laser beam and receives reflected light from any obstacle except reflective panels [19]. Microcontroller on the AGV can calculate the position after capturing the data of distance and angle of several reflective targets (Figure 21).

It is relatively flexible that the path plan can be easily modified without rearranging reflective targets. But it may lose efficiency and accuracy if the reflective

panels were obscured, so it has extra environmental requirements.



Figure 21: Laser target AGV [37]

5-8 Laser-based SLAM navigation

A kind of natural targeting navigation that recognize the natural feature of surrounding environment by laser scanner for localization and navigation (Figure 22).



Figure 22: SLAM NAVIGATION AGV [37]

Simultaneous localization and mapping (SLAM) is a process for mobile robots to generate a map of an unknown area and determine its position in the map while traveling around [37]. This approach is of highly flexibility that it does not require any artificial guidance infrastructure. it's also generally used with inertial navigation together. But the precision is lower than laser target navigation.

5-9 Visual navigation

It is a hot spot of research and not as mature as other navigation methodologies. It is based on cameras such as monocular camera, stereo camera and RGBD-camera, typically use SLAM for localization approach. The vision guided AGV acquire and process image texture to build a 3D map and locate itself. As same as laser-

based SLAM navigation, it's matched with inertial navigation and can be implemented without guidance infrastructure. Precision is a fatal drawback for industrial applications [38].

6- Conclusion

In this paper, the AGV robot types review from various point of view. The main aim of this study is to compare and give the designer critical hint to understand and analysis the AGV robot better. As it stated number of using AGV systems in industries are increasing day by day [22]. This type of robot is used in various applications and domain like warehousing, logistics, factory and hazardous locations, etc as shown in Figure 23.

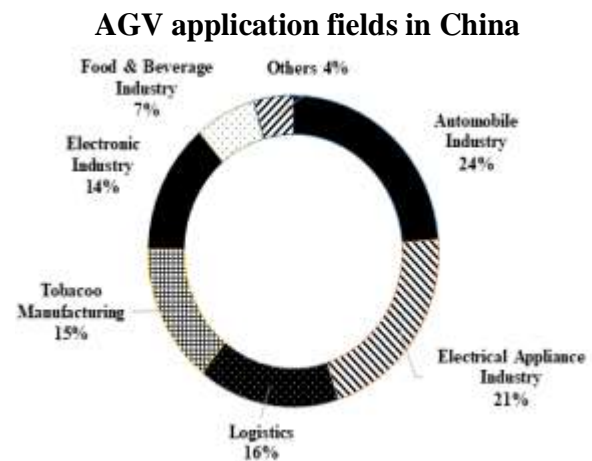


Figure 23: proportion of AGV application fields in China[39]

As the Figure 23 as the sample in china, shows the highest demand belongs to automobile industries and six specific domains till today use this robot meanwhile of their working process [39]. With respect to market point of view the statistical study shows the market size of AGV system all over the world is approximately 4 billion USD in 2018.

It will probably reach 10 billion USD in 5 years as a fast-growing market [40]. To compare the reported AGV design over

than shape and motor system the comparison between designed systems are shown in Table (1).

Table 1: Comparison of AGV designs.

Controller	Sensor	Navigation Methodology	Communication
Arduino Mega	Infrared Ultrasonic	Optical Guidance	N/A
Unknown	Web Camera	OpenCV for Marker Recognition	
EPC-8900	Encoder Laser Scanners	Laser Target	WiFi
Motorola 68331	Encoders & 2MP Web Camera	monocular SLAM & neural extended Kalman filter (NEKF)	RS232 cable & USB cable
Lattice & Freescale MPC5123 & ADI ADSP-BF548	infrared sensors & pressure sensors & dual camera	QR Code Guidance	WiFi

The Table (1) showed the brief comparison between reported design with respect to CPU/MCU, Sensor, Navigation and Communication. More comparison from navigation methods are shown in Figure 24.

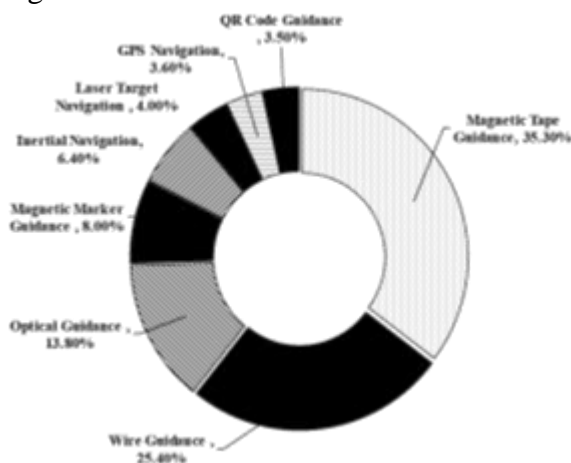


Figure 24: Used AGV navigation methods [39]

As is shown in chart that proportion of several of navigation methods and

difference between navigation methods are summarized in Table (2).

Table 2: Pros and cons of each navigation approaches [41]

Navigation Types	Pros	Cons
Wire guidance	Very durable	Inflexible Hard to install and change sensible for electromagnetic interference
Magnetic tape guidance	Low cost	Requires maintenance Relatively inflexible
magnetic marker guidance and inertial	Relatively durable and High environmental adoptability	Inflexible time consuming to install and modify
QR code guidance and inertial	Low cost	Requires maintenance Relatively inflexible
Optical track guidance	Low cost	Requires maintenance Relatively inflexible
GPS	flexible Easy for installation	Imprecise Not suitable for indoor environment
Laser target	High Accuracy Relatively flexible	Extra environmental requirements
Laser-based SLAM	flexible and Easy for installation	Relatively imprecise
Visual	<ul style="list-style-type: none"> flexible Easy for installation 	<ul style="list-style-type: none"> Imprecise

Then as Tables 2, shows, the magnetic navigation method is more demanded and QR navigation method is less used. Finally, as the brief, the AGV robot is a system which typically made up of vehicle chassis, embedded controller, motors, drivers, navigation and collision avoidance sensors, communication device and battery, some of which have load transfer device. This part with the famous named used technology is presented in Figure 18.

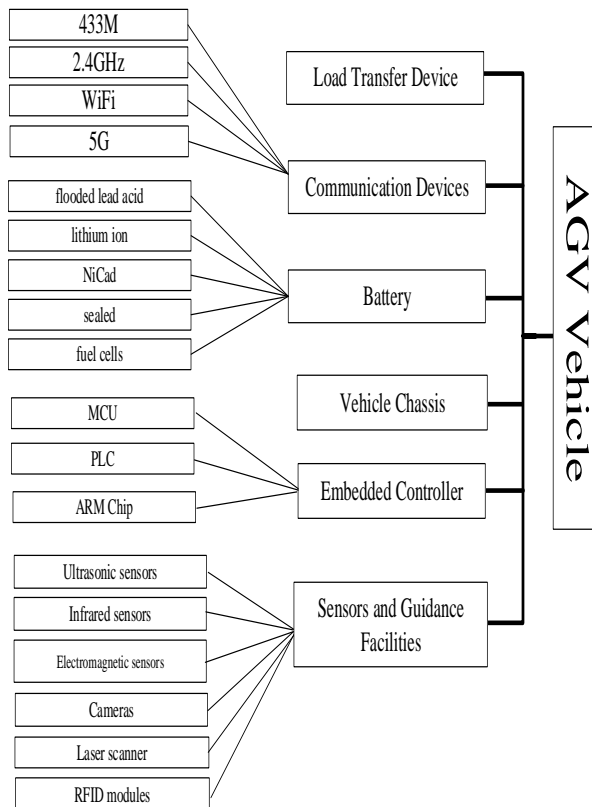


Figure 7: categories of AGV components

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