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SURVEY

A Survey on Navigation Approaches for Automated Guided Vehicle Robots in Dynamic Surrounding

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ABSTRACT Automated Guided Vehicles (AGV) have received a lot of attention in recent years in terms of both hardware and software research. Nowadays, the AGV offers more adaptable and effective industrial and transportation system solutions. An AGV's navigation technique is essential to its operation. The decision to use AGV navigation is not straightforward, even if it appears appropriate and sufficient. This paper surveys the navigation approaches applied to AGV in the past five years of published academic research. In doing so, this work responds to three related questions: 1) are the AGV's classical navigation techniques still relevant to the current application area?; 2) are heuristic navigation techniques themselves able to optimize AGV movement in terms of guide and strategy?; and 3) is the use of artificial intelligence (AI) in AGV navigation techniques able to increase system performance? As a result, numerous techniques for AGV navigation have been developed globally. On the other hand, the most popular navigation approaches are provided below for more research.

INDEX TERMS Automated guided vehicle, classical navigation, SLAM, Lidar, heuristic navigation, A-star, D-star lite, Dijkstra, artificial intelligence, fuzzy logic, neural network, particle swarm optimization, genetic algorithm.

I. INTRODUCTION

Mobile robots, known as Automated Guided Vehicles (AGV), are widely utilised in the industry to move things from a starting location (point A) to a target or goal location (point B). AGV technology has been around since 1955 and was introduced as autonomous mobile robots (AMR) in the early 2000s. This generation of mobile robots has been widely used in industrial applications to streamline intralogistics and material handling procedures by utilising advanced navigation in complex environments [1]. According to a Grand View Research report published in 2017, the market for AGV is rapidly expanding and very active [2]. Moreover, beginning in 2020, the worldwide pandemic Coronavirus 2019 (Covid-19) has limited some human daily operations, especially in the manufacturing industry field [3]. Therefore, AGV technology has piqued the interest of the manufacturing industry in order to ensure that operations are not disrupted while also maintaining business quality [4], [5]. This technology can also take the position of a human for duties like transporting materials from the kitting area to the production line, from the production line to the packaging area, and vice versa. Furthermore, the development of this technology is capable of overcoming the pandemic problem that is affecting the world in other applications such as hospitals, restaurant food delivery services, and civil construction and is not only focused on the manufacturing industry [6], [7]. In addition, this technology may also

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complete transportation tasks faster by ensuring quality and efficiency.

AGV technology has drawn a lot of attention from researchers working on both hardware and software. The AGV hardware part include sensors, robot mechanisms, batteries, and manipulating unit [8]. While the software part, which is computer algorithms, includes simultaneously localization and mapping (SLAM), motion planning, artificial intelligence (AI) and machine learning (ML) [1]. The AGV system is divided into three major components: vehicle capability, path guidance, and comprehensive addressing method [9]. Vehicle capability is focused on either multiple or single unit loads to be carried. For path guidance, the static and dynamic paths are what we are focusing on, while the addressing methods are divided into two: direct and indirect methods.

The AGV offers more adaptable and effective industrial and transportation system solutions [10]. The problem of AGV navigation is crucial to the field of robotics [11]. They are known for their intelligence [12]. They also have a broad range of applications, including transportation, material handling, searching, and rescuing [1]. One of the most visible and important aspects of AGV navigation is path finding [13]. Path finding is defined as the discovery of collision-free handling paths that meet the requirements of AGV operation according to predefined rules. A path-finding approach can be classified as static or dynamic, depending on the nature of the environment [14]. If obstacles do not change their position over time, this is referred to as a static environment. If obstacles change their position and orientation without regard to time, this is referred to as a dynamic environment.

To navigate and adapt to changing conditions, AGVs operating in dynamic environments must be equipped with advanced sensors, algorithms, and decision-making processes. Unpredictable obstacles, changes in terrain, variations in lighting, and other environmental factors all pose challenges in dynamic environments. An AGV must be able to perceive and interpret these changes in order to decide how to move and interact with their surroundings. Furthermore, AGV in dynamic environments must be able to operate autonomously, without human intervention, in order to adapt to the unpredictable nature of the environment.

Recently, AI has been applied to the AGV navigation technique [15]. AI is the science of understanding and making things intelligent, which aids in decision-making and task performance. The goal of using AI is to improve a system's ability to become intelligent, particularly in making decisions based on predetermined rules. This paper surveys the navigation techniques applied in AGV in the past five years of published academic research. In doing so, this work responds to three related questions:

1) Are the AGV's classical navigation techniques still relevant to the current application area?
2) Are the heuristic navigation techniques themselves able to optimise AGV movement in terms of guide and strategy?
3) Is the use of artificial intelligence (AI) in AGV navigation techniques able to increase system performance?

II. CLASSICAL NAVIGATION APPROACH

This section will go over the two main approaches for navigating an AGV. Local and global are the two classical types of AGV navigation [13]. Local also known as conventional navigation, and global also known as heuristic navigation for path finding purposes. There are three divisions of local navigation: direct, relative, and absolute [9]. The direct division is utilising wire guidance and magnetic tape. Relative division implements the positioning marker and laser scanner system, while absolute division implements an odometry and inertial system. Prior knowledge of the environment is required for global navigation, so the navigation strategy must be able to train the AGV for a data set and perform a set of rules, especially in path finding [16]. Examples of the AGV global navigation approach that are widely used are A-Star (A*), D-Star Lite (D* Lite), and Dijkstra [17]. Figure 1 shows the class of navigation approaches in an AGV application.

A. LOCAL NAVIGATION

The local navigation techniques are a mode in which the AGV decides its position and orientation and is able to control its motion using externally equipped sensors, including an infrared sensor, an ultrasonic sensor, a laser, and a vision sensor, which is a camera [18], [19]. Magnetic tape, inductive wire, magnetic spots, laser guided, and optical types are the primary AGV local navigation techniques. When AGV act as AMR, they rely on natural features or free navigation, such as SLAM using Light Detection and Ranging (LiDAR) sensors or camera-based visual navigation systems, to find their way around [20]. Figure 2 shows the local navigation techniques, including positioning, orientation, and path trajectory.

1) MAGNETIC TAPE

In this technique, the AGVs are outfitted with magnetic sensors and travel along a predefined track created by a magnetic tape track [21]. A magnetic tape placed on the floor surface creates the guided route. The magnetic field will drive the AGV along the path. Liu et al. [22] designed an AGV motion control system based on magnetic navigation for logistic demand. The system design shows higher efficiency and safer workplaces, and magnetic tape is simple to apply. The magnetic tracks are laid using a high-bond adhesive. Next, Chen et al. [23] developed an AGV system with independent guidance and an integrated network. By using Radio Frequency Identification (RFID) tags or magnetic indications that are placed on the floor, the AGV management system may tell the AGV how and where to drive. The AGV can select what to do at these specified locations, like turn left, stop, engage a trolley, etc.

Besides, Su et al. [24] proposed a magnetic tracking approach to improve the positioning accuracy of AGVs. A super-strong magnetic nail is tracked by a two-dimensional

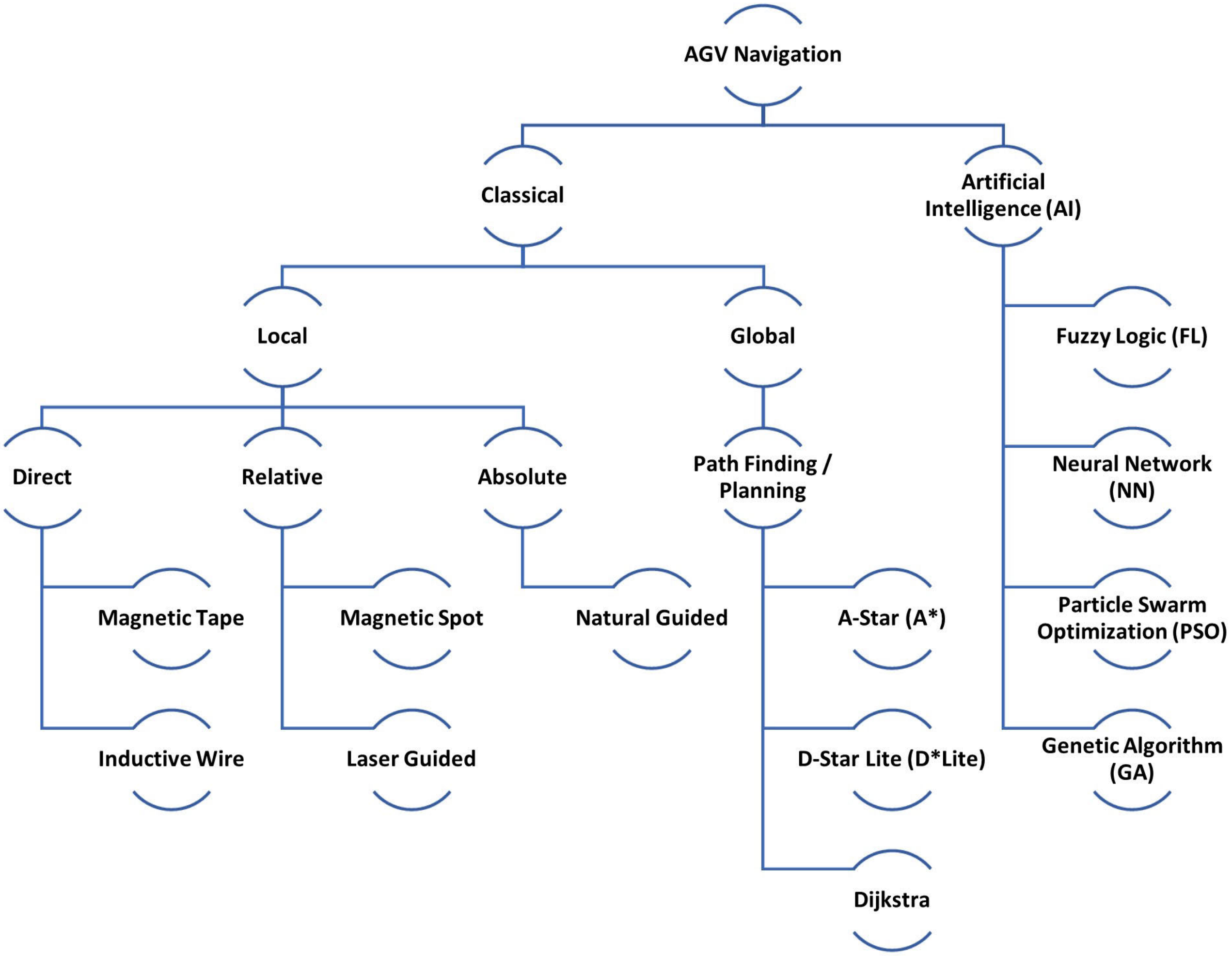

FIGURE 1. Class of AGV navigation approach.

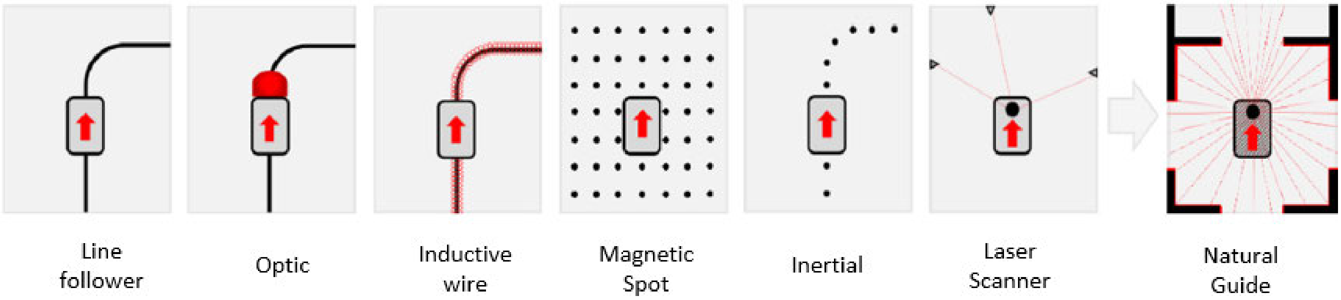

FIGURE 2. AGV local navigation techniques [1].

(2D) sensor array. The location and orientation were computed via sensor array data and hybrid computational optimization algorithms, which are Levenberg-Marquardt (LM) and Particle Swarm Optimization (PSO). Then, Zhou et al. [25] has used magnetic tape as guidance in an experimental platform for an AGV with a six-wheel dual-drive mechanical structure. They also design a multi-AGV scheduling system for unmanned factories, while the A-star (A*) algorithm is implemented on collision-free and efficient paths. Other studies have been conducted to demonstrate that this existing magnetic guided technique can be improved and applied in the real world, such as Prabowo et al. [26], which attempt to transfer a tool using an AGV in a material handling operation; Zhou et al. [27], which model and simulate a heavy-duty AGV tracking system using established fuzzy control; and Tamara et al. [28] developed a fork AGV robotic navigation system aims to increase the speed of goods mobilization.

Therefore, magnetic tape guided technique has shown that a designed tracking system has a good tracking effect on straight, circular, and mixed trajectories and that it can correct distance and angle deviations during AGV movement. Furthermore, the effectiveness at reducing operational costs and the high level of error was provided by this technique, but unfortunately it is limited to the static path and static environment only.

2) INDUCTIVE WIRE

The basic principle of inductive wire for AGV guidance is the generation of a magnetic field around a conductor as a result of current flowing through it. When a conductor is present, the magnetic field is stronger near it and weaker elsewhere. When current flows through the coil, an electromotive force corresponding to the strength of the magnetic field is created at its end terminal. Maximum voltage is induced when an AGV is positioned in the centre of an inductive wire buried in the ground, whereas minimum or no voltage is produced at the coils on the left and right that are symmetrical to the reference point (centre) of the inductive wire.

Rubanov et al. [29] was developed a low-cost AGV utilising a metal-line sensor for track guidance and RFID tags for localization. The results show that the proposed navigation technology is consistent between computer simulation and pilot testing. However, the author still suggests making improvements in terms of the number of sensors employed and the thickness of the metal lines in order to decrease lateral deviation. Recently, Stancu et al. [30] implemented an AGV in the operational production flow using OSMOZE 3 AGV. The induction sensor detected the inductive line to transfer parts from the kitting area to the welding lines. The RFID was used as an AGV checkpoint. Next, Zhang et al. [31] try to solve the issue for actual operations, where an AGV will invariably encounter overexposure or shadowy areas, as well as unclear or even damaged guide wires, which interfere with guide wire identification. In their research, a Fast Guide Filter (FGF), Ant-Colony Optimization (ACO) and a variable universe Fuzzy Sliding Mode Control (FSMC) algorithm were used. The authors concluded that an AGV can continue to drive stably according to guidelines in extreme cases such as uneven illumination, line interference, and unclear or even damaged guidelines and improve the motion quality and robustness by using visual guidance.

Therefore, this technique has the benefit of making exact position control and navigation feasible through accurate position tracking. However, somehow a guided wire must be buried in the floor and the floor surface must be sliced for navigation guidance; the cost of implementation is incredibly expensive. Additionally, regular maintenance is necessary, and it is challenging to change the process and layout arrangement.

3) MAGNETIC SPOT

AGV can follow small cylindrical magnetic spots embedded in the floor to navigate. Magnetic spots are typically cylindrical magnets, also known as magnetic nails and pins [32]. A virtual trail is created by installing magnetic dots every ±10 mm [33]. AGV use sensors and controllers, including hall-effect sensors, encoders, counters, gyro sensors, and other types of encoders, to calibrate against steering angle errors as they move from one location to another. The magnetic dots serve as a reference in line with the map as the AGV follows a Computer Aided Drafting (CAD) drawing that was previously stored on the AGV management system.

Yan et al. [34] proposed a method of using double magnetic nails to navigate an AGV. The input elements are an angle sensor and two high-precision magnetic sensors. The path tracking utilised the fuzzy controller, and their result shows good path tracking ability, rapid collection, and stable accuracy. Su et al. [35] enhances an AGV magnetic guidance approach by using Error Analysis and Prior Knowledge. They found that if the magnetic nails buried in the ground are improperly installed or the magnetic moments between them are irregular, the localization accuracy of the magnetic guidance approach will decrease. The experimental results show that the improved magnetic tracking approach is adaptable and robust, reducing the impact of magnetic nail installation errors and magnetic moment deviation while also increasing system accuracy.

Other researchers also show that the magnetic spot navigation was implemented to improve the inertial guidance system [36] and the improved magnetic spot navigation approach to replace the barcode navigation for path tracking [37]. Recently, Dai et al. [38] simplified the magnetic positioning approach based on the analytical method and data fusion for AGV movement. Latest, Erginli and Cil [39] has adapted a deep-learning-based floor path model for route tracking in autonomous vehicles that they are able to implement into AGV systems.

Therefore, path tracking by AGV using magnetic spot installation is not too easy. To place the magnet, a tiny hole must be made in the floor. Following installation, epoxy glue is used to seal the hole. The outcomes have shown that this navigation method may ensure the AGV's position is accurate while it is operating along its predetermined route. However, this method does not suit the dynamic environment application.

4) LASER GUIDED

A Laser Guided Vehicle (LGV) is a technique that enables an AGV to include positioning and movement using laser technology [40]. Nowadays, because of its dependability and accuracy, laser navigation is one of the most widely used navigation systems [41]. Each laser-guided device is usually mounted on top of a pole and interacts with targets in the working area as a device. The navigation device broadcasts a 360-degree pattern of rotating laser arrays [42]. Several reflector targets are reached by these arrays, which are tapes or cylinders of various types [43]. The laser array signal is returned to the AGV laser navigation device via reflectors. The laser-guided system must acquire at least three of these array feedbacks in order to calculate positioning in triangulation form using highly complex algorithms. The laser guides calculate and correct their positioning during the operation.

Shi [44] developed a laser-guided system for the four-wheel-drive AGV car and implemented path planning. The navigation system calculates position in two modes: static and continuous dynamic position. The three-point system called triangular positioning is detected by sensor reflectors for positioning a safe path. Ma et al. [45] developed a two-wheeled robot that serves as the AGV, and they designed and implemented a laser-based avoidance system for it. After information processing on the level of a computation platform, the system can swiftly gather obstacle distance information, successfully avoid the obstacles, and select a new direction and a new path. While Zhou et al. [46] highlighted their findings from their investigation on the multi-sensor fusion used in the most recent AGV navigation, which uses laser and inertial guidance.

Moreover, Du and Ren [47] found that the LGV was difficult to build an accurate dynamic model for path tracking control. In their work, they proposed deep reinforcement learning to realise the design of the system controller. The experiment was done in a simulation way. While Liang et al. [48] found that there was a problem of false matching or mismatch in AGV positioning when using the laser guided technique. In their research, they proposed a dynamic matching algorithm based on the initial positioning value, which will reduce calculation time and the likelihood of mismatches occurring. The Taylor series iteration was also proposed by them in order to improve AGV positioning. The laser guide can be used not only on the AGV but also as a sensor and target guide for the robotic arm that is mounted on top of the AGV to perform tasks [49]. Latest, Reger et al. [50] utilising a test series to evaluate LiDAR viability for outdoor use and navigation. The objective is to offer guidance on LiDAR's viability as a technology for navigation and collision avoidance in freely moving autonomous feeding systems, especially in agriculture field.

Therefore, it is found that the use of a laser as a guide is the best and most recent sensor for AGV navigation so far, regardless of any field. When dealing with changes or a complex environment, this navigation approach has no fixed infrastructures such as tape on the floor or wire beneath the surface, making it difficult and disrupting daily operations, particularly in the manufacturing industry. Only the markers used as laser references need to be changed to ensure the AGV successfully navigates to the target location. Furthermore, changing the marker is much easier than using tape or wire beneath. This laser technology can ensure that the AGVs are accurate, move safely, and operate effectively. The AGV relies entirely on the markers to determine its current location and movement, and these approaches are extremely precise. It becomes even more intriguing when AGV can determine its current location by itself without the use of markers. By storing an environment map in AGV memory, the AGV system itself is capable of identifying its current location, and this navigation approach can be successfully implemented using SLAM, which will be discussed in the following subtopic.

5) NATURAL GUIDED

The term "natural guided navigation" refers to a number of technologies, and simultaneous localization and mapping (SLAM) navigation is the most significant technological advancement as part of it [51], [52]. It means that an AGV equipped with LiDAR and SLAM navigation is able to map its surroundings and determine its location using data from the environment [53]. The AGV is able to map the surroundings using a variety of AGV sensors, including a vision camera [54]. An internal Inertial Measurement Unit (IMU) is integrated with all of this information to define and recalculate the actual AGV placement [55]. Figure 3 shows the AGV system block diagram. An extremely complicated algorithm known as SLAM performs all of these computations.

LiDAR and a camera are external input devices equipped with the AGV for remote sensing and measuring distances. LiDAR's work involves emitting laser beams and measuring the time it takes for the beams to bounce back after hitting an object to allow the creation of a map of the environment, including information about the shape, size, and location of objects. A camera is a device that is used to capture and record images and videos. It works by using a lens to focus light onto a light-sensitive surface. These input signals will be processed by the driver, respectively, to be fused in the computerization platform. The internal input components consist of the IMU, the central processing unit (CPU), and the physical brake pressure. The CPU is a primary component of a computer robot and Operating System (OS) machine that performs most of the processing tasks. It is often referred to as the "brain" of the computer, as it controls all the other components and processes data to perform calculations, run programmes, and execute instructions. Then, the physical brake pressure is essential for safety purposes to sense when the AGV hits or bumps an obstacle.

In the computerization process, a graphic processing unit (GPU) with the computer's CPU is the main component to process input signals. The GPU is a specialized electronic circuit designed to rapidly manipulate and alter memory to accelerate the creation of images in a frame buffer for output to a display device. It is a highly parallel processor that is optimised for performing the calculations required for rendering graphics and other computationally intensive tasks related to image processing in order to generate an environment map that makes sense. With the SLAM algorithm through a software platform, the system is capable of receiving input signals, processing the signals, and sending output signals to the robot controller to command actuators, which are wheels

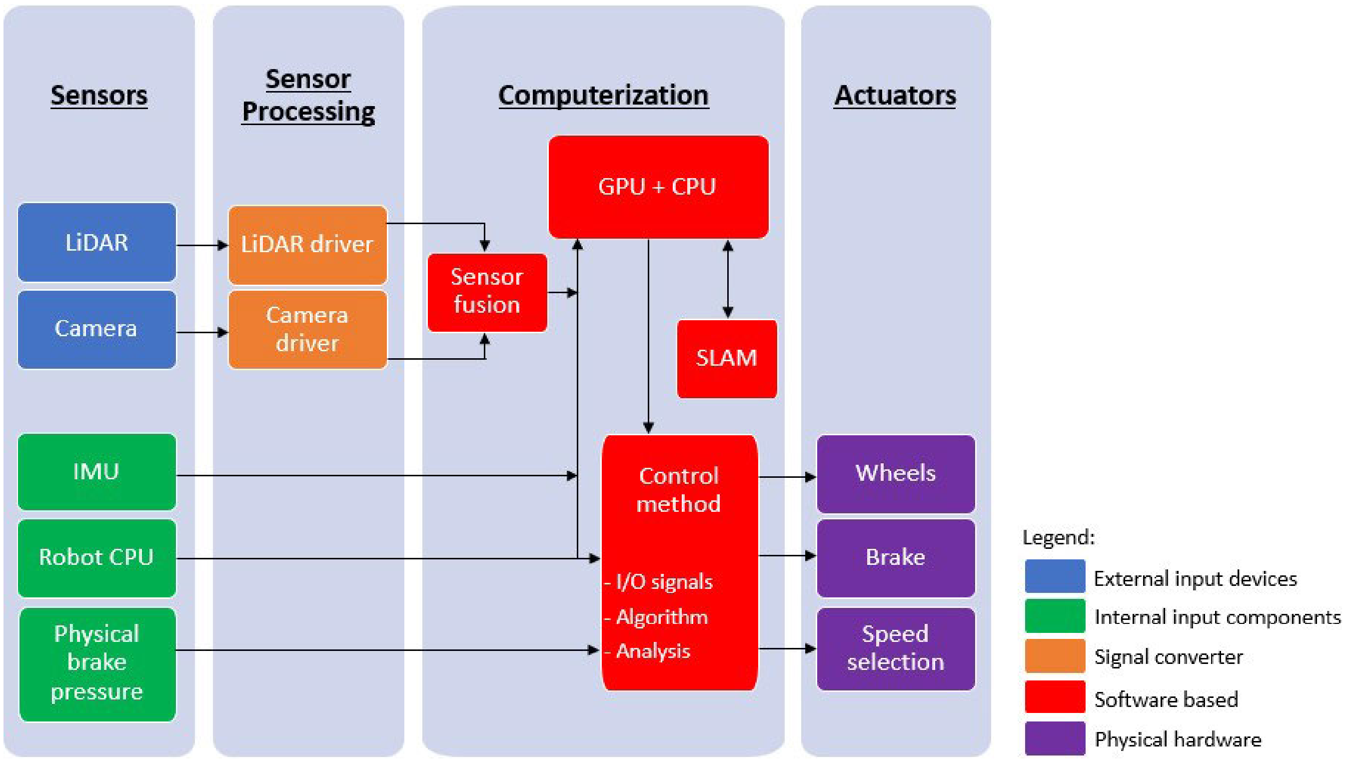

FIGURE 3. AGV natural navigation block diagram.

for robot movement, brakes for safety, and gears for speed selection along the process of mapping.

Liu et al. [56] conducted their experiments on multi-mobile robot systems using collaborative navigation. The navigation algorithm is based on the odometer or multi-source vision. They establish model robots with an ultra-wide band (UWB) for localization, LiDAR, and SLAM for navigation purposes. While Nguyen et al. [57] in their work, it uses backstepping control and SLAM to propose a trajectory tracking algorithm for a differential drive type of AGV. The SLAM was employed for AGV positioning. Ortiz and Yu [58] experimentally the combination between SLAM and Sliding Mode Control (SMC) for path planning methods in an unknown environment. The Genetic Algorithm (GA) was used to show good results and outcomes. Other than that, Li et al. [59] discovered that the localization and mapping accuracy of AGV using visual SLAM (vSLAM) in a dynamic environment is significantly lower than in a static environment due to inaccurate data association caused by dynamic or moving objects. They proposed a robust stereo SLAM algorithm based on dynamic region rejection to reduce absolute trajectory error.

Recently, Yan et al. [60] navigated a mobile robot in an indoor, dynamic, unknown environment by proposing the adaptive FAST SLAM optimise data from the odometer value and comparing it with the value of the yaw error from the IMU. Then the Decision Tree algorithm was applied to predict the correct moving direction of the mobile robot. The proposed method was tested and verified through real hardware testing. Additionally, it has been demonstrated that using this SLAM navigation methodology in conjunction with bio-inspired methodologies will result in an improved navigation method. Then, Dai [61] conducted research using SLAM-based for robot navigation and localization algorithms by proposing an attitude estimation algorithm based on Kalman filter (KF) information fusion from vision SLAM and IMU, and the ORB-SLAM algorithm was perfected. As a result, the accuracy and frequency of the robot attitude estimation were improved. In order to reduce the issue of particle deterioration and fatigue brought on by resampling in the Fast SLAM algorithm, Particle Swarm Optimization (PSO) technology is also used. PSO optimises the particle set.

In a nutshell, the presence of SLAM allows for the performance of natural navigation, also known as contour-based navigation. Without the aid of mechanical guidance devices like tapes or reflectors, the robot maps the area and is able to move and orient itself solely by “seeing” the surroundings. The robot is also capable of redefining routes and avoiding obstacles. Robots do not necessitate the establishment of specific pathways. It has the ability to change its course on the fly. When an obstacle is detected, the robot changes its course to avoid it. The SLAM is improving and will eventually replace other types of navigation, such as magnetic, optical, and so on. It is an excellent choice for AGV applications nowadays. Many of the world’s leading AGV manufacturers are developing and incorporating this technology into their AGVs.

The main concern with natural navigation technology is its dependability in variable environments such as production lines where people, items, boxes, pallets, and so on are constantly moving. In these circumstances, the AGV may be unable to localise where it is. As a result, SLAM with a LiDAR sensor is an excellent solution for AGV in environments with well-defined profiles and fixed structures such as walls and columns. The ability of LiDAR to distinguish between static and dynamic obstacles is extremely useful. Because of their ability to rotate 360 degrees with repeatability, static obstacles will provide a consistent reflection signal, whereas dynamic obstacles will cause changes in the reflection signal to LiDAR when rotated repeatedly. This inconsistency in reflection signal data will be removed and updated in the database throughout the mapping period. However, when an AGV receives a transportation task, SLAM with LiDAR alone is insufficient for successfully reaching the target position. After SLAM, a motion planning method is required to provide optimal trajectories for the AGV to follow while avoiding dynamic obstacles and meeting specific objectives. Previous research has shown that various motion planning algorithms, such as Timed Elastic Band (TEB), Dynamic Window Approach (DWA), and Model Predictive Control (MPC), are widely used in AGV navigation.

6) LOCAL NAVIGATION DISCUSSION

Based on the local navigation methods that have been discussed and presented, it is necessary to consider a number of crucial criteria when choosing a navigation method, including installation complexity, flexibility, installation cost, vehicle cost, dependability, accuracy, and installation maintenance. All criteria for local navigation methods are compared in Table 1. This will make it easier for readers to understand and decide which navigation method is best and most appropriate for the intended application.

All local navigation methods have advantages and disadvantages of their own. The best degree of installation complexity, flexibility, cost, and maintenance is revealed by the natural navigation approach. Only one vehicle cost criterion shows it has drawbacks. Additionally, this kind of navigation can adapt AGV capabilities in dynamic work environments. The AGV can change its path when an obstacle suddenly appears in front of it, as long as the travel space is clear of obstacles.

To answer the question "Are the classical AGV navigation techniques still relevant to the current application area?" the answer is yes, because local navigation is the foundation of the AGV tracking path, which involves physical systems such as sensors, a data processing module, and robot mechanisms such as actuators to ensure robot movement from the starting location point and successfully reach the target or goal location point. In the future, AGV will incorporate information fusion and artificial intelligence technology, such as fuzzy control, deep learning, and neural network algorithms, so that it does not require as much manual intervention and can complete self-learning and self-training based on the specific environment to achieve the best decision-making and real-time response.

B. GLOBAL NAVIGATION

Global navigation, sometimes referred to as heuristic path finding, is a crucial technique for ensuring that the AGV takes the shortest route to reach its destination. This technique also ensures that the AGV can avoid any pre-defined obstacles in its path [62]. Recently, the heuristics graph search algorithm which is paths finding methods have been widely used and famous applied into AGV navigation [1], [9]. An A-star (A*), D-star Lite (D* Lite) and Dijkstra are some of these graph search algorithms methods.

1) A-STAR

The A* is one of the most popular classical graph search algorithms [63]. This algorithm employs a weighted graph with nodes serving as locations and edges connecting these nodes, which contain the cost of travelling from one node to another. There is also a list of unvisited nodes and a list of visited nodes. To find an optimal solution much faster, the algorithm employs a search, which can be an estimated cost from a node to the goal node [64], [65]. The algorithm begins at the first node and progresses to the goal by visiting and evaluating each neighbouring node in the unvisited list. It is a complete and efficient algorithm, but it consumes a lot of memory.

Zheng et al. [66] and Zhang et al. [67] was improved A* algorithm for AGV path planning from the basis. They discover the path with the fewest inflection points and increase the node search mode and search speed. Additionally, the angle evaluation cost function is added to the traditional A* algorithm's cost function to help identify the path with the fewest inflection points. Chi et al. [68] and Li et al. [69] proposing an improved A* algorithm based on a time window to solve the conflict-free path planning problem for AGV. Next, Yang et al. [70] and Ballamajalu et al. [71] simulated the A* search method by applying it to a real warehouse application for materials handling. While Chen et al. [72] proposed a two-stage congestion-aware routing strategy based on the A* algorithm, In order to boost the production efficiency in the warehouse, they designed a strategy to alleviate traffic congestion in the multi-AGV system. Moreover, Tang et al. [73] simulated path planning in a port environment by introducing a Geometric A* algorithm. As a result, the algorithm is able to reduce the number of nodes, number of turns, turning angle, and total distance travelled for AGV movement.

Recently, it was established that numerous studies in AGV path finding and obstacle avoidance used the traditional A* algorithm combined with other algorithms for the purpose of increasing system capabilities. Chen et al. [74] stated in their research that the A* algorithm needs to be combined with other algorithms. Wu et al. [75] proposed a hybrid dynamic path planning algorithm for forklift AGV by improving A* with the Dynamic Window Algorithm (DWA).

TABLE 1. AGV local navigation technique comparison.

Item(s)	Laser Guided	Magnetic Tape	Natural Guided	Magnetic Spots	Inductive Wire
Installation complexity:	Good	Good	Excellent	Good	Worst
Flexibility:	Poor	Poor	Excellent	Poor	Worst
Installation cost:	Good	Poor	Excellent	Poor	Worst
Vehicle cost:	Poor	Excellent	Poor	Good	Good
Reliability:	Excellent	Good	Good	Good	Good
Accuracy:	Excellent	Good	Good	Poor	Excellent
Installation maintenance:	Good	Worst	Excellent	Excellent	Poor

Chen et al. [76] proposed the shortest path planning problem in an AGV static environment by integrating an A* and Sparrow Search Algorithm (SSA). Bai et al. [77] proposed an improved A* algorithm-based motion planning and tracking control strategy based on model-predictive control in order to solve the problem of tracking control for autonomous vehicles. Latest, Zheng and Lu [78] done research on AGV trackless guidance technology utilising camera vision. The A* algorithm was used to intelligently plan the driving path. As a result, their proposed method is able to automatically adjust the AGV's walking path in time for obstacle avoidance.

2) D-STAR LITE

The D* Lite, or Dynamic A*, was enhanced from A* [79]. It is operated in the opposite direction as A*, starting from the end rather than the goal. It is also a simplified version of the D* algorithm that is adaptable to changing external conditions [80]. In large areas and dynamic work environments, the D* Lite algorithm usually plans shorter paths faster than the A* algorithm, whereas the A* algorithm may be more effective than the D* Lite algorithm in static and small area work environments [81]. Still, searching is employed here, but it predicts a cost from the beginning. This algorithm employs trees from past searches and is an incremental search technique [82]. This will also expedite the search procedure. The D* Lite algorithm performs well in broad and intricate regions. Compared to A*, it plans shorter paths significantly more quickly. In straightforward and compact locations, it performs less well than A*.

Sebastian and Ben-tzvi [83] proposed to use a novel planning architecture to overcome the shortcomings of existing kinematic and artificial potential field-based path planning methods for mobile ground robot navigation in highly dynamic terrains. They proposed the D* Lite high-level planner navigation architecture to handle static obstacle avoidance. Francis et al. [84] proposed a D* Lite algorithm for improving computational efficiency in replanning operations in a large dynamic environment. In the next year, Mugarza and Mugarza [85] will propose the D* Lite algorithm for collision-free navigation for multi-AGV. The navigation and traffic control were simulated like an industrial shop floor. After that, they combined D* Lite and Coloured Petri Net-based AGV traffic controllers in the same environment [86].

More interestingly, Okumus et al. [87] also used D* Lite in their work to solve the problem of transporting goods in an indoor logistic environment. What's more interesting is that they demonstrated a decentralised technique to allow multiple AGVs to communicate with each other through the cloud platform. As a simulated result, the multiple-AGV work autonomously and simultaneously in collaboration, so basic problems such as optimised multitasking allocation, path planning, collision avoidance, mapping, and positioning problems seem to have the opportunity to be solved.

Moreover, obstacle avoidance utilises a multi-objective D* Lite algorithm that was proposed by Deng et al. [88] for mobile robots. The objective was to plan an optimal collision-free path from the starting point to the goal point on a two-dimensional grid map with some obstacles known and some unknown. They are also adopting the cubic Bezier curve in order to smooth the robot's path. Latest, Zagradjanin et al. [89] used the D* Lite algorithm in path planning in autonomous exploration based on multi-criteria decision-making (MCDC) strategies, which are standard SAW, COPRAS, and TOPSIS. These methods show that the exploration efficiency was improved by comparing several strategies during the exploration operations.

3) DIJKSTRA

The shortest path between any two graph vertices can be discovered by AGV using Dijkstra's technique [13]. Because not all the vertices of the graph may be included in the shortest distance between two vertices, it is different from the minimal spanning tree. This algorithm is frequently used in routing and in other graph algorithms as a subroutine. Optimal algorithms ensure that the global optimal solution is found by exploring the entire set of available solutions.

Marin-Plaza et al. [90] choose the Dijkstra algorithm in their research to integrate and analyse the performance of a path planning method based on time-elastic bands (TEB). The experiment involved the Robot Operating System (ROS), and they also proved the navigation can coexist and work together to achieve the goal point collision-free. While Fusic et al. [91] proposed a modified Dijkstra algorithm from the foundation in their robot path planning work. They simulated several different environments as part of a parameter algorithm in order to find the best time and velocity for robot movement. Next, Kim et al. [92] also conducted a similar study using Dijkstra's algorithm in AGV path planning and collision-free operation. The dynamic environment is also a parameter, but this time the purpose is different; they study optimal path planning aiming at minimization of energy consumption and degradation of operation time of an AGV under dynamic operation conditions in a graph containing random slopes and distances.

In the year 2020, various research was found implementing an extended, improved, and modified Dijkstra algorithm in mobile robot and AGV applications [93], [94], [95], [96], [97]. Among the applications concerned multiple AGV traffic control in warehouses and container terminals with different kinds of surfaces or ground. Recently, Dijkstra's algorithm is no longer limited to AGV and mobile robots in path planning and collision avoidance. Its application is becoming more widespread, with applications ranging from autonomous mobile robots to Industry 4.0. Van Truong et al. [98] developed a navigation system for autonomous mobile robot localization with measurement uncertainties. They deeply studied the optimal collision-free route planning for AGV. While Liu et al. [99] combined the Dijkstra algorithm with the Dynamic Window Approach (DWA) in their research work for autonomous driving cars in path planning and obstacle avoidance. Their finding shows that the system is able to perform the functions of establishing an environment map, path planning and navigation, and obstacle avoidance for smart car testing.

4) GLOBAL NAVIGATION DISCUSSION

There are numerous methods for representing AGV navigation in environments, as well as numerous heuristic search algorithms for finding the shortest path given a graph. A graph search algorithm approach is more commonly used in environments with no predefined paths and where a robot can freely move in the free configuration space. Following research into several types of global navigation that are commonly used in AGV systems, it was discovered that this global navigation technique needed exploration for the first time for gathering environment data and information. The movement of an AGV to reach the destination needs to be repeated several times so that data collection can be carried out based on the pseudocode that has been planned. As a result, AGV was able to determine the best path to take. Table 2 shows the summary of recent works that objectively implement the global navigation method and their work contributions.

To answer the question "Are the heuristic navigation techniques themselves able to optimise AGV movement in terms of guide and strategy?", the answer is yes if the surrounding conditions and obstacles are static but not dynamic. When the workspace changes and obstacles appear unexpectedly, an AGV with only local and global navigation must be retrained to carry out data collection activities and follow the new or updated pseudocode. It caused time waste, and some improvements need to be made. It has been proven in recent research findings that AGV with global navigation needs to be combined with other techniques to ensure intelligent and optimal operation, especially in a dynamic environment. The following subtopic will go over several optimistic navigation strategies from recent research studies.

III. ARTIFICIAL INTELLIGENCE APPROACH

A navigation approach using an artificial intelligence (AI) algorithm is developed to solve problems more quickly, accurately, and reliably in optimization [100]. This approach has proven to be effective and is now widely used in autonomous navigation [9], [101], [102]. Bitsch and Schweitzer [103] investigated that, in order to provide a conceptual framework for addressing a list of requirements that compares several machine learning algorithms in order to determine the most effective AI algorithm for intelligent AGV control.

Huo et al. [104] in their studied found that fuzzy logic (FL) and neural networks (NN) in AGV are trending, especially in scheduling that includes optimal task assignment, multi-AGV path planning, and traffic control. Guan et al. [105] proposed an improved fuzzy neural network (Neuro-Fuzzy) by combining these two methods in a nondeterministic environment for intelligent mobile robot obstacle avoidance purposes. Besides, bio-inspired algorithms also were found that are widely used in AGV or autonomous navigation, especially in searching and exploration, which are Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) [106], [107], [108]. In this survey, numerous AI techniques for path planning and obstacle avoidance in AGV navigation have been identified. The following subtopic will go over the foundation and application of AI approaches that are frequently used in AGV navigation in more detail.

A. FUZZY LOGIC

Fuzzy logic (FL) is a type of many-valued logic in which variables' truth values can be any real number between 0 and 1, introduced by Lotfi A. Zadeh in 1965 [109]. It is used to deal with the concept of partial truth, in which the truth value can range from completely true to completely false. These logics are capable of recognising, representing, manipulating, deciphering, and exploiting ambiguous and uncertain facts and information. Figure 4 shows the FL block diagram that consists of crisp input that contains a linguistic variable, fuzzification processing that contains a set of Membership Functions (MF), inference processing that contains the MF based on the rules "IF" and THEN," defuzzification that generates a logic plane, and finally crisp output that generates the best possible value.

Ngo and Tran [110] used the FL controller approach to teach an AGV to track and follow a path under various loads. The load and error are parameters input, and wheels left and right are parameters output, as declared in FL crisp input. The FL algorithm will ensure the AGV is fast enough to correct the wheel speed based on error gain and follow its path smoothly. Singh and Bera [111] proposed a FL in obstacle avoidance controllers in their work. Consist of three

TABLE 2. Summary of a few recent works performed using the global navigation.

Author(s)	Navigation Approach	Objective	Contribution
Sun et al. [17]	A*	To refresh shortest and plan dynamic path for AGV by eliminate or cutoff between points	77.5% success rate of proposed algorithm
Zhao et al. [25]	A*	To plan an efficient path and obstacle avoidance	Success to scheduling and find a shortest path for multi-AGV
Xue et al. [51]	A*	To search shortest path	Success to demonstrate to build reliable topological map with sparce and noisy map points and trajectories of SLAM
Zhang [62]	Dijkstra	To set predetermined route in server	Success to re-planned and find another shortest route for multi-AGV in new environment
Teleweck & Chandrasekaran [63]	A*	To develop path finding or planning for the best fit	Success to determine efficient path on the 20x20 grid map
Lian et al. [64]	A*	To propose algorithm to realize path planning and conflict avoidance strategy based on dynamic random network	Algorithm works well and success to improves the efficiency of the multi-AGV system
Fransen & Eekelen [65]	A*	To find the lowest-cost path in a geometric graph	Proposed algorithm successful self-configuring based on the graph and parameters such as turning costs
Zheng et al. [66]	Improved A*	To quickly find the optimal path for AGV	Success to search the optimal path and path search speed is faster than traditional A*
Zhang et al. [67]	Improved A*	To optimize the motion path, reduction of path length, number of AGV turns and path planning time	Success to provide efficient path planning with shorter routes, less turn times and shorter operation time compared with traditional A* algorithm and ACO
Cui et al. [68]	Improved A*	To solve the conflict-free in AGV path planning problem	Success to speed up the path searching process
Li et al. [69]	Improved A*	To eliminate the limitation of node movement direction in traditional A* algorithm	Success to simulate the working security and efficiency of mobile robot compared to traditional A*
Yang et al. [70]	Improved A*	To avoid collisions and search the idle path	Success to simulated effectively schedules in the warehouse with lower time complexity for multi-AGV
Ballamajalu et al. [71]	A*	To perform time-efficiency path optimization	Simulation has a 94% success rate, generated paths are smoother, have fewer turns, faster execution of tasks. The method also handles unexpected obstacles in the path robustly
Chen et al. [72]	Improved A*	To propose two-stage congestion-minimizing routing method	Success to increase efficiency and bringing huge economic benefits to the warehouses
Tang et al. [73]	Improved A*	To avoid the problems of several nodes, long distance and large turning angle. Traditional A* algorithm limitation usually exist in the sawtooth and cross paths	Success to reduces the number of nodes by 10% 40%, while the number of turns is reduced by 25%, the turning angle is reduced by 33.3%, and the total distance is reduced by 25.5%
Chen et al. [74]	A*	To find shortest path between two points in path planning	Success to identified that A* is better and shorter than ACO
Wu et al. [75]	Improved A*	To plan FAGV the global optimal path and more suitable	Success to improve A* algorithm in simulation the number of paths turns of the is reduced by 62.5%, the smoothness is higher, and the turning angle is smaller
Chen et al. [76]	A*	To find AGV shortest path planning in a static raster environment problem	Success to demonstrates the effectiveness of the method and provide some reference for the shortest path planning of AGV
Bai et al. [77]	Improved A*	To eliminate traditional A* algorithm by propose an A* combined with tracking control strategy	Success to demonstrated to plan the obstacle avoidance path effectively and accurately track the path in different environments
Zheng & Lu [78]	A*	To plan the AGV driving path intelligently and use wireless network communication to control AGV driving based on the planned path	Proposed method is feasible and has the advantages of high flexibility, high precision, low cost and strong expansibility, which is of great significance to the realization of intelligent warehouse and unmanned chemical plant successfully
Reyes et al. [79]	D* Lite	To efficiently address more complex path-planning problems in maze-like environments by modifying D* Lite strategically	The reduction in state expansions improve successfully as the complexity of the unknown terrain increases

TABLE 2. ***(Continued.)*** **Summary of a few recent works performed using the global navigation.**

Belanova et al. [80]	D* Lite	To compute the shortest path in real static environment and make trajectory for pepper robot	The command generation was successful, but sometime sensor detected false obstacles along the way and robot stopped instantly
Jin et al. [81]	Improved D* Lite	To automatically realize and path finding effectiveness in mixed environments with dynamic obstacles using Conflict Based Search D* Lite	Proposed algorithm shows 31% success rate of improving pathfinding compared to traditional D* Lite
Balan & Lua [82]	D* Lite	To map building under unknown environments	Success to demonstrate effectively the benefits of local navigator in conjunction with a path planner to reach multiple goals with optimized distance
Sebastian & Ben-Tzvi [83]	D* Lite	Algorithm used to work on a 2D grid representation of the terrain as the high-level planner	The proposed planner is more effective in providing an optimal feasible path, demonstrating clear advantages for rough and unstructured terrain planning successfully
Francis et al. [84]	D* Lite	To proposed re-planning operation in a large dynamic environment by improving computational efficiency	Success to developed algorithm by reducing computational time in dynamic and cluttered environment
Mugarza & Mugarza [85], [86]	D* Lite	To approach a traffic control and collision-free navigation for AGV	Success to computes a sequence of safe movements, reaching to a feasible set of ordered transition firings for AGV traffic control and motion
Okumus et al. [87]	D* Lite	To avoid static obstacle by calculate the optimum path between AGVs and goals	High efficiency was achieved in total path, energy and delivery times successfully
Zagradjanin et al. [89]	D* Lite	To use as multi-AGV path finding and planning	Success to calculate the shortest path to each AGV in dynamic environment
Marin-Plaza et al. [90]	Dijkstra	To use for vehicle global planning and the Time Elastic Bands used for vehicle local planning	Algorithm success to update the local path and useful when a dynamic obstacle suddenly appears in front of the vehicle
Fusic et al. [91]	Improved Dijkstra	To use for finding an appropriate path for reaching the destination by mobile robot	Modified Dijkstra success to increase velocity performance and also the distance travelled between any two given points in the environment is kept to a minimum
Kim et al. [92]	Improved Dijkstra	To find optimal path planning under dynamic conditions by AGV	Success to achieve minimization of AGV's energy consumption, reflecting AGV's tractive forces under dynamic conditions
Sun et al. [93]	Improved Dijkstra	Use for AGV Path optimization and path planning	Proposed algorithm is finds shorter path, less turning angle. This indicate that the improved algorithm is correct, feasible, effective and has a strong global search ability successfully
Dharmasiri et al. [94]	Dijkstra	To implement anti-collision by proposing the most efficient traffic control and path planning algorithm	Success to prove a timely and valuable insights into smart warehouses and logistics phenomenon, as a potential mechanism for optimizing material handling in warehouse management to be more efficient and collision free
Zhong et al. [95]	Dijkstra	To achieve AGV conflict-free in path planning	Success with effectively reduce the probability of AGVs coming into conflict, reduce the time to wait for their next task and improve the operational efficiency
Wu & Sun [96]	Dijkstra	To proposed to limit the running direction by adding path factor in AGV system	Success with effectively reduce the conflict of opposite encounter paths and achieve the purpose of orderly operation of multiple-AGV
Luo et al. [97]	Extended Dijkstra	To solve the optimal surface path	Success to improves the accuracy of the surface optimization path in single-robot single-target and multi-robot multi-target path planning tasks
Van Truong et al. [98]	Dijkstra	To find a feasible path which has random starting and ending points by applying into the visibility graph	Success to reveal that the proposed strategy well-adjusted in real-time applications not only reaches high precision indirect navigation but also achieves the CPU time scale
Liu et al. [99]	Dijkstra	To use as the global path planning algorithm and the DWA as its local path planning algorithm applied to the smart car	Success to prove the system able to complete the functions of environment map establishment, path planning and navigation, and obstacle avoidance

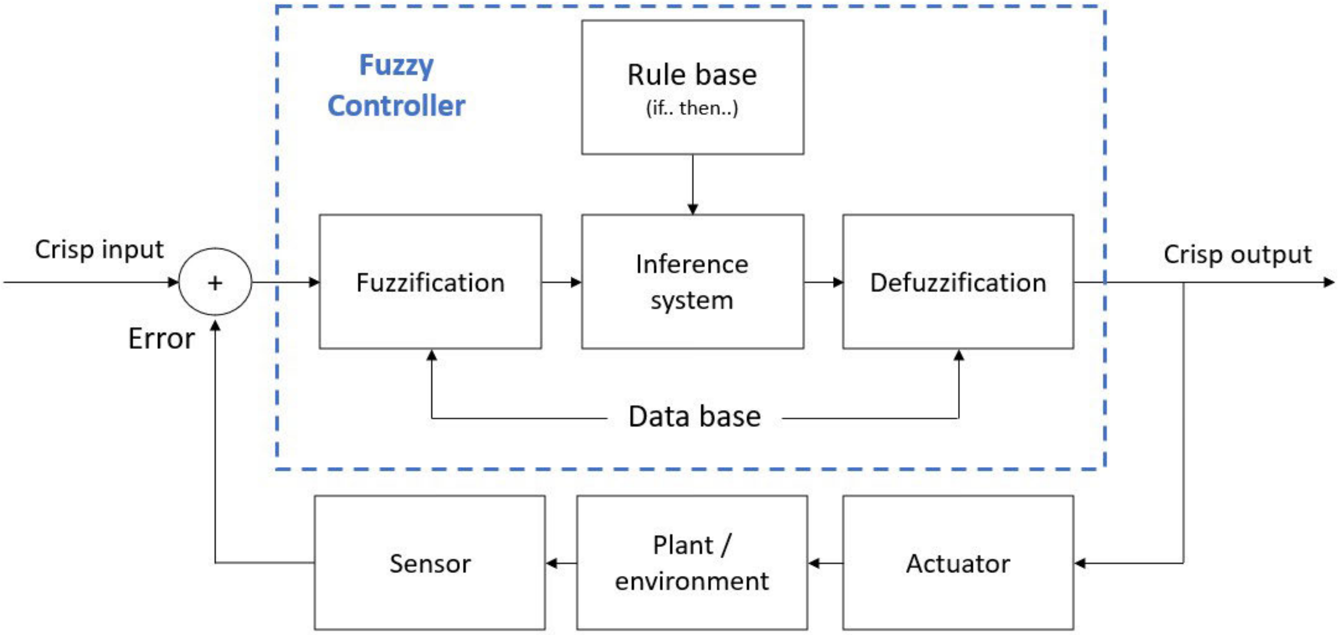

FIGURE 4. Fuzzy logic architecture.

ultrasonic sensors as input MF, one speed as output MF, and 23 sets of rules set in the fuzzy inference system. Findings show that the FL is able to avoid an obstacle with an optimum path.

The FL also provides a positive ability to increase the level of intelligence in the use of AGV in the manufacturing industry. Zacharia and Xidias [112] explored the problem of vehicle routing and motion planning for a fleet of AGV in a flexible manufacturing system (FMS). The proposed motion planner is combined with a scheduler, which allows each AGV to update its destination resource during navigation in order to finish the product transportation. Kafiev et al. [113] also describe the use of FL for the high-level control systems of the AGV in navigation. They simulated using the Mamdani method that is available in FL to navigate an AGV based on speed and distance towards the obstacle in order to achieve smooth and precise stopping during operation.

Moreover, the FL was found to be hybridised with other methods in order to optimise AGV navigation. Khadidja [114] simulated a hybridization of the Multi-Agent System (MAS) with FL. She proved that the FL was able to cater to the autonomous navigation problem. Baker and Ghadi [115] also hybridised the artificial neural network (ANN) with FL, called as neuro-fuzzy into a controller to navigate mobile robots in a dynamic environment. They try to increase the fuzzification time by implementing the ANN. Recently, Rahayu et al. [116] utilised the FL to navigate a mobile robot safely from its initial point to its destination point. The localization in the term of coordinates was gathered from cameras mounted at the ceiling and devices communicating via Bluetooth platform. The FL can provide a good response during navigation, but this study's use of optical sensors revealed that the time required to process data is too long and is not recommended for real-time use.

B. NEURAL NETWORK

A neural network (NN), also known as an artificial neural network (ANN) or simulated neural network (SNN), is a collection of algorithms that aims to identify underlying links in a set of data using a method that imitates how the human brain functions [117]. The NN has been applied in a variety of fields, including signal processing, pattern recognition, image processing, mobile robot path planning, discovery, search optimization, and many more. The NN is made up of various simple and highly interconnected processing elements that relocate data to external inputs. Figure 5 depicts the input layer, the hidden layer, and the output of the NN foundation.

In AGV navigation systems, the NN are widely used for a variety of purposes, such as path planning, scheduling, traffic control, and to prevent deadlock situations in multi-AGV operation [15]. Many recent research findings concerning AGV or mobile robots have revealed the use of combination, improvement, and modification from the NN basis, for example in deep learning. Yeboah et al. [118] proposed an efficient and robust deep learning-based indoor navigation framework for autonomous robot navigation. The navigation into orientation and localization was decomposed by using a Deep Convolutional Neural Network (DCNN). While Chuixin and Hanxiang [119] proposed an AGV robot based on computer vision and deep learning, the software also adopts CNN. The algorithm determined and corrected the steering angle for safe virtual path navigation.

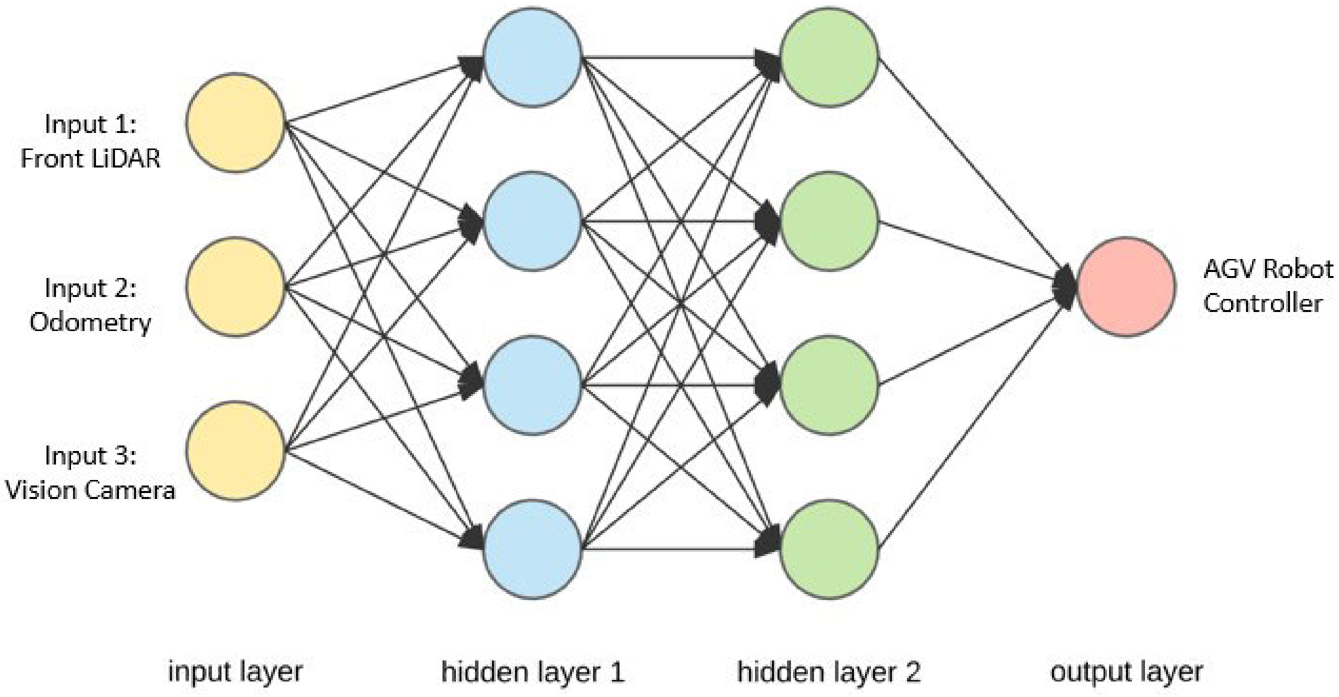

FIGURE 5. Neural network architecture.

Next, a path planning algorithm based on NN to avoid collision for smart AGV was proposed by Yuan et al. [120]. The NN algorithm implementing a four-layer network structure designs the energy function of the network. While the deep-learning NN is also used in the AGV navigation system, as demonstrated by Wong and Yu [121] in their research work. They focused on the anti-disturbance problem of mobile robots using vSLAM navigation. The algorithms used were the Lyapunov Direct Method (LDM) and Radial Basis Function Neural Network (RBFNN) to minimise robot path planning error. In the era of 2020, Huu et al. [122] focused their research on applying machine learning (ML) to a dynamic path planning problem by considering real-time randomised obstacle locations as mimicking the real industrial environment. While Teso-Fz-Betono et al. [123] in their study were created an indoor navigation system for an autonomous robot by implementing a CNN that segments the image to determine a navigable zone and calculates steering and speed commands using various mathematical operations.

Recently, Ma and Wang [124] proposed to overcome the problems of slow convergence speed, the highest number of iterations, and unstable convergence performance in the Q-learning algorithm by improving the NN algorithm for AGV path planning. Their finding was that the improved NN algorithm increased the convergence speed with better effect compared to the traditional Q-learning algorithm. While Ren et al. [125] proposed a hybrid intelligent real-time optimal control approach based on deep neural networks (DNN) in order to improve the autonomy and intelligence of AGVs in navigation control. Their experiments were conducted with static and dynamic obstacles as a nonlinear optimal control problem (OCP). They also demonstrated that a designed DNN-based optimal control approach can generate optimal control instructions on-board to steer the AGV to the desired location while being robust to initial conditions and satisfying various obstacle constraints. In view of robustness, Cabezas-Olivenza et al. [126] performed the dynamical analysis of a navigation algorithm for an autonomous industrial vehicle. As a result, they show that the CNN managed to calculate the trajectory that will be followed by the AGV as its path.

C. PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization (PSO) imitates a flock of birds' or school of fish's foraging and navigational patterns introduced by Kennedy and Eberhart [13]. It solves a problem by generating a population of candidate solutions, dubbed particles in this context, and moving these particles around in the search-space using a simple mathematical formula based on the particle's position and velocity. The movement of each particle is influenced by its local best-known position, but it is also guided towards the best-known positions in the search-space, which are updated as better positions are discovered by other particles. This should direct the swarm towards the best solutions.

The PSO is used in numerous fields of AGV, such as mobile robot path planning for navigation. Zhou et al. [127] improved AGV tracking accuracy to achieve navigation. An improvement to the PSO algorithm was used to optimise controller parameters, and simulated results showed that the processing time was shortened and the percent overshoot became smaller. It would seem that an AGV is highly significant in a flexible manufacturing system (FMS), and numerous studies were found regarding PSO involvement, for example, Zhang and Li [128] improved PSO algorithm for an integrated scheduling model in an AGV-served manufacturing system. They compare the improved version with the basic PSO and genetic algorithms (GA). While Chawla et al. [129], [130] proposed a combination of PSO for global search and Memetic Algorithm (MA) for local search to become Modified Memetic Particle Swarm Optimization (MMPSO) for scheduling of multi-load AGV with minimum travel and minimum waiting time in the FMS.

For path-planning purposes, Biswas et al. [131] presented a path-planning method based on PSO for autonomous systems operating in unknown terrain environments. This research proposes a new method for analysing and estimating terrain traversal ability. While Yu and Yan [132] optimised PSO for AGV's better adaptability for obstacle avoidance, they also made the running path shorter to the target and improved system efficiency for the intelligent warehouse application. Moreover, Cau and Zhu [133] proposed an optimization for multi-AGV path conflict and crashes to happen while the PSO was used to optimise the decision. An improved PSO (IPSO) was also introduced by them in order to improve search ability in working space.

Many researchers have recently expressed interest in an IPSO; Qi et al. [134] utilised the IPSO to improve the slow convergence speed, poor optimization result, and incomplete search during mobile robot path planning by using the classical navigation method, which is the Ant Colony Algorithm (ACO). While Xiao et al. [135] presented by simulating an IPSO for the multi-mode resource-constrained scheduling problem of an AGV task, Qiuyun et al. [136] used IPSO too in their study to improve the efficiency of AGV in material transfer and to determine the extent of effectiveness related to mechanism development. Recently, Song [137] proposed a multi-objective mathematical model was established for AGV to determine the shortest path and maximum smoothness, while improving the Levy Random Quantum PSO (LRQPSO) algorithm used to screen the AGV driving path. They tested their proposed algorithm in both static and dynamic environments. Another recent work in regard to PSO research was by Moshayedi et al. [138], who simulated and validated an optimised PID controller in an AGV model by using PSO and the Beetle Antennae Searching (BAS) algorithm. According to the simulation results, the PID controller with empirical tuning, the PSO, and the BAS performed well in tracking the path of movement.

D. GENETIC ALGORITHM

The Genetic Algorithm (GA) is one of the first and most highly regarded evolutionary search algorithms, invented by John Henry Holland in 1970 [13]. The key theory in this method is natural selection, or survival of the fittest. The GA is commonly used to generate high-quality solutions to optimization and search problems by utilising biologically inspired operators like mutation, crossover, and selection.

The GA is also used in numerous fields of AGV, such as mobile robot path planning for navigation. Al-Jarrah et al. [139] used GA to generate a time-based trajectory for the best path in mobile robot navigation. The goal was to propose and improve the robot's search capability towards an optimal path solution. While Nazahari et al. [140] improved the starting pathways in continuous space and discovered the best route between the start and destination locations by enhancing the GA (EGA). A multi-objective path planning problem is formed by combining path length, smoothness, and safety. Furthermore, the proposed method is extended to address the problem of multiple mobile robot path planning. To accomplish this, a new term is added to the objective function that measures the distance between robots, and a collision removal operator is added to the EGA to eliminate potential collisions between paths. Then, Chen et al. [141] proposed GA with the objective of deciding operation for each workstation and choosing a start time for each workstation to prevent multi-AGV deadlock situations due to the limited space. They found that the proposed algorithm has the potential to guide real-world applications in manufacturing systems.

Moreover, Lyu et al. [142] examines the machine and AGV scheduling problem in an FMS by taking into account the optimal number of AGV, the shortest transportation time, a path planning problem, and a conflict-free routing problem all at the same time by combining GA with the Dijkstra algorithm based on a time window. While Gola and Klosowki [143] create a novel approach to the problem of material handling control using AI or computer intelligence in relation to AGV path routing. The FL was used to determine the vector, or ordered set, of stations requesting transportation service, while the GA was used to optimise the sequence of stations in a loop.

Because GA is widely used in path planning [144], the following year's study included many combinations, improvements, and modifications of this algorithm to further improve AGV's navigation ability. For example, Jiang et al. [145] proposed an improved adaptive GA combining with simulated annealing in their work for AGV path planning to achieve a strong ability to avoid local optima and faster convergence speed. While Li et al. [146] proposed an improved GA to achieve efficient path planning capabilities in complicated maps for mobile robots. The improved GA makes use of the A* algorithm evaluation function. There are also those who combine this GA with other algorithms in their studies to be applied in path planning, like Multi-Population Migration Genetic Algorithm (MPMGA) [147] and GA are used to obtain the control points of the Bezier curve to solve the problem of redundant nodes and peak inflection points in the path planning process of traditional algorithms [148].

E. ARTIFICIAL INTELLIGENCE APPROACH DISCUSSION

To answer the question "Is the use of AI in AGV navigation techniques increase system performance?", the answer is yes. The AI approach has been found to have an effect in recent studies involving the navigation of an AGV. This approach is frequently discovered and tested in the form of simulations. Many of these navigation methods have yet to be implemented in physical AGVs, robots, or real-world workspaces. AGV typically use a combination of sensors, including cameras, LiDAR, radar, and other types of sensors, to detect and map their surroundings in order to operate effectively in dynamic environments. To process sensor data and identify objects, obstacles, and other relevant features in the environment, advanced algorithms are used. The AGV's decision-making process must be capable of analysing sensor data quickly and accurately, planning appropriate movements, and adjusting its behaviour in response to changes in the environment. When AI is integrated into the system, data processing capabilities become as quick and accurate as human thinking. Table 3 shows a summary of a few works performed using the heuristic's navigation approach for AGV navigation.

The FL proves to be more effective when programmed into an AGV system, where this approach can make an AGV capable of quickly returning to the reference point during movement. The FL is commonly used to move the robot smoothly towards the target point while avoiding obstacles along its path. While NN is viewed from the same perspective as the purpose of AGV navigation, which is to go to the target location while avoiding obstacles. The scope of the most recent research revealed that when deep learning is present, the foundation of this approach is improved. When it comes to navigation or route finding for an AGV, almost all the studies discussed have used deep learning and NN as the foundation. As a result, whether single or multi-AGV operations, the AGV system gains many advantages in terms of increasing its capability.

The bio-inspired method approach also demonstrates its effectiveness in AGV navigation, especially in searching and exploration. Recent studies, however, have discovered many improvements and combinations with other methods or algorithms based on PSO and GA. The PSO is the algorithm of choice for the most recent researchers because it can be adapted for scheduling, avoiding deadlock situations, path finding, and task division when involving many AGV in a workspace. While GA appears to contribute more to AGV path finding in various applications. The improvement of this algorithm is improved, modified, and combined with other algorithms to achieve the optimal path finding level, in accordance with the basis of finding a solution based on mutation, crossover, and selection.

IV. NAVIGATION TESTING ENVIRONMENT AND ENERGY MANAGEMENT

Figure 6 depicts a breakdown chart of applications or testing locations based on all the reading sources reviewed over the last five years involving navigation techniques used in an effort to make the AGV system operate optimally. There were four types of testing locations identified: indoor laboratories, FMS, simulation, and others. The indoor laboratories include those at institutions laboratories, research centres, and manufacturing laboratories. Logistics, warehouse, and production line are the real FMS categories. The simulation is computer-based, and the software does not include real hardware AGV system testing. While others include office floors, shops, a chicken barn, yards, terminals, and hospitals.

The total breakdown in overall foundation application is shown in Figure 6(a). While Figure 6(b) shows the conventional or local navigation techniques are mostly tested in the real work environment, with a significant contribution from indoor laboratories and in FMS. Using magnetic tape, lasers, and natural guidance are among the most popular navigation techniques in this category. This is because the equipment involving these navigation techniques has already been installed and is ready to be used in the real work environment, particularly in the FMS. Because the devices involved in this navigation technique are installed directly on the AGV or permanently located, such as in a reflector for the AGV to operate, the studies, research, or work involving simulation in this technique are the fewest.

More than half of the research reported was carried out in simulation for the portion of applications that entail heuristic or global navigation, as shown in Figure 6(c). Studies demonstrating the use of these techniques in FMS demonstrate their experiment in a real-world scenario. There are also researchers who carry out their research by creating an environment and obstacles that mimic the real work environment during indoor laboratory testing. However, three global navigation techniques, namely A*, D*-Lite, and Dijkstra, can only be used for static obstacles and off-line mode changes. Recently, Figure 6(d) shows research work involving the development of system intelligence (artificial intelligence) that has primarily focused on a dynamic environment and involves multiple AGV units operating in the same workspace. The majority of studies involving FL, NN, PSO, and GA are conducted solely through computer- or software-based simulation. Few research results have been shared or discovered that have embedded or combined their proposed intelligence algorithms into a real AGV system to operate.

The most important aspect to consider when attempting to make an AGV operate optimally, either as a single or multi-AGV, is energy management. This energy management comprised hardware power consumption as well as software memory processing. This is intended to ensure that AGV main functions or operations, such as communication, scheduling, routing, path planning, decision-making, and AGV movement speed, can be properly managed. AGV operations will be disrupted and inefficient if energy is not managed properly, especially when multiple AGVs are involved.

Because AGVs operate and move wirelessly, energy must also be supplied on the move via batteries. It is necessary

TABLE 3. Summary of a few works performed using AI.

Author(s)	AI Approach	Objective	Contribution
Li et al. [15]	NN	To prevent deadlock for multi-AGV system by improving the efficiency	Success to significantly improves the efficiency up to 20% to 30% compared to traditional method
Dias et al. [109]	FL	To elaborate a navigation system and able to avoid an obstacle for AMR	Success to offers a smoother transition in the AMR movements
Ngo & Tran [110]	FL	To stabilize AGV in tracking error with carrying different loads	The autonomous system successfully becomes easier to control and more flexible
Singh & Bera [111]	FL	To navigate mobile robot in obstacle avoidance	Success to optimize the robot free path which is close to the obstacles as compared to the hybrid obstacle avoidance algorithm
Zacharia & Xidias [112]	FL	To plan AGV routing and motion in FMS	Success to innovate for routing and motion planning a fleet of AVG used for logistics operations in indoor factory environments
Kafiev et al. [113]	FL	To navigate AGV based on high-level control systems	Success to develop and achieve smooth and precise stopping during operation
Khadija [114]	FL	To apply the multi-agents and FL paradigms in the design of a control architecture for mobile robot navigation in a constrained environment	Success is achieved when the robot manages to reach its target despite the complexity of the environment in which it is located
Baker & Ghadi [115]	Neuro-Fuzzy	To address the issue of autonomous mobile robot navigation in an unstructured environment	The real processing time has been reduced, while the mobile robot response has been increased
Rahayu et al. [116]	FL	To developed navigation system for wheeled robot	Cheaper wheel robot successfully developed, but navigation accuracy and stability require improvement
Yeboah et al. [118]	Deep-CNN	To proposes indoor navigation framework for robots with efficient and robust deep learning-based	Success to achieves accurate and efficient navigation and outperforms existing "navigation-by classification" variants
Chuixin & Hanxiang [119]	CNN	To determined steering angle of the robot through continuous training of the collected image information, allowing for virtual path navigation and safety protection	System is widely used in the automation industry and provides useful benchmark data for the research of artificial intelligence
Yuan et al. [120]	NN	To address the issue of route planning and obstruction avoidance during smart car walking	The algorithm's accuracy, obstacle avoidance, smooth path, and speed were successfully simulated and demonstrated in the ideal state
Wong & Yu [121]	RBF-NN	To improve AGV navigation performance and reduce robot path following inaccuracy	Success in demonstrating that the system performs reasonably and steadily even when there is large error
Huu et al. [122]	NN	To discover the connection between the dynamic path planning problem's input and output	Success achieved 98.5% prediction accuracy for the robot path predictions
Teso-Fz-Betono et al. [123]	CNN	To create a mobile robot indoor navigation system	Found that he CPU execution time is insufficient to deliver safety measures in emergency circumstances. Each result's average time was roughly 1.05 seconds, which is too short for industrial autonomous mobile robots
Ma & Wang [124]	CNN	To fix the issues with the classic Q-learning algorithm's poor convergence speed, excessive iterations, and unstable convergence performance	The new CNN-based Q-learning algorithm has been successfully simulated to demonstrate that it is stable, has a faster convergence speed, and requires less iterations
Ren et al. [125]	DNN	To increase the AGVs' navigational autonomy and intelligence	To drive the AGV to the intended position with great robustness to beginning conditions and while satisfying various obstacle limitations, it was successful in generating the best control instructions on board
Cabezas-Olivenza et al. [126]	NN	To create the most reliable and adaptable navigation algorithm by taking into account image processing	Success to produces a satisfactory result due to the following of any type of trajectory
Zhou et al. [127]	PSO	To reduce the AGV tracking bias as much as feasible by optimizing the AGV controller parameters	The improved PSO algorithm has significant effects on control accuracy and quick response for AGV path tracking, the adjustment time of the PID controller optimized by the improved PSO algorithm is obviously shortened and that the overshoot is very small

TABLE 3. ***(Continued.)*** **Summary of a few works performed using AI.**

Zhang & Li [128]	PSO	To find a workable schedule for manufacturing that is served by AGVs	The nested particle swarm optimization approach has significant advantages in convergence and solving effectiveness, according to numerical simulation successfully
Chawla et al. [129], [130]	MMPSO	To present a MMPSO for scheduling multi-load AGVs in FMS that combines PSO for global search and MA for local search	Successful and efficient investigation and exploitation approach produces encouraging outcomes for the scheduling issue for multiple-load AGVs
Biswas et al. [131]	PSO	To use as path planning method for autonomous systems in unknown terrain	Able to effectively plan a route in both simple and complicated outdoor environment conditions
Yu & Yan [132]	PSO	To address the obstacle avoidance and AGV path planning issues in intelligent warehouses	Success in enhancing the function's convergence and preventing the issue of the algorithm running into the local optimal solution
Cao & Zhu [133]	IPSO	To resolve multi-AGV path limitations and conflicts in the environment	Congestion-caused path conflict can be successfully reduced, and the multi-AGV system efficiency can be increased
Qi et al. [134]	IPSO	To address the issue of path planning	Success in resolving the path planning issue with standard PSO and ACO serves as references for future study on mobile robot path planning control
Xiao et al. [135]	IPSO	To schedule AGV task with Multi-mode resource-constrained	Success to demonstrate the algorithm's effectiveness in tackling challenges involving the scheduling of many modes of resource-constrained tasks
Qiuyun et al. [136]	IPSO	To find the best path in the one-line manufacturing AGV path planning problem	The AGV route optimization problem can be successfully solved by an algorithm, which has quick convergence and is difficult to successfully enter the local optimum
Song et al. [137]	LRQPSO	To solve the proposed model and test the driving path of the AGV	The AGV's efficiency of work, operating speed, and smoothness are all successfully increase
Moshayedi [138]	PSO	To test an improved PID controller in an AGV using simulation	Results showed good path tracking performance in Matlab and the CoppeliaSim (VREP) simulator tests. The path testing results reveal that the tracking error of the PID controller is smallest in the circle and largest in the spiral route
Al-Jarrah et al. [139]	GA	To create a time-based trajectory for the best route for a mobile robot	Proposed algorithm successfully detects edges with more accuracy and can lower noise in a picture
Nazarahari et al. [140]	EGA	To choose the best path by using the initial path planner with huge discretization size (in a grid environment with large grid size)	AGV performance is unaffected by EGA control parameters such as size and iterations, according to simulation results
Chen et al. [141]	GA	To prevent and avoid deadlock situations	Finite population size and incorrect parameter values have the potential to degrade a GA performance. It is possible to obtain both poor representations of good search regions and good representations of poor regions
Lyu et al. [142]	GA	To address an AGV scheduling problem in FMS by simultaneously considering the optimal number of AGVs, the shortest transportation time, a path planning problem, and a conflict free routing problem	The benchmark approaches and the suggested algorithm both solve the scheduling problem effectively and efficiently
Gola & Klosowki [143]	GA	To create a novel approach to the issue of material handling control with regard to AGV path routing using artificial or computer intelligence	Success to established method for solving optimization problems, which is why this solution was employed in an attempt to resolve the problem in the analyzed case
Sarkar et al. [144]	GA	To address the issue of path planning with both single and many independent targets	The proposed algorithm has effectively found a better path than the conventional GA
Jiang et al. [145]	Improve Adaptive GA	To address mobile robot material transportation planning with can be regarded as the ordered clustered traveling salesman problem	Strong ability to avoid local optima and successful faster convergence time are two features of the proposed approach

TABLE 3. ***(Continued.)*** **Summary of a few works performed using AI.**

Li et al. [146]	Improve GA	To enable mobile robots with effective path planning capabilities in complex maps	The proposed algorithm can obtain a better result than the conventional GA with fewer iterations
Hao et al. [147]	MPMGA	To overcome issues with the typical GA such as early maturation, insufficient population variety, low convergence route quality and trouble breaking the local optimal solution	The MPMGA not only works well for simulation maps with different scales and obstacle distributions, but it also performs better than the traditional GA and successfully addresses its issues
Ma et al. [148]	GA	To address the issue of redundant nodes and peak inflection points in standard algorithms' path planning method	Success to proposed method with more effective to generate a shorter, smoother, and safer path compared with traditional approaches

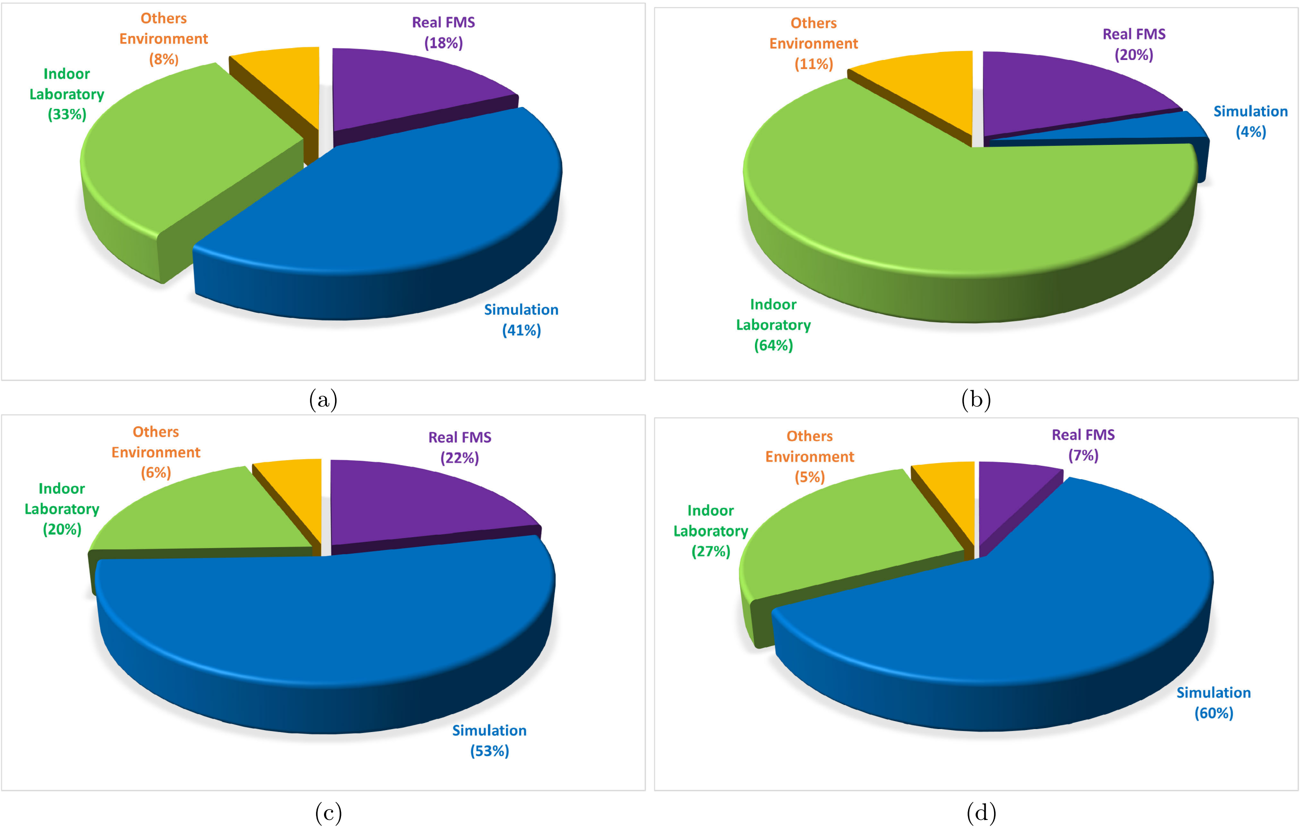

FIGURE 6. **Breakdown of navigation approach in applications: (a) Overall. (b) Classical approach. (c) Heuristic approach. (d) Artificial Intelligence approach.**

to consider the total power consumption, which includes all input elements such as sensors, processing elements such as electronic components, and output elements such as tyres and end effectors. According to recent research, Wireless Power Transfer (WPT) is the most up-to-date by incorporating areas for AGV charging into scheduling and routing. While memory processing has also become an important factor to consider in order to process heuristics and AI algorithms involved in path finding and decision-making. This memory percentage capacity also has an effect on power consumption, particularly when it comes to the ability to make quick decisions.

V. CONCLUSION

This survey work discussed the most commonly used navigation techniques, which are classical, global, and AI in AGV. Among the classical or local navigation approaches presented were magnetic tape, inductive wire, magnetic spot, and natural navigation, which rely on physical hardware mounted to the AGV and the environment as references during movement and positioning. While, among the global approaches presented to improve navigation strategy were the A*, D* Lite, and Dijkstra algorithms, especially on AGV path finding and planning. Fuzzy logic, neural networks, particle swarm optimization, and genetic algorithms are examples of AI approaches that have recently been implemented, especially in the optimization of AGV intelligent navigation.

Recent research findings indicate that combining, modifying, and improving algorithms is the latest trend in an effort to improve AGV systems in navigation operations, particularly in finding routes and avoiding obstacles in a dynamic environment. The ability to process data and make decisions is a priority in the proposed methods that have been implemented thus far. In terms of application, the use of AGV in industry or the real work environment necessitates the participation of more than one AGV, or multi-AGV. The methods used in this effort should prioritise several strategies, including scheduling, task division, communication, avoiding collisions, and deadlock situations. Furthermore, a dynamic work environment must be prioritised in the AGV's ability to operate with effective quality while not disrupting the quality of time while performing tasks. Unfortunately, most researchers only conducted simulations or software-based experiments to present their results for AGV to achieve optimum navigation. There is a lack of testing in the physical hardware that is being used to implement the heuristics approach practically.

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