# Analysis of the Application Scenarios of Different Sensors in Automated Guided Vehicles

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**Abstract.** This study offers a detailed examination of diverse sensor technologies employed in Automated Guided Vehicles (AGVs) across various settings, including warehouses, hospitals, and outdoor environments. The paper investigates the use of a wide range of sensors— Light Detection and Ranging (LiDAR), inertial, vision-based, and magnetic sensors—in AGVs to improve navigation accuracy, reliability, and flexibility. LiDAR generates precise 3D maps and identifies obstacles; inertial sensors, such as accelerometers and gyroscopes, deliver essential data for movement and orientation; vision-based sensors identify landmarks and facilitate predefined path navigation; magnetic sensors guarantee dependable indoor positioning in areas without GPS. Additional focus is given to the increasing trend of sensor fusion, which combines various sensor types to enhance localization, obstacle detection, and path planning. Sensor fusion improves accuracy, safety, and operational efficiency in AGVs. Furthermore, the paper explores the development of more autonomous navigation systems that utilize Artificial Intelligence-based (AI-based) models and advanced algorithms for dynamic decision-making and real-time adaptability. Such advancements propel innovation in robotics, automation, and intelligent transportation systems. As sensor technologies advance, AGVs and other autonomous systems are expected to exhibit enhanced capabilities, wider applications, and more efficient operational processes. This analysis not only underscores the current state of sensor technology in navigation systems but also paves the way for future research and development in this swiftly progressing field.

**Keywords:** Automated Guided Vehicles, LiDAR, sensor.

## 1. Introduction

Advancements in sensor fusion technologies have driven extensive research into intelligent ground vehicles, with a particular focus on obstacle detection as a crucial element of vehicle operation [1]. Sensor calibration is essential and must be executed with precision before implementing sensor fusion and obstacle detection processes [2]. Environmental perception technology is vital for intelligent vehicle decision-making, serving as a crucial link that enables vehicles to achieve intelligence, safety, and operational efficiency. Modern intelligent vehicles are equipped with numerous functional sensors, each playing a vital role in enhancing vehicle performance. Artificial Intelligence-based (AI-based) models have been developed to facilitate smart sensing, enabling the recognition of object classes in novel yet familiar scenarios. This comprehensive review seeks to explore common sensors used in Automated Guided Vehicles (AGVs), emphasizing their roles and importance across various application scenarios [3]. Understanding the application scenarios of different sensors in AGVs is crucial, as it significantly influences vehicle safety, stability, and overall driving experience. This comprehensive review aims to explore common sensors utilized in AGVs, highlighting their roles and significance across various application scenarios. When considering the inputs provided, it's crucial to understand their role in the context of AGVs. Inputs may include a broad array of data sources, such as sensor readings, environmental signals, user commands, and system feedback. Sensor data, collected from devices like LiDAR, cameras, and ultrasonic sensors, provides crucial information about the vehicle's surroundings. This data is processed using sensor fusion algorithms, which integrate inputs from multiple sensors to create a comprehensive understanding of the environment. User commands, including steering inputs or navigation instructions, are integral to the operation.

## 2. AGVs Navigation Technology

AGVs depend on a diverse array of sensors for effective navigation, each providing unique capabilities suited to particular applications. For instance, AGVs frequently employ laser-based LiDAR sensors for precise mapping and obstacle detection, facilitating navigation through complex environments. To generate maps and enhance positional accuracy, the Simultaneous Localization and Mapping (SLAM) technique which relies on LiDAR technology, is utilized [4]. Furthermore, AGVs incorporate inertial sensors, such as accelerometers and gyroscopes, to track movement and orientation, assisting in path planning and localization [5]. Magnetic sensors are used for indoor navigation, particularly in settings where GPS signals are unreliable. Vision-based sensors, like cameras, enable AGVs to recognize landmarks and visual markers for navigation [6].

### 2.1. Sensor Navigation Scheme and Characteristics Analysis

In the realm of AGVs, navigation technology is crucial for ensuring precise and efficient movement in diverse environments. AGVs utilize a variety of sensors tailored to specific use cases to navigate effectively.

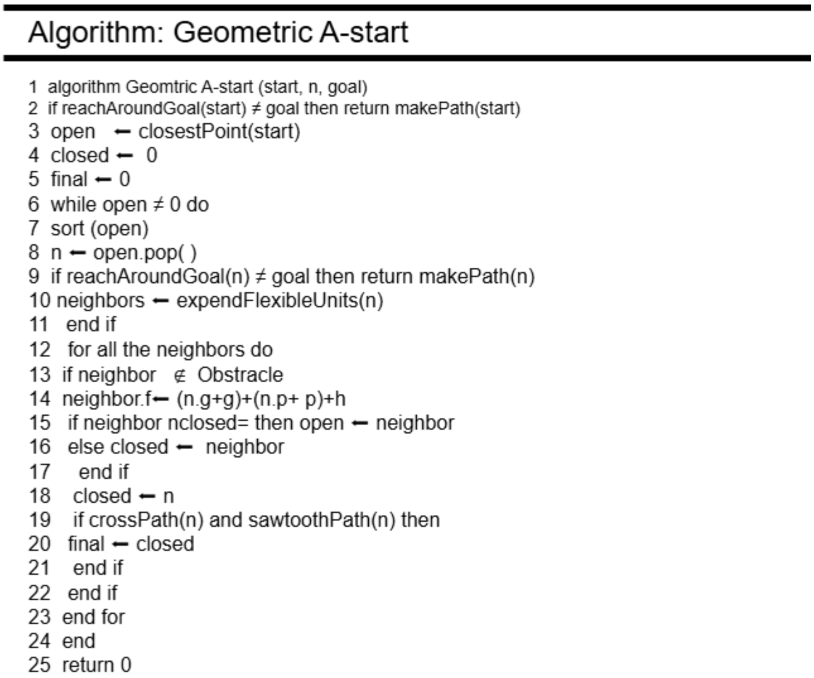
In evaluating sensor technologies for intelligent vehicles, each sensor type—LiDAR, RADAR, ultrasonic, and vision-based systems—presents unique advantages and challenges across diverse environmental conditions. LiDAR excels in high-resolution mapping but struggles in adverse weather and reflective environments. RADAR performs well in poor visibility like fog or rain, with long-distance detection capabilities but lower resolution. Ultrasonic sensors excel in short-range applications such as parking, though they have limitations in coverage and on absorbent surfaces. Vision-based systems are adept at color and pattern recognition for road signs but face issues with lens obstructions and varying light conditions. A comparative analysis reveals that infrared cameras and RADAR excel in low-light and adverse weather conditions, while LiDAR provides unmatched depth data in well-lit settings. The integration of multi-sensor fusion technologies is crucial for overcoming individual limitations and enhancing reliability and safety in autonomous navigation. LiDAR sensors, which are active sensors, emit electromagnetic waves, analyze reflected signals, and generate signals for detection. They deliver accurate 3D mapping of surroundings, allowing AGVs to navigate safely through complex environments by identifying obstacles, planning optimal paths, and ensuring secure navigation.

Inertial sensors, such as accelerometers and gyroscopes, provide real-time data on AGV acceleration, orientation, and angular velocity. They complement LiDAR to enhance navigation accuracy, supplying crucial information for precise vehicle navigation and control. By integrating inertial sensor data, AGVs can maintain accurate localization and navigate effectively in dynamic environments.

Vision-based sensors, like cameras, are crucial in AGV navigation for recognizing landmarks, detecting objects, and assisting in path planning. They capture visual data, enabling AGVs to identify navigational features, localize themselves, and maneuver through complex environments. Vision-based sensors improve AGV navigation capabilities, allowing them to adapt effectively to changing environments and navigate precisely.

### 2.2. Algorithms and Methods

The geometric A-Star algorithm functions through a series of structured steps. Initially, the algorithm places the eight nodes adjacent to the starting point into the open list, excluding any that are obstacles. Subsequently, it computes the cost function ($f(n) = g(n) + h(n)$) for adjacent nodes, selecting the node with the smallest ($f(n)$) value and transferring the start point to the closed list. Here, ($g(n)$) denotes the cost from the start point to the current node, while ($h(n)$) represents the estimated cost from the current node to the goal. Nodes adjacent to the current node that are not in the closed list are added to the open list, with the current node designated as their parent. If an adjacent node is already in the open list, the algorithm checks whether a new path provides a lower ($g(n)$) value and updates accordingly. This process is repeated until the goal point is in the closed list, at which point the path is retraced from the goal to the start point using parent nodes. The algorithm subsequently evaluates all nodes in the closed list using functions (P(x, y)) and (W(x, y)), removing those that do not meet the criteria. If the number of nodes in the closed list decreases, the evaluation is repeated; otherwise, the remaining nodes are preserved to form the final path. The final step involves connecting these nodes to form a smooth, optimized path [7]. This detailed process is summarized in Fig. 1.



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Algorithm: Geometric A-start

algorithm Geomtric A-start (start, n, goal)
if reachAroundGoal(start) ≠ goal then return makePath(start)
open ← closestPoint(start)
closed ← 0
final ← 0
while open ≠ 0 do
sort (open)
n ← open.pop( )
if reachAroundGoal(n) ≠ goal then return makePath(n)
neighbors ← expendFlexibleUnits(n)
  end if
  for all the neighbors do
 if neighbor ∉ Obstracle
 neighbor.f← (n.g+g)+(n.p+ p)+h
  if neighbor nclosed= then open ← neighbor
  else closed ← neighbor
    end if
   closed ← n
   if crossPath(n) and sawtoothPath(n) then
  final ← closed
   end if
  end if
 end for
 end
 return 0
```

**Figure 1.** The Flowchart of Geometric A-Star Algorithm

The Particle Swarm Optimization (PSO) algorithm, a form of swarm intelligence, was proposed by Dr. Eberhart and Dr. Kennedy in 1995 [8]. Particle filters aid in SLAM by representing the state space as a collection of discrete particles, each indicating a potential state of the system. This method is crucial for intelligent vehicles operating in unknown environments, as it employs data from LiDAR, cameras, and inertial sensors to simultaneously construct and refine a map while accurately tracking the vehicle's location within that environment. The formulas are defined as follows:

$$v_{id}^{k+1} = wv_{id}^{k} + c_1 r_1 \left(p_{id}^{k} - x_{i\cdot d}^{k}\right) + c_2 r_2 \left(p_{g_d}^{k} - x_{id}^{k}\right) \tag{1}$$

$$x_{id}^{k+1} = X_{id}^{k} + V_{id}^{k_{+1}} \tag{2}$$

Deep learning algorithms, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), are employed to enhance object detection, classification, and prediction systems in intelligent vehicles. These algorithms process vision-based data and LiDAR point clouds to accurately recognize and classify objects, predict pedestrian movements, and identify obstacles, thus significantly enhancing the vehicle's navigational and interactive capabilities within its environment. A multi-automated guided vehicle routing planning method based on Deep Reinforcement Learning (DRL) and Recurrent Neural Networks (RNN), specifically employing Proximal Policy Optimization (PPO) and Long Short-Term Memory (LSTM). The routing method utilizes LSTM to incorporate temporal step information, offering optimized performance in terms of rewards and convergence speed compared to existing PPO-based routing methods for AGVs. Each agent is equipped with its own actor-network and critic network. The actor-network directs the agent's actions, while the critic network assesses the quality of the current state and instructs the actor-network on necessary updates. As illustrated in Fig. 2, a sequence step length of five is employed. This indicates that at any given time t, the original state of one AGV, along with four different pieces of information from the four preceding moments (st−4, st−3, st−2, st−1), and its current state (st) can be captured. This approach facilitates a more comprehensive understanding of the AGV's environment and state, leading to more informed decision-making and enhanced navigation performance [9].

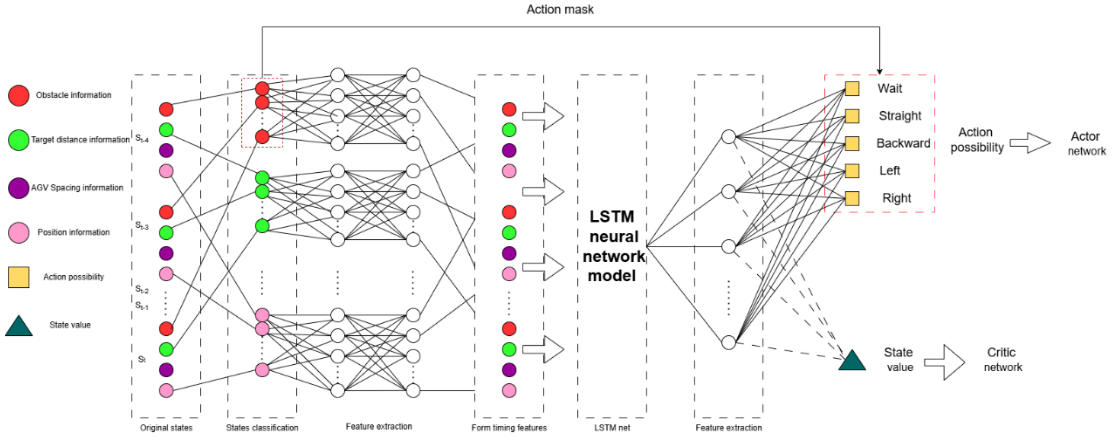

**Figure 2.** PPO with LSTM network structure

Point cloud processing entails using data generated by LiDAR to create a three-dimensional representation of the environment. This process encompasses filtering out noise, segmenting objects, and classifying obstacles. Techniques such as Random Sample Consensus (RANSAC), clustering methods like Density-Based Spatial Clustering of Applications with Noise (DBSCAN), and machine learning models are utilized to interpret and effectively use the point cloud data, thereby enhancing the vehicle's environmental perception and navigation capabilities.

By integrating these detailed algorithms, processing techniques, and integration strategies, intelligent vehicle systems become significantly more capable in terms of accuracy, reliability, and responsiveness to the dynamic conditions of real-world environments. This robust multi-sensor approach is crucial for advancing the field of autonomous navigation and developing safer, more efficient intelligent vehicles.

## 3. Sensor Application Scenarios

### 3.1. Scenarios Description

In warehouse logistics, AGVs employ LiDAR sensors for accurate environmental mapping and obstacle detection, enabling effective navigation through complex layouts and collision avoidance. Inertial sensors monitor the movement and orientation of AGVs within the warehouse, ensuring precise localization and improving path planning for efficient material handling. The navigation strategy emphasizes optimizing path planning to ensure seamless material flow and reduce travel time. By combining sensor inputs and advanced algorithms, AGVs achieve precise, agile navigation throughout the warehouse environment.

In hospital automation, AGVs equipped with vision-based sensors like cameras skillfully execute landmark recognition and path planning, facilitating precise navigation through corridors to deliver medical supplies to wards and operating rooms. Magnetic sensors enhance these systems by offering reliable indoor positioning, crucial in areas with weak or absent GPS signals, enabling precise AGV localization. The comprehensive navigation scheme aims to boost workflow efficiency, leveraging sensor-derived navigation data to ensure timely delivery of medical supplies, thereby improving patient care and the operational efficiency of healthcare services.

### 3.2. Suggestions for the Types of Sensors Suitable for Various Scenarios

When selecting suitable sensors for various scenarios, it is crucial to consider the specific needs and characteristics of each environment. In warehouse settings, LiDAR sensors are optimal for accurate mapping, obstacle detection, and navigation in complex conditions with variable lighting.

Inertial sensors provide precise localization and path planning for AGV movement, whereas ultrasonic sensors are effective at detecting proximity and preventing collisions in narrow or congested areas. In hospital environments, vision-based sensors such as cameras guide AGVs through corridors and assist in the efficient delivery of medical supplies. Radio Frequency Identification (RFID) sensors monitor inventory and assets, facilitating streamlined supply chain management and inventory control, while temperature sensors preserve the integrity of temperature-sensitive medical supplies during transport. In manufacturing facilities, proximity sensors detect nearby objects to prevent collisions and ensure safe navigation, pressure sensors monitor pressure-sensitive materials during transport, and vibration sensors detect machinery vibrations, alerting AGVs to potential hazards and ensuring smooth operations. For outdoor navigation, GPS sensors offer precise positioning and route planning, camera sensors identify landmarks, road signs, and traffic signals to enhance navigation accuracy, and LiDAR sensors excel in long-range object detection and obstacle avoidance, enhancing safety in open outdoor spaces.

### 3.3. Discussion for AGV

Despite significant advancements in sensor technologies for intelligent vehicles, challenges such as reliability issues, cost implications, and technical barriers continue to persist. Sensor reliability is paramount, as they must operate flawlessly under diverse environmental conditions such as rain, fog, and snow, which can impair performance. LiDAR sensors, for instance, struggle with accuracy in adverse weather conditions, while vision-based sensors are compromised by low light levels [10]. The high cost of advanced sensors, such as LiDAR, continues to be a barrier to widespread adoption, though economies of scale and advancements in manufacturing may mitigate these costs over time. Technical challenges encompass the integration and processing of data from multiple sensors, necessitating sophisticated algorithms and substantial processing power, as well as the development of universal standards for sensor integration. Furthermore, sensor systems are at risk of interference from external sources and heightened vulnerability to cyber-attacks as vehicles become increasingly connected. As intelligent vehicles become more common, the scalability of sensor technologies becomes essential, requiring sensors that are robust, maintainable, and replaceable to ensure long-term functionality and manage operational costs. Addressing these challenges through ongoing research and innovations in materials science, artificial intelligence, and cybersecurity is crucial for advancing sensor technologies in intelligent vehicles, with the goal of achieving more reliable, cost-effective, and secure systems.

The trajectory of research in sensor technologies for intelligent vehicles is directed towards overcoming existing challenges and unlocking innovative applications through new sensor types and refined AI algorithms for data processing. Future advancements, including nano-sensors, promise enhanced energy efficiency and ease of integration, significantly bolstering sensor fusion capabilities. The integration of LiDAR, inertial, vision-based, and the magnetic sensor enables AGVs and intelligent systems to achieve higher levels of accuracy, reliability, and adaptability in diverse environments such as warehouses, hospitals, and outdoor spaces. Emphasis on sensor fusion techniques and advanced algorithms improves localization, obstacle detection, and path planning, leading to enhanced efficiency and safety. Furthermore, the trend towards smarter, more autonomous navigation systems capable of adapting to dynamic conditions is driving innovation in robotics, automation, and smart transportation, paving the way for more sophisticated and efficient navigation applications in the future.

## 4. Conclusion

This paper offers a detailed analysis of the application and integration of various sensor technologies in navigation systems, with a particular focus on AGVs across diverse operational environments including warehouses, hospitals, and outdoor areas. The study explores how AGVs utilize a wide range of sensors—LiDAR, inertial, vision-based, and magnetic—to augment their navigation capabilities, ensuring precision, reliability, and adaptability in complex environments.

LiDAR sensors are emphasized for their capability to produce accurate 3D maps and detect obstacles, essential for safe navigation in cluttered or dynamically changing environments. Inertial sensors, such as accelerometers and gyroscopes, supply crucial data on the vehicle's movement and orientation, supporting effective path planning and localization. Vision-based sensors employ visual data to identify landmarks and navigate predefined paths, proving particularly valuable in environments where high-level visual cues are essential. Magnetic sensors provide reliable indoor positioning, proving indispensable in GPS-denied environments such as hospitals.

The paper highlights the growing trend towards sensor fusion, a technique that integrates data from multiple sensor types to improve the overall functionality of navigation systems. This fusion enables more robust localization, enhanced obstacle detection, and more efficient path planning. The integration of these technologies not only enhances the accuracy and safety of AGVs but also increases their operational efficiency.

Furthermore, the research addresses the development of smarter, more autonomous navigation systems that can adapt to various environmental conditions and user requirements. These advanced systems incorporate AI-based models and sophisticated algorithms that enable them to make intelligent decisions and adaptively respond to real-time changes in their surroundings.

The implications of these technological advancements are extensive, driving innovation in robotics, automation, and smart transportation. The paper suggests that as sensor technologies continue to evolve and integrate more deeply, the capabilities of AGVs and other autonomous navigation systems will significantly expand, leading to wider applications and more efficient, safer operational processes.

This analysis not only illuminates the current state of sensor technology in navigation systems but also sets the stage for future research and development in this rapidly advancing field. The integration of diverse sensor technologies and their application in real-world scenarios highlights the potential for significant improvements in how autonomous systems interact with and navigate their environments.

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