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Review on Sensors and Path Planning Algorithms of Automatic Driving

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Abstract. automatic driving developed rapidly in recent years. Environment perception and path planning are two key functions in automatic driving, and sensors and algorithms are the basis for realizing these two functions. Through literature review and comparative analysis, this paper discusses sensors and path planning algorithms in automatic driving. An analysis is conducted on the principles, benefits, limitations, and applications of various sensor types in automatic driving. The RRT algorithm and A* algorithm are also discussed, as well as their advantages and constraints. Finally, this paper proposes suggestions such as deep learning, sensor fusion and cost reduction to update automatic driving. This paper provides a reference for the further development of automatic driving.

Keywords: Automatic driving, sensor, path planning.

1. Introduction

With the progress of science and technology, automatic driving has become a key research direction in the automobile field. Automatic driving usually consists of a perception layer, a decision-making layer, and an executive layer [1]. The perception layer is mainly composed of sensors, which can identify road conditions and accurately perceive the surrounding environment. The decision-making layer mainly refers to the algorithms that control the operation of the vehicle, relying on advanced artificial intelligence technology to formulate different driving strategies in different situations. The executive layer mainly refers to the vehicle control system, which executes the decisions made by the algorithm. The executive layer can accurately control the acceleration and steer the vehicle.

However, the automatic driving technology is still immature, with issues such as insufficient sensor perception accuracy, unstable object recognition accuracy, and the automatic driving algorithm's inability to adapt to changing road conditions.

In view of the above problems, this paper adopts the method of literature review and comparative analysis, and mainly studies two aspects. The first aspect is the sensors of automatic driving. This paper mainly discusses cameras and LiDAR, including the monocular camera, multi-ocular camera, binocular camera, mechanical LiDAR, solid-state LiDAR, and hybrid solid-state LiDAR. The principles, advantages and limitations of each are discussed respectively, and a table is drawn for comparative analysis. The second aspect is to study the key path planning algorithms in the field of automatic driving, mainly about A* algorithm and RRT algorithm. This paper outlines the principles, advantages and

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limitations of each algorithm. In terms of these limitations, some relevant improvements studied by some scholars are also listed.

The research in this paper can provide ideas and suggestions for future sensor technology upgrades, path planning algorithm optimization, and safety improvement of automatic driving. Also, in view of the limitations of the current research on sensors and routing algorithms, the relevant improvement suggestions put forward in this paper are of great significance to promote the maturity of automatic driving technology. This paper hopes to play an auxiliary role in making future automatic driving more intelligent, so as to make people travel more convenient and safer.

2. Sensor

The sensor is responsible for receiving external information and processing external signals to identify objects. Therefore, as part of the perception layer in automatic driving, sensors are as important as human features. This paper will discuss the principles, characteristics and limitations of cameras and LiDAR.

2.1. Cameras

The camera is the most widely used sensor in autonomous vehicles, often referred to as the eyes of the car [2]. The camera is responsible for identifying objects in the surrounding environment, such as surrounding vehicles, passers-by and other obstacles, to fully analyze and judge the current driving environment. Among the many sensors, the camera performs better at interpreting information and distinguishing colors. Therefore, only the camera sensor can realize the functions of traffic light recognition and traffic sign recognition. Although the camera has significant features such as color perception, its performance is susceptible to light and weather conditions. Dark environments and bad weather, especially, can lead to reduced perceptual accuracy. As a result, autonomous vehicles often need to combine cameras and other sensors to provide redundancy in case the camera fails or to take the solution of having multiple cameras to cover different perspectives and tasks.

2.1.1. Monocular camera. Monocular camera, as a pioneer of autonomous vehicle sensors, is being used more and more widely by virtue of its advantages of low cost, simple structure and low spatial position requirements [3]. The monocular camera captures images through a camera module, converting objects in the three-dimensional world into two-dimensional images. Two-dimensional images can clearly display information such as the shape, color, texture and outline of the object, and can be used to recognize objects such as lane lines, traffic lights, road signs, pedestrians and vehicles. The realization of the above function depends on the huge database, that is, the collected information is compared with the marked object in the database, and the object is recognized. In this way, the recognition success rate can reach more than 90 percent.

However, the monocular camera cannot directly provide depth information, and the effective recognition distance is only about 80 to 120 meters. Therefore, when driving at high speed, distant objects cannot be effectively recognized, which may lead to security risks. In addition, monocular cameras have limited ability to recognize atypical objects, such as power poles falling to the ground, human beings who hunker down, and need to constantly iterate learning to improve recognition accuracy. These limitations indicate that monocular cameras still have challenges when dealing with complex road conditions.

2.1.2. Multi-camera. The multi-camera uses a variety of cameras for object recognition. Cameras with different focal lengths perform their respective duties and are respectively responsible for objects in different scenes, which helps to improve recognition stability. For example, Tesla's automatic driving uses a system composed of wide-angle cameras, medium-focus cameras, and telephoto cameras [3]. The wide-angle camera has a visual angle of about 150 degrees, which is mainly used to identify a large range of objects in a short distance. Since the recognition distance is so close, the resolution is not high. The medium focus camera has a visual angle of about 50 degrees and is dedicated to recognizing important information such as lane lines, vehicles, pedestrians, and traffic lights. Although the visual

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angle of the telephoto camera is only about 35 degrees, the recognition distance can reach 200 to 250 meters, which is used to capture information such as pedestrians, vehicles and road signs at a distance. It is evident that the multi-camera system can successfully address the issue of the monocular camera's insufficient effective recognition distance.

2.1.3. Binocular camera. The binocular camera is composed of two cameras, and generates stereoscopic images by the information collected by the two cameras, so as to achieve accurate measurement of object distance [2,3]. The binocular camera not only has all the recognition functions of the monocular camera, but also restores the depth of the left and right images through the algorithm to generate a dense depth map and provide rich depth information. The binocular camera can independently detect obstacles without relying on the database, and improve the recognition accuracy to the centimeter level, which is enough to meet the needs of Level 3 automatic driving.

However, the accuracy of binocular cameras depends on the distance between the two cameras. The further this distance is, the better the recognition of distant objects, but this also affects the recognition of close objects. In addition, although binocular cameras have the advantages of stereo vision and ranging, they still face the challenges of complex calibration, large computation and poor real-time performance, and cannot overcome the inherent limitations of camera resolution and visual angle.

2.2. LiDAR

LiDAR is one of the indispensable sensors in autonomous vehicles, and most automatic driving systems choose to be equipped with LiDAR [2]. Despite the higher cost, LiDAR is still the optimal option for automatic driving due to the consideration of safety. The principle of LiDAR is to emit visible or near-infrared light (usually near the 950nm band) to the target, and measure the arrival time and strength of the reflected or scattered signal to determine the distance, orientation, motion state and surface optical characteristics of the target. LiDAR systems are usually composed of three parts: a transmitter, a receiver and an information processing module, which can accurately detect objects and provide critical environmental perception capabilities for automatic driving.

The application of LiDAR in autonomous vehicles has several advantages [4,5]. First, LiDAR is excellent in terms of penetration and echo effect, especially in vegetation or complex terrain. It is able to reflect the light beam multiple times, providing high-precision surface detection capabilities. Second, LiDAR is light in weight and small in size, which makes it easy to be arranged on autonomous vehicles. Third, the detection capability of LiDAR is strong, and it can monitor about 100,000 target points per second, which is suitable for restoring terrain. Fourth, LiDAR travels at the speed of light, has high static and dynamic detection capabilities, and can provide rich point cloud information and accurately outline the target profile. Fifth, LiDAR can be integrated with other sensors (such as cameras) to further improve the accuracy of environmental perception.

LiDAR can be divided into the following three categories: Mechanical Rotary LiDAR, Solid-state LiDAR, and Hybrid Solid-state LiDAR. This section will discuss the principles, characteristics, and limitations of the three LiDAR types mentioned above.

The following Table 1 shows the difference among cameras and LiDAR.

Table 1. The comparison of sensors.

	Advantage	Limitation
Monocular camera	low cost, simple structure and low spatial position requirements	no depth information, low effective recognition distance, limited recognition ability to atypical objects
Multi-camera	enhanced recognition stability	no depth information
Binocular camera	rich depth information, work independently without the database	complex calibration, large computation and poor real-time performance
LiDAR	excellent performance in complex terrain, lightweight and small size	high cost

2.2.1. Mechanical rotary LiDAR. Mechanical Rotary LiDAR converts the laser from line to surface by rotating its transmitting and receiving system [2,6]. Therefore, Mechanical Rotary LiDAR can arrange multiple laser beams in the vertical direction and achieve 360-degree dynamic scanning. Due to the mechanical rotation structure, this technology has the advantages of fast scanning speed, wide field of view and high laser power.

However, the complex mechanical structure of Mechanical Rotary LiDAR is easy to cause the stability to be affected by temperature changes. Also, problems of the large volume, weight, and high cost are difficult to solve. Therefore, Mechanical Rotary LiDAR is troublesome to apply to autonomous vehicles and has been gradually abandoned.

2.2.2. Solid-state LiDAR. Compared with Mechanical Rotary LiDAR, Solid-state LiDAR has no complex mechanical structure inside [2]. Therefore, Solid-state LiDAR has a more compact structure, smaller size, lower cost, higher durability, and reliability. Such characteristics meet the requirements of radar for automatic driving. In terms of technology, Solid-state LiDAR is divided into OPA and Flash two types.

OPA LiDAR uses optical phased array technology to control the luminescence time difference through an array of multiple light sources and synthesizes the main beam with a specific direction to achieve high-speed, accurate, and flexible scanning. However, the scanning Angle of each OPA LiDAR is only 60 degrees. To achieve all-round scanning, multiple devices need to be installed in different directions. In addition, the production of OPA LiDAR is difficult, and the current technology is still immature.

Flash Solid-state LiDAR quickly records the entire scene by emitting a laser that covers the entire detection area for a short period of time, coupled with a highly sensitive receiver. With no rotating parts or lens wear, Flash Solid-state LiDAR is more stable. However, Flash Solid-state LiDAR also has obvious drawbacks, such as its detection range of only about 100 meters, high requirements for the processor, difficulty in overcoming heat problems, and high costs.

2.2.3. Hybrid solid-state LiDAR. Traditional Mechanical Rotary LiDAR needs to rotate the laser transmitter to achieve all-round scanning, while Hybrid Solid-state LiDAR uses a semiconductor micro device to drive a rotating mirror or prism, which can achieve an all-round scanning function equivalent to Mechanical Rotary LiDAR [2]. Therefore, the Hybrid Solid-state LiDAR itself does not need to be substantially rotated, which effectively reduces the possibility of failure of the system in the driving environment and has higher reliability. Hybrid Solid-state LiDAR combines the advantages of both solid-state and moving forms, allowing flexible distribution of detection points. For example, on a wide road with less traffic, the main scanning is carried out in the far front, and only a small amount of scanning is carried out on the side; In the scene where the side is prone to visual blindness (such as parking lots and intersections), the side is mainly scanned. The above functions cannot be realized by traditional Mechanical Rotary LiDAR. In addition, the detection range of Hybrid Solid-state LiDAR is also in line with the current needs of automatic driving, so it has been widely used.

3. Path planning

Path planning plays a significant role in vehicle automatic driving and is an important part of connecting sensors and actuators. In the field of automatic driving, how to plan the smoothest and shortest path in a shorter time is a long-term problem. This section will discuss the principle, advantages, limitations, and research status of and A* algorithm RRT algorithm.

3.1. The A algorithm*

The A* algorithm is based on the Dijkstra algorithm and is also called heuristic search. The traditional Dijkstra algorithm is purposeless, usually starting from a point and exploring all the surrounding points, so the calculation amount is usually very large. However, the A* algorithm introduces the concept of valuation function. In order to find the shortest path value function requires the sum of the distance,

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from the current point to the target point, and the distance, from the current point to the next point, is minimal

The advantage of the A* algorithm is that it avoids the purposelessness of the search and makes each search closer to the target point. However, the disadvantage is that the path turns too much, which cannot guarantee smoothness. Also, the A* algorithm is inefficient and the speed of this algorithm is slow.

To solve the above problems, HU proposed a hybrid A* path planning method based on DBSCAN and dichotomy, which adopted the simplified unstructured scene map with multiple obstacles and the node expansion method based on dichotomy [7]. It not only ensured high computational efficiency but also effectively improved the smoothness of the path. LIU proposed a fusion algorithm of bidirectional A* algorithm and dynamic window algorithm to remove redundant nodes in global path nodes and smooth the processed global path nodes with Bessel curves [8]. Compared with the traditional A* algorithm, the time used for finding the path and the number of path nodes is greatly reduced, and it also achieves a better obstacle avoidance function. REN proposed a fusion algorithm of the improved A* algorithm and the Lattice algorithm, which made the simultaneous path and velocity planning come true [9]. This algorithm used the Frenet coordinate system to decouple longitudinal and lateral motion planning in three-dimensional space, so the complexity of the algorithm is reduced, and safety and comfort are ensured.

3.2. RRT algorithm

The RRT algorithm starts from the starting point of the car as the root node of the random tree [10,11]. The algorithm randomly samples the environment model, generates new nodes, and connects these nodes with the nearest existing nodes to form an extension path. This path will grow in a certain number of steps, preferentially toward the direction away from the obstacle. When the path extends near the destination, tree growth stops. The starting and ending points of the algorithm are then connected to generate the shortest path from the starting point to the destination as the final planned path. This approach effectively helps autonomous vehicles avoid obstacles and find the appropriate path.

The RRT technique is commonly used in complicated and high-dimensional environments due to its robust searching capability and ease of solving non-holonomic constraint optimization problems. However, the traditional RRT algorithm has some shortcomings when applied to path planning. For example, in the process of path search, RRT algorithm requires a large amount of computation and the expansion randomness of nodes is too strong, resulting in the lack of guidance of the searched path and many turning points of the path.

In order to reduce the limitations of traditional RRT algorithms, relevant scholars proposed the RRT* algorithm [11]. RRT* algorithm is an asymptotic optimal path algorithm, by re-selecting the parent node, and reconnecting the node within a certain range, through several iterations to achieve asymptotic optimization. Compared with the traditional RRT algorithm, the path of RRT* algorithm is obviously shorter. However, the size of the step, the number of nodes, and the number of redundant nodes still affect the search efficiency and path length. Luo proposed an improved RRT* algorithm to solve the above problems [12]. By introducing global adaptive step size, the search speed is improved. The strategy of refusing to partition sampling points is adopted to make the distribution of sampling points more favorable to the expansion of the random tree. The planned path is also optimized, and the number of nodes and path costs are reduced through pruning operations.

4. Suggestions

The review of different sensors in this paper manifests that the use of a specific sensor alone has some limitations. In the future, sensor fusion will become a trend. Different sensors working together can complement each other to improve the accuracy and stability of environmental perception. For example, on sunny days, automatic driving systems can mainly rely on the camera. On rainy days or foggy days, the system can rely more on radar.

The traditional path planning algorithms A* and RRT have limitations to a certain extent. In the future, scholars in relevant fields can use deep learning (such as convolutional neural networks), combining historical driving data and environmental data, to make more reasonable planning for driving routes. For example, it is valuable to predict road congestion in advance, avoid congested routes in time, and shorten the time to reach the destination. Reinforcement learning can also be used for automatic driving. By introducing a reward function, the automatic driving system can continuously optimize the path and make the most reasonable planning.

It is also important to note that many autonomous vehicles are still expensive, hindering the popularization of automatic driving. In the future, the cost of autonomous vehicles can be gradually reduced by replacing high-cost sensors with low-cost sensors. More people will be able to experience automatic driving, accelerating the popularization of automatic driving.

5. Conclusion

This paper analyzes sensors and path planning algorithms in automatic driving. It is found that the camera, as a common tool for object recognition, has been widely used due to its advantages of low cost and rich information, but its performance in the dark environment is still limited. LiDAR compensates for this limitation, it performs well in accuracy and stability, making it an important sensor in automatic driving. In addition, in the algorithm part, this paper analyzes the basic principles and limitations of A* and RRT algorithms. The A* algorithm avoids the blindness of the search but does not guarantee smoothness. RRT algorithm generates paths through random sampling, which is suitable for path planning in complex environments, but it requires a lot of computation.

The analysis of sensors and path planning algorithms in this paper not only helps to understand the technical advantages and limitations of current automatic driving, but also provides a theoretical basis and direction for future technology research and development.

Although automatic driving still faces many challenges, it will be further developed in the future. First of all, sensor fusion will become a direction of development. By combining various sensors, automatic driving systems can obtain more precise information about the environment. Secondly, the use of deep learning and reinforcement learning can further optimize the path planning algorithm, so that the automatic driving system can cope with a variety of complex road conditions, and improve the safety and stability of automatic driving. In addition, with the decrease in sensor costs and the popularization of technology, more people will experience automatic driving earlier.

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