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Application of sensors in autonomous driving technology

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ABSTRACT
Nowadays, autonomous driving technology has become a frontier area of great concern to both academia and industry, and the importance of autonomous driving sensors, as the key core components supporting this technology, cannot be ignored. For self-driving cars, the sensor is like the vehicle's "sense organs", with the help of various advanced sensing technologies, can be real-time and accurate collection of the vehicle's surrounding complex environmental information, and to obtain the data to be efficient, in-depth analysis and processing. Based on this, the vehicle can make scientific and accurate decision-making judgment, so as to achieve safe and stable automatic driving. Following this logical relationship, the innovation and breakthrough of sensor technology, to a great extent, directly determines the evolution trend and development level of automatic driving technology. In this paper, the main categories of common sensors in the field of automatic driving are comprehensively sorted out, and the technical advantages and performance deficiencies of each type of sensor are discussed in depth, which are expected to give useful reference and reference for the subsequent research and engineering practice in this field.

KEYWORDS
autonomous driving; sensors

1 Introduction

1.1 Background and significance of the study

In recent years, the development of autonomous driving technology has been extremely rapid. Many automobile manufacturers and technology giants have invested a lot of resources to launch fierce competition in research and development. According to the automated driving grading standards formulated by the Society of Automotive Engineers International (SAE), each level, from L1 assisted driving to L5 fully automated driving, symbolizes a major breakthrough in technology.

In the huge system of automatic driving technology, sensors obviously occupy a crucial core position. It is just like the vehicle's "eyes", "ears" and "tentacles" in general, undertaking the important mission of collecting information about the vehicle's surrounding environment. Through the sensor, the vehicle can instantly perceive the road situation, the position and speed of other vehicles, the dynamics of pedestrians and traffic signal changes and other key information, to the subsequent decision-making and control to build a solid data foundation. Different kinds of sensors have their own unique advantages and limitations, they work together, complement each other's strengths, together to build an all-round, multi-level sensing network.

The present study is an in-depth exploration of the use of sensors in autonomous driving technology, which is of critical theoretical and practical value. From the theoretical point of view, the in-depth investigation of sensor technology is helpful for us to have a more comprehensive and in-depth understanding of the sensing principle and information processing mechanism of the automatic driving system, so as to give solid theoretical support for further optimization of algorithms and enhancement of system performance. By analyzing the characteristics and performance indexes of different sensors as well as their fusion strategies, we can reveal the inherent law of multi-sensor fusion system in improving the accuracy, reliability and stability of environment perception, and contribute to the theoretical development of automatic driving technology.

In practical terms, breakthroughs and innovations in sensor technology are the key elements in promoting the maturity of automated driving technology and achieving widespread application. In terms of traffic safety, accurate and reliable sensors can significantly enhance the vehicle's ability to perceive complicated road conditions and potential dangers, effectively reduce traffic accidents caused by human driving errors, and provide more solid protection for people's lives and properties. According to relevant statistics, the number of casualties caused by traffic accidents around the world reaches millions every year, and autonomous driving technology is expected to reduce this number significantly. In terms of traffic efficiency, self-driving vehicles are able to achieve more efficient driving planning and cooperative control with the help of intelligent algorithms to ease traffic congestion and improve road capacity. For example, in urban traffic, self-driving vehicles can adjust their speed and route according to real-time road conditions, avoiding unnecessary stops and starts, and thus reducing energy consumption and exhaust emissions. Advances in sensor technology will also promote the transformation and upgrading of the entire automotive industry, creating new business models and employment opportunities, and injecting a strong impetus for economic and social development.

1.2 The current status of domestic and international research

Overseas, the United States, Germany, Japan and other countries are leading the world in the exploration and utilization of autonomous driving sensors. In the Americas, by the University of Toronto, Massachusetts Institute of Technology and Waabi AI researchers proposed UniSim is a new automatic driving simulation platform, which uses Neural Radiation Field (NeRF) rendering technology to simulate real-world camera and radar data to achieve a high degree of fidelity of all-around simulation; Innoviz company launched InnovizOne InnovizOne automotive-grade solid-state LIDAR sensor, which adopts ONSEMI's Silicon Photomultiplier (SiPM) technology to detect returning laser pulses, measure the distance to the surrounding environment, and then achieve true autonomous driving capabilities.

Domestic research in the field of automated driving sensors started a little later, but has made rapid progress in recent years, obtaining a series of remarkable results. The government attaches great importance to the progress of autonomous driving technology and has promulgated a series of policies to support the development of related research and industry. Under the guidance of national policies, universities, research institutes and enterprises have increased their R&D investment in the field of autonomous driving sensors. Wang Yongtao's group at Wang Xuan Institute of Computer Science, Peking University, has achieved many results in intelligent driving technology. They have constructed a 4D millimeter wave radar - surround view camera multimodal sensing model frame RCBEVDet, this architecture by fusing 4D millimeter wave radar and the bird's-eye view features of the surround view camera, improve the accuracy of 3D target detection and real-time inference speed, and modal signal loss and interference has a strong robustness; Tsinghua University, College of Vehicles and Transportation, academician Li Jun's team has announced the first international automated driving system for the Dual Radar, the first international 4D imaging millimeter-wave radar dataset for autonomous driving in China's urban and complex climatic environments, is free and open source. This dataset provides a new test benchmark for 4D millimeter-wave sensing algorithms in complex climates, which is helpful to improve the sensing capability of autonomous vehicles in complex situations.

1.3 Research methodology

This study focuses on the application of sensors in many aspects of autonomous driving technology, and analyzes them comprehensively from the types of sensors, application scenarios, fusion technologies to the challenges and strategies to cope with them. In the study of sensor types, various common sensors such as LIDAR, camera, millimeter-wave radar, ultrasonic sensors, etc. will be discussed in detail.

2 common types of sensors used in autonomous driving

2.1 Camera

2.1.1 Relevant cases

In vehicles equipped with L2 assisted driving function, a front camera is usually installed to recognize the road route, which provides information about the deviation of the vehicle's driving direction from the target path for the road holding (LKA) function, and realizes centering of the vehicle through negative feedback adjustment. In addition to detecting the environment in front of the vehicle, side and rear environment detection can also provide more necessary information for the vehicle's decision-making, such as lane changing and overtaking. Automatic driving to the L2 + level of the Peng P7 Peng Wing Edition, the car is equipped with as many as 14 cameras, can realize the vehicle 360 ° panoramic visual perception; and the world's leading smart car Tesla Model 3 car has a total of 8 cameras, including left and right on the fender each has a camera toward the side of the rear, and side turn signals integrated together, the B-pillar on the upper left and right each has a camera in the front of the bottom of the front windshield. There are eight cameras in the Model 3, including a rear-facing camera on the left and right wing panels, integrated with the side turn signals, a forward-facing camera on the top of the B-pillar, three forward-facing cameras on the top of the front windshield, and a rear-facing camera on the top of the license plate, which provide comprehensive environmental awareness for the Autopilot system[1].

2.1.2 monocular camera

Monocular cameras are the most common type, which only use a lens to collect image information. Monocular cameras are simple and inexpensive, and can recognize and classify traffic signs, lane lines, pedestrians, vehicles and other targets with image recognition algorithms. By analyzing the size, shape, color and other characteristics of the object in the image, the monocular camera is able to determine the category of the object and the approximate distance. However, since the monocular camera can only obtain two-dimensional image information, there are some limitations in the depth perception of the object, and it is difficult to accurately measure the distance and spatial position of the object. In this paper, we propose a new method for measuring the distance and spatial position of an object.

Figure 1 Mobileye EyeQ4 monocular camera

2.1.3 binocular camera

A binocular camera consists of two lenses that simulate the principle of human binocular vision. There is a certain baseline distance between the two lenses, and by taking a picture of the same object together, images from different viewpoints are obtained. By virtue of the parallax principle, that is, based on the difference in the position of the object in the image captured by the two lenses, the distance between the object and the camera is calculated, and then the three-dimensional spatial perception of the object is achieved. The binocular camera has a significant advantage in depth perception, and can more accurately measure the distance and position of objects, which is extremely critical for obstacle detection and obstacle avoidance in autonomous driving. However, its accuracy is limited by the baseline distance and camera resolution, the baseline distance is too short, which will result in a decrease in depth measurement accuracy, while too high a resolution will increase the difficulty and cost of data processing.

Figure 2 Xiaopeng P7 + rear binocular vision camera

2.1.4 looking around the camera

Surround view camera is usually composed of multiple cameras, distributed in the front, back, left, right and right of the vehicle in these four directions, can be real-time access to the 360-degree panoramic image information around the vehicle. With the help of image stitching technology, the images captured by each camera are seamlessly stitched together to form a complete panoramic image, giving the driver an all-around view and helping the driver to better understand the environment around the vehicle. In automated driving, surround view cameras are often used in parking assistance, obstacle detection at low speeds, and blind spot monitoring to prevent accidents caused by blind spots in the field of view.

Figure 3 Moriun SG3-AR0341C-G2F-H190X

2.2 radar sensors

2.2.1 Millimeter-wave radar

Millimeter-wave radar is one of the key sensors in the field of automated driving, and its principle of operation is based on the characteristics of electromagnetic waves in the millimeter-wave frequency band, and it detects the relevant information of the target object by transmitting and receiving electromagnetic waves. Millimeter-wave refers to electromagnetic waves with a wavelength of 1 to 10 millimeters, corresponding to a frequency range of 30 to 300 GHz. millimeter-wave radar has a shorter wavelength and higher frequency than traditional microwave radar, which gives it a series of unique performance advantages.

In the process of operation, the transmitting antenna of the millimeter-wave radar transmits electromagnetic wave beams in the millimeter-wave frequency band towards the surrounding space. When these electromagnetic waves touch the target object, they are reflected, and some of the reflected waves are captured by the radar's receiving antenna. By accurately measuring the time difference between the transmitted and reflected waves, the millimeter-wave radar can accurately calculate the distance between the target object and the radar.

Figure 4 EasyWay ALRR300

2.2.2 LIDAR

The working principle of LIDAR is that the laser transmitter sends out a beam of laser pulses, and when the laser pulses irradiate the target to be detected, they will be reflected, and the reflected signals will be received by the laser receiver and transmitted to the signal processing system, and at the same time, they will be fed back to the control system, so that the distance between the target to be detected and the radar's position can be calculated[2].

LIDAR also has a strong real-time capability, scanning and updating its surroundings quickly to capture the movement of objects. On urban roads with heavy traffic flow, where the movement of vehicles and pedestrians is constantly changing, LIDAR is able to scan the surrounding environment at a high frequency and update the point cloud map in real time, giving the autonomous driving system the latest information about the environment and ensuring that the vehicle can make appropriate decisions in a timely manner.

Figure 5 Livox Horizon LIDAR

2.3 other sensors

2.3.1 Ultrasonic sensors

The cornerstone of ultrasonic sensors is the reflective properties of sound waves, a principle that is both sophisticated and efficient. The sensors can emit ultrasound at frequencies above 20kHz, which is well above the upper limit of human hearing, and have excellent directionality and penetration capabilities. When the emitted ultrasound waves hit an obstacle during propagation, they are instantly reflected back, and the sensor's receiving end is able to capture these reflected waves acutely.

In the field of autonomous driving, ultrasonic sensors play an irreplaceable key role in proximity detection situations. In the parking assistance system, it can be said to be a powerful helper for the driver. When the vehicle is reversing into a parking space, ultrasonic sensors mounted on the front and rear bumpers of the vehicle turn on and detect in real time the distance between the vehicle and surrounding obstacles, such as walls and other vehicles.

2.3.2 Inertial Measurement Unit (IMU)

Inertial Measurement Units (IMUs) help autonomous vehicles maintain proper attitudes by accurately measuring acceleration and angular velocity, and incorporate two core sensors, accelerometers and gyroscopes, which work in tandem to provide the vehicle with critical motion information.

3 Future perspectives and conclusions

3.1 Future trends

Along with the upgrading of automatic driving technology and the evolution of multiple technology paths for automatic driving, the sensors applied to automatic driving are also developing towards multi-sensor fusion, neuromorphism and network connectivity. Multi-sensor fusion is the deep integration of data from different kinds of sensors, such as the high-precision distance measurement of LiDAR and the rich visual information of cameras to complement each other, so as to perceive the road conditions in a comprehensive way. Neuromorphism is to simulate the neuron working mode of the human brain, so that the sensor has more powerful information processing ability, and can quickly identify complex scenes. As for network connectivity, by virtue of 5G and other communication technologies, vehicles and the surrounding environment to promote real-time interaction, the sensor can not only sense their own surroundings, but also access to distant dynamics, and respond in advance, which greatly improves the safety and reliability of automated driving[3].

3.2 Conclusion

This paper takes automatic vehicle driving as an entry point, describes the composition of automatic vehicle driving systems and the related roles.

The key role of the environment sensing system and the related sensors, and in the form of a table for the various types of sensors to be compared and analyzed, the analysis shows that, in order to improve the reliability, accuracy and robustness of the self-driving car, multi-sensor fusion technology is indispensable, combined with the characteristics of the different sensors, each sensor technology can be highly integrated system to play its own advantages, to obtain more accurate environmental information.

At present, the automatic driving technology is developing from L3 to L4 level, which brings higher standard to the environment sensing system, the improvement of the product technology needs the upgrade of software and hardware, and the synergy of software and hardware is an effective way, with the help of the continuous upgrading and replacement of the technology, the environment sensing system with high precision, high efficiency and high response will be reached as soon as possible, and the fully automatic driving technology will be a reality. The fully automated driving technology will become a reality [4].

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