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Research on the Application of Sensor Technology in the Field of Intelligent Driving

Jiayu Yang[1,a,*]

[1]*Suzhou Foreign Language School, Suzhou, 215000, China*
a. m18015561829@163.com
**corresponding author*

Abstract: With the dramatic speed of developing the advanced technology and the huge demand for the traffic. In order to minimize the cost and also to use the human resources more efficiently, autonomous driving was encouraged. There are plenty of embedded systems which are associated in the driving operating system and sensor technique is one of the most important appliance in the whole system. This essay is going to focus on all kinds of applications of sensors used in the autonomous driving technique and also the improvements that the sensors can have.The advancement of sensor technology is pivotal in the development of intelligent driving systems, significantly enhancing vehicle safety, navigation, and automation. This research paper explores various sensor technologies, including LiDAR, radar, cameras, and ultrasonic sensors, and their applications in intelligent driving. By examining the functions, advantages, and limitations of each sensor type, this study highlights their roles in critical driving tasks such as obstacle detection, lane keeping, and adaptive cruise control. Furthermore, the integration of these sensors within vehicle systems is discussed, emphasizing the importance of data fusion and machine learning algorithms in processing sensor data for real-time decision-making. The paper concludes with a discussion on future trends and challenges in sensor technology for intelligent driving, suggesting areas for further research and development.

Keywords: Senor techonology, Intelligent driving, Embedded systems

1. Introduction

Sensors are crucial components in intelligent systems, particularly in autonomous driving. There are five primary sensor types utilized in these systems: 1) Long-range radar sensors, which detect targets through obstacles like rain and fog; 2) Camera sensors, typically combined for short-range detection and long-distance feature recognition; 3) Radar sensors, primarily for 3D mapping and object detection; 4) Short- to medium-range radar sensors, effective for side and rear detection; and 5) Ultrasonic sensors for close-range target identification. Despite advancements in autonomous driving, improvements are still needed, particularly in vehicle information exchange systems. This essay will explore the applications of these sensor categories, potential enhancements, and compare sensor usage across companies alongside accident rates. The study aims to forecast future developments in autonomous driving sensors and propose solutions to identified challenges.

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2. Literarute Review

The working principle of the sensor: the sensor usually feels non-electrical quantities through the sensitive elements, while it uses the conversion elements to output usually electrical quantities, such as voltage, current, charge, etc.[1]

The sensor is generally composed of four parts: sensitive element, conversion element, conversion circuit and auxiliary power supply, and its working principle is shown in the figure. 1

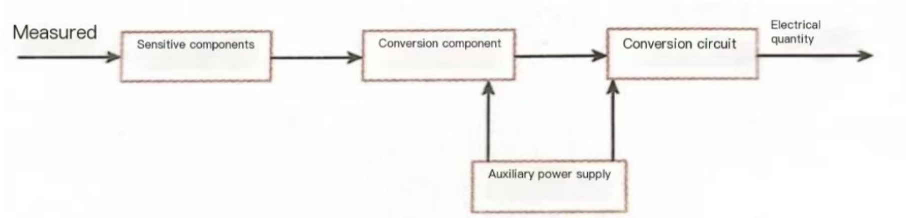

Figure 1: The sensor working principles

Autonomous driving technology is divided into three core processes in terms of business process, namely environmental perception and positioning, decision-making and planning, and execution control. The specific values of these 3 core processes are as follows:

Environmental perception and positioning involve acquiring indicators during driving via sensor technology, including cameras and GPS. Decision planning utilizes this data to determine and guide the vehicle's subsequent actions. Execution decision-making relies on drive-by-wire systems to control acceleration, braking, and related functions through signal commands. Sensor-based intelligent driving technology is a focal point in the automotive sector, with sensors being pivotal for real-time environmental awareness, enhancing driving assistance and safety. Key components include lidar, cameras, millimeter-wave radar, and ultrasonic sensors, which collectively monitor road conditions, vehicle positioning, obstacles, and pedestrians to ensure accurate driving support and safety.

3. Application of Sensor Technology in the Field of Intelligent Driving

3.1. Millimeter-Wave Radar

Millimeter-wave radar is a radar working in the range of millimeter wave detection. Generally, millimeter wave refers to the 30-300GHz frequency domain (wavelength is 1~10mm). The wavelength of millimeter wave is between microwave and centimeter wave, so millimeter wave radar has some advantages of both microwave radar and photoelectric radar. There are a lot of features for millimeter-wave radar to support it becoming a popular radar used in the intelligent driving.[2]

(1)Compact antenna aperture with a narrow beam ensures precise tracking and guidance; effective at low elevation angles, resilient to ground multipath and clutter; superior lateral resolution for near-air targets; enhanced angular resolution for area imaging and target surveillance; robust anti-interference capabilities; elevated antenna gain; proficient in detecting small targets such as power lines, poles, and projectiles.

(2)Large bandwidth: with high information rate, it is easy to use narrow pulse or broadband frequency modulation signal to obtain the detailed structural characteristics of the target; It has a wide spectrum expansion ability, reduces multipath, clutter and enhances anti-interference ability; Radar or millimeter-wave recognizers of adjacent frequencies work and are easy to overcome mutual interference; High distance resolution, easy to obtain accurate target tracking and recognition ability.

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(3)High Doppler frequency: good detection and recognition of slow and vibrating targets; It is easy to use the target Doppler frequency characteristics for target feature recognition; Penetration characteristics for dry air pollution, providing good detection in dust, soot and dry snow conditions.

(4)Good anti-stealth performance: The absorbing materials coated on the current stealth aircraft are all aimed at centimeter waves. According to foreign research, the stealth target irradiated by millimeter-wave radar can form strong electromagnetic scattering in multiple parts, which greatly reduces its stealth performance, so millimeter-wave radar also has the potential of anti-stealth.

Millimeter-wave radar presents several drawbacks alongside its advantages. Key limitations include attenuation in high humidity conditions like rain, fog, and wet snow, as well as the impact of high-power devices and insertion loss, which diminish detection range. Its penetration through dense foliage is inferior to that of microwaves. Additionally, component costs are high, processing accuracy demands are significant, and the development of monolithic transceiver integrated circuits is progressing slowly.

4D millimeter-wave imaging radar enhances traditional millimeter-wave radar by overcoming its limitations. While conventional millimeter-wave radar, often referred to as 3D radar, primarily measures angle, distance, and speed, it fails to assess object height, hindering its ability to evaluate stationary obstacles' impact on vehicle traffic. In contrast, 4D imaging radar incorporates pitch angle measurement, achieving sub-degree angular resolution (<1°) and providing detailed target outlines through extensive measurement points. Utilizing neural network technology, 4D imaging radar can detect, classify, and track multiple stationary and moving targets within a 300m range based on point cloud data. In addition, the 4D imaging radar can maintain good performance in cornercase scenarios such as braking in front of the vehicle, preventing continuous rear-end collisions, large light ratio, and bad weather.[3]

3.2. Camera Sensor

The camera sensor is essential for autonomous driving, comprising a lens, lens module, filter, CMOS/CCD, ISP, and data transmission components. Utilizing optical imaging principles, light reflected from objects passes through the lens to the image sensor (CMOS/CCD), which converts the light into an analog electrical signal. This signal is then digitized via an analog-to-digital converter based on pixel distribution, brightness, and color. The image signal processor (ISP) enhances these digital signals through filtering and grayscale processing, employing algorithms like adaptive binary words and deep learning to enable self-driving cars to interpret their environment. For example: monitoring of road users such as vehicles and pedestrians, lane line monitoring, traffic sign monitoring, traffic light monitoring, etc.[4]

According to the installation position, the camera can be divided into front view, side view, rear view, built-in and surround view. Its functions are as follows:

- -Front-view camera: Generally used as the main camera in ADAS/autonomous driving, it is installed above the front windshield of the car, and can realize the identification of obstacles, lane markings, road teeth, traffic lights, traffic signs and drivable areas.
- -Side-view camera: The side-view camera generally has three installation positions, the rearview mirror, the B-pillar of the vehicle and the rear fender of the vehicle, which is generally used for lateral obstacle monitoring, blind spot monitoring, etc.
- -Rearview camera: Generally installed in the trunk of the vehicle, it can be used to implement parking assistance functions.
- -Surround view camera: The surround view camera is generally installed around the body, and generally uses 4~8 fisheye cameras to achieve 360 panoramic images, parking space monitoring, and low-speed perception functions.

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- -Built-in camera: The common installation positions are the inside of the vehicle's A-pillar, on the steering wheel, and in the rearview mirror for pet baby monitoring in the car, driver fatigue monitoring and other functions.

Camera sensors present several advantages and disadvantages. Camera sensor technology is well-established and cost-effective, particularly when compared to the expensive lidar market, making it the preferred choice for mass production in autonomous vehicles. Additionally, cameras capture rich image data, including color, texture, contour, and brightness, which are essential for tasks like traffic light monitoring and sign recognition, capabilities that other sensors like lidar and millimeter-wave radar cannot match. As passive sensors, cameras are highly sensitive to variations in light. Adverse weather conditions such as rain, fog, and low light significantly degrade imaging quality, complicating object detection and identification for perception algorithms. In addition, as a passive sensor, the camera sensor is inferior to LiDAR and millimeter-wave radar in terms of ranging and speed measurement.[5]

3.3. Lidar Sensor

LiDAR, or Light Detection and Ranging, is a laser-based system that measures the distance between the sensor and a target by analyzing the reflected energy, including amplitude, frequency, and phase, to generate precise three-dimensional structural data. It comprises components such as laser transmitters, receivers, scanners, lenses, and signal processing circuits. The primary laser emission types are laser diodes, typically made from silicon or gallium arsenide, and vertical cavity surface emitting lasers (VCSELs), like those used in iPhones. VCSELs are cost-effective, compact, and energy-efficient, but have a limited effective range, necessitating multi-stage amplification for optimal vehicle distance measurement.[6]

3.3.1. The Functions of Lidar Sensor:

(1)Perceive

LiDAR's sparse 3D representation reveals that scanned obstacle point clouds are typically denser than the background, facilitating obstacle perception through classification and clustering. Advances in deep learning have enhanced detection and segmentation capabilities, enabling efficient identification of pedestrians and vehicles, generating 3D bounding boxes, and labeling individual points in the point cloud, including lane markings.

Initial research in 3D object recognition concentrated on simple geometric shapes like cubes and cylinders, which inadequately represent real-world objects. Subsequent studies shifted towards recognizing 3D free-form targets—objects characterized by continuous normal vectors, such as vehicles and buildings—broadening the applicability of recognition systems. Over the past two decades, the volume of data for 3D object recognition has surged, alongside increasing recognition complexity and success rates. Nonetheless, challenges remain in detecting, identifying, and segmenting objects in complex scenes affected by occlusion, background noise, and varying data resolutions.

(2)Registration

In 3D model reconstruction, initial research concentrated on point cloud fine registration, fusion, and surface reconstruction with known adjacency and initial pose. Adjacencies indicate overlapping point clouds, typically derived from the scanning order. The initial pose relies on turntable calibration, surface marking, or manual point selection, necessitating significant human intervention and reducing automation. Subsequently, researchers explored reconstruction with known point cloud adjacency but unknown initial pose, employing key-based, line-based, and area-based matching algorithms. However, adjacency is often unknown in practice. To address this, the minimum tension tree and connection graph algorithms were developed for adjacency calculation. Overall, the trend in 3D model reconstruction algorithms is toward increased automation, reduced manual intervention, and broader applications. Nonetheless, existing algorithms face challenges such as high computational complexity, single-object targeting, and sensitivity to background interference, making the development of a fully automated, low-complexity algorithm independent of prior knowledge a significant challenge.

(3)Odometer and positioning

Using the relative pose transformation derived from the registration of two frame point clouds, we can leverage lidar sensor data to estimate the temporal pose changes of the carrier object. This involves matching the current frame with the previous frame or with accumulated sub-maps to derive the pose transformation, effectively functioning as an odometer. By aligning the current frame with the complete point cloud map, we can ascertain the sensor's pose within the overall map, facilitating accurate positioning.[7]

3.3.2. The Tendency of the Development of Lidar Sensor

(1)Sensors are automotively regulated

Solid-state lidar cancels the mechanical structure and can hit the pain points of the current mechanical rotation cost and reliability, which is the development direction of lidar. In addition to these two pain points that need to be solved urgently, the detection range of the currently mass-produced LiDAR is insufficient, and it can only meet the application of low-speed scenarios (such as in factories and campuses). Scenarios for daily driving, high-speed driving are still being tested.

(2)Multi-sensor fusion

Ultrasonic radar is primarily utilized for reversing and proximity detection in automated parking, while cameras, millimeter-wave radar, and lidar are extensively employed in various ADAS functions. Each sensor type varies in detection parameters, including range, resolution, and angular resolution, which influence their object detection, recognition, classification, 3D modeling, and performance in adverse weather. The integration of diverse sensors offers complementary advantages, making sensor fusion the prevailing solution.[8]

4. The Challenges and Prospects of Sensor Technology in the Field of Intelligent Driving.

4.1. In Terms of Sensor Performance

Accuracy and reliability: In complex traffic scenarios, sensors must effectively perceive environmental data, including vehicle location, speed, and shape, as well as pedestrian and traffic sign information. However, all sensor types face inherent accuracy limitations and error sources. For instance, LiDAR accuracy diminishes with long-distance measurements, leading to noise and distortion in point cloud data. Camera image recognition is vulnerable to light, shadow, and occlusion, resulting in misjudgments or omissions. Environmental adaptability: Autonomous vehicles must operate under diverse weather and lighting conditions, yet sensor performance often deteriorates in adverse weather. Heavy rain, fog, and snow can impair camera image quality and visual range, hindering recognition capabilities. LiDAR's effectiveness is limited in fog, while millimeter-wave radar may experience signal attenuation in heavy rain, compromising environmental perception. [9]

4.2. Sensor Fusion Challenges

Data synchronization challenges arise from the disparate operational frequencies of various sensors; for instance, cameras typically operate at 30fps or 60fps, while radar scanning frequencies range from 10Hz to 20Hz. Ensuring that these asynchronous data accurately reflect environmental conditions at

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a given moment during fusion presents a significant challenge. In high-velocity scenarios, synchronization errors can result in miscalculations of target position and speed by the system. [10, 11]

Complex computing resources and algorithms: Sensor fusion requires powerful computing power to process large amounts of data and run complex fusion algorithms. As the number of sensors increases and the amount of data increases, the performance requirements for the vehicle computing platform are also increasing, which not only increases the hardware cost, but also may lead to a decrease in the real-time performance of the system. For example, when multi-sensor data fusion, if the computing resources are insufficient, the data processing and decision-making may not be completed in time, which will affect the response speed of the intelligent driving system [10][12]

5. Conclusion

This article reviews and synthesizes research in sensor technology for intelligent driving. It highlights significant advancements and ongoing challenges, supported by diverse studies that enhance our understanding and application of sensor technology. However, unresolved issues, such as sensor fusion and high costs, hinder further research development. Future studies should emphasize interdisciplinary collaboration, integrating knowledge and technology across fields to innovate and explore new research avenues. In addition, with the rapid development of technology and the continuous changes in the social environment, sensor technology in the field of intelligent driving will undoubtedly face more opportunities and challenges. Researchers should closely monitor industry trends and cutting-edge technologies, adjust research strategies in a timely manner, and ensure that their work closely aligns with practical needs. This will provide forward-looking and practical theoretical guidance and practical solutions for the sustainable development of sensor technology in the field of intelligent driving.

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