An Overview of ADAS System Sensors in The Automotive Electronics Sector

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Abstract. ADAS systems are auxiliary devices designed to help drivers better control the vehicles, providing safer driving conditions or a more comfortable user experience. The perception of objects in the environment around the vehicles is an important function of the ADAS system. The automobile can use this function to warn impending dangers and alert the driver. The core of this technology is the sensor which has the ability to measure speed and distance. The most commonly used sensors include radar, lidar and camera. This paper focuses on three kinds of sensors: millimeter wave radar, laser radar and monocular vision camera, and explains their working principles on speed and distance measurement. By comparing with each other, the differences, strengths and weaknesses of the three sensors will be analyzed. Finally, their applications and prospects in automobiles are expounded to picture future research.

Keywords: ADAS system; radar; lidar; monocular vision camera.

1. Introduction

In the last several years, the world economic system has been in a period of rapid development, making the automobile industry has entered a stage of mature development. Because of the progress of technology, the car's function has become more and more perfect and humanized. Driving cars is becoming easier. At the same time, people's expectations for automotive products are also rising. In addition to performance and appearance, customers will also pay more attention to comfort and safety [1]. The obstacles around the car are not all visible to the driver, causing a lot of blind spots. Drivers need to spend a lot of vigor paying attention to various situations. Without the help of outside assistance, drivers need an elevated level of proficiency to ensure the safety of themselves and their vehicles to prevent accidents. Therefore, to enhance the safety of driving and provide more convenience for customers, Advanced Driver Assistance Systems (ADAS) were born and gradually became the main research area of many researchers. By developing and applying different sensors to ADAS systems, the drivers can obtain the necessary information around the vehicle in different ways. When a driver relaxes his vigilance due to fatigue, drowsiness or other reasons, it is very possible to cause an accident because of temporary negligence. It can lead to scratches on the vehicle, serious cases will even threaten the safety of the people in the car. The ADAS system will detect the environmental information around the car to give timely warnings to the driver to avoid such accidents [2]. Its essence is assisted driving, the core is surrounding awareness. ADAS systems include Adaptive Cruise Control (ACC), Driver Fatigue Monitor System (DFMS), Forward Collision Warning (FCW), Blind Spot Detection (BSD) and other multiple technology categories. The detection and range of surrounding impediments is a crucial component of Advanced Driver Assistance Systems (ADAS) and plays a significant role in enhancing vehicle safety.

Millimeter wave radar, lidar and camera are the three commonly used sensors in ADAS systems. They are all primarily responsible for getting information around the vehicle. Due to the different working principles, the performance of the sensor under various conditions is also different. Herein, aiming at the function of sensing the surrounding objects through sensors in ADAS system, this paper reviews the working principle of each sensor, analyzes its advantages and disadvantages, and discusses their role in ADAS.

2. Sensors

2.1. Radar

The technique known as Radio Detection and Ranging was initially developed approximately in the 1800s. In the beginning, its primary uses were in the military and for security applications involving surveillance [3]. The main function of radar is detecting objects in the surrounding environment and estimating relevant parameters, such as distance and relative radial velocity.

There are two modes that millimeter wave radar operates: “pulse” and “continuous wave” (CW). Pulse radar is used to measure the distance between vehicles and objects by calculating the Time-of-Flight (ToF) of the signal. Firstly, radar sends out a pulsed electromagnetic signal. The emitted wave is reflected back when it hits an object and is subsequently picked up by the radar's receiver. By measuring the time from transmission to return of the pulse signal, the radar can determine the precise coordinates of the object hit by the pulse signal. Since the radar transmits a single pulse signal each time, the length of the pulse will affect the working performance. The shorter the pulse, the more accurate the radar measurement will be. However, the longer the pulse, the better the signal-to-noise ratio will be. CW radar measures the radial velocity of a target by transmitting a constant unmodulated frequency. But this approach also leaves it without the ability to measure range information, which is one of the main drawbacks of CW radar [3]. CW radar is based on the Doppler theorem to measure the relative velocity of objects and vehicles. When the measured object moves in the direction of the wave source (radar), the wave will be compressed due to the difference in the propagation distance. The frequency of the waves picked up by the radar will increase. Conversely, when the object moves away from the source, the frequency becomes lower. This change is called the Doppler frequency shift.

Nowadays, most of the radars installed in cars are using FMCW (Frequency Modulated Continuous Wave) method. FMCW millimeter wave radar uses frequency modulation in its transmitting signal. Triangle, sawtooth, and sine waves are examples of frequently used modulation signals. When the signal is sent from the transmitting port of the radar, an echo signal is produced when the transmitting signal touches the target item and is reflected. The transmitted signal and the echo signal have the same form but the delay in time is calculated as distance divided by the speed of light multiplied by two. By mixing part of the two signals coherently, a medium frequency signal can be obtained, which contains the distance and speed of the target [4]. The MF signal frequency of the mixing output is the frequency difference between the transmitted and echo signal. When the modulation period and frequency modulation bandwidth are defined, the objective distance proportionates to the MF signal frequency. No matter if the target is at relative stillness or in relative movement, as long as the frequency of the MF signal modulating the wave at the rising and falling borders is obtained respectively, the distance and speed of targets are calculated.

Compared with pulse radar systems, FMCW radar possesses the benefits of low transmission power, small dimensions, and low cost. The radar can achieve zero blind zones when the transmitter and receiver are both working and can directly measure the Doppler shift and static target probability, which allows it for the simultaneous estimation of the range and radial velocity of numerous objects with great resolution. Those advantages are very suitable for the performance requirements of vehicle-mounted radar. FMCW has become the most used on-board millimeter wave radar.

Since the limitation of spectrum resources, the operating frequency of vehicle-mounted millimeter wave radar is generally 24GHz and 77GHz. Nowadays, regulations have increasingly high requirements for intelligent driving safety, which means that the speed measurement and ranging property of millimeter-wave radar needs to be improved. In principle, 77GHz millimeter wave radar can be stronger than 24GHz in all the above aspects of performance, so 77GHz to replace 24GHz has been the trend.

2.2. Lidar

Light Detection and Ranging is a kind of optical remote sensing technology. The first laser generator was developed in 1960, which opened the prelude to the use of lasers [5]. It is widely applied in many different sectors. The idea of lidar was considered immediately following the invention of the laser generator. Initially introduced in 1971, Lidar was utilized for surveying the lunar surface during the Apollo 15 mission. Then it is designed to be mounted on vehicles, acting like the eyes of a self-driving car, providing location and avoidance services.

Typical lidar operates on a similar premise to millimeter wave radar. Both calculate the ToF by counting the round-trip delay of the wave signal to the object and use that to figure out the distance between the objective and the car.

There are four components in the lidar sensor, which are avalanche photo diode, time-to-digital converter, laser diode and signal processing apparatus. The lidar measurement process is as follows: First, the laser diode sends a laser beam and focuses it through the lens. The avalanche photo diode receives the laser beam through the lens when the target object reflects the laser back. The interval between the time of laser diode sending laser and avalanche photo diode receiving laser is calculated by the time-to-digital converter. Next, transform it into the ToF. The ToF is obtained from time-to-digital converter. The distance of the object from the lidar sensor is computed by the signal-processing unit, represented by the microprocessor [6]. Because of their excellent beam characteristics and narrow spectrum, the laser is the predominant source of light. Based on the transmission approach, it can be categorized into three types: pulsed, Amplitude Modulated Continuous Wave (AMCW), or Frequency Modulated Continuous Wave (FMCW) [7]. Pulsed lidar's ToF technique can function in beam-steering or flash modes. In many cases, it is the best option for long-range applications. Nevertheless, the tiny effective sectional area of the silicon-photonic waveguides and the maximum output of the pulsed lidars may amplify undesired nonlinear optical processes in the silicon. The working principle of AMCW lidar is the same as the pulsed scheme. It operates depending on the intensity of light. The latter can be dominated by altering the diode's bias current in the electrical realm.

However, FMCW lidar is fundamentally different from the above two modes of operation. Pulsed lidar and AMCW lidar perform detection functions by modulating the intensity of light. By contrast, FMCW lidar relies on the wave characteristics of the light. FMCW lidar emits light that is modulated linearly over time. When light strikes and reflects from an item, it creates an echo signal, then picked up by a radar receiver. For static targets, the Doppler effect of light waves is negligible. The delay between the echo signal and the light source keeps the frequency difference between them constant [7]. The frequency difference is proportional to the delay time, which allows the distance to be calculated. For moving objects, Doppler shift occurs during detection. The variation in frequency between the ascending and descending edges between the light source and the echo signal is different. Distance and speed detection can be achieved through these two frequency differences. The wideband electrical circuits are not required because of the interferometric conversion of the received signal in the optical domain. The FMCW technique can provide substantially improved sensitivity and robustness against environmental disturbances in addition to improved resolution in terms of range.

2.3. Monocular Vision Camera

In 1956, Buick introduced the Centurion, the first car with camera technology concept. But by that time the camera technology was still immature, and the cost was extremely high. The concept of in-car cameras has not been recognized for a long time, and even comes to a standstill. Until 1991, Toyota Soarer, the first commercial vehicle equipped with an on-board camera, was born, the car camera officially entered the practical stage.

There are two types of application systems for cameras installed on vehicles: stereo vision and monocular vision. Stereo cameras use stereo image pairs to make matching. The depth of the target is obtained by generating parallax images. Then the distance of the target is recovered. Stereo vision cameras can detect long-distance targets more accurately and intuitively. However, due to the complexity of calibration and matching between two cameras, implementing this function requires a high computational complexity and takes a long time to execute. As a result, the operational efficiency of stereo vision cameras is low. The monocular vision system realizes the measurement function by combining the geometric relationship obtained from the image with the parameters inside the camera [8]. Compared with the stereo camera, its structure is simpler, the amount of calculation is smaller, and the real-time performance of the function is higher. Therefore, it is more suitable to be embedded in ADAS systems. More and more researchers pay attention to the method of distance estimation between vehicles based on monocular vision.

The vehicle-mounted monocular camera consists of four main parts: lens, imaging sensor, Image Signal Processor (ISP), and Camera Serial Interface (CSI).

When the laser is reflected by the object, it will be collected by the lens. It's equivalent to the pinhole in a small aperture image. The focal length and field of view (FOV) of the lens will directly affect its performance. The former determines the degree to which light is concentrated or divergent by the lens. The latter is a parameter that represents the field of view of the lens. The two influence each other. The smaller the focal length, the larger the field Angle will be, vice versa.

An Imaging Sensor is an electronic imaging medium. The image sensor converts the optical signal aggregated by the lens into an electrical signal. It determines several important parameters in the camera. Examples include pixels, sensitivity, and optical dimensions.

ISP processes the output signal of the front-end image sensor. ISP can be responsible for a variety of functions, including white balance, color correction, and color space conversion.

CSI is a standard camera interface developed by the MIPI Consortium. Due to its characteristics of high speed and low power consumption, it is particularly suitable for data transmission of vehicle camera.

At first, the camera takes an image of the scene. This process transforms the 3D road coordinate system of the objective world into the 2D camera coordinate system of the camera. After the image acquisition, the camera performs distance measurements based on the collected information. The range procedure, on the other hand, is the opposite of image capture [9]. The location of the object on the camera platform is calculated first. The coordinates of the camera platform are translated into 3D road coordinates based on horizontal and vertical views of the camera, quadrant angle, height, and sharpness. Then the distance behind the object and camera is calculated by the system.

2.4. Comparison of Three Sensors

Different sensors all have their different advantages and disadvantages, making them play distinct roles in different scenarios. Both radar and lidar are capable of accurate distance and speed measurements but are unable to identify the class of the object. Since the wavelength of light is about 100,000 times smaller than the wavelength of radio, by comparing the two, the accuracy and resolution of the lidar are superior. However, this also means that the amount of data it collects will be huge, requiring higher performance processors to process the data. In terms of detection range and anti-interference ability, the performance of millimeter wave radar will be more prominent. Since millimeter wave radar can easily pass through smoke, dust, and haze under severe weather conditions, the measurement function remains unaffected. Considering the cost, because Lidar requires a large bandwidth and complex hardware architecture, the price is more expensive than millimeter wave radar.

Cameras usually have even greater resolution than lidar, but their narrow field of view is not suitable for remote target detection. Cameras can provide richer sensing data than the first two, not only detecting distance, but also providing specific information about the type of detected object. But cameras are highly susceptible to environmental influences. In harsh weather conditions, the camera performed the worst of the three. But in terms of price, the camera wins by an absolute margin.

3. Sensors Application in ADAS

3.1. Radar

As the first sensor to be applied to autonomous vehicles (mass production), researchers have been very proficient in the technical research of millimeter wave radar. It is also the most important link in the perception system. The main function of radar is to detect the objects around the car and calculate the required parameters, such as distance or relative radial velocity. Because of its good anti-interference performance, millimeter wave radar can achieve all-weather operation. When other sensors are greatly affected, the millimeter wave radar can still be unaffected and continue to perform its function. However, millimeter wave radar cannot detect objects with narrow reflective interfaces. Pedestrians are the classic example. This is because its detection resolution cannot meet such high requirements.

There are two types of vehicle-mounted radar: forward and backward. It was distinguished by the installation location. The forward radar is usually mounted in the middle of the front bumper of the vehicle, performing collision warning and adaptive cruise functions. There are usually two backward radars, mounted at each end of the car's rear. Performing blind spot detection and collision warning functions.

3.2. Lidar

Lidar has higher resolution and accuracy, so it is used to send laser beams to sense the environment around the vehicle, creating a three-dimensional image or point cloud to more specifically depict the objects around the vehicle. Due to the relatively large volume of lidar, its layout is mainly divided into two ways: forward and side [10]. At present, the more popular layout is to embed the main Lidar on the roof of the vehicle, which can bring a good detection effect and is not easy to be blocked by objects [11]. However, the disadvantage of such a layout is that the impact will be aggravated in rain and snow weather. The sideways lidar is designed to complement the lateral view of the system. It is generally installed on both sides of the front fender of the car.

At present, the biggest problem in front of lidar is the cost problem, which is the biggest obstacle to the large-scale promotion of vehicle lidar. Lidar applications are only developed for the use of a specific scenario, the scope is very limited.

3.3. Monocular Vision Camera

The information obtained through the camera is more intuitive and closer to human vision. It is an significant source of external information for cars. The applications of cameras are very wide, most autonomous driving functions can be implemented using cameras. And because of its low price, the number of cameras mounted on vehicles is increasing.

The car camera in the ADAS system can be divided into five types according to the installation position: front view, side view, around view, rear view and built in. The monocular camera is generally used as a front view camera. This is the core camera of ADAS, which is the "eye" right in front of the car. Including the execution of ranging, front collision warning, traffic sign recognition and other functions [12]. The front view camera is generally installed in the top center of the windscreen or under the inner rearview mirror, to avoid being blocked by the wiper.

However, the image quality of the camera will be greatly reduced under harsh conditions, and it is difficult to achieve the required functions. At present, the camera is still not as accurate as lidar and millimeter wave radar in ranging and speed measurement performance. To better play the camera in the application of the ADAS system, the technology and performance of the camera need to continue to improve and optimize.

4. Summary

This study found that the above three sensors have different advantages and disadvantages for ADAS systems in perceiving the surrounding environment. This means that using different sensors in different conditions can make the function of the system more efficient. ADAS is becoming a key technology affecting the future of the industry, which is no longer exclusive to top models, and many low-end models are also equipped with fully functional ADAS systems. This proves that it has a good application prospect. As sensors are the key to this, it is important to make them function more effectively. In the future, multi-sensor fusion technology can be developed according to the advantages of each sensor. The data sources obtained by different sensors with different principles can make the perception results of the system more stable and reliable. When one of the sensors fails, the other sensors will continue to work and ensure that the system can operate normally, providing a certain degree of redundancy. This way can increase the utilization degree of each sensor under its advantages, avoid its disadvantages, and improve the overall safety factor and comfort of the vehicle more effectively.

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