Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 3, No. 3, 2022

A Review of LiDAR sensor Technologies for Perception in Automated Driving

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Abstract: After more than 20 years of research, ADAS is common in modern vehicles on the market. Automated driving systems have gradually moved from the research stage to public roads for commercial testing. These systems rely on information provided by onboard sensors that describe the state of the vehicle, its environment, and other participants. The selection and placement of sensing sensors are key factors in system design. In order to better understand the principles and functional implementation of sensing sensors, this paper reviews the existing and latest sensing sensor technologies and presents a detailed analysis of the principles, advantages, and disadvantages, as well as common types and performance of LiDAR sensor technologies, and then introduces two proposed solutions to the problem of how to improve the recognition accuracy of LiDAR sensors under the influence of different weather factors by selecting. Finally, this paper briefly introduces several latest LiDAR sensors under research and proposes an innovative multi-sensor fusion solution based on the existing research, and analyzes the feasibility.

Keywords: ADAS, Automated driving, Sensing sensors, LiDAR, Multi-sensor fusion.

1. Introduction

More than one million people die in traffic accidents each year, and millions more are injured. In addition to its social costs, it has important economic impacts on countries around the world. According to some survey literature, the most common causes of car accidents in the EU are related to perceptions: speeding, driving under the influence of alcohol or drugs, reckless driving, distraction, or just plain misjudgment.

Automated driving systems[1] are designed to take the human driver out of the equation. This makes them a tool that has the potential to reduce the number of traffic accidents. Based on recent developments and demonstrations worldwide, a trend suggests that highly automated driving will be available within a few years. This raises questions about their safety.

The architecture of self-driving cars is usually divided into three categories: environment sensing, behavior planning, and motion execution. Self-driving cars use different sensors to obtain information about their surroundings. The raw data is processed to extract relevant features that are inputs for the following phases (behavior planning and motion execution) that perform tasks such as path planning, collision avoidance, or vehicle control.

Perception is a very challenging problem for a number of reasons. First, the environment is complex and highly dynamic, with some cases designed for a large number of participants (dense traffic and densely populated cities). Second, it needs to work reliably under a wide range of external conditions, including light and weather (rain, fog, snow, dust). Sensing errors can propagate and can lead to serious accidents. Therefore, there is an extremely high demand for the accuracy of sensor transducers. Current sensor technology is usually focused on the general level of ADAS implementation or automated driving. On the other hand, the application of LIDAR for ADAS offers unparalleled performance advantages for solving these challenging problems and is therefore always in demand for software testing and development vehicles.

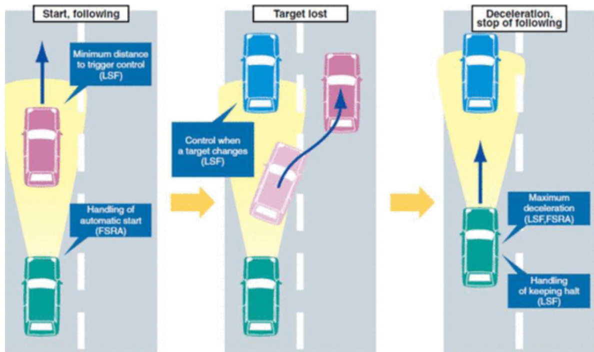

Figure 1. Adaptive crouse control system

The main contribution of this work is to present the disadvantages and advantages of LiDAR sensors in automated driving technology and to give sort out and discuss the solutions proposed in different papers for the disadvantage that LiDAR sensors are highly influenced by weather factors.

The content of the article is organized as follows. Section II reviews the sensor technologies commonly used for sensing, their drawbacks and advantages, and the related emerging technologies that can be used in the future. Section III starts to focus on the LiDAR sensor technology and gives and discusses the solutions proposed in different papers for its disadvantage of being highly influenced by weather conditions. Section IV contains a discussion of the current state of the discipline and future challenges of sensors and perception in automated driving systems, and Section V concludes the whole paper in an integrated manner.

2. Sensor Technology

The focus of this work is on external receptors, excluding proprioception and communication from the scope of the review. External sensing in automated driving relates to information in the vehicle's surroundings, rather than proprioception related to the state of the vehicle itself (speed, acceleration, component integrity).

The next subsections describe the advantages, disadvantages, and current challenges of the three main sensor technologies used for external sensing in automated driving: artificial vision, radar, and LIDAR. Each article is followed by a review of relevant emerging technologies in the field.

2.1. Artificial Vision

Artificial vision is a popular technology that has been used for decades in disciplines such as mobile robotics, surveillance, and industrial inspection. This technology offers interesting capabilities because of the low cost of sensors - for most popular types - and provides a range of information types including spatial (shape, size, distance), dynamic (moving objects by analyzing displacement between consecutive frames), and semantic (shape analysis).

Cameras on the market offer a wide range of configurations in terms of resolution (from less than 0.25 to greater than 40 Mpx), frame rate (up to thousands of frames per second (FPS)), sensor size, and optical parameters. However, automated driving poses some special challenges for camera sensors and artificial vision techniques.

Different light and visibility conditions. Driving occurs during the day, at night, indoors, or at dusk or dawn when the sun is near the horizon. Dark spots, shadows, glare, reflections, and other effects complicate the implementation of reliable artificial visibility algorithms. Extended capture spectroscopy can solve some of these problems. Far infrared (FIR) cameras (wavelengths 900-1400 nm) can effectively detect pedestrians and animals in the dark and through dust and smoke. Near-infrared (NIR) (750-900 nm) complements the visible spectrum with better contrast and better nighttime visibility in high dynamic range scenes. in his paper, N. Pinchon compares visible, NIR, and FIR cameras under different lighting and atmospheric conditions.

Scenes with high dynamic range (HDR) contain dark and bright areas in the same frame as they enter or leave the tunnel. Common sensor technologies have a single dynamic range of 60-75 dB, which can lead to information loss in extreme cases (underexposure or overexposure.) In 2017, Sony introduced a 120 dB automotive sensor and 2k resolution. In the work of S. Maddalena, an automotive-grade sensor combining HDR capabilities and NIR light detection is analyzed and a sensor with a 130/170 dB range (global/roll shutter configuration) is proposed.

2.1.1. 3D technology

Traditional camera technology is inherently two-dimensional, but there are types of vision sensors that can sense depth information. This section describes three main types that have been offered as commercial devices, but not always for the automotive market.

Stereo vision. Depth is calculated from the apparent displacement of visual features in an image captured by two carefully calibrated monocular cameras, pointing in the same direction and separated by a certain distance (called the baseline).

One of the greatest advantages of stereo vision systems is their ability to provide dense depth maps rather than sparse sensors (e.g., LiDAR). Disadvantages of stereo vision include the problem of low-texture patterns (e.g., solid colors) that are difficult to establish correspondence between frames.

Monocular SLAM (simultaneous localization and mapping) algorithms share some of the working principles of stereo systems: the motion of a single monocular camera creates an artificial baseline between consecutive frames from which depth and camera motion are estimated. Some works represent a good alternative to stereo sensors for localization and mapping.

Structured Light. A monocular camera is combined with a device that illuminates the scene with a known infrared light pattern. Irregular surfaces produce significant distortion of the light pattern, which is captured by the camera and converted to a depth map.

Structured light devices overcome some of the limitations of stereo systems: they are not dependent on textured surfaces and have a lower computational cost. However, they require the same high-precision calibration, and their operating range (typically below 20 m) is limited by emitter power and ambient light intensity. Reflections can affect their performance.

Time-of-flight. is an active sensing technology based on the same round-trip time principle as the LiDAR sensor: an emitter consisting of an infrared LED fills the scene with modulated light, which is captured by the sensor in the environment after being reflected by the element. The round-trip time of each pixel can be calculated based on the phase shift of the incident light and then converted to distance.

The use of a non-directional light source (as opposed to a low-dispersion laser emitter in LiDAR) has the ability to create dense depth maps and high refresh rates in excess of 50 Hz. However, it has a short operating range for automotive applications (10-20 m) and has problems working in intense ambient light. Some research lines such as indirect time-of-flight, pulsed light time-of-flight, or avalanche photodiodes can increase the operating range to 50-250 meters.

2.1.2. Emerging vision technologies

In event-based vision, elements[3] of the sensor (pixels) are triggered asynchronously and independently when a change in light intensity (event) is detected. The sensor generates a stream of events that can be grouped in a time window to obtain a frame-like image. The independence of the sensor element increases the dynamic range of the sensor to 120 dB, allowing for high-speed applications in low-light conditions. Displays are tracked at 1000 FPS under regular indoor lighting conditions, even though the sensor operates on a sub-microsecond time scale. Events can be used as input to visual odometry and SLAM applications, thus alleviating the CPU from time-consuming operations on the raw image.

A number of papers are actively investigating sensors for capturing light polarization that consistently perform under adverse meteorological conditions and provide exotic types of information (e.g., materials, composition, water in roads).

2.2. Radar

Radar technology uses high-frequency electromagnetic waves to measure the distance to an object based on the round-trip time principle, i.e. the time it takes for the wave to reach the object, bounce off it and return to the sensor.

Most modern automotive radars are based on frequency-modulated continuous wave (FMCW) technology and use digital beamforming to control the direction of the transmitted wave. fmcw consists of transmitting a signal with a well-known and stable frequency that is modulated by another continuous signal that varies its frequency up and down (usually using triangles). The frequency shift between the transmitted and reflected signals is used to determine the distance. Radar also uses the Doppler effect to directly observe the relative velocity of the target with respect to the sensor.

One of the strongest arguments for including radar sensing in self-driving cars is that it is unaffected by light and weather conditions. It works in the dark and detection is almost equally applicable to snow, rain, fog, or dust. In very adverse conditions, long-range radar can see up to 250m without any other sensor working.

Radar sensors have a number of difficulties and drawbacks：

Sensitivity to target reflectivity. Processing radar data is a tricky task, partly because of the different reflectivities of different materials. Metal amplifies radar signals for vehicle detection, but increases the size of the appearance of small objects such as discarded cans on the road, while other materials (such as wood) are almost transparent. This can lead to false alarms (detection of non-existent obstacles) and false alarms (no detection of actual obstacles).

Resolution and accuracy. The radar very accurately measures the distance and speed of the line connecting the sensor to the target. However, the horizontal resolution depends on the characteristics of the emitted beam. The raw angular resolution in digital beamforming systems is between 2 and 5 degrees, which can be improved to 0.1-1 degree using advanced processing techniques. Using this angular resolution, it is difficult to separate pedestrians from nearby cars at a distance of 30 m (detected as separate targets). At a distance of 100 m, it is not possible to separate vehicles in adjacent lanes and determine whether vehicles are in the same lane, even if the detection is of a vehicle or a bridge over the road.

2.2.1. Emerging radar technologies

One of the most active research areas is related to high-resolution radar imaging of vehicles. In addition to the benefits of target tracking and object separation, the higher resolution allows for richer semantic information and can be further applied to target classification and environment mapping. An example can be found when a 90 GHz rotating radar on the roof of a car is used to map the environment, including vehicles, static objects, and the ground. Some demonstrate the feasibility of radar operation between 100 and 300 GHz, analyzing the atmospheric absorption and reflectivity of materials commonly found in driving scenarios.

One of the key technologies that can enable high-resolution radar imaging is metamaterial antennas for efficient synthetic aperture radar. Some manufacturers such as Metawave are starting to offer products based on this technology for the automotive sector.

2.3. LiDAR

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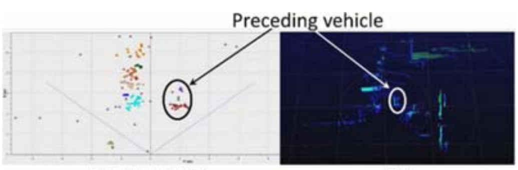

Figure 2. Radar and LIDAR comparison

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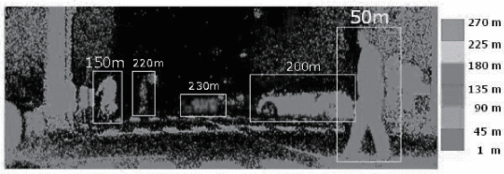

Figure 3. High-resolution, long-range flash LIDAR images at 940nm and 264K pixels

One of the key technologies that can enable high-resolution radar imaging is metamaterial antennas for efficient synthetic aperture radar. Some manufacturers such as Metawave are beginning to offer products based on this technology for the automotive sector. LiDAR (Light Detection and Ranging) is an active ranging technology that calculates the distance to an object by measuring the round-trip time of a laser pulse. The sensor for robotic and automotive applications uses an invisible and human eye safe low power NIR laser (900-1050nm). The laser beam has a low divergence angle, which reduces power attenuation over distance and allows measurement of distances up to 200m in direct sunlight. Typically, a rotating mirror is used to change the direction of the laser pulse to achieve 360-degree horizontal coverage. Commercial solutions use an array of emitters to produce several vertical layers (4 to 128 layers). This generates a 3D point cloud representing the environment.

LiDAR sensors are a good choice for creating accurate digital maps, however, they have several drawbacks to consider.

Low vertical resolution. In low-cost models that typically have fewer than 16 layers, the vertical resolution (separation between successive layers) drops to 2 degrees. At a 100m distance, this is converted to a 1.7m vertical distance. High-end models reduce this to 0.2 to 0,4 degrees, but at a much higher cost.

Sparse metric (not dense). The commercial device Velodyne HDL64 has a divergence angle of 2 mrad (0.11 degrees) and a vertical resolution of 0.42 degrees. At a 50 m distance, a 0.3-degree gap between layers corresponds to a blind band of 0.26 m in height. In the low-end device (Velodyne VLP16), this gap grows to 1.5 meters. Small targets may not be detected, and line and rod-based structures are nearly invisible.

Poor detection of dark and specular objects. Black cars may be invisible to LIDAR because they combine a color that absorbs most of the radiation with a non-Lambert material that does not scatter the radiation back to the receiver.

Affected by weather conditions. the NIR laser beam can be affected by rain and fog, as water droplets scatter the light, reducing its operating range and producing erroneous measurements ahead of clouds. These are scenarios where LiDAR performs worse than radar, but still outperforms cameras and the human eye.

2.3.2. Emerging LiDAR Technologies

FMCW LiDAR continuously emits light to measure object velocity based on the Doppler effect. In the last few years, several research prototypes suitable for the automotive market started to appear [39]. In addition to improving target tracking capabilities, velocity observation also helps to enhance activity recognition and behavior prediction, for example by detecting different velocities of the limbs and bodies of cyclists and pedestrians.

Solid-state LIDAR is an umbrella term that includes several technologies, two of which are oscillating micromirrors and optical phased arrays (OPA). The first technology uses micromirrors that can rotate around two axes to guide the laser beam. The manufacturer LeddarTech commercializes devices based on this technology. Quanergy is one of the few manufacturers to commercialize equipment based on this technology, which is similar to the technology used in EBF radars, allowing the direction of the beam to be controlled with high precision and speed.

The OPA technology allows the application of a random access scanning pattern over the entire FoV (field of view). This allows only specific areas of interest to be observed and dynamically changes the beam density (resolution). These features can be combined to quickly examine the complete FoV at low resolution and then track the object of interest at higher resolution, enhancing shape recognition even at long distances.

3. Issues and Applications of LiDAR Sensors

This section focuses on the principle part to introduce LiDAR sensor technology and analyzes the latest technology for automated driving perception systems. Then a systematic literature review is conducted, and solutions of different papers are given and discussed for its drawback of being highly influenced by weather conditions, and finally, several common LiDARs and their performance analysis are introduced.

3.1. Principle of LiDAR

In a medium that emits light of a certain wavelength when returning from the excited state to the ground state, the laser beam is oscillating in a uniform phase and waveform, while repeatedly reflecting at both ends of the medium, protruding from the semi-permeable and semi-transmissive side of the mirror. This laser medium has solids, liquids, and gases. As shown in Fig.4, LiDAR uses a semiconductor medium.

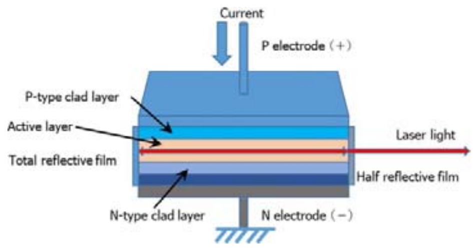

Figure 4. Construction of LIDAR diodes

As shown in Fig.4, it represents the structure of a semiconductor laser. This structure is called an edge-emitting semiconductor laser because the laser beam is emitted from the edge. It is also called a Laser Diode LD (Laser Diode) because the light-emitting principle itself is the same as that of an LED. The commonly used wavelength is 905 nm near-infrared light. This wavelength is invisible to humans and must be considered safe for the eye due to the absorption band of the retina.

LiDAR's range measurement method is a time-of-flight measurement. This measures the time it takes for a pulse of light emitted from a laser diode to be reflected from an object and received by a photodiode. This requires two measurements to obtain the relative velocity, which is slower than radar and can cause latency problems. As shown in Fig.5, pulsed light transmission is affected by weather, which can be suppressed by repeating the measurement.

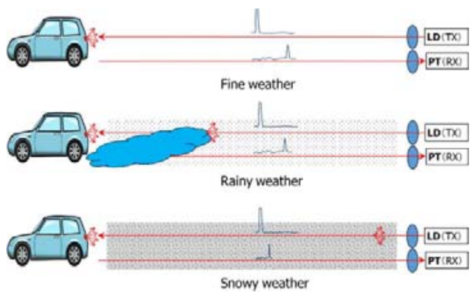

Figure 5. Impact of weather conditions on LiDAR

There are three ways to generate a fan beam by scanning the laser beam through the LiDAR. As shown in Fig.6 In conventional vehicle-mounted LiDAR, the choice of multifaceted and tilting mirrors is universal, and the rotating head itself has emerged from Velodyne. As shown in the latter figure, LiDAR plans to move to a mechanical-free system with no moving parts.

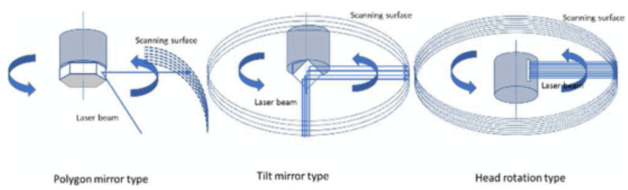

Figure 6. The representative mechanism for generating a fan-shaped beam

The biggest feature of LiDAR is the SLAM (simultaneous localization and mapping) of the primary vehicle position. This SLAM can never be done with radar. Due to the high spatial resolution and accuracy of the point cloud obtained by LiDAR, the position on the point cloud map can be easily detected if the point cloud of the surrounding environment is obtained beforehand and by scan matching with the measured point cloud.

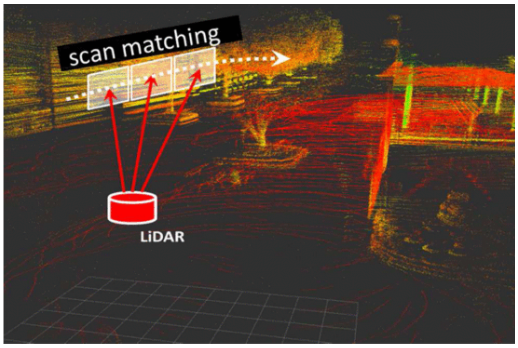

Figure 7. SLAM principl*e*

Then Fig.8 shows the state of object detection in LiDAR. This red rectangle is the location of the vehicle detected from the point cloud in LiDAR, and these circles are pedestrians and bicycles. Detecting vehicles and pedestrians is easier than the camera system.

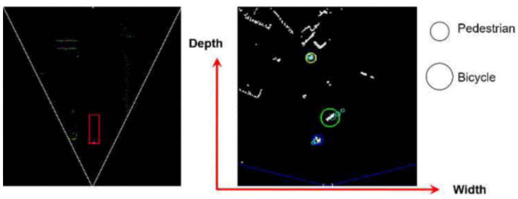

Figure 8. *Detection results of LiDAR*

3.2. Problems and Solutions

As mentioned in the previous narrative, perception capabilities are very challenging issues. Environmental complexity, lighting, and weather can all affect the perception efforts of LIDAR sensors, and perception errors can be cascaded and can lead to serious accidents. Some real-life examples include the 2016 Tesla AutoPilot accident in which a man was killed after his car crashed into a truck: the camera failed to detect the gray truck in bright skies, and the radar detection was discarded as background noise by the perception algorithm. later in 2018, a Tesla Model X crashed into a highway divider after the lane following system failed to detect faded lines and the concrete divider was not crashed into a highway divider after the system failed to detect faded lines and the concrete divider was not recognized, killing the driver. Also in 2018, an experimental Uber vehicle killed a woman wearing dark clothing who was crossing the street at night. Only LIDAR provided a positive detection, which the perception algorithm discarded as a false alarm.

Tyson Govan Phillips and Wang M[4][5] give solutions to improve the accuracy of LIDAR sensors under the influence of two weather factors, dust and rain, and fog, respectively.

3.2.1. Behavior of LiDAR in the presence of fine particulate dust

The behavior of LIDAR sensors in the presence of dust is described in detail in the paper by Tyson Govan Phillips. This work was motivated by the need to develop sensing systems that must operate in the presence of dust. The paper shows that the measurement behavior of the sensor is systematic and predictable. LiDAR sensors exhibit four behaviors that can be elaborated and understood in terms of the shape of the return signal from the emitted light pulse.

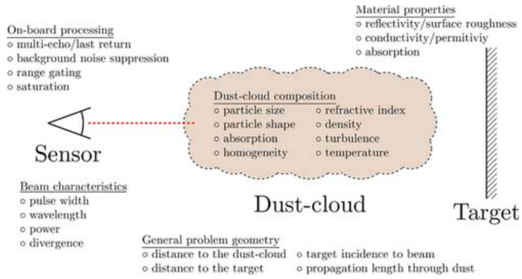

Figure 9. capability of LiDAR in the presence of dust

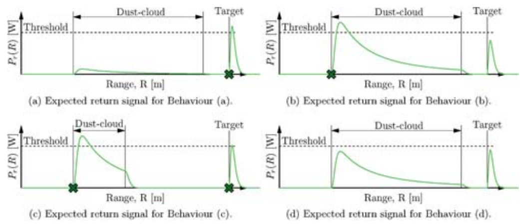

Figure 10. LiDAR equation for propagation paths of sorts depicts

The authors performed a series of tests on commercial sensors measuring return pulses and showed that they are consistent with the theoretical predictions of behavior. Several important conclusions emerge: (i) in the case of LiDAR measurements of dust, it is measured against the leading edge of the dust cloud rather than as random noise; (ii) dust starts to affect the measurements when the atmospheric transmittance is below 71%-74%, but this varies considerably with conditions; (iii) LiDAR is able to range targets in dust clouds if the target is retroreflective, the transmittance is as low as 2% if the target is retroreflective and as low as 6% if the target has low reflectivity; (iv) the effect of airborne particles (e.g., dust) is less pronounced in the far-field. The significance of this paper is to provide insight into how to better use measurements from off-the-shelf LiDAR sensors to solve perception problems. (iv) The effect of airborne particulate matter (e.g. dust) is less visible in the far field. The point of this paper is to gain insight into how to better use measurements from off-the-shelf LiDAR sensors to solve perception problems. (iv) The effect of airborne particles (e.g. dust) is less visible in the far field.

3.2.2. Behavior of LiDAR under the effect of atmospheric rain and fog extinction

FMCW is a method of detecting distance and relative velocity at a time by continuously changing the wavelength of the emitted wave to produce a chirp signal. The frequency of the transmitted radio wave increases and decreases linearly with time. The transmitted wave is then reflected by the object in front of it, and the reflected radio wave is input to the receiver with a time delay of 2R for the reciprocal distance R between the radar and the target. By mixing the received and transmitted waves in the receiver section, a signal with a beat frequency proportional to the distance R is extracted. Then, the differential beat signal is analyzed by FFT and the frequency is extracted by peak detection. When there is a relative velocity between the radar and the target ahead, the frequency of the reflected radio wave is shifted due to the Doppler effect. By combining the beat frequency fbu of the rising section and the beat frequency fbd of the falling section, the frequency fb corresponding to the distance and the frequency fd corresponding to the relative velocity can be obtained as follows. FM continuous wave is applied to LIDAR by changing the resonant frequency through mechanical or thermal deformation of the laser medium of the laser diode, thus changing the wavelength of the laser beam, which results in a uniform chirp signal from the laser beam.

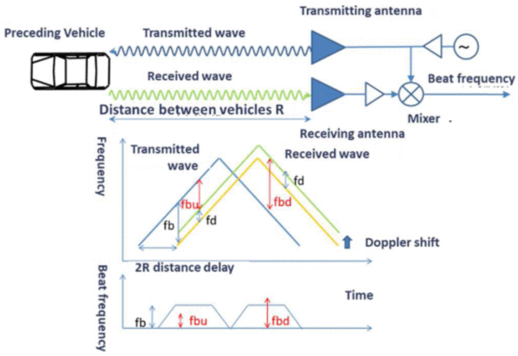

Figure 11. Principle of FMCW

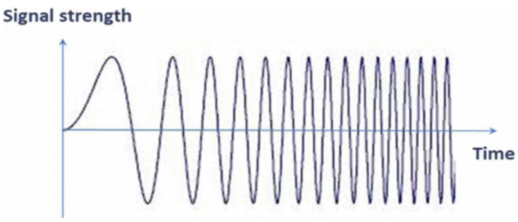

Figure 12. Chirp signal

Wang M, on the other hand, has solved the delay problem by using FMCW to calculate the distribution of fog and rain of different sizes. And a comparison has been made between extinction measurements using two FMCWs and manual observations during fog rain. The results show that the FMCW extinction coefficients are 20% to 60% larger than the manual observations during rain. This result can be used to define correction factors so that the FMCW using forward scattering NIR spectra can be used to estimate extinction not only during fog and haze but also during rain. An appropriate ratio of the scattering signal to the rainfall extinction coefficient will be found.

3.3. Several common LIDARs and performance analysis

With the increase of LiDAR types, [6]each LiDAR has different characteristics such as the number of laser emitters, resolution, field of view, and price tag, so a more in-depth comparison of their characteristics and performance is needed. This section compares 10 commonly used 3DLiDARs, establishing several metrics to evaluate their performance.

The test was conducted at the Japan Automotive Research Institute (JARI) weather room in Tsukuba, Japan, from September 24 to 26, 2019. [7][8]The enclosed 200m-long test site provided stable and comfortable conditions for the long evaluation process. Otherwise, it was a fairly standard road surface and the proposed experiments were fully repeatable. The LiDAR was tested under normal lighting and weather conditions, but also under extreme weather conditions including rain, fog, and bright light. Given the amount of data collected, this paper focuses on conventional so-called static tests. The data collected was publicly distributed to the research community and also included dynamic outdoor scenarios.

	Velodyne					Hesai		Ouster		RoboSense
	VLS-128*	HDL-64S2	HDL-32E	VLP-32c	VLP-16	Pandar64	Pandar40p	OS1-64	OS1-16	RS-LiDAR-32
Channels	128	64	32	32	16	64	40	64	16	32
FPS[Hz]	5-20	5-20	5-20	5-20	5-20	10,20	10,20	10,20	10,20	5,10,20
Precision[m]	±0.03	±0.02[a]	±0.02	±0.03	±0.03	±0.02[c]	±0.02[c]	±0.03[d]	±0.03[d]	±0.03[c]
Max.Range[m]	300	120	100	200	100	200	200	120	120	200
Min.Range[m]	N/A	3	2	1	1	0.3	0.3	0.8	0.8	0.4
vFOV[deg]	40	26.9	41.33	40	30	40	40	33.2	33.2	40
vRes[deg]	0.11[b]	0.33[b]	1.33	0.33[b]	2.0	0.167[b]	0.33[b]	0.53	0.53	0.33[b]
hRes[deg]10hz	0.2	0.16	0.16	0.2	0.2	0.2	0.2	0.35	0.35	0.2
λ[nm]	903	903	903	903	903	905	905	850	850	905
d[mm]	165.5	223.5	85.3	103	103.3	116	116	85	85	114
Weight(kg)	3.5	13.5	1.0	0.925	0.830	1.52	1.52	0.425	0.425	1.17
Firmware Ver.	—[e]	4.07	2.1.7.1	N/A	3.0.29.0	5.10	4.29	—[f]	1.12.0	1.12.0
Price[g][USD]	$$$$	$$$	$$	$$	$	$$$	$$$	$	$	$$

Figure 13. LIDAR tested

This work provides a comparative evaluation of the performance of 10 popular 3D LiDARs used in automated driving systems. This research was made possible by the first LiDAR Benchmark and Reference Dataset (LIBRE) [3]. This work and supporting datasets represent the starting point for a series of fundamental, direct comparisons of 3D LiDAR for automated driving. Since 3D LiDAR sensing is a relatively new technology with applications in safety-critical driving, the development of this research area is critical.

3.4. Latest and Future LIDAR

For future LiDAR, the trend is toward a mechanization-free scanning method, and the actual direction of the mechanization-free system used is the flash method as shown in the figure, in which many beams are illuminated simultaneously. The disadvantage of the flash method is that the resolution is lower but higher than the radar resolution.

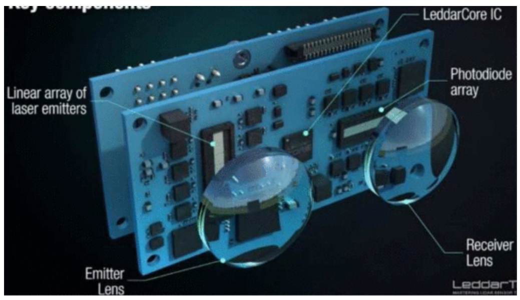

Figure 14. Example of flash method

Another mechanization-free method for commercial use is the use of MEMS mirrors, as shown in Fig. MEMS mirrors scan the laser beam to mention the resolution point cloud.

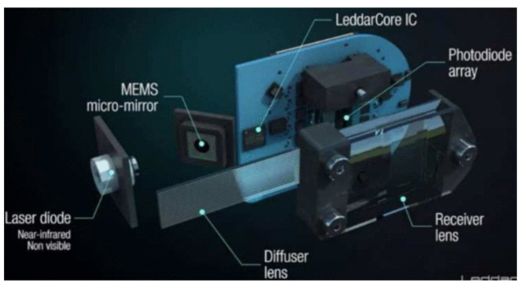

Figure 15. Example of MEMS method

To sum up, in the era of automated driving, in-vehicle sensors will shift from radar to LiDAR. This is because future improvements in LiDAR will bring many advantages over the radar, as shown here. LiDAR will also be used for automated indoor robots. LiDAR will become an increasingly popular in-vehicle sensor by using a mechanical-free scanning approach and by using FMCW to address latency issues.

Based on the above research, the authors believe that multi-sensor fusion solutions are also an important solution for future detection problems in automated driving. This capability requires the simultaneous estimation of a large number of variables, which poses difficulties for any single-sensor solution. This is a good scenario for sensor fusion systems that can combine the strengths of each sensor to improve the solution. For example, radar and LiDAR fusion improves the speed accuracy obtained with LiDAR alone and maintains good quality of position and speed estimation when the radar is not available, especially on curved roads. Radar and vision fusion techniques use radar information to locate areas of interest on an image, which is then processed to detect vehicles and improve their position estimation. LiDAR and vision sensors are fused in. Obstacles are detected and tracked using LiDAR, and targets are classified using a combination of camera and LiDAR detection.

4. Summary

Choosing a sensor configuration for self-driving vehicles can be challenging, with each sensor having different advantages and disadvantages in terms of the type of information acquired, overall accuracy, and operating conditions. This review reviews the most popular sensor technologies, describing their characteristics and how they can be applied to obtain useful information to address key sensing capabilities. It then focuses on the principles, and problems of LiDAR sensors, gives some papers that propose solutions to these problems, and finally looks at the latest technologies for LiDAR sensors and proposes the feasibility of multi-sensor fusion solutions based on these studies.

Acknowledgment

I would like to express my sincere gratitude and thanks to Prof. Bu Ling. This work was inspired by the fourth chapter of Light and Radiation in Professor Bu Ling's course Sensors and Transducers and the review article on automated driving in the Center for Electronic Research, Chinese Academy of Sciences. With the help of Prof. Bu Ling, I have improved my ability to collect literature, accumulate data, summarize and analyze.

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