Analysis of ADAS Technology Principle and Application Scenario

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Abstract. With the development of vehicle sensors, artificial intelligence and vehicle network technique, Advanced Driving Assistant System (ADAS) technology is now experiencing a rapid development. However the interaction of the sensors' data in the real scene is seldom discussed. This paper firstly describes the application scenarios and typical working mechanism of ADAS. Then it analyses the advantages and deficiencies of the environment perception only based on vehicle-self sensors. Secondly, it describes the main research of vehicle networking. Lastly through two typical scenes it analyses the possibility and problem of communicating the sensors' data via vehicle networking. Through the application scenarios analysis, it proposes a new potential research route for the ADAS.

Keywords: Advanced Driving Assistant System (ADAS) · Vehicle-mounted sensors · Vehicle to Everything (V2X) · Vehicular Ad-hoc Network (VANET)

1 Introduction

At present ADAS [1–4] is mainly to use the vehicle-mounted sensors to perceive the surrounding environment and to make the identification of static or dynamic targets. To track the surrounding objects, and combine with the navigation map, it finally can make the automatic driving decision. This effectively increase the car driving comfort and safety.

In recent years, V2X technology represented by Long Term Evolution for Vehicle (LTE-V) and Dedicated Short Range Communications (DSRC) have brought new opportunities for ADAS [5–8] which provides the possibilities for communication between vehicles, road units, pedestrians and so on. However its design did not provide a reliable enough mechanism for vehicle-mounted sensor data interaction.

This paper introduces the main achievements of ADAS. Through the construction of typical scenarios, it indicates the defect of ADAS only make the

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usage of its own vehicle-mounted sensor information. Further it illustrates the potential threat caused by the vehicle-mounted sensor data collision and points out that it may be an important development direction of ADAS technology to take the transmission efficiency of sensor data into the design consideration of V2X.

2 ADAS Technology Principle

At present, the main approach of the ADAS system is to perceive the surrounding environment through the vehicle-mounted sensors, so as to track the obstacles and realize the safe driving of vehicles. This section explains the advantages and limitations of the current ADAS approach through the introduction and comparison of different vehicle-mounted sensors and related technologies.

2.1 Camera Sensors

Vehicle-mounted camera is the eye of this system, and the environment perception technology based on image recognition is the mainstream of ADAS technology at present [9,10]. In addition, vehicle-mounted cameras play an irreplaceable role in realizing automatic driving, such as identifying traffic signs and traffic lights. The basic principle of camera imaging is as follows:

$$\frac{Z}{f} = \frac{W}{W'} \tag{1}$$

Where Z is the distance from the target to the camera, f is the focal length of the camera, W is the width of the transverse scene, W' is the imaging width. It can be seen that the shorter the focal length, the smaller the magnification, and the larger the field of view. That is, the wider the camera Angle is, the shorter the length of the accurate detection distance will be; and the narrower the Angle is, the longer the detection distance will be. Therefore, to perceive the surrounding environment, different types of cameras need to be installed around the vehicle. A typical car camera layout is shown in the following figure:

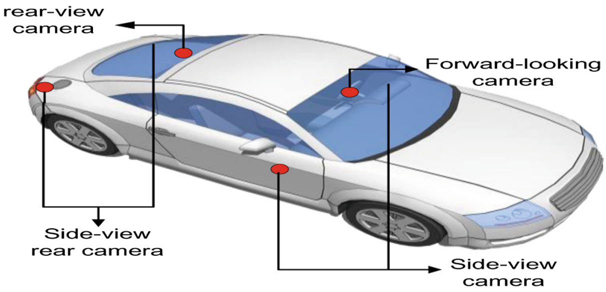

Fig. 1. Vehicle camera sensors distribution diagram

In Fig. 1, the forward-looking-camera is usually a combination of binocular or trinocular camera, including a fish-eye camera, a narrow-angle camera (and a medium-range camera). Side-view-camera is made of two wide-angle cameras, side-view-rear-camera is a medium-range camera, and rear-view-camera is a fish-eye camera.

Night vision function and AI automatic recognition function applying to vehicle-mounted cameras will be the foreseeable trend in the future [11,12]. But relying solely on cameras as ADAS sensors still has obvious defects, that is in extreme weather conditions such as strong light, sudden illumination or fog and haze, the environmental perception ability of the camera will be greatly hindered, and it is easy to cause misjudgment.

2.2 Radar Sensors

Radar is a sensor that determines the target distance through time delay. The vehicle-mounted radar sensors can be divided into three main categories: ultrasonic radar, millimeter-wave radar and lidar. Its ranging formula is as follows:

$$R = V_c \cdot T/2 \tag{2}$$

Where, R is the target's distance, V_c is the propagation speed of the wave emitted by the sensor in the air, and T is time delay. The frequency of the vehicle-mounted ultrasonic wave is about $f_S \approx 40\,\mathrm{KHz}$, and the propagation speed of the ultrasonic wave is $V_S \approx 340\,\mathrm{m/s}$. The vehicle-mounted millimeter-wave radar is mainly constrained in $f_{R1} = 24\,\mathrm{GHz}$ and $f_{R2} = 77\,\mathrm{GHz}$ frequency bands. The wavelength of the vehicle-mounted laser sensor is about $\lambda_L = 900\,\mathrm{nm}$, and the propagation speed of the millimeter-wave and optical-wave is $V_{RL} \approx 3 \times 10^8\,\mathrm{m/s}$. Among these three kinds of radar sensors, ultrasonic radar has the lowest cost and the highest assembly amount in the automobile market. However, because ultrasonic wave attenuates too fast in the air [13], it is mainly used for obstacle detection for $R < 3\,\mathrm{m}$.

The vehicle-mounted millimeter-wave radar is almost unaffected by rain, snow and other weather conditions [14]. Due to these all-weather fits and doppler measurement characteristics, millimeter-wave radar has become an important vehicle-mounted sensor recently. However although the spatial beam scanning can be realized by Digital Beam Forming (DBF) through coherent processing [15], its angular resolution is limited by wavelength and aperture, that is:

$$\theta \approx \lambda/D \tag{3}$$

Where θ is the angular resolution, λ is the transmitting wavelength of the sensor, and D is the radar aperture size.

Because of its small wavelength, lidar has the highest resolution and accuracy in these three radar systems, the resolution of the beam can be controlled within 0.1°. By means of multi-line scanning or phased array [16], it is possible to accurately construct the surrounding scenes. However the disadvantage is that the cost of multi-line lidar is too high to be used in consumer electronics. On the other hand, the use of laser is limited by rain, snow, fog and other weather effects.

For different sensors have diverse feature, it always has a combination of different sensors in ADAS as below [17].

Table 1. Typical sensors installation in ADAS system

	L2	L3	L4 and L5
MMW radar	≥ 3	≥ 6	≥ 10
Camera	≥ 1	≥ 4	≥ 8
LIDAR	0	≥ 1	≥ 1
Others	Ultrasonic	Ultrasonic interior camera	Ultrasonic interior camera V2x

As can be seen from Table 1, the number of cameras and millimeter-wave radars increases from low to high with the level of autonomous driving rank, and they are complemented for each other.

2.3 SLAM

Simultaneous Localization and Mapping (SLAM) as an environment model built technique, is a high-order technology in recent years. It emerges the image recognition, remote sensing, digital map and other technologies [18,19].

Through GPS the vehicle can obtain its own general position information, but the accuracy is poor, the accuracy of urban environment is about 3–10 m. For unmanned usage, digital map positioning accuracy is often required within 1m. SLAM accurately calibrates its position by matching the data acquired by the camera or lidar sensor with high-precision digital map information.

SLAM technology can well realize the high-precision map under the known scenes. Thus, it can assist vehicles to make driving decisions to achieve autonomous driving. However, the problem of multi-vehicle collaborative driving in complex environment still brings safety risks for ADAS.

3 V2X Communication

V2X technology supports the communication between vehicles and the surrounding environment, which enables real-time interaction of road traffic environment information. V2X is currently the route of the smart transportation system predetermined by the governments of various countries, making the ADAS technology transform from autonomous mode to network connected mode.

This section summarizes the advantages and disadvantages of the current V2X technology by explaining and comparing the current mainstream of LTEV & DSRC and the research hotspot of VANET.

3.1 LTE-V and DSRC

At present, the two main standardization development ways of V2X in the world are LTE-V and DSRC. The former is mainly supported by 4G/5G mobile communication technology of 3GPP, while the latter is mainly supported by 802.11 technology of IEEE.

DSRC's standardization can retrospect back to 2004. At that time, IEEE began to develop new vehicle-mounted communication standards under its 802.11 (Wireless Local Area Networks) WLAN standard series. This standard is known as 802.11p. Around 2007, the IEEE 802.11p standard had been stabilized. IEEE then proceeded to develop the 1609.x family of standards as a security framework for V2X. Around the same time, the Society of Automotive Engineers (SAE) began to develop standards for vehicle to vehicle (V2V) applications based on the needs of the automotive industry and named DSRC. The communication standards adopted by DSRC are IEEE 802.11p and 1609.x. The technology allows all traffic participants to interact with their dynamic information at a rate of 10 to 20 times per second.

The LTE-V was newly released by 3GPP in 2017. Unlike the IEEE 802.11 WLAN standard, LTE-V is a set of vehicle-to-infrastructure (V2I) and V2V communication physical layer protocols based on cellular communication networks. LTE-V technology is considered as an important cornerstone for realizing the Internet of vehicles, and is valued by people in the field of Intelligent Transport System (ITS). LTE-V is based on 4.5 G network to LTE cellular networks as the basis of V2X, the key research direction of the 5G. It is the exclusive vehicle networking protocol, networking application scenario for V2V, V2I, vehicle-to-pedestrian (V2P), vehicle-to-network (V2N). The core of these set of V2X protocols is V2V interconnection. In order to meet the multi-scene business requirements of vehicle safety, driving efficiency and on-board entertainment, LTE-V adopts "LTE-V-Cell" and "LTE-V-Direct". The former is based on the expansion of the existing cellular technology, mainly carrying the traditional Internet business of vehicles. The latter introduces LTE device-to-device (D2D) to realize the direct communication of V2V and V2I, and carries active security services of vehicles, mainly meeting the requirements of low delay and high reliability of terminal security.

The main differences between DSRC and LTE-V are shown in the table below [20].

Table 2. Difference between DSRC and LTE-V design parameters

	DSRC (IEEE802.11p)	LTE-V
Multi-user allocation	Single user per symbol	Multiple users share the same symbol
Synchronization requirements	Asynchronous	Tight synchronization
OFDM parameters	Short symbol duration	Long symbol duration
Channel access mechanism	(Carrier Sense Multiple Access with Collision Avoidance) CSMA-CA	Sensing based Semi-Persistent Scheduling (SPS)

As can be seen from Table 2, the symbol duration of OFDM in DSRC is much shorter than that in LTE-V. That result in the OFDM subcarriers are 10 times closer in LTE-V than in IEEE802.11p. Eventually LTE-V application is strictly limited to speeds below 140 km/h by doppler effect, however IEEE802.11p can perform well at speeds of 250 km/h. Nevertheless the channel scheduling mechanism of LTE-V is more flexible, cause OFDM subcarrier is divided in much more detail. Another difference between LTE-V and DSRC is that the former requires network time synchronization mechanism, and Media Access Control (MAC) layer adopts SPS mechanism so it requires coordination of base station terminal. That makes LTE-V's application environment is more subject to the base station coverage.

Due to the periodic and real-time characteristics of the data generated by vehicle sensors, the data of vehicle sensors is usually communicated in the broadcasted way [21]. However, CSMA-CA in DSRC is difficult to apply in broadcast mode. And in the absence of base station coverage, it is difficult to make channel reservation based on SPS in LTE-V. For the above problems, the application of VANET in the field of intelligent transportation has attracted extensive attention.

3.2 VANET Protocols

Since LTE-V and DSRC protocols do not involve the concept of clustering, and vehicle networking is characterized by high mobility, if vehicles traveling in different directions are grouped in the same cluster, it will create a lot of clustering overhead for re-clustering frequently. So it is feasible to divide different clusters by driving directions [22].

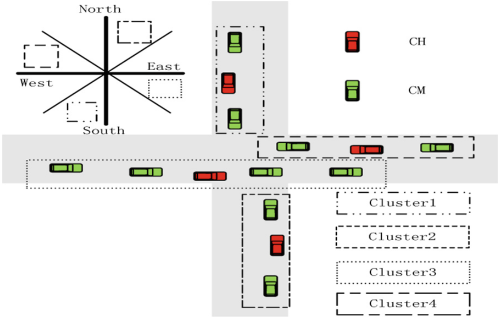

Fig. 2. Basic vehicle cluster diagram

As shown in Fig. 2, the vehicles are divided into four clusters according to different driving orientations. The specific dividing basis is as follows:

$$\begin{cases} \alpha \in [-45°, 45°), \quad m \in C_1 \\ \alpha \in [45°, 135°), \quad m \in C_2 \\ \alpha \in [135°, -135°), \quad m \in C_3 \\ \alpha \in [-135°, 45°), \quad m \in C_4 \end{cases} \tag{4}$$

Where, m represents the vehicle, and α is the north-to-east angle value of vehicle's orientation, and there are four basic classes $C_1 \sim C_4$ divided according to driving direction. The advantage of cluster-based VANET is that, the information interaction within the cluster can be carried out under the coordination of the cluster header. The cluster header can make MAC layer channel reservation and division mechanism like TDMA for each cluster member, that can avoid the data collision effectively in the cluster [23]. Meanwhile, the cluster head can acts as the gateway node for information interaction between clusters.

The use of cluster-based VANET protocol for sensor-based information exchange can effectively avoid information collision, but this kind of protocol is still in the research stage, and the corresponding V2X standard has not been carried out yet.

4 Typical Scenarios

This section illustrates the necessity of sensor data interaction through two typical scenarios. Further more points out the potential danger of sensor data collision in the free broadcast way.

As shown in Fig. 3, when the pedestrian is crossing the road in this scenario, Car1 can detect the pedestrian by its vehicle-mounted sensor like millimeter-wave radar, but the electromagnetic wave emitted by Car2's radar is blocked by Car1, so it can't detect this pedestrian in time.

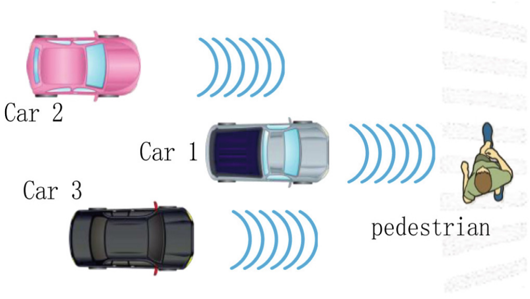

Fig. 3. The pedestrian crossing scenario

When Car1 or Car2 senses the pedestrian, friction is used to slow down the moving vehicle. That is:

$$F_f \cdot d = \mu \cdot m \cdot g \cdot d = 0.5m \cdot v_\circ^2 \tag{5}$$

Where F_f is the friction force, d is the braking distance, μ is the friction coefficient of road surface, m is the vehicle quality, $v_\circ$ is the speed before braking. The braking distance is:

$$d = \frac{v_\circ^2}{2\mu g} \tag{6}$$

Take $\mu = 0.5$ (wet asphalt pavement) and $\mu = 0.8$ (dry asphalt pavement), then the relationship between braking distance and speed is shown in the figure below.

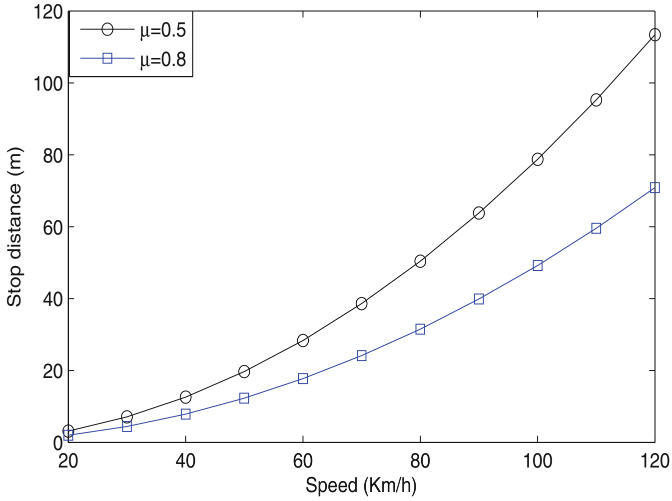

Fig. 4. Relationship between stop distance and speed

As shown in Fig. 4, when the driving speed is under 120 Km/h, the braking distance of the car is lower than 120 m, while the detection distance of the front anti-collision laser or millimeter-wave radar is generally greater than 150 m. Therefore, in Fig. 3, the braking distance of Car1 is sufficient, and the key for Car2 to break in time, is that Car2 can timely get the pedestrian's information.

The braking time of the vehicle is:

$$t = \frac{v_\circ}{\mu g} \tag{7}$$

Therefore, the average sensor data transmission delay and collision probability of vehicle-mounted sensor data is the key of the problem. To illustrate this further, introduce the scenario shown below.

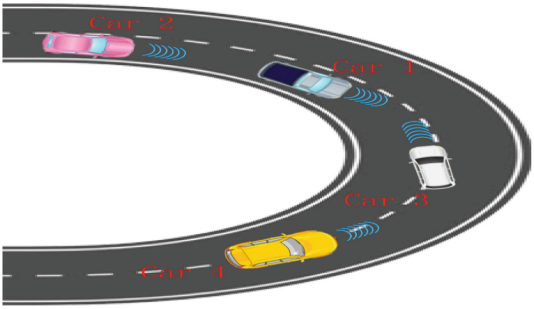

Fig. 5. Mountain road roundabout

Figure 5 constructs the scene of vehicles trudging on the mountain road. Due to the block in sight of the mountain road, it is difficult to detect the coming vehicle. In order to prevent collision, vehicles in both orientations need to detect each other in advance. That means the vehicles' GPS/INS information should be known by the opposite side vehicles. In Fig. 5, Car1 and Car3 need to receive the position information sent by each other in advance to effectively slow down and control the driving path, so as to avoid the collision when they meet.

It is assumed that all vehicles are equipped with vehicle-mounted sensor, and vehicles transmit sensor data packets by broadcast, with random time interval between 50 ms to 100 ms (update frequency of vehicle-mounted sensor data is between 10–20 Hz), and the data packets' duration is 1 ms (LTE-V Fixed Transmission duration). The collision probability (collision packet number/total number of packets sent) and the average delivery delay (non-collision packet sending time interval) are counted.

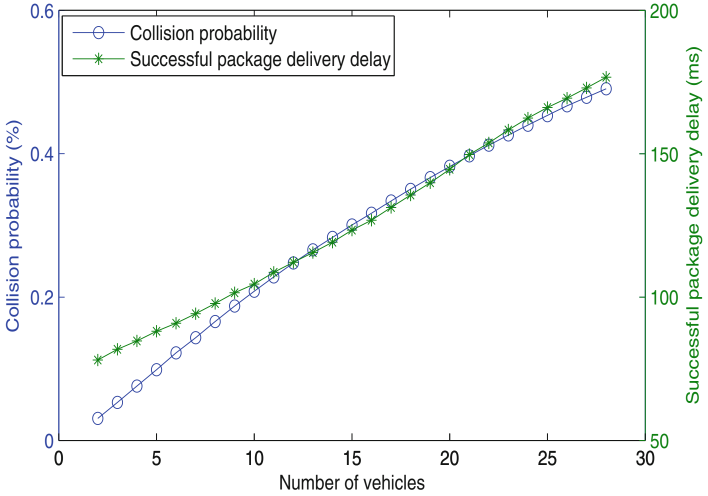

Fig. 6. The statistical probability of packet collision and delivery delay

As shown in Fig. 6, the number of simulated vehicles increases from 2 to 28, and 500 Monte Carlo experiments were carried out for each. The statistical probability of packet collision gradually increases from 3% *to* 49%, and the average successful time interval of packet delivery gradually increases from 78 ms to 176 ms. Therefore, with the increase of the vehicle, the collision probability of sensor data packets increases, and the average packet arrival delay increases too. However if the TDMA channel is allocated to the cluster-member and different clusters work in different frequency channel in the way of clustering network, the collision of data packets can be avoided and the effective delivery of sensor data packets can be guaranteed. Therefore, fusing the VANET technology of cluster communication into the mainstream of LTE-V and DSRC technologies will effectively promote the interaction ability of the sensor data in V2X network.

5 Conclusion

This paper summarizes the current ADAS technology development on vehicle-mounted sensors and V2X communication. It points out the defects of the recent ADAS technology only relies on vehicle-mounted sensors for environmental perception, and asserts the interaction of vehicle-mounted sensor information through V2X technology is an important direction for the development of ADAS in the future. Through the analysis of specific scenarios, it points out that to apply the broadcast random competition way to the current LTE-V or DSRC standard has some disadvantages. It predicts that to introduce the cluster-based channel allocation method in VANET into LTE-V and DSRC may be the next technical development direction of V2X.

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