Analysis of key technologies to achieve autonomous driving on closed roads in the near future

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Abstract. In recent years, autonomous driving has received widespread attention worldwide. Many car companies and Internet companies have been competing for research and development. This article first reviews the current status of autonomous driving at home and abroad, then discusses key technologies for autonomous driving such as environmental perception, high-precision maps and navigation and positioning, path planning, and motion control. At the same time, the current situation, problems and solutions of autonomous driving on closed roads are discussed.

1. Introduction
A self-driving car is a smart car that does not require human control. It is equipped with various sensing devices and intelligent software to sense the surrounding environment of the vehicle, so as to obtain road information and control the speed and direction of the vehicle. Then the car will follow the navigation route established by the software to reach the intended destination [1]. As an important part of future intelligent transportation, autonomous driving has obvious advantages over traditional manual driving in terms of intelligence, safety, comfort, and environmental friendliness. It can alleviate traffic congestion and improve driving safety. The National Highway Traffic Safety Administration classifies the level of autonomous driving into five levels. Currently, only a small number of autonomous vehicles have reached the level of L3, which is the conditional level of autonomous driving, and most of autonomous vehicles are still at the level of L2. According to the energy-saving and new energy vehicle technology roadmap released by China in 2016, it is expected that highly autonomous vehicles and fully autonomous vehicles will reach a certain market share in the next 5-10 years. With the development of artificial intelligence, big data, cloud computing, 5G communication, and high-precision maps, autonomous driving will continue to usher in good application prospects.

2. Development status of autonomous driving
2.1. Development status of foreign autonomous driving
Since the 1970s, foreign developed countries such as Britain and the United States have begun to study autonomous vehicles [2]. Google and Tesla, as self-driving industry giants, have rapid research and development processes. Google has been researching autonomous driving since 2009. In 2016, a new autonomous driving company called Waymo was established. Google adopts the technology route led by lidar. It relies on high-precision maps and street view advantages accumulated over the years to devote to the development of L4-level autonomous driving, and it has recently began to prepare commercial projects for autonomous driving rental and logistics distribution [3-4]. Tesla uses a
technology route dominated by machine vision. Since 2014, it has deployed its own self-developed auto-assisted driving function Autopilot, which can realize many functions such as automatic lane keeping, automatic lane change, and automatic parking. Autopilot has been continuously updated since then to obtain more comprehensive driver assistance functions. Tesla has now achieved commercial mass production, but users are recommended to use it on highways and slow traffic sections [5]. In addition, the special car company Uber conducted a trial operation of self-driving taxis in 2016. In the same year, it acquired the self-driving truck company Otto, which can realize the control of self-driving systems on highways and return the driving rights to drivers when driving out of highways, thereby reducing the burden on long-distance freight drivers. NVIDIA, a chip company, is using artificial intelligence and deep learning to develop hardware and software for autonomous vehicles. Traditional car companies such as Ford, Audi, and Toyota are also conducting corresponding technology research. According to relevant data, in 2020 the world will usher in an explosion of autonomous vehicles.

2.2. Development status of domestic autonomous driving
Domestic autonomous driving is led by the National University of Defense Technology. In 1992, China's first autonomous vehicle was developed. Then it cooperated with FAW to develop the Hongqi HQ3 autonomous vehicle, and completed the highway test from Changsha to Wuhan. Baidu began to enter the field of autonomous driving in 2013. The core of its technology is the "Baidu Automotive Brain", which includes four modules: high-precision mapping, positioning, perception, intelligent decision-making and control [6]. JD company is also conducting self-driving research. The object is L4-level self-driving heavy trucks, which are mainly used for highway transportation tasks. At the end of 2019, Tucson Futures completed China's first self-driving truck queue follow-up test under a fully enclosed highway environment in China. It adopted the manual driving mode of the front vehicle and the autonomous mode of the rear vehicle to complete the parade cruising, line changing lanes, line deceleration, and line Vehicle-road collaboration. At the same time, China is also actively constructing intelligent roads to achieve vehicle-road coordination. Typical representatives are Jingxiong Expressway, Yanchong Expressway, and Hangzhou-Shaoxing Expressway. Among them, Jingxiong Expressway will build two inner lanes as dedicated lanes for smart driving. Although China's self-driving has started late, it has shown a huge latecomer advantage. Many Internet companies, car companies, and universities have participated in it, providing strong technical support for autonomous driving.

3. Key technologies for autonomous driving
The overall functions of autonomous vehicles can be divided into perception layer, decision-making layer and execution layer, which are used to sense the vehicle and its surrounding information, modeling and path planning, and controlling the effective movement of the vehicle. The key technologies include environmental perception, high-precision maps, and Navigation and positioning, path planning and motion control, etc.

3.1. Environmental perception
Environmental perception is one of the autonomous driving’s cores. It uses various types of sensors to sense the surrounding environment information of vehicles, which is equivalent to human eyes and ears. At present, there are many mainstream sensors, including millimeter wave radar, lidar, ultrasonic radar, vision sensors, etc. The advantages, disadvantages and uses of various sensors are shown in Table 1. It can be seen that different sensors have different functions. Autonomous vehicles use various sensors in combination according to different application requirements. The obtained multi-source sensor data is fused to complement each other, thereby obtaining more accurate data and greatly improving the safety of autonomous driving.
## Table 1. Comparative study of major sensors

| Sensors            | Advantages and disadvantages                                                                 | Applications                                                                 |
|--------------------|------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Ultrasonic Radar   | Low cost, close detection range, high precision. Vulnerable to weather, poor directivity. Lower cost, accurate speed and range measurement, strong ability to penetrate fog, smoke and dust. Low angle resolution, poor obstacle feature recognition. | Reversing warning, detection of parking spaces and obstacles, and automatic parking. Adaptive cruise, parallel assist, early warning auxiliary braking (including front and rear collision warning and automatic emergency braking). |
| Millimeter Wave Radar | Extremely high angle, distance and speed resolution, long distance measurement, high measurement accuracy and strong anti-interference ability. High cost, greatly affected by weather and atmosphere. | To obtain the three-dimensional point data of the surrounding environment and draw a three-dimensional space map in real time, to measure the distance, speed, acceleration and other information of the surrounding vehicles. Multiple functions, such as driving records, lane departure warning, forward collision warning, driver fatigue warning, pedestrian recognition, parking assistance, etc. |
| Lidar              | Low cost, intuitive, rich information, good feature recognition. Light interference, unable to obtain speed and distance information accurately.                                     |                                                                                   |
| Vision sensors     |                                                                                                 |                                                                               |

### 3.2. High-precision map and navigation and positioning

For high-level autonomous driving, high-precision maps are indispensable, which can provide prior knowledge for many modules of autonomous driving, such as perception, positioning, planning, and decision-making. High-precision maps refer to electronic navigation maps with higher accuracy and wider dimensions. The differences from traditional navigation maps are shown in Table 2. The high-precision map has rich lane information. Using high-precision map matching, it can accurately determine the vehicle position and the next road conditions of the vehicle, and help the vehicle to plan the route. Navigation and positioning provides real-time motion information for autonomous vehicles, including current position, driving speed, attitude and orientation, etc. At present, the most common navigation and positioning methods on autonomous vehicles are based on GPS and inertial sensor fusion positioning. GPS system has the characteristics of global coverage, all-weather work and high positioning accuracy, and the positioning accuracy can be improved to the centimeter level through differential positioning technology. However, high-rise buildings and tunnels will both shield signals and cause positioning deviations. Inertial sensors are needed to assist in order to improve positioning stability. In addition, other mainstream positioning methods include position based on lidar and high-precision map matching, and position based on computer vision.

## Table 2. Comparison between traditional navigation maps and high-precision maps

| Comparison         | Traditional navigation map                                                                 | High-precision map                                                                 |
|--------------------|-------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Accuracy           | Meter level, civilian GPS accuracy is about 5 meters.                                       | Centimeter level, Google high-precision map accuracy is 10-20 cm level.            |
| Data dimension     | Only road-level data, such as road shape, slope, curvature, heading, etc.                    | To add lane attribute information, including lane line type and width, as well as roadside landmarks, guardrails, road edge types and other data. |
| Application        | Assisted navigation                                                                       | To assist environment awareness, positioning and lane-level path planning           |
| Real-time nature   | Low                                                                                       | High                                                                            |
3.3. High-precision map and navigation and positioning
After determining the surrounding environment and its own location, autonomous vehicles need to plan their driving paths, which can avoid all static and dynamic obstacles and reach their destination smoothly. Path planning is divided into global path planning and local path planning. In global path planning, a known map is used to calculate the global optimal path from the start point to the end point. However, there are dynamic obstacles and various emergencies in actual road conditions, so local path planning is needed to adjust the driving route in time. At present, commonly used path planning algorithms include graph-based search methods, sampling-based methods, and reinforcement learning methods.

3.4. Motion control
The task of the control system is to control the speed and direction of the vehicle so that it can track the planned speed curve and path [7]. The control instruction sent by the decision planning module controls the vehicle's throttle, steering, and brakes. It can achieve effective control of the vehicle, including longitudinal and lateral motion control. Adaptive cruise is a longitudinal control system. By coordinating with the anti-lock braking system and the engine control system, it can realize autonomous driving with following other vehicles and release the driver from the operation of the throttle and brake in specific scenarios.

4. Realization of autonomous driving on closed roads
With years of development, autonomous driving technology is becoming more and more mature. However, to achieve fully autonomous driving, there are still problems in technology such as insufficient intelligent perception in complex environments, insufficient positioning accuracy, and low communication efficiency and stability. At present, autonomous driving is rapidly developed and gradually realized in simple scenarios like closed roads. Closed roads include highways and urban expressways. The lane lines are clear, and the road conditions are relatively simple and standardized. It is expected to realize autonomous driving in the short term and solve long-distance fatigue driving problems.

4.1. Current status
The characteristics of basic roads such as lane lines and signs on closed roads are clear, and the traffic environment is simple. Therefore, closed roads are considered to be one of the first landing scenarios for autonomous driving, especially highways. Various countries have successively conducted road tests for highway autonomous driving, including passenger cars and self-driving trucks for logistics transportation. At present, the L2 intelligent driving assistance system already has a variety of mature auxiliary functions, including lane keeping, adaptive cruise, automatic emergency braking, auxiliary lane change and automatic parking. It can achieve automatically follow the front car and keep the lane on closed road scenarios with good road conditions, which brings a lot of convenience to the user. But it still requires the user to be aware of the environment and ready to take over at any time. Various car companies have launched mass-produced models equipped with L2-level autonomous driving. The Changan CS55 model has an integrated adaptive cruise system. In addition to normal lane keeping and autonomous following, it can also recognize traffic signs and curve deceleration. In September 2019, the ZF L2 highway autopilot system debuted, which can automatically follow the preceding car in the lane for a long time by the driver setting speed. At the same time, with the rapid development of Internet of Vehicles, 5G communication and intelligent roads, single-vehicle autonomous driving will develop in concert with intelligent connected vehicles, which will speed up the development process of autonomous driving.

4.2. Existing problems
Although the intelligent driving assistance system has played a very good role in assisting and enhancing the driver's operation, it has been able to temporarily liberate both hands on roads with better road conditions, but there are still many defects in technology. The premise of the lane keeping function is
that there must be a clear lane line. When the lane line is damaged or missing, the function will be invalid, and there is no obvious warning. Because the intelligent driving assistance system does not have the function of environment perception, it cannot recognize traffic signs. On roads where the speed limit changes frequently, manual intervention is required to adjust the speed limit. When the vehicle in the outer lane is going to change lanes and overtake, the current adaptive cruise technology cannot predict the deceleration in advance, and may even be accelerating to shorten the distance to the front vehicle. At this time, the risk of collision is extremely great. When the ground fluctuations cause the vehicle state to change, the vehicle cannot determine whether the cause is an emergency or a user's artificial steering. There is also a certain degree of risk. At present, the laws and regulations on autonomous driving in various countries are not perfect, and the standard regulations for drivers opening their hands to drive cars have not yet been clarified. Liability cannot be determined when a traffic accident occurs. In addition, the autonomous driving system is highly networked and informatized. Once it is attacked by a hacker, it will seriously threaten the safety performance of autonomous driving, and the consequences will be unimaginable.

4.3. Solutions
First, to step up the introduction of relevant test evaluation standards and laws and regulations. The regulatory department should strictly control the testing phase of autonomous vehicles. It should require each autonomous driving company to report on various accidents and failures that occurred during the testing process. At the same time, the state should formulate scientific and detailed evaluation standards in accordance with relevant laws on road traffic, and make provisions on the bill of responsibility for autonomous driving accidents. Through the inspection of manual factors and autonomous cars, the responsibilities of drivers and car manufacturers could be determined.

Secondly, to accelerate the construction of road infrastructure with uniform standards and improve high-precision maps. By laying intelligent sensing devices such as radar, sensors, and intelligent traffic signs on the road, the road information can be transmitted to the vehicle through the network, which helps the vehicle to perceive more accurate and rich digital road information. It can make up for the insufficiency of vehicle sensor perception. High-precision maps have an irreplaceable role in autonomous driving due to lane-level road information. Major map vendors should speed up the construction of high-precision maps for roads at all levels. At the same time, artificial intelligence technology should be fully applied to enhance the ability to predict dynamic events and make environmental perception more reliable.

Finally, to actively promote the construction of Internet of Vehicles and 5G communication on both sides of the road. At present, the coordinated development of single-vehicle autonomous driving and intelligent connected vehicles is a new development trend of autonomous driving. The Internet of Vehicles can realize the effective coordination of people, vehicles, roads and service platforms. It can transmit road conditions and vehicle information through sensors, V2X and other technologies. The 5G communication technology with high speed, low latency, and large capacity can effectively transmit and process a large amount of data, which can ensure the real-time update of high-precision maps. It can also improve the intelligent driving level and traffic operation efficiency of vehicles. In addition, we must improve network security construction and reduce the risk of cyber hackers intruding into autonomous vehicles.

5. Conclusion
In the future, smart transportation cannot be separated from autonomous driving. The key technologies of autonomous driving have experienced long-term development and have made major breakthroughs in all aspects. The fusion of multi-source sensor data can improve the accuracy of environmental perception. The development of high-precision maps and positioning provides a powerful guarantee for subsequent path planning and decision-making execution. Closed roads are the first application scenarios for autonomous driving, which can effectively solve the problem of long-distance traffic
fatigue driving. It needs the support of unified standards, policies and laws to promote. Through the transformation of road infrastructure and the construction of dedicated lanes, as well as the gradual improvement of high-precision maps, the vehicle's environmental awareness is continuously improved. And the further development of Internet of Vehicles and 5G communication will quickly promote the commercialization of autonomous driving. In short, with the continuous development of autonomous driving technology, the performance of autonomous vehicles will gradually improve. Autonomous driving will be realized in stages, and social benefits will be improved. We will also usher in an unprecedented driving experience.

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