

Collaborative innovation of sensors, mechanical structures, and materials in the field of intelligent driving can enhance passenger safety.

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Abstract. As a core direction of future transportation, intelligent vehicles rely on the integrated advancement of sensors, mechanical structures, and innovative materials. Sensors are indispensable for environmental perception, real-time decision-making, and driving safety, yet current studies remain largely focused on external detection, with in-cabin passenger monitoring still underexplored. In terms of mechanical design, technologies such as by-wire chassis, distributed drive systems, and brake-by-wire significantly enhance vehicle handling and safety, offering faster responsiveness and higher precision than traditional systems. Material innovations provide foundational support: lightweight composites, high-performance optical materials, and thermal conductive components not only improve sensor and battery performance but also ensure system stability and durability. Looking forward, the development of intelligent driving will extend to large vehicles, driven by further optimization of sensing, structural design, and material application, enabling higher levels of automation. In parallel, the establishment of comprehensive legal frameworks and insurance mechanisms will reduce adoption barriers and accelerate large-scale deployment. Overall, the deep integration of sensor technologies, structural innovations, and material advances will provide robust guarantees for the safety, reliability, and sustainable development of intelligent driving systems.

Keywords: Intelligent Driving, Sensors, Mechanical Structures, Innovative Materials, Development Trends.

1. Introduction

Automobiles are one of the most commonly used tools for commuting in our daily lives. The advent of automatic transmissions has made driving easier for the majority of people. Furthermore, cars are the most efficient mode of transportation for medium and short distances, making them indispensable in our lives. In recent years, the development of intelligent driving systems has made driving even more convenient, with some systems now enabling autonomous driving. The advancement of intelligent driving technology has become a key criterion for consumers when purchasing vehicles. Although some brands' vehicles are now capable of intelligent driving, it is still uncertain whether these systems can fully ensure passenger safety, as road conditions change rapidly during travel. There have been recent reports of accidents, such as explosions on highways, due to passengers' complete trust in the intelligent driving system, where the system failed to provide the optimal response to road conditions. Additionally, in such dangerous situations, the survival of passengers is often impossible. Therefore, ensuring the safety of passengers in emergencies is one of the key challenges in intelligent driving. Previous research has mainly focused on external environmental signal recognition using sensors such as cameras. For instance, the Auto Vision project develops positioning and 3D scene perception for autonomous vehicles [1]. However, little research has focused on innovations in the mechanical structures and materials specifically designed for intelligent driving systems. By integrating sensor and mechanical innovations, the safety of intelligent driving could potentially be improved. This paper summarizes various sensors for measuring both the interior and exterior of the vehicle, applying different noise reduction methods to ensure the accuracy of the sensor's information reception, and innovating mechanical structures to improve operational safety measures. Furthermore, the use of different materials in mechanical structures might improve

automotive safety, providing valuable suggestions for future research in the field of intelligent driving. (see Fig. 1)

This study examines intelligent driving systems through the lenses of sensors, mechanical structures, and materials, with the aim of providing a comprehensive overview of current technologies and contrasting them with those employed in conventional fuel-powered vehicles. By analyzing these three dimensions, the paper highlights their interdependencies within intelligent driving systems and identifies areas where technological innovation is most needed. Building on this foundation, it further proposes novel approaches to the design and integration of sensors, mechanical structures, and materials, with particular emphasis on enhancing passenger safety.

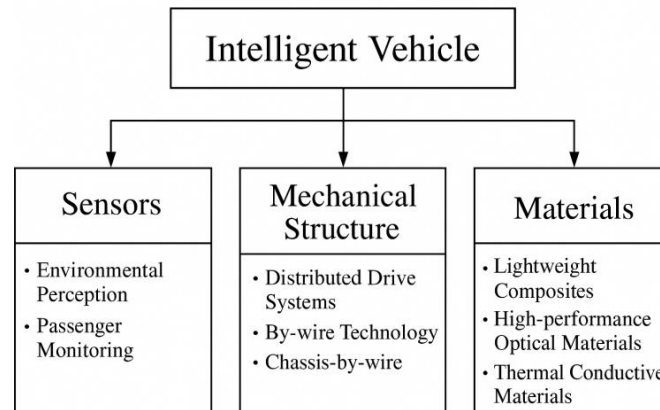


Fig. 1 Intelligent Vehicles Relies on The Synergy between Sensors, Mechanical Structures, and Materials.

2. Organization of the Text

2.1. Sensor Technology and Innovation in Intelligent Driving

The importance of sensors in the automotive field is as indispensable as eyesight is to human beings, since intelligent driving systems rely extensively on various sensors to ensure safe and efficient autonomous driving. These sensors perceive the surrounding environment and provide real-time data to support decision-making and control. Common sensor types include LiDAR, radar, cameras, and ultrasonic sensors. LiDAR plays a critical role in intelligent driving systems by emitting laser beams and receiving reflected signals to construct a three-dimensional map of the environment, thereby assisting the system in identifying obstacles, pedestrians, and other road infrastructure. Radar is primarily employed to detect the distance and velocity of objects, and is particularly valuable under adverse weather conditions or low-visibility environments. Cameras capture visual information regarding road conditions, traffic signs, traffic lights, and the vehicle’s surroundings; when combined with specialized image recognition algorithms, they enable the detection of traffic signs, lane markings, and pedestrians. Ultrasonic sensors, in contrast, are used for short-range object detection and are primarily applied in automatic parking and low-speed driving to identify nearby obstacles.

The collaboration of these sensors enables intelligent driving systems to accurately perceive the environment, providing decision support to the vehicle, ensuring driving safety, and enhancing the stability and reliability of autonomous driving. The role of sensors in intelligent driving is even more critical than in traditional cars, as traditional vehicles depend on the skill level of the driver, while intelligent driving systems rely on the information provided by sensors in combination with system algorithms to drive the vehicle correctly. Currently, most scholarly research focuses on whether sensors can quickly transmit all the collected information to the intelligent driving system, and whether they can be reasonably distributed across the vehicle body. Another consideration is whether sensors can promptly receive information and make appropriate judgments at different speeds. However, one often overlooked factor is whether sensors can detect the status of passengers inside

the vehicle to make driving decisions accordingly. If more research focuses on innovating sensors that can simultaneously detect both interior and exterior conditions, it would significantly improve the safety of intelligent driving systems. When an intelligent driving system operates a vehicle, the most critical function of sensors is to identify nearby obstacles and vehicles that could influence driving. The surround-view fisheye camera system is one such solution. Cameras are essential sensors in autonomous driving systems, providing high-density information and serving as the best choice for detecting road infrastructure markers visualized by human vision. Surround-view camera systems typically consist of four fisheye cameras, providing a field of view exceeding 190° , covering 360° around the vehicle, and focusing on near-field perception. (see **Fig. 2**) These cameras are vital sensors for low-speed, high-precision, and short-range perception applications, such as automated parking, traffic jam assistance, and low-speed emergency braking [2].

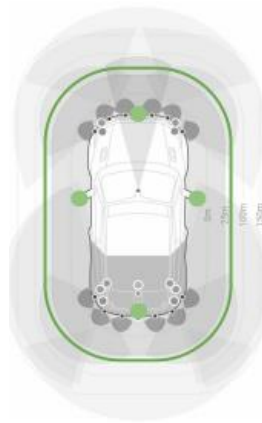


Fig. 2 Green Perimeter Shows 360° Near-Field Sensing around The Vehicle.

Research has shown that drawing environmental maps is crucial for the path planning and obstacle avoidance of autonomous vehicles and other robots. One study on ground vehicles proposed a method to detect static obstacles from depth maps computed from multiple consecutive images. Compared to existing methods, this system does not require precise visual-inertial odometry but only relies on existing wheel encoders. To handle the resulting higher pose uncertainty, the system fuses obstacle detection data from different times and cameras to estimate the free and occupied spaces around the vehicle [3]. It is evident that much research has been conducted on using different cameras to detect external information. At low speeds, the information provided by sensors is rich enough to meet the requirements for safe driving. However, real-world studies show that the likelihood of accidents at high speeds is much higher than at low speeds. Therefore, future research could focus on optimizing sensors or using noise reduction techniques to enhance sensor signals, particularly for high-speed driving. However, there is a notable gap in the use of sensors for monitoring the vehicle's interior. When an intelligent driving system operates the vehicle, passengers are often in a relaxed state. In the event of an accident, sensors should detect the internal environment of the vehicle to assess the passengers' condition. For example, temperature sensors can monitor the car's internal temperature during a crash, while infrared sensors can detect injuries to passengers and provide timely feedback to the intelligent driving system to call for assistance.

Recent news reports have highlighted incidents where intelligent driving vehicles, while traveling at high speeds, locked their doors during an accident, preventing passengers from escaping, which led to fatalities. Therefore, intelligent driving systems need to make the best possible judgment to minimize harm to passengers during accidents and have protective measures in place for passenger safety. This is a crucial issue that should be addressed by automotive developers, as current intelligent driving systems lack such features. The first step is to prevent door locking during emergencies. When external distance sensors trigger an alarm, the system should automatically unlock the doors. Additionally, when passengers recline their seats to rest, they may be unable to protect themselves in an emergency. The seats should be quickly adjusted upon receiving an alarm, ensuring that passengers are in the correct posture to respond to sudden situations.

2.2. Automobile Mechanical Structures in Intelligent Driving

The automobile is a product of the modern industrial revolution, and its powertrain system has evolved from the steam engine to the internal combustion engine, and more recently, to electric vehicles. The appearance of cars has also become increasingly diverse, with vehicles of different performance levels featuring distinct mechanical structures and designs. However, in recent years, intelligent driving vehicles seem to resemble conventional cars in appearance, which is largely due to the fact that the current intelligent driving systems are still not fully developed. They can only serve as auxiliary systems and cannot entirely replace human drivers. Therefore, with the driving seat still in place, it is challenging to make significant changes in the appearance. In fact, the mechanical structure of traditional cars and those equipped with intelligent systems has already undergone changes, which are specifically reflected in the drivetrain, steering, braking, and chassis systems. (see Fig. 3)

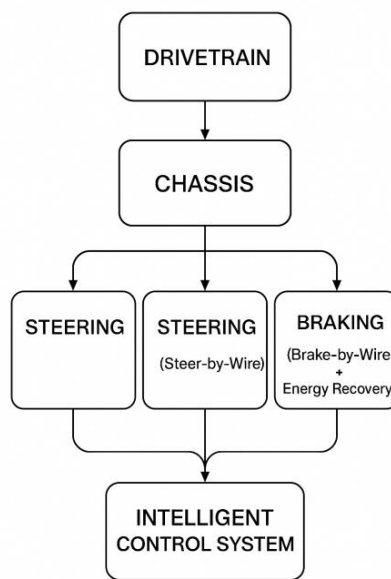


Fig. 3 Collaborative Workflow of Mechanical Structures in Intelligent Vehicles.

In terms of the drivetrain system, traditional vehicles rely on mechanical components like differentials and drive shafts to transmit power, while intelligent driving vehicles often adopt distributed drive line-control chassis, such as in-wheel motor drives. The in-wheel motor drive technology is an advanced electric vehicle drive technology that integrates the motor, reducer, and brake into the wheel rim, turning the wheel itself into a power unit. This simplifies the vehicle's drivetrain structure, allowing for the installation of more battery packs inside the vehicle [4], which not only increases the internal space but also almost eliminates the mechanical transmission system. Multiple systems are integrated within the wheel module, simplifying the structure, improving axle load distribution, and increasing braking energy recovery efficiency.

As for the steering system, traditional vehicles use mechanical steering systems or hydraulic power steering systems, while intelligent driving vehicles generally adopt steer-by-wire systems, which control steering through electronic signals without mechanical connections. This results in faster response times and more precise control. For example, in intelligent mining vehicles, steering control directly affects the driving stability and safety of autonomous mining trucks. In order to achieve active steering in a fully hydraulic steering system for autonomous scenarios, a study on a certain type of 135 electric drive mining vehicle in China was conducted. A hydraulic steering system model was established, and AMESim - Adams co-simulation analysis and field tests were performed. The results revealed that this steering system model could simulate the dynamic characteristics of the prototype vehicle's steering system, offering theoretical insights for the study of autonomous steer-by-wire performance [5].

In the braking system, the hydraulic braking system of traditional vehicles has relatively slower response times, while intelligent driving vehicles tend to adopt steer-by-wire braking systems. A study addressing vehicle instability caused by single-wheel brake failure in vehicles equipped with steer-by-wire braking systems proposed a coordinated control method for vehicle stability, combining steer-by-wire and steer-by-wire braking systems. The simulation results indicated that the proposed control strategy reduced the lateral deviation distance by 89.98%, 91.90%, 96.96%, and 89.62% under light, moderate, and severe braking conditions of single-wheel brake failure, compared to no control. The braking strength was at least 97.5% of that in normal braking conditions [6]. This data suggests that steer-by-wire braking systems can achieve faster braking operations, meeting the high demands for safety and precise control in intelligent driving, thereby ensuring passenger safety. Regarding the chassis system, the steer-by-wire chassis in intelligent driving vehicles offers high controllability and freedom of movement. The controllers provide more precise control, and actuators respond more quickly, leading to better vehicle performance, traction, and maneuverability. On the other hand, traditional car chassis have more mechanical connection components, resulting in lower control accuracy and response speed.

From the above, it can be concluded that the internal structure of intelligent driving vehicles has many optimizations compared to traditional cars, and only such an advanced mechanical structure can effectively handle external conditions in real time. In the future, the mechanical structure of intelligent driving vehicles can be widely applied, such as optimizing the mechanical structure of traditional vehicles, and performing structural optimization for different types of vehicles to improve operational efficiency or reduce manufacturing costs.

2.3. Material Innovation in Intelligent Driving

Innovative materials are a core support for the development of intelligent vehicles. This is because without material innovation, it is difficult for intelligent driving systems to function effectively on existing vehicles, and optimizing materials is key to connecting sensors and mechanical structures.

The importance of material innovation in intelligent driving sensors cannot be overlooked, as intelligent driving systems rely on high-precision sensors to perceive the environment in real time, while such sensors, in turn, depend on advanced materials to ensure accurate decision-making and safe driving. The performance of sensors is directly influenced by material properties such as sensitivity, stability, durability, and response speed. For instance, the effectiveness of LiDAR, cameras, and radar sensors largely depends on innovations in optoelectronic and semiconductor materials. Moreover, lightweight, high-strength, and environmentally resilient materials are essential for improving both sensor efficiency and the overall safety of vehicles. With the emergence of new material classes such as nanomaterials, smart materials, and flexible materials, the accuracy, adaptability, and cost-effectiveness of intelligent driving sensors can be significantly enhanced. Nanomaterials can increase sensor sensitivity, thereby improving a vehicle's ability to detect small obstacles. Smart materials can self-adapt to environmental changes, enhancing sensor performance under diverse conditions. Flexible materials allow sensors to be effectively integrated into vehicle bodies of various shapes and sizes, thereby expanding the design flexibility of sensors. (see **Table 1**)

Firstly, lightweight materials such as carbon fiber composites and magnesium alloys can reduce vehicle weight by more than 30%, directly improving range and reducing energy consumption, while providing a structural foundation for carrying hardware devices such as multi-sensors and high-performance chips required for intelligent driving. Secondly, high-performance optical materials are crucial for intelligent sensing. For example, polycarbonate can enhance the detection accuracy of LiDAR and millimeter-wave radar. Polycarbonate (PC) is one of the five major engineering plastics, and its molecular chain contains carbonate groups $[-O-C(=O)-O-]$. Based on different substituents, polycarbonate is divided into three types: aromatic, aliphatic, and aliphatic-aromatic. Aromatic polycarbonate (PC) is widely used in industries such as construction, automotive, medical devices, and electronics due to its excellent mechanical, thermal, aging resistance, optical, and processing properties [7]. Optical diffusing materials optimize the lighting effects of intelligent

headlights, ensuring reliable environmental perception in complex road conditions. Moreover, thermally conductive materials such as graphene pads can solve chip heat dissipation issues, ensuring the continuous and stable operation of autonomous driving systems. Polymer materials also play a crucial role in automotive batteries. By modifying or adding polymer materials such as polyacetylene, polypyrrole, polyaniline, and polythiophene to the surface of electrode materials, a uniform and interconnected conductive network is formed, which improves battery conductivity and capacity, further enhancing overall battery performance and its stability during cycling [8]. This is a fundamental building block for achieving high-level autonomous driving.

Combining the above factors, it is evident that innovative materials are an essential step in optimizing sensors and mechanical structures. In the future, with advancements in 3D printing, smart coatings, and composite material technologies, sensors will become more efficient, durable, and cost-effective. These material innovations will not only accelerate the development of intelligent driving technology but also promote the widespread adoption of the systems, ensuring efficient performance in various complex driving scenarios. Furthermore, there is still considerable room for improvement in automotive material innovation, which will reduce energy consumption and enhance the lifespan of vehicles.

Table 1. Three Material Comparing.

Material Type	Key Characteristics	Role in Sensors	Advantages
Nanomaterials	Size effect, large surface area, quantum effects	Enhance sensitivity and signal detection capability	Improve the detection of small obstacles
Smart Materials	Adaptive properties, responsiveness to environmental changes	Automatically adjust performance under varying conditions	Ensure stability in extreme environments
Flexible Materials	High ductility, bendability, lightweight	Integration into vehicle bodies of various shapes and sizes	Increase design flexibility and support diverse sensor layouts

2.4. Development Trends and Future Outlook

The widespread adoption of intelligent driving vehicles is one of the future development trends in the automotive sector. Currently, Shenzhen already has intelligent driving taxis operating on the roads, though they are few in number. However, in the future, most vehicles on the road will likely be driven by intelligent driving systems. Research has shown that the evolution of autonomous driving technology can be seen as a microcosm of the revolution in human mobility. Since the debut of the first radio-controlled car in 1925, the field has undergone three major technological leaps: the initial driver assistance systems based on rule-based algorithms in the late 20th century, the breakthroughs in perception and decision-making through deep learning in the 2010s, and the current intelligent driving system based on vehicle-road-cloud collaboration. According to the International Society of Automotive Engineers (SAE) classification standards, L2-level driver assistance has already been widely implemented in mass-produced vehicles, and leading companies are accelerating the commercialization of L4-level systems. Market research firm Statista reports that the global autonomous driving market reached USD 205.9 billion in 2023, with projections to surpass USD 2 trillion by 2030. McKinsey forecasts that by 2030, China will become the largest market for autonomous driving, with a market size of USD 500 billion and an annual compound growth rate of 40.1% [9]. This indicates a promising future for the development of intelligent driving technologies.

Currently, intelligent driving systems face challenges in being applied to large vehicles traveling at high speeds. These vehicles need to consider a wider range of external factors, such as the significant weight differences between empty and fully-loaded trains or buses. When encountering weather conditions like rain, the system must account for even more variables. For instance, in the case of a collision between a large vehicle and a smaller one, a study employed a 1:20 scale intelligent tracking truck model to simulate a small-angle side collision test, providing new insights for studying intelligent truck collisions. The study examined the scattering patterns of four different bulk materials

and found that parameters such as particle density, volume, and elastic modulus significantly affect the distribution of scattered materials. The researchers developed a mathematical model for estimating the collision speed of intelligent tracking trucks based on the area and mass of scattered debris post-collision. Compared to previous models that used the farthest scattering distance to estimate vehicle speed, this new model is more practical as the data is easier to obtain, offering important references for determining vehicle speed during a collision [10]. This demonstrates that numerous factors must be considered, and each factor is significant. Sensors need to transmit more external information and handle it under varying conditions. Additionally, the drivetrain system of large vehicles must be optimized, or the existing mechanical structure needs to be altered, so that intelligent driving systems can be applied without compromising the maximum load capacity. Innovations in materials should not be overlooked either, and 3D printing technologies could be employed to print new materials for use. While intelligent driving systems may occasionally make errors in judgment, they can significantly reduce accident rates compared to human drivers. Higher-level intelligent driving systems are expected to eliminate 90% of human errors, improving traffic flow efficiency and reducing congestion during peak hours, while ensuring safety and enhancing vehicle utilization.

Of course, there will be concerns about who should bear the responsibility in the event of an accident involving an intelligent driving vehicle. Governments will continue to refine relevant laws and regulations in the future, clarify the responsibility of the driver, establish exclusive insurance for autonomous vehicles, lower the barriers for adoption, and protect the rights of all parties. This will eventually lead to an era where everyone feels confident in using intelligent driving systems in their vehicles. The analysis presented in this paper demonstrates that sensors, mechanical structures, and materials constitute the core foundations of intelligent driving systems (see **Table 2**).

Table 2. Three Aspects Comparing.

Aspect	Traditional Vehicles	Intelligent Vehicles	Innovation & Significance
Sensors	Relies on human perception; few sensors, limited functions	Multi-sensor fusion (LiDAR, cameras, radar, ultrasonic) for real-time perception	High precision, low cost, all-weather sensing; nanomaterials, smart and flexible materials enhance sensitivity and reliability
Mechanics	Mechanical transmission; hydraulic steering/braking; slow response, complex structure	Distributed drive, steer-by-wire and brake-by-wire; simplified structure, precise and fast control	Integrated x-by-wire chassis for complex conditions; optimized design for heavy vehicles to improve load capacity and stability
Materials	Mainly steel/aluminum; heavy, limited durability	Lightweight composites (carbon fiber, magnesium alloys); advanced optical/thermal materials; polymer-based batteries	Improved range, safety, and durability; 3D printing and composites enable scalable applications

3. Conclusion

Intelligent vehicles represent a transformative advancement in the automotive industry, integrating sensing technologies, structural innovations, and novel materials to enhance safety, efficiency, and adaptability. External sensors such as LiDAR, radar, cameras, and ultrasonic devices currently support environmental perception and obstacle detection, yet accident risks remain elevated at high speeds due to sensing limitations. Meanwhile, in-cabin sensing—using infrared or temperature sensors—offers untapped potential for monitoring passenger states and enabling timely emergency responses, addressing safety gaps highlighted in recent accidents. Complementing sensing technologies, intelligent vehicles demonstrate significant structural improvements compared with traditional automobiles. Distributed drive systems with in-wheel motors simplify transmission,

increase energy recovery, and optimize space, while steer-by-wire and brake-by-wire technologies deliver higher precision, faster responsiveness, and enhanced reliability. Chassis-by-wire designs further improve maneuverability and stability under diverse driving conditions. Material innovations also play a pivotal role in supporting intelligent driving systems. Lightweight composites such as carbon fiber and magnesium alloys reduce vehicle weight and extend range, while high-performance optical and thermal conductive materials improve sensor accuracy and heat dissipation for continuous system reliability. Advances in nanomaterials, smart materials, and additive manufacturing will further boost sensor sensitivity, adaptability, and energy efficiency. The evolution of autonomous driving has progressed from rule-based assistance to perception-driven deep learning and now toward vehicle–road–cloud collaborative systems. Most mass-produced models currently achieve SAE Level 2, with commercialization of Level 4 underway. By 2030, the global autonomous driving market is projected to exceed USD 2.2 trillion, including USD 500 billion in China. Nevertheless, challenges persist in heavy-vehicle applications, requiring robust sensing and decision-making capabilities alongside clearer regulatory and insurance frameworks. Future innovations integrating optimized sensors, advanced mechanical architectures, and material breakthroughs will accelerate high-level autonomy, minimize human error, and promote safer, more efficient transportation systems.

The analysis presented in this paper demonstrates that sensors, mechanical structures, and materials constitute the core foundations of intelligent driving systems. While existing studies have achieved notable progress and provided valuable insights, significant challenges remain, particularly with regard to safety and system robustness. By synthesizing current advances and identifying directions for material innovation, structural optimization, and sensor enhancement, this study offers a reference framework for future research. It is expected that these perspectives will assist scholars in developing more comprehensive, efficient, and reliable intelligent driving systems, thereby accelerating their large-scale adoption and practical application.

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