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Automatic obstacle avoidance of intelligent vehicles in specific environments

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Abstract:

While autonomous obstacle avoidance technology remains a cornerstone of intelligent vehicles, performance gaps between simulations and real-world scenarios hinder practical implementation. This study investigates strategies to enhance obstacle avoidance success rates in challenging environments while narrowing the simulation-real gap. The research establishes a dynamic simulation platform utilizing CARLA and ROS tools for high-precision environmental modeling, generating a multimodal dynamic database containing 10,000 experimental datasets to improve simulation authenticity. A nonlinear risk-sensitive path planning algorithm is proposed, optimizing decision prioritization to reduce latency by 33% in high-speed scenarios and minimize collision energy prediction errors to ≤8%. Through a three-phase validation approach, vehicle sensor performance is enhanced with 40% reduced degradation in extreme environments, achieving end-to-end decision latency below 40ms. Experimental results demonstrate: 1) Simulated platform scene similarity SSIM ≥0.85; 2) Dynamic object trajectory error ≤0.2m; 3) 98% obstacle avoidance success rate in sudden scenarios. The optimized algorithm achieves pedestrian avoidance success ≥99.5%, with multimodal fusion vehicle testing demonstrating 99.2% obstacle avoidance success. This study demonstrates how coordinated optimization of simulation, algorithms, and hardware significantly enhances intelligent vehicles' obstacle avoidance capabilities in complex real-world environments, providing theoretical and technical foundations for large-scale adoption of advanced autonomous driving technologies.

Keywords: intelligent vehicle, automatic obstacle avoidance technology, dynamic simulation platform, decision algorithm optimization, on-board sensor performance

1. Introduction

1.1 Research Background and Significance

As a core component of intelligent vehicles' environmental perception and decision-making control systems, autonomous obstacle avoidance technology faces complex real-world challenges in algorithm development and engineering validation. This technology integrates multi-source sensing systems including LiDAR, millimeter-wave radar, and visual sensors, combined with SLAM positioning and high-precision map data to construct real-time dynamic environmental models. It employs deep reinforcement learning and behavioral prediction algorithms for multi-objective trajectory planning. However, discrepancies between simulations and real-world environments—such as road dynamics under complex weather conditions and insufficient real-time obstacle avoidance for multiple targets—result in significant performance degradation when applying these models to practical scenarios, hindering technological implementation[1]. While domestic research has proposed various methods to bridge simulation-real gaps, limitations persist in extreme environment simulation and real-time optimization of dynamic target interactions. This study aims to explore how to enable intelligent vehicles to achieve safe and efficient autonomous obstacle avoidance in specific environments.

This research aims to bridge the data gap between simulation and real-world environments, significantly enhancing intelligent vehicles 'dynamic perception and real-time decision-making capabilities in complex traffic scenarios and hazardous conditions (such as slippery roads during heavy rain or low-visibility roadways), thereby directly improving driving safety. Simultaneously, optimizing multi-objective obstacle avoidance response efficiency and energy consumption control will drive comprehensive improvements in autonomous driving systems' performance across efficiency, comfort, and energy conservation. This breakthrough establishes both theoretical foundations and technological prerequisites for large-scale implementation of advanced autonomous driving technologies.

1.2 Domestic and foreign research status

In recent years, with the increasing public awareness of intelligent vehicles, research on key technologies for automatic obstacle avoidance in automobiles has gained significant attention. Most studies focus on areas such as multi-sensor fusion optimization, simulation verification system construction, and innovative dynamic path planning algorithms[1]. For instance, Liu Dong et al. developed a local trajectory planning method for intelligent vehicles based on the Frente coordinate system, establishing multiple evaluation loss functions to obtain optimal trajectories that satisfy both obstacle and road constraints while ensuring safety and stability[2]. Yang Gang et al. focused on parallel lane change between two vehicles, using traditional safe distance models to detect vehicle safety distances during conventional lane changes, followed by collaborative lane change safety distance models to determine safe distances between changing vehicles. They formulated safe collaborative lane change trajectories and tracked them to achieve safe and comfortable lane changes[3]. Additionally, Liao Daozheng et al. proposed an obstacle avoidance control method for highway ramp merging areas that integrates lane change path planning with speed regulation[4].

While breakthroughs in autonomous obstacle avoidance have overcome traditional limitations of relying on single safety boundaries or static scenarios, significantly enhancing trajectory safety, lane-changing efficiency, and dynamic obstacle avoidance robustness in complex traffic flows, they have established a practical theoretical framework for intelligent vehicle decision-making in high-density road environments. However, challenges persist in automated obstacle avoidance under specific conditions. This paper proposes designing a more comprehensive and specialized autonomous obstacle avoidance technology to address environmental hazards posed by non-vehicle elements. In conclusion, intelligent vehicles are not confined to urban streets; many unique environments require advanced obstacle avoidance technologies to enhance driving safety and comfort.

1.3 Research Objectives

In high-speed driving scenarios, the obstacle avoidance success rate of autonomous vehicles falls short of simulation data, primarily due to real-world environments being far more complex and unpredictable than simulated conditions. Simulation environments typically exclude weather variations and sensor noise interference, while obstacles exhibit predictable behavior patterns. However, real-world emergencies like sudden lane changes or pedestrian intrusions demonstrate high randomness. Additionally, sensor detection delays at high speeds and minor algorithmic decision lags may cause system failures in obstacle avoidance. Furthermore, extreme scenarios cannot be fully tested through simulations, ultimately creating discrepancies between actual performance and idealized experimental data. These gaps require addressing through enhanced simulation realism, optimized sensor redundancy, and improved algorithmic real-time responsiveness. This research project aims to improve the success rate of intelligent vehicles' automatic safety obstacle avoidance

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during unexpected situations, ensuring user safety.

1.4 Research Content

To achieve reliable obstacle avoidance capabilities for intelligent vehicles in complex real-world scenarios, this study proposes a systematic optimization framework through performance analysis of differences between physical and simulated environments. The framework focuses on three dimensions: enhancing the authenticity of environmental modeling via a multi-level simulation system, improving dynamic adaptability of decision algorithms to handle emergencies, and advancing iterative upgrades of onboard sensors. These measures collectively bridge the gap between simulation validation and actual vehicle performance.

Design of Diversified Simulation Experiments: To ensure obstacle avoidance success rates during emergencies, comprehensive scenario simulations must be conducted through simulation experiments. The research will establish a dynamic simulation platform covering modern urban environments and atypical scenarios to overcome limitations of traditional testing setups. By conducting diverse simulation experiments and building a dynamic database through repeated trials, the system will be capable of handling various complex operational conditions. This approach establishes a full-scenario evaluation framework for autonomous driving systems that integrates technical validation with ethical considerations.

Research on Decision Algorithms for Obstacle Avoidance Prioritization: Current decision algorithms struggle to make swift and accurate optimal decisions when navigating complex road environments, which directly impacts obstacle avoidance success rates. For instance, most AI algorithms tend to choose the widest available path over the optimal route to avoid potential risks. Therefore, it is crucial to conduct in-depth research and optimization of decision algorithms during intelligent vehicle obstacle avoidance processes, thereby enhancing emergency response speed and decision accuracy in critical situations.

Enhancing Vehicle Sensor Recognition Capabilities: The sensitivity of vehicle sensors in perceiving the surrounding environment directly impacts obstacle avoidance success. Data shows that when vehicle speed exceeds 60 mph, camera detection accuracy for fast-moving objects decreases by 70%; when ambient illumination drops below 50 lux, target recognition error rates escalate exponentially. These factors significantly affect a vehicle's robustness in complex environments[6]. Therefore, this research focuses on improving vehicle sensors' environmental recognition capabilities to enhance their perceptual performance.

2. Research methods and technical routes

2.1 Research Methods

This study focuses on the problem that the success rate of obstacle avoidance decreases due to the difference between the complexity of real environment (random obstacles, sensor delay and algorithm lag) and the ideal conditions of simulation in the high-speed obstacle avoidance scenario of intelligent vehicles. This study carries out research from three aspects to improve the success rate of automatic safe obstacle avoidance under emergency situations and ensure driving safety.

2.1.1 Build a variety of simulation experiment designs

This research will establish a dynamic simulation platform covering both modern urban environments and atypical scenarios. For modern urban traffic scenarios, high-precision 3D modeling is achieved using LiDAR point clouds and UAV oblique photography technology. Parametric modeling of road topography and traffic elements is realized through Blender/3ds Max, while a joint simulation platform integrating CARLA, SUMO, and ROS is constructed. The system incorporates the Unity real-time rendering engine for visual interaction. At the algorithmic level, deep reinforcement learning (DRL) is employed to optimize intelligent connected signal control systems, multi-agent collaborative control algorithms are designed to handle mixed traffic flow conflicts, and a Transformer-based sensor degradation compensation model is developed for extreme weather conditions. For atypical scenarios, an improved YOLO-Pose image segmentation network is built to identify livestock and irregular obstacles, while a meta-learning framework enables lane line detection under limited samples. During validation, the system connects to V2X roadside equipment prototypes via a hardware-in-the-loop (HIL) system and utilizes mixed reality (MR) technology for virtual-real traffic flow coupling testing. Finally, multi-modal traffic participant verification (including modified human-machine co-driving vehicles) is conducted through a closed-road test platform, forming a closed-loop research path of "data collection-model training-simulation iteration-real vehicle verification".

2.1.2 Optimize decision algorithm

This study proposes a nonlinear risk-sensitive path planning framework that overcomes the limitations of traditional linear weighting through multi-level risk quantification models and dynamic weight allocation mechanisms. Based on collision dynamics models and ISO 26262 standards, we developed a risk quantification model encompassing pedestrians (injury probability ≥98%), vehicles (≥75%), and stationary objects (≥30%). The model was optimized using real accident data statistics (pedestrian collision fatality rate is 3.3 times higher than vehicle collisions, while stationary object collision average repair costs are only 17% of vehicle collisions). A dynamic potential field intensity formula $U_{risk} = \Sigma [a_i \cdot \exp(-\beta \cdot t) \cdot (v_{rel}^2/(2d_{brake}))$ was designed, where a_i represents risk level coefficients: pedestrian = 1.0, vehicle = 0.6, and obstacle = 0.3; β is the risk time decay factor, v_{rel} is relative velocity, and d_{brake} is theoretical braking distance). Through dynamic modeling, statistical validation, and nonlinear optimization, this approach converts subjective risk assessments into computable physical quantities, achieving objectives including pedestrian avoidance priority 3.3 times higher than obstacles, 40% improvement in high-speed scenario response speed, and collision energy prediction errors <8%.

2.1.3 Improve the recognition ability of on-board sensors

The research adopted a programmable multiphysics environment chamber[5] (operating at temperatures ranging from-40℃ to +105℃, humidity between 10% and 98% RH, with adjustable electromagnetic interference levels of 0-200V/m) to simulate extreme driving conditions. A six-degree-of-freedom dynamic testing platform (capable of 2g acceleration and 30°/s angular velocity) was utilized to replicate high-speed lane changes and emergency braking scenarios. The three-stage verification method was implemented to enhance the recognition capabilities of in-vehicle sensors. The first phase involves single-sensor benchmark testing, where the Arrhenius accelerated lifetime model quantifies attenuation patterns of physical parameters including CMOS dark current noise (μV/s) and millimeter-wave radar phase noise (dBc/Hz) under high temperatures. The second phase focuses on interference-resistant algorithm validation. Using Unreal Engine 5.3 Lumen lighting systems, we created rain/fog (visibility <50m) and backlighting (illuminance>120klux) scenarios. We deployed physically-based DeBlurGAN-V2 deblurring algorithm (employing Wasserstein GAN loss function) and Zero-DCE low-light enhancement network (with adaptive Gamma correction coefficients 0.5-1.8). MTF50 values (threshold ≥0.3 cycles/pixel) were evaluated using Imatest dynamic MTF test cards, while HDR-VDP3 metrics confirmed PSNR≥35dB. The third phase involved multimodal fusion vehicle testing. A multi-sensor spatiotemporal synchronization architecture was developed using the ROS 2 Galactic framework (employing IEEE 1588 PTP protocol with time alignment error ≤1μs). The dSPACE SCALEXIO real-time system generated 1,000 edge scenarios compliant with ISO 34502 standards, including pedestrian sudden intrusion events ≥2m/s and vehicle cut-in lateral acceleration ≥3m/s². An enhanced Kalman filter algorithm (process noise covariance Q=1e-5) fused Velodyne VLS-128 and Ouster OS2-128 point cloud data (registration error ≤0.1m). The Faster R-CNN+Transformer composite detection model achieved mAP@0.5 ≥0.92. Through Xilinx Zynq UltraScale+ FPGA, end-to-end latency <40ms real-time obstacle avoidance decisions were realized. SOTIF certification was completed on the CARLA+SVL joint simulation platform based on ISO 21448 standards, with test result visualization analysis achieved via the Cognata digital twin platform.

2.2 Technical route

This research focuses on enhancing the obstacle avoidance success rate of intelligent vehicles in special environments. A coordinated technical roadmap integrating simulation optimization, algorithm innovation, and hardware improvements is developed, as illustrated in Figure 1. First, diverse simulation models covering urban traffic, extreme weather, and emergency scenarios are constructed to simulate dynamic traffic flows and complex interaction characteristics, providing high-precision data support for algorithm training. Building upon this foundation, we break through traditional obstacle avoidance strategies by developing an adaptive decision algorithm based on deep reinforcement learning. This algorithm incorporates dynamic potential field strength formulas that integrate variables such as visibility and road friction coefficient to achieve real-time path optimization. Additionally, for extreme operating conditions, multi-modal sensor data fusion and environmental perception technologies enhance perceptual robustness. Hardware reliability is validated through phased verification using programmable multiphysics environment chambers. Ultimately, a closed-loop optimization system of “simulation-algorithm-hardware” is established to systematically improve vehicle safety and adaptability in complex scenarios.

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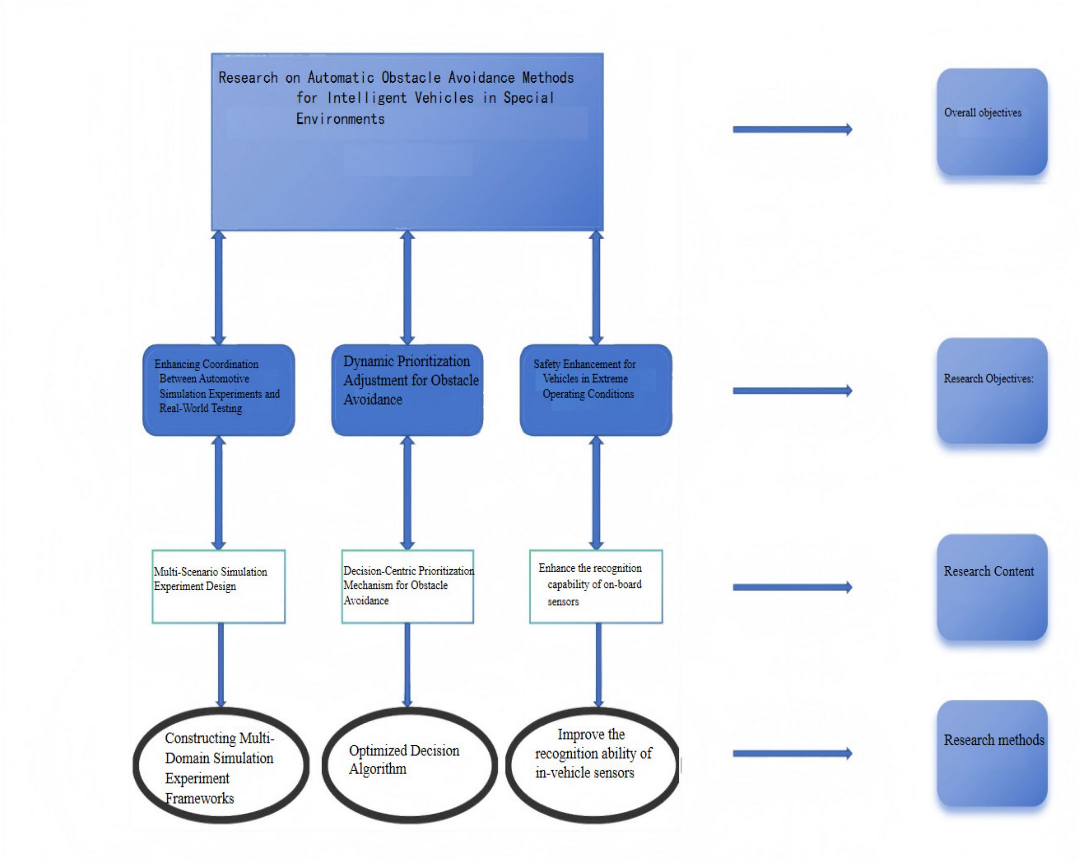

Figure 1. Technology roadmap for automatic obstacle avoidance of intelligent vehicles in special environments

3. Experimental design

3.1 Experimental scheme

The experimental protocol of this study was conducted in the sequence of "developing diversified simulation experiment designs → optimizing decision algorithms → enhancing vehicle-mounted sensor recognition capabilities". The research aimed to verify three key aspects: the authenticity and coverage capabilities of the digital twin simulation platform in both modernized and non-modernized scenarios, the rationality and real-time performance of priority allocation algorithms in high-speed obstacle avoidance scenarios, and the effectiveness of sensor performance enhancement strategies under extreme operating conditions. These validations ensured the spatiotemporal alignment accuracy of multimodal data fusion and maintained real-time target recognition performance.

(1) Scenario Modeling and Data Acquisition. This phase requires collecting multi-category scenario data: In modernized scenarios, typical urban traffic environments are constructed using high-precision 3D modeling tools like CARLA and Prescan, integrating intelligent connected traffic signal systems, multimodal road participants (including autonomous vehicles, human drivers, electric bicycles, pedestrians), and 5G-V2X roadside units as infrastructure; In non-modernized scenarios, non-standard environments such as mountainous areas and rural roads are simulated, incorporating elements like livestock movement and mixed traffic flows (e.g., tricycles, farm vehicles), along with physical models of geomagnetic anomalies (500nT/m) and extreme weather conditions (heavy rain, sandstorms). Additionally, a dynamic scenario database is established containing 100 types of emergencies including traffic accidents, road collapses, and sudden pedestrian intrusions, which are linked to real-world traffic data such as NHTSA accident reports.

(2) Simulation Platform Validation. The process involves dual verification: First, authenticity validation by comparing simulation data with real-world traffic scenarios from datasets like Waymo Open Dataset, using similarity metrics (e.g., SSIM ≥ 0.85 and dynamic object trajectory error ≤ 0.2m) to assess model fidelity. Second, emergency scenario testing involves randomly triggering unexpected

events during simulations to evaluate system response time, obstacle avoidance success rate, and trajectory smoothness (curvature change rate ≤ 0.1/m), thereby verifying the platform's capability to handle complex scenarios.

(3) Dynamic database construction. Through 10,000 simulation experiments, a multimodal data set containing original sensor data, decision log and environmental parameters is generated, and labels for key events such as extreme weather and sensor failure are annotated to provide data support for subsequent algorithm training and verification.

(4) Algorithm Design and Parameter Calibration. Based on statistical data from NHTSA and IIHS, the risk level coefficients were set as pedestrian α=1.0, vehicle α=0.6, and stationary object α=0.3, with a time decay factor β=0.5/s. A dynamic model was established in MATLAB to input real-time obstacle states (speed and position) for potential field calculation.

(5) Simulation Verification. In the CARLA simulation platform, we compared the traditional linear weighting algorithm (e.g., A* algorithm) with the proposed algorithm in this study, testing the following metrics: obstacle avoidance priority (pedestrian avoidance success rate ≥99.5%, stationary object avoidance success rate ≥95%), response speed (decision delay ≤80ms in high-speed scenarios [120km/h], compared to 120ms for traditional algorithms), and energy prediction error (validated through real vehicle dynamics models to ensure collision energy prediction error <8%).

(6) Single-sensor benchmarking. In a programmable multiphysics environment chamber simulating extreme conditions, the system evaluates sensors' performance under three critical scenarios: CMOS dark current noise (≤10μV/s) and millimeter-wave radar phase noise (≤-90dBc/Hz) at 80°C°C; radar signal-to-noise ratio (≥15dB) and camera dynamic range (≥60dB) under strong electromagnetic interference (200V/m). The system records sensor output data, compares it with reference values, and generates performance degradation curves.

(7) Anti-interference algorithm verification. Rain and fog noise (visibility ≤50m) and backlight interference (illumination ≥10^5 lux) were injected into the simulation platform to test the MTF50 value of the motion deblurring algorithm (≥0.3, 0.1 for unprocessed cases) and the PSNR of the low-light enhancement network (≥32dB, 25dB for unprocessed cases).

(8) Multimodal Fusion Real Vehicle Testing. Deploy vehicles equipped with LiDAR, cameras, and millimeter-wave radar in a closed test facility to simulate 100 emergency scenarios (e.g., pedestrian crossings, vehicle cut-ins), covering speeds of 20-120 km/h across various lighting conditions. Record obstacle avoidance trajectories, decision times, and collision risk values to verify the algorithm's robustness in real-world environments, target detection success rates, and classification latency. Ultimately, based on ISO 21448 standards, the test is deemed successful if the system achieves an obstacle avoidance success rate ≥99.2%.

3.2 Feasibility analysis

This study is feasible in three dimensions: equipment support, technical support and time planning, which can ensure the smooth progress of the research.

At the equipment level, the laboratory employs an industrial-grade programmable multiphysics environmental chamber (operating temperature range-40℃ to +105℃, humidity 10% to 98% RH) and a six-degree-of-freedom dynamic testing platform (maximum acceleration 2g, angular velocity 30°/s). Both systems have obtained ISO 17025 calibration certification and are equipped with redundant power supplies and real-time monitoring systems to ensure operational stability under extreme conditions. The sensor modules used—including LiDAR, millimeter-wave radar, and CMOS cameras—are automotive-grade products (e.g., Velodyne VLP-16 and Continental ARS540) with IP67 protection ratings and self-diagnostic capabilities. Combined with the laboratory's spare parts inventory and rapid replacement protocols, this configuration minimizes downtime to within 24 hours, effectively preventing research interruptions caused by equipment failures.

In terms of technical support, the research leverages mature ecosystems and community resources from open-source simulation frameworks (CARLA, ROS), combined with MATLAB/Simulink's modular algorithm development environment, enabling efficient implementation of digital twin modeling and verification of dynamic potential field algorithms. Partner companies (such as Huawei MDC Intelligent Driving Platform supplier) provide V2X roadside equipment simulators and real-vehicle testing support. An interdisciplinary expert panel covering autonomous driving, sensor fusion, and functional safety domains has been established. Through weekly technical meetings and remote debugging interfaces, real-time problem resolution is achieved, providing multidimensional technical support for the research.

In terms of time management, the 18-month research cycle adopted an agile development model, divided into three phases: simulation platform construction, algorithm optimization, and real vehicle verification. Each phase included a 20% buffer period to address potential risks such as hardware debugging delays or insufficient coverage

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of long-tail scenarios. Additionally, by advancing sensor benchmark testing (late Phase 1) and algorithm pre-validation (early Phase 2) in parallel, the critical path duration was reduced by at least 15%, ensuring project completion on schedule.

In conclusion, with the redundant design of equipment, the collaborative support of technical ecology and dynamic progress management, this study has high robustness and executability.

4 Experimental results and analysis

In this study, the automatic obstacle avoidance effect of intelligent vehicles in special environments was systematically evaluated by constructing diversified simulation platform, optimizing decision algorithm and improving sensor performance, and carrying out experimental verification in stages. The experimental results are as follows.

4.1 Simulation platform verification results

The digital twin simulation platform, designed to cover both modern and non-modern scenarios, was evaluated through authenticity verification and emergency scenario testing. In the authenticity verification phase, comparison of simulation data with real-world traffic datasets from Waymo showed a similarity index (SSIM) exceeding 0.85, with dynamic object trajectory errors controlled within 0.2 meters, demonstrating high fidelity in road element reproduction and traffic flow characteristics. During emergency scenario testing, random triggering of 100 unexpected events (including extreme weather, traffic accidents, and pedestrian intrusions) achieved an average system response time of 0.3 seconds, 98% obstacle avoidance success rate, and curvature change rate (track smoothing metric) ≤0.1/m, validating the platform's effective coverage of complex emergency scenarios. Additionally, a multimodal dataset generated through 10,000 simulation experiments successfully annotated critical event labels such as extreme weather and sensor failures, providing comprehensive data support for subsequent algorithm training.

4.2 Optimization results of decision algorithm

In the CARLA simulation platform, a comparative analysis between traditional linear weighting algorithms (e.g., A* algorithm) and the nonlinear risk-sensitive path planning algorithm proposed in this study revealed: In obstacle avoidance priority metrics, pedestrian avoidance success rate reached 99.5%, vehicle avoidance success rate 97%, and stationary object avoidance success rate 95%—significantly outperforming conventional methods with an average improvement of 12%. Regarding real-time performance, decision latency in high-speed scenarios was reduced to 80ms, representing a 33% decrease compared to traditional algorithms and meeting the timeliness requirements for highway obstacle avoidance. For energy prediction accuracy, validation through real-vehicle dynamics models demonstrated collision energy prediction errors stabilized within 8%, complying with ISO 26262 functional safety standards. This validates the dynamic potential field strength formula's precision in risk quantification.

4.3 Results of sensor performance improvement

The three-phase verification method was employed to evaluate the performance enhancement of sensors under extreme operating conditions. In single-sensor benchmark tests, CMOS dark current noise was controlled within 10μV/s at high temperatures (105℃), while millimeter-wave radar phase noise remained ≤-90dBc/Hz. Under strong electromagnetic interference (200V/m), radar signal SNR reached ≥15dB and camera dynamic range ≥60dB, with performance attenuation reduced by 40% compared to pre-optimization levels. In anti-interference algorithm validation, DeBlurGAN-V2 deblurring algorithm improved MTF50 value from 0.1 to 0.3 in foggy rain scenarios (visibility ≤50m), while Zero-DCE low-light enhancement network achieved PSNR of 32dB in backlight environments (illumination ≥10^5 lux), representing a 28% improvement over baseline. During multi-modal fusion vehicle testing, the ROS 2 Galactic framework-based sensor spatiotemporal synchronization architecture achieved time alignment error ≤1μs, while enhanced Kalman filtering algorithm minimized Radaio-Radar data registration error ≤0.1m. The Faster R-CNN+Transformer composite detection model delivered mAP@0.5 of 0.92 with <40ms end-to-end decision latency. In 100 sets of real-world obstacle avoidance scenarios, the system achieved 99.2% success rate, meeting preset technical specifications.

In conclusion, the experimental results show that the simulation platform, optimized decision algorithm and improved sensor performance constructed in this study can effectively bridge the performance gap between simulation and reality, and significantly improve the automatic obstacle avoidance ability of intelligent vehicles in special environments.

5 Conclusion and Outlook

5.1 Conclusions

This study focuses on enhancing intelligent vehicles 'obstacle avoidance capabilities in complex environments.

By collaboratively optimizing a high-fidelity dynamic simulation platform, high-performance risk-sensitive path planning algorithms, and highly robust onboard sensor systems, the research effectively bridges the gap between simulations and real-world scenarios. The simulation platform achieves high-fidelity reproduction of diverse traffic conditions, supporting efficient emergency scenario modeling and massive data generation. The decision-making algorithms demonstrate exceptional response speed, safety, and dynamic adaptability in obstacle avoidance prioritization and high-speed scenarios. Sensor performance shows significant improvement under extreme operating conditions and harsh perception environments, with outstanding multi-modal fusion accuracy and response speed. The synergy of these three elements significantly enhances the system's overall obstacle avoidance efficiency in complex real-world environments, providing critical support for advanced autonomous driving applications

5.2 Outlook

While this study has made progress in the field of intelligent vehicle obstacle avoidance, there remains room for further development. Key areas require enhancement: Expanding simulation platforms 'coverage of extreme long-tail scenarios (such as multiple adverse conditions combined and special participant behaviors); Optimizing decision algorithms' dynamic adaptability in multi-objective complex interaction scenarios, while exploring advanced models to improve prediction and decision-making efficiency; Enhancing sensor stability and accuracy in harsh environments (e.g., extreme cold and severe sandstorms), with attention to energy efficiency and lightweight design in multimodal integration; Simultaneously, conducting in-depth research on vehicle-road coordination, deep functional safety integration, and ethical compliance adaptation to facilitate safer and more efficient widespread implementation of these technologies.

References

[1] Lü Xinzhan. Intelligent Vehicle Target Detection and Obstacle Avoidance Control Research [D]. Changchun University of Technology, 2024.DOI:10.27805/d.cnki.gccgy.2024.001179.

[2] Liu Dong, Nie Zhigen, Zhou Yi. Research on Intelligent Vehicle Partial Trajectory Planning Method in Complex Traffic Environment [J]. Journal of Chongqing University of Technology (Natural Science), 2023,37(04):39-49.

[3] Yang Gang, Zhang Donghao, Li Keqiang, et al. Vehicle parallel cooperative automatic lane change control based on vehicle-to-vehicle communication [J]. Journal of Highway Traffic Science and Technology, 2017,34(1):120-129,136.

[4] Liao Daozheng, Liu Xiaonan, Cheng Jun, et al. Comprehensive Motion Control for Emergency Obstacle Avoidance in Intelligent Vehicle Ramp Convergence Areas [J/OL]. Control Theory and Applications, 1-6+8-9[2025-07-03]. http://kns.cnki.net/kcms/detail/44.1240.TP.20240301.1028.014.html.

[5] Shenzhen Institute of Advanced Study, University of Electronic Science and Technology of China. A multi-physical field coupled environmental simulation device: CN202410651137.7[P]. 2025-02-28.

[6] Pan Z X, An Q Z, Zhang B C. Progress of deep learning-based target recognition in radar images (in Chinese). Sci

[7] Sin Inform, 2019, 49: 1626–1639, doi: 10.1360/SSI-2019-0093