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A Review Paper on Smart Controllers to Manage the Collision

Jyoti[1], Dr. VK Shrivastava[2]

[1]P.hD Research Scholar, Department of Computer Science and Applications, Baba Mastnath University Rohtak, Haryana, India
[2]Professor, Department of Computer Science and Applications, Baba Mastnath University, Rohtak, Haryana, India

Abstract

The rapid growth of intelligent transportation systems has made vehicle safety a top priority in automotive innovation. One of the most important improvements is the addition of smart controllers to collision avoidance management systems. These systems use real-time sensing, decision-making, and actuation to help keep people safe on the road. This review paper provides the introduction of smart controller-based system. This paper also deals with the working and functions of smart controllers that are implemented in a vehicle. Intelligent controllers use data from different sensors, such LiDAR, radar, ultrasonic, and cameras, to find potential dangers and take quick action, like autonomous breaking, lane correction, and adaptive cruise control. The paper reviews several control methods, such as fuzzy logic, PID, model predictive control (MPC), and neural network-based systems, and focuses on the working of them in making decisions in changing and uncertain driving situations. This discusses the use of vehicle-to-everything (V2X) communication and artificial intelligence to improve situational awareness and predictive responsiveness. This review discusses the working of functions by using both simulation studies and real-world applications.

Keywords: Smart Controllers, Collision Avoidance, Autonomous Systems, Safety Management etc.

INTRODUCTION

Collisions in autonomous systems, vehicles, and industrial environments represent a critical challenge for safety, efficiency, and reliability. Rapid advancements in automation and artificial intelligence have created the need for intelligent mechanisms capable of predicting, preventing, and mitigating collision risks. Smart controllers, designed with adaptive algorithms and real-time decision-making capabilities, have emerged as a promising solution to address these challenges.

Smart controllers integrate advanced computational techniques such as fuzzy logic, neural networks, and model predictive control to manage dynamic environments. These controllers continuously analyze sensor data, predict potential collision scenarios, and implement corrective actions within milliseconds. The ability to adapt to uncertain and complex operating conditions makes smart controllers essential for applications in autonomous vehicles, robotics, aviation, and industrial automation [1].

The development of smart controllers for collision management is closely linked to innovations in sensor technology, communication systems, and machine learning. High-resolution sensors, combined with real-time data processing, enable accurate detection of obstacles and hazards. Machine learning algorithms enhance predictive capabilities, allowing controllers to anticipate collision risks and optimize responses. Integration of these technologies ensures that collision management systems are not only reactive but also proactive in maintaining safety.

Research on smart controllers highlights their role in reducing accidents, improving operational efficiency, and supporting sustainable technological growth. By embedding intelligence into control systems, industries can achieve higher levels of automation while maintaining safety standards. The review of smart controllers [2] for collision management provides insights into current methodologies, emerging trends, and future directions, emphasizing their importance in modern engineering and safety-critical applications. This paper's goal is to give a full overview of how smart controllers are currently used in collision avoidance management systems. It looks at their design structures, control methods, sensor integration methods, and how it is used in the actual world. It also talks about the problems and future directions in this subject, which are changing quickly. It stresses the necessity for strong, scalable, and morally good solutions to make sure that intelligent safety technologies are widely used in current cars.

RELATED WORK

Li & Hou (2025) [3] highlighted the growing importance of unmanned surface vehicles (USVs) in marine operations due to efficiency and versatility. The objective of the study was to enhance collision avoidance capabilities in complex maritime environments where traditional artificial potential field (APF) methods face limitations such as local minimum and dynamic traffic challenges. The methodology involved the development of an improved APF algorithm that integrated the boundary potential field method with International Regulations for Preventing Collisions at Sea (COLREGs). Simulation experiments were conducted using electronic navigational charts to evaluate performance. Results indicated that the incorporation of the boundary potential field method reduced computational burden caused by clustered land obstacles, thereby improving efficiency. Findings confirmed that the refined APF algorithm strictly adhered to COLREGs in head-on, overtaking, and crossing encounters, generating smooth and safe paths. The scope of the study extends to providing reliable technical support for autonomous obstacle avoidance in dynamic ocean conditions, ensuring robustness and efficiency in real-world maritime navigation.

Hamidaoui et al. (2025) [4] examined the critical need for safe and effective navigation in autonomous vehicles as the field continues to expand rapidly. The objective of the survey was to analyze existing collision avoidance algorithms employed in self-driving cars. The methodology involved a comprehensive review of sensor-based techniques for obstacle detection, advanced path-planning algorithms for reliable navigation, and decision-making systems for adaptive responses in diverse driving scenarios. Results of the survey highlighted the effectiveness of these methods in ensuring dependable and safe vehicle movement. Findings emphasized the role of machine learning in enhancing obstacle avoidance capabilities, thereby improving overall system reliability. The scope of the survey extends to strengthening public confidence in autonomous driving technologies by demonstrating how integrated approaches combining sensors, path planning, and machine learning can significantly improve safety and dependability.

Aoki et al. (2024) [5] focused on the objective of developing an Advanced Driver Assistance System (ADAS) capable of preventing collisions with oncoming vehicles emerging from occluded areas at intersections in left-hand traffic. The methodology involved designing an ADAS that relies on on-board sensors rather than infrastructure-based communication systems, thereby overcoming limitations of designated intersection coverage. Hazardous speed criteria of the ego vehicle were calculated to identify high-risk collision scenarios, and speed control assistance was provided to guide the vehicle out of dangerous speed regions. Simulation results demonstrated that the proposed system significantly reduced collision risks compared to conventional Autonomous Emergency Braking Systems (AEBS). Findings confirmed that the sensor-based ADAS offered effective collision avoidance even under occlusion conditions. The scope of this research extends to enhancing safety in real-world intersections without dependence on external infrastructure.

Goudarzi & Hassanzadeh (2024) [6] examined the objective of improving safety and reliability in self-driving vehicles by addressing instability in car-following behavior controlled by human drivers. The methodology incorporated hazard warning systems into adaptive control frameworks, with “time to contact” used as a key indicator of potential collisions. Various techniques including image processing, machine learning, deep learning, and sensor-based approaches were classified and analyzed to determine their effectiveness in collision prediction and prevention. Results highlighted the importance of integrating alarms and adaptive systems to mitigate unavoidable collision risks. Findings emphasized that advanced computational methods enhance obstacle detection and response reliability. The scope of the study includes identifying challenges, future research directions, and unresolved problems in collision avoidance systems for autonomous driving.

Yoo et al. (2024) [7] addressed the objective of improving emergency avoidance path planning in autonomous driving systems. The methodology involved integrating prediction data of surrounding vehicle paths into the artificial potential field (APF) method and optimizing quintic Bézier curve control points using sequential quadratic planning. Simulations were conducted using IPG CarMaker 12.0.1 and MATLAB/Simulink 2022b to validate the proposed approach. Results revealed that the integration of prediction data and curve optimization improved efficiency and stability in path planning, overcoming the local minimum problem associated with gradient descent in conventional APF methods. Findings confirmed that the enhanced approach generated safer and more reliable avoidance strategies. The scope of this research extends to advancing autonomous driving safety by embedding predictive intelligence into path planning algorithms.

Dong et al. (2024) [8] addressed the objective of developing an active collision avoidance method for autonomous vehicles that goes beyond emergency braking. The methodology involved designing a model predictive control (MPC)-based trajectory tracking controller derived from vehicle dynamics, integrating MPC with adaptive cruise control (ACC) for braking strategies, and incorporating active steering based on a safety distance model. An obstacle avoidance function was constructed by considering vehicle–obstacle distance and relative speed, while nonlinear model predictive control (NMPC) was applied for path planning. To accelerate computation and enhance safety, the alternating direction multiplier method (ADMM) was employed. The algorithm was tested on the Simulink and CarSim co-simulation platform across static and dynamic obstacle scenarios. Results demonstrated effective collision avoidance through braking, with strong stability and robustness in steering maneuvers at high speeds. Findings confirmed that vehicles could return to the desired path after obstacle avoidance, validating the efficiency of the proposed algorithm. The scope of this research extends to improving autonomous vehicle safety in complex, high-speed environments through advanced predictive control strategies.

Kim et al. (2024) [9] focused on the objective of developing and validating a collision avoidance algorithm for unmanned surface vehicles (USVs). The methodology involved designing a catamaran-type USV equipped with multiple sensors integrated into a guidance, navigation, and control system. Thrusters on the port and starboard sides enabled turning maneuvers, while the robot operating system streamlined communication of sensor data such as position, orientation, and situational awareness. The collision risk index (CRI) method was applied to calculate risk based on obstacle distance and waypoint angle, guiding the USV along paths with minimized risk. Noise from two-dimensional LiDAR data was filtered using k-dimensional tree and Euclidean distance methods to ensure accurate obstacle identification. The algorithm was benchmarked against artificial potential field and safety zone methods in an artificial tank environment. Results highlighted the superior time efficiency and optimality of the CRI-based approach compared to its counterparts. Findings validated the effectiveness of CRI in real-world free-running tests. The scope of this study extends to enhancing maritime safety by providing robust, sensor-driven collision avoidance solutions for autonomous surface navigation.

Lin et al. (2024) [10] addressed the objective of improving path planning and collision avoidance for unmanned surface vehicles (USVs). The methodology involved developing an adaptive differential evolution algorithm integrated with the analytic hierarchy process (AHP-ADE). Enhancements included the introduction of an elite archive strategy and adaptive adjustment of the scale factor (F) and crossover factor (CR) to balance global and local search capabilities, thereby preventing premature convergence and improving accuracy. The collision risk index (CRI) model was optimized and combined with the quaternion ship domain to enhance precision in collision risk calculations. Evaluation factors such as the improved CRI model, International Regulations for Preventing Collisions at Sea, and optimal collision avoidance distance were incorporated into a fitness function, with weights determined through AHP. Results from MATLAB simulations demonstrated that the AHP-ADE algorithm outperformed the improved particle swarm algorithm in safety, economy, and operational efficiency. Findings confirmed superior performance in multiple ship encounter scenarios. The scope of this research extends to providing a robust and efficient framework for USV autonomous navigation in complex maritime environments.

Verstraete & Muhammad (2024) [11] focused on the objective of reviewing pedestrian collision avoidance systems in autonomous vehicles over the past decade. The methodology involved classifying existing studies into five categories: pedestrian detection methods, collision avoidance approaches, actions, computing methods, and test methods. Results of the review provided a comprehensive overview of the techniques and technologies employed in pedestrian collision avoidance. Findings emphasized the diversity of approaches and the importance of integrating detection, decision-making, and testing frameworks to ensure safety. The scope of this review extends to democratizing autonomous vehicle technology by making pedestrian collision avoidance systems more accessible and reliable for widespread adoption.

Liu et al. (2023) [12] examined the objective of enhancing adaptability in intelligent vehicle collision avoidance systems under varying operating conditions. The methodology introduced the NGSIM road dataset to analyze driver collision avoidance behavior and developed a two-layer fuzzy controller considering overlap rate to design a switching strategy. A lane change collision avoidance model based on model predictive control (MPC) was also incorporated to enable real-time system activation. Simulation experiments conducted in Matlab/CarSim validated the proposed system. Results demonstrated improved responsiveness, shorter start-up distance, and greater adaptability to diverse driving conditions. Findings confirmed the effectiveness of the switching system in enhancing collision avoidance performance. The scope of this study extends to advancing intelligent vehicle safety by providing adaptable and responsive collision avoidance strategies suitable for real-world traffic scenarios.

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A. Research Gap

Most ML models are trained on region-specific data and

Table 1: Summary of Literature Survey

Author(s)	Year	Objectives	Results	Research Gap
Li, Y., Hou, P., Cheng, C., & Wang, B. [3]	2025	To develop improved collision avoidance methods for USVs using boundary potential field integrated with COLREGs.	Proposed algorithms reduced computational burden in complex environments and adhered to COLREGs, producing safe paths.	Limited validation in real-world maritime conditions focus mainly on simulations.
Hamidaoui, M., Talhaoui, M. Z., Li, M., Midoun, M. A., & Haouassi, S. [4]	2025	To survey collision avoidance algorithms in autonomous vehicles.	Classified sensor-based, path-planning, and decision-making approaches; highlighted role of machine learning.	Lack of unified framework; insufficient integration of algorithms for diverse traffic scenarios.
Aoki, S., Fujinami, Y., & Raksincharoensak, P. [5]	2024	To design proactive braking control for right turns with occluded vision in intersections.	Proposed ADAS using onboard sensors; simulations showed reduced collision risk compared to conventional AEBS.	Limited to intersection scenarios; broader applicability in varied traffic conditions not tested.
Goudarzi, P., & Hassanzadeh, B. [6]	2024	To classify collision risks and highlight challenges in autonomous vehicles.	Identified time-to-contact as key indicator; reviewed hazard warning systems.	Need for real-world deployment and integration with adaptive control systems.
Ahn, S., Oh, T., & Yoo, J. [7]	2024	To improve path planning using prediction information integrated with APF.	Combined prediction data with quintic Bézier curve optimization; simulations showed improved stability and efficiency.	Real-world testing absent; scalability in dense traffic remains unexplored.

Dong, D., Ye, H., & Luo, W. [8]	2024	To design MPC-based path planning and tracking control for autonomous vehicles.	MPC with ACC and active steering achieved robust collision avoidance in simulations.	Requires validation in real traffic; computational efficiency under high-speed conditions needs further study.
Kim, J.-H., Jo, H.-J., & Kim, S.-R. [9]	2024	To compare collision avoidance algorithms for USVs.	CRI method outperformed APF and safety zone methods in time efficiency and optimality.	Limited to artificial tank tests; broader maritime scenarios not addressed.
Lin, B., Xiao, Z., Hou, B., & Ning, J. [10]	2024	To propose AHP-ADE algorithm for USV collision avoidance in multi-ship encounters.	Algorithm showed superior safety, economy, and efficiency compared to particle swarm optimization.	Needs validation in real-world maritime navigation; focus on simulation only.
Verstraete, T., & Muhammad, N. [11]	2024	To review pedestrian collision avoidance systems in autonomous vehicles.	Classified methods into detection, avoidance, actions, computing, and testing.	Lack of standardized pedestrian safety protocols; integration with urban ITS remains incomplete.
Liu, G., Bei, S., Li, B., Liu, T., Daoud, W., & Tang, H. [12]	2023	To study collision avoidance systems considering driver behavior.	Developed fuzzy controller and MPC-based lane change model; simulations showed improved responsiveness and adaptability.	Real-world driver variability not fully captured; limited to controlled simulation environments.

REVIEW AREAS OF PAPER

The review areas of this paper are discussed as given below:

- To identify current challenges, technological limitations, and research gaps in the implementation of smart controllers for collision avoidance
- To propose future directions for enhancing their reliability, adaptability, performances and real-world applicability.

D. Performance Evaluation

Performance evaluation of a model involves systematically assessing how well it performs on given tasks using quantitative metrics. Accuracy, one of the most widely used measures, calculates the proportion of correctly predicted outcomes relative to the total predictions, thereby reflecting the model's overall effectiveness. While accuracy provides a straightforward indication of performance, it is often complemented by other metrics such as precision, recall, F1-score, and confusion matrix analysis to capture more nuanced aspects of prediction quality, especially in cases of imbalanced datasets. Together, these metrics ensure a comprehensive evaluation of the model's strengths and weaknesses, guiding improvements and validating its reliability for practical applications.

E. Tools and Environment

The implementation will be carried out using Python-based libraries such as TensorFlow, Keras, for smart controller. Data visualization and analysis will be supported by tools like Matplotlib, Seaborn, and Pandas.

COLLISION AVOIDANCE MANAGEMENT SYSTEMS

Collision Avoidance Management Systems (CAMS) are high-tech safety systems that find possible dangers and take action to stop or lessen car accidents before they happen. These technologies are an important part of modern Advanced Driver-Assistance technologies (ADAS) and are being used more in both passenger and commercial vehicles. The main goal of CAMS is to make roads safer by lowering the chance of accidents through real-time monitoring, threat assessment, and automated action. As roads get busier and driving conditions get more complicated, these technologies have become essential for keeping drivers and pedestrians safe [11].

A collision avoidance system has a network of sensors and control units at its core that work together to see what's around the car. Radar, LiDAR, ultrasonic sensors, and high-resolution cameras are some of the most common types of sensors. These sensors are always gathering information about cars, people, road signs, and other things that are in the way. An onboard electronic control unit (ECU) or smart controller then processes the data. It utilizes algorithms to figure out how likely it is that the car would hit something depending on things like its speed, distance to objects, and trajectory. The system can warn the driver visually or audibly if it sees a threat. In more advanced versions, it can even apply the brakes, turn the car, or slow down on its own. There are two main types of collision avoidance systems, i.e. passive and active. Passive systems mostly work as warning systems, letting the driver know about any threats without assuming control of the car. On the other hand, active systems can automatically respond to avoid or lessen the severity of a collision. These are Adaptive Cruise Control (ACC), Forward Collision Warning (FCW), Lane Departure Warning (LDW), and Automatic Emergency Braking (AEB). Adding these features not only makes driving safer, but it also makes traffic move more smoothly and keeps drivers from getting tired.

The precision of the sensor data, the strength of the decision-making algorithms, and the quickness of the vehicle's actuators all have a big impact on how well CAMS works. Rain, fog, or bad lighting might make sensors less accurate, and complicated city situations may make it harder for the system to understand how things change over time. To get around these problems, newer systems are using more artificial intelligence and machine learning. This lets them learn from real-world driving data and get better over time. Vehicle-to-everything (V2X) communication is also being investigated to improve situational awareness by letting vehicles share information with each other and with infrastructure [12].

A. How Does a Collision Avoidance System Work

1. Acquisition of Sensor Data

Contemporary automobiles are outfitted with a multitude of sensors, radar, and cameras that incessantly collect real-time information regarding the vehicle's environment. These systems monitor multiple data parameters, including vehicle velocity, inter-vehicle spacing, lane alignment, and possible road obstructions. Starkenn Brake's collision mitigation system employs radar and sensors to monitor these data points, offering critical information for accident prevention.

2. Object Recognition and Hazard Assessment

Upon data collection, the system's software analyzes it to identify potential threats. The system evaluates speed, distance, and trajectory to ascertain the probability of a collision.

3. Alerting the Operator

Upon detection of a high-risk situation, the system promptly transmits visual, audio, or tactile alerts (e.g., vibrations in the steering wheel) to the driver. These signals are essential for mitigating distracted driving and affording the driver additional reaction time to avert an accident.

4. Autonomous Maneuvers (Emergency Braking and Steering)

When the driver neglects to heed warnings, the system can independently engage emergency brakes when a collision is near, typically when the time to contact is under one second. In sophisticated systems, autonomous steering can be activated to assist in obstacle avoidance or to maintain the vehicle securely within its lane [12].

METHODS TO AVOID COLLISION IN AUTOMOTIVES

Collision avoidance in automotive systems involves a combination of sensing technologies, decision-making algorithms, and control mechanisms that work together to detect potential hazards and prevent accidents. These methods can be broadly categorized into sensor-based detection, control strategies, and communication-based systems. Below is a detailed explanation of the key methods used to avoid collisions in modern vehicles [13]:

A. Sensor-Based Detection Systems

Collision avoidance systems rely on a suite of sensing technologies that continuously monitor the vehicle’s surroundings to ensure safety. Radar is widely used to measure distance and speed, functioning reliably even in poor weather, while LiDAR provides precise 3D environmental mapping for accurate obstacle detection and localization. Ultrasonic sensors are effective in short-range, low-speed scenarios such as parking, and cameras—both monocular and stereo—capture visual data for tasks like lane detection, traffic sign recognition, and pedestrian identification. To enhance reliability, sensor fusion integrates inputs from multiple sources (e.g., radar and cameras), enabling more accurate object detection and classification. Together, these technologies form the backbone of modern collision avoidance systems, supporting both driver assistance and autonomous vehicle operations [13].

B. Control and Decision-Making Algorithms

Once a potential collision is detected, control algorithms determine the most appropriate response to ensure safety. Rule-based systems rely on predefined thresholds such as distance or speed to trigger warnings or braking, offering simplicity but limited adaptability in complex scenarios. Fuzzy logic controllers address uncertainty in sensor data, enabling human-like decision-making in ambiguous traffic conditions. PID controllers, widely used in cruise control and lane-keeping, continuously adjust vehicle behavior by correcting deviations between desired and actual states. More advanced approaches like Model Predictive Control (MPC) forecast future vehicle states and optimize actions over a time horizon, though they demand significant computational resources. Meanwhile, machine learning and deep learning models, including LSTM networks, CNNs, and reinforcement learning, leverage large datasets to predict driver behavior, classify objects, and make real-time decisions, making them increasingly vital in autonomous driving systems [13].

C. Actuation and Vehicle Control

After the decision-making stage, collision avoidance systems must execute rapid and precise actions to prevent accidents. Automatic Emergency Braking (AEB) engages autonomously when a collision is imminent and the driver fails to respond, while steering assistance either guides the driver or automatically adjusts the steering to avoid obstacles. Throttle control reduces engine power or halts acceleration to decelerate the vehicle when necessary, and lane keeping or lane departure prevention systems use camera inputs to detect lane markings, ensuring the vehicle remains centered or preventing unintended lane changes. Together, these coordinated interventions provide a comprehensive safety net, minimizing collision risks and enhancing overall driving safety [13].

4. Communication-Based Systems (V2X)

Vehicle-to-Everything (V2X) communication strengthens collision avoidance by enabling vehicles to exchange critical information with other vehicles, infrastructure, and even pedestrians. Vehicle-to-Vehicle (V2V) systems allow cars to share data such as speed, position, and direction, helping anticipate and prevent collisions during lane changes or at intersections. Vehicle-to-Infrastructure (V2I) communication connects vehicles with traffic signals, road signs, and other roadside units to provide timely warnings about hazards or changing road conditions. Vehicle-to-Pedestrian (V2P) systems extend this safety net by detecting and interacting with smartphones or wearable devices carried by pedestrians, reducing accident risks in busy urban environments. Together, these interconnected technologies create a cooperative safety ecosystem that enhances situational awareness and significantly improves road safety [13].

CONCLUSION

Collision avoidance in automotive systems is a multi-layered process involving perception, prediction, decision-making, and actuation. The integration of smart controllers, AI algorithms, and V2X communication is pushing the boundaries of what vehicles can do autonomously. As these technologies evolve, they promise to significantly reduce road accidents and pave the way for safer, smarter transportation systems. The incorporation of intelligent controllers into automobile collision avoidance systems represents a notable step in the quest for safer and more sophisticated transportation. These controllers, utilizing real-time sensor data and adaptive control algorithms, allow vehicles to identify, evaluate, and react to possible threats with exceptional accuracy and rapidity. Smart controllers have proven their capacity to improve decision-making in intricate and dynamic driving contexts through approaches such as fuzzy logic, model predictive control, and machine learning. The assessment emphasizes that, despite significant advancements in the development and implementation of collision avoidance technologies, numerous problems persist. This encompasses the necessity for enhanced sensor fusion, diminished computing delay, and increased resilience in varied environmental situations. The ethical and regulatory ramifications of autonomous decision-making in safety-critical situations necessitate meticulous examination as these systems gain autonomy.

FUTURE SCOPE

The future of automotive safety depends on the ongoing advancement of intelligent control systems, especially with the incorporation of artificial intelligence, vehicle-to-everything (V2X) communication, and multi-agent coordination. These developments will enhance the responsiveness and dependability of collision avoidance systems and facilitate the development of fully autonomous vehicles capable of safely traversing real-world settings. Consequently, smart controllers will continue to be fundamental to the advancement of automobile safety, propelling innovation towards a more secure and intelligent transportation framework.

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