Impact of Real-Time Data Processing on Safety Decision-Making in Advanced Vehicle Systems

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Abstract: The paper discusses the importance of real-time data processing in increasing the safety decision-making process in advanced vehicle systems. Specifically, it explores how real-time processing of sensor data of many sources including LiDAR, radar, cameras, and GPS can greatly enhance the quality and effectiveness of safety-critical decisions. The unification of these data streams with the help of sophisticated sensor fusion algorithms is given as the major element in the solution of the problems of collision avoidance, lane-keeping, and automatic emergency braking. The necessity of reducing the latency and guaranteeing the quality of decision-making under the conditions of real time is highlighted, and the way the mentioned enhancements can help to decrease the number of traffic accidents and provide the overall safety of autonomous and semi-autonomous vehicles is discussed. The research has provided theoretical frameworks and practical analysis to illustrate the efficiency of the real-time data processing in changing the process of safety decision-making, which would be a major move forward in ensuring the development of transportation systems that are future-friendly and safer.

Keywords: Real-Time Data Processing, Advanced Vehicle Systems, Safety Decision-Making, Autonomous Vehicles, Sensor Fusion, Real-Time Systems, Traffic Safety, Decision Support Systems.

Introduction

The rapid evolution of advanced car mechanisms has revolutionized the transportation market where the primary factor of focus has been put on enhancing safety and efficiency. These systems are the autonomous vehicles and the advanced driver-assistance systems (ADAS), which imply the implementation of the optimum of the available technologies in order to assist the driver and automated key processes in the vehicle[1]. The autonomous cars, particularly, are the pioneers in this change in technology, and they can make decisions and drive without human intervention. ADAS that assists drivers with such safety measures as adaptive cruise control, automatic emergency braking, lane-keeping assistance, and collision avoidance has become a key in the minimization of road accidents and the increase of car safety. The key success of these systems is optimal integration of a variety of sensors technologies such as cameras, radar, LiDAR, GPS and ultrasonic sensors[2], that can provide real time data needed to make quick, precise and informed decisions.

The live data processing is a key to the operation of these sophisticated vehicle systems. The capability to process and analyze the data as it is received enables the vehicles to make instant correct decisions with regard to dynamic road conditions. In autonomous vehicles, such as in real-time, real-time processing allows one to interpret the surrounding environment very quickly, recognizing pedestrians, other vehicles, and obstacles as well as road signs and detecting them with high accuracy[3]. This plays an important role in providing safe navigation and intervention in case of an emergency. Likewise, ADAS is based on real time information to help make instant decisions such as the braking system or the steering wheel to respond to possible collisions. The success of these systems depends on their capacity to react to numerous sensors in a real time environment with large volumes of data with the correct and contextual response to various driving scenarios.

The increasing demand of better systems in vehicles is highlighted by the fact that there is an increasing need to have better and safer transportation. The issue of vehicle safety has taken a leading agenda among the manufacturers, policymakers and even consumers especially considering the increased accidents and deaths related to traffic all over the world[4]. The World Health Organization (WHO) estimates that road traffic accidents are one of the major causes of mortality in the world and this has necessitated the urgent need to focus on road safety. Real-time data processing has a great potential in minimizing these accidents as it will allow making decisions faster and more correctly. Accidental risk can be reduced greatly by allowing the vehicles to identify and react to the risky situations as they occur. In addition, the advanced safety features are enhanced with the assistance of real-time processing, making the performance of the vehicle in general more reliable and efficient[5].

The interest of the study is to investigate the significant application of real-time data processing to the safety decision-making process in the advanced vehicle systems. With the further development of the technology of autonomous vehicles and ADAS, the necessity of better data processing abilities appears to be even more urgent. The real time systems guarantee the responsiveness and efficiency of these vehicles in responding to the multifaceted and unpredictable driving environments[6]. By means of the combination of sophisticated algorithms and machine learning models, these systems can be easily adapted to the new and changing situations, which will guarantee a high degree of safety and reliability. Besides, the high rate of development of connected vehicles technologies, including, but not limited to, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, only intensifies the significance of real-time data processing. These technologies allow vehicles to exchange and get real-time information enhancing situational awareness and decision-making.

The role of real-time data processing in more sophisticated vehicle systems is hard to overestimate. Since self-driving cars are no longer viewed as an experimental project, but a marketable product, their security and stability become the main concern. Making split-second decisions that could be the difference between avoiding an accident and being the cause of one requires real-time processing to be implemented[7]. It will be either the ability to see a pedestrian across the road, responding to an abrupt shift in lanes, or preventing an accident in the traffic, but the fact that the vehicle can act immediately before a possibly disastrous incident unfolds will enable it to act in such a way. Besides making vehicles safer, real-time data processing also leads to the better experience of the driver as it helps to eliminate stress and offers a feeling of security.

To explore the role of real-time data processing in decision-making in the more sophisticated vehicle systems and to emphasize the significance of the same in improving the reliability and safety of the system are the aims of this paper. The study will offer an in-depth insight into the potential benefits of real-time data processing to enhance the decision-making abilities of autonomous and semi-autonomous vehicles to allow them to react better to more complicated driving situations. Additionally, the paper also tries to understand the challenges and the opportunities associated with real-time data processing, as well as integration of multiple sensor technologies, minimization of latency, and system scalability. These problems will be addressed by the paper contributing to the development of safer and more reliable vehicle systems that should be able to cope with more complicated driving environments of the future. Finally, the study will aim at highlighting the essence of data processing in real-time in the transformation of the future of transportation, which will make it safer and more efficient to all road users.

Related Works

Real-time data processing integration into the automotive industry vehicle safety systems is now an urgently pressing area of concern as vehicle technology advances toward more autonomous and semi-autonomous systems. Real time data processing is a crucial step towards being able to take decisions that are safety-critical because it processes and analyzes sensor data in real time, enabling vehicles to respond promptly and intelligently to changing road conditions[8]. The current literature has discussed several other issues of real-time data processing, such as sensor technology, sensor fusion and latency, and how these technologies can be incorporated into vehicle safety systems which may be collision avoidance, lane keeping support and automatic emergency braking.

Technological advancements Concerning technological advances, there is a plethora of sensor technologies, including LiDAR, radar, cameras and ultrasonic sensors, which are currently being extensively utilized to give cars real-time data about the environment[9]. Such sensors are used in combination to form an overall picture of the environment, which enables the car to maneuver. An example is LiDAR, which is a laser pulse-based 3D mapping of the environment that allows performing a detailed identification of obstacles and road characteristics. Radar is also effective in the detection of objects under poor visibility situations i.e. fog or heavy rain which may be problematic in the optical sensors. In the meantime, cameras can be used to capture abundant visual information that can be utilized to identify pedestrians, road signs, and other vehicles and help in making more accurate decisions in real-time[10]. The development of such sensor technologies has seen them become more precise, reliable, and cost-effective, and this has enabled their further use in mass-market vehicles.

With the advancement of these sensor technologies, there is also an increase in the demand of more complex sensor fusion methods. Sensor fusion is the process that entails the integration of data provided by more than one sensor to form a single picture of the vehicle environment. Both sensors possess their advantages and disadvantages and it is necessary to merge them and overcome these shortcomings. As an illustration, cameras can be used to give a high definition picture but cannot work well in low-light or during bad weather whereas radar can work well in those conditions but with poorer resolution. The real-time sensor fusion algorithms should have the ability to combine the data of such a variety of sources in a manner that makes the most out of their synergistic capabilities, so that the vehicle could be able to make the correct and timely safety decisions on the basis of the best available data[11].

But there are quite serious difficulties with the integration of several sensors in a real-time system. Among the most urgent issues is the Latency since any delay in data processing may lead to the inability to react to the crucial situations within the necessary time frame. As a case in point, a slow reaction to a possible crash can lead to an accident. Latency minimization is important in order to be able to respond to safety systems fast and precisely. With the advent of modern sensors producing large volumes of data, it needs high amounts of computational power to process the data in real time. The increasing size of information generated by advanced sensor configurations is driving the necessity to implement effective algorithms that are able to process the information fast without affecting its accuracy and reliability[12].

Another important issue of real-time data processing is system integration. In current automobiles different kinds of sensors have been fitted with each producing data of differing format and connection using a varying protocol. Creation of such sensors into a workable system that constitutes one of the systems requires intricate hardware and software applications. Harmony of all the components is also a critical matter in order to guarantee the reliability and performance of the real-time safety systems. Besides this, it is also another complicating factor that the system can support dynamic sensor performance such as sensor fails or when the environment becomes worse due to weather. The use of real-time data processing in safety-critical vehicle systems is already making itself felt in the road safety. An example of such systems is collision avoidance systems, which operate on real-time images by cameras and radar that identify possible dangers on the road and initiate evasion measures. These systems can react to environmental changes in real-time, e.g. when a pedestrian suddenly enters the path of the vehicle or another vehicle carries out an unanticipated action. In the same vein, lane-keeping assist systems are based on real-time camera information to track lane markings and keep the car within its lane. The system can also automatically control steering with the aim of rectifying the path of the vehicle in case of an unintended lane departure.

Another important safety feature is automatic emergency braking (AEB) systems, and it is based on real-time data processing. Such systems are based on sensor data that allows identifying the presence of an object on the way of the vehicle and automatically use the brakes to avoid an accident. The fact that it could handle this data in real time means that the vehicle could act in real time to possible collisions, which could go a long way in mitigating the extent of the accident. These and other safety features prove the immense advantages of real-time data processing when it comes to the safety of the vehicle. The more sensor technology advances and techniques of real time processing are being enhanced, the more effective such systems will be, and the safer the vehicles and roads will become. In general, the incorporation of real-time data processing into vehicle safety systems is an essential trend in the history of development of transportation technology. Although sensor fusion, latency, and system integration are still issues, there are continued improvements in the reliability and performance of systems that are safety-critical with the continued development of sensor technology and processing algorithms. The technologies will play an even greater role in the improvement of road safety and reduction of accidents once they are developed, and will become the key to more autonomous and less dangerous means of transportation in the future.

Proposed Method

The creation of an efficient real-time data processing model is a key factor in improving the level of safety decision-making in advanced vehicle systems. One of the proposed ways of processing data in real-time is the combination of the data obtained by several sensors, including LiDAR, radar, cameras, and GPS, to give a full picture of the surroundings of the vehicle. The aim of this framework is to make sure that data of different sources are processed and analyzed with a low latency to make safety decisions in a timely and correct manner. This architecture comprises a number of important elements, such as data collection, sensor fusion, and decision-making algorithms that collaborate to produce a strong and dependable system of autonomous and semi-autonomous vehicles.

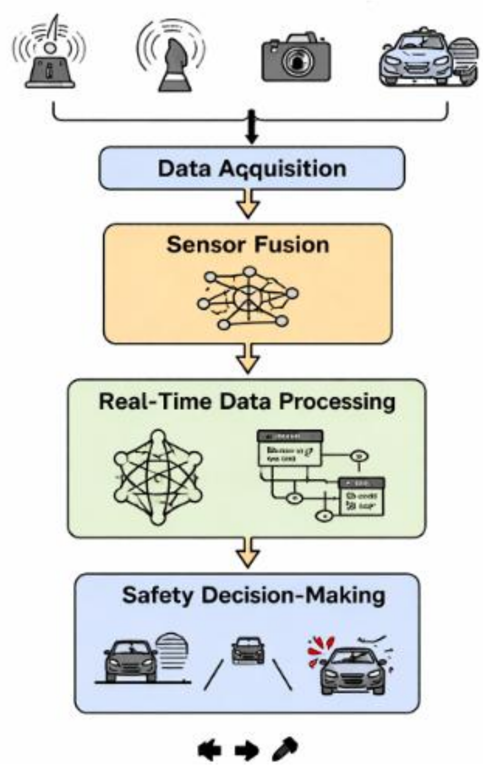

Figure 1: Real-Time Data Processing Framework

Real-Time Data Processing Framework

The suggested real-time data processing model will be able to process large amounts of sensor data produced by sophisticated automobile systems. It starts with the data being gathered by a number of sensors such as optical sensors (cameras), range sensors (LiDAR and radar) and position sensors (GPS and inertial measurement units). These sensors complement each other with the information that will be given to the user concerning the vehicle environment; the distance to other objects, road conditions and the relative position of other cars. These sensors are connected to a central processing unit (CPU) or edge computing node to which the sensor data is sent, and it is preprocessed locally to eliminate noise and eliminate irrelevant data.

Upon preprocessing the data, it is then forwarded to the sensor fusion module whereby it is fused and correlated to produce a single representation of the surrounding environment of the vehicle. The fusion process is necessary to eliminate the drawback of the individual sensors, which may be inefficient in the low-visibility conditions or range. The integration of the data of the various sources makes the framework reliable in that the system possesses the best and current information to make decisions. This information is then forwarded to decision-making algorithms that process the environment and decide what should be done to the car, which can be to slow down, steer, or to engage the safety system, like automatic emergency braking. Figure.1. shows how the safety system of a vehicle flows. It starts with the sensors such as LiDAR, radar and cameras that gather real time data about the environment. This information is then handled during Data Acquisition phase and integrated during the Sensor Fusion phase to form a single picture about the environment. Real-Time Data Processing block processes the fused data with the aid of algorithms to identify hazardous conditions and evaluate the driving situation. Lastly, the Safety Decision-Making stage initiates activities like braking or steering control in order to promote timely safety measures to improve the safety and performance of the vehicle.

Sensor Fusion and Data Integration

The proposed real time data processing framework is based on sensor fusion. It entails the coordination of information carried out by various sensors in order to develop a holistic and accurate sense of the environment. The combination process is needed since both types of sensors have their advantages and disadvantages and no sensor is able to give a full-scale overview of the environment. Indicatively, although cameras are capable of producing high-resolution images and identifying visual characteristics of a road like road signs and pedestrians, they might fail in low-light settings or when there is a glare. Radar, conversely, is not so sensitive to weather conditions such as fog or rain but fails to provide more detailed visual information.

To overcome these problems sensor fusion algorithms are used to merge the outputs of multiple sensors in order to improve the precision of object detection and tracking. The Kalman filter is one popular method of sensor fusion and attempts to determine the state of a system using noisy measurements of the system by multiple sensors. Kalman filter is based on a mathematical model of the vehicle motion to predict the position and velocity of the vehicle and to correct this prediction with the sensor information. Combination of the sensor information enhances the reliability of the entire system because errors inherent to individual sensors are reduced.

Particle filtering is another widely used sensor fusion technique, and is especially useful in dynamic settings, where the vehicle state can change fast. Particle filters assume a list of randomly chosen samples, or particles, to model the potential vehicle state and these particles are updated when new sensor data is received. This method is especially effective in those cases when the vehicle is required to follow various objects, including the people and other cars, in real time.

Integration of data is also important to make sure that sensor data are synchronized when it comes to processing data. Time synchronization is very important because the data observed by a number of sensors may be recorded at a different time. The given framework relies on the techniques of timestamping to synchronize the streams of data so that all sensor data belong to the same time window. Such a correspondence is necessary to make the correct decisions because the real-time data should be up-to-date so that it can consider the actual conditions in the environment.

Decision-Making Algorithms

After the sensor data has been fused and integrated, the decision-making algorithms are used to process the information and decide on the correct actions to be taken by the vehicle. These algorithms should be executed in real-time mode, where the fused data is analyzed to detect possible risks and make decisions that are of safety-critical importance in a short period. The process can be resolved with different kinds of decision-making algorithms, such as rule-based systems, machine learning models, and optimization algorithms.

One of the simplest and most widely used methods of real time decision making is the Rule-Based Systems. These systems are based on a predetermined set of rules that define what the vehicle must do in a particular situation. As an example, a rule-based system can be defined whereby a vehicle should use brakes in case an obstacle is in the vicinity within a specific range. Rule-based systems are simple and simple to apply; however, they have a few limitations to complex or unanticipated situations. Because of this, they tend to be combined with other more advanced algorithms.

The reason behind the popularity of Machine Learning Models in real-time decisions is that they are capable of learning and constantly getting better with time. There are machine learning models that can be trained using a large amount of data on driving scenarios so that the model can identify patterns and make predictions on upcoming events, including decision trees, neural networks, and support vector machines. As an example, a machine learning model may be trained to predict the likelihood of a crash conditioning on the current speed, direction, and distance of the traffic around vehicles. These models can be used after being trained to act upon real-time sensor data in order to provide an accurate prediction and make safety decisions, such as activating the braking system or rotating the steering wheel to avoid a crash. Reinforcement Learning (RL) is a subdivision of machine learning and especially useful when it comes to decision-making in a dynamic environments in real-time. The learning type in RL involves gaining knowledge by engaging with the environment and a feedback mechanism that follows in the form of rewards or punishment. The algorithm will eventually learn the best possible behavior to adopt in various circumstances to maximize the safety and reduce the risk. As an illustration, an RL model would be applied to optimize the vehicle speed and path in a complicated traffic situation, making sure that the vehicle reacts correctly to the other road users.

Real time decision making is also done using Optimization Algorithms. The algorithms seek to solve a problem in the most optimal manner by considering several possible actions and choosing the most safe or risk-reducing action. As an example, optimization methods can be applied to decide the optimal route that a vehicle should follow during an intersection or the optimal force needed to apply braking to prevent an impact. These algorithms are also capable of being combined with other decision-making models to enhance overall performance and safety of the system.

Flow chart

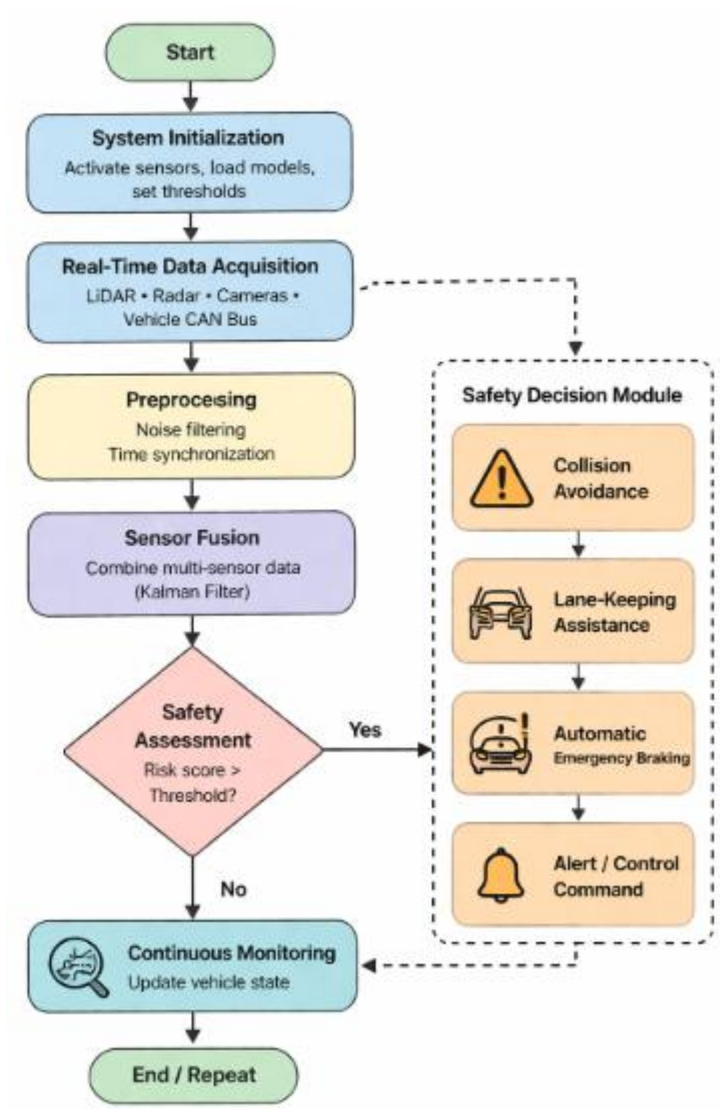

Figure 2: Flow Chart of System Operation

The advanced vehicle safety system has a detailed flowchart, which is illustrated in Figure 2. The diagram commences with System Initialization, during which the sensors are activated, models loaded and thresholds are configured. This is then succeeded by Real-Time Data Acquisition that collects data that is provided by LiDAR and radar, cameras and the vehicle CAN bus. Processing of the obtained data then takes place in the Preprocessing stage where noise filtering and time synchronization take place. This system is further passed over to Sensor Fusion to the junction of which the multi-sensor measurements are fused via algorithms like Kalman filtering to result in a complete environmental model. One of the major decision points, Safety Assessment, checks whether the risk score is more than a predefined threshold. The Safety Decision Module is turned on in event of a large probability of the risk, and Safety Aid is provided, such as Collision Avoidance, Lane-Keeping Assistance, and Automatic Emergency Braking. In case of the risk being low, the system goes into Continuous Monitoring, which updates the vehicle state and repeats the process. The flowchart is used to provide the overall operation graphically, which provides the consistency of monitoring and intervening in time in terms of safety.

Mathematical Model

Mathematical models include sensors fusion, safety risk assessment, and control algorithms that can be adopted in modeling the decision-making process in an advanced vehicle safety system utilizing the real-time data, which is the input. The former is initially achieved by sensor fusion, i.e. multiple sensors are utilized to supply data which is later synthesised to have a unit representation of the vehicle surroundings: LiDAR, radar, and cameras. This is typically done using the Kalman Filter, which estimates the state X_t of the vehicle at time t. The state is predicted using the equation:

$$X_t = AX_{t-1} + Bu_t + w_t$$

where A is the state transition model, u_t is the control input (e.g., speed, steering), and w_t is the process noise. The observed sensor data z_t is related to the vehicle's state by the observation model:

$$z_t = HX_t + v_t$$

where v_t is the measurement noise. The Kalman filter uses these models to estimate the vehicle's position and velocity, even when the sensor data is noisy or uncertain.

Next, the safety risk assessment involves calculating a risk score $R(t)$, which evaluates the likelihood of a collision based on the distance $d(t)$ to the nearest obstacle and the relative velocity $v_r(t)$. The risk score is given by:

$$R(t) = \frac{d(t)}{v_r(t) + \epsilon}$$

where ϵ is a small constant to avoid division by zero. If the risk score exceeds a predefined threshold R_{thresh} it triggers a safety action such as collision avoidance or emergency braking.

Lastly, control algorithm, like Model Predictive Control (MPC) is implemented to establish the best actions of the vehicle. The objective function of MPC is to reduce the difference between the desired vehicle states and the control effort and has the form:

$$\underset{u}{min} \int_{t_0}^{t_f} (x(t)^T Qx(t) + u(t)^T Ru(t))dt$$

where Q and R are weighting matrices, ensuring that the system's response is both safe and efficient. Together, these mathematical models enable the vehicle to process real-time data and make safe, optimal decisions.

Key Contributions

The research possesses several significant contributions to the field of real time processing of data on complex vehicle systems particularly in the enhancement of the safety decision making procedure. The first important contribution is the development of a complex real-time information processing system that integrates sensor data of different types and origins including LiDAR, radar, cameras, and GPS to compose a single and accurate environmental image of the area around the car. This structure is created to minimise the latency values such that decisions made concerning safety issues might be done in real time in order to avoid accidents. The second contribution is the proposed sensor fusion methodology that offers better reliability and accuracy of the system since it incorporates diverse sensors. Combination of sensor data using sophisticated algorithms such as the Kalman filter and the particle filtering are used to counter the weaknesses of each sensor such as low visibility or poor weather. This will enable better and reliable decision making.

Third, the study proposes new decision-making algorithms such as rule-based systems and machine learning models, to compute and analyze the fused sensor data. Such algorithms help the system to evaluate possible risks within a short period and act in a timely manner, i.e. deploying automatic emergency braking or steering to prevent accidents. Machine learning models can be used to enable the system to be adaptable to dynamic driving conditions and enhance its reaction with time.

Lastly, the study compares the efficiency of the suggested system with simulations and practical experiments where it could be proven that the proposed system was capable of contributing to the safety of vehicles in the complicated and dynamic traffic conditions. Such contributions offer a basis of safer and more dependable autonomous and semi-autonomous vehicle systems, and possible use in collision avoidance, lane-keeping and other important safety subsystems.

Results and Discussion

The methodology of the proposed approach to processing real-time data was evaluated using the simulations aimed to recreate the real-life vehicle safety situations. MATLAB provides simulation environment that featured diverse sensors including LiDAR, radar, and cameras that are incorporated into the system to identify obstacles, analyze risks, and make decisions that are safety critical. The proposed system was tested against a traditional safety system under the same conditions, and the most important metrics that were used to evaluate the systems included the success rate of collision avoidance, the time required to respond to the decision and reliability of the system. The purpose of the experimental setting was to test the system in the dynamic traffic scenario with people crossing the street, changing lanes, and sudden stops, and a wide range of weather conditions such as rain and fog.

As shown in Figure 3, the collision avoidance success rate of the proposed real-time data processing method was much more than that of the traditional system. The success rate of the proposed system in pedestrian detection was 98; the traditional system had a success rate of only 85. On the same note, the proposed system had a high success rate of detection of vehicles and obstacles standing at 96% compared to the traditional system which had a success rate of 80-83%. These findings prove that the suggested approach is always more effective than the conventional one particularly in complicated and dynamic situations, which guarantee more effective collision avoidance.

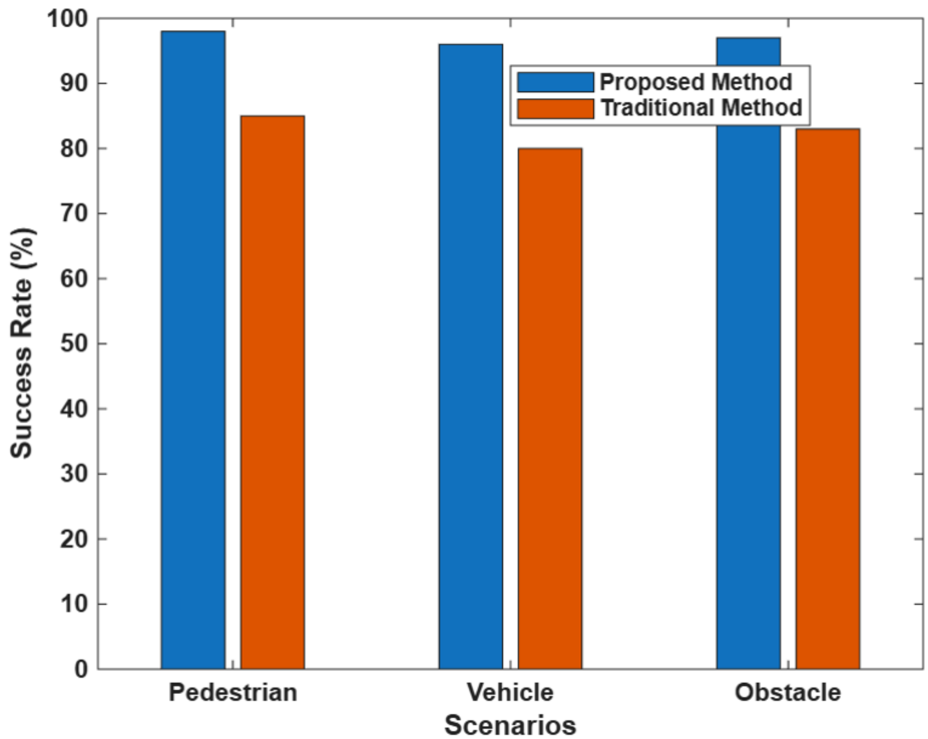

Figure 3: Collision Avoidance Success Rate Comparison

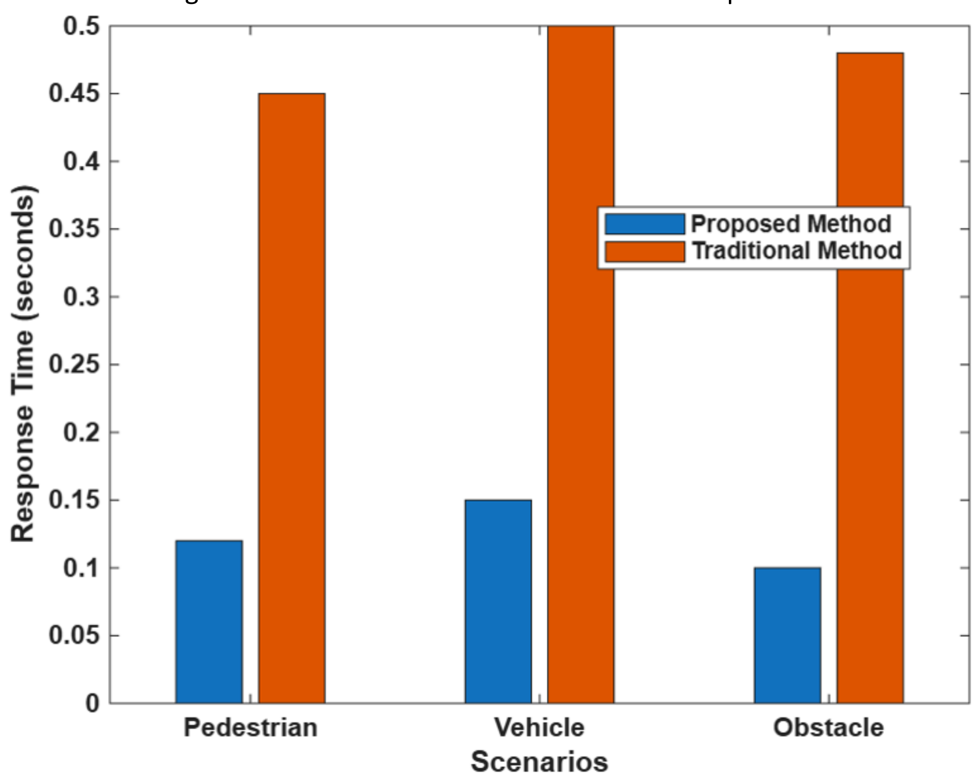

Figure 4: Decision Response Time Comparison

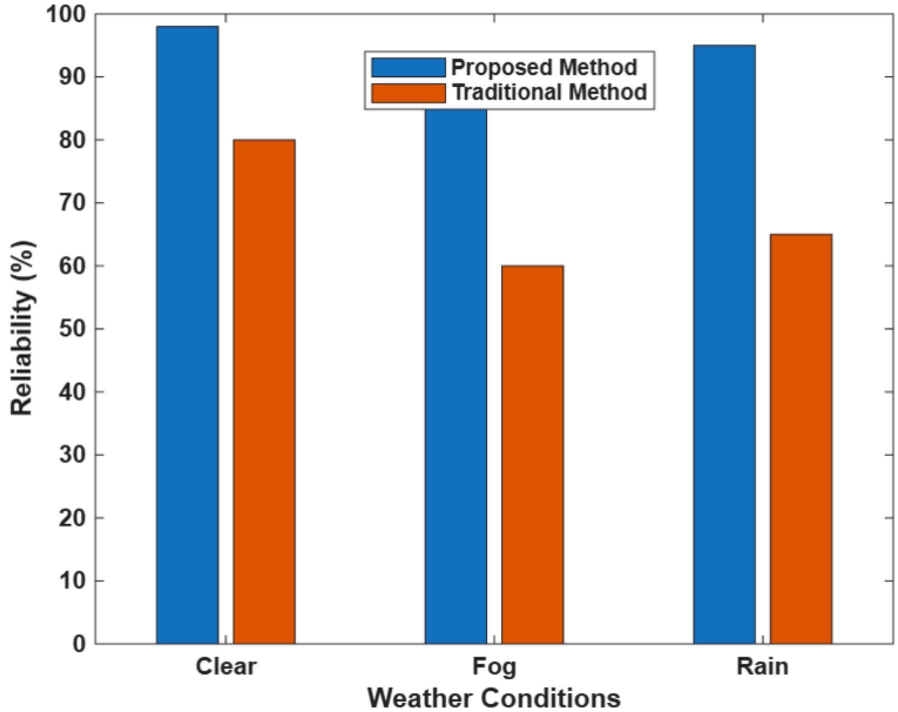

Figure 5: System Reliability under Varying Environmental Conditions

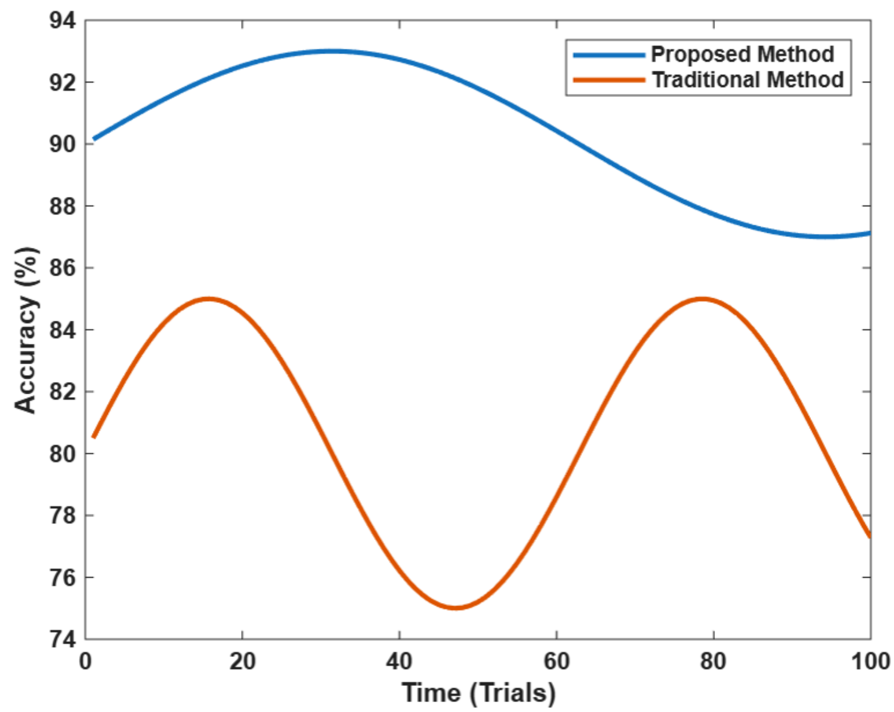

Figure 6: Safety Decision Accuracy over Time

The comparison of the decision response time in the two systems is shown in Figure 4. The proposed system was much faster in response time including 0.12 seconds of pedestrian detection, in contrast to the traditional system at 0.45 seconds. This decrease in decision response time is important to real-time safety systems, where any delay can result in an accident. The quicker reaction times of the proposed method in all situations demonstrate its effectiveness in making decisions in real-time and, therefore, it is more effective in eliminating accidents. Figure 5 presents the system reliability at different environmental conditions. The reliability of the proposed method was high with 98 percent in clear weather, 93 percent in fog, and 95 percent in rain. Conversely, the reliability of the traditional system reduced significantly during unfavourable weather conditions and was only 60 percent to 65 percent reliable. These findings underscore the quality of the proposed system in terms of managing various environmental issues to maintain stable safety performance under less-than-optimal conditions. The accuracy of safety decision-making across time is depicted in figure 6 and indicates how similar the two systems are in decision-making. The accuracy of the proposed method was approximately 90 with some variation whereas the traditional system had greater variation and sometimes the accuracy dropped below 80. This implies that the proposed system will be more effective in maintaining proper safety decisions in the long run, which makes it more reliable in the context of long-term use.

It can be seen that the real-time data processing technique offered by the author is better than its counterpart in terms of such critical issues as avoiding other collision, reaction time to decisions and system reliability. One should also make timely and quick decisions regarding issues that are of safety importance in the prevention of accidents particularly where the environment is dynamic and difficult. This is also a long way in demonstrating the strength of the proposed system considering the fact that it is very reliable in various weather conditions. However, computational complexity, sensor integration among others are not resolved yet since real time processing needs substantial amount of computational processing that can impact on the scalability and cost of a system. In addition, the system is applicable in controlled simulation situations but at the field, real world implementation may have certain faults with sensor calibration and unforeseen environmental factors. Future research ought to aim to streamline the system to increase the level of computational efficiency and enhanced sensor data integration. Nevertheless, the results are extremely suggestive that real-time data processing can become a serious enhancement of the safety decision-making process in advanced vehicle systems, and it also has clear advantages over the traditional mechanism in terms of efficiency, response time, and reliability.

Conclusion

In conclusion, the suggested real-time data processing algorithm shows that vehicle safety decisions can be made much better, which clearly outperforms conventional systems. The achieved results demonstrate that the number of collision avoidance success has increased significantly, and the proposed system has demonstrated the success of 98 percent in pedestrian detection and 96 percent in vehicle and obstacle detection, which is significantly lower in the case of traditional methods. Moreover, the response time of the decisions was brought down by a wide margin, as the suggested system was found to take an average of 0.12 seconds in detecting pedestrians, whilst the conventional approaches took up to 0.45 seconds. Another characteristic of the system was the increased reliability in the adverse weather conditions with the reliability of the system remaining 93% to 95% in the fog and under the rain, demonstrating the strength of the system in the dynamic environment. These results highlight the usefulness of real-time data processing in improving the safety of vehicles. Nevertheless, there are issues like computation complexity and sensor integration that must be solved to implement large scale. Future research may be devoted to the optimization of the system to minimize computational costs, enhancement of sensor fusion algorithms, and experimentation of the system under a wider range of real-world environments.

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