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Vehicle Automation and Car-Following Models for Accident Avoidance

***Abstract**. Road accidents contribute to the greatest number of deaths in the world. Deaths and injuries due to road accidents result in financial losses as well as physical and mental suffering. Even though a good driver is attentive enough to take sudden decisions, at some point, there is a requirement for an automatic decision-making ability in the car. Cars that can take prompt actions based on the environment without the driver involved is called a smart car. The car-following models are methods used in smart cars for accident avoidance. This paper presents an in-depth survey of various car following models based on IoT sensors, weather & road conditions, V2V networks, machine learning algorithms. A comparative analysis of multiple research articles with its techniques, merits and research gap is presented. Finally, the inference of the literature survey is provided.*

Streszczenie.** W artykule zaprezentowano analizę autonomicznego pojazdu wyposażonego w szereg czujników, połączenie sieciowego I metody uczenia. Przedstawiono przegląd literatury na ten temat. **Model autonomicznego pojazdu wyposażonego w układy unikania wypadku

Keywords: V2V, Car-following models, accident avoidance, sensors, road accident.
Słowa kluczowe: pojazd autonomiczny, czujniki, układy unikania wypadku

Introduction

Around the world, 1.35 million people die on road accidents each year. Road accidents are approximated to be the eighth major cause of death worldwide. More people now die in road traffic collisions than from HIV/AIDS or cancer. Even a small mistake by a professional driver can result in dire consequences. We can't solely rely on the driver to be aware of the car surrounding all the time. There is a need to provide the car with an ability to make decisions instead of the driver whenever there is a probability of a mishap. Car automation is the ability to use IoT sensors [1], mechanics, electronics and Artificial Intelligence [2] to aid a vehicle driver. A vehicle utilizing such features may be labelled as intelligent or smart. Researchers and Manufacturers have added a variety of self-operating functions to vehicles.

Talking about IoT sensors, the first thought that comes to our mind is that, it is an instrument that detects and responds to a physical input from the environment. The specific input could be any natural phenomena like light, heat, motion, moisture, pressure, etc. for which we have sensors such as Ultrasonic sensor, DHT sensor, touch sensor, LDR (Light Dependent Resistor) sensor, IR (Infra-red) sensor, etc. The result is data that is transformed into a human-understandable format for collection and data analytics. Car-following models [3] mostly use sensors to calculate the distance between vehicles, crash sensors, temperature sensors, tire pressure sensors, etc.

Weather and road conditions also impact driving. In case of snowfall, the roads become extremely slippery and if a fast-moving car applies sudden brakes it might skid out of the road and crash. On the other hand, if the visibility is less due to fog, the driver won't be able to perceive the cars or people in front and won't be able to apply brakes on time that can obviously result in an accident. In order to tackle this problem, the car should be able to dynamically change the speed based on weather and road conditions. This is possible only if the car is installed with an Intelligent system.

Artificial Intelligence (AI) and Machine Learning (ML)

AI is the development of machines that bear a resemblance to human thinking capability for e.g. visual recognition, decision making, speech recognition, and natural language understanding. ML can be called as a subset of AI where the systems are able to simultaneously learn and improve from past events without being explicitly coded to perform a task.

Table 1: Abbreviations

CRI	Chosen Risk Index
RSI	Road surface Index
DSRC	Dedicated short-range communication
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
LTE	Long Term Evolution
CVT	Connected Vehicle Technology
BPNN	Back Propagation Neural Network
RF	Random Forrest
ACC	Adaptive cruise control
CCF	Combination Car Following
VANET	Vehicular Ad-hoc Network
CIoV	Cognitive Internet of Vehicles
ITS	Intelligent Transport System
CGPN	Collision Prediction based on Genetic Algorithm optimized Neural Network
SIoV	Social Internet of Vehicles
SDN	Software-Defined Network
V2X	Vehicle to Everything
OBU	On-Board Unit
GLM	Generalized Linear Models
NGSM	New Generation Simulation
CA	Congestion area
Ts	Stable time

Car-Following models

The car-following [3] concept came into existence in the year 1963. It is a study of how a car follows another car on the road. It ensures that the car maintains a minimum distance (following or leading). Car automation decreases the likelihood of car crash by improving safety, performance and comfort of the drivers. There are sufficient reasons to believe that more automated the vehicles are, more relieved the driver will be while driving. Human errors and distraction is the main cause of road accident [4]. ML based Vehicle-following models are able to predict the risk and chance of encountering an accident based on factors like weather condition, road condition, time, speed of vehicles, driver's behavior, number of lanes, etc. The algorithm is designed by collecting the information about driving situations to control actions like increase or decrease in the speed, where the variables such as acceleration, time gap and space between a leading-following pair are usually considered. The following is a thorough study of state-of-research articles about various car-following models and accident avoidance techniques.

Survey of Vehicle-Following Models

In this section a survey of different car-following models are presented they are (a) Vehicle-following models based on sensors (b) Vehicle-following models based on weather and road condition (c) Vehicle-following models based on networking (d) Vehicle-following models based on ML algorithm.

A. Vehicle-following models based on sensors

As mentioned above there are many different sensors that are applicable to car-following models. Few of them are mentioned they are - a parking sensor, impact sensor, crash sensor, seat-belt sensor, night vision sensor, high beam sensor etc.

D. Singh et. al., [5] have put forth the idea to use the dashboard camera also known as smart eye and a set of other sensors to improve the control and crash tracking ability. The smart eye attached with sensors has a potential to collect and update the real-time traffic or accident tape into audio, text as well as video forms to the related authorities like passerby, hospital[6], police staff, family members and insurance company along with the location and health condition through cellular network or Wi-Fi [7].

A similar model is presented by V. Nyamati et. al., [4] an ultrasonic sensor based model to detect any object or person in-front or around the car while driving. A motor driver is used to control the speed of motors and automatically apply brakes in case the driver is unable to do so. The ultrasonic sensor is used to calculate the distance between the car body and the object and gives off a high-pitched alarm if an object is getting too close to the car in order to alert the driver of a probable accident. In case if the driver is unable to apply the brake, it automatically stops the car when 5 cm away from the object Figure. 1. illustrates various sensors such as radar sensor, high beam sensor, seat belt sensor, impact sensor, ultrasonic sensor, door, parking sensor, etc. fitted in a vehicle to capture the data that the sensor is supposed to collect.

B. Vehicle-following models based on weather and road conditions

Be it rainy weather, snowy roads or foggy atmosphere all of these escalate the risk of accidents. Weather and road conditions not only create unsafe conditions for the car but also increase the response time of the driver driving the car. A. Hjelkrem and E. O. Ryeng [8] have analyzed how rain, light and surface conditions affect the driver's perception of driving a car. CRI denotes the level of risk the drivers face in a vehicle-following condition. The research is carried out on a dataset that consists of more than 70,200 records of driver habits and weather update. The driving behavior changes according to the weather and road conditions. The conclusion is, the car drivers are at a greater risk on snow-covered roads with moderate rain whereas truck drivers can face difficulty in snow-covered roads but not in rainfall. They have also created a dataset from a research done in Norway that contains 3,11,908 vehicle observations with 21 different parameters related to weather and road conditions which have been collected over a long time period so that every possible weather and road situation can be taken under consideration that ranges from dry summer to adverse winter [9]. Table 1 presents some 17 different factors - vehicle weight, speed, length, weather, road condition, temperature etc. that are being considered in the research to device a car-following model.

Donghao Xu's [10] has studied vehicle-following behaviors based on scene cars as the dominant aspect in an approach for modelling varied vehicle-following behaviors, and the performance is indicated on a large set of naturalistic driving data. The research done by Loannis Galanis and Priya [11] tested the road and weather conditions and predict an RSI based system is proposed. The system is able to dynamically predict the speed limit that the vehicle should adapt to. Four weather conditions such as dry, wet, snow, and ice slippery track are considered. But the demerit is that the research is not dependent on the weight and momentum of the vehicle this can have a huge impact on the braking angle and might cause accidents.

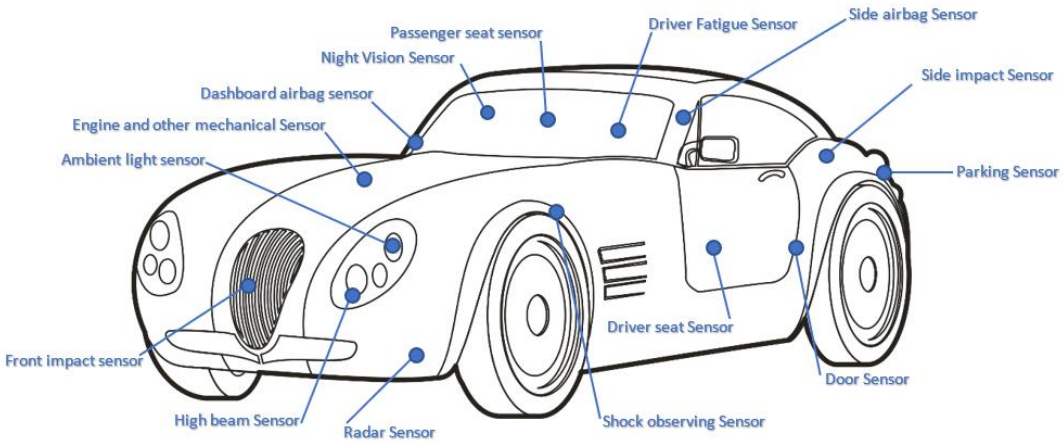

Figure. 1. Potential sensors available in a vehicle

C. Vehicle-following models based on networking techniques

There are many networking technologies that are mentioned in the following papers i.e. VANET, Wi-Fi, LTE, SDN, WiMAX, DSRC, V2I etc. The research carried out by K. C. Dey, A. Rayamajhi, M. Chowdhury [12] discussed about CVT that works on the transmission of data between vehicles and vehicle to infrastructure wirelessly. A thorough comparison has been done between DCRS is comparatively costly and other technologies like Wi-Fi, LTE, and WiMAX allows long-range communication and efficient output that cannot be provided by DCRS [13]. It evaluates the performance of Het-Net. Het-Net is a combination of Wi-Fi, DSRC and LTE [14]. They have developed a handoff method to enable communication for CVT that guarantees the ideal use of accessible transmission options. The field study that has been carried out demonstrated that the use of Het-Net increased the radius of V2V [15] and V2I [16]. The drawback is, it requires an extra amount of time when switching between Wi-Fi and LTE.

C. M. Huang, M. S. Chiang [17] discussed a prediction control scheme called offloading with handover decision based on SDN Architecture. The SDN controller monitors information that includes the speed, geographical position, direction and closest car from the current vehicle using the OBU such works on cellular network and Wi-Fi. The SDN controller is responsible enable what time the decision should be made to shift to Wi-Fi from cellular network and notify the car so that it stays in a cellular network if connecting to Wi-Fi is not suitable. It results in reducing the cellular network load and traffic and the communication quality of the car being in a Wi-Fi network be assured using SDN control scheme.

Table 2: Car-following model Dataset

Attribute	**Range**	**Data Type**
ID	19 to 7,94,438	*Integer*
Timestamp	2012/03/21 to 2014/03/30	*Text*
Vehicle length	1.02 to 29.81 m	*Float*
Vehicle speed	0 to 105 m/hr	*Float*
Vehicle weight	0 to 153327.09 pounds	*Integer*
Lead Vehicle ID	19 to 7,94,438	*Integer*
Lead Vehicle speed	0 to 170 km/hr	*Float*
Lead Vehicle weight	0 to 153327.09 pounds	*Float*
Lead Vehicle length	1.02 to 29.81 m	*Float*
Time gap	0 to 530331 secs	*Float*
Relative humidity	17 to 98 %	*Float*
Direction of Wind	0 to 360 degree	*Integer*
Speed of Wind	0 to 24 m/s	*Float*
Surface type	Snow-covered, Wet, Dry, Visible Tracks	*Text*
Air temperature	-14 to 25 Celsius	*Float*
Weather type	Snow, Rain, Clear	*Text*
Precipitation intensity	High, Low, Moderate, None	*Text*

M. Chen and Y. Tian [18] proposed a CIoV based improved version of IoT to bolster the cognitive perception of IoV that is an outcome of AI, cloud computing, and 5G network. Their research aims to enhance user experience as per private demand and improving driving safety in traffic systems by creating robust data safety in a network by optimizing network resource allocation. A thorough comparison of CIoV is done with other techniques like ITS, VANET, and IoV. It shows that CIoV proves to be better than the three. CIoV faces various challenges concerning privacy and security [19]. SIoV is a concept to empower IoT devices, which are easily accessible appliances that can offer various provisions by communicating with each other, with consciousness. This paper applied SIoV in the cars to change the existing IT system by combining it with existing VANET [20]. It presents various SIoV use case scenarios such as safety and point of interest, accident warning application, highway information application has proved to reduce the rate of accidents to a considerable level [21].

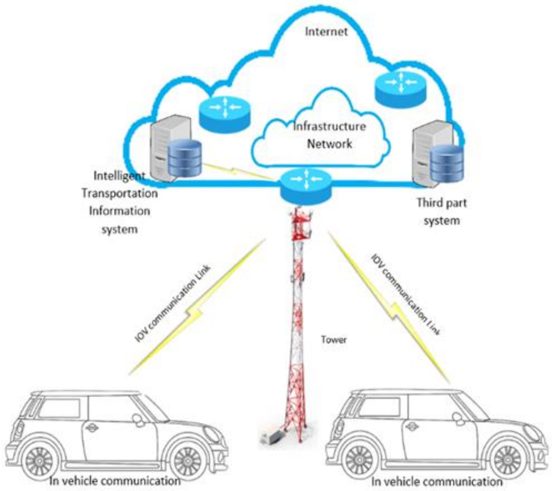

Figure. 2. Communication network architecture in the IoV &V2I

M. Muhammad et. al., have discussed the integration of IoT [22] into cellular network infrastructures that enable data links over an existing cellular network infrastructure. Study shows that LTE and emerging 5G network are well known as the prime force for communicating vehicles. The research is done on basic details on V2X communications and services, basic issues and survey on V2X authentication solutions and presents the security problems related to V2X communications in the cellular network leading to the research challenges [23].

K. Raghava Rao [24] proposed Li-Fi [25] technology-based V2V communication which is similar to Wi-Fi but works through light and is faster than Wi-Fi [26]. Wi-Fi uses radio waves and therefore has limit speed. For vehicles to communicate the head and tail lamps are to be replaced with LED's and photo-diodes that acts as transmitters and receivers simultaneously. The main aim is to exchange data related to speed between leading and the following vehicle in order to reduce the probability of accidents. This same technology can also be used in street lights in order to send data to all the cars on that route. Figure.2 represents the communication network architecture of IoV and V2I depicts how the sensor network in the car transfers the collected data to the cloud where it is analyzed and communicated back to it and the neighboring cars.

D. Vehicle-following models based on machine learning algorithms.

This section discusses about the various machine learning algorithms used in the car following models they are BPNN [27], RF [28], CCF, NGSIM etc. C. Chen and H. Xiang's is based on using a probabilistic model named as CGPN for the rear-end collision avoidance system focusing on the likelihood of crashes in the IoV. Specifically, BPNN is used to evaluate the probable crash risk with V2I communication and V2V communication support with which the training dataset is generated from VISSIM with several important points taken into consideration.

The most suitable procedure for data interchange is to send data to each and every node in the network. The data header contains the broadcast address in the corresponding field. Thus broadcasted data blocks will immediately reach all of the systems within the broadcasting range. It also chooses a GA to increase the efficiency of the coefficient array and threshold of the proposed NN, further the converging speed of the model that is proposed is enhanced to improve the studying rate based on the relation of the original and predicted values of the 2 closest iterations [29].

D. Yang, L. Zhu [30] studied Google Car automation and movements. According to the author, the motion of this Google car is designed to copy the human driver's car maneuvering but such models do not produce secure motions for driverless vehicles for each and every condition. To overcome this, it aims to join the ML architecture with kinematics-based vehicle-following models that can improve the efficiency and create a robust system using an optimum prediction method, known as CCF model also known as Gipps model. This model uses BPNN and RF model resulting in two CCF models, the Gipps-RF model and Gipps-BPNN model. Proposed models can make the vehicle-following more robust and efficient. Both Gipps-BPNN and Gipps-RF algorithms are efficient compared to simple ones in decreasing crowding, by stabilizing the flow of traffic and avoiding accidents.

Table 3. denotes two datasets, NGSIM and S1. CA (Congestion area), *Ts (Stable time)* and *Rc (Crash rate)* are calculated in both the datasets [30]. The 3rd, 4th and 5th column shows the optimal value after the Gipps, BPNN and RF algorithm is applied to the data simultaneously. Whereas the last 2 columns show the optimized value obtained as a combination of Gipps with BPNN and RF. It shows that the value after combining Gipps with BPNN and RF generates more optimal values than when it is used individually.

Yingshi Guo et. al., [31] proposed an ACC model that is to be installed with an ability to predict the target in advance. The author has put forth a vehicle-following strategy based on merging prediction of adjacent vehicles, from the results of on-road experiments. Based on the study of merging behavior parameters, the Fisher discriminant process is employed to set up a merging behavior prediction model of neighboring vehicles. The proposed merging prediction model improves the desired vehicle-following model. Better car manipulation, enhancing comfort and safety is enabled by the improved vehicle-following model. They have designed a correlation coefficient matrix for improving smart vehicle control algorithms and ameliorating the correctness of intelligent systems.

Table 3: Result of road test using Gipps model

		Gipps model	BPNN model	RF model	Gipps-BPNN model	Gipps-RF model
NGSIM	CA	224.9	171.1	158.4	78.2	104.9
	Rc	0.074	0.388	0.348	0.075	0.235
	Ts	62.3	321.6	68.6	57.9	50.7
S1	CA	183.7	152.6	125.6	65.9	87.4
	Rc	0.065	0.321	0.376	0.068	0.211
	Ts	74.3	275.6	71.2	61.1	51.3

Table 4: Comparision of Car-following models

Year	Reference	Objective	Technique	Merits	Research Gap
2019	[18]	New unified communication architecture for IoT	TCP/IP protocol	Improved performance of network data collection, real-time data collection	Cooperative communication architecture can be further optimized
2019	[25]	Detect potholes and speed breakers and transmit data between cars using Wi-Fi	Li-Fi	Faster transmission of data between cars.	Altitude cannot be calculated
2019	[30]	Movements of automated vehicles	BPNN (Backpropagation neural network) RF (Random Forest) Gipps, Gipps-RF, Gipps-BPNN model	Enhance the safety and robustness of vehicles, better performance than BPNN, RF	No detail about other algorithms, an only linear function is used to combine the prediction results.
2019	[10]	The car-following models based on driver state (normal, slow response, strong/prompt, unresponsive)	SRM (Stimulus-response model) DBN (Dynamic Bayesian Network) MCGEM (Monte Carlo generalized EM)	Error is reduced compared to existing models	Accuracy can be further increased
2018	[32]	To provide an alert and safe driving scenario by placing an LCD for the drivers following the car.	Using LCD	Alert the drivers by showing a message according to the situation	Messages can be customized according to our needs
2018	[29]	Rear-end collision prediction Enhance convergence speed	GA (Genetic Algorithm) NN (Neural Network)	Convergence speed is enhanced	Not preferable for driverless cars
2018	[20]	Enhance vehicular networks	Broadcasting messages	Good for MANET	No details about the merging of IoT and IOV
2018	[33]	V2V communication	NFC (near field communication)	Faster communication after connection	Devices need to be very close to exchange data
2018	[7]	Detect anomalies in vehicle movements (overtaking, one-way, wrong side etc.)	K-nearest neighbour, image processing, unsupervised learning, using CCTV	Can detect vehicles travelling opposite the traffic flow	Non-vehicle entities are not considered, requires a dedicated camera to each lane,
2018	[19]	Inter/Intra vehicle network	CIoV (Cognitive internet of vehicles)	Efficient communication between vehicles	Vulnerable to cyber attacks
2018	[13]	V2V communication,	VANET, Wi-Fi,	Performance of VANET and Wi-Fi is enhanced	Other communication methods are not evaluated like Vo-LTE

2018	[11]	Predicts speed of the car based on weather data	Calculate RSI (Road surface index)	Predicts speed based on weather	Only dry, wet, snow and ice weather is considered
2018	[14]	V2V communication,	DSRC (Dedicated short-range communication)	Quality and scalability of	Other communication methods are not evaluated like Vo-LTE
2017	[34]	Study driver behavior	Probabilistic method- Markov chain	Online update of live stream data	Other probabilistic algorithms are not considered
2017	[35]	Estimate road friction coefficient in real-time and resist external disturbance	Calculating coefficient of Friction	Robust in all conditions	Accuracy can be further increased
2016	[8]	To determine the risk index based on adverse weather conditions	CRI (Chosen Risk Index) GLM (Generalized Linear Models)	Works efficiently for snow-covered roads.	Does not talk about other weather conditions
2016	[12]	Het-Net communication for 2 CVT applications.	CVT (Connected Vehicle Tech) DSRC (Dedicated short-range communication) V2I (Vehicle to Infrastructure)	Het-Net is better than LTE and Wi-Fi.	The time required to switch between WiFi and LTE

E. Other Accident avoidance technique

Besides car-following models M. Ateeq Alanezi puts forth a concept to alert the drivers who are following a car, using an LCD which is to be, attached behind the vehicle for showing caution signs like hazard, wrong entry, fog/mist, sandstorm, accident, damaged road, crowed, crossing ahead, keep distance etc. which are controlled by touch-enabled or voice recognition devices. The conclusion is that the system is cheap as it does not require any device other than a screen to display the caution signs and a smartphone [32]. But this system cannot be customized in real-time according to the requirements of the driver or road.

Table 4. shows the comparison of various vehicle-following models. This table consists of the year in which the paper was published, the reference, objective or purpose of the research, the techniques used in it, its merits and the research gap. Through this table, it is easier to identify, which part of the research is yet to be explored and what improvements can be made further.

Table 5: Techniques mentioned in the following papers

Reference	V2V, V2I	Wi-Fi, Vanet	ML Algorithm	Sensors	Network	Weather
[36]	✓	×	✓	×	×	✓
[32]	✓	×	×	✓	×	×
[29]	✓	×	✓	×	×	×
[18]	✓	✓	×	✓	×	×
[12]	✓	✓	×	×	✓	×
[25]	✓	✓	×	×	✓	×
[33]	✓	✓	×	✓	×	×
[34]	✓	×	×	✓	×	×
[7]	×	×	✓	✓	×	×
[10]	×	×	✓	×	×	×
[4]	✓	✓	×	✓	×	×
[8]	×	×	✓	×	✓	✓
[11]	✓	×	✓	×	×	✓
[14]	✓	×	✓	✓	×	×

Table 5. indicates the techniques used in various car-following models. They are V2V, V2I, Wi-Fi, Vanet, ML algorithm, IoT sensors, network and weather. This table can help in easily identifying the research paper in which the required technique is used. Wherever there is a tick it means that the paper mentions that technique and wherever cross mark is there it means it is not present in the paper.

The comparison of various car-following models with its strength and weakness are shown in Table 4 and Table 5. It is inferred that the V2V and V2I communication uses LTE, Wi-Fi, MANET and VANET but it lacks to portray the conditions (weather/road) in which the efficiency is better. The risk of different weather/road conditions are predicted through CRI but the intensity of adverse conditions details is inadequate. It is also inferred that in most of the existing car following model's road friction alone is considered as the prime parameter but it is directly proportional to the height and weight of the vehicle. So, it is important to consider such factors while developing a car-following model. Driver attentiveness is another major factor in a car-following model that consists of various alerting methods.

Based on the aforementioned study, we summarize that a good car-following model should be a subtle combination of the parameters that influence driving such as the road/ weather conditions, friction on the road, attentiveness of the driver, precise car conditions, safe distance maintained between 2 cars, communication between the cars etc. Integrating machine learning techniques in the car-following model can further increase the effectiveness of the car-following model in terms of safe distance prediction based on the other prime factors.

Conclusion

It is assumed that road traffic accidents will be the 3rd leading cause of death by the end of 2019 among leading causes of the global disease burden. No doubt, the reasons for accidents are vast, but, several of them can be managed only with a few improvements in the vehicles by adding a set of sensors integrated with a machine learning algorithm and high-speed networking technologies for V2V communication. Though it's true that accidents are inevitable but their occurrence can be reduced up to some extent. Such are the Car-following models and Accident avoidance systems mentioned in the above papers an ideal combination of hardware, software and networking components that help in bringing about a change. The sensors, machine learning algorithms and networking technologies mentioned in the above paper have limitations. The transfer from LTE to Wi-Fi takes a lot of time, the efficiency of some ML algorithms is less.

Future scope

It is observed that the ML plays a vital role in accident avoidance and car-following models. Future car-following models can be built with appropriate ML algorithms that can increase the efficiency of the Car-following models and accident avoidance technique. Future implementations of the mentioned sensors can be replaced with high-quality and low power alternative which can sense data faster and help in predicting the risk of accidents much faster. Weather and road condition data set can be further improved by replacing the given options with a degree of intensity of rain, friction, visibility etc.

Thus, the future work is to propose a machine learning based car-following model that can analyze the weather/road conditions and to predict the safe speed, distance to be maintained with the leading car and to provide a faster communication medium to alert the neighboring cars in case of an accident.

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