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CASD: A Framework of Context-Awareness Safety Driving in Vehicular Networks

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***Abstract*—Inspired by the advancement of vehicular networks and increasing concerns on driving safety, this paper proposes a framework of Context-Awareness Safety Driving (CASD). In vehicular networks, vehicles communicate with each other and share a variety of information. By utilizing those capability, CASD provides vehicles with a class-based safety action plan that considers three situations such as the Line-of-Sight unsafe, the Non-Line-of-Sight unsafe and the safe situations. In the Line-of-Sight unsafe situation, a hybrid take-action scheme is provided. If human's action fails, the vehicle will take over the driving control to guarantee the minimum risk. A timing for the vehicle to take over the control is based on an optimized threshold by examining context information. Moreover, a dynamic path maneuver planning scheme is suggested to avoid a crash in real-time. The driving safety can be substantially improved using CASD.**

***Index Terms*—IoV, Vehicular Networks, Vehicle Driving Safety, Context Awareness, Safety Protocol, VANET.**

I. Introduction

As the ever exploration of the electronics, semiconductor, information and communication technologies, the demands for intelligent life have sprouted. The Internet of Things (IoT) [1] is a promising paradigm by satisfying the needs to change humans' life. Since both academia and industry are investing more resources than ever on the research of IoT technologies, which expect everything to be connected, and perform smart operations for people. Most consumer electronics giants in this arena initiated their IoT plans. In May 2015, Google delivered key components, Brillo [2] and Weave [3], for its IoT platform. Apple invested HomeKit framework for smart home [4]. Samsung proclaimed that by 2017, 90% of the products including home appliance, TV, smart phone, etc. will be IoT functioned [5]. Another essential part of IoT, the Internet of Vehicles (IoV) or connected vehicles [6] has drawn a great interest from consumer. IoV consists of vehicles that could be driverless, autonomous and smart by installing various sensors and communication modules, which is a vital component in the future smart city. As shown in Fig. 1, smart vehicles are equipped with a vehicle central computer, external camera, GPS navigator, wireless communication devices, mobility sensors, LIDAR/Laser scanner (for light detection and ranging), vehicle radar, etc.

The current smart vehicles are mostly sensor-dominated for autonomous driving. Vehicles are equipped with several types of sensors, such as sound, infrared, light (laser), distance, image (video), and so on. The On-Board Unit (OBU) of the vehicle collects and processes the information from the sensors, which provide fast, smart control instructions reaching to vehicle's control system. Google has devoted to the development of autonomous vehicle [7] by employing various sensors and claimed that the full-functional prototype of autonomous vehicle will be ready in 2020. Yet due to physical limitations of the sensors, e.g., the feature of Line-of-Sight image, or noise of laser signal in heavy rain (or snow) weather, the sensors can only work within a restricted area, which confines their effectiveness and applicability. For instance, in the road test of Google car, the sensors failed to recognize humans on the road from time to time, which substantially undermines its dependability [8].

Vehicle communication has been recognized as a promising technology for Intelligent Transportation Systems (ITS) in the forthcoming IoT world [9]. The Vehicular Ad-hoc Networks (VANET) [10] based on vehicle communication suggest a self-organized, cooperative and intelligent road transportation paradigm in which every vehicles can have real-time information of surrounding vehicles as well as environments. The US Federal Communication Commission had allocated 75MHz with 7 channels in 5.9GHz band to the use of ITS, namely

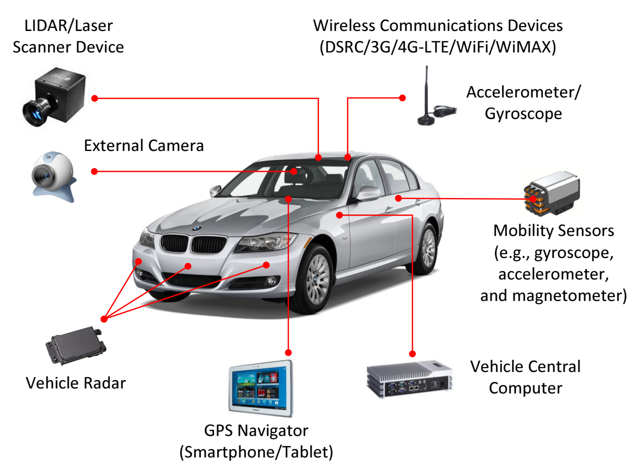

Fig. 1. An Example of Smart Vehicle

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Dedicated Short-Range Communications (DSRC) [11]–[13]. To operate the multiple channels and develop basic applications of vehicle environments, the IEEE 802.11p [14], [15] and Wireless Access in Vehicular Environments (WAVE) [15] have been standardized. Furthermore, various vehicle-to-vehicle (V2V) [16], [17], vehicle-to-infrastructure (V2I) [18] and infrastructure-to-vehicle (I2V) [19] schemes were proposed to support message exchanges. Since this paper considers the driving safety issue, the information exchange must be performed within the strict delay bound with high reliability. Investigating the performance of vehicle communication, many researchers [20]–[23] have proved that packet exchange delay can be within a safe-bound.

Communication-enabled smart vehicles can obtain information itself as well as from various other sources using wirless communication. The vehicles can interact with other vehicles, pedestrians, traffic light, Road-Side Unit (RSU) [15], etc. The enormous data from the interaction provide more comprehensive, meaningful and accurate information to smart vehicles to perform efficiently and precisely in intricate environments. Moreover, vehicular networks formed by the connected autonomous vehicles will be able to show a new paradigm in which the dependency of the sensor-based method can provide lower cost, and safer smart vehicles. Several researches, however, have been done to improve the driving safety by using the shared information delivered by vehicle communication [24]–[26].

Motivated by the current limitations and advancement of vehicular networks, we propose a framework of Context-Awareness Safety Driving (CASD) that utilizes the information shared among vehicles with vehicular networks. **The objective of CASD is to provide vehicles with safety navigation services that aware the context of road environment based on GPS navigator and DSRC device.** In CASD the neighboring vehicles of a vehicle are categorized into three classes such as *the Line-of-Sight Unsafe*, *the Non-Line-of-Sight Unsafe* and *the Safe* vehicles. Each class has different action plan and will coordinate with others to minimize accident risk in an emergency situation. Especially a hybrid take-action scheme is proposed to control a driving behavior when human

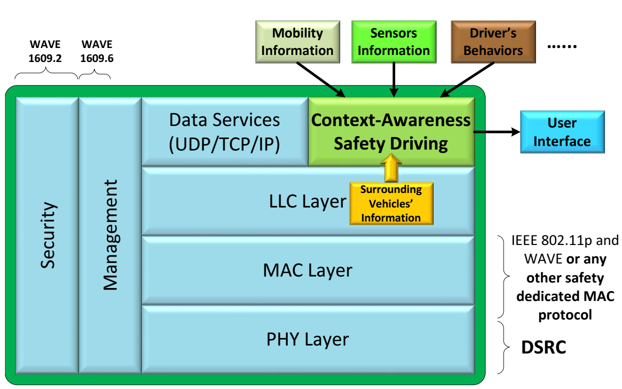

Fig. 2. The Overview of CASD Framework

fails to respond to an emergency situation, and the timing to take the action from machine is optimized based on vehicle's position, speed, direction, driver's behavior, etc. In addition, a dynamic path maneuver planning scheme is suggested to coordinate vehicles' motion when an accident happens. Through CASD, the safety of driving in road transportation systems can be improved as well as reducing the loss of lives and property.

The overview of CASD protocol framework is illustrated in Fig. 2. CASD protocol is an application-service above logical link control (LLC) layer [14] and can receive mobility information, sensors information, driver's behaviors, etc. It can also receive surrounding vehicles' information via wireless link. It provides a user interface with real-time environment information. The physical layer conforms DSRC standard [11], and MAC layer can be IEEE 802.11p [14] and WAVE standard [15], or any other safety dedicated MAC protocol.

The rest of this paper is organized as follows. Section II summarizes and analyzes the current research work about driving safety. Section III describes the design of context-awareness safety driving protocol. Section IV suggests related research issues. Finally, in Section V, we conclude this paper along with future work.

II. Related Work

Safety in driving is always a critical issue for people. Many researchers and engineers have been devoted to the enhancement for driving safety. Azimi et al. proposed spatio-temporal intersection protocols for autonomous vehicles [24]. The paper focused on a safe and efficient method to deal with safety issue when vehicles are moving through intersections and roundabout (i.e., curved area). They investigated the benefits from vehicular networks to control and navigate vehicles in intersection and roundabout environments, and influence from the inaccuracy of GPS localization. Based on the considerations, they presented two protocols: *Advanced Cross Intersection Protocol* (AC-IP) and *Advanced Progression Intersection Protocol* (AP-IP). The interesting part of their implementation for the protocols is employing an AutoSim simulator derived from the GrooveNet [27] that connects real cars to simulated cars via DSRC radio devices by exchanging Basic Safety Message (BSM) [15].

In order to provide vehicles with autonomous capability, Kim proposed a motion planning framework based on Model Predictive Control (MPC) approach to generate a feasible trajectory for a vehicle [25]. To avoid collision among vehicles, the paper specified constraints about vehicle's states and inputs for MPC framework. In system of view, several coordination rules are investigated for the interactions of vehicles or vehicle and infrastructure, e.g., *Lane Change Protocol* and *Yield Protocol*. Especially for vehicle-intersection coordination, an *Intersection Crossing Protocol* was proposed to provide a safe and live moving schedule.

Due to the importance of intersections in ITS, a hybrid architecture of systemwide safety for intelligent intersection was proposed in [26]. It considered an appropriate interaction between centralized coordination and distributed actions in

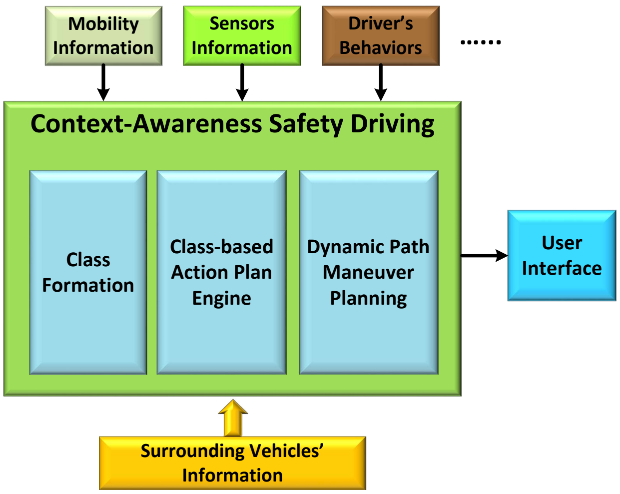

Fig. 3. The Components of Context-Awareness Safety Driving Framework

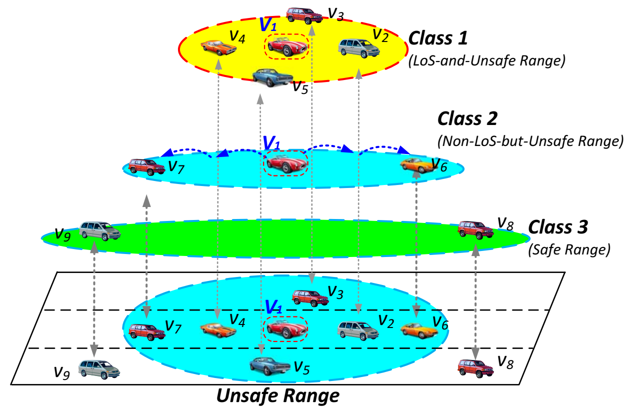

Fig. 4. The Network Architecture of CASD

intersection environments. It also described a dynamic changing partial-order relation that worst-case behaviors should be guarded among vehicles. Although with through simulation, it shows good performance but the quantized mathematical formulation remains a challenge.

For a real-time vehicle motion planning, Kuwata et al. proposed an approach employing rapidly-exploring random tree (RRT) to plan a vehicle's path [28]. A closed-loop prediction is used in RRT framework. This approach was the core part of planning and control software for a MIT Team in 2007 DARPA Urban Challenge [29]. A demonstration in the challenge showed an ability to finish a 60 mile journey while performing maneuvering tasks efficiently as well as safely interact with other vehicles. Their focus was on the planning and control of vehicles, but the ability of communication among vehicles was not considered.

CASD, however, explores the instant information sharing among vehicles, and allows the vehicles have a more comprehensive sensing ability for the driving environment. When vehicles are facing emergency situation, a class-based safe plan can be scheduled, and as the situation continue to change, vehicles can adapt to a new situation in a more robust way.

III. Safety Driving

In this section, the design of Context-Awareness Safety Driving protocol is described and a goal of CASD is to provide vehicles with safe navigation services that evaluate the driving situation in the road environment. On the basis of vehicular networks and GPS navigator, vehicles can share information such as planned driving route, speed, drivers' behaviors, distance between any two vehicles, etc. When vehicles are in an emergency situation, an avoidance maneuver can be taken proactively by employing the information so that the probability of a vehicle accident can be reduced. Fig. 3 illustrates the components for CASD, which includes Class Formation, Class-based Action Plan Engine, and Dynamic Path Maneuver Planning.

A. Network Architecture

To deal with an emergency situation, micro-scoped navigation service is considered in the case of collision avoidance or obstacle avoidance, which means that other vehicles within a vehicle's vicinity area are observed. By this sense to each vehicle the CASD categorizes the surrounding vehicles into three classes based on distance:

- *Class-1*: Line-of-Sight (LoS) unsafe vehicles. The vehicles need to perform immediate action for avoiding a possible crash or collision;
- *Class-2*: Non-Line-of-Sight (NLoS) unsafe vehicles. The two-hop away vehicles are in the blind spot blocked by LoS vehicles. They can be affected by the collision between a vehicle and its LoS vehicles;
- *Class-3*: Safe vehicles. The vehicles that multi-hops away can be affected by the propagation of crash information with some probability.

As shown in Fig. 4, we take vehicle V_1 as an example. The vehicles, V_2, V_3, V_4, V_5, in LoS of the vehicle V_1, belong to the *Class-1*. Whenever there is any vehicle in this class taking emergent action, V_1 needs to respond to it immediately. Next, V_6 and V_7 are in *Class-2*, which are in blind area for V_1. Due to NLoS, they would fail to be observed by V_1, which can cause a serious unexpected result. The remaining vehicles are in *Class-3*. Even though they are relatively safe but still can be involved into a crash.

B. Class-based Action Plan

In this section, the action plan to the emergency circumstances will be explained. Based on the classification of vehicles discussed in Section III-A, specialized actions are proposed to apply for their motions. In an action plan, human factors are considered for action decision. Also, a user interface to show the surrounding situation is suggested. Then for taking action, an approach for threshold-based optimization is discussed. Note that each vehicle (called host vehicle) classifies its neighboring vehicles into three classes.

The vehicles in *Class-1* are in distance very close to the host vehicle. If any vehicle in it encounters a problem from either

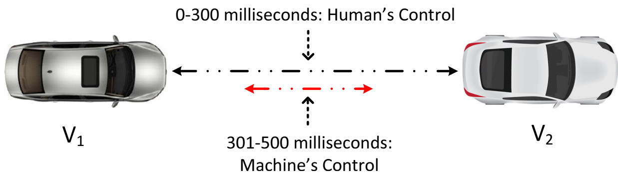

Fig. 5. Control Timing of Hybrid Action Scheme

an internal aberration or external factors, all of them may be in dangerous situation in a couple of seconds. They need to instantly react to such an abnormal event. A driver may take a response to the event, but if their reaction time is slower than the course of the event (e.g., elders, women, and teenagers). Thus, we consider a hybrid take-action scheme that allow the driver react first and then machine react if needed. The driver can have a chance to take an action within a threshold. If the driver fails to take the appropriate action by the threshold, the vehicle system takes over the control of vehicle. As shown in Fig. 5, the vehicle V_1 and V_2, assumed that $500ms$ is collision avoidance time. For the first $300ms$ (from 0 to $300ms$), the vehicle gives human a chance to take an action. After the $300ms$ (from 301 to $500ms$), the machine takes the control of the vehicle.

To improve the reaction time of a driver, an user interface is suggested. The navigator application needs to show the situation, i.e., the locations of neighboring vehicles. The application needs to provide alarms of dangerous situation with visual or audio warning. If the driver takes a wrong action, the navigator needs display the right direction. If the driver cannot follow the direction right away, the vehicle takes over the control and disseminates a message to its neighboring vehicles in a fast and reliable manner to take the corresponding actions.

The threshold for each scenario also needs to be optimized by considering a vehicle's mobility information (position, speed, and direction), the vehicle's weight, a driver's behavior, and the distance between vehicles. We suggest two approaches: proactive approach and reactive approach. Proactive approach is for vehicles in *Class-1* that prepare the actions in advance. Reactive approach is for vehicles in *Classes-2* and *3*. For vehicles in *Class-1*, when an abnormal situation happens, vehicles start the calculation of the thresholds for actions. To optimize the threshold, the trajectory overlapping are considered as a possible collision through the current positions, speeds, directions of vehicles, as well as drivers' behavior (e.g., acceleration/deceleration, straight going, and right/left turn). Also a weight of the vehicle is considered since the heavier vehicle, longer distance is needed. Also, we need to consider a group of vehicles along with road layout (e.g., the number of lanes, the entrances of ramps, and terrain) and road surface status (e.g., slippery by snow or rain) in order to orchestrate the actions of the vehicles for crash avoidance.

For vehicles in *Class-2*, the vehicles have similar action plan as *Class-1*. However, the vehicles in *Class-3*, need to make space for other vehicles in *Class-1* and *2* so the vehicles in both classes can have enough space to take actions for collision avoidance. In addition, *Class-3* vehicles have more space to maneuver, e.g., change lane, slow down speed.

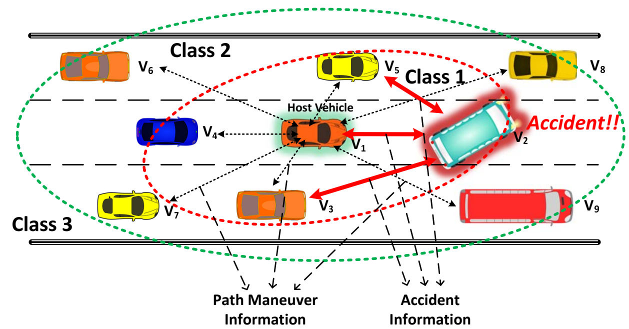

Fig. 6. Dynamic Path Maneuver Planning

C. Dynamic Path Maneuver Planning

This section will introduce an approach of dynamic path maneuver for vehicles that are in emergency circumstances. Based on dynamic path maneuver planning, vehicles can adjust directions and paths to avoid the collision in real-time.

A primary vehicle, or host vehicle, assigned as a Maneuver Planner (MP) needs to orchestrate the maneuvers of its neighboring vehicles, i.e., *Class-1* and *Class-2* vehicles. Note that a vehicle is decided to be an host vehicle in a distributed way based on a rule that a vehicle is on the same lane as the accident vehicle is on and belongs to the *Class-1* of the accident vehicle. If these two conditions can not be fulfilled, a vehicle which is closest to the accident vehicle is determined to be an host vehicle. In an accident event, only one vehicle takes the role of MP to orchestrate the maneuver plan, and other vehicles follow the plan disseminated by the MP.

Through the continuous communication, the host vehicle calculates the action plan for *Class-1* vehicles and disseminates it to the vehicles. According to the last plan and actual actions of *Class-1* vehicles, the path maneuver planning algorithm adjusts the actions of *Class-2* vehicles and disseminates these actions to them. Furthermore, the actions of the vehicles in *Class-3* are also modified based on the original plan and the real actions of *Class-1* and *2*.

For example, as shown in Fig. 6, the vehicle V_2 ahead of host vehicle V_1 suddenly loses control. Due to the persistent exchange of data packet, V_1 as well as other surrounding vehicles immediately get informed, and V_1 becomes an orchestrator of path maneuver and sends other vehicles packets including the possible upcoming crashes that may be caused by V_2, based on the estimated trajectories of other vehicles. The plans of path maneuver let all vehicles in *Class-1* coordinate. Relying on the maneuver plan of *Class-1*, vehicles in *Class-2* also get the orchestrated maneuver plans, so do *Class-3* vehicles. This process will continue and the maneuver plans will be updated through information exchange until the accident stops and surrounding vehicles safely dodge.

IV. Research Issues

In this section, we introduce some research issues related to context-awareness safety driving as follows:

- **Low latency vehicular MAC protocol for CASD.** Because of the real-time requirement for driving safety, the delay of message exchange becomes a key issue. Thus, a MAC protocol with low latency by efficiently utilizing multiple channels as well as considering vehicle environments shall be designed.
- **Efficient forming or clustering algorithm of *Class-1, 2*, and *3*.** Since CASD classifies vehicles into three classes for every vehicle, this gives rise to more research issues, such as how to form and maintain the classification, how to handle vehicles' joining and leaving, and how to minimize the overhead of control messages, etc.
- **Comprehensive optimized path maneuver planning algorithm.** In Section III-C, the proposed dynamic path maneuver planning needs to calculate action plans, so how to calculate and optimize the action plans shall be investigated. The action plans shall consider vehicle mobility, kinematics, physical constraints, etc.

V. Conclusion

In this paper, we proposed a framework of context-awareness safety driving (called CASD) based on vehicular networks. CASD takes advantage of the instant information sharing of vehicular networks in order to provide vehicles with a road-environment-context-awareness safety navigation service. CASD classifies neighboring vehicles into three classes, and for each class, different action plans are applied. In particular, a hybrid take-action scheme is proposed to handle the failure on driving control from a human. Moreover, between classes, vehicles can cooperate with each other in giving a safer driving motion planning. Also, an approach for dynamic path maneuver is described. As future work, we will implement the proposed ideas in simulation and compare the performance with the state-of-art schemes.

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