Current Collision Mitigation Technologies for Advanced Driver Assistance Systems – A Survey

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Current Collision Mitigation Technologies for Advanced Driver Assistance Systems – A Survey

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ABSTRACT

Road accidents remain a major cause for fatalities globally. A lot of researches have been done and it is widely reported that vehicle automation can reduce human errors, thus reducing road fatalities. The construction of a fully autonomous vehicle is among the major developments of vehicle automation. Many surveys have been done about vehicle automation and Advanced Driver Assistance Systems (ADAS) is one of the fundamental features of a fully autonomous vehicle. Main ADAS features include Automatic Cruise Control, Automatic Parking, Collision Avoidance as well as Lane Departure Warning systems. In this paper, current advances of collision mitigation technologies for ADAS are reviewed as an introductory idea for researchers and general audiences who are new to this field. Each of the systems are discussed in their own sections. The highlights and future directions for each system are brought to light. Several future work suggestions for a comprehensive ADAS systems are highlighted. As this work is intended as a general survey on ADAS, the technical specifications of each system are not discussed in details.

***Keywords** : Advanced Driver Assistance Systems, ADAS, Vehicle Safety, Vehicle Automation, Review.*

1.0 INTRODUCTION

According to [1], 1.2 million deaths occured due to road accidents globally. It is expected to increase in numbers by 2030 [2]. Toroyan in his work mentioned that most of road fatalities occured in the low-income countries, compared to the higher-income countries, due to the proactive enforcements to reduce the accident rates and the inclusion of latest safety features into the vehicles in the latter countries [3]. Vahidi et al. has reported that road accidents can be prevented by assimilating the automation elements into the vehicle driving and safety systems, thus reducing the human error – the main cause of road fatalities [4]. Vehicle automation has been a rapid progressing field since last few decades. Among the latest example of its progress are the development of autonomous vehicles. Recently, major carmakers have been racing to develop their own on-the-road fully autonomous vehicles. Among them are Volvo, General Motors as well as startup companies such as Faraday Future, Tesla and Google [5, 6]. In addition, companies which are not frequently associated with automotive sectors are joining the aforementioned race, i.e. NVIDIA with their NVIDIA DRIVE™ PX [7], and Ericsson with 5G Tactile Internet developments which are implemented for autonomous driving process [8]. Development of autonomous vehicle is a vast research area, which include many systems. For example, Advanced Driver Assistance Systems (ADAS), the fundamental core of autonomous vehicle developments. It is developed to provide partial automation to the vehicle and aims to lead a safer and stress-free driving experience [9].

As a combination of several complex systems, ADAS consists of Adaptive Cruise Control, Automatic Parking, Collision Avoidance as well as lane change assistance, among many others. Though much progress have been done in the field, and a lot of review papers have been published about the systems of ADAS as in [10-13], but to the best of our knowledge, a recent general discussion of current collision mitigation technologies of ADAS aimed at the general audiences has not been written yet. Thus, the objective of this paper is to discuss several well-known systems under the ADAS umbrella, as an introductory idea for new researchers and industry members, as well as general audiences who are new to this field.

This paper is divided into four sections and is written as follows: in Section 2.0, several of the well-known systems of ADAS will be briefly reviewed separately in their own subsections. In Section 3.0, future trends of ADAS systems developments are denoted. In the final sections, a concise conclusion are written.

2.0 ADVANCED DRIVER ASSISTANCE SYSTEMS

According to Fleming [14], ADAS developments have been developed since the $1970s$. It is an umbrella term for a collection of systems which is developed for driver convenience, safety, traffic assistance as well as a multi-purpose lateral and longitudinal control systems. In this section, several of the main ADAS systems are reviewed. The examples of ADAS are shown in the Figure 1 [9, 15]. As can be seen, ADAS is divided into several main categories, i.e. driving comfort, safety, traffic assistance as well as lateral and longitudinal motion controls.

2.1 Adaptive Cruise Control

Adaptive cruise control (ACC) is among the earliest example of ADAS. It is an extension of cruise control for road vehicles. ACC is used as a mean to maintain a safe distance of host vehicle towards the frontal vehicle on a road. It does not utilize any satellite usage, rather it only obtains the environmental information from on-board vehicle sensors. A typical ACC system comprises of radar (lidar) which measures the distance to surrounding or preceding vehicle [16]. In the occurence of a frontal moving vehicle, the controller helps to determine and switch the vehicle maneuver from speed control to spacing control. Spacing control refers to where the vehicle speed is controlled to a desired value, while maintaining the safe distance. It is useful to prevent forward collisions [17]. The fundamental idea of ACC helps to develop much complex systems such as Collision Avoidance Systems and Vehicle Platooning strategy. Recently, ACC has became the most common feature of ADAS which is available for new vehicles [17]. According to [17], in 2013, 29% of road vehicles possess the ACC feature.

However, despite of its simplicity in calculation methods and development, it is not reliable in more complex hazardous road scenarios. Thus, other ADAS systems should be included in the vehicle to accommodate the ACC. Figure 2 depicts the typical architecture of Adaptive Cruise Control.

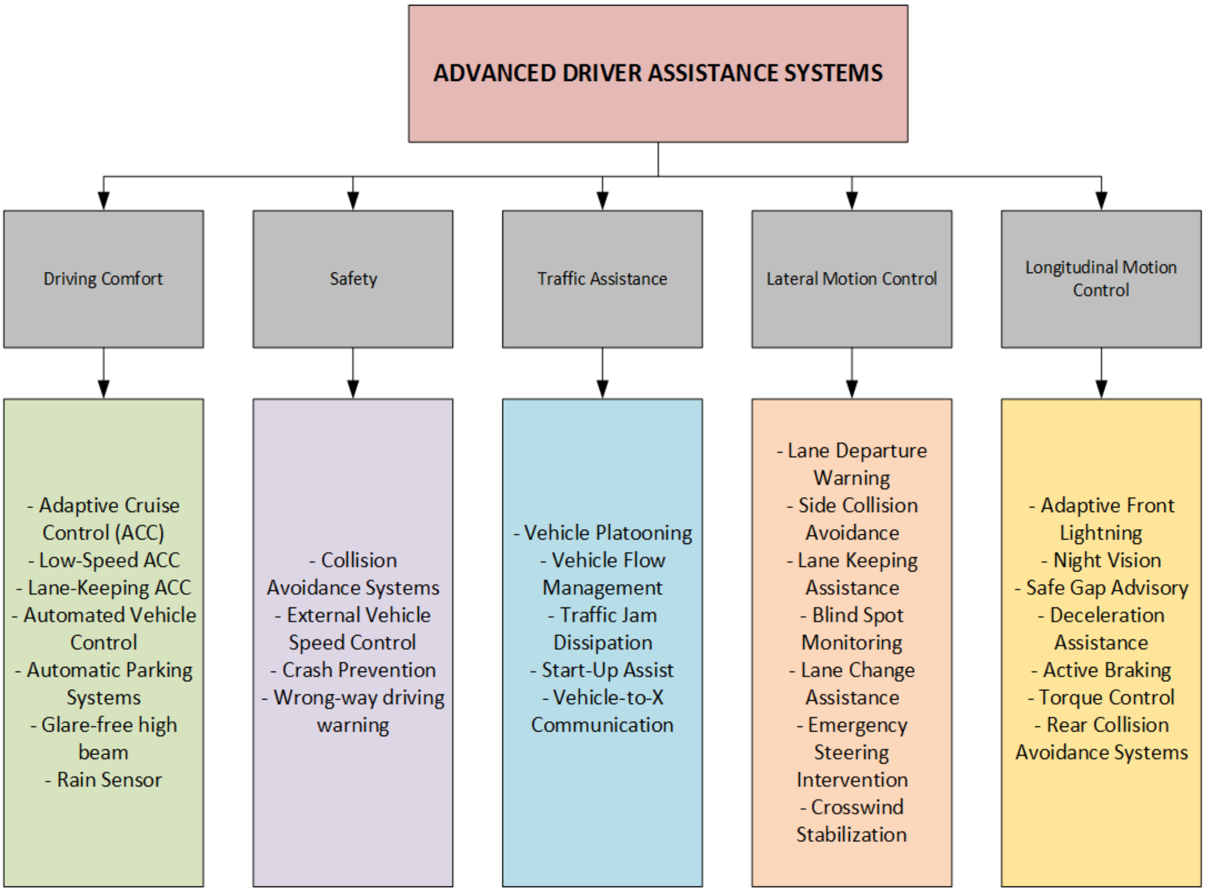

Figure 1: Examples of ADAS Systems (Based on the works of [9] and [15]).

2.2 Automatic Parking

Among the features of an intelligent vehicle is the ability for an automatic parking maneuver. It allows the vehicle to independently perform a parralel, angle or perpendicular parking [18]. Automatic parking systems demands knowledge of motion planning and environmental information from the sensors [18]. According to a study by [19], automated parking has the ability to reduce the driver stress during the parking maneuver. Current examples of automatic parking can be found in [20] and [21].

Researchers and industry members who are going to develop the automatic parking system for autonomous vehicles must consider the vehicle dynamics constraints carefully. This is due to the difficulties in the vehicle navigation, which includes a lot of complex factors. Thus, the motion planning must reflect on the vehicle movements for a comfortable automatic parking maneuver.

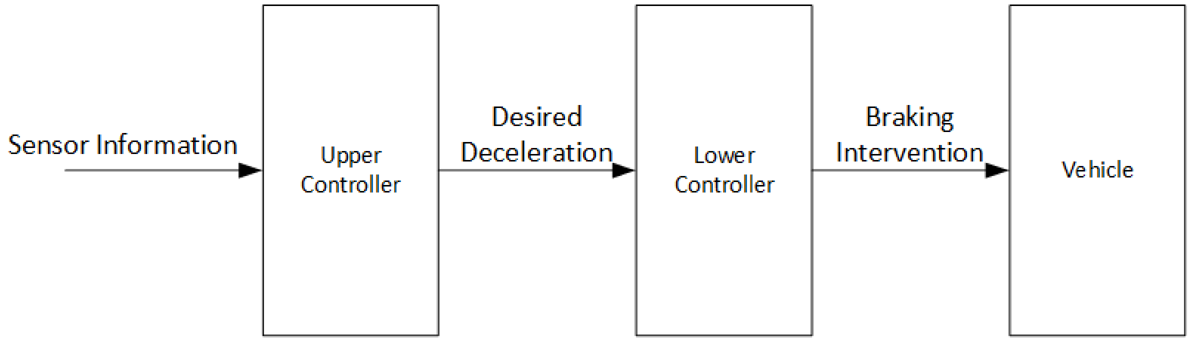

Figure 2: Typical architecture of Adaptive Cruise Control [16].

2.3 Driver Drowsiness Detection

According to a safety report of the National Highway Traffic Safety Administration of the United States (NHTSA) [22], there are 56,000 cases of road crashes which happened due to the drowsiness and fatigue of the drivers in the United States of America. Most of the accidents happened in non-urban areas [22]. Thus, a system of ADAS, namely driver drowsiness detection is developed to prevent accidents caused by the driver drowsiness. According to a work by Veenendaal et al. [23], there are several ways to measure the risk of driver drowsiness. Among them is the steering pattern monitoring, which utilizes the steering input angle. The angle is obtained from the sensor which detects the drowsiness level of the driver [24].

For further improvements of this system, future works include providing haptic feedback to prevent crash due to the fatigueness of the driver. Inclusion of user friendly Human-Machine Interface technology is helpful in making a more reliable Driver Drowsiness Detection systems.

2.4 Collision Avoidance System

Collision Avoidance Systems (CA) are one of the most complex systems which came out from the ADAS family. The National Highway Traffic Safety Board made compulsory of this system in their 2016 list of safety [25]. It prevents the potential collision from happening. It usually comprises of three main submodels strategies: Threat Assessment [12], Path Planning [28] and Path Tracking Strategies [26, 27]. In a typical CA architecture, the threat assessment measures the metrics of collision risk. The threat measurement will then be fed to the Path Planning system, which replans the current trajectory of the vehicle. The vehicle will then follow the replanned trajectory using Path Tracking Strategies [12]. As collisions in the real world usually involve high speed moving vehicles, thus a precise selection of each strategy is important to ensure a feasible collision avoidance maneuver. CA helps the vehicle to navigate in emergency situations with the help of low-level control actuations such as braking and steering actuators. Figure 3 illustrates some of the collision scenarios where the vehicle should avoid.

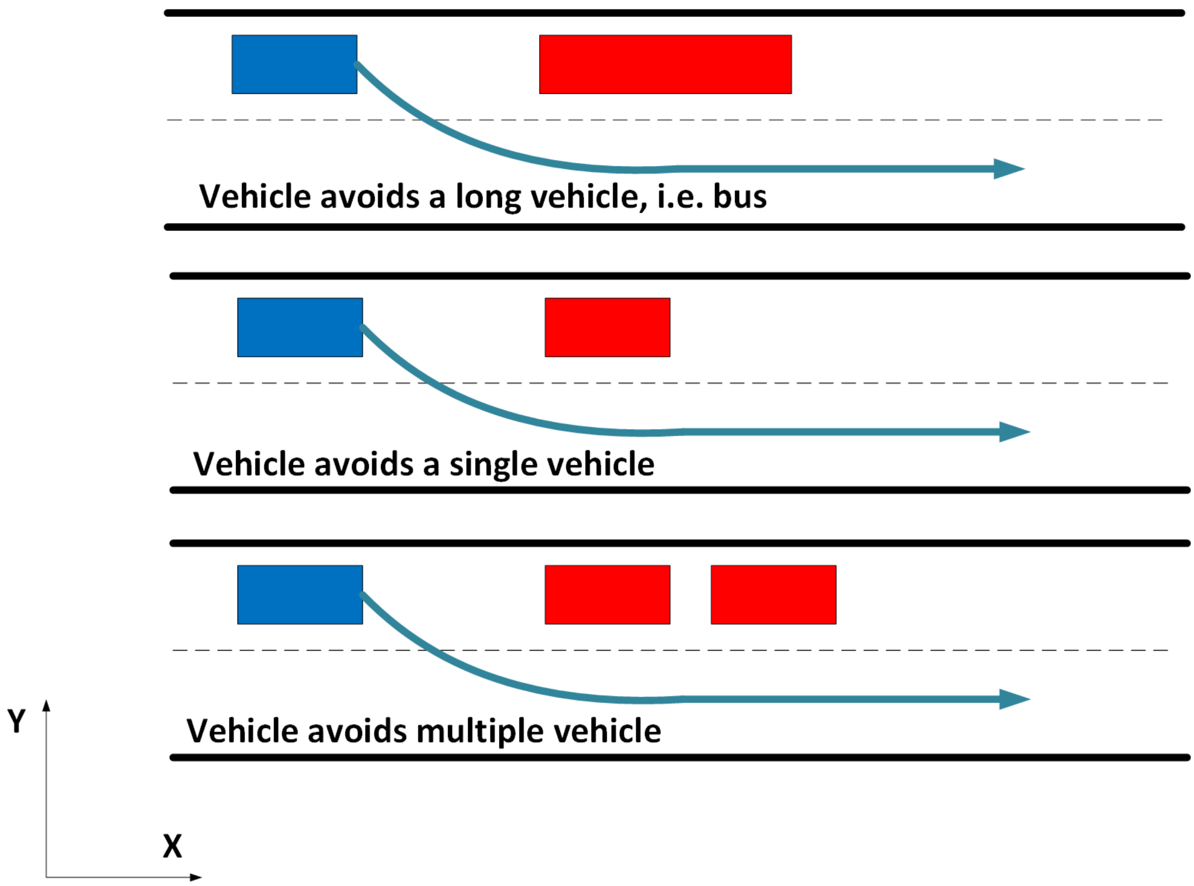

Figure 3: The potential collision scenarios which the system must be able to avoid.

It is shown that the collisions might happen in many situations, where the vehicle needs to avoid a long bus, a single vehicle or multiple vehicles. Thus, the CA algorithms must possess a good combination of Threat Assessment, Path Planning and Path Tracking strategies. Besides, wrong selections of the CA strategies will result in high cost calculation algorithms.

2.5 Lane Departure Warning

For most of the conventional roadways worldwide, lane markings are painted on the road to keep the driver inside the lane to prevent accidents. However, in the case of the drowsiness and driver errors, a lane departure warning system are designed to help the lane keeping of the vehicle. There are two types of lane departure warning system. The first one is the Lane Departure warning which provides the driver with a visual, audible or haptic feedback as a warning in the case of lane departure. The second one is Lane Keeping System, which will override the driver's input of the vehicle environment if no further actions are taken by the driver. Some studies of the Lane Keeping System is conducted in [29] and [30]. Most of the latest marketed vehicles are now manufactured with Lane Departure Warning feature [31].

The drawback of Lane Departure Warning system is its dependency on the visible lane markings of the roads. Thus, recent studies include the needs for better image processing to capture the lane markings especially in the night time. Examples can be seen in [32] and [33].

2.6 Intersection Assistant

The numbers of the road accidents occurred at the junctions of crowded urban areas have increased relatively to the global rapid expansion of the cities [34]. These accidents usually happen in the highly populated urban areas, where sudden darting obstacle or pedestrian might appear in front of the vehicle. The collisions at intersection are caused mainly due to the driver distractions [34]. Figure 4 shows the example of the situations, based on [35].

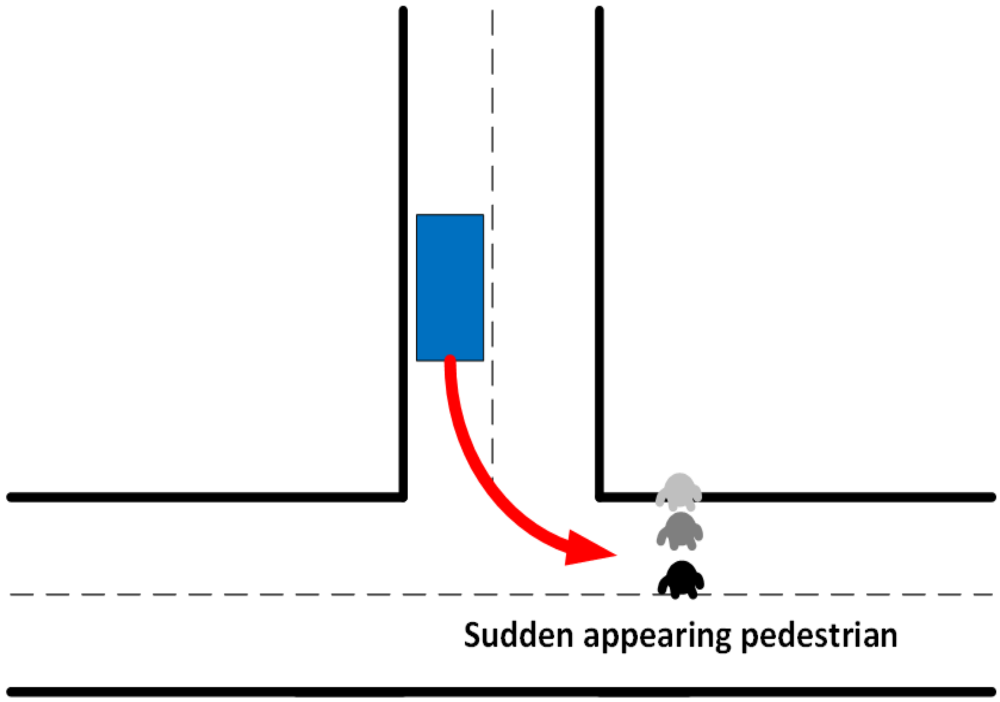

Figure 4: Intersection Assistant System helps to prevent collisions and ensure safety in the depicted scenario.

The usage of Vehicle-to-Infrastructure communication for a better intersection assistant system is denoted in [36]. The examples of Intersection Assistant can be seen in the prevention of traffic light violation, prevention of wrong turnings, crossing-path collisions as well as prevention of collision with pedestrians.

2.7 Vehicular Communication System

Vehicular communication systems consist of a network, where the vehicles and environments are communicating nodes. They exchange information among each other for safety purpose and traffic informations. Among the examples are the Vehicle-to-Vehicle and Vehicle-to-Infrastructure strategies [37-40]. With the latest developments of Internet-of-Vehicle [41], which is a branch of Internet-of-Technology, the developments of Vehicular Communication System are progressing now more than ever. Vehicle-to-X (X refers to any medium which relates to the vehicle, e.g. another vehicle, infrastructure) enables the vehicles to communicate with each other and send the messages regarding the environments, traffic flow as well as the future appearing vehicle beyond the driver's limited visual range. The combination of this technology with Collision Avoidance Systems have been done in [42], and is proven to be helpful in warning the driver about the potential risks prior to the accidents. Extensive technical surveys on this particular technology is available in the works of [43] and [44].

2.8 Vehicle Platooning

One of the major problems of road traffic globally is road congestions. In addition to the collision risks due to the heavy traffic congestions, according to the Bureau of Transportation Statistics of United States, the aforementioned problem is responsible for about a third of vehicle carbon emissions in the United States [45]. One of the technology which was introduced to help in reducing the traffic congestions is vehicle platooning. It is an interdisciplinary system which aims to improve the fuel consumption, mileage as well as enhancing the safety of a vehicle. Vehicle Platooning is a centralized system where several autonomous vehicles in close space, are computer controlled thus creating a vehicle platoon which will provide essential solution to the traffic congestion and air pollution problems [46]. The communication between the vehicles in the platoon enables the vehicles to exchange the information about their surroundings, thus cooperating to improve their future navigations (Figure 5). Until recently, several detailed survey on vehicle platooning has been written. For example, the survey works of Bergenhem et al. in [46] and Kavathekar et al. in [47]. In addition, the truck platooning is also introduced, to reduce the rate of truck accidents due to driver inattentiveness and drowsiness [48].

The combination of vehicle platooning concept with other ADAS systems such as ACC, will help in producing better collision mitigation technology [49]. Besides, the information obtained from the leading vehicle of the platoon can help the vehicles to plan their longitudinal and lateral motions precisely. However, vehicle platooning remains a challenging concept to be implemented globally due to the needs to modify existing road infrastructure, which demands the collaboration between various sectors.

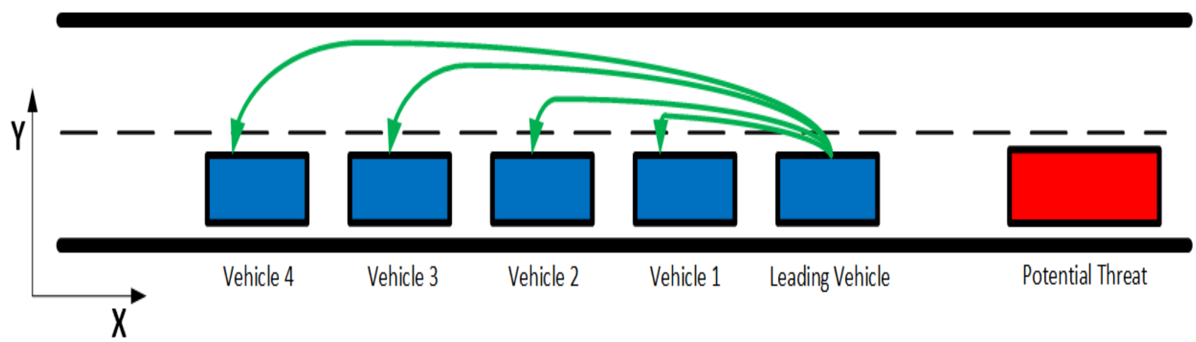

Figure 5: Simple illustration of vehicle platooning in an automated highway system, where each of the vehicles in the platoon receives information about the future environment from the leading vehicle.

3.0 FUTURE TRENDS OF ADAS AND AUTONOMOUS VEHICLES

SAE has defined the automation of vehicle into five levels (Table 1). Until 2015, several levels have reached full production phase (Level 0 and 1), while other levels are still in the research phase [50]. In the recent roadmap of ADAS [51], it is noted that the next phase of ADAS development, which commenced from the year 2016 – 2025, includes the works to make partially autonomous vehicles to be available on the road. These works include the constructions of single lane highway (which will enable the vehicle to navigate without driver interventions, as long as it stays in a single lane) and highway autopilot with lane changing system [51]. The fully urban autopilot vehicles implementation is expected in the year 2025 [51].

Table 1: Vehicle Automation Levels, as designated by Society of Automotive Engineers (SAE) [50].

LEVELS	**0**	Human Driver
	1	Assisted
	2	Partially Automated
	3	Conditionally Automated
	4	Highly Automated
	5	Fully Automated

With the latest collaboration news between Volvo and UBER (Online Transportation Network Company) to develop autonomous vehicles [52], it is important to notice that autonomous vehicle is a widely expanding sector. In addition, the recent collaboration between General Motors with Lyft, a startup transportation network company [53], is the evidence that the collaborations between many sectors of the industry are required for the successful autonomous vehicles development.

The progress of the autonomous vehicles will speed up the development of Smart City [54, 55]. This is because as autonomous vehicles are mostly developed on the electric vehicle platform, it will help to provide a clean and greener environment. In addition, the idea of ride-sharing using the autonomous vehicles will reduce the entire vehicles population as well as the parking areas in the cities [56]. These vacant areas can substantially reduce the crowdedness of the megalopolises like Tokyo, Moscow and Seoul.

4.0 CONCLUSIONS

This work is intended to provide introductory ideas of current available collision mitigation technologies of ADAS to researchers who are new to this field. ADAS is a fundamental feature in developing the intelligent autonomous vehicles. It is shown that prior ADAS implementations are beneficial and further addition of more systems into the vehicle will subsequently reduce the human error and preventing more road fatalities. Notable examples of

ADAS systems are discussed in the work. Several suggestions are hinted in each subsections. The authors also briefly mention the future directions of ADAS and Autonomous Vehicles.

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