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Safety Engineering and Communication System for Autonomous Vehicles: A Review, Challenges and Solutions

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***Abstract:** Statistics show that a large number of automobile injuries and fatalities occur as a consequence of human errors. This calls for the need of principles related to safety engineering and an intelligent communication system that can significantly reduce the probability of the occurrences of these accidents. This paper surveys the same idea in terms of autonomous vehicles. These are driverless or automatic vehicles that are designed and programmed in such a way that they can sense the surrounding environment and move possibly without any human or external interference. This paper constructively surveys the need for such a system, environmental challenges and constraints it could face, different communication scenarios, and finally the risks that autonomous vehicles can pose in short and long term.*
***Keywords:** autonomous vehicles; communication technology; crash avoidance; driving assistance; self-driving cars*

I. INTRODUCTION

Assistance systems for driving provide a helping hand to both experienced drivers and beginners on busy roads or to those who are learning how to drive. Almost every year, around 20 to 50 million people suffer injuries and more than a million deaths are caused around the world due to reckless driving and road accidents. The major causes for accidents caused on the road include drink and drive, overspeeding, not following the traffic rules, misjudgement of other vehicles in terms of size, angle of movement, speed and acceleration, immediate braking, incorrect overtaking, not paying attention while driving and ignoring the conditions of road. It may also happen that some person who is a professional driver may make mistakes while making a decision to overtake another vehicle. Another major issue comes when driving in bad weather conditions. All of these factors lead to a great loss of human lives, time and money. According to a survey conducted by the Ministry of Road Transport and Highways of India, the following tables, Table 1 and Table 2 [1,2] show statistics of total number of road accidents in a certain period of years from 2015 to 2019 along with the percent change over that time span and the categories of roads on which the accidents occured along with number of persons killed or injured.

Year	Total Number of Road Accidents (in numbers)	% change	Total Number of Persons Killed (in numbers)	% change	Total Number of Persons Injured (in numbers)	% change
2015	5,01,423		1,46,133		5,00,279	
2016	4,80,652	-4.14	1,50,785	3.18	4,94,624	-1.13
2017	4,64,910	-3.28	1,47,913	-1.90	4,70,975	-4.78
2018	4,67,044	0.46	1,51,417	2.37	4,69,418	-0.33
2019	4,49,002	-3.86	1,51,113	-0.20	4,51,361	-3.85

Table 1. Road accidents, Number of persons killed and injured from 2015-2019

Category of Roads	Accidents		Persons killed		Persons injured	
	Number	% age share in total	Number	% age share in total	Number	% age share in total
National Highways	1,37,191	30.55	53,872	35.65	1,37,549	30.47
State Highways	1,08,976	24.27	38,472	25.46	1,11,831	24.78
Other roads	2,02,835	45.17	58,769	38.89	2,01,981	44.75
Total	4,49,002	100	1,51,113	100	4,51,361	100

Table 2. Number of accidents, Number of persons killed and those injured by the category of Roads in 2019

The advancements in communication technologies and its emergence in the automobile industries across the world has led to the embracement of ADAS (Advanced Driver Assistance System) through significant development (Chavhan and Venkataram, 2019a; Chavhan and Venkataram, 2019b) [3,4]. This type of modern technology aims to ensure hassle-free travel, lesser accidents, conservation of fuel, improve energy efficiency and reduction in the levels of pollution. ADAS is able to perform such tasks by combining various complex subtasks including speed controlling, object detection, overtaking advice, parking assistance, deciding shortest paths, obstacle avoidance, gear shifting, lane change advice, etc.

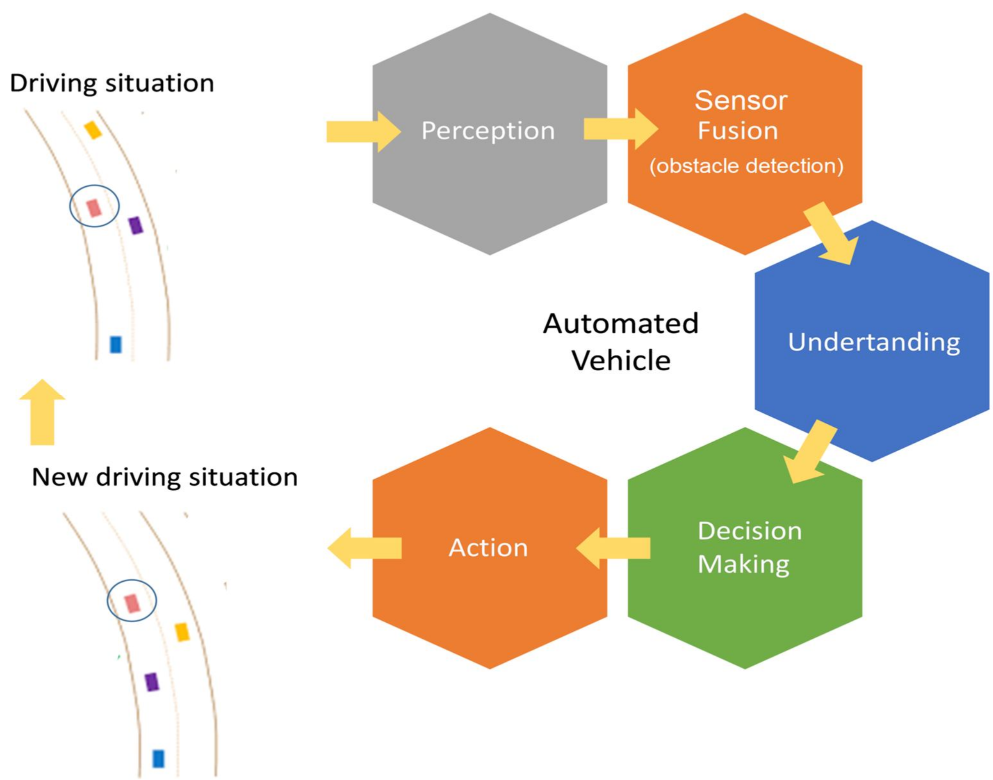

Fig 1. Process cycle of autonomous vehicle

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II. PROBLEMS IN HUMAN DRIVING INTELLIGENCE

A. Perception/Visibility Issues For Drivers In Low Light And Adverse Overhead Conditions

Human drivers are bound to experience a lot of challenges while driving through glares, low or improper lighting conditions and unfavourable weather conditions such as fog, snow, rain etc. During such adverse climatic conditions, human drivers are not able to perceive the operating environment clearly in order to detect obstacles in their path, which ultimately leads to road accidents. Drivers should be able to properly sense the trajectory and its obstacles and manage their driving according to the visibility in terms of light and overhead conditions. In such conditions, inexperienced or learner drivers do not have the required skill set to drive safely by following various measures like by turning on light beam headlamps, fog lights, speeding adjustments, maintaining a proper braking distance with other vehicles on the road and pulling over when safe operation is not possible. In order for an ADAS to work efficiently, it should be able to understand these perceptual challenges to help drivers for safe travel.

Fig 2. Poor visibility in adverse weather conditions

One of the most easy solutions to improve visibility during the night time is by using high beam lights along with fog lights for lower ground clarity. But at the same time, these high beam lights can create hazardous glare to drivers who are driving in the opposite lane. Also it is really difficult for the driver to manually control and switch between high beam and low beam lighting as it requires the driver's attention on time, which cannot be achieved most of the time. This is more of a hassle and can create confusion therefore resulting in misuse or under use of high beam lighting. To overcome the problem of high beam light, an Artificial Intelligence based solution has been proposed by the NVIDIA Drive Labs by reducing glare for oncoming traffic using perception. A camera based deep neural network is used by this approach known as Auto High Beam Net. It creates controlling outputs for high beam lighting systems of vehicles without the driver intervening to improve visibility during night and safety. An automatic braking system using infrared cameras was developed by Han and Song (2016) [5] which identifies pedestrians in low light. Aggregated channels and AdaBoost algorithm is used to differentiate the reflected light from the pedestrians. Then amplification is done of the contrast of pedestrians through Otsu's segmentation algorithm. By implementing a fully convolutional network to process the images in low light, an algorithm is proposed in Chen et al. (2018a) [6]. The camera images are pre processed using various image processing methods and colors are converted accurately.

B. Inattention of Drivers and Misjudgements

Inattention such as sleepy driving and poor judgements of human drivers is also a major reason for many of the road accidents. Therefore, a robust Crash Avoidance and Overtaking Advise System (CAOA) system should be able to keep a track of drivers to monitor their mistakes and inattention and thus inform them well before to ensure safety while travelling on roads. A method proposed in Rani et al. (2016) [10] makes use of image processing techniques to measure eye closing frequency and sleepy behaviour of drivers. This method triggers the warning alarms to give alert notifications to the driver to prevent accidents. An analysis of vehicle overtaking behaviour on two way undivided lanes was performed in Asaithambi and Shravani (2017) [11] by taking into consideration flying and accelerative overtaking cases. The effects like overtaking on time, distance, vehicle size, speed, acceleration, flow rate, opposing gap, etc. has been considered in this approach. Micro sleep is dangerous while road travelling. After the driver wakes up from the micro sleep, they are bound to apply a sudden brake or sudden change in steering wheel. These kinds of behaviours have been explored in Ashouri et al. (2018) [12] by analyzing the vehicle yaw rate, yaw angle, steering wheel angle and lateral position. A simulation software for car overtaking decision and lane changing support for avoiding collisions is proposed in Li et al. (2019) [13]. This approach makes use of sinusoidal and polynomial functions to calculate optimal trajectories by taking into consideration various parameters such as lateral speed, maximum lateral acceleration, longitudinal displacement of vehicles. For the purpose of calculating critical collision time, the longitudinal relative speed and condition of roads which is fetched from the speed sensors and RADAR is used. An approach known as Strategy Selection and Transition (SSAT) is used in Sun et al. (2019) [14] to monitor the driver's intention by using a risk motion field based motivational layer. A replica of the mindset of the drivers in a mixed traffic flow environment is created by implementing a sense think act concept.

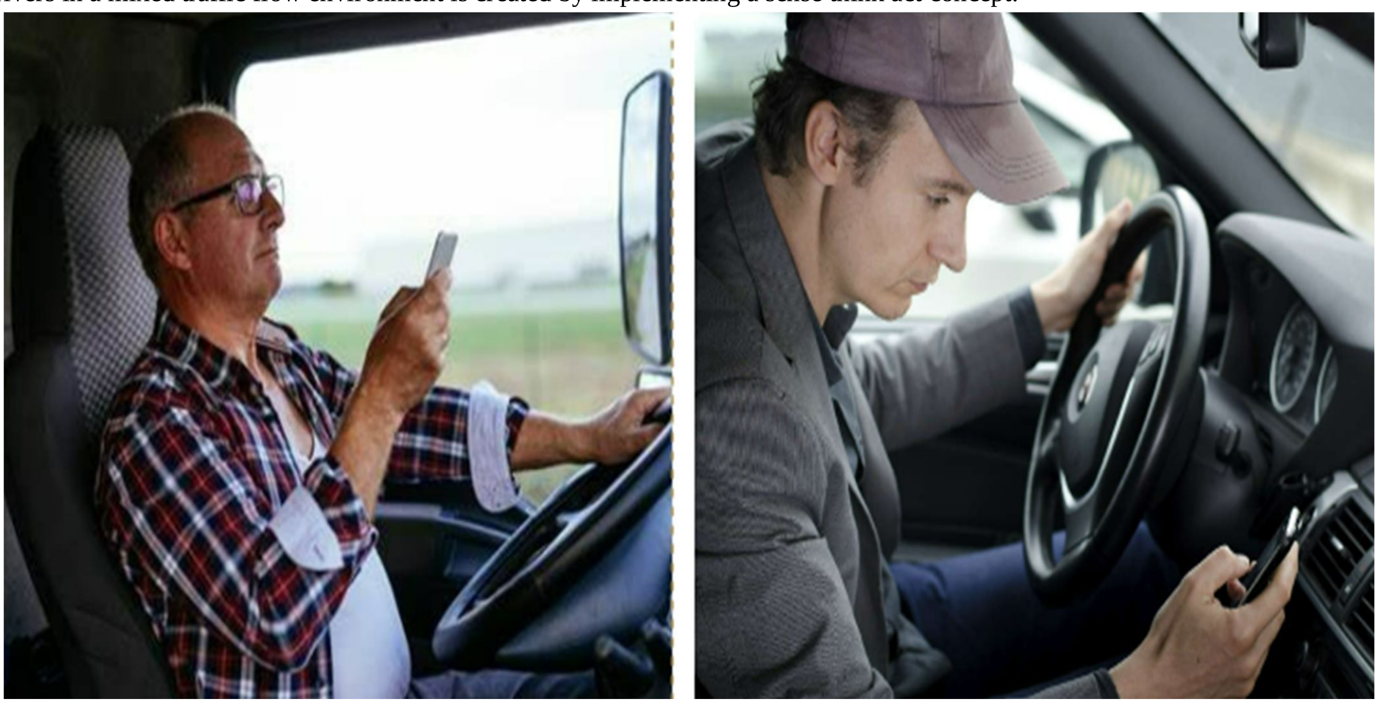

Fig 3. Driver inattention

C. Driver's Blind Spots

It is quite common that while driving on the road, blindspots are possible. They can cause harmful consequences to both drivers and their vehicles along with the other vehicles present on the road. The blind spots are those areas which are not visible through the mirrors. When two vehicles, one being a small one and the other being a big vehicle, it may be possible that the small vehicle moves in the blindspot region of the big vehicle which can be a truck or bus. In such a situation, drivers of both vehicles do not know that the smaller vehicle is under the blindspot of the other. Drivers must pay extra attention and be cautious about such adverse conditions while changing lanes for overtaking other vehicles, moving after clearance of traffic signals, turning vehicles in road bends, etc. to avoid collision with vehicles which are not at all visible in the blind spots.

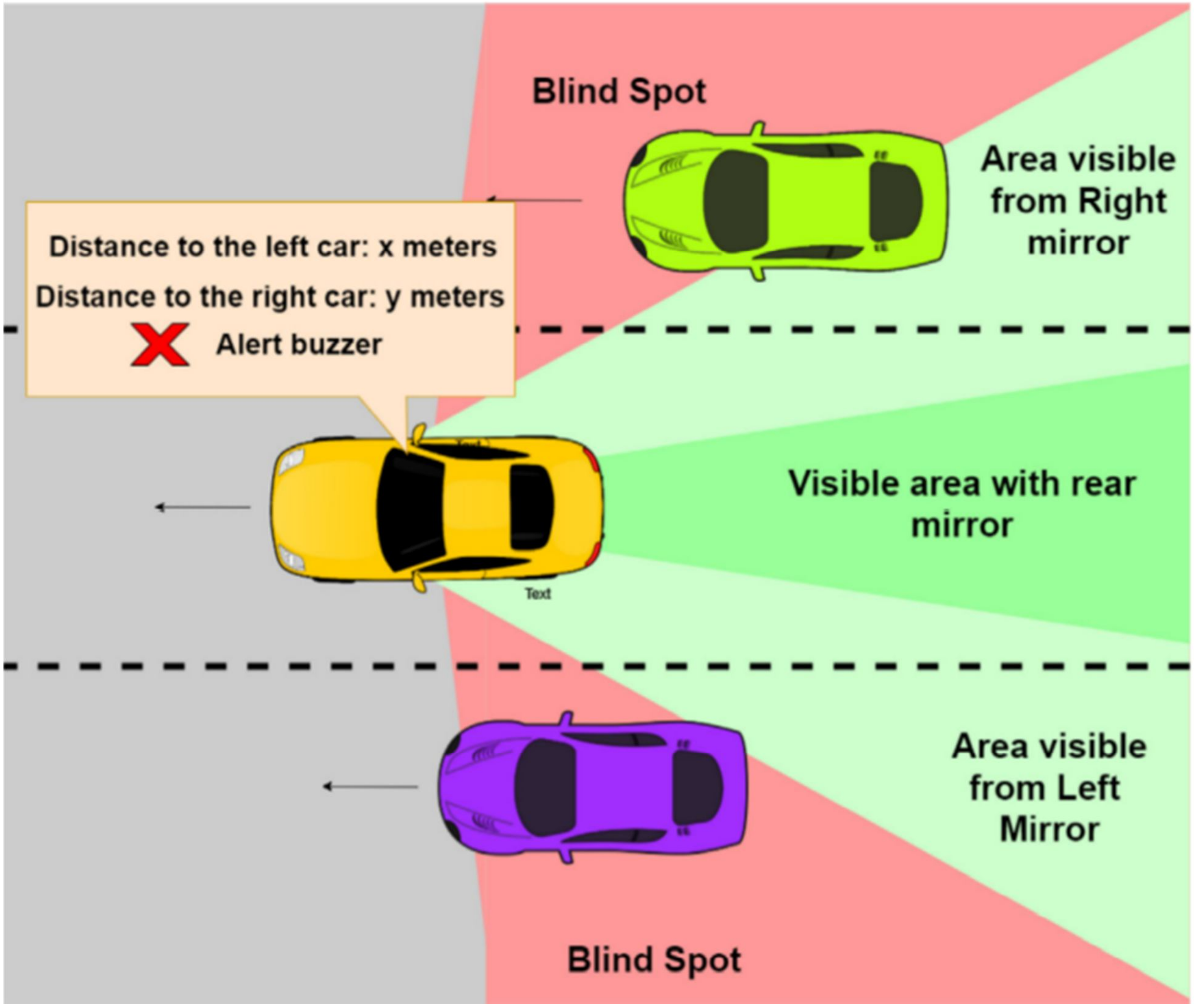

Fig 4. Blindspots around a car [51]

But it is not possible for human drivers to always be careful about blindspots and thus accidents occur in most of the cases. Hence, a robust CAOA system should be able to monitor the blindspots and be aware of them and at the same time provide the drivers of both vehicles with an alert well on time to prevent collisions. An approach proposed in Racine et al. (2010) [18] uses an active blindspot crash avoidance system to reduce and prevent blindspot accidents. A simulator made for driving and force detecting gas pedals are implemented for improving the detection purpose of such spots. By applying the optical flow algorithm for enhancing safety while lane changing, a blindspot detection system is proposed in Saboune et al. (2011) [19]. To monitor blindspots, a deep learning based model has been proposed in Shen and Yan (2018) [20] which uses the concept of probability and a neural networking model. It calculates the chances of collision/ accidents in blindspot regions and also the driver of the vehicle receives an alert whenever the car comes under the blindspot of the vehicle. The use of geometrical concepts has been proposed in Hashim et al. (2018) [21] where the blindspots are detected using a grid approach by measuring the angle of visibility of various objects for six drivers having different heights and area of visibility which in turn is used to find an average blind spot area and angle. The investigation regarding blindspot risks of trucks has been done by Mazankova (2015) [22] by taking into account the attentiveness of driver and the driver's height for blind spots from the right and left door perspectives.

III. CONSTRAINTS AND CHALLENGES RELATED TO OPERATING ENVIRONMENTS

This segment of the paper discusses the challenges that vehicles face due to the environment that they operate in or the surrounding environment that may include such things as condition of roads, presence of obstacles, or weather conditions. These are the conditions that must be incorporated into our AI system so that it can produce accurate and reliable results.

A. Design and Condition of the Roads

While a vehicle is in the driving mode, an autonomous driving system is responsible for analyzing the road that the vehicle is currently traversing through and generate suitable responses such as application of breaks in suitable proportions, avoiding potholes, ditches, changing direction according to the curvature etc. The system must consider all these factors without which it may result in accidents.

1) Lane Markings and width of Road

Lane markings assist with making a decision about the width of roads and along these lines keep the vehicles inside their limits to forestall crashes. They provide a sense of attention to the driver that ensures safety. An inside and out study on crash examination was worked upon in Islam and Kanitpong (2008)[7]. This top to bottom review presumed that insufficient lane markings and perceivability are increasing the quantity and severity of road accidents. An architecture for detecting and tracking the lane markings with the help of Hough Transform is put forward in Bounini et al. The further boundaries are determined by minimizing the area of interest using the Canny edge detectors, Kalman filter and least square method. A control technique is created utilizing fuzzy logic. Hough transform is applied after the canny edge detector is applied on the grayscale image which is converted from Red Green Blue (RGB). ROI is smoothened by convolving it with a Gaussian mask. A lane mark quality assessment algorithm is proposed in Li et al. (2018). Data from GPS, camera and Light Detection and Ranging (LiDAR) are used to assess the correctness, shape and visibility of the lane markings. The inputs from prior maps and sensors are used to measure the correctness i.e. the divergence between the lane marks that are expected. The width range and road curvature smoothness are measured by sharp metrics and the difference of contrast between road background surfaces and lane marks are assessed by visibility metrics.

2) Slopes and Road Curves

Curves are non uniform horizontal bends which have a high probability of an accident taking place if the driving is not being done cautiously. To successfully drive through a road curve, sufficient application of brakes and steering is required, which causes the driver to lose control over the vehicle. Road accident rate increases as the level of bend increases. Road inclination (slopes) present a similar set of problems as well. Road slopes sometimes block the driver’s views and thus become a cause of accidents. Thus the AI system must be designed in such a way that it detects the road curve or a sloppy road and as a consequence, applies appropriate brakes and steering. Forces that are acting on the vehicle, between the roads and tyres influence how the vehicle would move on the road. As stated above, these systems must estimate the parameters surrounding the motion of the vehicle. Such a model for estimation of the slope of road and vehicle parameters is proposed in Sebsadji et al[8]. This methodology utilizes rotational speed of tyres, lateral and longitudinal change in velocity, steering angle and yaw rate to ascertain the longitudinal power. Through the survey, it is understood that crash rate is more in the road curves which is because of speed, lack of clarity, more limited field of view, slope and other objects being there on the road[9].

3) Debris and Potholes

Debris in the road is created due to various parameters such as rain, waste, mud, dust, etc. Due to this, control of the vehicle is often lost and leads to accidents. With time, roads require regular maintenance, ignoring which leads to the generation of potholes. Potholes jeopardize street security, vehicle wellbeing and transportation productivity. Additionally, potholes, ditches on streets additionally cause vehicle crashes and harms. Both debris and potholes are to be thought about genuinely while designing tough and intelligent autonomous systems, intelligent enough to estimate the positions and size of potholes to prevent the vehicle damage and possibility of accidents. One methodology is to foster refined road maintenance procedures utilizing a pothole data set. As proposed in Jo and Ryu (2015) [15], detection of potholes could be carried out with the aid of black box camera system. This can detect potholes on wide roads at optimised cost. This methodology records pictures utilizing black box cameras and harvests the pictures to lessen computational complexity. The resized pictures are changed over into gray scale pictures, which are additionally changed into binary pictures utilizing histogram-based thresholding strategy. From the images that are captured, the areas containing potholes are segregated from the background. Further, this methodology utilizes variance threshold strategy to recognize potholes uniquely from other comparative items like patches. A neural organization based arrangement calculation is proposed in Ebadi and Norouzi (2017) [16] to separate out the color features from the road pictures to group land as black-top, grass, soil and rough. Autonomous systems should be designed to know about the potholes on the streets and control the speed appropriately to ensure that the vehicle doesn't let go completely and furthermore doesn't cause any harm to the pedestrians or other vehicles. The impacts of potholes on vehicular traffic is concentrated in Naveen et al. (2018) [17].

B. Detection of Obstacles on Roads

Detecting obstacles and the subsequent collision avoidance is a necessary part of autonomous systems. These obstacles can be divided into two categories, stationary and mobile obstacles. The ones that are not moving for instance, trees, speed breakers, poles, imobile vehicles i.e. stationary are comparatively easier to detect and avoid than the ones that are in motion such as animals, moving vehicles and pedestrians. Once the obstacle is detected, the system must shift to some other direction of motion or trajectory in order to avoid the obstacle and thus the collision. But the prediction of the moving pattern and trajectory of mobile obstacles in a situation, is not an easy task due to which it becomes difficult to find a collision free path in an environment full of such obstacles. Due to blockage of obstacles from the field of view, the complexity of object detection applications increases. A possible solution to this problem is provided within an approach proposed by Chen et al. (2016) [23]. This approach makes use of the Likelihood Field model which collects data from Velodyne LiDAR sensors and GPS. The velocity of the vehicle is estimated with the help of scaling series algorithms in addition to the bayesian filters. Vehicle is then tracked using bayesian filters with ego motion compensation. A three dimensional obstacle avoidance system using ellipsoid geometry is proposed in Sasongko and Rawikara (2016). Robust autonomous systems must be equipped with powerful feature extraction capabilities and robust classification properties. Another approach using neural networks (Convolutional Neural Networks) and Support Vector Machines is proposed by Uçar et al. (2017) [25]. The proposed approach supports driver assistance systems that detect objects around the vehicle, thereby using efficient feature extraction and robust classification properties. The driver assistance system needs support for the hybrid vision, as 2D RGB data alone is not sufficient to recognize the operating environment. Thus, along with the data from camera LiDAR data is required as well for object detection. Obstacle detection reaction times need to be shortened for drivers to prevent accidents as soon as possible. The Yolo V2 object recognition model outperforms the Yolo V1, RetinaNet, Mobilent SSD, and ShuffleNet with a response time for obstacle recognition.

IV. COMMUNICATION TECHNOLOGY IN AUTONOMOUS VEHICLES

A. Literature Review

This paper reviews the development in the field of autonomous vehicles. The focus is on understanding the problems and challenges in human driving and how the same can be resolved with the help of autonomous vehicles, the key points and characteristics that must be adopted in order to develop an efficient AV. [38] describes the architectural design and implementation of AV, and [39] describes various strategies for multi-sensor fusion. The latest developments and advances in AV perception and sensing technology are shown in [40]. In [41], multi-target and multi-source are integrated into the onboard sensor framework. The AV 5-tier architecture is described in [43]. However, none of the 4,444 of these research papers cover the most important wireless technologies for data communications. [42] describes the DSRC and CV2X resource allocation schemes. However, these two technologies are only valid for medium and long haul communications and lack low latency applications.

For short-distance communication with a transmission distance of less than 25 m, four technologies have been proposed: Bluetooth [44], Bluetooth Low Energy (BLE) [45], ZigBee [46], and UWB [47]. Several publications have been published that compare these wireless technologies and evaluate key characteristics such as power consumption, data rate, and transmission time (see [48,49] and references in it).

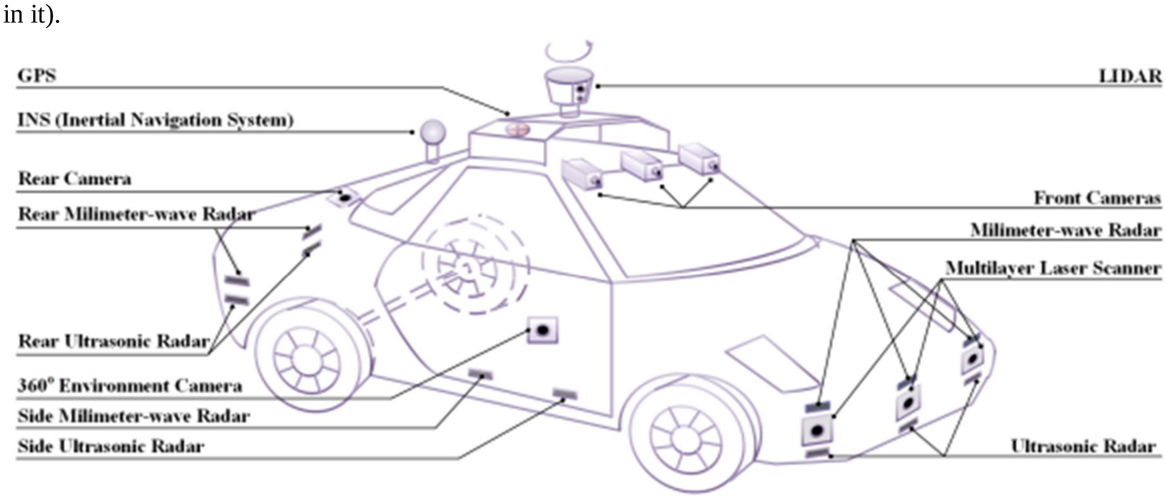

Fig 5. A representative automated vehicle stocked with various sensors [50]

B. Components for Communication and its Challenges

An autonomous vehicle has some additional features in comparison with a normal vehicle. It has some add-on components such as sensors which helps the vehicle to detect and act accordingly, that is, to take decisions on its own in various situations by analysing the environment around it and controlling the movement of the vehicle [32,33,34,35]. There are mainly four components that make a vehicle fully autonomous and thus enables the communication of the automated car with other entities such as vehicles, pedestrians, objects etc. Those components include ultrasonic sensors, RADAR, LiDAR and cameras. But there may be certain constraints and challenges that need to be considered for their proper functioning. The component and its challenges have been compared as below.

- Ultrasonic sensors
  - Low resolution in comparison to RADAR
  - Can't be used if vehicle is in high speed
  - The maximum possible range is 2 meters [36]

- Cameras
  - Overheads involved in computation increase the application time in critical situations [37]
  - Based on the lens used, the maximum possible range is 250 m [36]
  - Resolution gap between cameras and LiDAR/ RADAR

- LiDAR
  - Working is highly affected/ disturbed by adverse weather conditions
  - Highly priced, hence costly to use
  - The maximum possible range is 200 metres [36]

- RADAR
  - Low resolution pictures are generated in comparison to LiDAR and camera
  - The range lies between 5 metres to 200 metres
  - False alarms may be generated if metal objects are present in the surrounding environment

V. RISKS IN AUTONOMOUS DRIVING

In recent years, more and more attention has been given to the ethics and morality of autonomous vehicles. There has been a major devotion regarding their decision ideas and policies in accident scenarios where human life is at danger. In Ryan (2020) [26], several impacts of deploying autonomous vehicles in the year 2025 were explored. These impacts included legal, economic, ethical and social areas. If the idea of automated driving is imagined at a higher intensity then it may decrease the situational awareness of human drivers while driving. The assessment of global risk indicators in autonomous driving has been done in Demmel et al. (2019) [27]. According to the actions taken by self driving cars in collision scenarios, if they cause any harm to humans, it is quite likely that legal issues will be occurring in different aspects. Hence, ethics is essential for each and every entity including humans and autonomous vehicles. As discussed in Bellet et al. (2019) [28], when self driving cars which have been deployed on public roads cause harm to humans, consequences have to be faced by insurance companies and it becomes an issue of concern in that particular scenario.

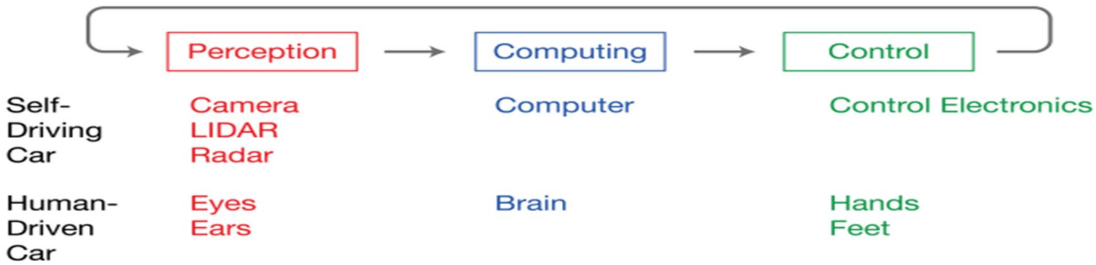

Fig 6. A self driving car goes through a cycle of perception, thinking about the situation and executing the decision made. Technology driven devices perform these tasks similar to a human driver [29].

It is believed by the top automobile companies that autonomous vehicles can decide a risk free and ethical choice, when coders train them properly to perform calculations of real life cases. These automotive companies make sure that their algorithms which manage and control the vehicles are ethical. The algorithm developed by Google for automated vehicles executes a specific set of actions whenever an automated car comes across a cyclist. The car will provide extra space to the cyclist by keeping itself slightly over in its marked lane. The self driving algorithm of Google makes the use of a point system based calculations by giving specific values to animals, pedestrians, surrounding cars, etc. and takes fast and valuable decisions ensuring the best possible set of actions. According to that algorithm, the probability calculation allots a risk value of 5000 whenever side swiping is done by a truck, a value of 1,00,000 for head on collision with pedestrians and 20,000 for lead vehicle. The autonomous vehicles are programmed in such a way that they obey traffic rules, school zones, hospital zones, etc. Moreover they don't use mobile phones while driving, do not yawn or fall asleep while driving and also don't drink and drive. This is an added advantage to ensure safe travels and safety on the roads. These are some of the most important ethics which are neglected by human drivers and are thus violated leading to collisions and road accidents. The essential aspect of reducing fuel consumption while stuck in a traffic jam is ignored by many of the human drivers but an automated vehicle takes care of it properly. Various outlooks of ethics in autonomous driving consisting of unpreventable accidents of automated vehicles have been explored in Geisslinger et al. (2021) [30]. The roles and duties of automotive industries and institutions to incorporate ethics on automated vehicle development have been proposed in Martinho et al. (2021) [31].

VI. CONCLUSION

This paper comprehensively reviews the development in the field of autonomous vehicles. The focus is on understanding the problems and challenges in human driving and how the same can be resolved with the help of autonomous vehicles, the key points and characteristics that must be adopted in order to develop an efficient AV. We live in unprecedented times of great technological progress. Cars have started becoming driverless. Vaccines appear to kill deadly virus diseases in less than a year. Mars Rover is looking for evidence of alien life in some other part of the universe. The advent of digital ecosystems tells us that all new technologies continue to evolve when co-creation, open sharing and collaboration by the development community is the norm. Autonomous vehicles and artificial intelligence are no exception to this. Furthermore, we have provided the literature review describing a brief work of the papers that have been used as reference papers. At the end of the paper, we have considered the risks related to autonomous vehicles and driving.

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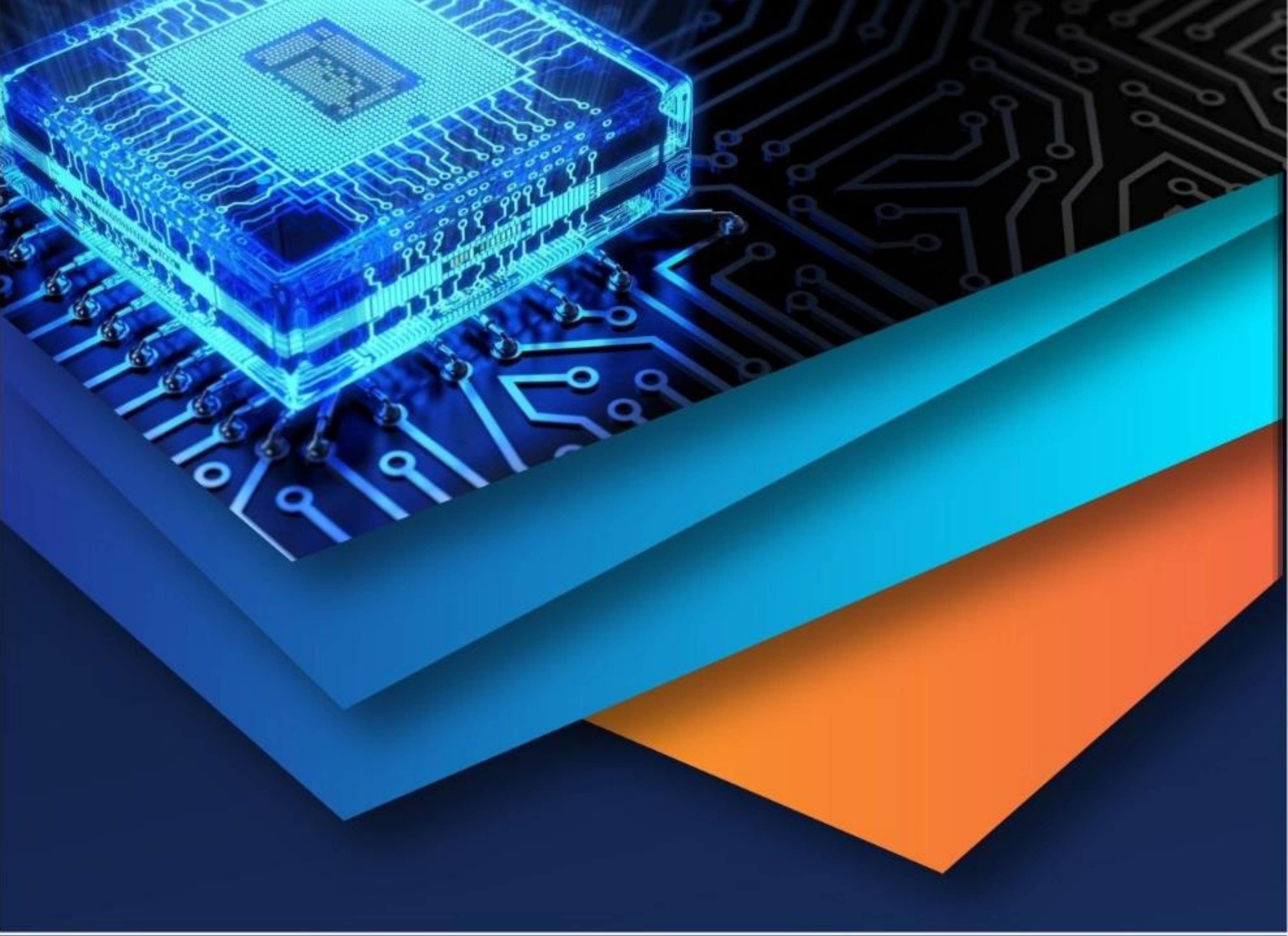

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