# ADAS

*Advanced Driver Assistant Systems*


Prajwal M EE23BTECH11217

भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

# Contents

# Abstract

Advanced Driver-Assistance Systems (ADAS) represent an evolution in automotive technology, aimed at enhancing safety, efficiency, and the overall driving experience. The adoption of ADAS is driven by a pressing need to mitigate road accidents and fatalities, improve traffic management, and usher in a new era of autonomous driving.

A pivotal aspect of ADAS lies in its sensors like cameras, radar, LiDAR, and ultrasonic sensors, enabling the system to perceive its environment accurately. Furthermore, the integration of Vehicle-to-Everything (V2X) communication augments ADAS capabilities by allowing vehicles to communicate with each other and with infrastructure elements. The report delineates the different levels of ADAS, elucidating how these hierarchical levels progressively delegate control from the driver to the vehicle, leading to fully autonomous driving.

Notable features such as Adaptive Cruise Control (ACC), Blind Spot Warning (BSW), and the utilization of algorithms like YOLO (You Only Look Once) for object detection, depth map estimation and the challenges of integrating diverse sensor inputs, are explicated.

Additionally, the report investigates the intricate Electrical/Electronic architecture for ADAS automotive systems, emphasizing the significance of robust architecture for seamless functionality and scalability. This report comprehensively explores the significance of ADAS, delving into its rationale, challenges, components, and functionalities. Despite its promising potential, ADAS deployment encounters multifaceted challenges, including regulatory frameworks, technological limitations, and integration complexities.

# Introduction

An *advanced driver-assistance system* (ADAS) includes technologies that assist drivers with the safe operation of a vehicle. Through a human-machine interface, ADAS increases car and road safety. ADAS uses automated technology, such as sensors and cameras, to detect nearby obstacles or driver errors, and respond accordingly. [1]

## 2.1 Why ADAS?

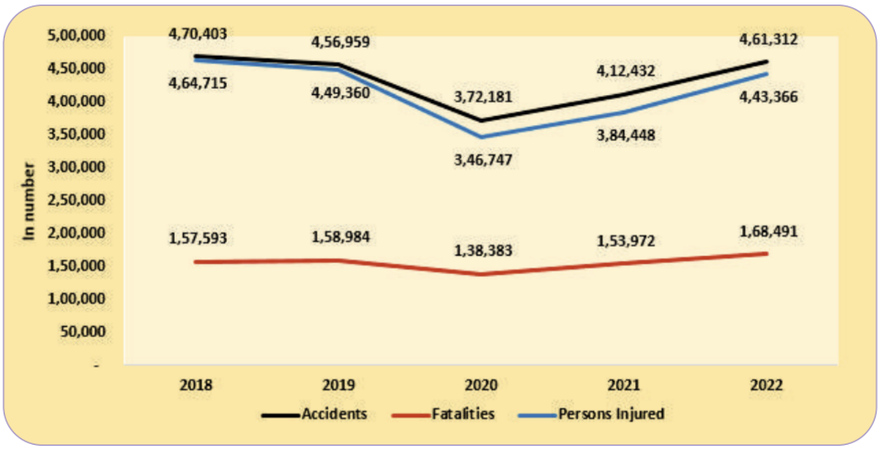


Figure 2.1: Road accident and fatalities trend

As per the data collected by the *Ministry of Road Transport and Highways*[2], a total number of **4,61,312** road accidents have been reported by States and Union Territories (UTs) during the calendar year 2022, claiming 1,68,491 lives and causing injuries to 4,43,366 persons as shown in Figure 2.1.

Figure 2.2 is a pie chart depicting the various reasons causing road crashes in the year 2022. Hit from back, hit from side and head on collisions are the major causes. Such accidents could have been reduced if ADAS was present in the vehicle.

In Figure 2.3, the left-hand values represent the accidents count for the accident types according to the *UK road safety reports of 2019.* The right-hand values show the potential percentage decrease in number of crashes if all vehicles are equipped with the ADAS features designed to mitigate each respective accident type.

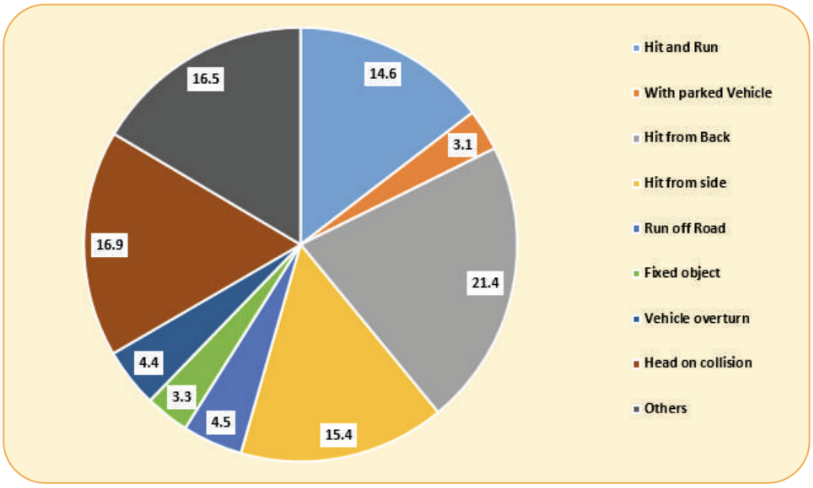


Figure 2.2: Reasons for road crashes during 2022

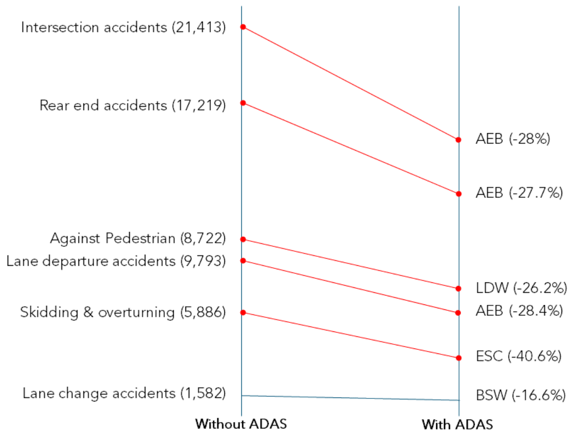


Figure 2.3: Accident reductions using ADAS for the six most frequent accident types[3]

## 2.2 Challenges of ADAS

1. **Increasing Demand for Safety Features:**
   The fatality and mortality rate due to road accidents is increasing day by day. Automotive companies are developing and implementing safety features to meet the customer's needs and safety.

2. **Strict Safety Rules and Regulations:**
   Countries have enacted vehicle laws and regulations to install ADAS safety features such as LDWs and TPMSs on vehicles within a set period of time. Beginning in April 2015, the Government of India amended the *Automobile Law* to require the use of advanced braking systems in all new models of commercial vehicles. Automobile manufactures need to obtain safety ratings from the Insurance Institute of Highway Safety (**IIHS**), New Car Assessment Program (**NCAP**), and International Centre for Automotive Technology (**ICAT**) to access the sales license of vehicles in the market.

3. **High initial cost and complex structure:**
   The high cost associated with sensors, processing chips, ECUs, in vehicles reduces the growth of the advanced driver assistance systems market as this factor leads to higher cost of the car.

## 2.3 Global Market

| | |
|---|---|
| Automotive ADAS Market Size, 2023 | US$ 56,830.30 million |
| Automotive ADAS Market Size, 2024 | US$ 64,047.75 million |
| Automotive ADAS Market Size, 2034 | US$ 2,11,710.80 million |

Table 2.1: Future prediction of market trends by FMI

According to Future Market Insights, in table 2.1, the Automotive ADAS market size is predicted to increase 4 folds by the year *2034* to US$ *211* billion. The Top 4 Automotive Suppliers of ADAS are all European: Bosch, Valeo, ZF and Continental, according to *Auto2x's Global Supplier Ranking by ADAS Revenues.*[4].

Figure 2.4 depicts the market sales percentage of Top 4 ADAS suppliers in Europe for the past 5 years.

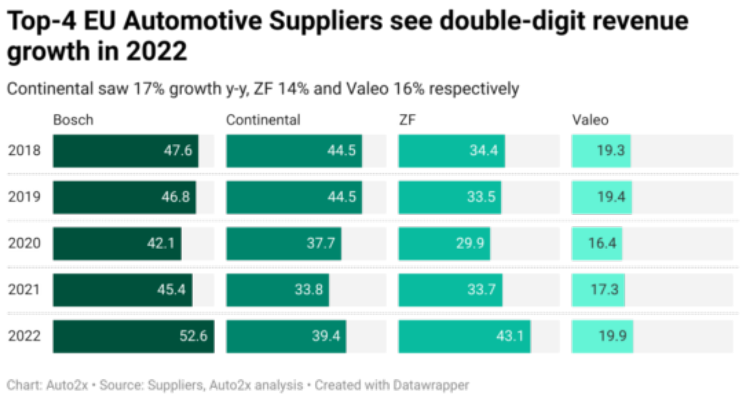


Figure 2.4: Top 4 ADAS suppliers

These companies aim to make the ADAS systems more affordable so that they can be brought to mass-automobile market economies like USA, India. **Asia-Pacific** is estimated to account for the *largest ADAS market share by 2030.*[5]. Many Countries like USA, South Korea, and Europe are developing self driving vehicles and testing them on public roads.

## 2.4 Sensors

A sensor is a device that detects and responds to environmental input. Figure 2.5 gives the functionality of the sensors used for ADAS. **LiDAR** sensors are used for object detection, distance estimation and object edge precision. **Radar** sensors are used for object detection and distance estimation. **Cameras** are used for object classification, lane tracking and object edge precision. The **ultrasonic** sensors has similar functionality to LiDAR. The best fusion of sensors is LIDAR+RADAR+Camera.

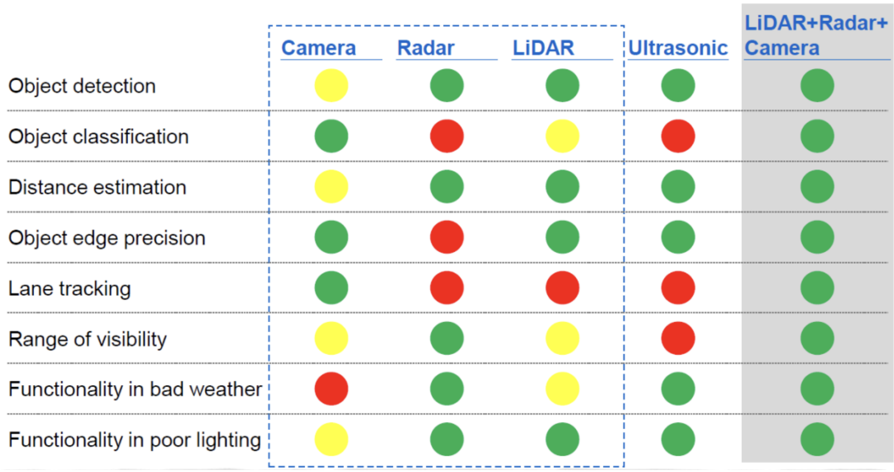


Figure 2.5: Sensors and their functions

Based on a report - *Woodside Capital Partners (WCP), "Beyond the Headlights: ADAS and Autonomous Sensing"*, the approximate cost of components used for ADAS is provided in Figure 2.6. On average the sensors cost around $150.

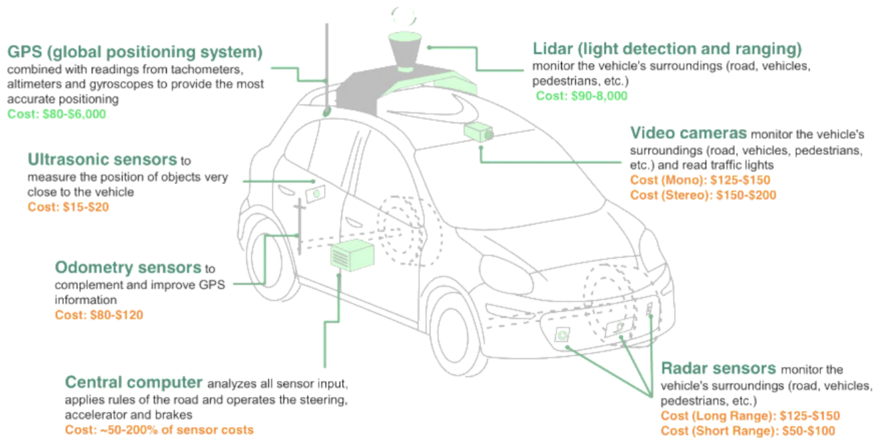


Figure 2.6: Different sensors used and their cost

## 2.5 V2X

V2X stands for vehicle-to-everything. V2X is an exciting technology that will allow modern cars to communicate with other cars, public infrastructure, pedestrians, and even the global network. V2X will communicate with the technology around it—kind of like a Bluetooth device. This allows split-second data transfers allowing extremely fast response times.

1. V2V - Vehicle to Vehicle
2. V2I - Vehicle to Infrastructure

## 2.6 Levels of ADAS

The *Society of Automotive Engineers* (SAE) defines 6 levels of driving automation:

1. Level 0: No automation
2. Level 1: Driver assistance
3. Level 2: Partial automation
4. Level 3: Conditional automation
5. Level 4: High automation
6. Level 5: Full automation

Figure 2.7 provides the various definitions of these levels.

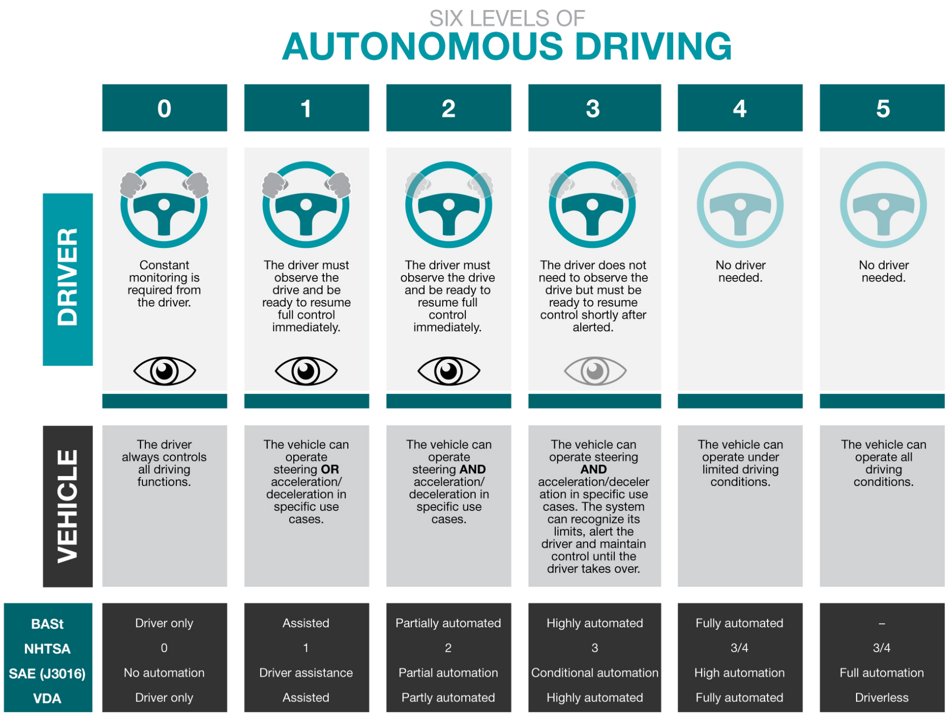


Figure 2.7: Six levels of autonomous driving as defined by the Bundesanstalt für Straßenwesen (BASt), National Highway Traffic Safety Administration (NHTSA), Society of Automotive Engineers (SAE) International, and Verband der Automobilindustrie (VDA)[6]

The more we advance in technology, higher the level of ADAS we reach. The existing ADAS features in the market and the Level of automation they provide is

| | | |
|---|---|---|
| Level 0 | reversing cameras, blind spot warnings, ABS | most of the vehicles |
| Level 1 | adaptive cruise control | most of the vehicles |
| Level 2 | lane-keep assist, Tesla's Autopilot, auto parking | MG Astor, Hyundai Tucson, the Honda City Hybrid |
| Level 3 | Mercedes' Drive Pilot, Traffic Jam Pilot | Audi A8L in Germany |
| Level 4 | region specific | taxi business only |
| Level 5 | no pedals, steering wheel | steering wheel optional automation |

Table 2.2: ADAS fetures vs Levels

shown in Table 2.2

Currently we can see *Level 2 ADAS in the Indian automobile market.* According to *CMR India Auto Market Review Report*, looking ahead, ADAS technology is set to expand beyond the car segment and into 3-wheelers and commercial vehicles. *Level 2 and Level 3* is predicted to account for more than *50% of overall market share.*

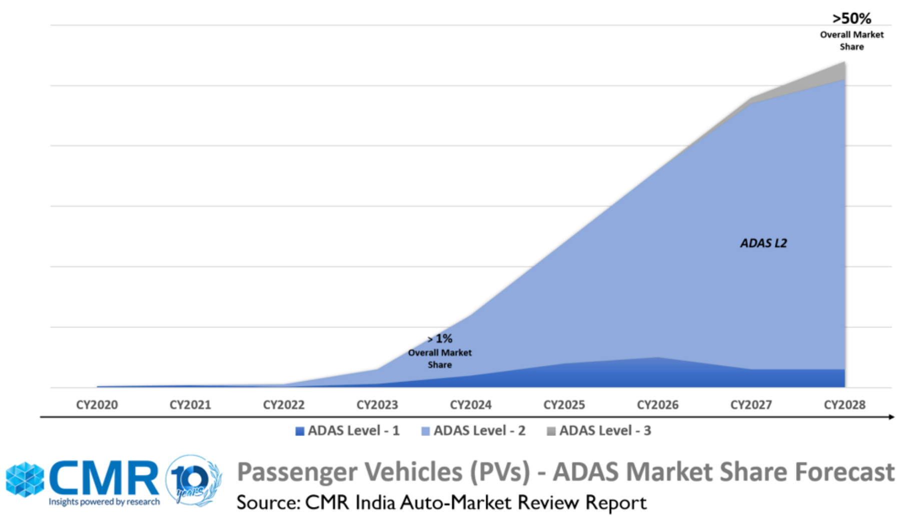


Figure 2.8: ADAS Market share forecast

The future predictions say that we will reach level 5 in the coming decades.

## 2.7 Features of ADAS

The following are the main features of ADAS which are available in the market:

1. Adaptive Cruise Control (ACC)
2. Automatic Emergency Braking (AEB)
3. Blind Spot Warning (BSW)
4. Electronic Stability Control (ESC)
5. Forward Collision Warning (FCW)
6. Lane Departure Warning (LDW)

Based on a report, On the road safety benefits of advanced driver assistance systems in different driving contexts[7] , Table 2.3 is obtained.

Table 3.1 summarises the performance of the six studied ADAS features across the contextual conditions analysed in previous studies. It can be observed that, in general, *clear weather and lighting conditions* relate to better performance in most technologies. Variability in performance is observed across road type categories — motorway, rural, or urban roads. In particular, as motorways have standardised and well maintained lane markings, it leads to a good performance in technologies that rely on lane boundary detection. On the other hand, their high speed ranges imply a constraint on technologies that depend on the braking system, such as AEB.

The **Boston Consulting Group** proposed rating system utilizes diamonds to grade an automobile's ADAS feature performance from one to five. Figure 3.3 and Figure 4.9 provide the guidelines for *standardised 5 diamond rating* for *Adaptive Cruise Control* and *Blind Spot Warning System.*

| ADAS | Road Type | Weather Condition | Lighting condition |
|---|---|---|---|
| ACC | Best performance on motorways. Limitations in rural roads due to curves and roundabouts. Limitations in urban roads due to traffic conditions and road layout | Best performance in clear weather. Limitations with inclement weather leading to higher lost detection rates | Potential limitations in dark environments leading to a higher lost detection rates |
| AEB | Best performance in urban roads due to the low-speed range. Limitations in highspeed roads since the system performs only partial braking at moderate-to-high speeds | Best performance in clear weather due to good road friction coefficient and visibility | Potential limitations in camera-based systems in dark environments |
| BSW | Best performance on motorways due to standardised lane width and traffic flow. Worst performance in rural roads | Best performance in clear weather and limitations with inclement weather due to sensor impairment | Potential limitations in camera-based systems in darkness |
| ESC | Best performance on high-speed roads. Motorways reported better effectiveness than rural | Best performance as conditions worsens and decrease the road friction coefficient | No differences due to system design |
| FCW | No differences due to system design | Best performance in clear weather and limitations with inclement weather due to sensor impairment and braking constraints | Potential limitations in camera-based systems in darkness |
| LDW | Best performance in motorways due to standardised lane markings. Urban roads have the lowest effectiveness due to low-speed system restrictions | Best performance in clear weather and limitations with inclement weather due to sensor impairment and obstructed lane markings | Potential limitations due to obscured lane markings |

Table 2.3: Assessment of performance of ADAS across different driving contexts

# Adaptive cruise control

Adaptive cruise control (ACC) is a driver-assistance system that automatically adjusts a vehicle's speed to maintain a safe distance from the car ahead. As the speed of the vehicle increases less motor force is required as shown in Figure 3.1 and hence *cruising at higher speeds is energy efficient.*

Based on the report, *Learning-based Ecological Adaptive Cruise Control of Autonomous Electric Vehicles*[8] , an optimal control problem for the purpose of ACC was defined, and the speed profile as an optimal solution was obtained through:

1. Dynamic Programming (DP)
2. Approximate Dynamic Programming (ADP)
3. Reinforcement Learning (RL)

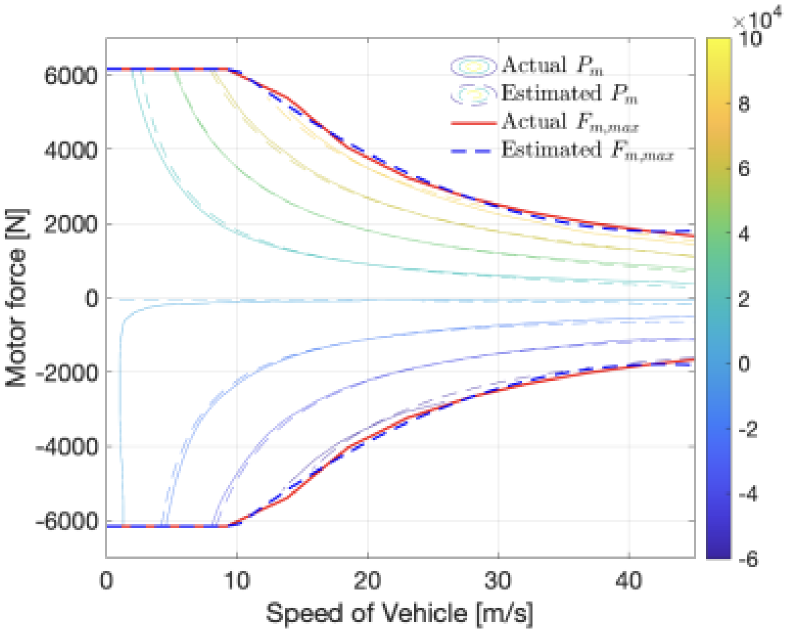


Figure 3.1: Motor power according to vehicle speed and motor force

The host vehicle maintains a distance gap between 0m and safe distance (here *2000m*) from the front vehicle, not crossing the maximum vehicle speed (here *40kmph*), and minimizes the energy in this process. This is considered as the objective function to be minimized in the **optimal control problem.**

$$
\begin{aligned}
&\underset{F_m(\cdot),F_b(\cdot)}{\text{minimize}} \quad J = \int_0^{t_f} P_{mot}\left(v(t), F_m(t)\right) dt \\
&\text{subject to} \quad \frac{d}{dt}d(t) = v_f(t) - v(t) \\
&m\frac{d}{dt}v(t) = F_m(t) - F_b(t) - F_{air}(t) - F_\alpha(t) \\
&v \in [0, 40] \\
&F_{m,\,\min}\left(v(t)\right) \leq F_m(t) \leq F_{m,\,\max}\left(v(t)\right) \\
&F_{b,\,\min} \ \leq F_b(t) \leq F_{b,\,\max} \\
&F_m(t)F_b(t) \leq 0 \\
&d(t) \in (0, 2000] \\
&where, \\
&F_m : MotorForce \\
&F_b : BreakingForce \\
&d : distance between the vehicles \\
&v : velocity of the host vehicle
\end{aligned}
\tag{3.1}
$$

## 3.1 Dynamic Programming

DP is based on the *principle of optimality,* that is, optimization in the future does not depend on the initial conditions and past-control inputs. The algorithm solves complex problems by dividing them into sub problems, and it reuses the solution of the sub problems in the process of solving more complex problems.

## 3.2 Approximate Dynamic Programming

The values obtained in Dynamic Programming is approximated by approximate value functions:

1. **Polynomial regression**:
   describe the relationship between the independent variable x and the dependent variable y using an nth-degree polynomial in x.

2. **Gaussian process regression:**
   makes predictions incorporating prior knowledge (kernels) and provide uncertainty measures over predictions.

3. **Neural network approximation**

## 3.3 Reinforcement Learning

Adaptive Cruise Control works on the Reinforcement Learning Framework. Reinforcement learning (RL) is a machine learning technique that uses *feedback* to teach agents how to behave in an environment. The agent performs actions and receives positive or negative feedback based on the results. The main goal is to maximize the reward. Here it is *maximise the energy efficiency*. Figure 3.2 provides a basic framework of Reinforcement Learning.

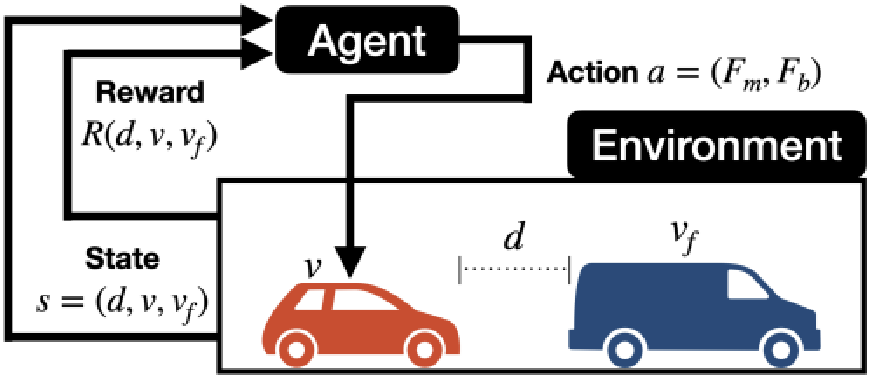


Figure 3.2: Basic framework of model-free RL-based Eco-ACC

| Vehicle System Performance Criteria | ♦ | ♦♦ | ♦♦♦ | ♦♦♦♦ | ♦♦♦♦♦ |
|---|---|---|---|---|---|
| Maintains programmed following distance | Uncomfortable, late deceleration | Improved decelera-tion response | Good deceleration response | Excellent deceleration response | Excellent deceleration response |
| Automatic resume after slow/stop | Does not automati-cally resume | Improved accelera-tion response | Good acceleration response | Excellent acceleration response | Excellent acceleration response |
| Roadway Functionality | Freeway only | Freeway only | Freeway/highway | Rural and city streets and freeways/highways | Rural and city streets and freeways/highways |
| Stationary object detection and classification range | May not detect | May not detect | May not detect | Mid-range detection and classification | Far-range detection and classification |
| Peripheral object detection and classification coverage | No perception coverage | Limited perception coverage | Limited perception coverage | Good perception and classification coverage | Broad detection and classification coverage |
| Light and Weather Performance | Suffers in low light and inclement weather | Better in low light and inclement weather | Better in low light and inclement weather | Performs well in all light and most weather | Performs well in all light and most weather |

Figure 3.3: guidelines for standardized five diamond rating system for Adaptive Cruise Control proposed by Boston Consulting Group

According to Figure 3.3, if ACC is able to provide excellent deceleration response, excellent acceleration response, good functionality in all roadways, far-range detection, good performance in all light and most weather, a *5 diamond rating* can be obtained.

# Blind Spot Warning

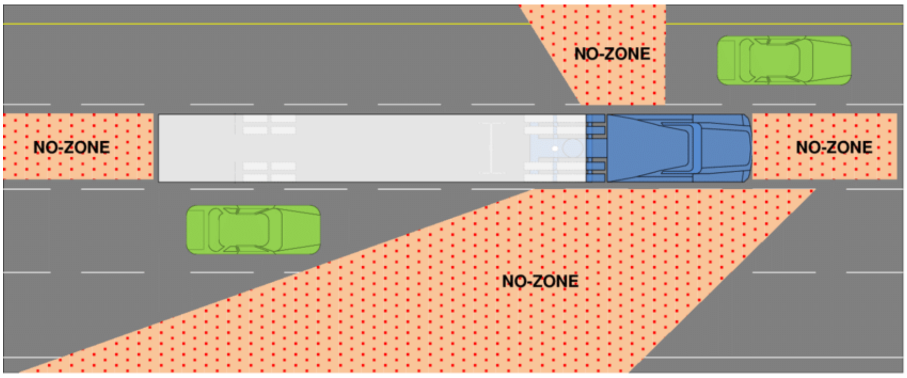


Figure 4.1: Tractor-trailer blindspots adapted from the FMCSA NO-ZONE campaign

The blind spot warning is a vehicle-based sensor device that detects other vehicles located to the driver's *blindspots* (see Figure 4.1). Warnings can be visual, audible, vibrating, or tactile. These warnings are based on a **Blind Spot Model.** Figure 4.2 provides a schematic diagram of a blind spot model.

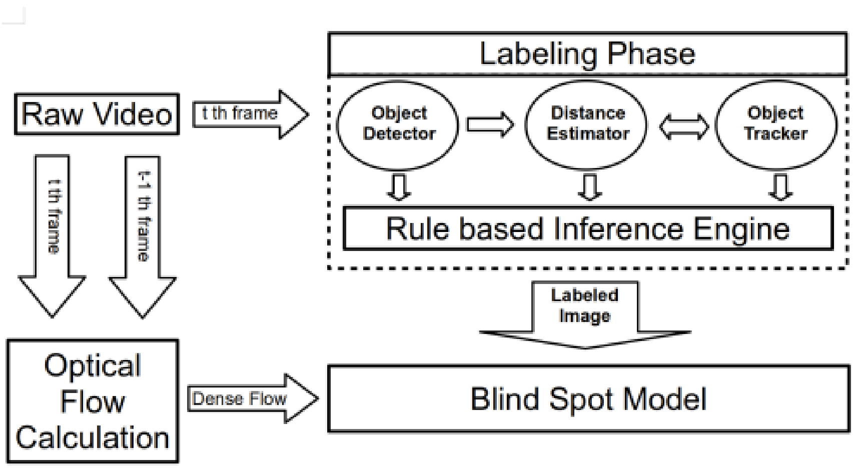


Figure 4.2: Blind Spot Model

The Blind Spot Model includes:

1. instance segmentation using *YOLOv2* or RCNN [9] .
2. depth map [10] .

Hence we obtain a rough 3d map of the environment with labelled objects. If the class of the object belongs to pedestrian or a vehicle, the distance between them is calculated using the 3d map and warning based on the distance is sent to the driver.

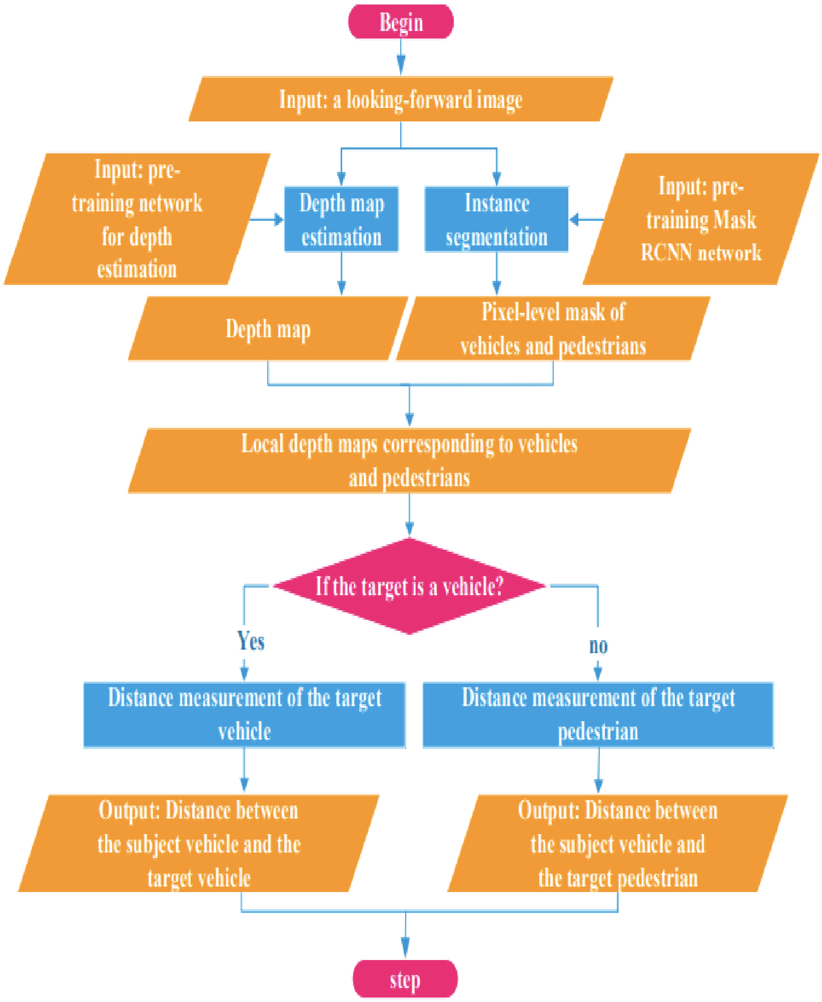


Figure 4.3: The flowchart of distance approximation

## 4.1 YOLO

YOLOv2 is a state-of-the-art, real time object detection system that can detect over *9000 object categories* (see Figure 4.4). YOLOv2 method leverages labeled detection images to learn to precisely identify the boundaries of an object while it uses classification images to increase its vocabulary and robustness. Features of YOLOv2 are:

### High Resolution Classifier

Detection methods use classifier pre-trained on ImageNet.

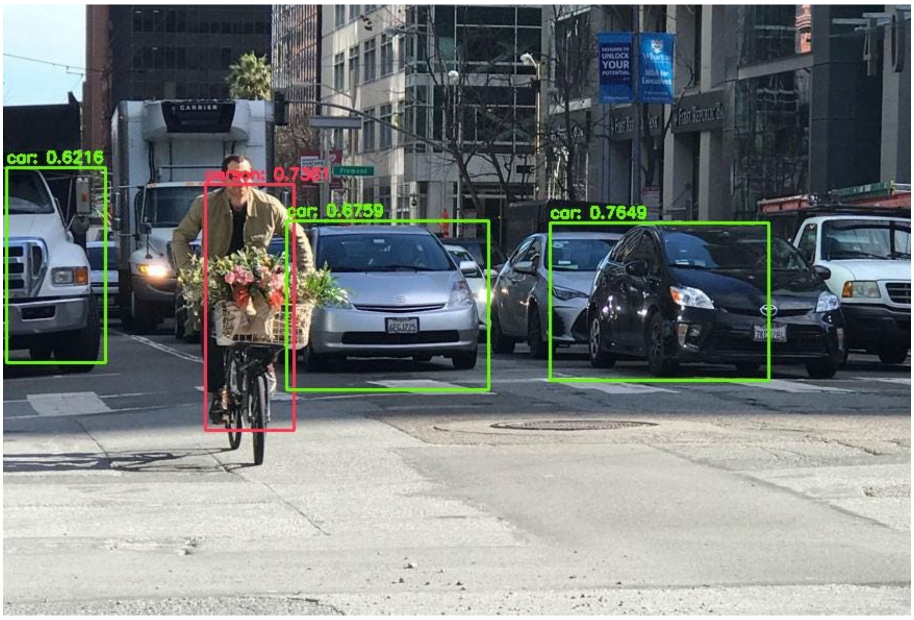


Figure 4.4: YOLO object detection

### Convolutional With Anchor Boxes

YOLO predicts the coordinates of bounding boxes directly using fully connected layers on top of the convolutional feature extractor.

### Direct location prediction

### Fine-Grained Features

YOLOv2 turns 26 $\times$ 26 $\times$ 512 feature map into a *13 $\times$ 13 $\times$ 2048 feature map,* which can be concatenated with the original features. It predicts detections on a 13 $\times$ 13 feature map. At low resolutions YOLOv2 operates as a cheap, fairly accurate detector.

### Darknet-19

Darknet-19, a classification model, only requires 5.58 billion operations to process an image yet achieves 72.9% top-1 accuracy and 91.2% top-5 accuracy on ImageNet.

### Hierarchial classification

ImageNet labels are pulled from *WordNet*, a language database that structures concepts and the relation between one another. WordTree is a hierarchical model of labelling objects. WordTree combines the labels from ImageNet and *COCO*. Figure 4.5 provides the hierarchical structure of WordTree.

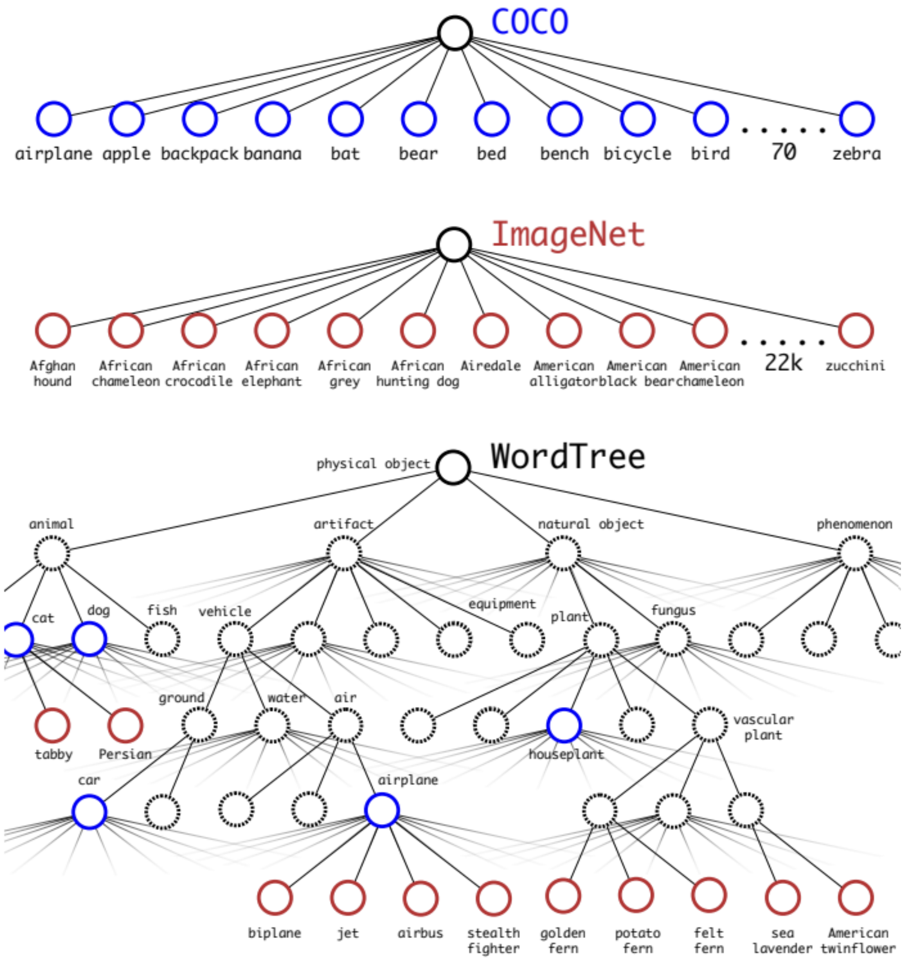


Figure 4.5: Combining datasets using WordTree hierarchy

## 4.2 Depth map estimation

### Relationship between Disparity and Depth

From Figure 4.6, we can derive and obtain the depth coordinates.

$$
\begin{aligned}
&\frac{x_p^l}{x_l} = \frac{z_p^l}{f}, \frac{x_p^r}{x_r} = \frac{z_p^r}{f} \\
&\frac{x_p^l}{x_l} = \frac{z_p^l}{f}, \frac{x_p^l - b}{x_r} = \frac{z_p^l}{f} \\
&z_p^l = \frac{fb}{d} \\
&where \\
&z_p^l : depthcoordinateofleftview \\
&d : x_l - x_r \\
&f : focallength \\
&b : baselinedistance
\end{aligned}
\tag{4.1}
$$

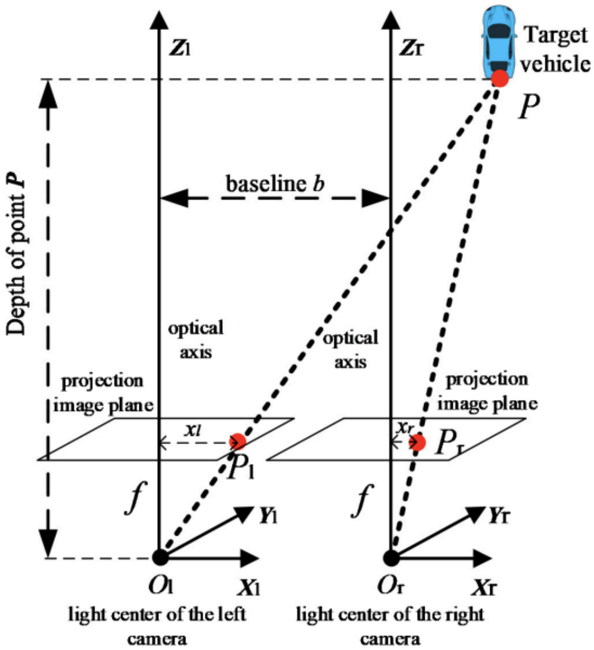


Figure 4.6: The depth estimation principle based on the left and right views

### Semi-Supervised Learning Network for Depth Map Estimation

During the training process, the inputs are the left and right views, and the corresponding sparse depth labels that have been matched with the left and right views, respectively. The outputs of the deep network are two disparity maps corresponding to the left and right views. The loss functions used for training this network contain *appearance matching loss, disparity smoothness loss, left–right disparity consistency loss,* and *supervised loss* (see Figure 4.7).

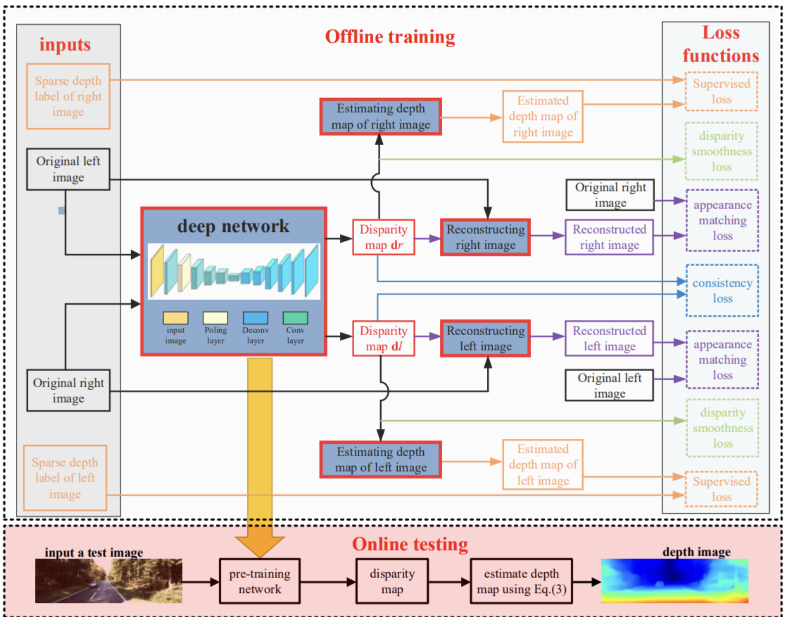


Figure 4.7: Depth estimation network and its loss functions

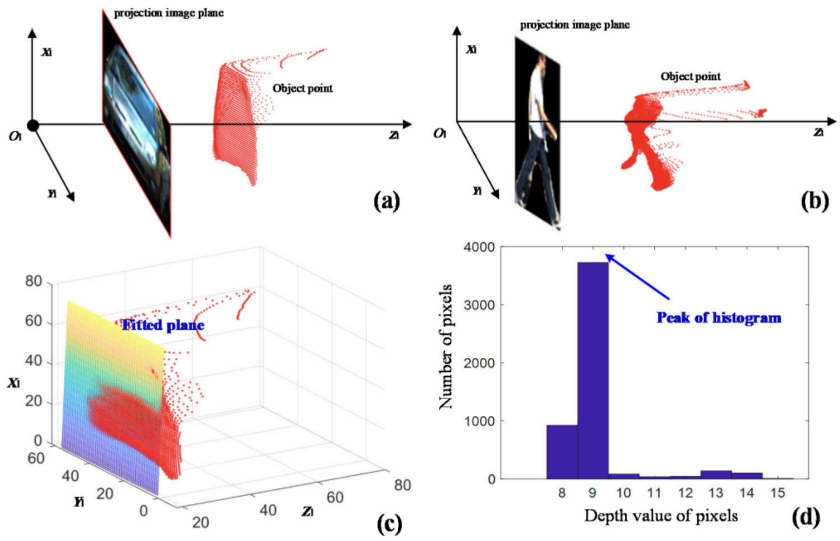


Figure 4.8: Locations of the object points in the camera body coordinate system. (a) The object point locations of the car. (b) The object point locations of the pedestrian. (c) The fitted plane using the object points of the car. (d) The depth histogram of the object points of the pedestrian

When the offline training is completed, we can obtain a *pre-trained depth estimation network*. The depth values of all pixels form a depth map corresponding to the input image as shown in Figure 4.8

| Vehicle System Performance Criteria | ♦ | ♦♦ | ♦♦♦ | ♦♦♦♦ | ♦♦♦♦♦ |
|---|---|---|---|---|---|
| Peripheral field of view | Narrow | Wider | Wider | Broad, 180 degree field of view | Broader than 180 degree field of view |
| Peripheral vehicle detection and classification coverage | Near range detection | Mid-range detection | Mid-range detection | Mid-range detection and classification | Expansive mid-range detection and classification |
| Peripheral object detection and classification coverage | May not detect | May not detect | Mid-range detection | Mid-range detection and classification | Expansive mid-range detection and classification |
| Dynamic driving intervention capability | Warning only | Warning only | Active collision avoidance with vehicle in blindspot | Active avoidance of vehicles, motorcycles, bicycles, and pedestrians | Active avoidance of vehicles, motorcycles, bicycles, and pedestrians; Lane Change Assist |
| Light and Weather Performance | Suffers in low light and inclement weather | Better in low light and inclement weather | Better in low light and inclement weather | Performs well in all light and most weather | Performs well in all light and most weather |

Figure 4.9: guidelines for standardized five diamond rating system for Blind Spot Warning proposed by Boston Consulting Group

According to Figure 4.9, if the Blind Spot Warning system is able to provide a field of view greater than 180 degree, to provide an expansive mid range detection and classification of objects and vehicles, to provide active avoidance of vehicles, and performs well in all light and most weather, a *five diamond rating* can be obtained.

# E/E architecture

Electrical/electronic (E/E) architecture in automobiles is a system that integrates electronics hardware, software applications, network communications, and wiring. Figure 5.1 shows the evolution in E/E architecture and their features.

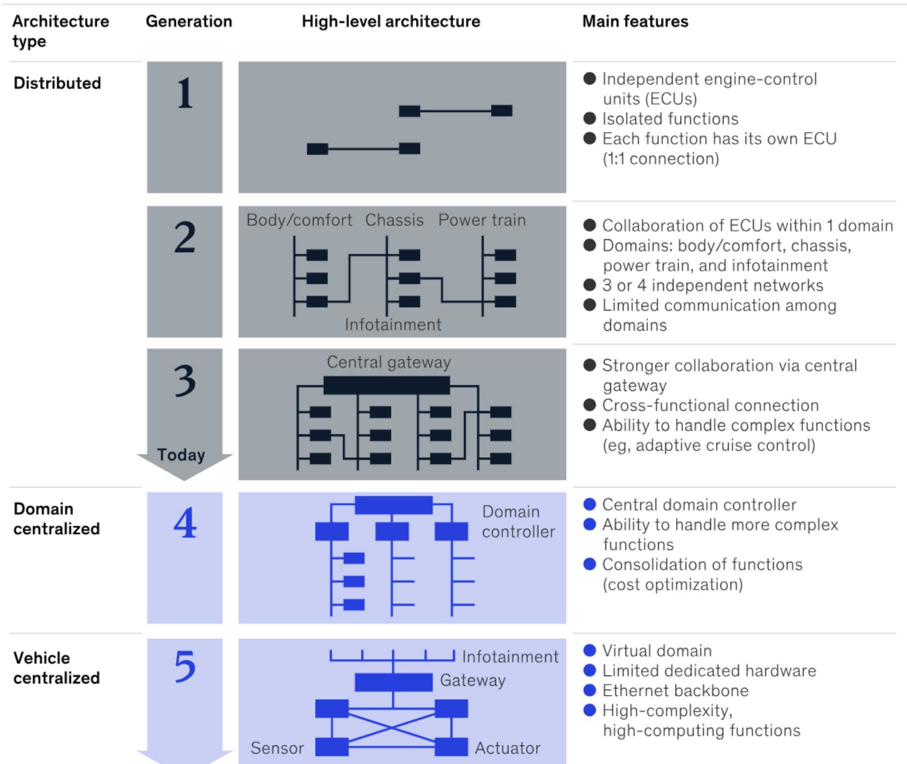


Figure 5.1: E/E architecture and their features[11]

Automakers are now evolving towards **Zonal E/E architecture** to address increasingly complex ADAS and autonomous driving requirements. As evidence of these shifts, *Qualcomm* announced in late 2021 that it was working with *BMW* on its next generation of AV systems.

In domain architectures, dedicated *ECU*s that are typically in proximity to the sensors or actuators perform these functions. New features and functions usually result in new ECUs, each with dedicated battery power and networking wires, further increasing harness complexity. The introduction of zonal modules can greatly *reduce harness complexity* by merging the logical input/output (I/O) functions of multiple ECUs into the zonal module, and by maintaining sensor and actuator locations.

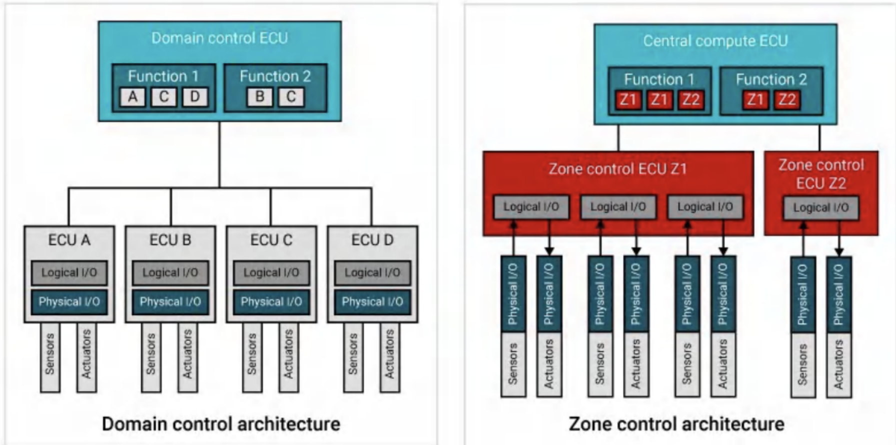


Figure 5.2: Difference in Domain and Zonal architectures

This results in separation of physical and logical I/O functionality as shown in Figure 5.2. [12]

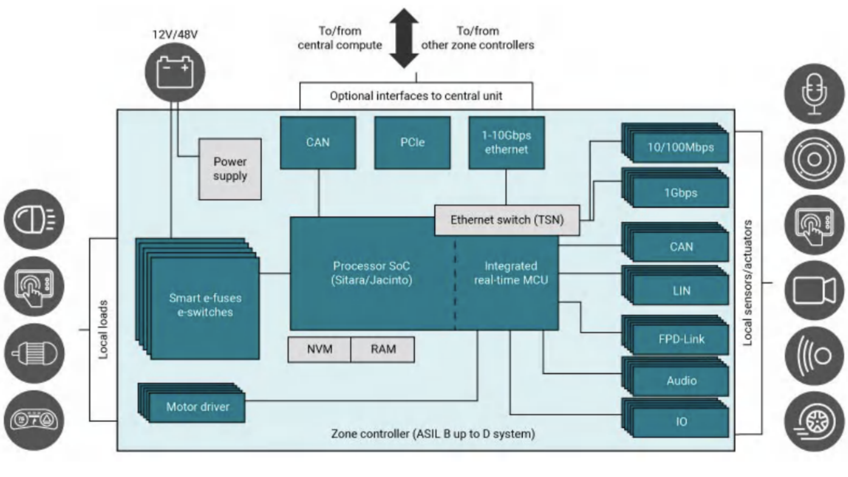


Figure 5.3: Zonal module block diagram with communication interfaces

Figure 5.3 is a block diagram of a typical zonal module that includes high-speed communication links. For the different throughput needs, and to provide bandwidth for a combination of traffic between the zonal module and central computing, gigabit *Ethernet*, and potentially PCIe could be vital. The data from the *sensors* is processed in the *processor Soc* and *MCU*s. The ADAS features are ensured and the action signal is sent to the *Actuators.*

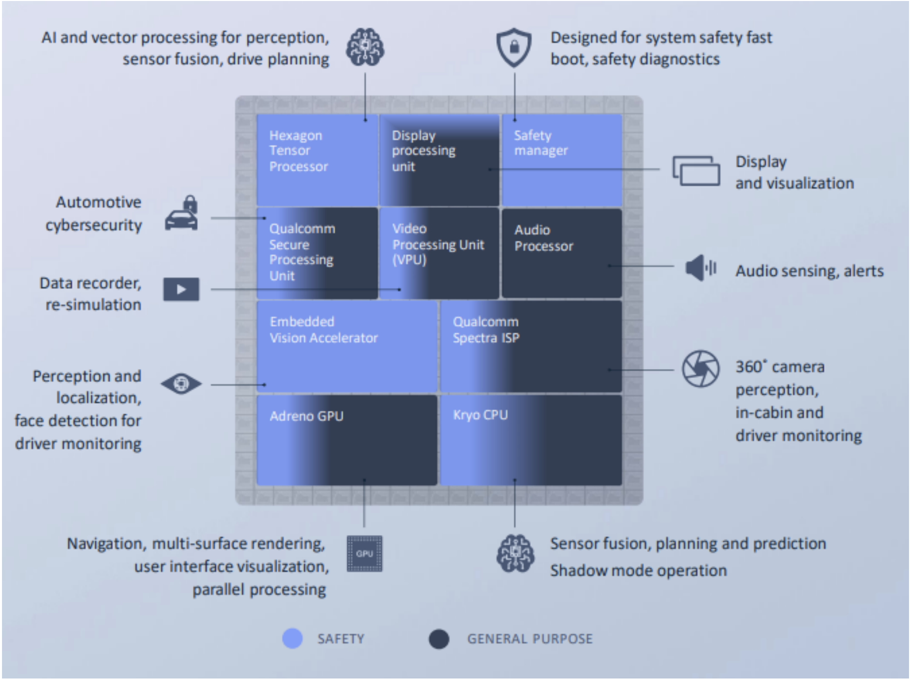


Figure 5.4: Snapdragon Ride SoC

Figure 5.4 is an example of SoC used in Zonal modules which was introduced on *Auto-Investor-Day-Sep2022* by Qualcomm. This SoC is scalable and can provide ADAS features upto *Level 4 automation*. It Offers software compatibility across generations and provides Cutting-edge AI with Hexagon Tensor Processor and Qualcomm® AI Stack.[13]

# Conclusion

In conclusion, the advent of Advanced Driver-Assistance Systems (ADAS) marks a significant stride towards enhancing vehicle safety and road security. The alarming statistics of road accidents and associated casualties underscore the critical need for ADAS. ADAS is poised to address the complex challenges of modern road safety. The report emphasizes the potential impact of ADAS in reducing accidents, especially those caused by rear-end collisions, side impacts, and head-on collisions.

Despite the increasing demand for safety features and stringent safety regulations, the high initial cost and complex structure of ADAS present challenges to widespread adoption. However, the commitment of automotive companies to make these systems more affordable, as highlighted by the market sales percentage of top ADAS suppliers, signals a positive trajectory for the future.

Sensors play a pivotal role in the effectiveness of ADAS, with LiDAR, Radar, and Cameras offering distinct functionalities. The fusion of these sensors into a comprehensive system enhances object detection, distance estimation, and object edge precision. The report provides insights into the approximate cost of these sensors, indicating a trend toward affordability.

The report also delves into the standardized five diamond rating system for Adaptive Cruise Control and Blind Spot Warning, emphasizing the importance of expansive mid-range detection and classification of objects.

The evolution of Electrical/Electronic (E/E) architecture, particularly the shift towards Zonal E/E architecture, addresses the complexities associated with advanced ADAS and autonomous driving requirements. The introduction of zonal modules and scalable System-on-Chip (SoC), such as the Snapdragon Ride SoC, exemplifies the industry's commitment to innovation.

In conclusion, the future of ADAS appears promising, with advancements in technology, collaborative efforts between automotive giants, and a collective commitment to making roads safer for all. The journey towards intelligent, connected, and autonomous vehicles is underway, shaping a future where road accidents are substantially reduced, and transportation becomes more secure, efficient, and accessible.

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