Otto-von-Guericke-University Magdeburg
Faculty of Electrical Engineering and Information Technology
Chair for Electromagnetic Compatibility

Non Technical Project Report

An Overview of Self-Driving Car

submitted: October 10, 2021

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born on February 1, 1991
in Magura, Bangladesh

Abstract

This report focuses on the recent growing industry of Self-Driving Car. A brief history of this industry. Classification of an autonomous car based on its operational capabilities and design domain. Some projects regarding this industry are the point of discussion. The first driving task is perceiving the environment and seeing the environment around the car through sensors. The second task is driving decision planning and actions. Typical sensors that autonomous car uses to observe the surroundings are also the point of discussion. Some basic maps for path planning are finally the point of focus.

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

EIT

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY

Non-Technical Project Task Assignment

for Mr. Md Yasin ARAFAT (born on 01.02.1991 in Magura, Bangladesh)

Topic: Overview of Self-Driving Cars

Almost all giant car manufacturing companies are working on the idea of autonomous vehicle nowadays. In a meeting on 8. September 2020, the German chancellor together with the CEO's of the German automotive industry agreed that Germany should take a pioneering role in the development of fully automated self-driving cars. In February 2021, BMW and Mercedes-Benz started a collaboration to develop automated driving and driving assistance systems as a joint competitor to technological companies like Google, who have also entered this market. On 10 February 2021, the German federal government adopted a draft in order to initiate the regular operation of autonomous vehicles on the road. However, the technology is still a barrier towards the issue of safety and security.

The goal of this work is to give an overview on current self-driving cars, their taxonomy of different driving modes, requirements for perception, driving decisions and actions, required sensors, computing hardware and their purpose, as well as different map types traditionally used for autonomous vehicles.

The main objective of this work is literature analysis.

In detail the following things must be done:

- literature research,
- writing a report (at least 30 pages, at most 40 pages, from the introduction to the summary), and
- giving a final presentation of 15 minutes.

Magdeburg, May 25, 2021

Date of issue:	25.05.2021
Date of submit:	19.07.2021
Editing time:	8 weeks

R. V

Prof. Dr.-Ing. R. Vick
Assignor of the task

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Examiner: Prof. Dr.-Ing. R. Vick

Declaration by the candidate

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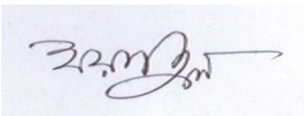

Contents

List of Acronyms

ADS	Automated Driving System
ASIC	Application Specific Integrated Circuit
CPU	Central Processing Unit
DARPA	Defense Advanced Research Projects Agency
DDT	Dynamic Driving Task
FOV	Field-of-View
FPGA	Field Programmable Gate Array
GM	General Motors
GPS	Global Positioning System
GPU	Graphics Processing Unit
IMU	Inertial Measurement Unit
LIDAR	Light Detection And Ranging
NHTSA	National Highway Traffic Safety Administration
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
RADAR	Radio Detection And Ranging
RCA	Royal College of Arts
SAE	Society of Automotive Engineers
SONAR	Sound Navigation And Ranging

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1 Introduction

In the last couple of decades self-driving car industry is blooming. Road crash statistics are shown that around 95% are related to the error done by human. 30000 people during 2011 were killed in the European Union, and more were injured on roads [10]. Self-driving car potential to reduce accidents on road, as well as empower driver to invest time to do other activities on road. It may help to improve overall driving system more efficient and effective, hence it will reduce fuel cost and decrease impact on environment.

The prime concern of the car manufacturers is to achieve different level autonomy. In this paper has discussed about its different level, some research projects and examples at those levels. Both Europe, and Americans automobile industries are actively working on self-driving car in order to get market advantage. Though multi-agents support and id Governments are also supporting through adapting different legislation and reconstructing roads.

This report is consisted with nine division starts from the background history, to some recommendation for legislation by NHTSA at the last. In between taxonomy of self-driving cars, how it perceives the encountered driving environment and makes decision, basic sensors that are used in common, and maps to navigate its way from starting to destination have been discussed in each division.

2 Background of Self-Driving Car

Self-driving cars are being driven through digital technologies without having human help. It is empowered of driving and routing itself by analyzing the surrounding environment and considering its impact [1].

Historic events in the past shaped today's autonomous vehicle industry. The most primitive form was Radio controlled car. That was the first leap of this industry, that was demonstrated in 1926 in New York City and called as 'Linriccan Wonder'. Later in 1939 GM (General Motors), developed embedded circuits to power electric cars. Royal College of Arts (RCA) Labs generated an idea in laboratory floor, later it was developed by Leland Hancock and L. N. Ress in large scale. They performed several tests in 1953 on a decorated highway prepared for the car. Later, General Motors collaborated with them and updated the model further. This updated model was showcased in on an automatic highway without having driver's intervention. This triggered Ohio State University's Communication and Control Systems Laboratory in 1966 to develop cars that was activated using electronic devices incorporated in roadway. The United State's Bureau of Public Roads took into account that the development of an experimental electronically controlled roadway, for which, states like: Ohio, Massachusetts, New York, and California - went to bade for the development. Finally Governor, DiSalle got the opportunity for this future robotization project. Within the 1980s, a vision-guided driverless Mercedes-Benz automated van, which was modeled by Ernst Dickmanns and his team the Bundeswehr University Munich, Germany, reached a speed of 63 $\frac{\mathrm{km}}{\mathrm{h}}$ on streets without traffic [2].

The journey of self-driving car has been geared up with early advances in Europe in the 1980s. Most of the giants in car industry - Mercedes Benz, Audi, BMW, Tesla, Hyundai etc. - have started creating or shaping associations around independent innovation. They have already invested sizable assents into this, and doing so they are eager to be pioneer in this industry by showcasing their self-driving cars. Till now, various funds, computer program and sensors have been put into these cars, but it is still yet to seen full autonomy [1].

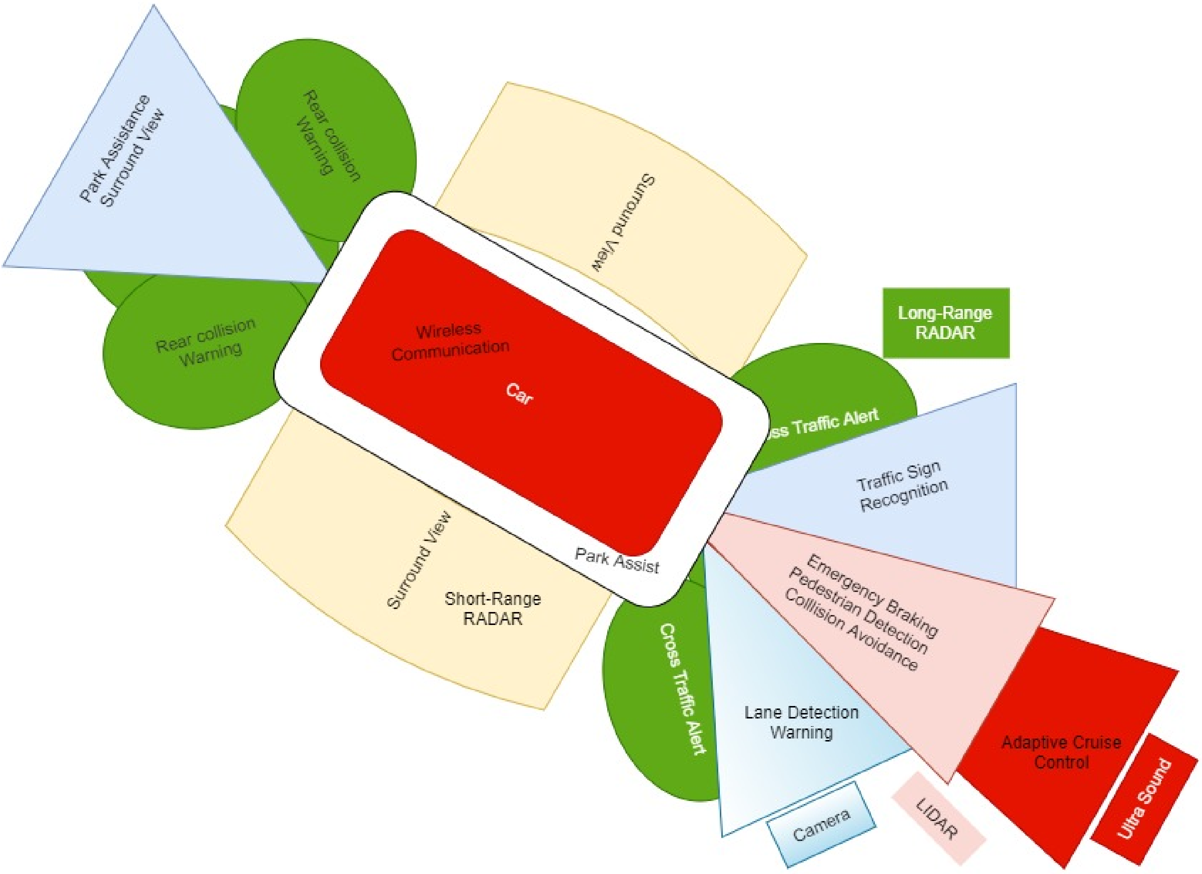

Figure 2.1: Common View of Self-Driving Car [3]

we can see a common self-driving car showing its different wireless communication strategy based on short and long range. The figure is also showing that the range of doing different driving tasks like identifying pedestrians, parking, lane changing, or traffic light detection usually uses different types of sensors that covers different range for that specific driving tasks (see Fig. 2.1).

3 Taxonomy of Self-Driving Car

The level of driving automation are defined by the three primary actors in performance of DDT, active safety systems - like stability control system, crash avoidance functions - intervention avoidance systems. It also needs to consider: lateral Control, longitudinal Control, OEDR, and Planning [4]. The NHTSA received the levels of the SAE for computerized driving frameworks, which gives a wide range of holistic human participation to full autonomy. NHTSA suggested car producers to classify each vehicle in upcoming days using SAE 0 to 5 levels [1]. These levels have been discussed below.

3.1 Level 0: No Automation

This is based on human perception, regular driving. No automation is shown in this level. Example of this type is simply human driving [5].

3.2 Level 1: Driver Assistance

It includes either lateral or longitudinal control. It can not handle both. One example are adaptive cruise control and lane keeping assistance – driver can stay in the lane, if drifts. Driver must put hand on steer [5].

3.3 Level 2: Partial Driving Automation

Both longitudinal and lateral control can be handled automatically, but driver monitoring is required. Driver can put off hands from steer, but have to monitor road.Tesla's Autopilot is running using this level since 2014 [5].

Figure 3.1: Tesla Autopilot with Level 2 Automation [6]

Fig. 3.1 is showing Tesla autopilot with level 2 automation. Though lateral and longitudinal control can be achieved by this car, but constant monitoring is a must by the driver.

3.4 Level 3: Conditional Driving Automation

Both longitudinal and lateral control can be done automatically, and Object and Event Detection Response can be handle to some degree. That means hand and eyes can be off from driving. But in case of failure, driver must take over the control. System should alert driver while intervention is approaching. Audi A8 Sedan can navigate with out being monitored in slow traffic [5].

Figure 3.2: Conditionally automated driving with the Drive Pilot [7]

Traffic jams could be seen from a new perspective in this level of automation (see Fig. 3.2). Drive Pilot is currently placed in Germany as the country developed a legal basis for level 3 in 2017. It will penetrate the European, American, and Chinese markets as soon as legal framework is established [7].

3.5 Level 4: High Driving Automation

Longitudinal, lateral, and OEDR can be handled automatically. It also reacts to emergencies by its own. Driver can entirely focus on other task at this level. However, it may ask for human help during extreme intervention, and it will not allow passengers harm if human help is absent. Waymo is running on this level for few years now [5].

Figure 3.3: Waymo's on Street Car showing Level 4 Automation [8]

3.6 Level 5: Full Driving Automation

Along with longitudinal, lateral, and OEDR control, it has unlimited Operational Design Domain. It allows to drive under any condition necessary. In this stage, society will undergo transformational change. At this stage, all car seats might face each other to make a social space as car neither demands help. Cars are allowed to move by itself if no human is on-board at all. There are no example as of yet shown this level of autonomy. This type of autonomy are yet to be shown in real world [5].

4 Self-Driving Cars Research Projects

This chapter will describe some major autonomous car research projects focusing on sensing. Since most of the projects are done by giant automotive car manufacturing companies, hence there is little information available for public [9].

4.1 Google Driver-Less Car

Figure 4.1: Google's automated Car [10]

This car visited over 30000 km on public roads. The main sensor of it is Velodyne HDL64E LIDAR mounted on roof. This helps to create very good resolution map of the environment, and 360 degrees view. Along with it 4 RADAR units also are used with high range for the identification of others vehicle. A camera is used on rear-view to detect the traffic lights. GPS and wheel encoder are used to perfectly find out the car position. The car is necessary to start manually first for the safety purpose and to create a map of the environment. After successfully starting, the car refresh the data taken by sensors withing the environment and starts differentiating among stationary objects, and pedestrians (see Fig. 4.1) [9].

4.2 BMW Connected Drive

Figure 4.2: BMW connected Drive Project Car [11]

This report focuses primarily on automating highway functions. This test car is equipped with RADAR, LIDAR, Ultrasonic and vision systems. The company is also working together with automotive sensor supplier Continental (see Fig. 4.2) [9].

4.3 Mercedes S500 Intelligent Drive

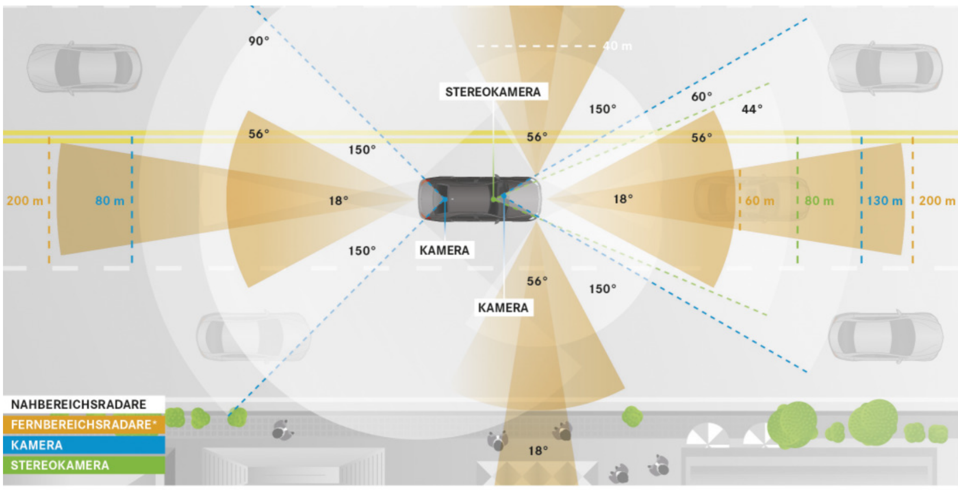

Figure 4.3: Intelligent Drive Car Layout of Sensors [12]

In reality sensor overlapping is higher. It has extra two long-range RADAR for lateral detection, while previously 4 short-range RADAR was installed to cover surroundings and others agents of the roads. An extra camera is installed behind the windscreen to detect traffic lights. Another camera is helping GPS system to find exact pose of the vehicle (see Fig. 4.3) [9].

4.4 Toyota / Lexus Research Car

Figure 4.4: Research Car of Toyota/Lexus [13]

On its roof a 360 degree FOV LIDAR is mounted with a range of 70 meter, 3 colored cameras (1 is forward facing, and another 2 are facing sideways) with a range of 150 meter. There is a RADAR in front to detect traffic light, and two more RADAR facing side-ways to detect speed of other vehicles. And a GPS is also installed to determine the position (see Fig. 4.4) [9].

4.5 VisLab BRAiVE

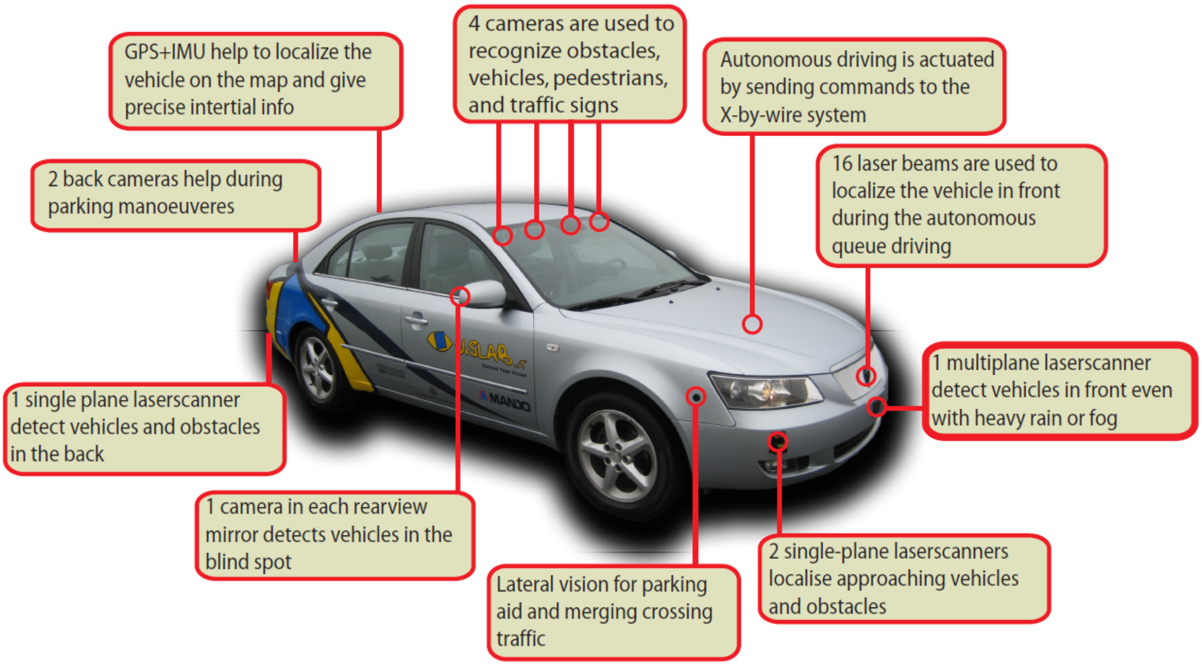

Figure 4.5: BRAiVE Car with Sensors Location [14]

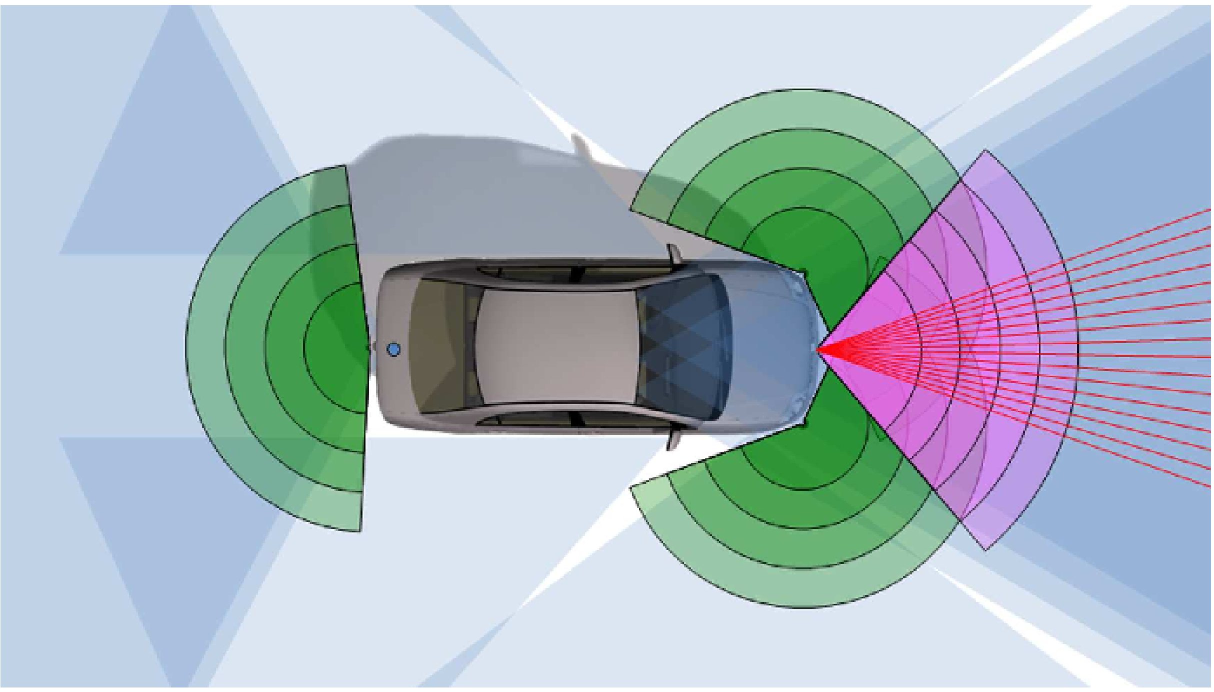

Figure 4.6: Coverage of Detection by Sensors on BRAiVE Car [14]

The BRAiVE car is automated car made by VisLab, lead by Alberto Broggi, a pioneer in automated vehicle research field. The company has 15 years of experience in self-driving field. It has main focuses on 3D vision sensing as input for the car. It features 10 cameras, 5 LIDARs, and a GPS unit. The placement of these hardware is shown in Fig. 4.5 and Fig. 4.6 [9].

4.6 BOSS Car

Fully automated cars take participate in DARPA Urban Challenge. They perform on driving tasks like headway, and turning. They also perform on special tasks like parking, and U-turns. Many academic as well as companies participate in this challenge. The figure shows a Boss vehicle that uses 11 LIDAR sensors, 2 Cameras, and 5 long range RADARs [9].

Figure 4.7: Boss Car for DARPA Urban Challenge [15]

5 Perception and its Importance

People are continually taking in information from the world around them utilizing five essential senses. One listens ones' phone ring, sees a notification on computer screen, or touches something hot. However, without recognition, there is no way to decode those inputs and decide what is relevant. During driving consistent stream of data encompasses us. From path markings and road signs to lane-splitting motorcyclists, blending trucks, and traffic jams - the capacity to form instant, educated choices is not fair expertise, it is an imperative. Just as perception enables humans to form moment affiliations and act on them, the capacity to extricate pertinent information from prompt environment may be a crucial pillar for the secure operation of an autonomous car. With the control of perception, a car can identify vehicles ahead utilizing cameras and other sensors, recognize in case they become potential risks and know to persistently track their developments. This capability amplifies to the 360 degree field around the vehicle, empowering the car to distinguish and track all moving and inactive objects because it travels. Perception is the primary organize within the computational pipeline for the secure working of a self-driving car. Once the vehicle is able to extricate important information from the encompassing environment, it can arrange the path ahead and activate, all without human intervention [16].

Perception is accountable for creating a model of the environment and behavior subsystems. At first car needs to understand what is happening around it and what is its position within the environment. Driving tasks demand Object and Event Detection and Response. It means that car needs to identify car, a cyclist, a bus, lane markings etc. Humans are good at identifying patterns. But it is still difficult to understand it by computers to recognize as efficiently as humans. Humans can see and predict if a car will remain stand still or start moving, but for cars it is difficult. Hence the ability of predicting this trajectory of a moving object is crucial for perception. Informed decision is dependent on identifying perception correctly. It needs to identify static objects like roads and lane markings, segregation regions like zebra crossing, and symbols or messages like schools or hospitals are ahead. These are all on-roads elements. Similarly there are off-roads elements like curbs that define the boundaries in which car is allowed to move. On-road traffic signals that changes sequentially and signal for the car to move forward or left, or right, or stay idle. Also there are signals like speed limits, limitation of blowing horn, indicating direction and so on. There may have road obstructions symbols that tell construction is going on, or roadblock edge. Autonomous car needs to identify these all to predict perception. These element's motion need to predict in order to make informed driving decisions. So, the can also need to learn other dynamic elements like four wheeler, two wheeler. Also the movement of pedestrians need to observe as they have more freedom and erratic on-road than four wheeler.

Another crucial target for perception will be ego localization. Car needs to be able to calculate where it is and how it is moving in time domain. To know the position and movement in the environment is important to make informed and safe driving decision. Ego estimation data comes from GPS, Odometry sensors, IMU, and required to be combined in order to create coherent picture into the perception tasks. But robust performance of perception is challenging. Modern machine learning algorithms are being used for detection and segmentation in perception tasks. There are much on-going research to improve the reliability and performance in order to achieve human level capability. But access to large data-sets is difficult. Along with more training data, detection and segmentation would wold more robustly. But collecting and labeling data-sets like vehicle types, conditions of weather, and road surfaces correctly is huge expensive and time consuming. On the other hand perception is not immune to sensor uncertainty. There may have time when visibility can be challenging, or GPS measurement can be corrupted, or LIDAR and RADAR catches noisy position value. Subsystems that depend on these sensors must take into account uncertainty. Hence, subsystems designing tasks are also very important. There may have some reflection or refraction in camera or LIDAR data. It may lead to confusion in perception with ambiguous information that may be challenging to deal with in order to identify objects and estimate locations. Effects like drastic illumination changes, lens flare, or GPS outages or tunnels that may make sensor data unusable. Therefore, calculating perception methods need multi-sourced information to avoid sensor data loss. Though it is very difficult in nature, but relevant performance has been shown by different car manufacturing pioneers on road [17, 18].

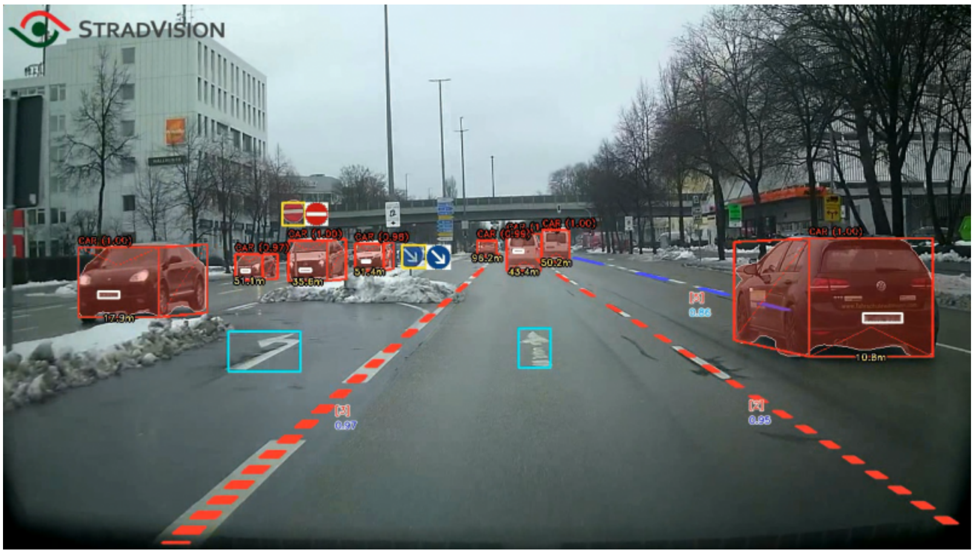

Figure 5.1: Vision processing by StradVision's Self-Driving Car [19]

Fig. 5.1 is showing that how StradVision's self-driving car is detecting both dynamic objects like cars and stationary objects like lane markings, directions in order to make safe decision.

Figure 5.2: Perception process by NVIDIA's Self-Driving Car [16]

Fig. 5.2 is depicting the objects tracking strategy of NVIDIA's self-driving car. It is tracking dynamic objects like pedestrians, cars above of it, and stationary sign that is indicating speed limit of this road.

Figure 5.3: Empowering Driver to do other work [20]

Fig. 5.3 is showing that how self-driving car is empowering driver to do other work. However, to have a precise perception of the road is very crucial in order to ensure safety.

6 Driving Decision Planning and Actions

Planning is another crucial steps for performing self-driving tasks. It can be categorized over time and decision is made on the same time duration. It considers logic and priority in order to action successfully. The important thing here to check that whether logic is well-defined that helps to react on available data about the environment or it considers decisions based on others agents on the car. Planning can be described into three categories: long-term planning, short-term planning, and immediate planning.

Long-term planning includes questions like: how should a car navigate from point ‘A’ to point ‘B’. In order to answer that question, overall mission plan can be achieved. Mapping will be performed based on this like: which roads are convenient, which lane is for the car to be and so on. Overall driving is required more than this. Short-term planning includes questions like: whether lane change is safe or not now, during intersection when should it move to its desired path and so on. Immediate planning includes questions like: how to follow the curved road, steering input, acceleration or brake and so on.

If long-term planning requires a turn in the upcoming curb, then short-term and immediate decisions would be different. For that let us assume that the intersection is controlled with traffic light. In order to turn left or right at the intersection, it has to decide if the car requires lane change on not. If so, the car needs to slow down as intersection comes closer. And then the car needs to stop before the pedestrian crossing line. These tasks are based on short-term decisions. But in the way, the car also needs to identify and detect object and event detection and response. In case of others vehicle in front or over-taking vehicles movement change suddenly then the car needs to stop earlier in order to give space to the other vehicles. There may be absent of road stop sign, many others possible scenarios may arise too. These all cases are come under the immediate decision planning sector. It demands safety from the planning system. The overall end result would be to avoid an exploding list of decision to ensure safety on different time-scale. Every scenario should be evaluated in real time under a set of consisted choices for the same intersection scenario, and should be updated as further new information comes into consideration.

Decision in software also needs to be made. This can be done using the method either reactive planning, or predictive planning. Reactive planning method takes into account the current state of vehicle and the others agents or objects in the environment and perform immediately. This only considers current situation, but does not predict future. Example of this type of planning could be, if a pedestrian is present on the road, then stop. Or if the speed of other object changes then match the relative speed as soon as possible. In both the mentioned cases, car will have to perform based on current scenarios and react immediately. Predictive planning method is different in a sense that it predicts others objects trajectory in the environment. In this case, car will take into account both the current state of other vehicle or pedestrian and the predicted information in order to make decisions. Examples of this type of planning would be, if a car is stopped for fifteen seconds then it may stop for longer time, hence there may have a chance to pass it safely. Or if a pedestrian may walk towards the crossing, hence the car needs to slow down in order to give pedestrian an opportunity to cross the road safely. Now a days predictive planning is predominant method for autonomous cars as it includes expanded scenarios into action for the safety [17, 18].

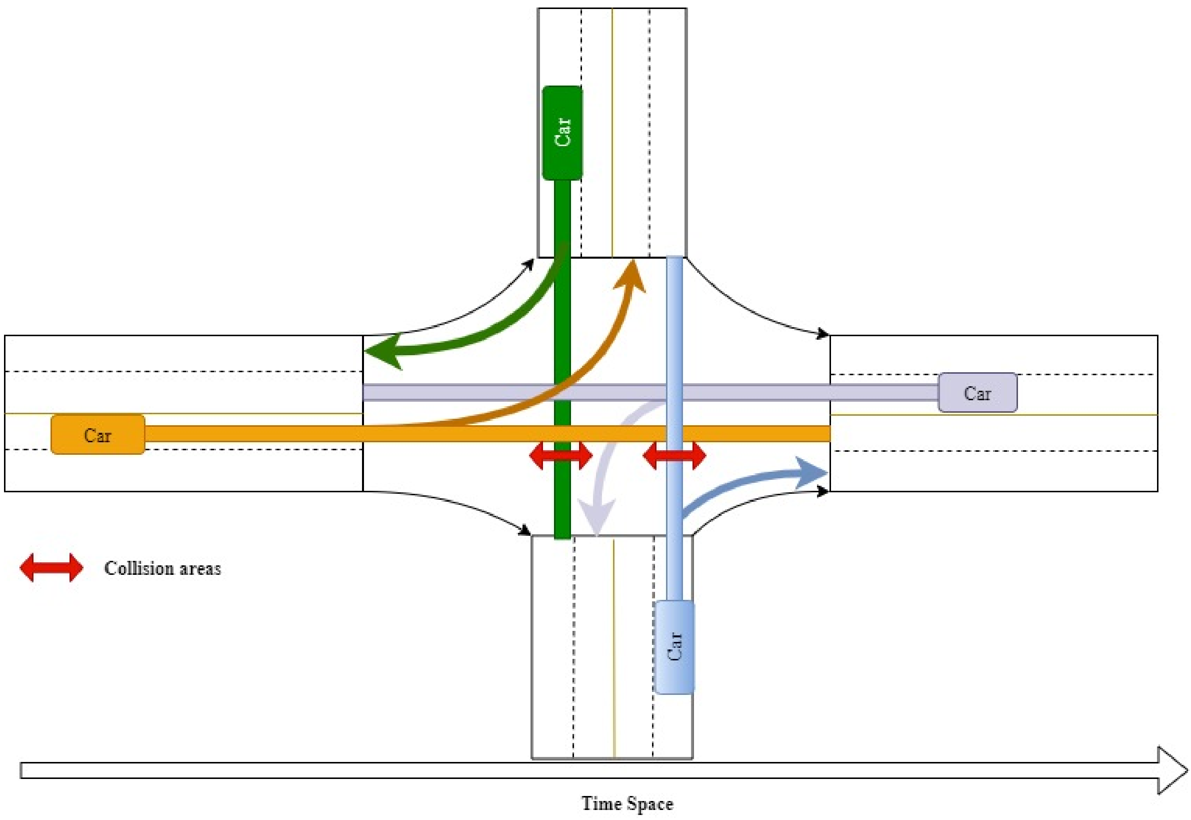

Figure 6.1: Potential Threat Identification [21]

Fig. 6.1 is showing that how an autonomous car predicting collision zone and predicting it earlier to avoid accidents. Self-driving car also needs to distinguish between the relevant or irrelevant cars in order to safe transition at the intersection.

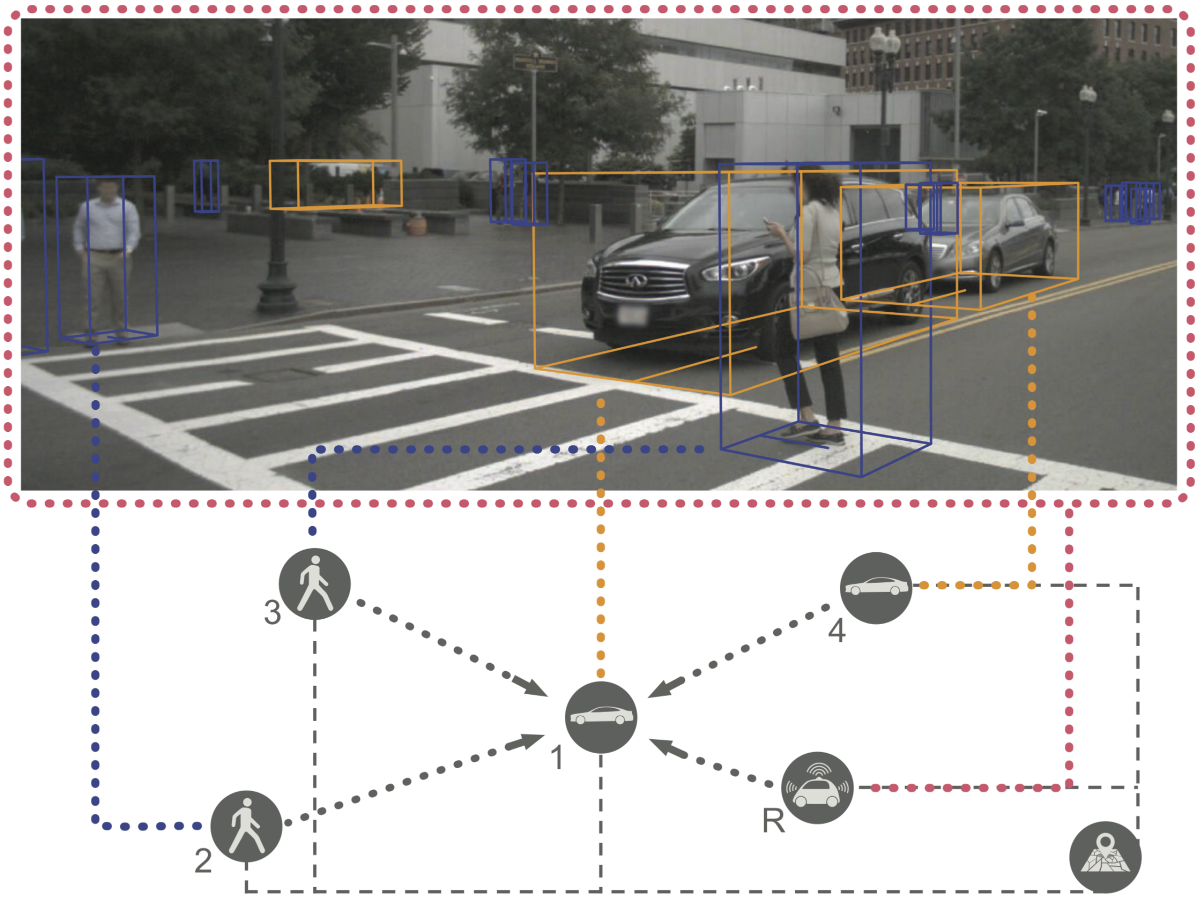

Figure 6.2: Multi-Agent forecasting on Road [22]

Fig. 6.2 is showing a self-driving car's various objects detection (like pedestrians, others vehicles both close and far ones) in order to take a safe right turn.

7 Sensors and Computing Hardware

7.1 Importance of Sensors

Sensors are the eyes and ears of an automated vehicle. An automated vehicle should distinguish other street agents, and ought to be able to associated with them in a secure way, consequently it is vital to get it what the vehicle's sensors ought to be competent of [9].

Figure 7.1: Hardware Configuration of an Experimental Vehicle [21]

Fig. 7.1 is a typical autonomous car that shows the locations of various sensors and hardware, like computational unit, wireless communication unit and so on.

Autonomous car sensors produce enormous sums of information each moment. From other cars, to people on foot, to road sings, to activity lights, each mile contains pointers for where the self-driving car ought to and should not go. Therefore, recognize these symbols and fix those required safety move is huge complex and demands a diversify computational network, hardware and software. In addition to the excess inside the discernment layer, these networks reinforcement the overall function of the vehicle, upgrading security at each level. For illustration, the car's high-definition outline can demonstrate a four-way crossing point, and when combined with real-time sensor information, the discernment layer appears the car accurately where to halt, empowering a more effective way to pinpoint the car's location. Perception too contributes to the differences of autonomous car capabilities, empowering the car to see the world with the same modernity as people. Instead of fair distinguish obstacles, it can observe stationary objects as well as moving ones, and decide their way [16].

7.2 Different types of Sensors

There are two types of functions for which sensors are required. One is exterioceptive, and the other is proprioceptive. Extero refers to surroundings or outside the vehicle. Hence exterioceptive record the data of surroundings. On the other hand, if the sensors measure and record the property of car itself then it is proprioceptive, proprio means internal or ones itself [9].

Exterioceptive sensors are widely used Camera, LIDAR, RADAR, SONAR, Ultrasonic. In order to evaluate the performance of these sensor, a metrics is used. Among those metrics Field-of-view, Range/Dynamic range, and Resolution are the most significant ones. Range indicates the distance a sensor can cover, resolution is the number of pixels that build a image, FOV is defined by horizontal and vertical angular extent that is visible to camera [9].

Range and FOV

FOV and Range both have trade-off to determine a camera or sensor to see. The FOV is made of a horizontal and vertical components. Range covers the distance of host car has to detect other events or traffic. Like for emergency stop scenario, a minimum distance needs to be fixed by calculating the stopping distance [9].

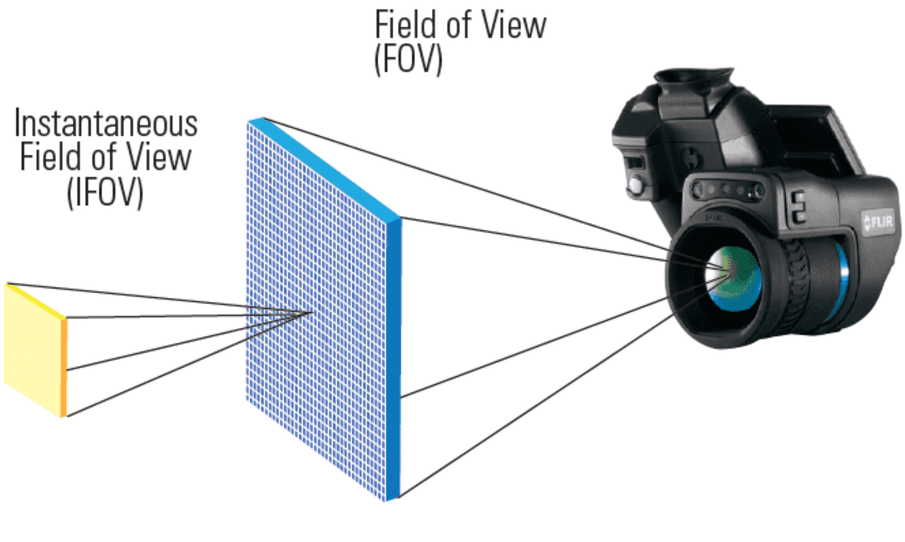

Figure 7.2: Typical Field-of-View of a Camera [16]

The picture is showing a typical FOV of a camera. It may be two dimensional or three dimensional (see Fig. 7.2).

Angular Resolution

For measuring the detected cars or vehicles and how they pose a threat to self-driving car is crucial. If angular resolution is low, then it may end up to calculate two vehicle those are running next to each other as one vehicle. This may lead to false decision making and increase risks [9].

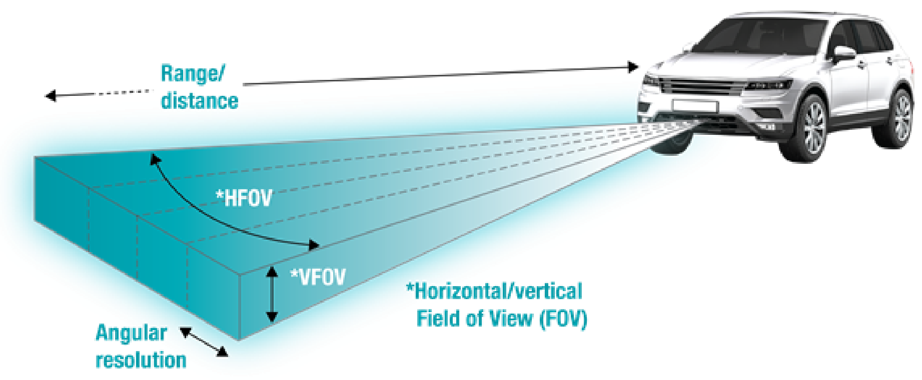

Figure 7.3: Typical Demonstration of Angular Resolution [23]

Fig. 7.3 is showing the angular resolution with a range and FOV. This is very important to identify objects. In order to detect objects that are close to brake, angular resolution plays a vital role.

7.2.1 RADAR

This stands for radio detection and ranging. It helps to detect large objects in the driving environment. It is also helpful during adverse weather conditions. It is selected by the metrics like detection range, FOV, and the speed and position measurement accuracy [24].

7.2.2 LIDAR

This sensor involves shooting light beams through environment and measures the reflected beam return. Then it measures the reflected returned beam and time of flight. The intensity range from reflected object can be estimated. LIDAR is active sensor with its own light sources. Hence it is better in poor lighting conditions where camera can not work properly. The matrices for LIDAR are number of light sources, collection of points per second, rotation rate. The higher the point collection and rotation rate, the better the 3D points clouds are updated [24].

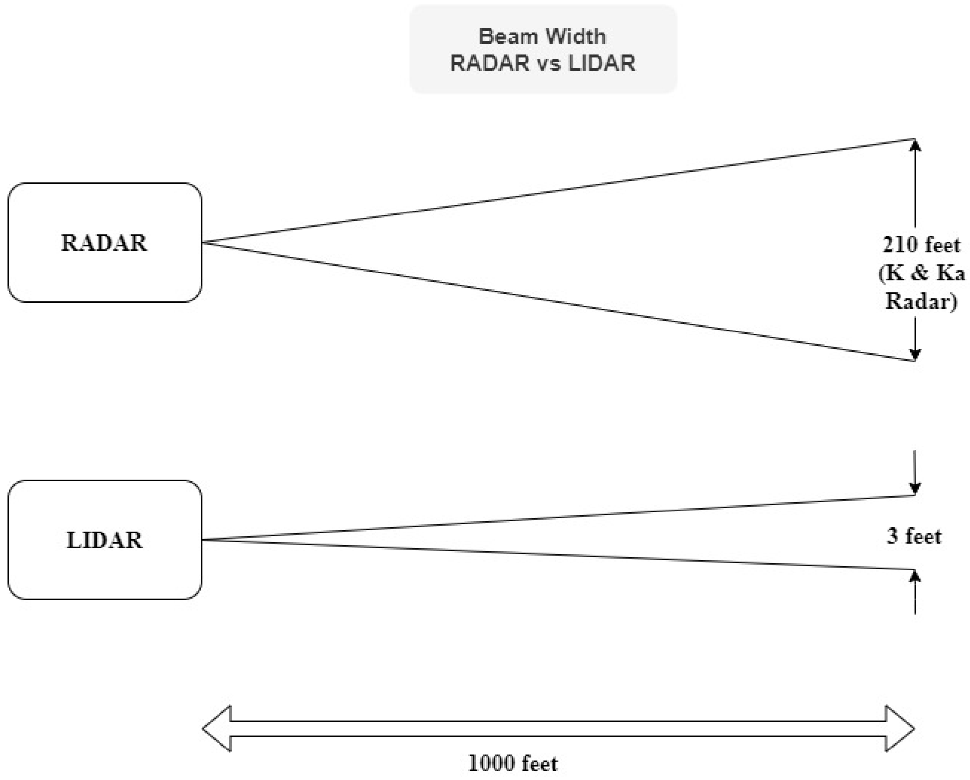

Figure 7.4: Typical Comparison between RADAR and LIDAR [24]

Fig.7.4 is showing a typical comparison of angular resolution between RADAR and LIDAR with a fixed range.

7.2.3 Ultrasonic or SONAR

This is actually stands for sound navigation and ranging. This calculates range by using sound waves. Sonars are short range sensors and good for inexpensive ranging device. Like for parking scenarios, where ego vehicle needs to use place very next to other cars. This is cost efficient than other sensors. The matrices for Sonars are maximum range of measurement, detection FOV, and the expense [24].

Above mentioned sensors have many characteristics and can be used widely along with the resolution, field-of-view, and detection range. Choosing an appropriate sensor for autonomous car is yet to be trivial.

7.3 Computing Hardware

Propioceptive sensors that computes the properties of the car itself. These are Global Positioning System (GPS), Inertial Measurement Unit (IMU), Wheel Odometry Sensors [25].

7.3.1 GPS

It provides information about the position of the car itself. Global navigation satellite system is used to measure the position of the car itself inside the environment, velocity, and direction. The efficiency and accuracy depends of finding the actual position. User segment receive the GPS signals, then the receiver decodes the coded signal and estimates the position, velocity, and time from it [25].

7.3.2 IMU

This also estimates and measure the acceleration of the ego car, and angular rotation. Then the combined estimation can be used for 3D orientation of the car control [25].

7.3.3 Wheel Odometry Sensors

This sensors keep track of the wheel rotation, and calculate the current speed of the car, and heading rate. This sensor is the same that tracks mileage on a car [25].

The crucial part of these is to do the computation after collecting the raw data. It accepts all data from sensors and derive a command for the vehicle to act. Every car-manufacturer is using their own computational devices. Most common example of this can be Nvidia's Drive PX, and Intel &. Mobileye's EyeQ. Computation drive usually requires both serial and parallel module to compute. For LIDAR and image processing in order to object detection, mapping, and segmentation, one can employ GPU, FPGA, and custom ASIC. These help to do specific computation. Like Drive PX units add multiple GPU, on the other hand EyeQ has FPGA to gear up computation for both calculation like image processing and neural network interface. Along with these, ego car need synchronized decision in order to safe travel. Though GPS is highly rely on real time, but others work like: lane changing, maintain speed, intersection approaching ahead, parking scenarios etc. are highly depended on perfect sensor fusions [9].

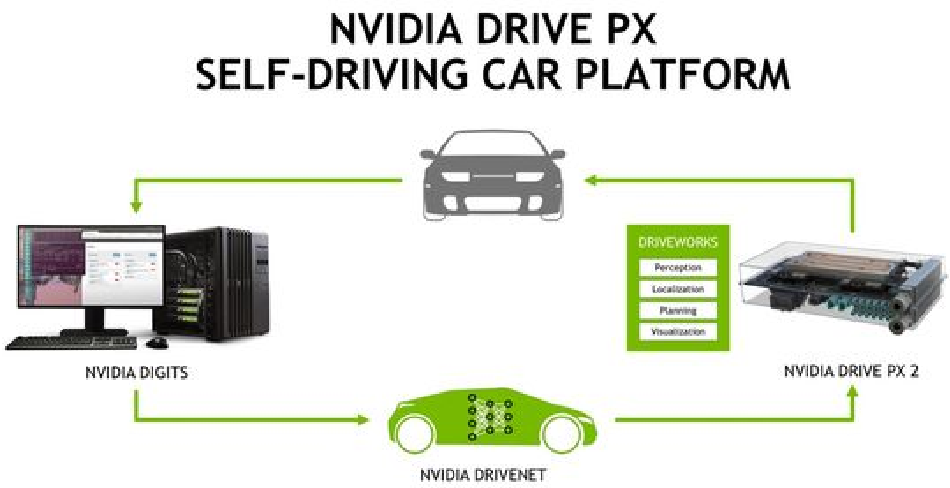

Figure 7.5: Nvidia Drive PX for Autonomous Car [26]

Fig. 7.5 is showing the closed loop from data collection by sensors to calculation and decision making by Nvidia's Drive PX for self-driving car.

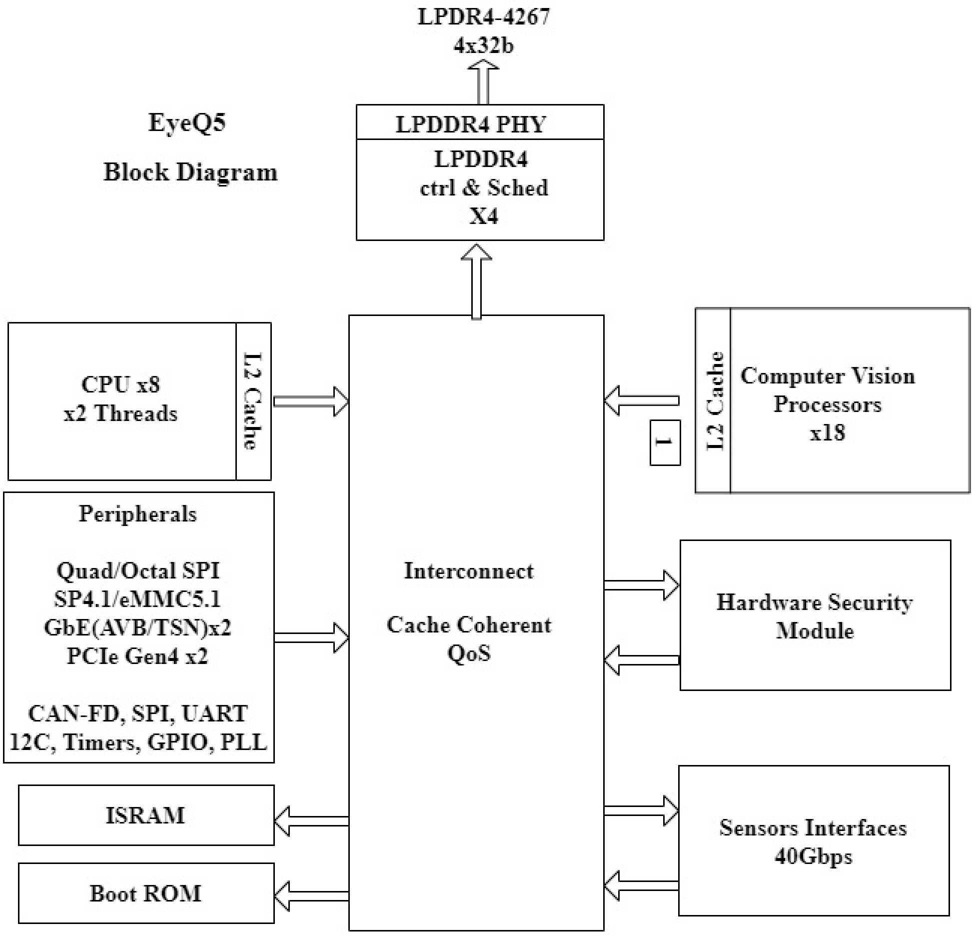

Figure 7.6: Computational Block Diagram of Intel and Mobile EyeQ [27]

Block diagram in Fig. 7.6 is computational interfacing of sensors, processors, CPU, and memories of Intel and Mobile EyeQs' computational block.

8 Common types of map for Self-Driving Car

8.1 Maps used in Self-Driving Car

Path planning is crucial in several domain of self-driving car. Each domain demands different events. Most common types of mappings are localization map, occupancy grid map, and detailed road map [28].

8.2 Localization Map

A map is created by using continuous set of LIDAR values or camera images as car moves through environment. Then it uses this information with GPS, IMU and wheel odometry to estimate exact location of itself at all time. This map helps to find out the ego vehicles own position [28].

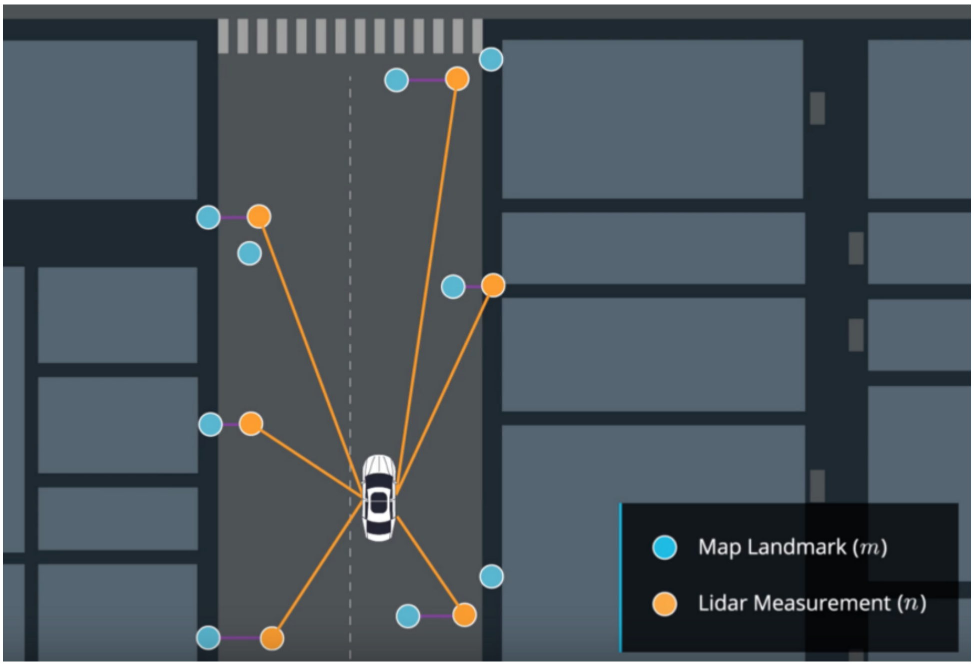

Figure 8.1: Demonstration of Localization Map [29]

Fig. 8.1 is showing how an autonomous car is identifying its location by using LIDAR measuremenr.

8.3 Occupancy Grid Map

It uses a continuous set of LIDAR values to create a map of the surroundings that indicates the location of all stationary obstacles. It helps to plan a safe, barrier-free path for the car [28].

Figure 8.2: Occupancy Grid Map showing lane change [30]

Fig. 8.2 is demonstrating a prediction done by an autonomous car for the line change using sensor data and arithmetic calculation.

8.4 Detailed Road Map

It holds all regulatory elements position, attributes, and lane markings. Its purpose is to plan a path from starting to its destination using all the data available [28].

9 Road Safety and Operation

Facts that are counted for the safe operations are behaviour of self-driving car, its concerning regarding sensing, perception, and control. These are the prime concerns till now in both academia and companies. The future of this industry will be affected by:

- Following a master car or convoy
- Changing the lane
- Effectively and efficiently stopping during emergency
- Collision identification and mitigation, and avoidance of obstacles
- Control capabilities in terms of routing and traffic [31].

Automated Driving Safety (ADS) comprises with several point of view. National Highway Traffic Safety Administration (NHTSA) - focuses on live savings, prevent injuries, and makes road crashes minimum through awareness, education, research, safety protocols, and enforcement of activity. It approaches a non-regulatory offers to automated driving vehicle safety. It considers 12 prime concerns for safety design elements. In order to deploy self-driving car on road, both state and federal government should work together on legislation [32]. The recommended 12 ADS safety elements, that are provided by NHTSA are:

- Safety of the overall system
- Operational Design Domain (ODD)
- Object and Event Detection and Response (OEDR)
- Introducing minimum risk conditions
- Mehtods for jurisdiction, or validation of ADS
- Human Machine Interfacing
- Cybersecurity for the ADS
- Crashworthiness
- ADS behavior after crash

- Recording of data before and after the crash
- Education and training for consumers
- Laws from Federal, and State [32]

NHTSA has recommended some practices in order to draft legislation for ADS. These are:

- Technology-neutral environment should be provided. States should not encourage competition that stresses limited ADS testing to vehicle companies. There is no data supports that effectiveness or efficiency of making cars does not mean that the company will have good ADS
- Licensing and registration for the road will be done by States. It should have knowledge about the layout of the road, ADS, company, and the consumer identity recorded
- States may support public officials to monitor safe ADS by communicating and reporting so that agencies can coordinate with each other
- States may review the laws that are hindering ADS vehicle on road. It may redesign, or adapt regulations in order to integrate vehicles by testing or development of ADS on public road [32]

NHTSA has recommendation for the highway safety officials to reduces crashes on road, injuries, and damage of property in their jurisdiction. These are:

- Different administrative level to look after the roles and activities as the relate to ADS
- States may demand testing of ADS at local level. If so, then this jurisdiction should be followed. States may request information and identification of the consumers
- Agency led by State may involve to test the entity. It may suspend the test if the entity does not comply with the state rules
- If a state concerns about that training of ADS test driver, it may request the information of training provider. Provider should also known to the safety rules and regulations about ADS
- Training public officials may be requires to increase state level safety. Coordination among different states may be beneficial in order to increase human operator behaviors

- Liability and Insurance is one of the crucial topic in order to get the vehicle on road, as it demands a broad discussion among incident scenarios, technology adaptation, and knowledge about the ADS. Hence, state may start to consider the liability allocation among owners, operators, pedestrians, companies, and vehicle insurer on different level [32]

10 Summary

In-a-nutshell, self-driving car is an active research field now-a-days in both academia and industry level. There are little amount of information available due to corporate reasons. In this work, different level of self-driving car, its working strategy on road, equipped elements on the car, some research projects have been discussed. Correlation among legislation team, manufacturer, insurer, and consumer are yet to be see light. Both Europe and American industry have been working actively to put this industry in light. In the recent years, sensor industry has also been improved fast in order to support other industry, like autonomous sector.

During the recent pandemic situation, we have been encountered severe immobility in every step of life. Hence booming this sector has felt urgency to support mobility of human life. Autonomous road environment are challenging as other agents in the road have more autonomy like pedestrians or cyclist. Redesign of roads are need to be done to support self-driving car as it will help to compute more effective and efficient prediction for the car. Perception to catch event like over-taking requires more sensing range, and fast computation. With the current sensors in the industry it is a bigger challenge to achieve this.

The main limitation of this paper is the mainly theory based. Besides few research withing academia, data or equipment used by the companies are private. Most recent sensors, and its qualities to achieve the goal on road is also unavailable, as sensor industry is still improving day by day. Besides construction of the roads and speed limits, the perception or decision taking style, and capabilities of self-driving car may be evaluated with the available existing limited resource.

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