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Exploring Key Technologies in Autonomous Vehicles

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Abstract: ***This paper dives deep into the technologies used in Autonomous Vehicles. The Global Positioning System (GPS) is a key technology employed by autonomous cars. It is a satellite-based navigation system that determines the exact location of an object. Another technology used by autonomous cars is cameras, which are utilized to detect road signs, identify red lights, and determine lanes on the road, among other functions. Typically, the digital images of the road are presented as unrelated pixels, and this data is structured for better utilization. The algorithm for lane detection interprets this data in four basic steps: preprocessing, feature detection, fitting, and tracking. The other two technologies detailed in this paper are RADAR (Radio Detection and Ranging) and LiDAR (Light Imaging, Detection, and Ranging). RADAR technology uses radio waves to identify objects on the road and is effective in any type of weather conditions. Contrastingly, LiDAR is a laser analyzing device that allows 3D mapping of the surroundings of the vehicle. Unlike RADAR, LiDAR utilizes lasers instead of radio waves.***

Keywords: Autonomous Vehicles, Driverless Cars, Global Positioning System (GPS), Radio detection and Ranging (RADAR), Light Detection and Ranging (LiDAR), Inertial Measuring Unit (IMU), Vehicle Communication

1. Introduction

The world of self-driving vehicles is driven by a varied range of technologies that enable these autonomous machines to perform a multitude of tasks with accuracy and efficiency. This paper examines key technologies guiding the path of autonomous vehicles, uncovering their complex mechanisms and practical applications.

At the center of every autonomous vehicle lies the Global Positioning System (GPS) and Inertial Measuring Unit (IMU). Utilizing 24-satellite clusters, GPS pinpoints the vehicle's location on Earth, offering unmatched precision. This technology, reliant on trilateration principles, needs a minimum of four satellites for accurate 3D positioning. Augmenting this, the Differential Global Positioning System (DGPS) refines accuracy to a remarkable 2 cm. Despite its effectiveness, GPS faces challenges such as signal obstruction, which can result in momentary misguidance.

Integrated with GPS, IMU acts as a fail-safe, taking charge when GPS accuracy wavers. In situations where GPS signals are weak, particularly in urban landscapes with obstructions like buildings and tunnels, IMU adeptly steers the vehicle. The interplay between GPS and IMU, crucial for autonomous navigation, exhibits a symbiotic relationship ensuring robust performance.

The widespread presence of cameras in autonomous vehicles is pivotal for several applications. From detecting stop signs to gauging distances, cameras play a vital role in ensuring safety. Stereo cameras, combined with advanced algorithms, facilitate tasks like red-light detection and lane tracking. A four-step process - preprocessing, feature detection, fitting, and tracking - defines the algorithm for lane detection, optimizing the interpretation of digital road images. Overcoming challenges such as noise reduction and shadow elimination, cameras in autonomous vehicles underscore their significance in providing crucial data for informed decision-making.

RADAR technology has established itself as a robust presence in the autonomous vehicle domain, steadily surpassing technologies such as ultrasonics. Versatile and weather-resistant, radar systems offer short, medium, and long-range capabilities. From adaptive cruise control to blind-spot detection, radar contributes to a several safety features. The imminent future envisions radar's integral role in Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, ushering in a new era of intelligent transportation systems.

Light Detection and Ranging (LiDAR) heralds a revolution in remote sensing technology for autonomous vehicles. Facilitating 3D mapping with laser precision, LiDAR's prowess extends to detecting the minutest obstacles even at a considerable distance. This technology, initially conceived for military applications, has transcended its conventional bounds to become a linchpin in autonomous vehicle development. Velodyne LiDAR's sophisticated sensor, with a rotating head housing 64 semiconductors, stands testament to LiDAR's transformative capabilities.

This exploration ventures beyond the technologies' surface, scrutinizing their intricate workings and real-world applications. From the realms of GPS and IMU collaboration to the precision of cameras, the resilience of radar, and the laser precision of LiDAR, each technology unveils a layer of autonomy, shaping the future of transportation.

2. Technologies Used

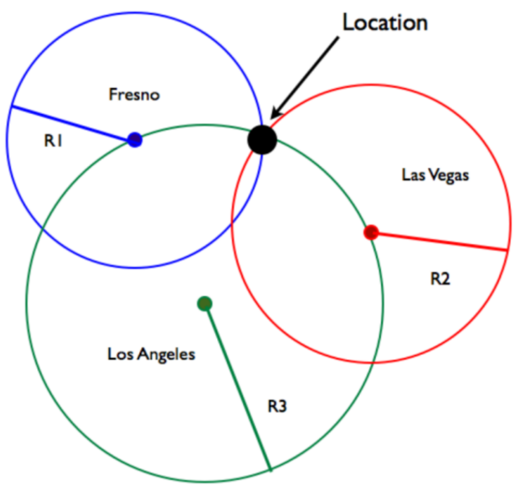
Various technologies are employed in autonomous vehicles. As driverless vehicles need to perform a multitude of tasks, they depend on specific technologies to fulfill these operations. The following are descriptions of some of these technologies.

1) Global Positioning System (GPS) and Inertial Measuring Unit (IMU)

This technology is fundamental for all autonomous vehicles. The system is based on 24-satellite clusters, which determine the exact location of the object on the Earth regardless of time and weather. It is a precise method for determining the position of vehicle. Global Positioning System (GPS) requires a receiver and a minimum of four satellites to determine its position in three coordinates (x, y, z). The resulting position is highly accurate, with less than 20 m precision error.

Further it is possible to reduce this error and achieve a precision error of 2 cm. This can be accomplished with a minimum of 5 satellites, utilizing the Differential Global Positioning System (DGPS). However, this type of car navigation has limitations. Signal blocking can occur due to obstacles like trees, buildings, bridges and tunnels. Prolonged obstruction of signals may result in information loss, potentially causing the system to misguide the user.

GPS is based on a method in which position is determined by measuring distances to known coordinates on the plane, this process is called as Trilateration. For Trilateration, data from a minimum of 3 satellites is needed. Each satellite provides a range of locations in circular form, the true location can be determined from the intersection point of these three circles (location range from 3 satellites). The figure below explains trilateration in simpler way. Let's assume that signals are transmitted from radios from Fresno, Los Angeles (LA) and Las Vegas. We can determine how far away we are from each radio tower; let say R1, R2, R3 are the distances from the towers. Using these radii draw the circles from their location in the space. For two circles, it will give us two meeting points, and using 3rd radius, we can precisely determine our location, as there will be only one intersection point for these circles. Instead of circles, now think of each GPS satellite signal drawing a sphere. The receiver is located at the intersection of these sphere on Earth.



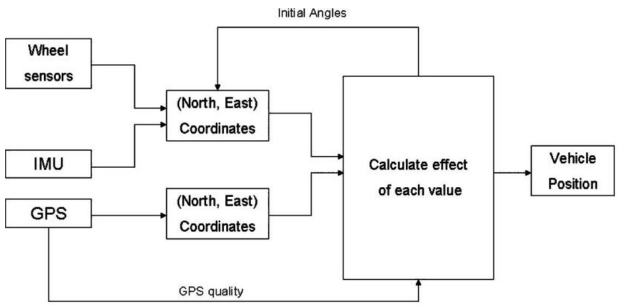
Source: [25]

On the other hand, GPS point positioning needs 4 "pseudoranges" to 4 satellites. A pseudorange is like a range, except that it incorporates clock errors, given that receiver clocks are far from perfect. Each satellite transmits a signal in the direction of the Earth, encoded with the "Navigation Message," which can be read by the user's GPS receivers.
The broadcast ephemeris or orbit parameters are included in this Navigation Message and receiver can compute satellite coordinates (X,Y,Z). These co-ordinates are known as WGS-84. They represent Cartesian coordinates in a geocentric system which has its origin at the Earth center. The Z axis and X axis point towards the North Pole and Prime Meridian (which crosses Greenwich) respectively, while Y axis at right angles to X and Z, forming a right-handed orthogonal coordinate system. At any specified time the "Ephemeris Algorithm" is the algorithm that transforms the orbit parameters into WGS-84 satellite coordinates.

GPS has five different operation modes depending on positioning accuracy:

- Mode 0: The GPS does not receive a signal in this mode.
- Mode 1: GPS is accurate to 15 and 20 meters in this mode.
- Mode 2: GPS is accurate to 2 meters, but it is impossible to obtain guidance with this mode.
- Mode 4: GPS is accurate to 2 cm in this mode and is convenient for determining the vehicle's position in a global coordinate system.
- Mode 5: Steering wheel behavior is abrupt in this mode, where accuracy is less than one meter.

GPS usually come with Inertial Measuring Unit (IMU). The decision unit is setup to measure the accuracy output at every moment. When the accuracy of GPS drops to mode 0, 1, or 2, the IMU controls the system, as the errors are significant enough to reject GPS values in these modes. GPS usually controls in mode 4, where it causes deterioration of signal due to the inclusion of other sensors. IMU and GPS are combined in mode 5 because even though initially the IMU is more accurate, it degrades due to drift, and to correct this error, it need a small percentage of the GPS. A director vector is an essential function. The figure below illustrates the block diagram for the decision unit.



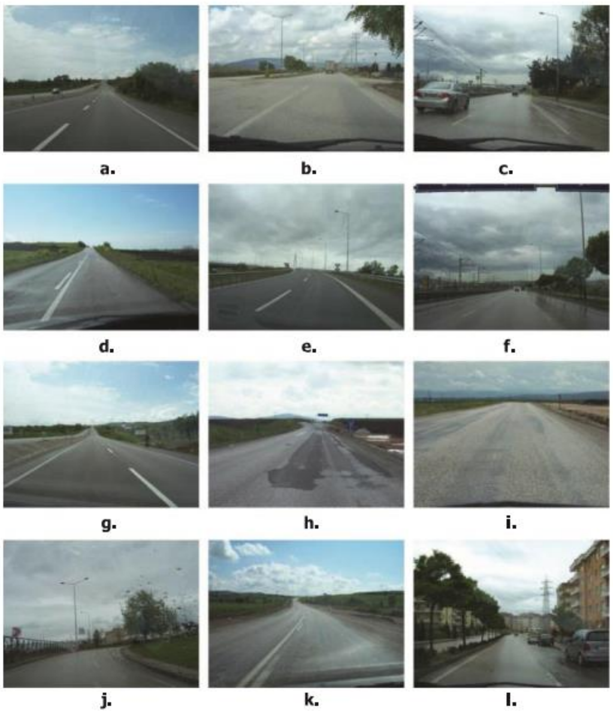
Decision unit scheme.

Source: [13]

To mitigate this error, another system is essential in autonomous vehicles: INS (inertial navigation system). This system incorporates a decision unit that assesses the precision of each system's results. When GPS operates with high accuracy, it takes control. Conversely when GPS signals are weak, the inertial control system guides the car. Experimental findings highlight situations: in an urban area where GPS signal can be distracted by buildings, trees, tunnels or even bridges, relying on GPS during brief time intervals is lead to misguided guidance or significant errors. Nevertheless, the use of INS has demonstrated positive outcomes in experiments, illustrates how a collaborated system improves the guidance for autonomous vehicles.

2) *Camera*

In autonomous vehicles, camera play a significant role in various applications. For instance, camera can be used to detect the stop sign, determine their distance and prompt the vehicle to stop accordingly. Similarly, they can be deployed for tasks such as red-light detection and lane detection. Stereo cameras, combined with sign detection algorithms, facilitate these functionalities. The detection and localization of lanes from a digital image of the road are crucial components in the application of many intelligent transportation systems. Traditionally, digital images are represented by a set of unrelated pixels. In such unstructured data, valuable information is often available. To better utilize this information, the data should be represented in a more structured form. One effective solution to visualize this data is by grouping visually meaningful portions in the image data. This grouping of image regions involves categorizing them into different objects and is guided by a semantic interpretation of the screen. Furthermore, the resulting information can be improved by using dependent information. Following image shows different road scenarios:



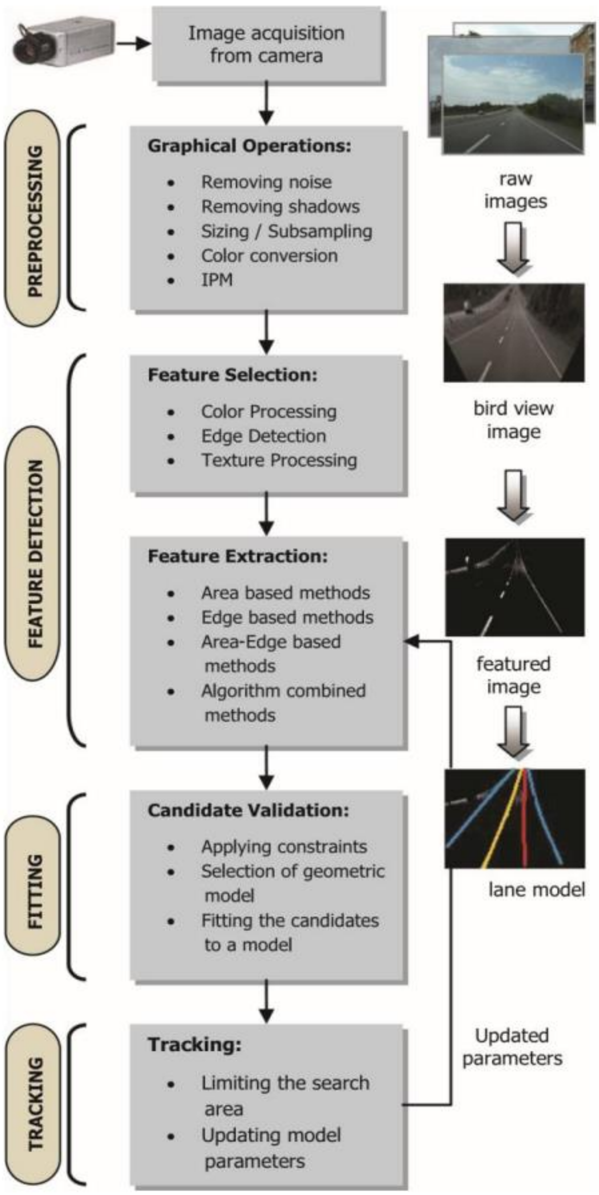
Source: [15]

Algorithm for road detection is interpreted by the following four basic steps: preprocessing, feature detection, fitting, and tracking.

a) Preprocessing

Preprocessing is the first stage in detection of images captured by the camera. It involves noise reduction or removal and prepares the image for subsequent step. Many researchers worldwide consider noise reduction as the first step in image acquisition of cameras. During this process, a significant challenge arises that there is no guarantee that the identified pixels are absolutely accurate. It is possible that the identified pixels may not be of any significance for image detection, especially in shadowed regions. Roads often include shadows cast by numerous objects such as buildings, trees, vehicles themselves etc. During the preprocessing stage, shadows are also removed.

This step is no just about removing noise or shadow region, it also involves reducing the resolution of the image for more convenience. Monochrome images are preferred over colored ones as they render better resolution and significantly reduce data load. Many researchers have changed the image format from RGB to HIS/HSV/HSI to achieve better results in detecting data, even though it causes loss of data. While performing these processes, the complex computational vision system may have some problems because of the processing time. It's impractical to process every image captured by the camera. Therefore, it is important to focus only on the important region called Region of Interest (ROI). ROI is the focus area, which is absolutely critical for the car driving functionality, rest of the region can be ignored. From the above description, it can be inferred that lane tracking is easier as compared to lane detection.



Source: [15]

b) Feature Detection

Feature detection can be carried out in two main steps: Feature Selection and Feature Extraction. Most often, the features in an image can either be stable or repetitive elements found in objects on the road, such as trees, edges, and boundaries.

Feature Selection: As stated earlier, there are many features on the road and of the road that can be selected for recognition. In autonomous vehicles, features like color, texture, and edges are of key importance. The problem of recognizing traffic lights has been overcome using color detection, with approximate matching of colors for signals in different countries and their various sizes. In autonomous vehicles, color processing is useful for obtaining more data than monochromatic imagery. This is possible due to camera's information richness. However, it demands high computer processing, which suppresses its usefulness. Edge is defined mathematically by the gradient of intensity function. In standard road design, lane marking, boundaries markings usually significantly help to keep vehicle on road. This is because these boundaries have clear edges and higher intensities. However, they can be misleading due to small errors, if the color of the edges match with color of vehicle in front of the camera or due to shadow etc. On non-standard roads and off roads where lane marking is not available, it becomes challenging for the vehicle to manage this task. In such cases, the camera detects the border between the road and its surroundings, likely by using the road shoulder. Texture detection also plays an important role in providing useful information for recognizing and interpreting the road conditions. It provides data about the terrain and other information such as plants, surfaces and more.

It is the function that extracts features of the image mentioned in the previous section using various filters or statistical methods. This can be broadly classified into area-based, edge-based, area-edge-based and algorithm combined method. The road detection problem is considered in the area-based method, where the main idea is to classify the image into road and non-road areas. This classification is crucial and aims to overcome obstacles such as puddles, shadows, tire skid marks etc. on the road. This process has to be carried out in real-time application to make it useful. It uses various implementation on VLSI or Digital Signal Processor.

In edge-based method, the edge map of the road is extracted and using a predefined geometric model, a matching of model process is carried out to detect the road. In area-edge-based methods, one of the algorithms, either area or edge, is supported by the other to detect the road map. Meanwhile, in algorithm combined method, many methods are carried out along with each other to get the better performance of road detection.

a. b.

Source: [15] Area detection: (a) Original image; (b) area detected image (pure black fields).

c) Candidate Validation

In this the detected features are validated to obtain the correct road location. Three basic ways of validation includes applying domain constraints to the results of extraction, fitting the candidates to geometric model and applying both together.

Applying domain constraints: Usually while describing lane detection no prior information is considered about road positions. However, by imposing spatial or temporal constraints, the robustness of the detection can be improved. Some domain constraints includes symmetry, smoothness, continuity, lane marker width, road width, road orientation etc.

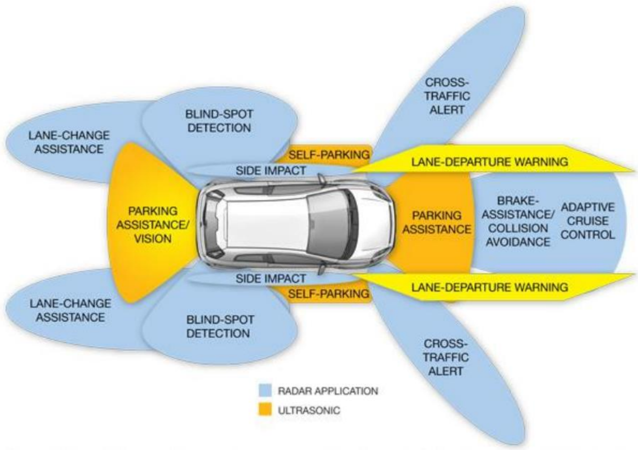
Geometric models: Many geometric models are needed and used to represent the road appearance. Especially the trapezoidal model, in which vehicle moves through trapezium to trapezium consecutively. Other geometric models used to represent road appearance are straight line, circular arc, spline, parabolic, hyperbolic line etc.

d) Tracking

In this process, the detected features are validated to determine correct road location. There are three basic ways of validation methods: applying domain constraints to the results of extraction, fitting the candidates to geometric model and applying both together.

3) Radio Detection and Ranging (RADAR)

Radar is gaining increasing popularity in vehicles due to its powerful and flexible technologies. Technologies like ultrasonics are being seen as replaceable by radars. The figure below illustrates how useful radars can be in vehicle technology. They provide a significant amount of data to the system regarding the environment, especially obstacles in the vehicles path. RADAR was named by US navy during World War 2, *RAdio Detection And Ranging*. It was named so because of its application using radio waves.

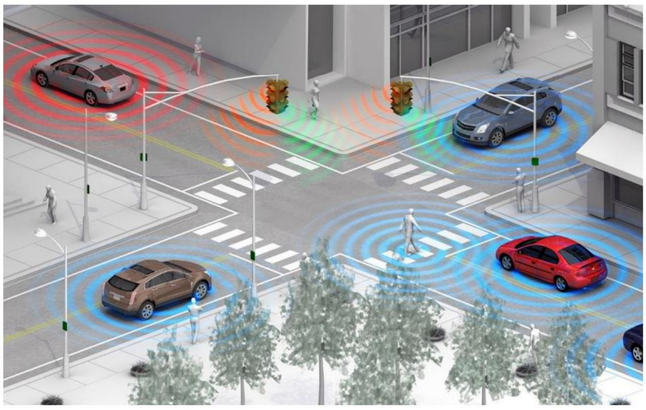


Source: [26] edn.com

Radar has the advantage that it can operate in any type of weather conditions and can have characteristics like short range, medium range and long range. Some applications of these include adaptive cruise control, which works with long range radars, as well as features such as lane change assistance, blind spot detection, cross traffic alert, side impact, pre-crash sensor, parking assistance etc. It provides numerous safety features to any autonomous vehicle. One major application of radar in future vehicles can be seen in V2V (Vehicle to Vehicle) communication and in V2I (Vehicle to Infrastructure) communication. These are essential components of Intelligent Transportation Systems (ITS). Radars also play a significant role V2V communications, usually located close to the road surface, typically on the fascia.

Application in V2V and V2I

Safety of passengers and everything associated with traffic is becoming crucial year by year. Companies are realizing this fact and working on major scale to address it. In doing so, many are developing various technologies such as autonomous vehicles, connected vehicles and communication between vehicles or infrastructure. The aim is to liberate vehicles from dependency on drivers to minimize mistakes. Two main topics to discuss here are Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. Other objectives includes improving energy efficiency, reducing road construction and ensuring safety of pedestrians and bicyclists



Source: [28] wired.com

Vehicle-to-Infrastructure (V2I)

- In this, the vehicle communicates with the infrastructure, i.e. it co-ordinates with the local information on the traffic and informs the driver or give required instructions. For example, ramp metering, already implemented in many places, utilizes sensors and actuators to measure traffic density on highway or control traffic lights on ramps.
- In the broader context, infrastructure must suggest the appropriate distance, velocity and acceleration between vehicles based on traffic conditions around each vehicle.
- This should lead to optimization of overall fuel consumption, reduction of emissions, and regulation of traffic velocities.
- Suggestion can be delivered to the driver through a screen, voice or both. The connection between infrastructure and vehicles can be done using Wi-Fi networks connected to the vehicle.
- Moreover, suggestions must be provided to the vehicle and controlled semi-automatically. For instance, information about red light can be communicated to the driver. Any vehicle approaching blind turns can be informed using such Infrastructure-to-Vehicle communications.
- Surveys indicate that the first V2I systems may be implemented by year 2020.

Vehicle-to-Vehicle (V2V)

- V2V is challenging due to its decentralized structure.
- Its primary objective is to communicate with other vehicles around and, if possible, foster collaboration among them.
- Suggestions are given, or decisions are made on a local basis by exchanging information between vehicles.
- To develop such a system, there must be an agreement among car makers and their suppliers in terms of technology.
- Communication technology may again be based on Wi-Fi, or wireless LAN systems.
- Research is already being conducted using DSRC (Dedicated Short-Range Communication) technology in many universities.
- In the V2V, when two or more vehicles or infrastructure elements comes within communication range, they automatically connect to establish an ad-hoc network, enabling the sharing of position, speed, and direction data.
- Every vehicle, in turn, also acts as a router and allows sending messages to more distant vehicles and infrastructure.
- It can handle fast changes in network topology since the routing algorithm is based on the position of the vehicles.
- At the local and higher layers of the architecture, control technology comes into play.
- Minimal considerations, such as uncertainties, delays, incomplete measurements, safety and performance objective must be taken into account when implementing such technology.
- Vehicles, in turn, should also be capable of making voluntary decisions, which can be automatic or semi-automatic in nature.

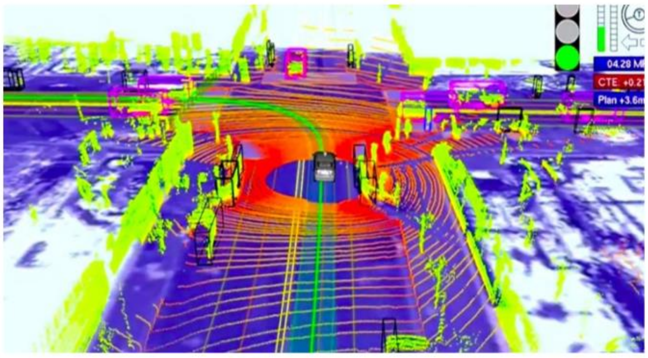
Various types of radars, such as Short Range Radar (SRR) and Long Range Radar (LRR), are used to for various applications. SRR operates in the range of 4-6 GHz band and has a range of up to 30m, while LRR operates in the 76-77 GHz range with a range up to 150m. SRR utilizes the Doppler effect at millimeter-wave frequencies to allow precise measurements of speed. Target directions are obtained using two or more sensors combined with localization techniques, which includes measurements of Angles of Arrivals (AOA), Time of Arrival (TOA), or combination of these techniques. These radars are used in blind spot detection, lane change assistance, side impact, cross traffic alert etc. LRR is mainly used for adaptive cruise control as it can range up to 150m. It used sharp radiation lobes to detect objects on the lane which are 150m ahead.

4) Light Detection and Ranging (LiDAR)

Remote sensing technology has played a significant role in Autonomous Vehicle Technology, enabling the sensing of obstacles, roads, vehicles, etc. Light Detection and Ranging (LiDAR) is a laser analyzing device that allows 3D mapping of the surroundings and environment of the vehicle. Its phenomenon is similar to that of RADAR, with the difference that LiDAR used laser and RADAR uses radio waves. LIDAR works on heterodyne detection. The figure below illustrates how LIDAR receives information from the environment. In the field of cartography, the introduction of LiDAR has ushered in significant change. Geographic Information Systems and land surveyors have found relief from the time-consuming process of hand mapping.

Source: [27] slideshare.net

This 3D mapping technology has found its advantage in Autonomous Vehicles sector as well. Velodyne LiDAR has been successfully tested and is available in the market. Most LIDARs have a single laser emitter that passes through a mirror. This high definition sensor uses a rotating head which has 64 semiconductors. The firing of the laser is done by these semiconductors at the rate of 20 thousand per second. Each semiconductor has its dedicated detector, while the laser-detector is aligned at a fixed angle of 28.60 vertical angle, providing a vertical field of view. The field of view is generated by rotating the entire unit at a rotating speed of 900rpm around the vertical axis. Each second, the unit collects a data of 1.3 million points. The collected data is sufficient for the system to detect the smallest objects, such as overhead wires, even when they are 100m away from the vehicle. The figure below shows the 3D mapping output of Velodyne LIDAR used in the Google Car.



Source: [11]

The development of LIDAR initially started with a competition sponsored by US department of defense. The competition was the Defense Advanced Research Project Agency's (DARPA) Grand Challenge. Contestants were required to develop an autonomous vehicle capable of finding a path through desert terrain. Out of the six contestants, five used LIDAR. Moreover, both the winner and runner-up had vehicles with the application of LIDAR. This technology proved to be so powerful that it was not necessary to utilize it to its highest potential. Nevertheless, vehicles designed for conventional use may require more detailed data, which in turn, may slower the speed of the vehicle. This slowdown is mainly because it takes more data which consumes time to process.

Conventionally, LIDAR was created to use in indoor industrial application. These LIDAR were restricted to a weather friendly environment and won't sustain harsh weather condition, which are common in the case of vehicles. These restriction were eliminated in high definition, which was also more economical. Software developers developed a system based on algorithms that could connect to LIDAR points and identify objects such as building, pedestrians, poles, roads, etc.

3. Conclusion

Technologies that support autonomous cars are crucial to ensuring the effective performance of driverless vehicles. GPS, cameras, LIDAR, and RADAR, when working in harmony, all play important roles in building driverless cars. In addition to these, there are other integrating technologies that bring these systems together.

Understanding these technologies deeply will help in making effective driverless cars, allowing humans to reclaim time for other activities. The realm of driverless cars remains a dynamic area of research and a controversial subject, particularly concerning passenger safety. However, as these technologies evolve and improve, the dream of driverless cars seems closer.

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