German Jordanian University

School of Applied Technical Sciences

Department of Mechatronics

Engineering ME362 – Sensors and Actuators

Self-driving cars (autonomous cars)

Done by:

Amro Habboush 20181102011

Mohammad Mahfouz 20191102056

Rami Abu Al Nadi 20181102047

Supervised by: Dr. Mariam Ibrahim

Date: 22 / 12 / 2021

Section: 1

Abstract

Although the future is ultimately unpredictable, planning necessitates anticipating impending situations and requirements. Many decision-makers and practitioners (planners, engineers, and analysts) are interested in learning more about how autonomous (also known as self-driving or robotic) vehicles will impact future travel demand. As a result, the demand for roads, parking lots, and public transportation, as well as what types of public transportation are available, Policies can be designed to reduce risks while maximizing benefits.

Cars (automobiles): cars are defined that they are wheeled motor vehicles that runs on petrol, hydrogen, electricity and steam used mainly to transport people from one place to another.

at the beginning when Karl Benz invented cars in 1886 they were simple which they had controls for driving such as steering wheel and gear and pedals and here we can tell that the main factor in cars was human so people use these controls and drive the car

Table of content

Introduction

Self-driving cars

technology developments and new generations of cars additional features and controls have been added and car manufacturers started to give attention to the passenger comfort and these include air conditioning and in car entertainment and cars kept developing until they invented parking assistance then self-parking cars leading to self-driving cars.

self-driving cars (also known as autonomous or robotic cars): they are cars that are capable of sensing the environment and moving safely with a little or no human touch.

Levels of self-driving cars

Self-driving cars or autonomy in cars is often categorized in six levels according to society of automotive engineers (SAE) which are:

Level 0: no automation

The automated system issues warnings and may momentarily intervene but has no sustained vehicle control

Level 1: hands on

The driver and the automated system share control of the vehicle. Examples are systems where the driver controls steering and the automated system controls engine power to maintain a set speed (Cruise control) or engine and brake power to maintain and vary speed (Adaptive cruise control or ACC); and Parking Assistance, where steering is automated while speed is under manual control. The driver must be ready to retake full control at any time. Lane Keeping Assistance (LKA) Type II is a further example of Level 1 self-driving. Automatic emergency braking which alerts the driver to a crash and permits full braking

Level 2: hands off

The automated system takes full control of the vehicle: accelerating, braking, and steering. The driver must monitor the driving and be prepared to intervene immediately at any time if the automated system fails to respond properly. The shorthand "hands off" is not meant to be taken literally – contact between hand and wheel is often mandatory during SAE 2 driving, to confirm that the driver is ready to intervene. The eyes of the driver might be monitored by cameras to confirm that the driver is keeping their attention to traffic. Literal hands-off driving is considered level 2.5, although there are no half levels officially. A common example is adaptive cruise control which also utilizes lane keeping assist technology so that the driver simply monitors the vehicle, such as "Super-Cruise"

Level 3: eyes off

The driver can safely turn their attention away from the driving tasks, example the driver can text or watch a film. The vehicle will handle situations that call for an immediate response, like emergency braking. The driver must still be prepared to intervene within some limited time, specified by the manufacturer, when called upon by the vehicle to do so. You can think of the automated system as a co-driver that will alert you in an orderly fashion when it is your turn to drive. An example would be a Traffic Jam Chauffeur, another example would be a car satisfying the international Automated Lane Keeping System (ALKS) regulations.

Level 4: mind off

As level 3, but no driver attention is ever required for safety, example the driver may safely go to sleep or leave the driver's seat. However, self-driving is supported only in limited spatial areas (geofenced) or under special circumstances. Outside of these areas or circumstances, the vehicle must be able to safely abort the trip, example slow down and park the car, if the driver does not retake control. An example would be a robotic taxi or a robotic delivery service that covers selected locations in an area, at a specific time and quantities.

Level 5: optional steering wheel

No human intervention is required at all. An example would be a robotic vehicle that works on all kinds of surfaces, all over the world, all year around, in all weather conditions.

Background

Self-driving cars have been under trials since the late 1950s which the first semi first semi-automated car was developed in 1977, by Japan's Tsukuba Mechanical Engineering Laboratory, which required specially marked streets that were interpreted by two cameras on the vehicle and an analog computer. The vehicle reached speeds up to 30 kilometers per hour with the support of an elevated rail and car manufacturers kept testing their cars until these days which on 5 march 2021 Honda began leasing in Japan a limited edition of 100 Legend Hybrid EX sedans equipped with the newly approved Level 3 automated driving equipment which had been granted the safety certification by Japanese government to their autonomous "Traffic Jam Pilot" driving technology, and legally allow drivers to take their eyes off the road.

Like people, self-driving cars must sense their surroundings to safely navigate. People use senses like hearing, sight, taste, smell, and touch to interact with their environments. Autonomous car technology developers provision self-driving cars with high-tech sensor systems to sense analogously.

Sensor types

Self-driving cars combine a variety of sensors to perceive their surroundings and its environment as we mentioned before, such as radar, lidar, sonar, cameras, navigation sensor and odometry. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage.

1) Radars:

Automotive radars were first deployed several decades ago. The evolution of automotive radar from its inception to the present has been thoroughly discussed in. With highly integrated and inexpensive mm-wave circuits implemented in silicon, compact automotive radar safety systems have become a popular feature. Since then, review articles written on automotive radar mostly covered the circuit implementation, market analysis, and architectural-level signal processing. However, there are many aspects of automotive radar signal processing techniques scattered throughout the literature. For example, a part of the literature may concentrate on detecting the presence or absence of targets, while another might look at radar estimation problems concerning their location and velocity in space relative to the radar. This article's goal is to review principal developments in signal processing techniques applied to estimating significant target parameters such as range, velocity, and direction. The article also discusses the characterization of radar waveforms and advanced estimation techniques that enhance the operation of automotive radars. In particular, we review each topic with adequate mathematical framework so as to make newcomer in the field.

Advantages of radar:

- Less data intense than most sensors
- Does not need a direct line of sight – works well in dense fog, rain, and snow
- Effective for measuring relative speeds

Disadvantages of radar:

- Narrow field of view (stationary) requires multiple units for 360-degree coverage
- Lower resolution

- No color, contrast, or optical character recognition

Automotive radar classification

Both autonomous and human-driven cars are increasingly using radars to improve drivers' comfort and safety. For instance, park assist and adaptive cruise control provide comfort, while warning the driver of imminent collisions and overriding control of the vehicle to avoid accidents improve the safety. Figure 1 depicts various such radar subsystems that form ADASs. Each subsystem has unique functionality and specific requirements in terms of radar range and angular measurement capability. The next section explains the fundamentals of location and speed estimation using the radar measurements.

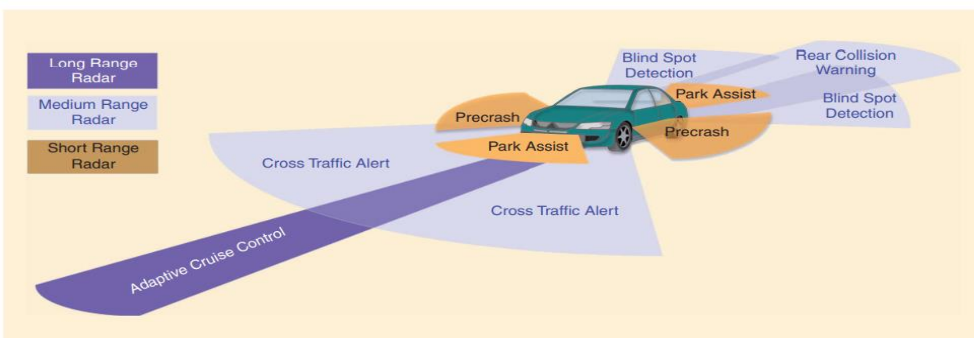


FIGURE 1. An ADAS consists of different range radars.

Basic automotive radar estimation problems

A radar can simultaneously transmit and receive EM waves in frequency bands ranging from 3 MHz to 300 GHz. It is designed to extract information [i.e., location, range, velocity and radar cross section (RCS)] about targets using the EM waves reflected from those targets. Automotive radar systems typically operate at bands in 24 GHz and 77 GHz portions of the EM spectrum known as mm-wave frequencies so that higher velocity and range resolution can be achieved. Fundamental radar operation involves three main tasks: range (distance), relative velocity, and direction estimation, as discussed next.

Range estimation

the range estimation is fundamental to automotive radars. The range R, to a target, is determined based on the round-trip time delay that the EM waves take to propagate to and from that target: R= (ct / x 2), where x is the round-trip time delay in seconds and c is the speed of light in meters per second ($c=3x10^8$) m/s. Thus, the estimation of x enables the range measurement. The form of the EM waves (signals) that a radar transmits is important for round-trip time delay estimation. For example, pulse-modulated continuous waves (CWs) consist of periodic and short power pulses and silent periods. Silent periods allow the radar to receive the reflected signals and serve as timing marks for radar to perform range estimation as illustrated in Figure 2.

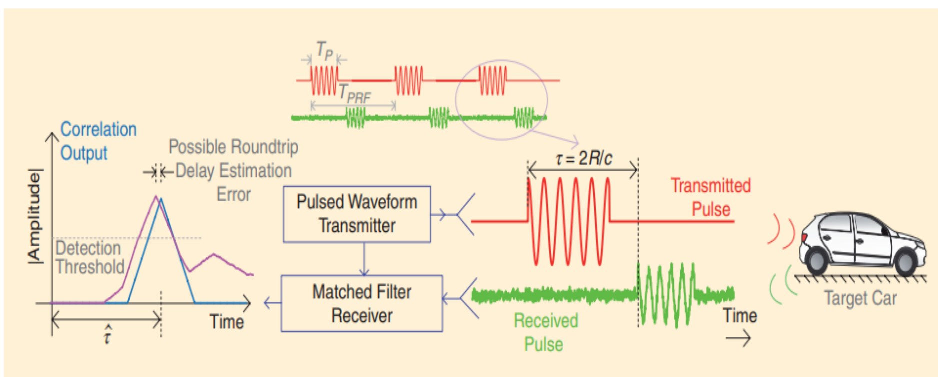


FIGURE 2. A pulsed CW radar with a correlation-based receiver can measure range *R* of the target car.

However, unmodulated CW signals (i.e., cos (2rf t c)) cannot be used for range estimation since they lack such timing marks. Additionally, the signal reflected from a target should arrive before the next pulse starts. Hence, the maximum detectable range of a radar depends on pulse repetition interval TPRF. The transmitted signal from the radar until it is received back undergoes attenuation due to the path loss and imperfect reflection from the target. In addition, received target signals are subject to internal noise in radar electronics and interference that may be a result of reflected signals from objects not of interest and may come from human-made sources (i.e., jamming). The typical round-trip time delay estimation problem considers only ambient noise in the form of additive white Gaussian random process. It is assumed that demodulation has already removed the carrier so that a target signal x (t) at baseband can be modeled as:

$$x(t) = \alpha s(t - \tau) + \omega(t),$$

where alpha is a complex scalar, whose magnitude represents attenuation due to antenna gain, path loss, and the RCS of the target and w (t) is additive white Gaussian noise with zero mean and variance. 2 v the goal is to estimate x with the complete knowledge of the transmitted radar waveform s (t). Assuming the signal s(t) has unit amplitude and finite energy Es, the ideal radar receiver can be found using a matched filter with the impulse response h (t) =s*(-t), which maximizes signal to noise ratio at the output. Thus, the matched filter-based receiver finds the correlation between the transmitted signal and received reflected pulses

$$y(\tau) = \int x(t) s^*(t - \tau) dt.$$

The maximum likelihood (ML) estimate of the time delay is the time that the magnitude of the matched filter output peaks at:

$$\hat{\tau} = \arg\max_{\tau} |y(\tau)|.$$

The presence of the noise can perturb the location of the peak, which will result in the estimation error. Furthermore, the radar needs to decide whether or not a received signal actually contains an echo signal from a target. A good deal of classical radar literature is devoted to developing strategies that provide the most favorable detection performance.

A typical decision strategy can be formulated based on statistical hypothesis testing (a target present or not). This leads to a simple threshold testing at the matched filter output. Range resolution, another key performance measure, denotes the ability to distinguish closely spaced targets. Two targets can be separated in the range domain only if they produce nonoverlapping returns in the time domain. Hence, the range resolution is proportional to the pulse width T_p. In other words, finer pulses provide higher resolution. However, shorter pulses contain less energy, which implies poor receiver signal to-noise ratio (SNR) and detection performance. As explained in the section “Radar Waveforms,” this problem is overcome by the technique called pulse compression, which uses phase or frequency modulated pulses.

Velocity estimation

Velocity estimation of the target velocity is based on the phenomenon called the Doppler effect. Suppose the car displayed in Figure 2 is moving ahead with differential velocity v. With the existence of relative motion between two cars, the reflected waves are delayed by time x = (r2 R v! t)/c). The time dependent delay term causes a frequency shift in the received wave known as the Doppler shift f v d=! 2 /m. The Doppler shift is inversely proportional to wavelength m, and its sign is positive or negative, depending on whether the target is approaching or moving away from the radar. While this frequency shift can be detected using CW radar, it lacks the ability to measure the targets range. Here, we discuss a pulsed radar configuration that uses frequency modulated (FM) CW pulses and provides simultaneous range velocity estimation in multitarget traffic scenarios. The FMCW radar transmits periodic wideband FM pulses, whose angular frequency increases linearly during the pulse.

$$s(t) = e^{j2\pi(f_c + 0.5Kt)t} \qquad 0 \le t \le T.$$

The signal reflected from a target is conjugately mixed with the transmitted signal to produce a low-frequency beat signal, whose frequency gives the range of the target. This operation is repeated for P consecutive pulses. Two-dimensional (2-D) waveforms in Figure 3(c) depict successive reflected pulses arranged across two-time indices. The slow time index p simply corresponds to pulse number. On the other hand, the fast time index n assumes that for each pulse, the corresponding continuous beat signal is sampled with frequency fs to collect N samples within the time duration T. Assuming single target and neglecting reflected signal distortions, the FMCW radar receiver output as a function of these two time indices is given by:

$$d(n,p) \approx \exp\left\{ j2\pi\left[\left(\frac{2KR}{c} + f_d\right)\frac{n}{f_s} + f_d p T_0 + \frac{2f_c R}{c}\right]\right\} + \omega(n,p).$$

Therefore, as illustrated in Figure 3(c), discrete Fourier transform across fast time n can be applied to obtain beat frequency f_b= (2KR/c) coupled with Doppler frequency f_d. This operation is also known as the range transform or range gating, which allows the estimation of Doppler shift corresponding to unique range gate by the application of second Fourier transform across the slow time. A range-Doppler map can be found efficiently by using 2-D fast Fourier transform (FFT) (5).

A demonstrative example based on the aforementioned discussion is shown in Figure 3.

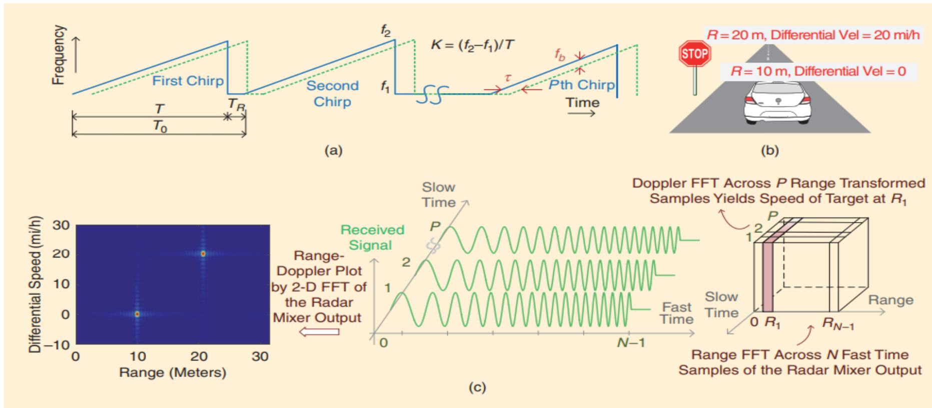


FIGURE 3. (a) A spectrogram of an FMCW waveform with modulation constant $K = (B/T)$, reset time T_R, and pulse period T_0; transmitting P successive chirps. Round-trip delay τ is converted to beat frequency f_b. (b) Typical traffic scenario: stationary traffic sign, the radar, and passenger car moves at 20 mi/h (range and differential velocity are displayed). (c) A 2-D joint range-Doppler estimation with 77-GHz FMCW radar $\{[N, P] = [64, 64],\ \mathrm{SNR} = 10\ \mathrm{dB},\ \mathrm{BW} = 300\ \mathrm{MHz},\ T = 300\ \mu s\}$.

Direction estimation

Direction estimation Use of wideband pulses such as FMCW provides discrimination of targets in both distance and velocity. The discrimination in direction can be made by means of an antenna array. Figure 4(a) depicts a realistic traffic scenario with several targets surrounding the radar that collects direct and multipath reflections from them. In such cases, to spatially resolve equidistant targets and deliver comprehensive representation of the traffic scene, angular location of targets should be estimated. Therefore, in automotive radars, the location of a target is often described in terms of a spherical coordinate system (R,θ,ϕ) where (θ,ϕ) denote azimuthal and elevation angles, respectively. However, in this case, the single antenna radar setup as used in the range-velocity estimation problems may not be sufficient, since the measured time delay t=(2(R±vt/c)) lacks the information in terms of angular locations of the targets. To enable direction estimation, the radar should collect reflected wave data across multiple distinct dimensions. For example, locating a target using EM waves in 2-D requires the reflected wave data from the object to be collected in two distinct dimensions. These distinct dimensions can be formed in many ways using combinations of time, frequency, and space. For instance, a linear antenna array and wideband waveforms such as FMCW form two unique dimensions. Additionally, smaller wavelengths in mm-wave bands correspond to smaller aperture sizes and, thus, many antenna elements can be densely packed into an antenna array. Hence, the effective radiation beam, which is stronger and sharper, in turn increases the resolution of angular measurements.

Consider an antenna array located in plane z = 0, and let l be the abscissa corresponding to each receiver antenna position [see Figure 4(b)].

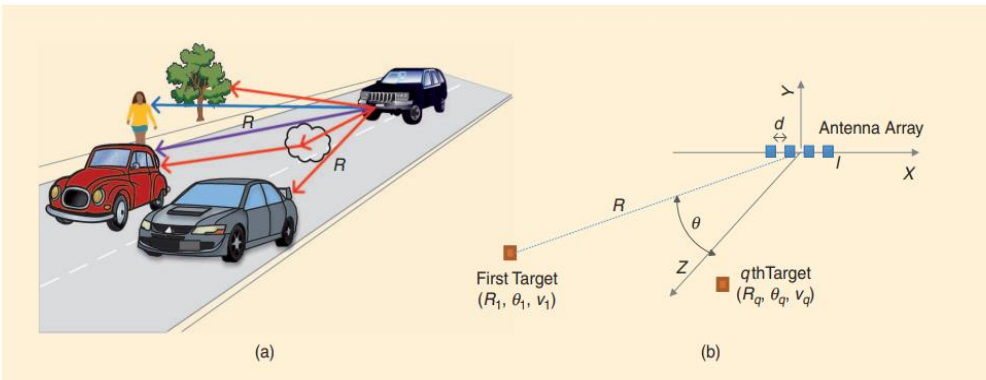


FIGURE 4. (a) A typical traffic scenario with reflections from different targets, including two cars at the same distance R. (b) The azimuth angle estimation setup using uniform linear antenna array.

Let (R_q,θ_q) be the position of the $_q^{th}$ target in spherical coordinates, moving with velocity v_q relative to the radar. With the help of far field approximation, for the qth target, the round-trip time delay between a transmitter located at the origin and the receiver positioned at coordinate l is given by:

$$\tau_{lq} = \frac{2(R_q + v_q t) + ld\sin\theta_q}{c},$$

where d is the distance between antenna elements (usually half the wavelength) arranged in a linear constellation. Combining (5) and (6) gives the three-dimensional (3-D) FMCW radar output signal, which enables estimation of range, velocity, and angle. For Q number of targets, the signal can be represented:

$$d(l,n,p) \approx \sum_{q=0}^{Q-1} \alpha_q \exp\left\{ j2\pi\left[\left(\frac{2K\,R_q}{c} + f_{dq}\right)\frac{n}{f_s} + \frac{f_c ld\sin\theta_q}{c} + f_{dq}pT_0 + \frac{2f_c R_q}{c}\right]\right\} + \omega(l,n,p),$$

where alpha and beta correspond to same quantities as explained in the range estimation problem. The delay term tlq creates uniform phase progression across antenna elements, which permits the estimation of the angle by FFT in spatial domain, as shown in (7). Thus, 2-D location (range and angle) and speed of targets can be jointly estimated by 3-D FFT. The target location and velocity estimation problems are revisited later in the section “Advanced Estimation Techniques” with more emphasis on the high-resolution algorithms and computational complexity analysis.

Radar waveforms

Various automotive radar classes, have diverse specifications in terms of several fundamental radar system performance metrics, such as range resolution, velocity resolution, angular direction, SNR, and the probability of target detection. The type of waveform employed by a radar is a major factor that affects these metrics. The radar waveforms, can be characterized whether or not they are CW, pulsed and frequency, or phase modulated. Modulated radar waveforms include FM CW, stepped frequency (SF) CW, orthogonal frequency-division multiplexing (OFDM), and frequency shift keying (FSK). Each waveform type has a certain advantage in processing, implementation, and performance as follows: In the CW radar, a conjugate mixing of a high-frequency transmitted and received signal produces the output signal at the Doppler frequency of the target. The resolution of frequency measurement is inversely proportional to the time duration of the signal capture. The continuous nature of the waveform precludes round-trip delay measurement, which is necessary for range estimation of the target.

Hence, apart from ease of implementation and ability to detect target speed, the CW radar cannot provide the range information. Pulsed CW radar can estimate the range information as explained previously in the section “Basic Automotive Radar Estimation Problems.” The Doppler frequency can be estimated by making each pulse longer and measuring the frequency difference between the transmitted and received pulses. The pulse duration and pulse repetition frequency (PRF) are the key parameters in designing pulsed CW radar with desired range and velocity resolution. FMCW, also known as linear frequency modulation (LFM) or chirp, is used for simultaneous range and velocity estimation. Due to the pulse compression, the range resolution is inversely proportional to the bandwidth of the FMCW signal and is independent of pulse width. For example, the short-range FMCW radar uses ultra wideband (UWB) waveforms to measure small distances with higher resolution. The Doppler resolution is a function of pulse width and the number of pulses used for the estimation. Thus, with the ability to measure both range and speed with high resolution, FMCW radar is widely used in the automotive industry. In contrast to FMCW waveforms, the frequency of FSK and SFCW varies in a discrete manner. In this case, the range profile of the target and the data collected at discrete frequencies form the inverse Fourier transform relationship. Also, hybrid waveform types can be employed to achieve additive performance. FSK waveform can be combined with multi slope FMCW waveform to overcome ghost targets in radar processing. Similarly, alternate pulses of CW and FMCW are used to accurately estimate range and Doppler. OFDM can be viewed as another multifrequency waveform that offers unique features of the joint implementation of automotive radar and vehicle-to-vehicle communications. For the radar operation, the orthogonality between OFDM subcarriers is ensured by choosing carrier spacing more than maximum Doppler shift, and the cyclic prefix duration is selected greater than the longest round-trip delay. The range profile is estimated through frequency domain channel estimation. OFDM radar processing along with simulation results is explained in. Based on the knowledge of target statistics, radar waveforms can be optimized. Radar waveform design is revisited along with multiple-input.

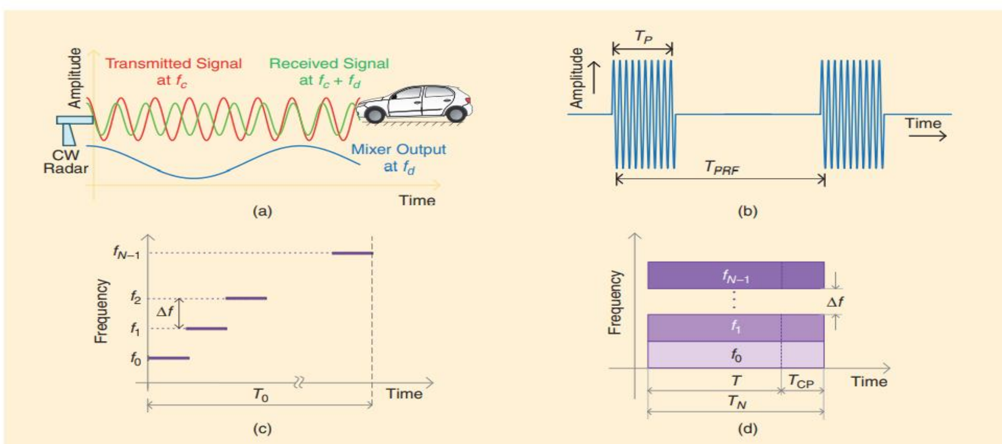


FIGURE 5. (a) Doppler frequency measurement with the CW radar. (b) A pulsed CW radar waveform with pulse repetition time T_{PRF} and pulsewidth T_p. (c) An SFCW signal with period T_0. (d) An OFDM block with symbols time T and cyclic prefix time T_{CP}.

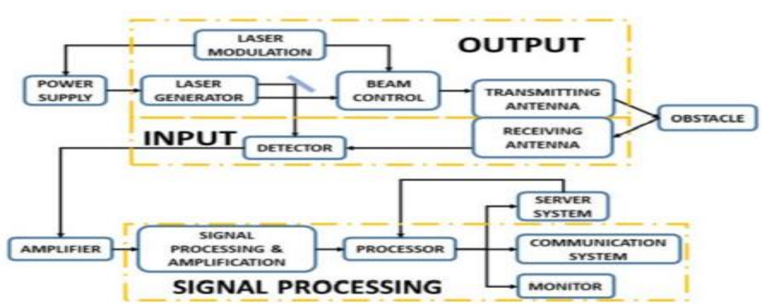
Radar calibration

Radar calibration is a method which allows to scale unknown signals by means of standardized signals. Since radar investigations are aimed to quantify radar echoes for studying target properties, there is a need to calibrate such systems.

Compare between radars from different manufacturers

2)Lidar:

Lidar is used to detect the position of the target by emitting a laser beam. The laser light is electromagnetic waves, which are quite different from mechanical waves. Lidar has two modes: two-dimensional scanning and three-dimensional scanning. The measurement principle is to calculate the distance by detecting the time from the laser emission to the reflection by the object. Among them, the part responsible for laser emission has a rotatable mirror. When the mirror poses a certain range of pitch angle after rotation, the effect of three-dimensional scanning is achieved. Lidar can be divided into three forms depending on the presence or absence of this mechanical rotating part: mechanical lidar (with macroscopic rotation), hybrid solid-state lidar (with both "moving part" and "solid part"), all-solid-state laser Radar (without macroscopic mechanical rotation). The reliability and integration of radar increase with the decrease of the number of radar mechanical structures. Therefore, the mature three-dimensional laser sensor technology should move closer to the all-solid state



A two-dimensional Lidar can only scan one plane, its structure is relatively simple, the calculation load and technical difficulty is less than those of the three-dimensional Lidar. However, once the potholes and uneven road surface occur, the data measured by the system will be unreliable. The three-dimensional Lidar can scan the contour edges of the object, and the obtained contour data constitute all the terrain within the detection range of the point cloud reconstruction, and outputs high-resolution data on the geometry, distance, and speed with an accuracy of up to the centimeter level. The resolution achieved by Lidar is higher than that obtained by a millimeter wave radar. However, due to the complicated structures and large load of calculation, Lidar entails high computing power of the computer system. In addition, the Lidar is extremely susceptible to impact of tough weather conditions, and its performance will be greatly reduced when it encounters rain and snow.

Lidar in traffic scenes

The traffic scene perception of autonomous vehicles is done with the help of different sensors and methodologies. Generally, the solution consists of four steps: pre-processing, Feature extraction, detection and post-processing. In ancient PC vision algorithms, these four steps are whole separated and also the extracted options are typically expressible. Apart from the traditional segmentation algorithms that use camera data whose accuracy is degraded by the effect of shadows, bright sunlight or headlight of other cars, this paper focus on lidar sensors. It provides 3-D geometry information of the vehicle surroundings with high accuracy. Apart from the previous works which deals only with segmentation using data from lidar sensor, it deals with predicting the probabilities of detecting things such as human, vehicles, traffic signals, stationary objects etc.

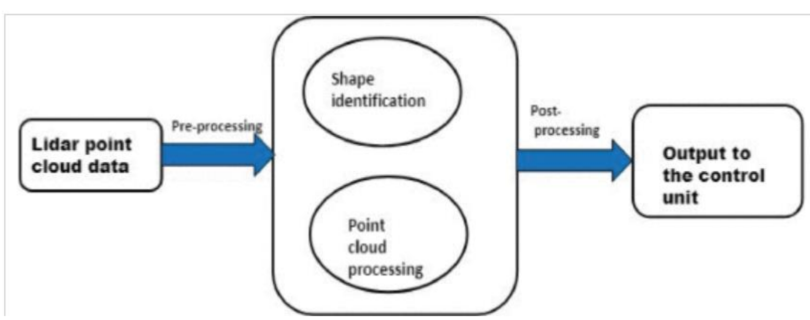


Fig. 1.
An illustration of data flow through the proposed approach

As shown in Fig. 1 the LiDAR point cloud is been initially fed to the model. The basic idea of LiDAR is a spinning laser beam that bounces its radiation in all directions and detecting its reflections. In autonomous vehicles it used along with GPS, accelerometers, inertial guidance systems and gyrocompasses. As a result, we end up with millions of data points extending as far as 60m away from the vehicle in all directions. Lidar used here emits an invisible, near-infrared laser (around 900-1100 nanometers). The LiDAR point includes x, y, z coordinates and a laser reflection intensity.

Point cloud processing and shape identification:

The next step in the Fig.1 deals with the processing of the input data. The input Lidar data represents every object as a collection of points thus known as a point cloud data. The data is unorganized in nature and is randomly arranged. So, we would require pre-processing for the conversion of raw Lidar data to an organized input tensor form.

Tensor is an array of numbers, or mathematical functions, which varies according to definite rules under a transition of coordinates. Converted data tensor is fed for training of the deep learning model. We build use of tensor flow for the analysis of those input tensors. Tensor flow is employed as an open-source library employed in neural network applications of machine learning. It was originally developed by Google brain team. It is used for the classification and processing of input tensors.

The block of shape identification is concerned with the identification of traffic signs and symbols. In the case of an autonomous vehicles the segmentation of traffic symbols is also equally important. Process of image segmentation is used for detecting the symbols with most accuracy.

Simulation and results:

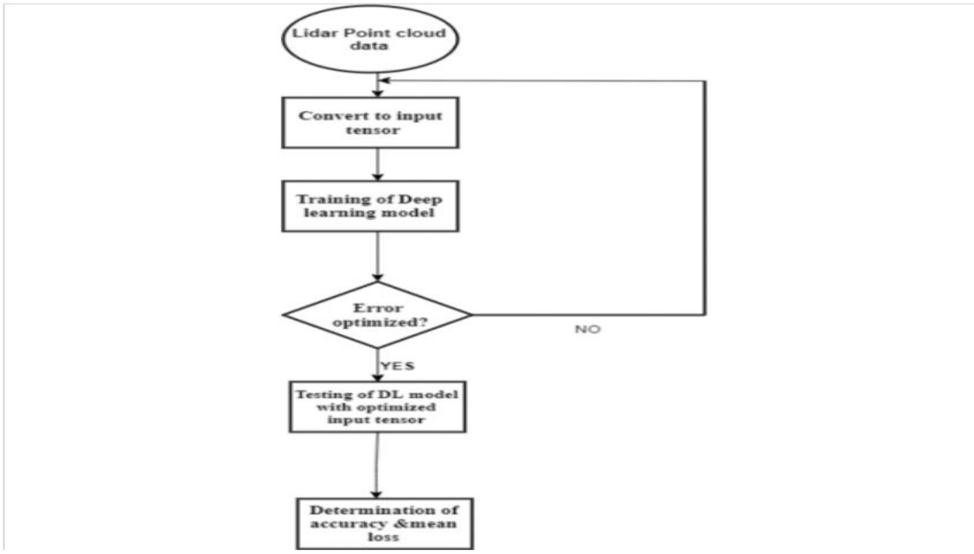


Fig. 2.
Flow chart

The Fig. 2 shows the flow chart of the model. Initially we begin with Lidar data which is in the form of point cloud. It is then converted to input tensor form that is in the form of arrays for the ease of processing. The deep learning model is trained with the help of these input data tensors. TensorFlow library is mainly used for the processing the input data tensors. The output of training phase is a.h5 file which is tested for optimizing error. Optimization is done with the help of Adam's optimization algorithm. Apart from classical optimization algorithms here the weights are updated at each stage of the iteration. If the error is found to be optimized, we move on to the testing phase.

Advantages:

- Creates an accurate 3D map of a vehicle's surroundings
- Operates well in low light

Disadvantages:

- Issues operating in dense fog, rain, and snow
- Most expensive of the sensor array
- No color, contrast, or optical character recognition

- Data intensive
- Needs direct line of sight

Lidar calibration

Extrinsic calibration of lidar and camera sensors generally uses calibration objects, such as planar boards with chessboard patterns, in the captured scene. The corner points of the calibration object are detected in the data captured by each sensor and used to establish the point correspondences between them.

Compare between lidar from different manufacturers

3)Sonar:

An ultrasonic sensor array system has been developed with group-sensor firing intervals. A binaural approach to the CLMR has been adopted for providing complete contactless sensory coverage of the entire workspace the CLMR can recognize the parking space and the obstacle position in dynamic environment. Therefore, the proposed controller installed in a car could ensure safe driving. Finally, practical experiments demonstrate that the proposed multifunctional intelligent autonomous parking controllers are feasible and effective.

An autonomous parking controller can provide a novice driver some convenience; however, an inadequate controller may damage the car and endanger the driver. Therefore, the autonomous parking controller for safe parking emphasizes improved parking safety measures.

The system developed in an earlier study comprised a host computer and a vision system and proved the feasibility of the proposed methods. However, the action of parking is restricted; it must employ a vision system above the working environment for every parking space. In an earlier study, a field-programmable gate array (FPGA) chip was applied to substitute the host computer, and six reflex infrared sensors were implemented to receive the data of the working environment. Nevertheless, infrared sensors are expensive. The detected value is influenced by the color of the detected object, and the detection beam is very narrow. In some cases, the corner may be regarded as a dead zone for reflex infrared sensors. On the contrary, ultrasonic sensors are much cheaper, the color of the object does not affect the accuracy of detection, and ultrasonic sensors have an elliptical detection cone of about 40 °. By applying the binaural method, the CLMR can detect the relative position of a wall or any obstacle to avoid collision.

To solve the problems of path planning, An et al. developed an online path-planning algorithm to guide an autonomous mobile robot to reach a goal and avoid obstacles in the unknown environment, with the use of a charge-coupled device (CCD) camera. In another study, a CCD camera was used to track a designed trajectory sketched on the ground; therefore, the tracking error could be obtained from the vision system and stability could be proved. Nevertheless, the designed trajectory cannot be detected in a real application. In this paper, an ultrasonic sensor system has been employed to detect environment information, and a heuristic fuzzy controller has been applied to complete the parking task. Piazzi et al. presented the η3-splines for the smooth path generation of wheeled mobile robots, where six parameters could be freely selected to shape the curve without changing the endpoint interpolation.

Considering that the CLMR travels in unknown and dynamic environment, the construction of complete and contactless sensory coverage of the workspace is essentially difficult. To overcome this problem, several sensor systems are used, such as infrared sensors, laser sensors, and ultrasonic sensors. Reinjures and Perelman's utilized spectral analysis to estimate the distance and bearing of reflectors, where a realistically complex environment was reconstructed based on the time–frequency representations of the echoes; however, the computational load of the proposed scheme was heavy.

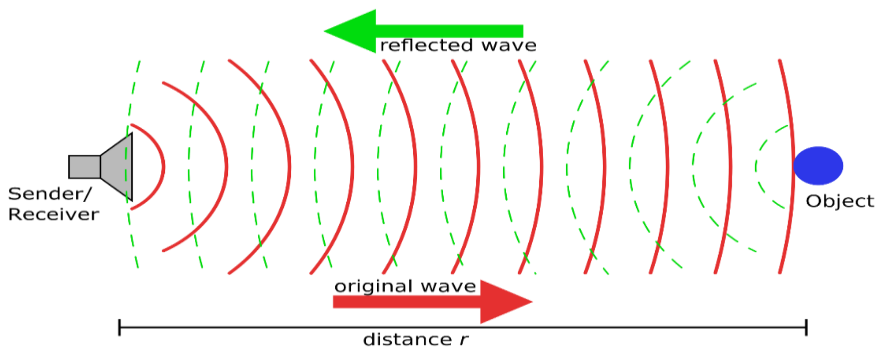
The binaural method is based on sensing the position of a reflector by a pair of ultrasonic transmitters–receivers placed at different locations. The distances are usually detected by an emitting–echoing method. From each pair of the ultrasonic sensors, two equidistant curves are determined by the elliptical detection cone, where the position of the reflector is to be found at the intersection point of these two equidistant curves. The locations of the transmitter and receiver are set as two focal points of the ellipse, and the reflector may be located anywhere on the elliptic curve in the detectable region.

Advantages:

- Very accurate in short distances
- Works well in dense fog, rain, and all light conditions
- Small and inexpensive

Disadvantages:

- Limited range
- No color, contrast, or optical character recognition
- Not useful for gauging speed



4) Cameras:

the camera is a sensor that has been used for a long time. The advantage is that the price is low, and the ability to secure rich data is also an advantage. However, it is vulnerable to environmental changes and requires a large amount of computing resources for computation. On the other hand, thermal cameras can classify and identify objects at high speed all day in the dark, where the field of view is disturbed (smoke, sunlight, fog). Since thermal imaging cameras sense heat, people and animals can be more effectively identified than other ADAS sensor technologies.

Advantages:

- Provides color, contrast, and optical character recognition
- Very affordable

Disadvantages:

- Limited field of view
- Issues with changing light and shadows, dense fog, rain, sun glare, low light conditions
- Very processor intensive

Camera calibration

Calibrating a thermal camera is the process of correlating what the camera sees (infrared radiation) with known temperatures, so that the camera can accurately measure the radiation it detects.

5) Navigation:

The safety features in autonomous driving and Advanced Driver Assistance Systems (ADAS) require lane-level positioning accuracy. Such accuracy can be obtained from the Global Navigation Satellite Systems (GNSS) through either differential techniques or Precise Point Positioning (PPP).

The new generation of navigation systems must tackle several challenges and address a wide range of navigation needs and preferences. The first challenge is how autonomous cars will use road infrastructures and how closely they can replicate human drivers' attitudes for navigating on roads. The second challenge is how to integrate real-time information from multiple types of commuters, namely autonomous cars, pedestrians, drivers, and bicyclists to provide useful information in making navigation decisions. The third challenge would be how to respond to the continually changing navigation needs and preferences of pedestrians who increasingly request paths that provide them with a full experience of their city (rather than simply get them to their destination fast).

Advantages:

- Worldwide coverage
- All weather operation
- Provides positioning between vehicles that cannot see each other
- Provides positioning when no road markings or signage are visible

Disadvantages:

- Accuracy dependent on number of satellites in field of view

- Overall accuracy is lower than other sensors (+/- 1m in public use)

Type	Parameter			
	Relative Cost	Accuracy	Measurement of the position	Environmental adaptability
HF and UHF RFID solutions	$$	High	Absolute position	Sensitive to foundation settlement
Differential GPS systems	$$$	Very high	Absolute position	Sensitive to metal and other shelter
Laser- based navigation systems	$$$	Very high	Absolute position	Sensitive to dust, water, humidity, oil, sun and reflector interferences
Inertial navigation systems	$$	High	Relative position	Sensitive to cumulative error, vibration and slip
Encoders	$	Low	Relative position	Sensitive to cumulative error, vibration and slip

Compare between navigation sensors from different manufacturers

uses of sensors

- Self-driving cars typically have many sensors with overlapping and redundant functions. This is so they have sensor system backup (in case one sensor fails, another will work) and can benefit from the strengths of different sensor types.
- Autonomous vehicle developers use novel data-processing techniques like sensor fusion to process information from multiple data sensors simultaneously in real-time. Sensor fusion can improve the ways self-driving cars interpret and respond to environmental variables and can therefore make cars safer.

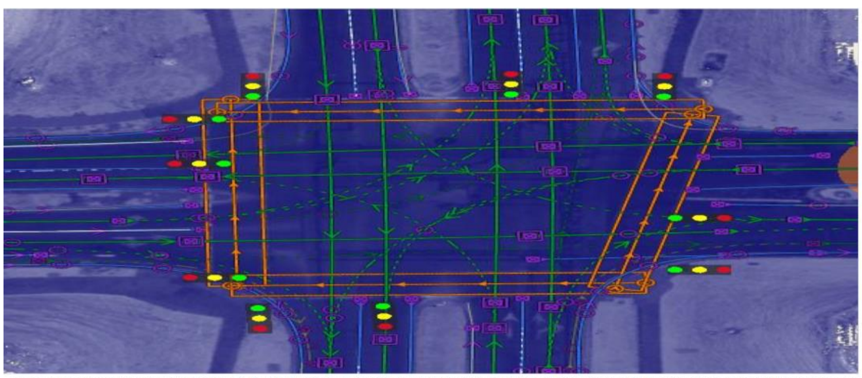
Map making in autonomous cars

A map for self-driving cars has a lot more detail than conventional maps (ex: the height of a curb, width of an intersection, and the exact location of a traffic light or stop sign), so developing a whole new way of mapping the world is needed.

Before driving in a new city or new part of town, car manufacturers should build a detailed picture of what's around the car using the sensors on the self-driving car. As we drive around town, lasers send out pulses of light that helps paint a three-dimensional portrait of the world. Autonomous cars are able to tell the distance and dimensions of road features based on the amount of time it takes for the laser beam to bounce back to the sensors. Mapping team in car companies turns this into useful information for the cars by categorizing interesting features on the road, such as driveways, fire hydrants, and intersections.

This level of detail helps the car know exactly where it is in the world. As the cars drive autonomously on the road, car software matches what the car sees in real-time with the maps that are already built, allowing the car to know its position on the road to within 10cm of accuracy.

Another benefit of knowing permanent features of the road is that car sensors and software can focus more on moving objects, like pedestrians, vehicles, and construction zones. This allows to do a better job of anticipating — and avoiding — tricky situations.



Self-driving cars can use a much greater level of detail than you'd find on Google Maps. Our mapping team highlights road features such as the length of a crosswalk, height of a traffic light, and the curve of a turn.

Of course, the streets change frequently, so cars need to be able to recognize new conditions and make adjustments in real-time. For example, cars can detect signs of construction (orange cones, workmen in vests, etc.) and understand that it might have to merge to bypass a closed lane, or that other road users may behave differently.

To keep the maps up-to-date, cars automatically send reports back to the mapping team whenever they detect changes like these. The team can then quickly update the map and share information with the whole autonomous fleet.

Path Planning in autonomous cars

Autonomous car planning and decision making for self-driving cars in urban environments enable transport to find the safest, most convenient, and most economically beneficial routes from point A to point B.

Finding routes is complicated by all of the static and maneuverable obstacles that a vehicle must identify and bypass. Today, the major path planning approaches include the predictive control model, feasible model, and behavior-based model. Let’s first get familiar with some terms to understand how these approaches work.

A **path** is a continuous sequence of configurations beginning and ending with boundary configurations. These configurations are also referred to as initial and terminating.

Path planning involves finding a geometric path from an initial configuration to a given configuration so that each configuration and state on the path is feasible (if time is taken into account).

A **maneuver** is a high-level characteristic of a vehicle’s motion, encompassing the position and speed of the vehicle on the road. Examples of maneuvers include going straight, changing lanes, turning, and overtaking.

Maneuver planning aims at taking the best high-level decision for a vehicle while taking into account the path specified by path planning mechanisms.

A **trajectory** is a sequence of states visited by the vehicle, parameterized by time and, most probably, velocity.

Trajectory planning or trajectory generation is the real-time planning of a vehicle’s move from one feasible state to the next, satisfying the car’s kinematic limits based on its dynamics and as constrained by the navigation mode.

major path planning algorithms

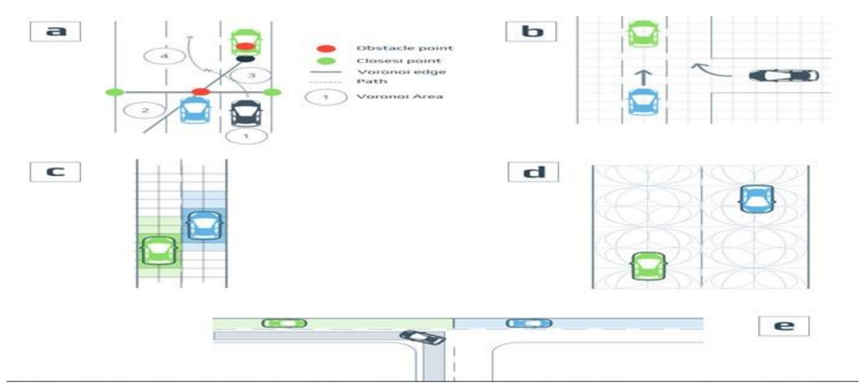
The **Voronoi diagram (a)** algorithm generates paths that maximize the distance between a vehicle and surrounding obstacles.

The **occupancy grid (b)** algorithm works similarly to the Voronoi diagram, though risk and feasibility are calculated primarily by considering the presence of obstacles and lane and road boundaries.

Whereas the occupancy grid consists almost exclusively of a grid with the obstacle's position, with the **cost maps (c)** algorithm, the higher cost of a cell results in its more intense representation on the map.

The **state lattices (d)** algorithm uses a generalization of grids. Grids are built by the repetition of rectangles or squares to discretize a continuous space, while lattices are constructed by regularly repeating primitive paths that connect possible states for the vehicle.

The **driving corridors (e)** algorithm recreates continuous collision-free spaces, bounded by lanes and other obstacles between which the vehicle is expected to drive. Driving corridors algorithms use data from digital maps built by Simultaneous Location and Mapping (SLAM) models.



Obstacle avoidance

Obstacle avoidance ability is the significant embodiment of the ground mobile robot, and the basic guarantee of the ground mobile robot to perform various tasks. Obstacle avoidance technologies are divided into two kinds, one is based on the global map and another is based on sensors respectively. This paper mainly aims at the local obstacle avoidance method based on sensors. The study of obstacle detection and obstacle avoidance are two inseparable parts in the research of obstacle avoidance ability. This paper proposes an efficient obstacle detection and obstacle avoidance algorithm based on 2-D lidar. A method is proposed to get the information of obstacles by filtering and clustering the laser-point cloud data. Also, this method generates the forward angle and velocity of robot based on the principle of minimum cost function. The obstacle detection and obstacle avoidance algorithm have advantages of a simple mathematical model and good real-time performance. The effectiveness of the proposed algorithm is verified on MATLAB simulation platform.

Obstacle avoidance technology is a hotspot in the field of the ground mobile robot, also is one of the most important embodiments of the intelligent robot. Good performance of obstacle avoidance is the basic premise of robot on a particular task.

The technology of obstacle avoidance can be divided into two parts, one is global obstacle avoidance method based on the known environment information and another is local obstacle avoidance method based on the information from sensors.

Lidar has the advantages of high precision, large detection range, and fast sweep frequency. It is widely used in the obstacle detection field of the ground mobile robot. Lidar can be divided into 2D lidar and 3D lidar. 3D lidar can get the height information of obstacles.

uses of sensors

Self-driving cars typically have many sensors with overlapping and redundant functions. This is so they have sensor system backup (in case one sensor fails, another will work) and can benefit from the strengths of different sensor types.

Autonomous vehicle developers use novel data-processing techniques like sensor fusion to process information from multiple data sensors simultaneously in real-time. Sensor fusion can improve the ways self-driving cars interpret and respond to environmental variables and can therefore make cars safer.

Actuators

1. **Acceleration** – Throttle Actuation

The Throttle Actuator Compact is a linear rotary screw (LRS) type throttle actuator used for controlling the mechanical throttle on an engine. The linear rotary screw type technology gives the Throttle Actuator excellent speed, force, and accuracy capabilities. The integrated controller allows for improved stability and accommodates a large input voltage range. The integrated mechanical flex-ball connection to the throttle and a pre-defined electrical connection to the automation system make it an excellent solution for engine control. The hardware component of the AVL Throttle Actuator Compact consists of the actuator with a push-pull cable and an integrated controller. All of the required power components and motion processors are contained in the actuator housing.

Throttle Actuation

2. **Direction** – Steering Actuation

A steering actuator is a device used to assist with the steering of a vehicle. The most common type of steering actuator resembles a double-ended, hydraulic ram that is able to push out both ends of the device. When the actuator is mounted to a chassis, the rams on either end of the actuator push against the steering linkage, effectively aiding in the steering of the vehicle. Sensors located on the steering linkage use computer assistance to activate the actuator and apply the correct amount of steering assistance or hydraulic pressure.

Nearly every type of vehicle, from sports cars to boats and farm tractors, uses a steering actuator to assist in the turning of the vehicle. Similar to a power-assist, hydraulic cylinder used on conventional steering-box equipped vehicles, the actuator is designed to work with rack-and-pinion steering systems. In some rear-wheel steer applications of four-wheel steer vehicles, the actuator works unassisted in steering the rear wheels. In a marine application, the steering actuator is typically mounted near the rear of the vessel and applies steering pressure to the outboard boat motor. This pressure causes the motor to pivot more easily in its mount, thereby allowing the operator to steer the boat using much less physical effort.

As the vehicle's steering wheel is turned, a sensor detects the movement and the direction of the movement, which sends a signal to the computer system. The computer reads several sensors to calculate the vehicle speed, the amount of effort that is being applied to the steering wheel and the gear that the transmission is being operated in. With this information gathered and processed in a fraction of a second, the computer signals the steering actuator to apply a specific amount of pressure in one direction or another to ease the steering system pressure that is being exerted against the steering system. In the case of a farm tractor, the steering may be requiring assistance due to the tires being submerged in deep mud, sand or soil.

Monitoring the vehicle's speed is essential on four-wheel steer vehicles and sports cars. If the computer was to apply even the slightest amount of excessive steering pressure on the steering system at high speeds, the vehicle could potentially snap out of control and crash. Most actuators rely on restrictive valves inside of the actuator body to prevent the application of excessive pressure at high speeds.

Steering Actuation

3. **Stopping** – Brake Actuation

A brake actuator is basically a relay device in a rear brake assembly. It throws out high pressure air into the rear brake assembly as soon as the driver touches the brake pedal and it's sound is characterized by a loud albeit short hiss when the brakes are applied. It recharges as soon as the brakes are released and the truck begins to roll. These brakes are usually used in multi axle vehicles such as in trucks with trailers, tractors, buses etc.

One more point to be noted is that the time taken by Air to travel from brake pedal to rear brake is longer which causes the rear brakes to engage after front brakes. In order to check this lag, the brake actuator stores air which is released when the brake is depressed and rear brakes are engaged quickly. If this were not there, then the truck would be unbalanced which would result in the skidding of the trailer. The use of brake actuator eliminates this lag, so for this purpose, brake actuators are used.

The mechanism is well known in devices which work on the principle of fluid pressure. These mechanisms are also used in application of brakes from vehicles to aerospace applications.

Brake Actuation

Example for autonomous cars

Figure 1 shows Google's autonomous driving car and devices for obstacle recognition. In order to recognize obstacles, we need sensors that can be used for recognition and a CPU that can process corresponding sensor data. There are four major sensors that are used in the recognition of the surrounding obstacles in autonomous vehicles.

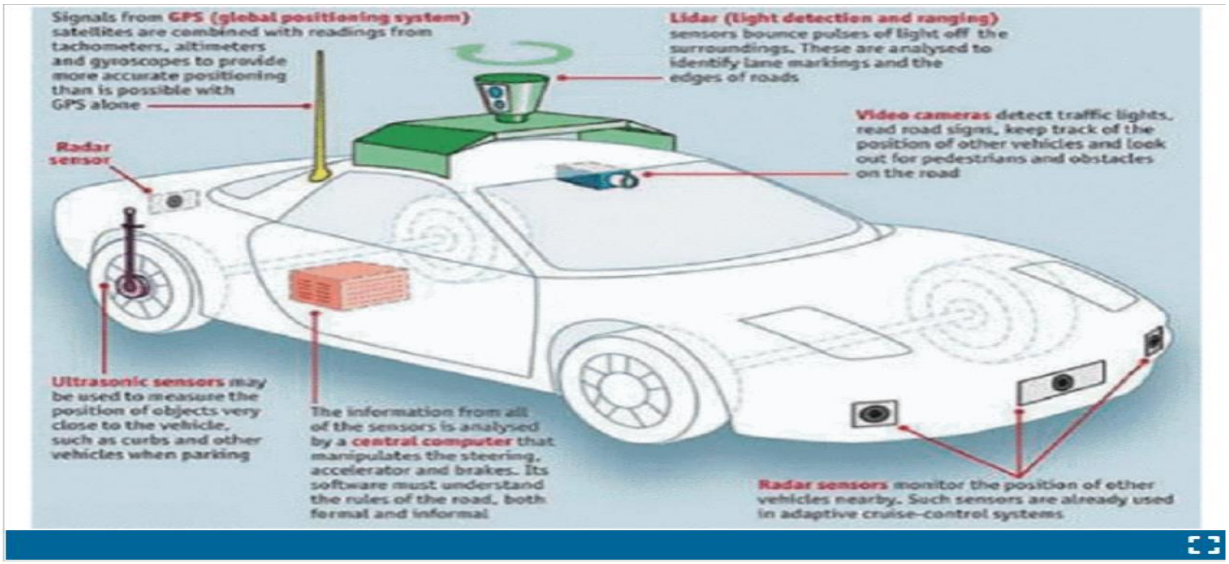


Fig. 1.
Google's autonomous driving car [10]

First, the LiDAR sensor can detect the distance from the obstacle by using light, distances from surrounding obstacles within a certain range are presented in the form of points by using the straightness of light. At this time, the acquired point data can detect the accurate surroundings only to have an error of about 1 to 2.

Second, Radar is the most commercially available sensor on the current vehicle. The radar uses the Doppler effect to measure the distance to the object after receiving the radio wave reflected by the object after shooting the radio wave. While Radar has the advantage of long sensing distances, when there are multiple objects in the same area or there are highly reflective metals, it is difficult to distinguish each object correctly.

Third, the ultrasonic sensor is widely used as a rear sensor, but its sensing distance is short and it cannot be utilized when driving on the road, but it can be used for automatic parking. Since the price is low and the performance is constant, it is commercialized and actively used.

Conclusion

As a huge number of cars can learn collectively from the experience of one single car, the need of implementing the training algorithm decreases from implementing it as many times as there are number of cars available to be trained too just once. The complexity of the procedure reduces from n to 1, where n can be as big as it can.

The proposed method improves the existing method of training driverless cars significantly by:

• eliminating the necessity of training each car separately.

• enabling thousands of cars to interact and share their experience.

• saving time, money and resources significantly.

• reducing human efforts to large extent.

• providing modularity in the process of learning.

Thus, integrating block chain features to the training process of autonomous cars enhances its efficiency to a considerably large extent.

References

- https://en.wikipedia.org/wiki/Self-driving_car
- https://www.udacity.com/blog/2021/03/how-self-driving-cars-work-sensor-systems.html
- https://link.springer.com/referenceworkentry/10.1007%2F978-3-540-30301-5_22
- https://intellias.com/path-planning-for-autonomous-vehicles-with-hyperloop-option/#:~:text=Motion%20planning%20for%20autonomous%20vehicles,configuration%20or%20a%20state%20space
- https://library.gju.edu.jo:2085/stamp/stamp.jsp?tp=&arnumber=8806152&tag=1
- https://www.robsonforensic.com/articles/autonomous-vehicles-sensors-expert/
- https://blog.waymo.com/2019/09/building-maps-for-self-driving-car.html
- https://library.gju.edu.jo:2085/document/9182175
- https://library.gju.edu.jo:2085/document/7368032
- https://library.gju.edu.jo:2085/stamp/stamp.jsp?tp=&arnumber=7870764
- https://www.quora.com/What-is-a-brake-actuating-system-and-how-it-works
- https://www.avl.com/-/avl-throttle-actuator-compact#:~:text=The%20AVL%20Throttle%20Actuator%20Compact,mechanical%20throttle%20on%20an%20engine.&text=All%20of%20the%20required%20power,contained%20in%20the%20actuator%20housing.
- https://www.infobloom.com/what-is-a-steering-actuator.htm