Cruise Control Devices

1. INTRODUCTION

Everyday the media brings us the horrible news on road accidents. Once a report said that the damaged property and other costs may equal 3% of the world’s gross domestic product. The concept of assisting driver in longitudinal vehicle control to avoid collisions has been a major focal point of research at many automobile companies and research organizations. The idea of driver assistance was started with the ‘cruise control devices’ first appeared in 1970’s in USA. When switched on, this device takes up the task of the task of accelerating or braking to maintain a constant speed. But it could not consider the other vehicles on the road.

An ‘Adaptive Cruise Control’ (ACC) system developed as the next generation assisted the driver to keep a safe distance from the vehicle in front. This system is now available only in some luxury cars like Mercedes S-class, Jaguar and Volvo trucks the U.S. Department of transportation and Japan’s ACAHSR have started developing ‘Intelligent Vehicles’ that can communicate with each other with the help of a system called ‘Co operative Adaptive Cruise Control’. This paper addresses the concept of Adaptive Cruise Control and its improved versions.
2. ADAPTIVE CRUISE CONTROL (ACC)

2.1 PRINCIPLE OF ACC

ACC works by detecting the distance and speed of the vehicles ahead by using either a Lidar system or a Radar system [1, 2]. The time taken by the transmission and reception is the key of the distance measurement while the shift in frequency of the reflected beam by Doppler Effect is measured to know the speed. According to this, the brake and throttle controls are done to keep the vehicle the vehicle in a safe position with respect to the other. These systems are characterized by a moderately low level of brake and throttle authority. These are predominantly designed for highway applications with rather homogenous traffic behavior. The second generation of ACC is the Stop and Go Cruise Control (SACC) [2] whose objective is to offer the customer longitudinal support on cruise control at lower speeds down to zero velocity [3]. The SACC can help a driver in situations where all lanes are occupied by vehicles or where it is not possible to set a constant speed or in a frequently stopped and congested traffic [2]. There is a clear distinction between ACC and SACC with respect to stationary targets. The ACC philosophy is that it will be operated in well structured roads with an orderly traffic flow with speed of vehicles around 40km/hour [3]. While SACC system should be able to deal with stationary targets because within its area of operation the system will encounter such objects very frequently.

2.2 CONSTITUENTS OF AN ACC SYSTEM:

1. A sensor (LIDAR or RADAR) usually kept behind the grill of the vehicle to obtain the information regarding the vehicle ahead. The relevant target data may be velocity, distance, angular position and lateral acceleration.
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2. Longitudinal controller which receives the sensor data and process it to generate the commands to the actuators of brakes throttle or gear box using Control Area Network (CAN) of the vehicle.

3. SENSOR OPTIONS:

Currently four means of object detection are technically feasible and applicable in a vehicle environment [2]. They are

1. RADAR
2. LIDAR
3. VISION SENSORS
4. ULTRASONIC SENSOR

The first ACC system used LIDAR sensor.

3.1 LIDAR (Light Detection and Ranging)

The first acc system introduced by Toyota used this method. By measuring the beat frequency difference between a Frequency Modulated Continuous light Wave (FMCW) and its reflection [3].

Fig 1.Range estimation using FMCW-LIDAR
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A company named Vorad Technologies has developed a system which measured up to one hundred meters. A low powered, high frequency modulated laser diode was used to generate the light signal.

Most of the current acc systems are based on 77GHz RADAR sensors. The RADAR systems have the great advantage that the relative velocity can be measured directly, and the performance is not affected by heavy rain and fog. LIDAR system is of low cost and provides good angular resolution although these weather conditions restrict its use within a 30 to 40 meters range.

3.2 RADAR (Radio Detection and Ranging):

RADAR is an electromagnetic system for the detection and location of reflecting objects like air crafts, ships, space crafts or vehicles. It is operated by radiating energy into space and detecting the echo signal reflected from an object (target) the reflected energy is not only indicative of the presence but on comparison with the transmitted signal, other information of the target can be obtained. The currently used ‘Pulse Doppler RADAR’ uses the principle of ‘Doppler effect’ in determining the velocity of the target [5].

3.2.1 PULSE DOPPLER RADAR:

The block diagram of pulse Doppler radar is as shown in figure.2.

The continuous wave oscillator produces the signal to be transmitted and it is pulse modulated and power amplified. The ‘duplexer’ is a switching device which is fast-acting to switch the single antenna from transmitter to receiver and back. The duplexer is a gas-discharge device called TR-switch. The high power pulse from transmitter causes the device to breakdown and to protect the
receiver. On reception, duplexer directs the echo signal to the receiver. The
detector demodulates the received signal and the Doppler filter removes the
noise and outputs the frequency shift ‘fd’.

3.2.2 EFFECT OF DOPPLER SHIFT:

The transmitter generates a continuous sinusoidal oscillation at
frequency ‘ft’ which is then radiated by the antenna. On reflection by a moving
object, the transmitted signal is shifted by the Doppler Effect by ‘fd’.

If the range to the target is ‘R’, total number of wavelength is ‘λ’ in the two
way-path is given by,

\[ n = \frac{2R}{\lambda} \]
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The phase change corresponding to each $\lambda = 2\pi$
So total phase change, $p = 2n \Pi$
$$= 2\left(\frac{2R}{\lambda}\right) \pi$$
So, if target moves, ‘R’ changes and hence ‘$\phi$’ also changes.

Now, the rate of change of phase, or the ‘angular frequency’ is
$$W = \frac{d\phi}{dt} = 4 \pi \frac{df}{dt}/\lambda$$

Let $V_r$ be the linear velocity, called as ‘radial velocity’
$$W_d = 4 \pi V_r/\lambda = 2\pi f_d.$$ 

$$F_d = 2V_r/\lambda$$
But $\lambda = \text{ft}$, the transmitted velocity.
$$F_d = \frac{2c V_r}{\text{ft}}$$

So by measuring the shift, $V_r$ is found. The ‘plus’ sign indicates that the target and the transmitter are closing in. i.e. if the target is near, the echoed signal will have larger frequency.

3.2.3 RADAR ANTENNA SCHEMES:

Radar systems employ a variety of sensing and processing methods to determine the position and speed of vehicles ahead. Two such important schemes are:

1. mechanically steered antenna
2. electronically steered antenna

1. Mechanically steered antenna:

A parabolic reflector is used as mechanically steered antenna. The parabolic surface is illuminated by the source of energy placed at the focus of
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the parabola. Rotating about its axis, a circular parabola is formed. A symmetrical beam can be thus obtained. The rays originating from focus are reflected parallel to the axis of parabola. [fig (3).]

Fig 3. Parabolic reflector antenna

2. Electronically steered phased array radar antenna

A phased array is a directive antenna made up of a number of individual antennas, or radiating elements. The radiation pattern is determined by the amplitude and phase of current at each of its elements. It has the advantage of being able to have its beam electronically steered in angles by changing phase of current at each element. The beam of a large fixed phased array antenna is therefore can be rapidly steered from one direction to another without mechanical positioning [1, 5].

Consider the following figure with ‘N elements placed (equally separated) with a distance‘d’ apart. Suppose they have uniform response to signals from all directions. Element ‘1’ is taken as reference with zero phase.
From simple geometry, we can get difference between path lengths of beam1 and that of beam2 is \( x = d \sin \theta \), where ‘\( \theta \)’ is the angle of incidence of the beams. This gives phase difference between adjacent elements as \( \Phi = \frac{2\pi (d \sin \theta)}{\lambda} \), where ‘\( \lambda \)’ is the wave length of the signal. But if the current through a ferro electric element is changed, the dielectric constant ‘\( \varepsilon \)’ is changed since electron density is changed, and for an electromagnetic radiation,

\[
\Phi = \frac{2\pi x}{\lambda} = \frac{2\pi f}{v},
\]

here the velocity \( v = f \lambda \)

\[
= \frac{1}{\sqrt{\mu \varepsilon}}
\]

Hence \( \Phi = 2\pi f \sqrt{\mu \varepsilon} \).

So if ‘\( \varepsilon \)’ is changed ‘\( \Phi \)’ also changes and inserting ‘\( N \)’ phase shifting elements to steer the beam, we can obtain an electronically steered beam.

Regardless of the scanning mechanism the radars typically operate in the millimeter wave region at 76-77 GHz.
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The system should be mounted inside the front grille of the car as shown in figure (5). So its size is to be small. A typical radar produced by Delphi-Delco Electronic systems is having the size of two stacked paper back books(14x7x10 cm)[1].

3.3 FUSION SENSOR

The new sensor system introduced by Fujitsu Ten Ltd. and Honda through their PATH program includes millimeter wave radar linked to a 640x480 pixel stereo camera with a 40 degree viewing angle. These two parts work together to track the car from the non-moving objects. While RADAR target is the car’s rear bumper, the stereo camera is constantly captures all objects in its field of view.

Fig5. A prototype of a car with fusion sensor arrangement
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Fig 6. Block diagram of sensing and controlling process

The image processor measures the distances to the objects through triangulation method. This method includes an algorithm based on the detection of the vertical edges and distance. Incorporating both the 16-degree field of view of radar and 40-degree field of view of camera enhances the performance in tight curves [4].

4. SPACE OF MANEUVERABILITY AND STOPPING DISTANCE

The space of maneuverability is the space required by the driver to maneuver a vehicle. An average driver uses larger sideways acceleration while vehicle speed is low. If the curve radius of a possible trajectory is ‘r’ for a given velocity ‘v’ and sideways acceleration ‘ay’, then \( r = \frac{v^2}{ay} \). So to get the required ‘r’, when ‘v’ is low, ‘ay’ is also to be low correspondingly. The
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stopping distance is given by, \( D_s = 0.5 \frac{u^2}{a_x} + t_d u \), where ‘u’ is the initial speed, ‘\( t_d \)’ is the time taken by the system to receive and process the sensor data and ‘a_x’ is the acceleration of the vehicle. The figure shows the detection of edges of the preceding vehicles.

![Detection of vehicle edges by the fusion sensor](image)

**Fig 7.** Detection of vehicle edges by the fusion sensor

### 5. CONTROLLER

The controller translates the situation into appropriate actions through brake and pedal and throttle control actions.

Depending on the present traffic situation, two types of controls are possible.

1. Speed control
2. Headway control

If there is no vehicle presently in front, then the speed is controlled about a set point just as in conventional cruise control. But in order to keep a safe distance between the vehicle’s, the headway control is required.

### 5.1 ARTIFICIAL COGNITION

The conversion of raw information from sensors to control actions by the two steps:-
1. Analyzing the traffic conditions
2. Deciding on a particular situation

The controller translates the desired situation into appropriate control action through brake and throttle actuation.[2]. The controller concept is simplified in the flow-diagram:

Fig 8. Flow diagram of controlling process

5.2. EXAMPLE OF ADAPTIVE CRUISE CONTROLLER (MOTOROLA ACC)

The Motorola ACC constitutes a DSP module having MGT5200 which provides a multiply-accumulator. The sensor data such as Radar information, that from camera and an IR sensor are processed in it, to generate the input data for the controller modules like HC12 and MPC565.[6].

5.2.1 MPC565

It is a throttle controller or an engine speed controller. It consists of the following features

1. SRAM (1MB to 10 MB)
2. FLASH 1MB
3. EEPROM (4KB to 32 KB)
4. Real time clock
5. 4 x UART interfaces
6. 3 X CAN interfaces
7. 64-bit floating point unit.

The MPC 565 can be programmed to generate the control signals according to the sensor data. ‘The Phycore-MPC 565 developers’ are available to program and develop the desired controller.
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The throttle valve is actuated and the air intake is controlled so the requirement of fuel for the right proportion with the air also increases. So more fuel is injected and engine speed is changed.

5.2.2 HC12

The HC12 is a breaking controller which receives data from the wheel speed sensors and from the DSP module. It generates the braking control signal.

5.2.3 CAN (Control Area Network) BUS

CAN BUS is the network established between microcontrollers. It is a 2-wire, half-duplex, high speed network for high speed applications with short messages. It can theoretically link up to 2032 devices on a network. But today the practical limit is 110 devices. It offers high speed communication rate up to 1 Mbits per second and allows real time control. [7].

Each module in the ACC connected to the CAN is called ‘a node’. All are acting as transceivers. The CAN bus carries data to and from all nodes and provides quicker control transfer to each module.

The actuator used for throttle control is a solenoid actuator. The signal through the coil can push or pull the plunger.

6. CO OPERATIVE ADAPTIVE CRUISE CONTROL

[CACC]

Though conventional ACC and SACC are still expensive novelties, the next generation called Cooperative ACC is already being tested. While ACC can respond to the difference between its own behavior and that of the preceding vehicle, the CACC system allows the vehicles to communicate and to work together to avoid collision.[2,4].
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Partners of Advanced Transit Highways (PATH) – a program of California Department of Transportation and University of California with companies like Honda conducted an experiment in which three test vehicles used a communication protocol in which the lead car can broadcast information about its speed, acceleration, breaking capacity to the rest of the groups in every 20ms.

PATH is dedicated to develop systems that allow cars to set up platoons of vehicles in which the cars communicate with each other by exchanging signals using protocols like Bluetooth.

6.1. MAIN POSTULATIONS ABOUT CACC:

1. In CACC mode, the preceding vehicles can communicate actively with the following vehicles so that their speed can be coordinated with each other.
2. Because communication is quicker, more reliable and responsive compared to autonomous sensing as in ACC.
3. Because braking rates, breaking capacity and other important information about the vehicles can be exchanged, safer and closer vehicle traffic is possible.
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Fig 10. Under CACC, both the leading and following vehicles are electronically “tied” to a virtual reference vehicle, as well as to each other.

7. ADVANTAGES

1. The driver is relieved from the task of careful acceleration, deceleration and braking in congested traffics.
2. A highly responsive traffic system that adjusts itself to avoid accidents can be developed.
3. Since the breaking and acceleration are done in a systematic way, the fuel efficiency of the vehicle is increased.

DISADVANTAGES

1. A cheap version is not yet realized.

2. A high market penetration is required if a society of intelligent vehicles is to be formed.

3. Encourages the driver to become careless. It can lead to severe accidents if the system is malfunctioning.
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4. The ACC systems yet evolved enable vehicles to cooperate with the other vehicles and hence do not respond directly to the traffic signals.

8. CONCLUSION

The accidents caused by automobiles are injuring lakhs of people every year. The safety measures starting from air bags and seat belts have now reached to ACC, SACC and CACC systems. The researchers of Intelligent Vehicles Initiative in USA and the Ertico program of Europe are working on technologies that may ultimately lead to vehicles that are wrapped in a cocoon of sensors with a 360-degree view of their surroundings. It will probably take decades, but car accidents may eventually become as rare as plane accidents are now, even though the road laws will have to be changed, upto an extent since the non-human part of the vehicle controlling will become predominant.
9. REFERENCES


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ABSTRACT

The concept of assisting driver in the task of longitudinal vehicle control is known as cruise control. Starting from the cruise control devices of the seventies and eighties, now the technology has reached cooperative adaptive cruise control. This paper will address the basic concept of adaptive cruise control and the requirement to realize its improved versions including stop and go adaptive cruise control and cooperative adaptive cruise control. The conventional cruise control was capable only to maintain a set speed by accelerating or decelerating the vehicle. Adaptive cruise control devices are capable of assisting the driver to keep a safe distance from the preceding vehicle by controlling the engine throttle and brake according to the sensor data about the vehicle. Most of the systems use RADAR as the sensor. A few use LIDAR also. Controller includes the digital signal processing modules and microcontroller chips specially designed for actuating throttle and brake. The stop and go cruise control is for the slow and congested traffic of the cities where the traffic may be frequently stopped. Cooperative controllers are not yet released but postulations are already there. This paper includes a brief theory of pulse Doppler radar and FM-CW LIDAR used as sensors and the basic concept of the controller.
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