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Adaptive Cruise Controllers – A Literature Review

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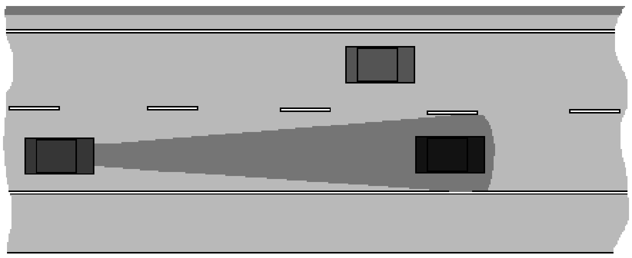
Abstract
An Adaptive Cruise Control (ACC) is an automobile system which purpose is control the velocity of the vehicle with regards to the surrounding environment. This report gives description of ACC models, a detailed description of the architecture of the ACC, and a survey of the ACCs on the market of today.

1 Introduction and Background

An ACC is an extension of a Cruise Control system, which is a rather simply system that keeps the velocity of the vehicle at a constant level. An ACC is more advanced; its task is to adjust the speed of the vehicle with regards to other vehicles, the conditions of the road, weather conditions, etc. In the figure below, the vehicle to the left is equipped with an ACC that keeps track of the vehicle to the right. The upper vehicle is not noticed by the ACC. However, if it should change lanes, it would be recognized.



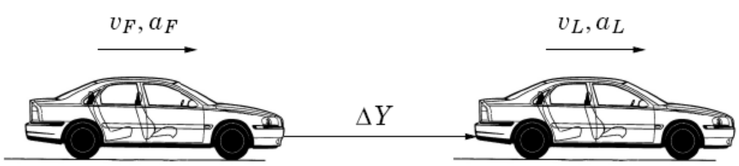
In 1987 the European Union's EUREKA program initiated the Prometheus project on autonomous vehicles (Zhang, 1991). Its purpose was to enhance traffic security by introducing different information systems for automobile. The first ACC prototype was developed in the early nineties as part of the program.

The objective of an ACC system is to reduce to driver's workload and make the drive more comfortable by automatically adjusting the velocity of the vehicle with regard to the surroundings, especially the vehicle ahead. Even thought that objective might increase the safety (Hitz et al. 2000, Bengtsson 2001) by making the driver more relaxed and less prone to fatigue, another kindred objective is to avoid collisions. The commercial available ACC systems on the market of today combine those two objectives. The main difference between an ACC and a collision avoiding system is that the latter needs access to the break system in order to rapidly reducing the velocity of the vehicle.

The second section gives an overview of the development of the models for ACCs. The third section gives a description of the components of an ACC. Finally, the fourth section presents modern car makes equipped with an ACC.

2 ACC Models

The general carfollowing driver model originals from the fifties and is based on the assumption that each driver reacts in a specific fashion to a stimulus, which leads to an actuation of the acceleration.



The basic model of a carfollowing system was formulated by Chandler et al. (1958):

$$a_F(t) = \frac{\lambda}{M}\left[v_L(t-\tau) \cdot v_F(t-\tau)\right]$$

$a_F(t)$ = acceleration of the following car
λ = sensitivity factor for the control mechanism
M = vehicle mass
v_L = velocity of the leader car
v_F = velocity of the following car

One drawback of the model is that sensitivity factor is constant. Gazis et al. (1959) suggested that the factor is dependent of the spacing headway between the cars:

$$a_F(t) = \frac{b}{\Delta Y(t-\tau)}\left[v_L(t-\tau)\cdot v_F(t-\tau)\right]$$

b = sensitivity constant
$\Delta Y(t-\tau)$ = the space headway at time $t-\tau$

However, as the space headway becomes large in dense traffic, the method's usefulness becomes limited. Therefore, Edie et al. (1963) suggested the following model:

$$a_F(t) = b\frac{v_L(t-\tau)}{\Delta Y(t-\tau)^2}\left[v_L(t-\tau)\cdot v_F(t-\tau)\right]$$

Gazis et al. (1965) developed a model that would be known as the General Motors Nonlinear (GM) model:

$$a_F(t) = \alpha\frac{v_L(t)^\beta}{\Delta Y(t-\tau)^\gamma}\left[v_L(t-\tau)\cdot v_F(t-\tau)\right]$$

α = constant
β = model parameter
γ =model parameter

Leutzbach (1988) introduced a psycho-physical model based on the driver's individual perception of safe distances. Widmann et al (2000) extended the model to include four driving situations:

- Uninfluenced driving. The driver is uninfluenced of any other cars on the road, and keeps his preferred velocity.
- Approaching. The driver is approaching the car ahead and has reached his maximal headway distance ΔY_{max} and begins to slow down.
- Braking. The headway distance sinks under the driver's minimal headway distance ΔY_{min}. The driver breaks in order to keep his minimal headway distance.
- Carfollowing. The driver follows the car ahead and tries to keep their distance between their minimal and maximal distance, ΔY_{min} and ΔY_{max}. If the distance falls below ΔY_{min}, then the breaking situation occurs; if the distance exceeds ΔY_{max}, the uninfluenced driving situation occurs.

Benekohal and Treiterer (1998) developed a similar model including start-and-stop situations. Lee (1976) proposed a difference approach, he meant that the driver use the simplest type of visual information from the optic flow to decide when to break and how to control the braking action. Van der Horst (1990) supported that approach and performed a framework which shows that both the decision when to start braking and how to control the braking progress are based on the optic field. Van Winsum and Heino (1996) proposed that the preferred timeheadway is constant over different velocities and that the preferred timeheadway is consistent within individual drivers, but differ between drivers. They performed experiments to validate their hypothesis, and their result indicates that timeheadway is determined by the individual driver rather than the velocity.

3 The ACC Architecture

The main part of the ACC system is a detector whose task is to measure the distance to the vehicle in front. There have been experiments with different types of detectors. Optical systems have been tested and been abandoned due to their high demands on clear and light-reflecting surfaces. Laser systems works well in clear weather, but has showed not to be up to the mark in rainy or snowy weather. Therefore, the dominating detector system of today is the radar. It sends an electromagnetic beam forward in the vehicle's direction, and the distance it measured by the time it takes for the beam to be reflected. It works well in all kinds of weather; its disadvantage is that it is more expensive that the other types of detectors.

Even though it is possible to measure the time of the beam, it is not done directly in ACC systems since it demands sophisticated and expensive equipment. Instead, the time is measured indirectly. One commonly used method is the Frequency Modulated Continuous Wave (FMCW) method. A Voltage Controlled Oscillator (VCO) generates a high frequency beam. One suitable VCO is the Gunn oscillator. It is build upon gallium arsenide semiconductors that generate very high frequencies when subjected to a strong electric field. It is capable of generating frequencies in the interval 76 – 77 GHz, which is the frequency assigned for ACCs.

When sending a beam of a known frequency (in the 76 – 77 GHz interval) and detect the differential (echoed) frequency, the distance can be calculated. The differential frequency can be obtained by a low-pass filter and converted to frequency spectrum by Fast Fourier transform (FFT). A peak in the spectrum corresponds to the transmission frequency. By comparing the transmitted and received frequency, the distance can be calculated. However, one problem that has to be taken into consideration is the Doppler Effect. That problem can be solved by comparing the result from several transmission frequencies.

In most cases, one beam is not enough. In order to detect obstacles also when the vehicle if moving through a sharp turn, it is necessary for the unit to scan an angular range. However, the angular range cannot be allowed to widen too much. If the beams are scanning a large angular range, a vehicle travelling in another lane can be considered an obstacle. Experiments have showed that an angular range of approximate eight degrees is optimal. The purpose is obtained by using three identical transmission and receiving devices. The actual distance is simple taken to be the smallest of the three calculated distances. Naturally, it is of outmost importance that the sensor is calibrated to follow the central line of the vehicle, both in horizontal and vertical directions.

Moreover, the outmost part of the ACC sensor unit is a lens directing the beam. In order for it to work it must not be covered with snow or ice, why it has to be heated in below-zero temperatures. Therefore, in vehicles aimed at the northern market, a small thermostat and a heating device is included in the ACC sensor unit. The lens must also be able to withstand splashwater, pressurised steam, and stone impact.

The scanned information is then sent to the ACC control unit, which task is to transform the differential frequency into a digital value, calculate the distance to the nearest obstacle, collect information from other sensors, inform the Electronic Trottle Controler (ETC) whether to increase or decrease the throttle, and if necessary, actuate the breaks.

The ACC control unit is constituted by two units: the Regulation Processing Unit (RPU) and the Signal Processing Unit (SPU). The RPU includes an amplifier, an Analogue-to-Digital Converter (ADC), RAM memory for temporary storing of calculations results, and an interface to the Control Area Network (CAN) bus. The ADC monitors the voltage level. If it falls below a certain level, the ACC is disabled and the driver is notified. Like all vehicle electronics, the ACC is driven by the vehicle battery. However, as a regular 24 V car battery can give voltage peaks up to 100 V, the ACC must be protected by a voltage regulator that makes sure the ACC is fed a consistent voltage, usually 8 V.

The SPU is responsible for calculating the distance to the nearest obstacle. This task demands a very fast processor. Bosch (2003) developed the CC610 circuit, which is a complex DSP developed especially for the ACC control unit. A fast SPU is able to interpret the information from the sensor in about 80 milliseconds. Therefore, the ACC control unit often runs at a frequency of 10 Hz.

In every vehicle, the driver always has the authority to disable the ACC. The driver can also set the preferred distance to the vehicle ahead and the preferred velocity. The display is also equipped with warning lamps (and in some case a sound alert) to warn the driver of obstacles on the road if the ACC should malfunction. In some ACCs, there is a gradual warning system: in case of an appropriate distance between the vehicles, a green lamp is shining. When the vehicles are closing in on each other, a yellow lamp start to shine, and when the distance is dangerously small, a red lamp shines. In most ACCs, when the red lamp shines, the brakes are automatically applied.

In order to keep the set distance, the ACC needs to notify the Electronic Throttle Control (ETC) when to increase or decrease the throttle. In some cases, the velocity has to be brought to a stop so rapidly that it is not enough to just decrease the throttle. In these cases, the ACC notifies the Electronic Stability Programme (ESP) to engage the brakes.

Apart from the radar sensor, the vehicle may be equipped with other sensors that provide information about the temperature, humidity, friction against the road, the cargo weight, etc. If this is the case, the SPU does include this information in its decision making.

4 Vehicles equipped with ACC

There is a number of automation manufactures that have equipped their products with ACC.

4.1 Lexus

Lexus (www.lexus.com) is the luxury vehicle division of Toyota Motor Corporation. It was originally introduced at the American market in 1989 and soon become the most selling luxury car make in the U. S. In 2007, consumer ratings firm J.D. Power and Associates (Power, 2007) ranked Lexus as the most reliable brand in the U.S.

Lexus was the first brand to introduce radar-based ACC in 1999. They were also first to introduce a laser-based system in 2001. However, due to poor performance in bad weather conditions, the system was later replaced by a radar-based system.

4.2 BMW

The BMW Group (www.bmw.com) has equipped their 5 and 6 series with Active Cruise Control (equivalent to Adaptive Cruise Control) with Stop & Go. The system controls the car's velocity with regard to the distance to the car ahead. It has also the ability to automatically start the car if it has been slowed down to a standstill and the car ahead accelerates within three seconds.

4.3 Acura RL

At present, the most advanced driver support system commercial available is delivered with the Honda Acura RL (www.acura.com). In the 2007 release, an ACC system was included in the Collision Mitigation Braking System (CMBS). The system is able to break the car slowly if the obstacle is far away or break hard if a collision is imminent. In the latter case, the seat belts are tightened. In the upcoming 2009 release, the Acura Real-Time Traffic Navigation System (only operational on the U.S. mainland) is included. It is a GPS navigation system that downloads information in real-time and suggests and alternative route if the shortest path is jammed or blocked. It is also equipped with the AcuraLink Real-Time Weather system that informs the driver of potential weather-related issues along the plotted route.

4.4 Mercedes Benz

In 2005, the Mercedes Benz S-class was equipped with the Pre-Safe system. Similar to an ACC, it used a radar to detect obstacles ahead and brakes automatically when risk for collision. The system also adjusts the seat belts as well as the driver and passengers seats if a collision is imminent. It does also close the side windows and sun roof (World Car Fans, 2005).

Future makes of Mercedes Benz will be equipped with a fatigue-detection system that warns the driver when it detects sign of sleepiness (when the eyes stay closed for more than the time of a natural blinking action). As fatigue normally sets in gradually, the system will also take into consideration information regarding driving style, the duration of the journey, the time of day and the current traffic situation (The Auto Channel, 2006).

4.5 Volvo

The Volvo V70 (www.volvo.com) comes with an ACC that keeps the distance to the car ahead. It is also equipped with the Collision Warning and Auto Break (CWAB) system. If the system detects an obstacle is warns the driver with a blinking lamp and an audio signal. It does also prepare the brakes for a hard braking. It the driver's in spite of these efforts still does not break, the system automatically activates the breaks.

The car is also equipped with the Driver Alert Control (DAC) system. It uses a digital camera to calculate the course of the road and compares that information with the wheel movements and raises an alarm if the driver behaves abnormal. Furthermore, the Lane Departure Warning (LDW) system registries the centre and edge lines with a digital camera and alerts the driver when the car is drifting to close to one of the lines.

5 Conclusions

Even though several automation manufactures have their models equipped with ACCs, it is not true for all makes. Up until today, the ACC tends to be included only in the more luxury models. However, it is likely that the ACCs will be included in more models. One major bottle neck of today is the price of the radar device. It has until recently only been used in aeroplane, ships, and air ports. The ACC does also need to become smaller; at present, it is hard to fit in many small cars. There is also the detection range problem. It is desirable for the ACC to detect obstacles at a broader range, without set off the alarm for vehicles in other lanes or obstacles beside the road. The ACC needs to learn how to separate between harmless and dangerous obstacles.

In the near future, maybe the ACCs can be used in more complex situations, such as traffic jams or traffic accidents. In some distant future, maybe the vehicle can find its own way.

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