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Topic 6: Advanced Driver Assistant Systems (ADAS)

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Given the legal liabilities and technical challenges of achieving 100% reliability for autonomous intelligent vehicles, it appears likely that motor vehicles will have pieces of autonomous functionality added progressively and that cars will eventually evolve into autonomous robots. The perception techniques described earlier can be used in a variety of ways to make driving safer, more efficient, and less demanding. Individual perception techniques, or combinations of sensing modes, are being used to provide warnings to drivers of dangerous situations. These warnings are being used to prevent collisions in a variety of situations, such as when backing up, when leaving a roadway, into rear ends, on lane changing/merging, with pedestrians, and at intersections.

ADAS

Developing a collision warning system requires many steps beyond building the perception system. For a typical example, roadway departure warning, the steps followed in a program initiated by the US National Highway Traffic Safety Administration include:

Statistical studies:

In the United States, crashes involving a single vehicle leaving the roadway are relatively rare, but disproportionately dangerous; approximately 40% of the 40 000 fatal crashes per year in the US are single-vehicle crashes where the vehicle leaves the roadway. The first part of the study looked at the prevalence of those crashes, and determined that this would be a good type of crash to prevent.

Causal factors:

The second step was to determine the causes of those crashes. Most run-off-road crashes are due to driver factors such as excessive speed, inattention, or loss of control. This is an important observation, because it means that alerting the driver, or warning of difficult situations, could prevent those incidents. For the fraction of crashes caused by mechanical failure a warning system would not be useful; in this type of crash, mechanical failure is involved in less than 5% of the crashes.

Opportunities or intervention:

This part of the study set out to determine whether a warning system could be effective, and, if so, how far in advance the warning would have to be given. Given typical road departure trajectories, typical widths of roads and shoulders, and the range of potential steering responses, this task generated requirements for how accurately the system would have to track vehicle trajectory in order to predict a roadway departure.

Human factors:

Since the system being designed is a warning system, rather than an active control, it is crucial to understand what kinds of warning a driver (who may be distracted or sleepy) would respond to, and how quickly and accurately the response will be. Reaction times vary widely across individuals: using one second for reaction time is a fairly standard estimate.

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Simulator studies:

A driving simulator is like an aircraft flight simulator for cars or trucks, with a variety of simulated roads and conditions. Simulator studies were used to test driver response to warnings: directional or nondirectional audio warnings, steering wheel shakes, and combinations. A nondirectional audio cue worked best.

System specification development:

Based on the preceding steps, in order for a system to be useful, it needs to work at day and night, in almost all weather conditions, needs to measure vehicle speed, lateral position relative to the road, lateral heading, and roadway curvature, and predict future vehicle trajectories long enough in advance to trigger a warning alarm.

Perception and system development:

Given those specifications, there are several ways that a perception system could be built to sense the road and the vehicle's trajectory relative to the road. For this particular test, a lane keeping system – rapidly adapting lane position handler (RALPH) was developed and tuned.

Collision Avoidance and Mitigation

The complete cycle from the idea of using perception to prevent crashes, to full system development, took over 10 years in this case. The pure *robotics part of the system* is a crucial element, but is only one piece of the development needed to make a useful product. Some active control has already been assumed by today's vehicles. Antilock brakes have been on the market for many years. Traction control systems which control throttle to stop wheel spin are being introduced. Electronic stability control systems take this the next step further, controlling throttle and individual wheel brakes to help in cornering performance. So, gradually, people are willing to cede some control to very reliable automated systems. We can expect this trend to continue. Each collision warning type has its own list of specific development challenges, as described below.

Backup Collisions

The sensing challenge is to see relatively small objects, such as fence posts or children's toys, while not picking up false alarms from pavement joints or leaves and debris. The sensors used in today's commercial vehicles are piezoelectric ultrasonic sensors, which are inexpensive. However, ultrasonic sensors have well-known limitations. The challenge of developing low-cost, accurate, reliable sensors remains.

Rear-End Collisions

These are among the most difficult collisions to prevent, with the most challenging sensing conditions. Rear end collisions often happen at high speeds, requiring long-distance sensing of other vehicles (up to 100m at US highway speeds, much longer at the high speeds found on some European roads or for the longer braking distances needed for heavy trucks). That in itself is not too demanding a challenge: the sensed objects in this case are relatively large and have high metal components, so radar and lidar are both feasible sensing modes. The biggest range-sensing challenge is sorting out true targets (slow or stopped vehicles) from false targets (overhead signs or bridges, and side lobes from strong reflectors on the side of the road).

Lane-Change/Merge Collisions

In the simplest case, the countermeasure to this kind of collision involves short-range sensing to cover the *blind spots on the rear corners of a vehicle, where it is difficult* to see with mirrors. For passenger cars, this area is quite small, and can be covered with a single sonar or radar. Often, the user interface is a warning light placed in the rear-view mirrors; this reinforces good driver behavior of checking mirrors before changing lanes. The sensing challenge for heavy trucks or transit buses is the same as for cars, except that the area not visible in planar mirrors can be much larger. Figure shows examples of blind-spot detection for cars and heavy vehicles.

Pedestrian Collisions

Pedestrians are particularly important to detect, because pedestrians are much more vulnerable than people in vehicles; as discussed earlier they are also unfortunately relatively difficult to detect and very hard to predict. Just detecting a pedestrian is not sufficient. In transit operations, for instance, a bus operates close to pedestrians much of the time. To do meaningful collision warning, it is important to detect the pedestrian, detect their current path, look for cues such as crosswalks or curb edges that modify the probability of the pedestrian's trajectory, and match all of these factors with the predicted trajectory of the vehicle. It is crucial to tune the warning system to produce few false alarms while not missing real alarms. A particularly dangerous situation is pedestrians slipping and falling underneath a bus: these are very dangerous situations, but very difficult to detect in time to warn the driver. For these reasons, automotive manufacturers have worked on products such as night vision to enhance driver perception

Intersection Collisions

Intersection collisions are particularly difficult to prevent because they often involve challenging sensing scenarios. Many of these collisions involve occluded vision, with lines of sight blocked either by large vehicles or by adjacent buildings. They also often involve high closing rates from oblique angles, making it necessary to see a long distance with a very wide field of view. The solution usually proposed is to add intelligence to the infrastructure, either in fixed sensing (such as radars looking down each approaching road) or in some kind of radio relay that takes data from approaching smart cars and passes it to other approaching vehicles. None of these solutions is particularly attractive: the large number of intersections makes it difficult to envision any universal solution.

Other Obstacle Collisions

Vehicles have collisions with many things other than other vehicles and pedestrians: animals (deer, dogs, cats), car parts (tire carcasses, rusted-out exhaust systems), cargo that falls off of trucks, construction debris, etc. Warning drivers about these kinds of objects on the roadway is a challenging task. A piece of construction timber on the roadway may be large enough to do significant damage to a car, but be small enough to be difficult to see, and be invisible to radar. Some interesting work has been done with high-resolution stereo vision, with polarimetric radar, and with high-resolution scanning laser range-finders. However, in general this remains a difficult problem.

Other Actions

Besides warning the driver, there are other actions that an intelligent vehicle can take short of assuming control. If a collision is inevitable, particularly from the side of the vehicle where there is limited crush space, the system can brake and deploy airbags even before physical contact. Of course, such a system would have to be nearly 100% reliable. More simply, if the system senses an imminent front collision, it can preload the power brakes, saving fractions of a second in brake reaction time. The driver must still actuate the brakes, but the onset of hard braking can be much quicker. At 100 km/*h, a 0.1 s* saving in braking actuation saves approximately 3m of stopping distance, which can be the difference between a severe rear-end collision and a much lighter crash. Such systems are being introduced into the high-end market by all the major automotive manufacturers.

Adaptive Cruise Control

Adaptive cruise control (ACC) is the logical extension of standard cruise control to also include keeping a safe distance from the preceding vehicle. If there are no vehicles in front of the smart car, it follows a set speed, as with standard cruise control. If a slower-moving vehicle is in front, an ACC-equipped car will sense the vehicle using radar or lidar, and slow to maintain a safe distance (typically set to a 1*.5–2 s following gap). Figure* shows an illustration of the ACC concept. The sensing challenge for ACC is much easier than the challenge of rear-end collision countermeasures, since ACC systems are only designed to deal with other moving vehicles. The biggest sensing difficulty for rear-end collision countermeasures is separating stopped vehicles on the road from objects off the road; for ACC this difficulty is bypassed by ignoring all stopped objects. Moving objects are classified as in-lane or out-of-lane based on a number of heuristics. Often, the smart car's own steering radius is used as an estimate of the road curvature ahead, in order to determine whether vehicles ahead are in the same lane. Since the systems are explicitly sold as *convenience instead of safety systems, they only need* to deal with normal situations with relatively low differences in velocity, and they leave the more difficult situations up to the human driver. The human is still alert, controlling the steering, and watching the traffic. These systems are being introduced by all the major car manufacturers.

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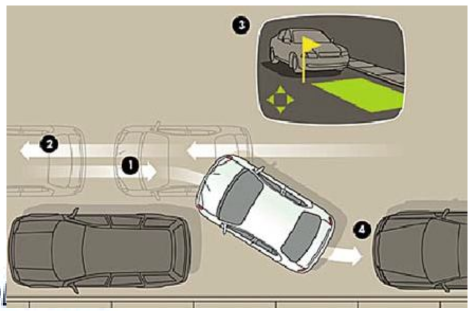
Stop and Go

Stop-and-Go driving assistance (also referred to as low speed ACC) is at the opposite end of the speed spectrum, when vehicles are creeping along in dense traffic. At slow speeds, it is easy to track the vehicle ahead, and to move when it moves, steer when it steers, and stop when it stops. If the traffic accelerates to a modest speed, the stop-and-go system disengages, and the human must assume control of the throttle, brake, and steering. Since the speeds are very slow and the distances are short, many different sensing systems will work such as stereo vision, radar, and lidar.

Parking Assist

Parking assistance is also a low-speed aid. In a typical scenario, the driver initiates the system by pushing a button when driving past an empty parking space. The system measures the length of the space using odometry, measures the positions of the cars in front and in back using short-range sensors, and infers the position of the curb by assuming that the surrounding cars are standardsized cars parked near the curb [51.54]. Figure 51.11 illustrates parking assistance. Once the system is fully engaged, it takes over steering, planning and executing the ideal parallel park steering sequence. In some systems, the human is still responsible for throttle and brake, again insuring that the human is alert, watching for encroaching pedestrians or other obstacles. Such a system has been introduced by Toyota.

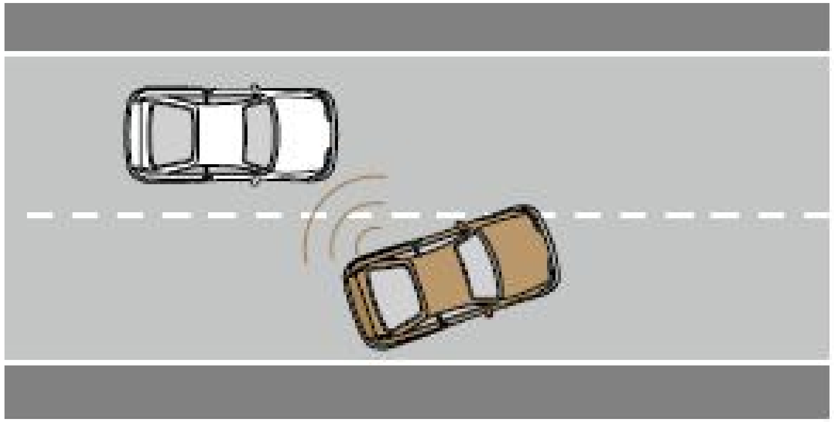


Lane Keeping

Lane keeping assistance is the natural extension to road departure warning systems. Given a lane tracking system, it is straightforward to add control of the steering wheel to keep the vehicle centered in its lane [51.1–3]. This has a number of uses. Some cities would like to run transit buses on narrow roadways, for instance the shoulder of highways or through narrow streets in old cities. Automated lane keeping systems using mechanical guide ways are in use in several places [51.56]. It is easier and less expensive if such systems can be electronic rather than relying on specially installed mechanical guides. A specific subcategory is precision docking: for a transit bus to pick up a passenger in a wheel chair, either the bus must deploy a special ramp (which is a slow process), or it must pull up to a level dock and leave a very small gap, so that the wheel chair can safely roll on or off. Short-range precision docking systems use either a downward-looking sensor, looking at painted lines or magnetic markers, or a sideways sensor looking at the curb or dock, in order to guide the bus to its parking spot. Finally lane-keeping assistance is a convenience for driving on highways, especially with gusty winds. Honda has released a vehicle equipped with both lane-keeping assistance and ACC [51.57]. The danger with such systems is that the driver no longer has an active moment-to-moment role, and may lose concentration or even fall asleep. These systems are not designed for full automation, and still require a driver to handle unusual circumstances. The next stage is to integrate driver state monitoring. If the driver is inattentive then all automatic systems are disengaged.

Lane Changing

Lane changing assistance is the next extension in partial autonomy. It combines lane keeping and ACC with blind-spot monitoring. If the car can safely overtake a vehicle, then a lane change is undertaken and speed is unchanged. Otherwise, the ACC slows the vehicle down. At its simplest such a driver assistance system can advise a driver whether a lane change can be safely undertaken [51.58]. In its most advanced form the lane change is undertaken completely automatically by the vehicle [51.1]. Such systems require an additional side-facing sensor, typically radar (shown in Fig. 51.12)



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There has been an evolution of thought regarding the role of the driver in intelligent vehicles. The grand goal has been to replace the driver with a fully automated system. As discussed earlier, full automation of intelligent vehicles is still some years away due to system reliability and legal liability reasons. The next step in the development of the motor vehicles is partial automation – where individual autonomous functions such as ACC, lane keeping, lane changing etc. are developed. Motor vehicle designers have realized that the driver cannot be removed from the vehicle, and must instead be supported by systems onboard a motor vehicle. Over 92% of motor vehicle accidents are caused by driver error. It is likely that the next generation of intelligent vehicles will work in the following way.

1. The vehicle will monitor the road scene using advanced driver assistance system technologies discussed earlier to assess the state of the environment and warn the driver of dangerous situations, e.g., lane departure warnings.
2. The vehicle will also monitor the driver using vision sensors to assess the state of the driver. If a driver is fatigued, drowsy, inattentive, distracted or under the influence of drugs then accidents can occur. The vehicle warns the driver of dangerous circumstances, e.g., drowsiness warning.
3. For legal liability reasons intelligent vehicles will not take control, rather the driver will be alerted using visual, audio, or tactile warnings. The vehicle will not perform collision avoidance; rather collision mitigation will occur through emergency braking.
4. If an accident is unavoidable the vehicle can autonomously apply emergency braking. To maximize the safety of the occupants in the vehicle, seatbelt restraints are tightened and airbags are safely Deployed.
5. After an accident has occurred knowing the state of the driver and the passengers is important. If an occupant has been injured a call to the emergency services can be dispatched automatically by the vehicle.

Driver Monitoring

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In all the steps described above monitoring the driver is critical. For future advanced driver assistance systems (ADAS) to work safely the driver should be put in the loop, for example, in a lane departure warning systems, it is not possible to determine whether a vehicle departing from a lane due to cause by driver intention or error. If the state of the driver is being monitored, and the system can detect that the driver's eyes are closed or the driver is looking away from the road, then it can be inferred that the lane departure was involuntary and that a lane departure warning should be given to the driver. For ADAS to be accepted by drivers the systems should not give false warnings. If the driver is looking directly at the road then lane departure warnings should not be given (or a different subtle warning should be given). Similarly more sophisticated systems such as lane keeping should not be engaged unless the driver is fully attentive and has their hands firmly on the steering wheel. The key point is that drivers must be fully engaged with and in control of the driving task. This is a most important consideration in the design of ADAS for intelligent vehicles. Combining perception with control gives partial automation for specific tasks, such as adaptive cruise control, lane keeping, assisted parking, and slow driving in stop-and-go situations.

Driver Fatigue, Inattention, and Impairment

By directly monitoring the driver using visual sensing opens up the possibility of developing a new class of ADAS applications. It is possible to monitor driver state through monitoring signals such as an electrocardiogram (ECG), temperature etc. However, market studies by automobile manufacturers have shown that people do not like any wires, or gadgets attached; driver monitoring must be noncontact and noninvasive. The only solution is to use vision as the sensing medium. The technical challenge to develop a computer vision system that can automatically detect a driver of any age, sex, race, with/without eye or sunglasses, and with/without facial hair is enormous. Recently significant progress has been made with systems being developed that can also detect where a person is looking (gaze direction).

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Once the driver’s state (head position, eye gaze, eye blink rate) can be measured then ADAS applications can be developed. Figure 51.13 shows the output of a commercial driver state detection system.

Driver Impairment

Safety authorities estimate that as many as 50% of all road accident fatalities are caused by driver impairment due to alcohol or drugs [51.60]. Recent research has shown that driver impairment can be detected by sensing abnormal scanning patterns of eye gaze. It promises to open up a new class of ADAS. There have been major education and legislative initiatives in many Organization for Economic Cooperation and Development (OECD) countries, resulting in a significant reduction in road fatalities. However, the difficult cases (fatigue, distraction, and inattention) have become more prominent. ADAS technologies could have a significant impact in further reducing the road toll.

Driver Fatigue

Safety authorities estimate that 25–30%of all road fatalities are caused by driver fatigue [51.61,62]. Research has shown that there are four visible factors that indicate the onset of fatigue – prolonged eye closure, uncontrolled head moments, drooping eyelids, and reduced eye-gaze scanning. Systems are under development that focus only on eye closure [51.63]; the challenge of fusing all four factors together into a robust algorithm that works for a wide range of drivers remains an open research problem.

Driver Inattention

Safety authorities estimate that up to 45% of all traffic accidents – from minor dents to serious incidents – are caused by driver inattention or distraction [51.64]. Research has shown that if the drivers consistently keep their eyes on the road then driving becomes a much safer experience [51.65]. All major automotive manufacturers are developing ADAS applications that warn the driver if they are distracted from the driving task. More sophisticated ADAS under development use the driver's gaze direction to check whether safe driving practices are being followed, for example, did the driver check the side mirror before a lane change was performed? If the driver fails to check the side mirror a warning would be issued.

Driver Workload

The increase in new electronic systems and gadgets that are being installed into today's motor vehicles is also another source of distraction. Questions arise about when and under circumstances should a driver change a compact disc (CD) or answer a phone call. Research is underway into the development of workload systems. These systems take into account the vehicle state (speed, acceleration, braking, gear-change yaw rate etc.) to determine whether information management tasks such as answering a phone call, sending a short message service (SMS) message are allowed [51.65]. The next stage of research is to include sate information about the road scene and the driver. If the car is driving on a country road, and the driver is attentive then distractive tasks could be allowed and managed.

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