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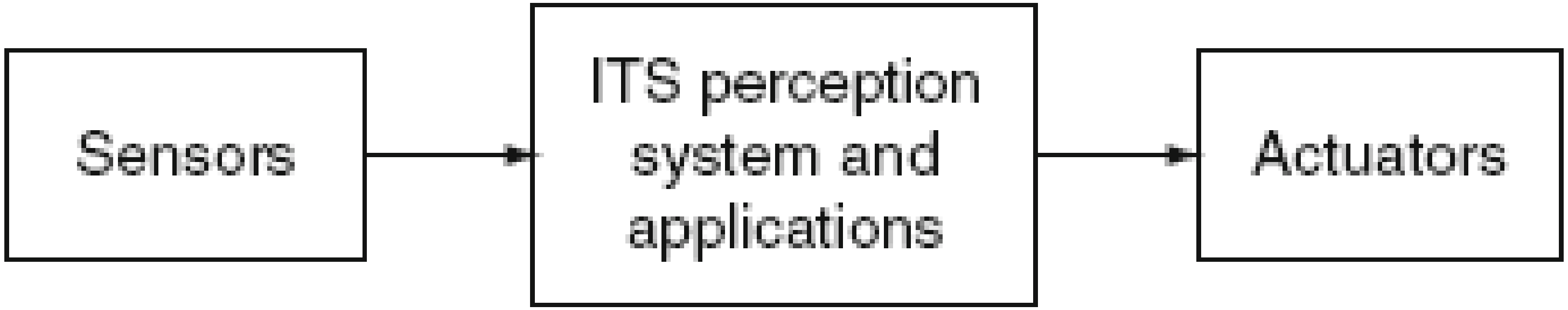
Topic: Sensing and Actuation in Intelligent Vehicles

Plan:
1. Sensors
2. Actuators



The concept of intelligent transportation systems

Sensing the environment is one of the key elements of the future intelligent transportation systems. There is an enormous variety of different sensors used in the automotive industry: from in-vehicle sensors built-up together with the vehicle, perception sensors such as radars and lidars, as well as ‘‘virtual’’ sensors. With the word ‘‘virtual,’’ we are referring to information sources used widely in the automotive industry without being real sensors with the usual sense. This category includes the general sensors which are installed in the vehicle during its construction phase. There are hundreds of sensors that belong to this category, but here the focus will be on these sensors that are of interest for ADAS applications. The selection of the sensors that are briefly described in the following.

Accelerometer

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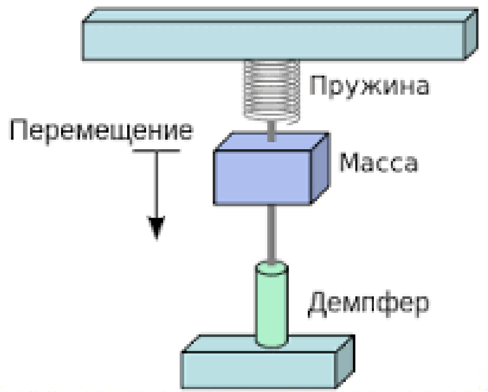
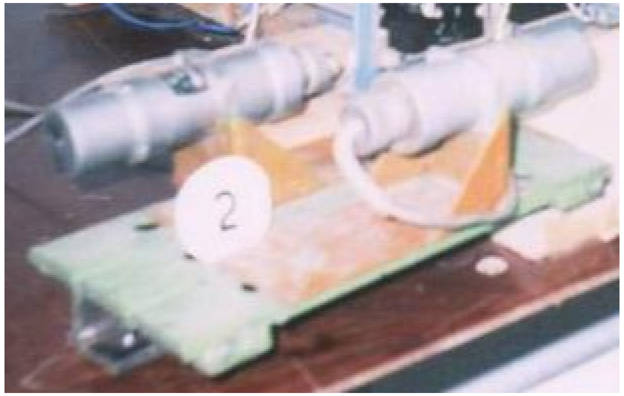
An accelerometer is a device that measures proper acceleration, which is the acceleration it experiences relative to freefall. Both single-axis and multi-axis accelerometer models are available in the market. At this point, it should be highlighted that in some cases the yaw rate and accelerometer sensors are placed together in the same integrated circuit.

There is a significant amount of applications based on accelerometers, from medical and biology to gaming and navigation. In the automotive sector, the accelerometer sensor is used mainly for navigation purposes. An inertial navigation system (INS) is a navigation aid that uses a computer and motion sensors, such as accelerometers and yaw rate sensors, to continuously calculate via dead-reckoning the position, orientation, and velocity of a moving object without the need for external references





Wheel Speed Sensor

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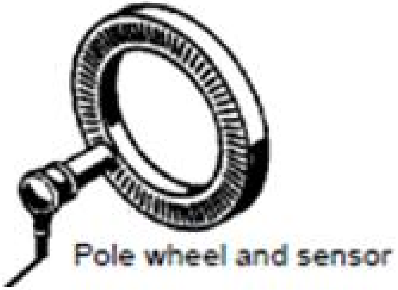
A wheel speed sensor is a type of tachometer. It does not monitor vehicle speed directly but it senses the movement of the circumference of the tire. It actually reads the speed of a vehicle's wheel rotation. There are two main categories of wheel speed sensors: passive and active. Passive sensors do not need a power supply, whereas active sensors require an external power supply for operation.

Wheel speed sensors attached to wheels of a vehicle, respectively, to detect wheel speeds of a running vehicle are designed to detect the rotation of rotors which rotate together with axles coupled to the respective wheels.Wheel speed sensors for automobiles typically utilize an indexing disc mounted on a wheel and a pickup that detects the passage of marker elements carried by the disc as the wheel turns. This pickup can be mechanical, optical, or magnetic.

Wheel speed sensors are critical components of antilock braking systems (ABS), traction control systems (TCS), and similar functions



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The overall steering wheel angle is measured by the steering angle sensor. The steering angle sensor is mounted on the steering shaft. Steering angle sensors were developed in the mid-1990s. Sensing a steering angle in automotive applications can be done in various ways using optical, magnetic, inductive, capacitive, or resistive sensor principles.

This sensor has two potentiometers offset by 90. The steering wheel angle determined by these two potentiometers covers one full steering wheel turn; each of these values is repeated after 180. The sensor knows this and counts the steering wheel revolutions accordingly. The overall steering wheel angle is thus made up of the current steering wheel angle together with the number of steering wheel rotations. In order that the overall steering wheel angle is available at any time, uninterrupted detection of all steering wheel movements – even when the vehicle is stationary – is required.

There are hundreds of other sensors that are used in a vehicle. Indicatively, some of them are tire pressure sensors, temperature sensors, rain sensors, and fuel sensors

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Perception Sensors

Perception sensors are widely used for research purposes all around the world, but their penetration to the market is not so straightforward because of their cost which makes them a privilege of the luxury cars. Environmental perceptions systems for driver assistance and safety functions are based on radar, laser, vision, or ultrasonic sensors. These are the most important perception sensors, and their characteristics are analyzed in the following.

Radar Sensors

Radar technology is starting to be developed in the automotive industry mainly for the interests of road safety. There are two main categories of radar sensors designed for different purposes and tailored for different applications, namely, the short-range radars and the long-range radars. These radar categories have different technical characteristics and are operating in different frequencies.

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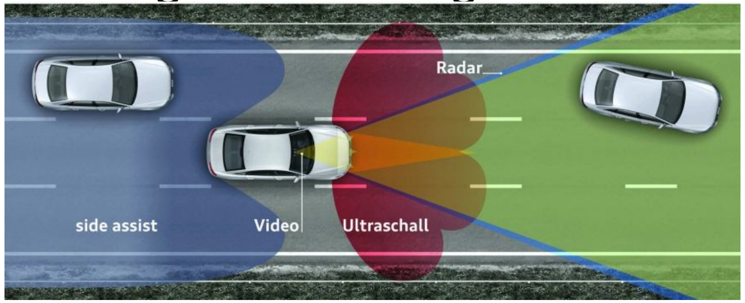
A ‘‘temporary’’ frequency band has been allocated at 24 GHz for the short-range radar sensors, allowing equipment to be marketed in the short term. However, this band is also used by other radio services that would suffer interference if too many radar devices were operated simultaneously in the same area. For this reason, this band will be closed for the introduction of new devices before the usage becomes too dense. A ‘‘permanent’’ band has been allocated at 79 GHz, allowing for long-term development of this radar service.

European Commission Decision 2004/545/EC requires this band to be made available in all EU member states.

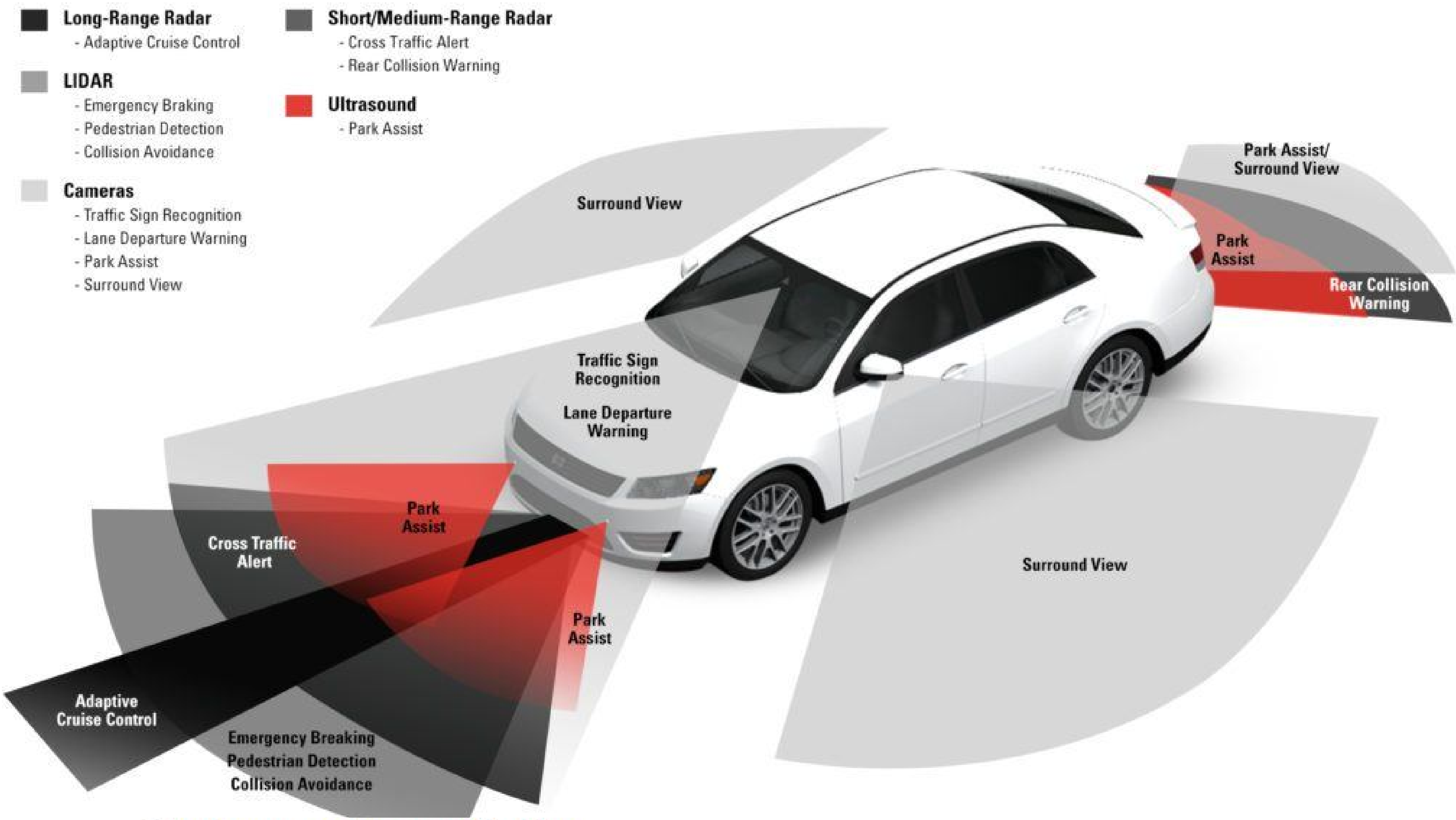
Anticollision is the main function relevant to an SRR sensor. This is being developed as part of a system to warn the driver of a pending collision, enabling avoiding action to be taken. In the event where collision is inevitable, the vehicle may prepare itself (e.g., by applying brakes, pretensioning seat belts) to minimize injury to passengers and others.

Moreover, this sensor opens up the possibility of achieving the following functions:

- Parking aid
- Blind spot detection
- Precrash detection for front and side
- Short-range sensor for ACC stop and go function



ADAS: THE CIRCLE OF SAFETY



Short range radar specification

Detection range	0.2–50 m
Detection angle	$\pm 35°$
Frequency	24 GHz (79 GHz)

The operating frequency of the LRR sensors is typically in the 76–77 GHz band applying frequency-modulated continuous wave (FMCW) or pulse-Doppler operation.

The range of this sensor is up to 150–200 m and its field-of-view is only 11–12o (more details in>Table 3.2). Usually, this sensor is located in the middle of the front bumper and it is used for frontal collision avoidance applications. Rarely this can also be found in the back bumper looking backward or two of them can be installed in the front bumper for extending the area covered in front.

Long-range radar specification

Detection range	2–150 m
Detection angle	±6°
Frequency	76–77 GHz

In principle, this sensor detects metallic objects in the vehicle surrounding. It is able to detect multiple objects and to measure distance, relative speed, and the angle to an object simultaneously.

A typical application that is strongly related to the LRR sensor is adaptive cruise control (ACC) which enables the equipped vehicle to maintain a safe distance and speed from a vehicle in front. However, the LRR sensor can be used for other safety applications as well, such as collision avoidance.

Despite the fact that LRR utilizes weather-resistant technology, overall robustness against weather cannot be achieved. In extreme weather situations, full functionality of the sensor cannot be guaranteed. Large amounts of dirt may also reduce the sensor function. Moreover, topology limitations exist in curved road segments due to the narrow horizontal detection angle of this sensor.

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Laser scanners take measurements according to the time-of-flight principle. A laser pulse with a defined duration is sent and reflected by an object. The reflection from the object is captured by a photodiode and transformed into signals in an optoelectronic circuit.

The time interval between the pulse of light being sent and its reflection being received, making due allowance for the speed of light, indicates the distance to the object that reflected the light.

Laser scanners are generally robust, but have decreased sensitivity in adverse weather conditions. This fact limits their availability and reliability. Most common laser scanners provide range and bearing information with sub-degree resolution and accuracies on the order of 1–10 cm for 10–50 m ranges.

Laser scanners can be used for detecting other vehicles or obstacles in the road scene and vulnerable road users, such as pedestrians and cyclists. Moreover, the road can be detected by a laser scanner, especially the road borders.

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Laser scanners exhibit much better lateral resolution as compared to radar sensors, but they come with comparatively slow scanning repetition rates, considerable physical size, and comparatively high production costs so far. Also they are significantly affected by the weather conditions.

The specification of different suppliers of laser scanners is not so identical. However, an indicative example of laser specifications is highlighted in >Table 3.3.

Both longitudinal and lateral vehicle control applications based on laser scanners exist but they are available only in expensive vehicles. Currently, the market penetration of these sensors is low and the penetration rate is slow.

Laser scanner specification

Detection range	min 0.3 m
	max 80 m (pedestrian, bike) 120 m (motorbike) 200 m (car, truck)
Field of view	Horizontal 150–240°
	Vertical ±2°

Virtual Sensors

The term ‘‘virtual’’ sensor is used for an information source which is not an actual sensor, but comprises an important input for the intelligent vehicle’s applications. The most important representatives of this category are the digital map and the wireless communication which are analyzed further in the following.

Digital Map

A standard digital map used in automotive applications mainly contains geometric information and other relevant attributes about the road. The core geometry consists of links and nodes connected together forming the road centerlines of the road network.

Connectivity is important for enabling routing in the network. The shape of a link, if it is not a straight line, may be represented by one or more shape points which are intermediate points between the start and end nodes of the link. As it is implied above, the shape points that describe a road segment are not placed at equidistant intervals.

All the map attributes are referenced to links, nodes, and shape points. These attributes can be points of interest (POI), traffic signs, speed limits, etc., which are sufficient for routing and navigation applications. Moreover, the map can be enhanced with further attributes such as the type of road, number of lanes, lane width, and type of lane markings which are needed for more sophisticated applications.

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The digital map data can be extracted and used by a vehicle when positioning information is available. Standard map positioning techniques are based on GPS technology combined also with inertial sensors such as gyroscopes and odometers in case the satellite connection with the GPS is unavailable.

The accuracy of standard digital maps is difficult to be measured. Nodes and shape points are represented in World Geodetic System 1984 (WGS84) global coordinates (latitude, longitude pairs). Coordinate resolution of current digital road maps is 10 micro degrees, which roughly corresponds to 1.1min latitude and 0.7min longitude at 50 latitude.

At this point, it should be highlighted that there might be significant differences in map data among different map vendors not only with respect to the available features and their corresponding accuracy but also in the topology of the road graphs and its completeness.

For advanced vehicular applications and especially for cooperative systems, the Local Dynamic Map (LDM) approach is promoted. The LDM is actually a map database which includes four different layers of information (see >Fig. 3.2). While moving from bottom to top layers in the LDM, static information are enhanced with dynamic information.

Local Dynamic Map

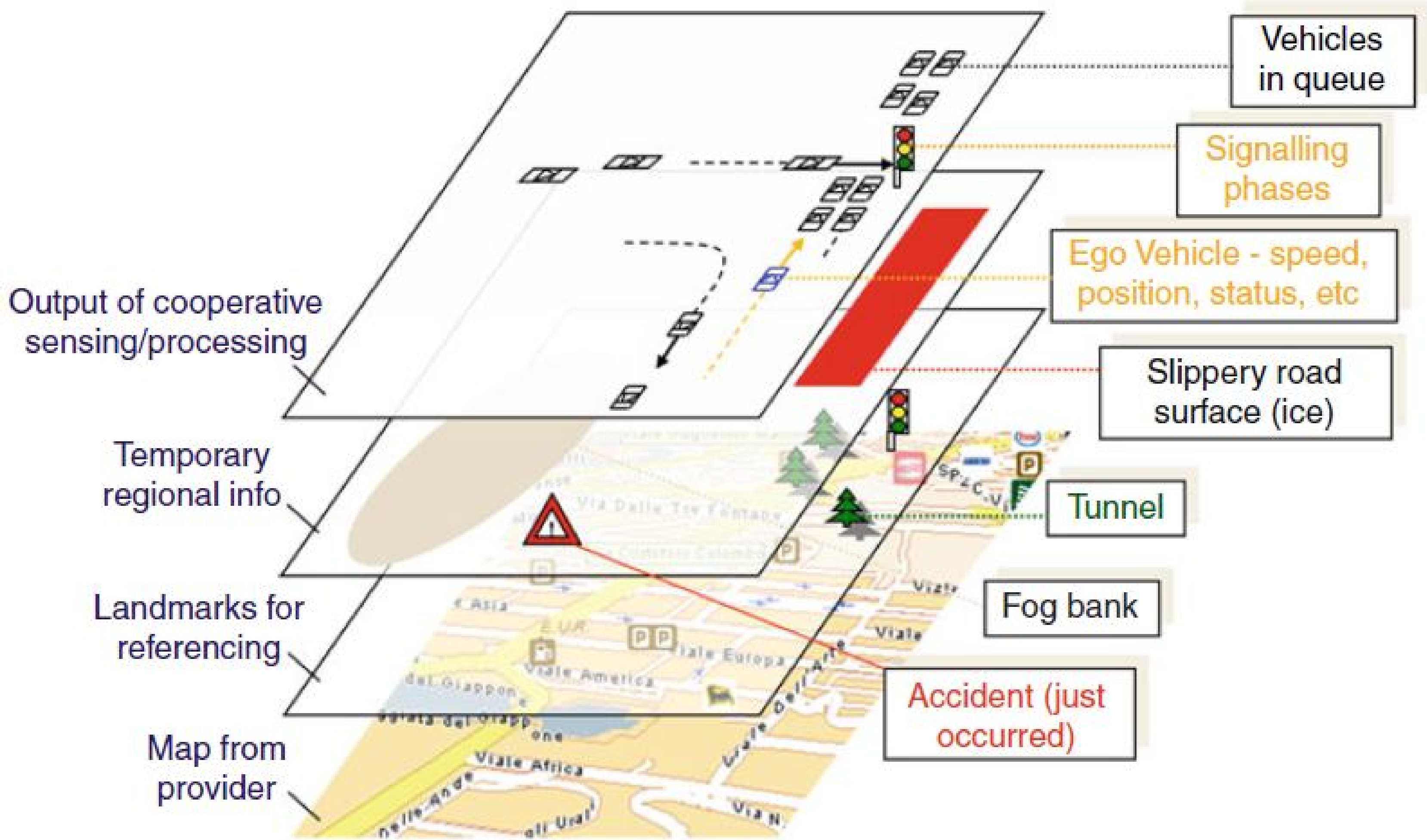

Fig. 3.2

The layered architecture of the LDM

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Due to some physical limitations of the perception sensors, such as their limited range and field of view, or due to other important parameters such as their degraded performance because of bad weather conditions and their significant cost, wireless communication is examined in order to complement or even substitute these sensors and enhance the awareness of the driver. There are two types of communication used in vehicular environments:

vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). An overview of

ITS applications that are based on the exploitation of wireless technologies is depicted in >Fig. 3.3.

There are many initiatives, working groups, and organizations studying the usage of wireless communication in road environments. The most important are given below:

Dedicated Short-Range Communications (DSRC) (ASTM2003) is a short- to medium range (1,000 m) communications service that supports both public safety and private operations in V2Vand V2I communication environments by providing very high data transfer rates. It operates at 5.9 GHz and provides a spectrum of 75 MHz.

Wireless Communication

●The design of an effective communication protocol that deals with privacy, security, multichannel propagation, and management of resources is a challenging task that is currently under intensive scientific research. A dedicated working group has been assigned this specific task by IEEE, and the ongoing protocol suite is the IEEE 1609, mostly known as Wireless Access in Vehicular Environments (WAVE) (IEEE Standards Association 2007).

● Continuous Air Interface Long and Medium range (CALM) (ISO 2007; ISO TC204 WG16) provides continuous communications between a vehicle and the infrastructure using a variety of communication media, including cellular, 5 GHz, 63 GHz, and infrared links. CALM will provide a range of applications, including vehicle safety and information, as well as entertainment for driver and passengers.

● The CAR 2 CAR Communication Consortium (C2C-CC) (CAR 2 CAR Communication consortium; CAR 2 CAR 2007) is a nonprofit organization initiated by European vehicle manufacturers, which is open for suppliers, research organizations, and other partners. The goal of the C2C-CC is to standardize interfaces and protocols of wireless communications between vehicles and their environment in order to make vehicles of different manufacturers interoperable and also enable them to communicate with roadside units.

● European Telecommunications Standards Institute (ETSI) and European Committee for Standardization (CEN) have joined their efforts in order to provide by July 2012 common standards to be used for cooperative systems. This cooperation was based on the European Commission Mandate M/453.

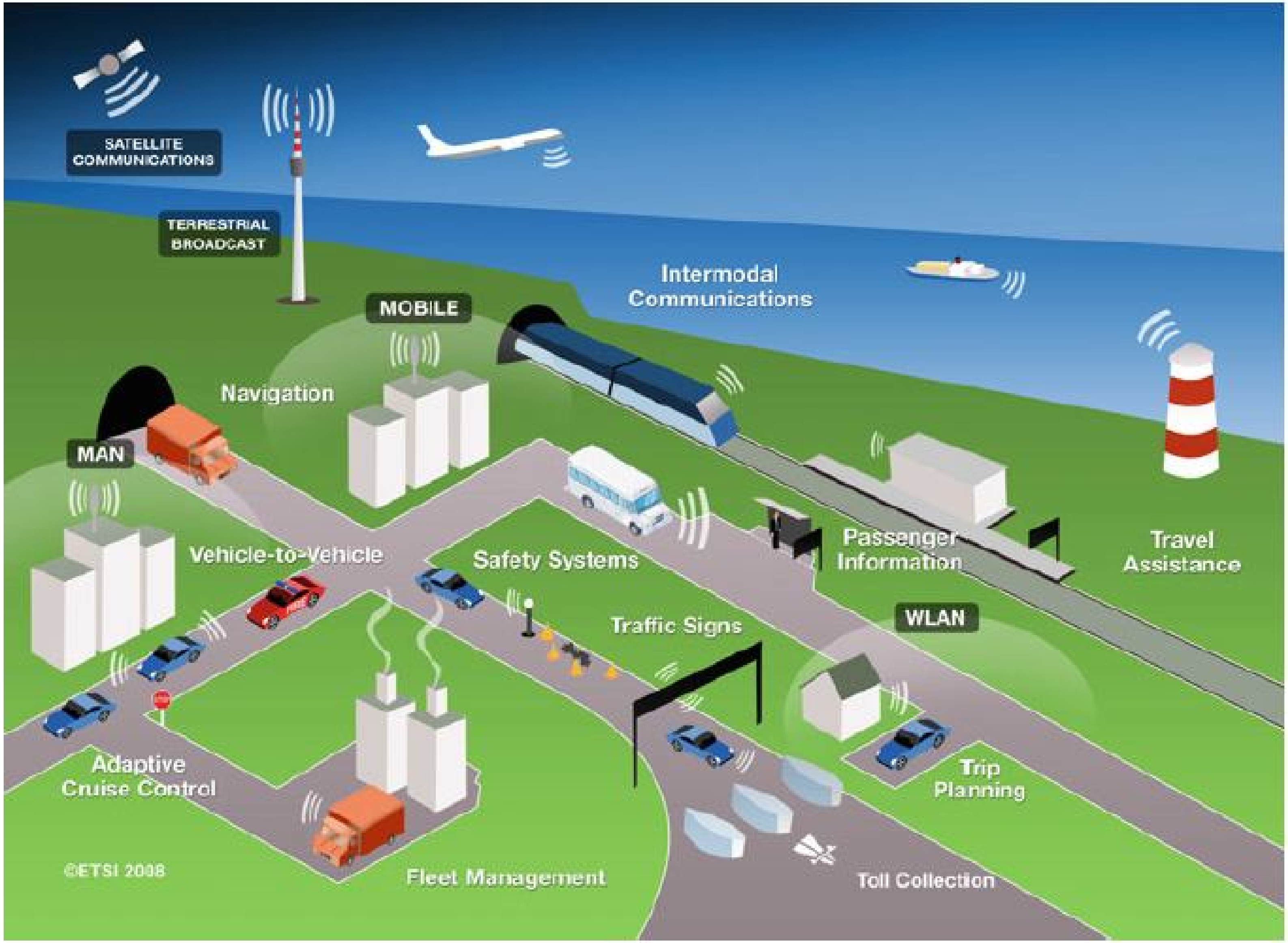

Fig. 3.3

Overview of ITS applications based on wireless communication (European Telecommunications Standards Institute)

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Actuators are devices that transform an input signal into motion. According to the energy source, they can be discerned into electrical motors, pneumatic or hydraulic actuators, relays, piezoelectric actuators, and thermal bimorphs. The generated motion can be linear or rotational.

Common actuators used in vehicles since long time are the fuel pump, injectors, fuel pressure regulators, idle speed actuators, spark plugs, ignition coils and controls for variable intake, cooling fan, and A/C compressor. Lately, actuators are used within the framework of more advanced systems intervening to the main vehicle subsystems, for example, within the framework of applications like ABS, electronic stability control, ACC, assisted braking, assisted steering, motor management, and chassis stabilization.

Apart from that, since the evolution of the intelligent transportation systems, actuators are being used for more sophisticated applications, that is, to actively brake the vehicle and undertake steering control in case of emergency, or even to drive the vehicle in a fully automatic way. The highly automated driving is one of the long-term visions for intelligent transport which is expected to enhance driver safety, since it is estimated that 97% of all accidents are due to human error.

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Mechanical actuators convert one type of motion into another, for example, conversion of rotational into linear motion and vice versa. They are mainly used in cooperation with other actuators. An example of machine screw actuator is given in >Fig. 3.4.

Machine screw actuator by Duff-Norton

Electrical Actuators

Various types of motors are used as actuators in vehicles, the most common being the electronically commutated (EC) DC motors. The rotational motion produced can be used as is or converted to linear using gears or other elements.

The general requirements from motors for in-vehicle use are that they must be quiet, and resistant to vibrations, to shock, to temperature, and to chemical agents. They should also be free from electromagnetic interference with other onboard systems. The modern EC DC motors offer a very high reliability and there is no need for preset positions. Their high power density in minimum space allows their positioning in almost any location in the vehicle. Therefore, they can fit almost any vehicle design.

External rotor motors are more adequate for fans. Internal rotor motors allow the quick realization of commands due to their lower moment of inertia, thus they can be used in a wide range of applications for booster and auxiliary generating sets, for example, for controlling steering. Requirements from a motor used for steering assistance could be speed between 0 and 6,000 rpm, very low idle click point, and high uniform torque.

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>Figure 3.5 shows a smart coolant pump by Continental. It is an EC motor with integrated control electronics, which allows precise engine temperature control through variation of the coolant volume flow.

Fig. 3.5
Smart coolant pump by Continental (www.conti-online.com)

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Another type of actuator commonly used in vehicles is the solenoid valves, shown in >Fig. 3.6. These are pneumatic or hydraulic valves controlled by an electric current passing through a solenoid coil (a coil in the form of a helix). The solenoid is an electromechanical actuator converting electricity into mechanical movement of the pin of the valve. In some cases, the solenoid acts directly on the main valve, in others a pilot solenoid valve acts on the main valve. The latter are called pilot solenoid valves and require less power but are slower.

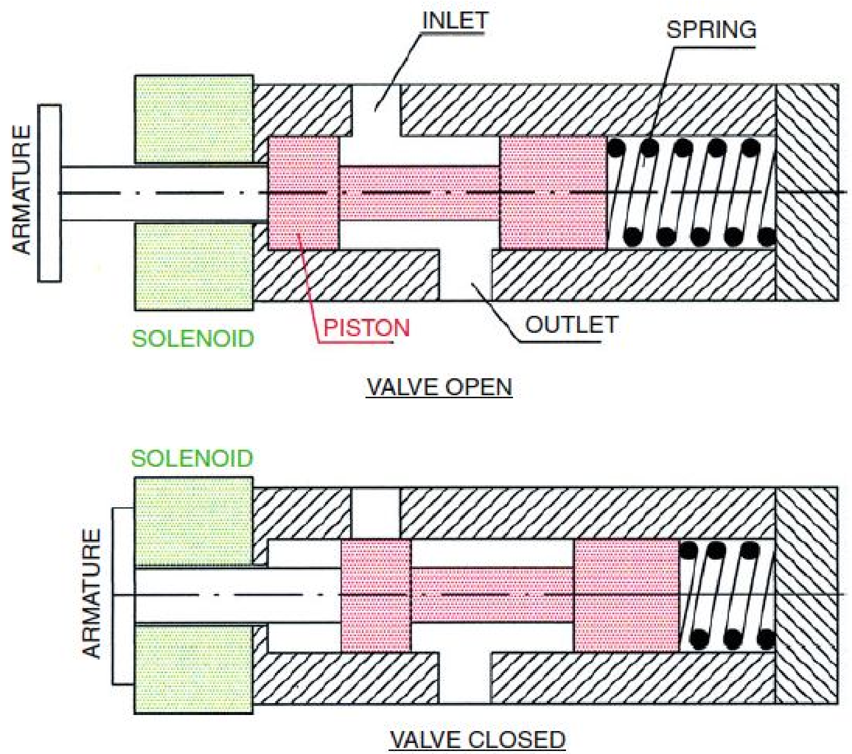

Fig. 3.6
A solenoid valve

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Another element that is commonly used as actuator in vehicles is the stepper motor, a device that converts electrical pulses into discrete movements. A drawing of a stepper motor is shown in >Fig. 3.7. This is an electric motor that rotates stepwise with high precision, each step has an accuracy of 3–5% and the error is not cumulative per step. Electromagnets are arranged on the stator around a multi-toothed rotor. When the first pair of electromagnets is powered, the stator rotates one ''step'' until its teeth are aligned to the energized electromagnet, being slightly offset from the next pair of electromagnets.

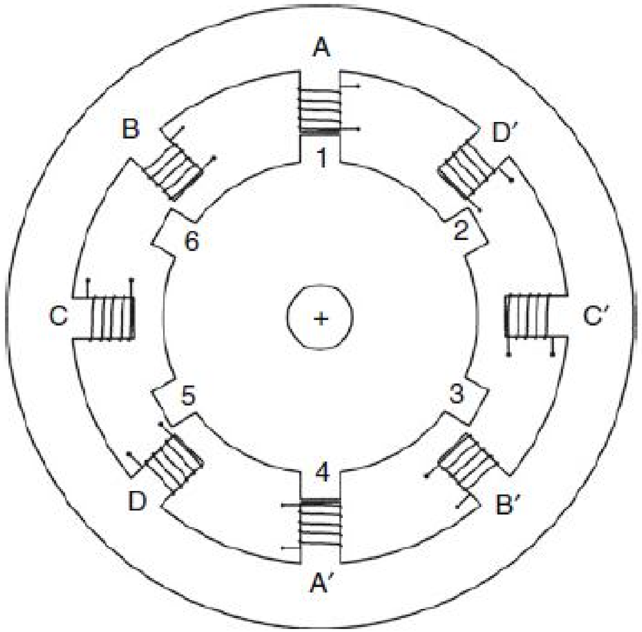

Fig. 3.7
A stepper motor

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