History and Future of Driver Assistance

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A simplified distinction between passive and active safety systems in the automotive industry is that while the former mitigate the consequences of an accident, the latter prevent its occurrence. In this overview, the reader can find a survey of the main active safety systems which can be classified as Driver Assistance Systems (DAS), although only Advanced DAS (ADAS) will be the focus.

Classifications of Safety Systems

The main difference between DAS and ADAS is the sensor set they use: DAS only rely on the reconstruction of ego vehicle state, thus using onboard inertial measurement units (IMU), odometers, etc. ADAS exploit superior knowledge of the surrounding environment, thanks to advanced sensors like cameras, radars, lidars, and map databases, composed of both a hardware (HW) layer for sensing and a software (SW) layer of intelligence for post processing and decision making.

Sensing the surrounding environment, and communicating with it, are the key challenges of the automotive industry, which is now enhancing its ADAS systems towards autonomous driving.

From the Origins to Autonomous Vehicles

Time Overview

Anti-lock braking systems (ABS) can be considered the first driver assistance systems introduced in the market, around 50 years ago. Simplifying, for their function it was sufficient just to measure one quantity, wheel speed, to consequently actuate a valve system in the braking circuit to prevent wheel blockage.

For ADAS systems, 50 years later, sensors carry intelligence, and they do not only *sense* the vehicle state and its surroundings but also need to *understand* what they measure, and *fuse* these half-processed data with those from other sensors, which may use a different technology to compensate their own limits. Based on this perception layer, the systems then *decide* the correct action to be taken, and either *inform/warn* the driver or directly *control* the vehicle themselves.

The scenarios which must be covered include basically all of the situations the vehicle can encounter in its life: thousands of road, traffic, and environmentally different conditions, which during development of such systems also need to be recorded and reconstructed for later debugging. This also complicates the development process, which requires a huge amount of data logging and additional equipment fitted onboard vehicles.

Automation Levels

Instead of analyzing the different systems from a chronologic point of view, it is more useful to classify them based on the level of automation they guarantee, which has more impact on the sensors, redundancy and system architecture.

The Society of Automotive Engineers (SAE) scale categorizes five levels of automated driving, as described in Fig. 1. There have been, and there are, DAS and ADAS on each level of automation.

Level 0 Systems

Level 0 ADAS do not perform any vehicle control task, but provide information to the driver, and help him monitor the surrounding environment or his own status. The main examples of such systems are:

Parking Sensors: introduced on cars in the 1980s, provide acoustic warning depending on the distance from surrounding obstacles while parking the car, to avoid damaging the vehicle. The functionality is usually enabled by 8 or 12 ultrasonic sensors, positioned on the front and rear car bumpers.

Surround View: a more sophisticated parking system which combines parking sensor information with that coming from usually four fish-eye cameras. Combining the information from them, the driver is informed about the surroundings of the vehicle, which are combined on a display into a unique birds-eye view, or as different layouts from specific points of view. The system works to project the 2D video streams from the camera on a unique 3D bowl. Then, different points of view

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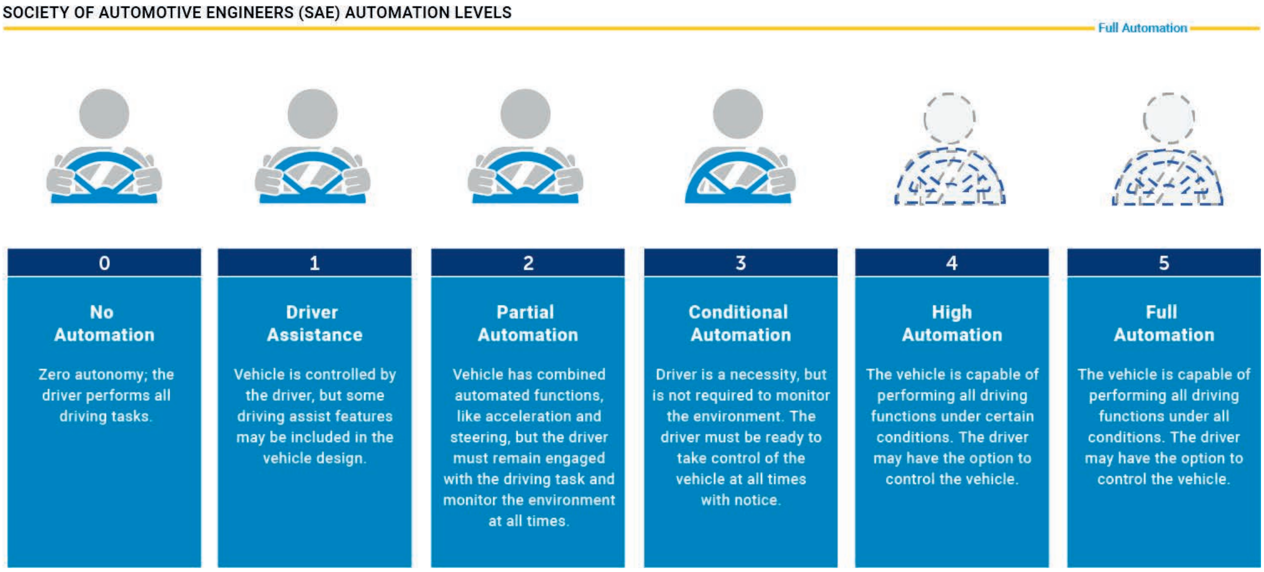

Fig. 1. Society of Automotive Engineers automated driving levels (from www.nhtsa.gov.).

of the bowl are conveniently set, and overlays such as parking lines, ego vehicle 3D model, and obstacle walls are superimposed to the video stream, to allow better surveillance of the surroundings by the driver. The coherence of the reconstructed bowl, and the shape and proportion of the surroundings in the video with the overlays are the most critical aspects for the effectiveness of the system, and they are all influenced by the quality of the calibration of the system.

Traffic Sign Recognition (TSR): shows the driver information such as current speed limits and other road rules and warnings such as overtaking prohibition, beginning of double-carriage ways, slippery road, etc. The functionality requires a forward-looking camera attached to the windshield, which detects road signs, and may also take advantage of additional information sources like navigation maps to provide fused information to the driver.

Lane Departure Warning (LDW): warns the driver by acoustic and/or visual and/or haptic feedback if he is accidentally leaving the current lane. Also, this function is supported by a forward-looking camera, which detects the lines of the vehicle lane and compares them with ego-vehicle direction (Fig. 2).

Night Vision: enhances driver's perception of the road ahead during darkness. The system is based on an IR illuminator and camera, which allow detecting objects in critical light conditions, e.g., overnight or when the driver is glared by the headlights of oncoming traffic.

Blind Spot Information System (Blis) or Blind Spot Detection (BSD): warns the driver if there is an obstacle in the blind spot of the rear-facing mirrors which the driver may have overlooked. The warning is usually visual, as in the side mirrors, and possibly acoustic and haptic, especially if the driver has showed the intention to change trajectory and collide with the obstacle, e.g., because he has turned the indicators on. The functionality is usually enabled by two short range radars, mounted in the two rear corners behind the bumper (Fig. 3).

Rear Cross-Traffic Alert (RCTA): using the same sensor set of BSD, the system helps the driver exiting backwards from parallel parking, where the rear field of view is obstructed by the vehicles parked at the sides. When the rear gear is engaged, the system visually and acoustically warns the driver if a vehicle is approaching from the main road, with a much higher range of detection than the parking sensors.

Forward Collision Warning (FCW): warns the driver about an imminent collision with an obstacle ahead, which may be either moving or stopped, and suggests that he brake. The feedback is usually acoustic and visual, to reduce the driver's reaction time. In some cases, if the driver does not react, the system can also actuate a short brake jerk to gain the driver's attention. Such a functionality is usually enabled by a mid-range radar plus a forward looking camera, as an additional source of information to be fused with the radar perception: the camera helps the radar to detect obstacles, refine their relative position and also classify them, i.e., understand if they are cars, trucks, or pedestrians. In other cases, the system can be implemented just using a forward looking camera, which can be mono or stereo, as the warning is usually triggered by close obstacles, so that short-range sensors can be sufficient (Fig. 4).

In any case, the camera shall be able to estimate the relative distance between ego vehicle and the obstacle: stereo vision intrinsically allows this just triangulating between obstacle and the two cameras, but this is also possible using a mono camera, and triangulating in time instead of space. This is possible by processing two consecutive frames from the same camera, instead of two contemporary frames from two cameras. Of course, this is possible only if the system is able to reconstruct the vehicle motion between one frame and the consecutive one.

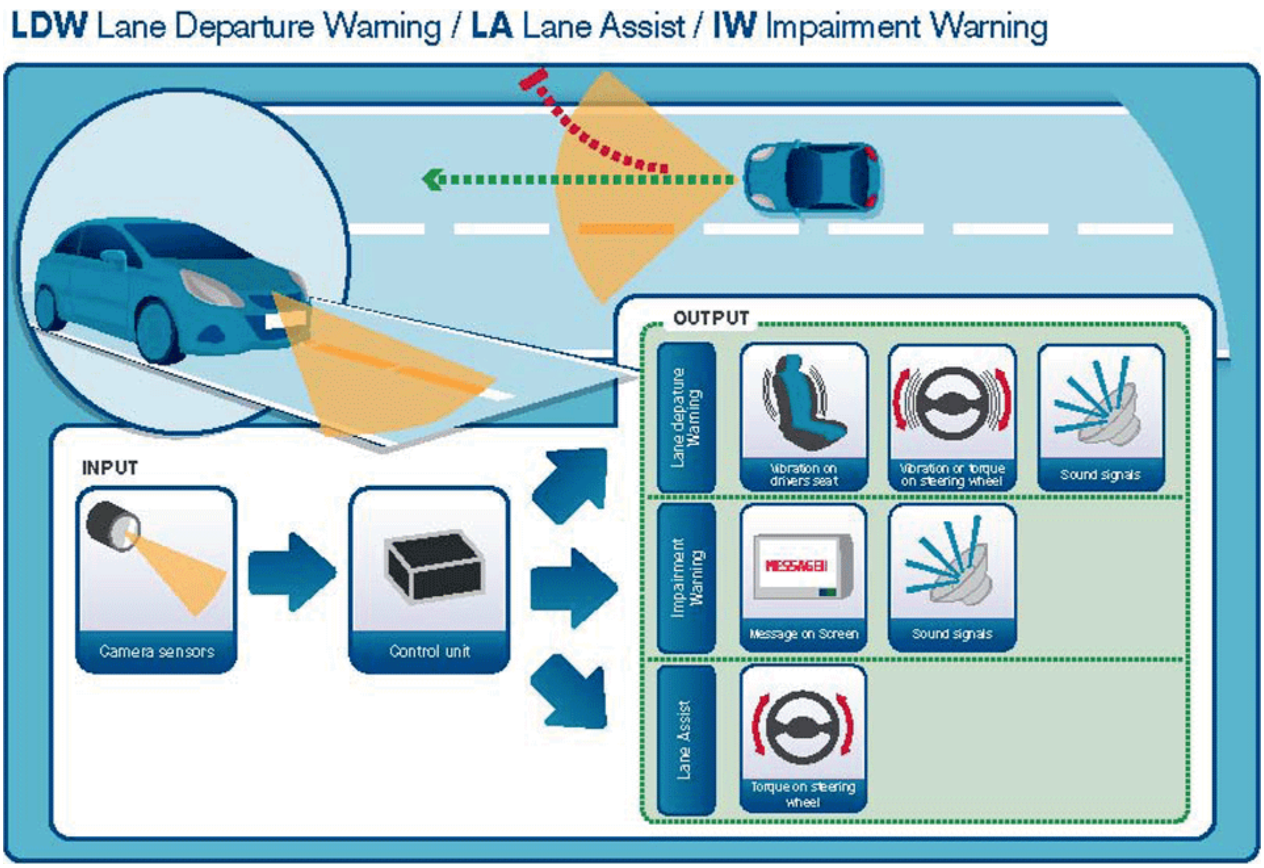

Fig. 2. Lane departure warning system overview (from Eurofot).

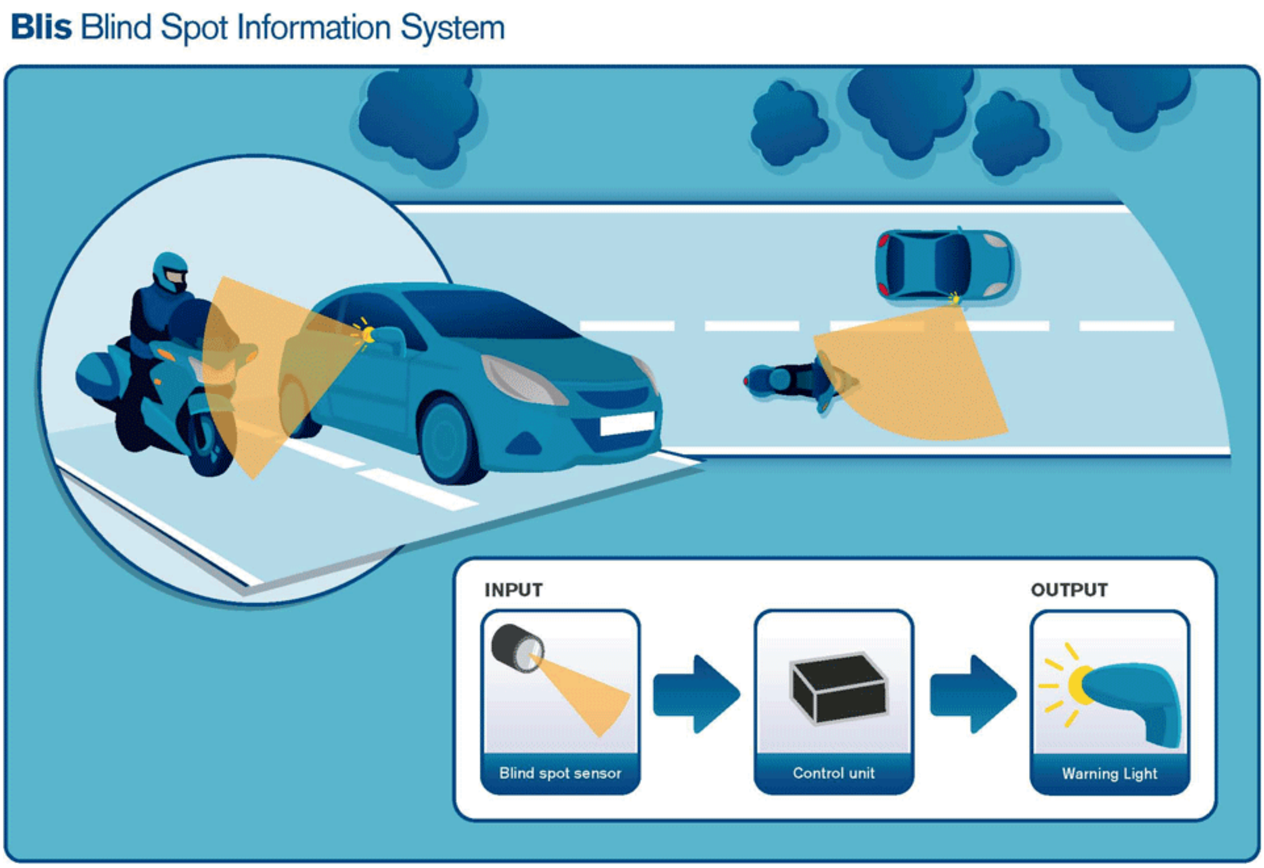

Fig. 3. Blind spot information system overview (from Eurofot).

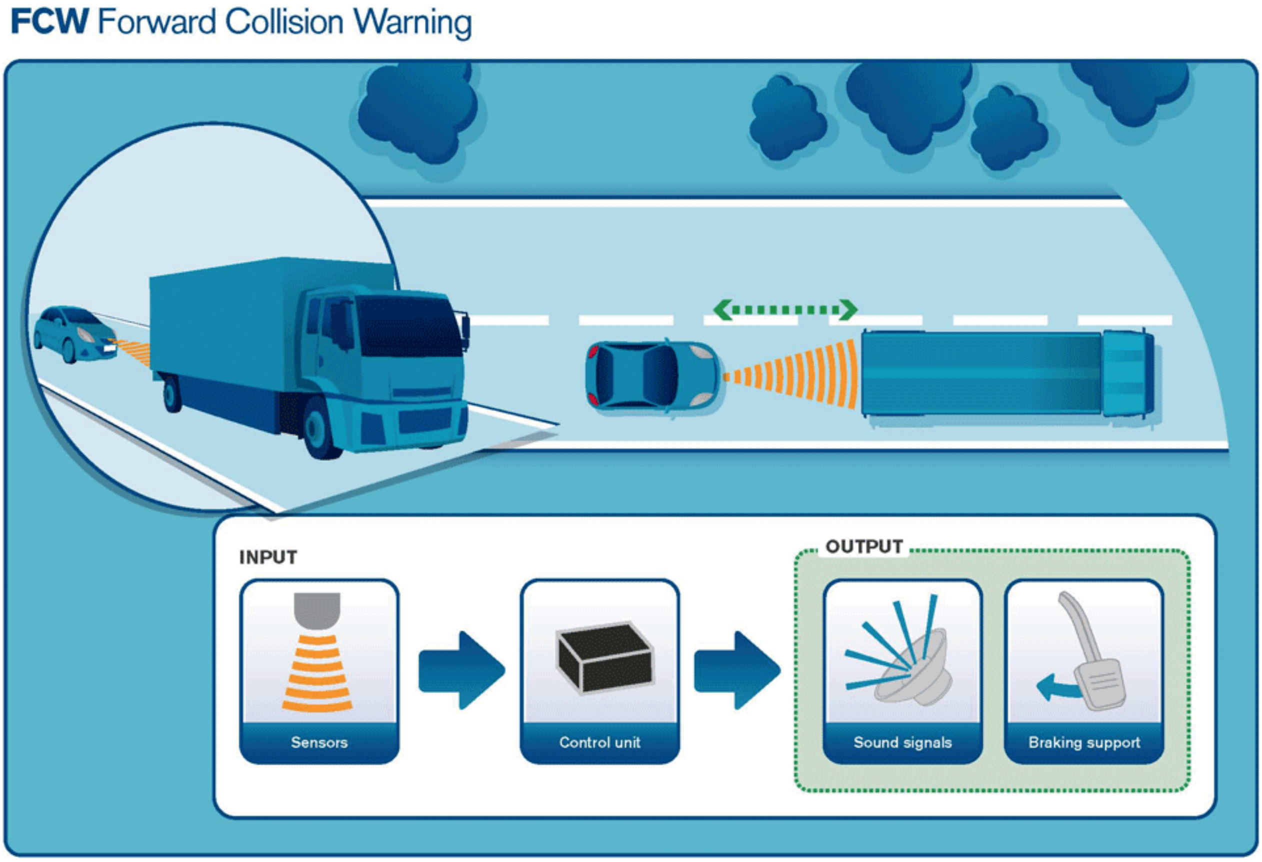

Fig. 4. Forward collision warning system overview (from Eurofot).

The key to develop such systems is to design a robust obstacle detection and ego trajectory estimation, to provide correct warnings with correct timing every time they are needed, but avoid false alarms which annoy the driver, and reduce his attention to them.

Level 1 Systems

Level 1 and 2 ADAS still leave the authority to the driver, but they take care of specific driving functions, also controlling the vehicle with suitable actuators.

Level 1 systems take care of single functionalities in specific cases. A category of such system includes the traditional DAS for vehicle dynamics, which are based on conventional sensors and were introduced in the market in the 1970s as anti lock braking systems (ABS) or in the 1990s as electronic stability control systems (ESC):

Anti Lock Braking System (ABS): supports the driver while braking, avoiding wheel blockage even if he is requiring full brake force, and thus avoids tire saturation, which allows reducing braking distance and keeping the vehicle controllable. The system is based on wheel speed sensors.

Electronic Stability Control (ESC): helps the driver maintain the vehicle stability, i.e., avoid excessive oversteering and understeering by selectively braking single wheels and thus giving the vehicle a suitable yaw moment to remain neutral. The system is based on vehicle motion information, coming from inertial platforms (longitudinal and lateral accelerometers plus vertical gyroscope), wheel speed sensors, driver action sensors like steering wheel angle and torque, and engine rpm and torque, combined into suitable vehicle models which monitor vehicle stability.

Traction Control System (TCS): assists the driver in the acceleration phase, preventing the wheels from spinning by cutting engine torque, thus improving the acceleration performance and keeping the vehicle stable. They are usually based on the same sensor set of ESC systems.

Cruise Control (CC): based on simple vehicle speed and pedal and engine monitoring, maintains the car at the speed selected by the driver, by controlling both the engine and the automatic gearbox.

In addition to DAS, there are also Level 1 ADAS, for comfort and safety purposes, which use non-conventional sensor sets:

Adaptive Cruise Control (ACC): like the CC, ACC maintains the vehicle at a desired speed. However, if there is another vehicle travelling ahead, the system is able to detect it and reduce the speed to keep a safe distance from it, by means of both cutting engine power and actuating the brakes. This is possible thanks to one or more radars mounted on the bumper, which can be

ACC Adaptive Cruise Control

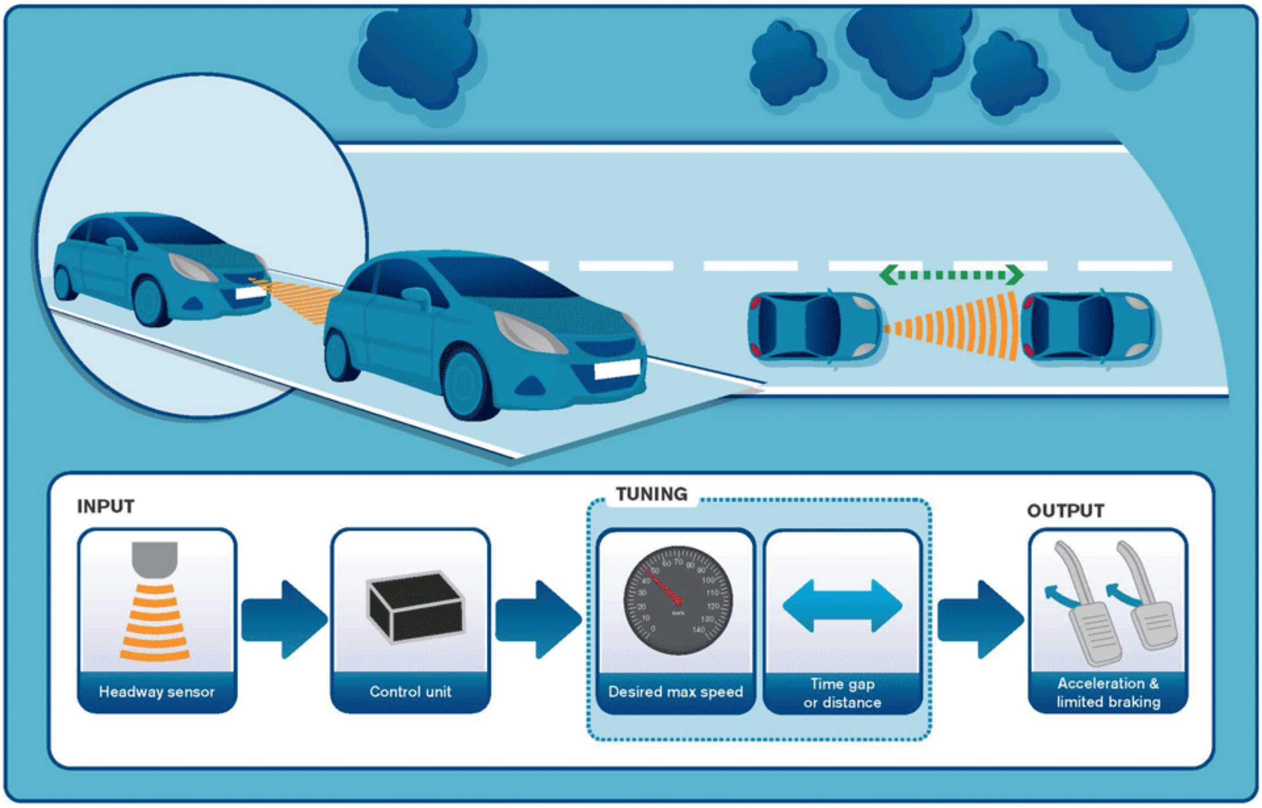

Fig. 5. Adaptive cruise control system overview (from Eurofot).

mid-range or long-range. Long-range radars (>250 m) allow setting higher speeds safely, being able to recognize further obstacles and thus having enough time for braking the vehicle (Fig. 5). However, usually the ACC is implemented also using a forward looking camera, for the same reasons described for FCW. The redundancy of sensors also enhances the overall functional safety.

Emergency Brake Assist (EBA): assists the driver in emergency braking, i.e., if an imminent collision is detected, the system prefills the braking pads, to provide a prompter response if braking is required. In addition, if the driver starts braking, or shows the intention to start by quickly releasing the gas pedal, the system can provide additional braking power to avoid a collision, in the case the driver is not braking enough. For such functionality, the sensor set is the same as in FCW and can be considered the second step of an FCW system, when the driver starts reacting to the warning but too late or with insufficient action.

Automatic Emergency Brake Assist (AEB): can be considered the latest stage of a FCW-EBA system, i.e., if the driver has not reacted at all, the system is able to autonomously brake the car. The sensor set is the same of FCW-AEB applications. This kind of system cannot always avoid a collision but mitigates its consequences, reducing the impact speed. Such systems need a high safety level, to avoid false positives, i.e., braking with no real emergency, and can be classified Asil D.

Lane Keeping (LK): an evolution of LDW, the system also laterally controls vehicle motion, in order to keep the vehicle within the current lane. This shall be avoided instead if the driver has shown the intention to change lane, by turning the indicators on or by applying a suitable steering wheel torque. The system can rely on a simple mono camera like LDW, but requires electric power steering to directly receive the inputs from the camera and control a steering torque. Since the driver is always responsible for vehicle behavior, usually such systems monitor the driver's activity by analyzing his actions on the steering wheel and on the pedals, recognizing patterns which indicate tiredness or distraction. For example, if the system detects the driver has not his hands on the steering wheel, it automatically disengages the steering control, and asks the driver visually or acoustically to take control of the vehicle, to discourage him to rely on the system and abandoning his controlling tasks.

Lane Centering (LC): similar to LK, it not only intervenes on the steering wheel when the vehicle is exceeding lane boundaries but continuously controls the steering wheel to keep the vehicle in the center of the lane. For such systems, which take care of even more controlling tasks from the driver and seem to encourage him to leave the authority to the car, it is also necessary to use capacitive sensors in the steering wheel, to really make sure that the driver is still able to control the vehicle promptly. LC can be based on a simple mono camera as for LDW and LK.

Level 2 Systems

Level 2 systems share the same level of authority with the driver as Level 1 but are able to perform more complex manoeuvres, combining longitudinal and lateral dynamics, which mainly lead to perform a desired trajectory with a desired speed.

Highway Assist (HA): basically combines ACC, LC and BSD, continuously controlling longitudinally and laterally the vehicle. In case of preceding vehicles to be passed, if for instance the driver turns the indicator on, the system both starts accelerating to overtake, and consequently steers the vehicle to perform a desired overtaking trajectory. In case a vehicle is detected behind, the system shall not overtake.

Autonomous Obstacle Avoidance: analog to highway assist, the system combines longitudinal and lateral control to avoid a collision with an obstacle, here braking instead of accelerating, and steering contemporarily, close to vehicle dynamic limits.

Autonomous Parking: assists the driver both in finding a suitable parking lot and in parking the car into it. The authority is left to the driver, who remains in charge of e.g., actuating the pedals according to system suggestions while the system controls the steering wheel, or simply monitoring the car behavior while it is performing the manoeuvre. This is possible by adding 4 additional Ultra Sonic parking sensors to the usual 8, directly looking in the lateral direction. In some cases, these systems also take advantage of additional sensors like lateral cameras.

Level 3 Systems

A big technological leap divides Level 2 systems from Level 3 systems, even if the functions are quite similar to Level 2. Level 3 systems assume the authority of the manoeuvres in the determined scenario, and only when they assess that they are not capable of handling the current situation, or they self detect a fault, they warn the driver and ask to take back vehicle control. Thus, the driver shall always be ready to take control, even if it is not required anymore that he continuously monitors the surrounding environment. Another way to describe this behavior is a 'fail-safe' system, i.e., a system which is safe in case of a fault, since it is able to self-detect it, warn the driver how to correct the situation and handle the transition of authority until he fully takes it back.

According to the SAE standard, to safely operate, these systems need redundancies both in sensors and in decision electronic control units (ECU). In this case, the sensor set usually extends at least to a front lidar, which both provides redundancy in scenarios where the radar may fail, such as bad weather conditions, and also adds resolution to the measurements to increase system reliability. Depending on how much the scenarios are extended, the system can also increase the sensing around, to cover the around area at a longer distance, or provide additional sources for sensor fusion and redundancy, e.g., rear or lateral cameras. Another important source of information for such systems is GPS combined with a map database, to enhance vehicle positioning, and also enable other kind of functions, e.g., green functions such as optimized powertrain management based on the characteristics of the road ahead.

For such systems, the architecture usually changes, and passes from distributed intelligence to centralized intelligence. In other words, in Level 1-2 ADAS each sensor not only hosts the logics to process sensed data and reconstruct the environment but also those to take decisions and command the actuators. This means that each function can be based on the perception of a single sensor, with the only exception of radar-camera sensor fusion, where one of the two is only used to confirm the perception of the other one. In Level 3 ADAS, the sensors mainly have a perception task, and send the processed information to an ADAS domain ECU, which collects all of the information and reaches a unique, all around reconstruction of the environment, takes decisions based on it and controls the actuators. An example of such system is *Highway Chauffeur*, an evolution of HA which also autonomously decides when to overtake, thus taking full responsibility on the manoeuver instead of being triggered by the driver by turning indicator.

Level 4 Systems

Level 4 systems extend the scenarios where they are able to take decisions and manage the situation, and in those specific scenarios perform all the necessary driving tasks so that driver intervention is not required most of the time. For this reason, a centralized intelligence with all around sensing is required. In addition, Level 4 systems shall be not only fail-safe but fail-operational, i.e., able to safely work also in case of failures without the intervention of the driver.

An example of Level 4 systems is *Automatic Valet Parking*, where the specific task of finding a parking lot and parking, in a confined environment is fully delegated to the vehicle, while the driver may have already left the car. For this kind of system, the communication between ego vehicle and the infrastructure is needed to improve the functionality.

Level 5 Systems

The final automation step is Level 5, which is a fully autonomous vehicle. Level 5 vehicles do not require the intervention of the driver and have such redundancy, sensing coverage, and a decision intelligence that they can even lack of interface with the driver to control the car, like the steering wheel and pedals. The driver becomes a passenger, who just sets a destination and sleeps while the vehicle is transporting him to his decided location. Although this level of automation may scare common road users, autonomous vehicles can actually increase road safety, outperforming driver's monitoring capabilities since they can constantly monitor the environment at 360°, they are not affected by tiredness and they are always at attention. This is true of course only if their capability of classifying the surrounding scenario, and assessing its risk level, is at least good as that of a human, and this is why artificial intelligence is widely used in the perception and decision layer of such systems. In addition, such systems have to be designed with conservative

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