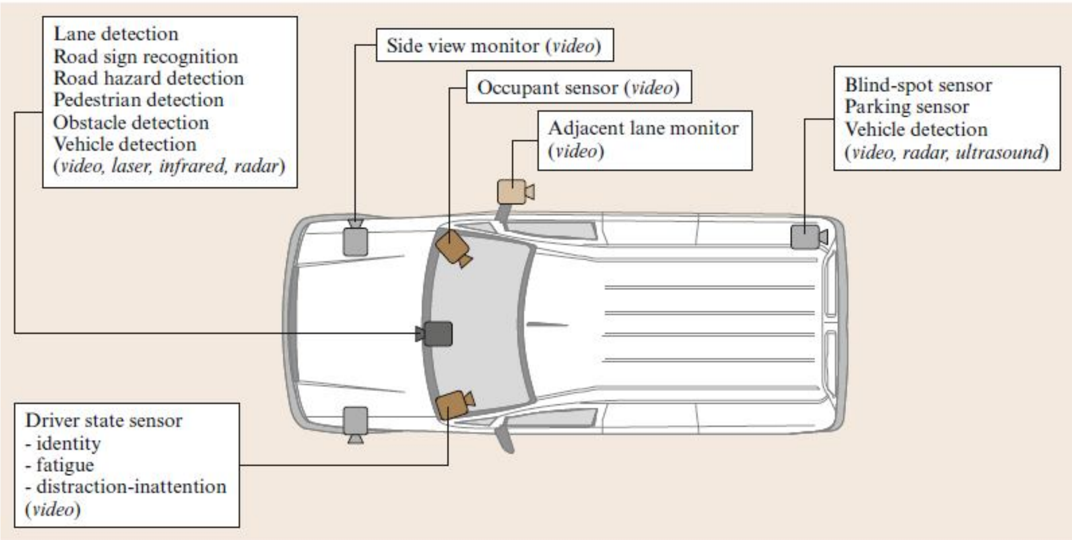
Topic: Road Scene Understanding

Environment State

Sensing the state of the environment surrounding the vehicle is a critical aspect of intelligent vehicle applications.

The most difficult function for intelligent vehicles is road scene understanding. This includes locating key landmarks: the road, other vehicles, pedestrians, traffic signals, road signs, and other unstructured obstacles. A more difficult challenge is speed control following the detection of event in the road scene. The common sensors are infrared, ultrasound, radar, laser range finders and computer vision, which continually scan the environment as shown in the picture.



Radar is generally used for obstacle detection at a distance, while infrared and ultrasound are used for close proximity obstacle detection. Laser ranging and image processing are used to more robustly recognize the road scene under various weather conditions.

Certain road scene conditions such as road signs and traffic lights can only be understood using vision sensing.

Sensor fusion is commonly used in intelligent vehicle applications, particularly between monocular vision and radar/laser sensors.

Driver State

Additionally an intelligent vehicle needs to understand the driver state, if it is to give appropriate warnings or need to take action. Vision sensors can monitor a driver's attentiveness and fatigue by observing the direction of the driver's gaze and eyelid behavior. In an emergency knowing the position of the driver's head can assist in the safe deployment of airbags. Also, after an accident, observing the state of the driver and other occupants could be useful for the dispatch of emergency services to the accident scene.

Driver State

Perception plays a key role in any robotic application. In the case of intelligent vehicles, the perception task is referred to as road scene understanding. It involves using different sensors combined with automatic reasoning, in order to create a synthetic representation of the environment around the vehicle. The knowledge base accumulated by this task is then used either to issue warnings to the driver in the case of advanced driving assistance systems (ADAS) or to control vehicle actuators in the case of complete autonomous driving.

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A complete and precise description of the state of surrounding environment is the key factor that allows the reduction of the number of false and missed alarms and provides the basis for smooth automatic driving. Needless to say, the perception of an outdoor environment – even if partially structured – is a challenging problem not only due to the intrinsic complexity of the driving environment itself, but also due to the impossibility of controlling many environmental parameters. The picture shows examples of day/night, sun/streetlight illumination, temperature, poor visibility, rain/snow, and different meteorological conditions, which in general are impossible to control and have to be faced by sensing devices.

Typical range of road scenes that intelligent vehicles must handle

The research community is addressing the issue of providing vehicles with robust and precise perception of the state of the environment from two different perspectives. One approach is to provide vehicles with ever-increasing sensing capabilities and processing power aimed at the provision of powerful onboard intelligent systems; Daimler-Chrysler is a world leader in this area. An alternative approach is to use road infrastructure as an active component capable of communicating with all vehicles and sharing information on road conditions in real time. Indeed these two perspectives can also be merged to provide a mixed solution to safely control a vehicle and in dynamic environments.

The task of road scene understanding may be addressed differently, depending on the availability of an intelligent infrastructure and on other players exhibiting cooperative behavior. The task of understanding the state of the environment can be simplified through the availability of information coming from other sources, thereby limiting the need to perform a robust and complete sensing onboard each vehicle. Helpful formation could come from the infrastructure itself (for example, road conditions and geometry, number of lanes, visibility, road signs, or even real-time information such as traffic-light status or traffic conditions) or other players (such as the presence of the vehicle with precise position, speed, and direction). The players may also carry real-time information gathered by and shared with other players.

Although research is currently focussed on both intelligent vehicles and intelligent infrastructures, the first generation of production intelligent vehicles will have to rely primarily on their own sensing capabilities since the availability of information coming from other sources such as the infrastructure and other vehicles will take awhile to be deployed in real-world situations. In fact, in order to be of practical use, intelligent roads must cover a large proportion of a country, and simultaneously cooperative intelligent vehicles must also be sufficiently widespread. It is important to note that the investment in intelligent infrastructures and intelligent vehicles comes from different sources: mainly from governmental institutions for the former, and vehicles owners for the Latter. The information that is owned by the infrastructure itself and that could be made available to the vehicles includes

- precise geometry of the lane/road
- road signs
- status of traffic lights

On the other hand, the infrastructure can also assess and deliver real-time data such as

- road conditions
- visibility
- traffic conditions

Another important piece of information that needs to be gathered by intelligent vehicles is the presence of other road players, such as

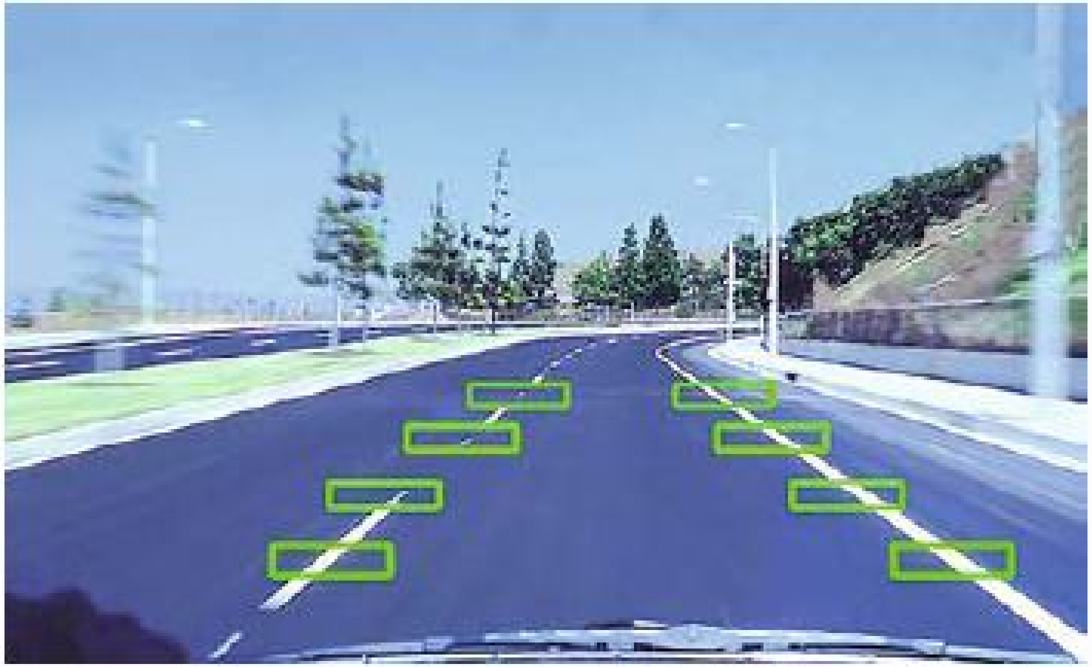
- vehicles
- vulnerable road users (pedestrians, motorcycles, bicycles)

Although it could be assumed that sometime in the future all vehicles will be equipped with active systems that allow them to be safely avoided by other vehicles, it is quite improbable that pedestrians and bicycles will have similar equipments: their presence will need to be detected using onboard sensors only. The same consideration also applies to obstacles that may unexpectedly be found on the road, or to temporary situations such as roadworks: if a vehicle needs to cope with the unexpected, then it needs to have the capability to assess the situation in real time with its own sensors. This is why onboard sensing is of paramount importance for future transportation systems; vehicle-to vehicle and vehicle-to-infrastructure communications may help and improve the sensing, but a complete sensor suite must also be installed on our future vehicles. The main challenges in road environment sensing are examined below.

Road/lane tracking

Many vehicles prototypes have been equipped with lane detection and tracking systems, starting from the very first implementations in the early 1980s. Indeed in this case computer vision plays a basic role; although generally the road can also be detected with laser scanners, the only generic technology able to detect lane geometry and lanemarkings with high precision is computer vision.

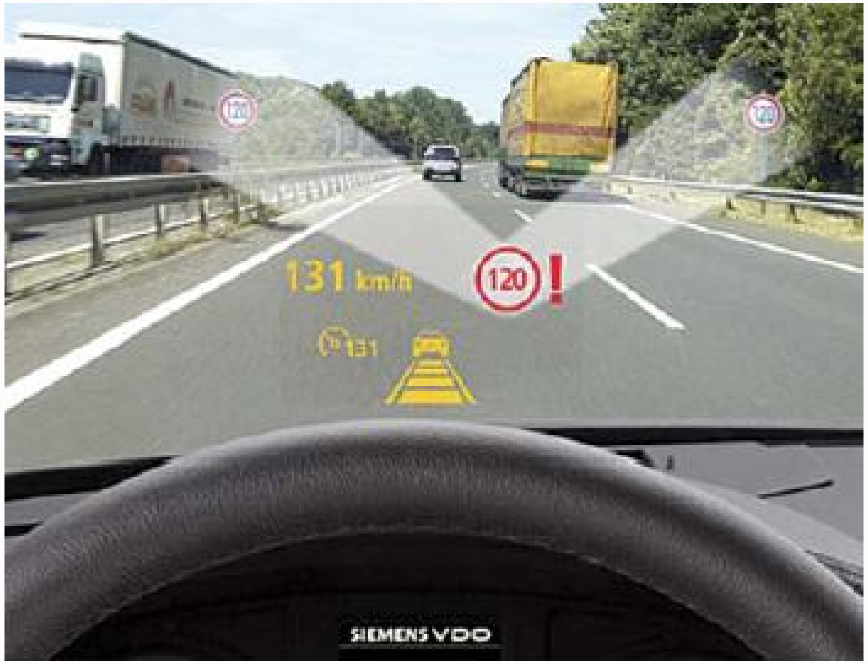
Most lane tracking approaches have focused on detecting lane markings and exploiting structure in the environment, such as the parallelism of the left and right lane markings, the invariance of road width, or the widely used flat-road assumption. These assumptions were mainly used to overcome the problem of having a single camera (a choice driven by cost). Some systems use stereo vision to detect lane markings and are able to work without such constraints. The problem of lane tracking in highway situations is basically a solved problem – with commercial systems being deployed in passenger and commercial vehicles. An example of the typical output of a commercial lane tracker is shown in Figure



However, such systems cannot guarantee that lane detection systems will work with 100% reliability; these systems typically work with 95–99% reliability. Therefore, lane tracking systems are only being used in lane departure warning systems since no failures can be tolerated for autonomous driving. Efforts are underway to develop algorithms that will tolerate a variety of driving conditions, and push the 100% reliability boundary.

Road sign detection

Another fairly straightforward use of computer vision is road sign detection and understanding. Road signage is deliberately structured to aid human drivers. Road signs use a set of well-defined shapes, colors, and patterns. The signs are placed at consistent heights and positions in relation to the road. Therefore reading road signs is an achievable task for computer vision.



Detection is done using a collection of shape and/or color detection schemes. After the detection and localization phase, recognition takes place. Normally this task is performed by pattern-matching techniques such as image cross-correlation, neural networks, or support vector machines since the possible set of road signs is limited and well defined. Figure illustrates the concept of a speeding warning system based on speed sign detection. The challenge for research work in this area lies in the robustness of detection and the reliability of classification of signs.

Traffic-Light Detection

Color and pattern matching are also the key techniques used for the detection of traffic lights. Although the detection of traffic lights is not overly complex, this application hides one further aspect that makes vehicular applications difficult: besides the correct localization and recognition of a signal, special care has to be taken in checking the signal position and orientation on the road/lane since that signal may not be addressed to the current vehicle. This is particularly true in downtown intersections at which many traffic lights are visible at the same time; in this case the vehicle must have the capability to select the correct traffic signal that must be obeyed. Some experiments have been undertaken with active traffic signals, able to emit the status of the traffic light using radiofrequencies. This involves additional infrastructure; at this stage vision seems to be the only simple viable solution.

Visibility Assessment

One of the key challenges is detection of fog. The meteorological visibility distance is defined by the International Commission on Illumination (CIE) as the distance beyond which a black object of an appropriate size is perceived with a contrast of less than 5%. Different techniques for measuring this parameter – and thus detect foggy conditions – have been implemented. Although many of the methods use vision, there are also efficient alternatives – generally used in fixed locations such as airports and traffic monitoring stations – based on the use of multiple scattering lidars. The main challenge of using vision to estimate visibility is that a moving vehicle generally cannot rely on a specific reference point/object/signal at a specific distance.

Vehicle Detection

The detection of vehicles has been addressed using a large variety of sensor technologies, ranging from vision to lidars, from radars to sonars.

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Despite being different in shape and color, vehicles share the same characteristics and feature a large size and reflective material. The position of vehicles is predictable once a rough indication of the road/lane position is available. Vehicles, in fact, can be successfully detected by many different sensors independently. Figure shows a vision-based vehicle detection system. Nevertheless, although the solution to this problem seems straightforward, each sensor has its own domain of application and its own challenges. Vision is generally powerful, but may fail in low visibility and bad-illumination scenarios (night or tunnels) or in heavy traffic conditions when vehicles may occlude each other. Vision in the infrared domain (thermal imaging) is able to detect vehicles with a high confidence since vehicle tires and mufflers generally exhibit high temperatures and are therefore easily detected in the image.

However, parked vehicles, trailers, and even vehicles which have just started to move are colder than running vehicles and therefore less visible. Lidars are generally robust, but have decreased sensitivity in adverse weather conditions. Radars, while cheap, can suffer from bias in lateral measurements due to the presence of other nearby re flecting objects. Finally sonars are applicable only for very short distances. The research challenge is to implement multisensor fusion robustly. A common approach is to fuse vision with radar.

Pedestrian Detection

The detection of vulnerable road users (pedestrians and bicycles) is one of the most difficult tasks for intelligent vehicles. The appearance of a pedestrian is challenging: a pedestrian shape can change greatly within a few tens of milliseconds, there are no clear invariants in color, texture, or size, and no assumptions can be made about posture, speed, or the visibility of parts of the human body such as the head. Machine learning methods have been successfully applied to this problem. Greater reliability and reduction in false alarms have been achieved through the incorporation of stereo vision. However, the detection of vulnerable road users is one of the most relevant research topics worldwide since a great number of benefits – including insurance reductions –may be achieved once a fully functional pedestrian detector is available on cars.

Countermeasures may be activated to reduce the consequences of vehicle–pedestrian accidents, such as the firing of external airbags or the opening of the hood to lessen the impact of a head-on collision. Currently, with all possible technologies under evaluation, no solution seems to offer reliable detection in every scenario: radars are not able to detect pedestrians reliably in crowded scenarios, while vision has the many drawbacks listed above. Even thermal imaging, which –although still very expensive – is generally believed to be one of the most promising technologies, fails in some situations, such as hot summer days and, in general, in high-temperature environments.

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