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INSPIRATION PAPER

Technologies for the next level of automated driving

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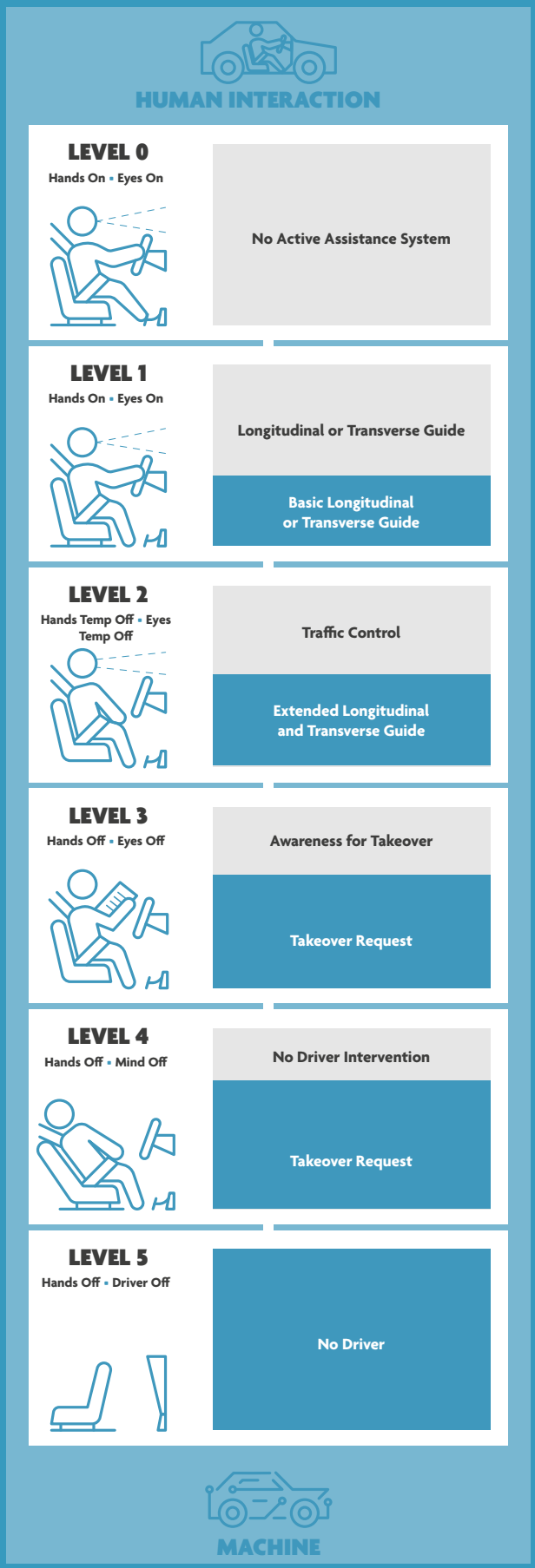
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Road safety, a worldwide strategic priority



Approximately **1.3 million people die each year** as a result of road traffic crashes, while another 20 to 50 million people suffer non-fatal injuries.

The United Nations General Assembly has set the ambitious goal to half this number of deaths by 2030. The EU is even more ambitious, aiming towards a **near-zero fatality rate by 2050**.



Human error – think of speeding, fatigue, and drunk or distracted driving – is at the basis of 94 to 96 percent of all motor vehicle accidents.

Therefore, all eyes are on technologies that can minimize or prevent these human driving errors. With the ultimate goal being a full autonomous driving car.

Meanwhile, cars are being equipped with ever more sensors. Think for example of advanced driver assistance systems (ADAS):

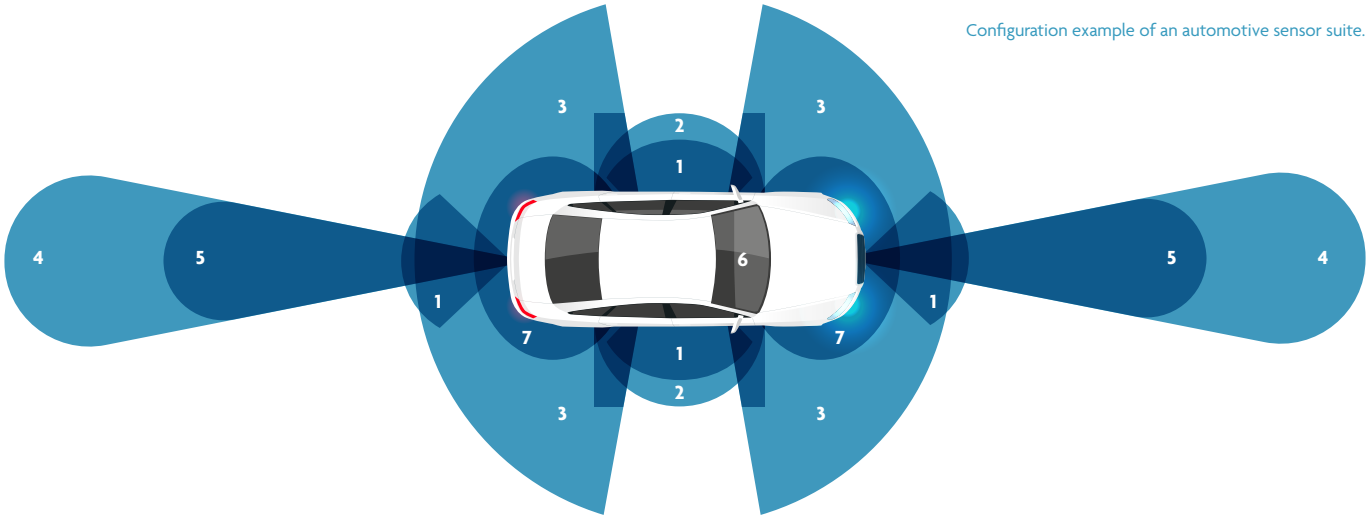
- Adaptive cruise control
- Lane keeping assistance
- Blind spot warning
- Pedestrian detection
- Automatic emergency braking
- Forward collision warning

The main shortcomings of ADAS today are the accuracy of the sensors, the fact that the sensors have no real 'understanding' of the vehicle's surroundings, and the action is still to be taken by a human driver.

For the next generation of ADAS several technologies will be key: camera, radar and lidar systems, sensor fusion and – in the far future - artificial intelligence (AI). Each technology gathers unique information on the vehicle's surroundings: road signs, pedestrians, cyclists, oncoming cars etc. and has its own specific pros & cons.

Technologies for the next level of automated driving

Configuration example of an automotive sensor suite.



1 **CAMERAS** 2 **RADARS UP TO 30 M** 3 **RADARS UP TO 50 M** 4 **RADARS UP TO 250 M** 5 **LIDAR** 6 **GPS** 7 **ULTRASOUND**

1 CAMERA SYSTEMS

Using visual input to monitor a vehicle's surroundings.

- ⊕ Proven, reliable and widespread technology
- ⊕ Comes with mature (pixel-based) image processing algorithms

- ⊖ Suffering from poor lighting/ weather conditions (heavy rain, fog, twilight, facing the sun)
- ⊖ 3D imaging requires use of multiple cameras, in combination with simultaneous localization & mapping (SLAM) algorithms

2 - 3 - 4 RADAR SYSTEMS

Detecting and calculating the range, velocity and position of approaching objects.

- ⊕ Robust (indifferent to lighting, only mildly affected by weather conditions)
- ⊕ Becoming cost-efficient (available as a silicon-based chip technology)
- ⊕ Working across all lighting (and most weather) conditions
- ⊕ Long range (up to 300 m)
- ⊕ Instant measurement of target speed and direction
- ⊕ Radar antennae can be integrated in prescribed car shapes
- ⊕ (Planned) support for 3D imaging

- ⊖ Limited angular resolution

5 LIDAR SYSTEMS

Using a laser scanner to generate a 3D image of a car's environment and to provide the exact location of objects in its vicinity.

- ⊕ Excellent range (up to 150 m)
- ⊕ Excellent resolution
- ⊕ Best technology option to create detailed 3D maps of the environment

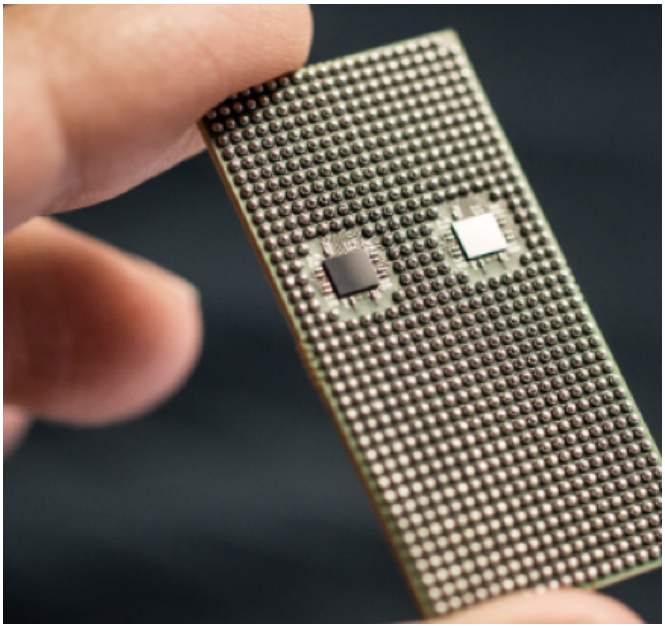
- ⊖ Expensive
- ⊖ Difficult to calibrate
- ⊖ Bulky, requiring external mounting
- ⊖ Limited performance in case of bad weather conditions (rain, snow, fog, dust)
- ⊖ Large amount of data to be processed
- ⊖ Full silicon-based solution not yet available

Camera systems: pros & cons and future developments

Today's camera systems, based on the visible light spectrum, are **reliable and mature** but cannot be used at night or in **harsh weather** conditions.

New developments focus on the **short-wave infrared spectrum (SWIR)**, thus supporting longer-range scanning and visibility in mist, smoke, and water vapor.

Up until recently, SWIR image sensors were based on III-V materials and were very expensive. A new approach is now available: stacking multiple nanometer-thick layers on top of a silicon CMOS readout circuit. These layers comprise one SWIR-sensitive layer, making up a **silicon-based SWIR image sensor** that is much more cost-effective than the III-V solutions from the past.



Radar systems: pros & cons and future developments

Radar systems use radio waves to scan the road across the horizontal plane, thereby identifying an object's distance, direction and relative velocity. They work well in all lighting and weather conditions.

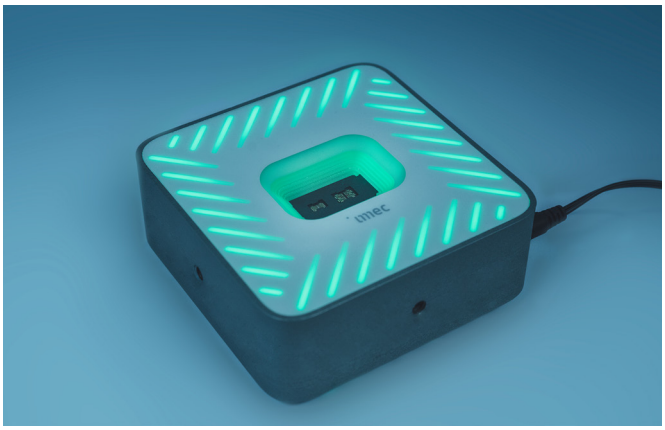
The evolution of radar sensors will focus on:

- Smaller size
- Lower energy consumption
- Lower price
- Higher (angular) resolution
- Higher precision
- 4D: also collecting 'vertical' information such as the height of objects

From a technology point of view, this means that current 77/79GHz radar systems will be complemented by **140GHz radars**. The advantage of using a higher signal frequency is that the radar can be made smaller, more precise and with a higher angular resolution. Ultimately, radars will become so good that they will be able to distinguish a person on foot from a cyclist, and perhaps even be able to recognize individuals by their gait. That way, a car would be able to identify its driver and allow access to the vehicle based on the radar information.

Radars will evolve towards **CMOS** based chips, making them more compact and low-cost. Today's radars are based mainly on SiGe technology. The performance of analog blocks can be improved by incorporating signal-processing and algorithms in the system.

Achieving higher angle accuracy in a radar unit is possible by implementing **more antennas**. Typical radar systems use an array of antenna elements, each with a wide beam. With '**digital beamforming**', these beams can be digitally combined to create an array of narrow beams. This is done to improve the resolution. For 4D radar, the antenna elements are arranged both horizontally and vertically.



imec's 140GHz radar

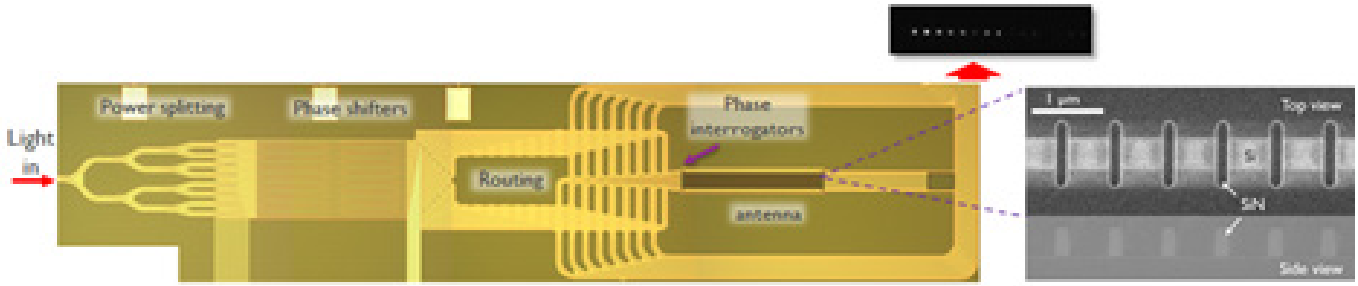
Lidar systems: pros & cons and future developments

Laser-based lidar systems can scan the car's environment up to 300m and create not only **very detailed 3D maps but also give information about speed and direction**. In mechanical lidars, a laser scanner moves the laser (light) around while a detector captures the light that bounces back.

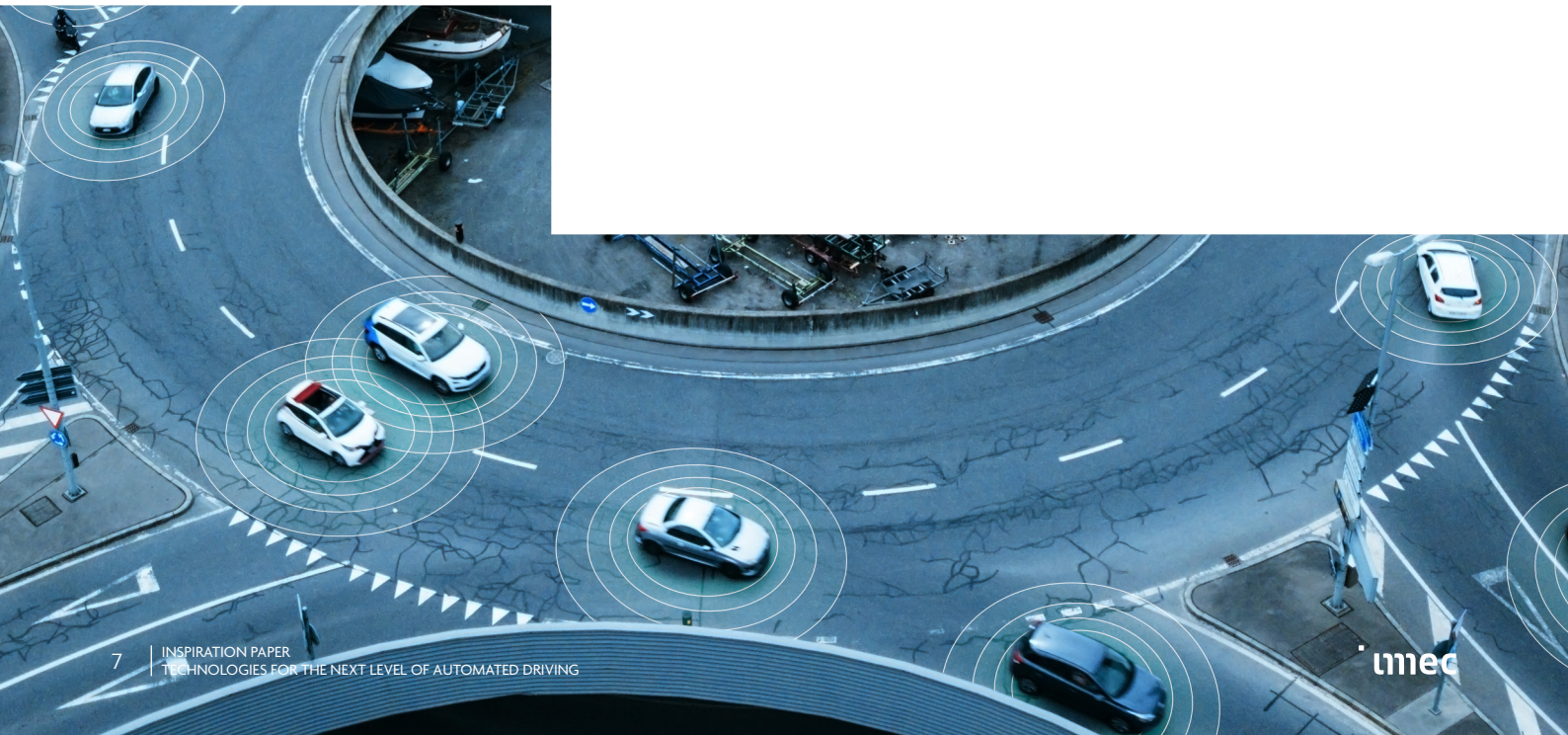
A downside of these systems is their **bulkiness and price**. Also, its moving parts require a complex calibration and make them vulnerable to vibrations and shocks.

Future systems will rely on **solid-state lidar systems**, built entirely on a silicon chip, and without any moving parts. This would result in more robust, smaller and cheaper lidars. R&D focuses on the **integration of the laser** on the chip, detector on the same chip and also optical beamforming parts.

Imec has developed a self-calibrating **optical beamformer**. It relies on a waveguide that passes through phase shifters to reach an array of on-chip antennas. Through controlled phase modulation, these antennas can transmit signals in a controlled direction. Both **silicon and silicon nitride** are used to make the optical components: Si for the phase shifters (ensuring low-power operation) and on-chip photodetectors and SiN for the waveguide and antennas (ensuring low-loss, high-power handling). When processing at the nanometer scale, there will always be slight process and material-related deviations, which in turn cause deviations in the phase modulation. Therefore, calibration is essential. Imec has embedded on-chip interferometers in between the phase shifters and the antennas to perform an on-chip self-calibration.



Left: optical beamforming chip fabricated in the imec 200mm photonic pilot line, based on SiN on Si technology for LiDAR application. Right: top view of the antenna elements.



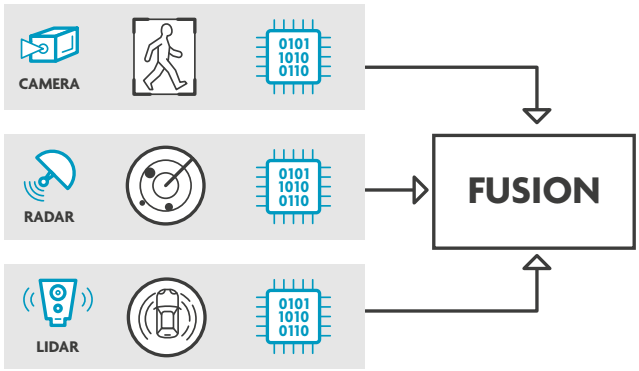
Sensor fusion

With sensor fusion, the **data from multiple sensor**s are merged and analysed to create a reliable and detailed 3D image of the world surrounding the car. When driving in poor lighting conditions, for instance, a vehicle's regular **cameras** only see what is being illuminated by the car's headlights. In such circumstances, it would be great to have the camera switch to the **infrared (IR) or near-infrared (NIR)** bands. And to complement with **radar and lidar data**. Also, sensor fusion allows the validation of various sensors' data to achieve the right level of precision and confidence and to avoid a false-positive warning.

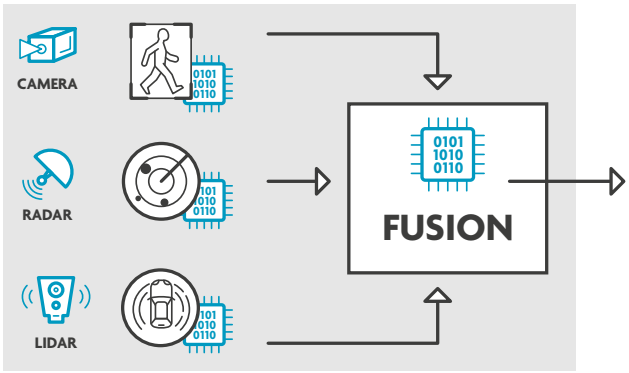
Today's most popular type of sensor fusion is so-called **'late' fusion**. It implies that sensor data are fused after each individual sensor has performed object detection and has taken its own 'decisions'. The main drawback is that each sensor throws away all the data it deems irrelevant.

'Early' fusion on the other hand builds on all low-level data from every sensor. It requires high amounts of computing power and massive bandwidths and requires all equipment to be procured with the same vendor.

In response to these drawbacks, researchers have developed **'cooperative' sensor fusion**. It features an extra feedback loop, with different sensors exchanging low-level or middle-level information to influence each other's detection processing. If a car's radar system suddenly experiences a higher degree of reflection, for instance, the threshold of the on-board cameras will automatically be adjusted to compensate for this – thus improving overall tracking performance.



Late fusion: sensor data are fused after each individual sensor has performed object detection and has drawn its own 'conclusions'. Source: imec.



Early fusion builds on all low-level data from every sensor – and combines those in one intelligent system that sees everything. Source: imec.



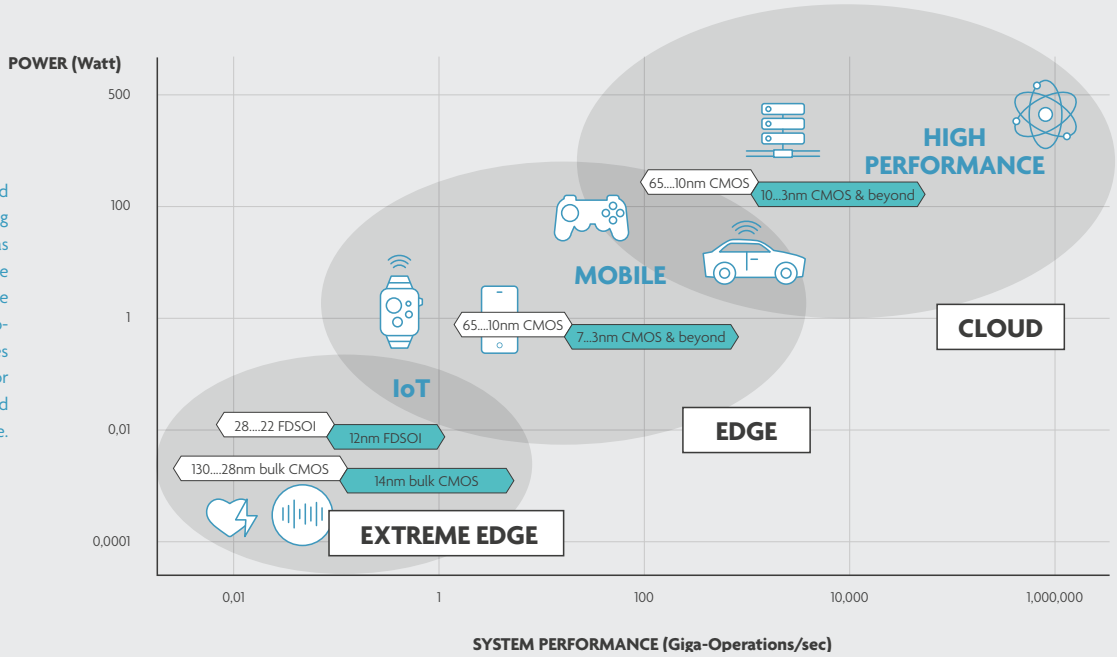
Future vision | **AI for autonomous driving**

Building smart cars that can assess – and adequately react to – the intentions of other road users will require a clever combination of increasingly powerful and versatile sensors. Moreover, they will need to be complemented with an AI engine that is capable of **learning and – ultimately – reasoning**.

Today, lots of (machine) intelligence resides in the cloud – where virtually unlimited computing power is available. The emergence of applications such as next-generation ADAS and autonomous driving will put an **end to cloud AI's dominant position**. A concept such as cooperative sensor fusion requires AI solutions to function autonomously – in a distributed way and running at the (extreme) edge.

Automotive sensors will need to be equipped with **embedded (edge) computing power** to react to dangerous situations much more quickly, without having to send each piece of data to the cloud and back. The work on memory chips will therefore play an important role as well. Today, experiments are ongoing with various form factors, from GPUs and FPGAs to ASICs.

Edge AI is characterized by local processing, using a microprocessor that has been decoupled from the sensing hardware. Extreme edge AI features local processing as well – yet makes use of a microprocessor that has been embedded on the sensing device. Source: imec.



Future vision | **mobility as a service**

Equipping a vehicle with next-generation ADAS comes with a considerable price tag. Therefore, it will probably be linked to a whole new business case, i.e. mobility-as-a-service. People will no longer acquire their own vehicles but will rather opt for a (subscription-based) mobility-as-a-service package, with the right type of (self-driving)car picking them up whenever they need one. In such a scenario, the cost equation of building and maintaining cars will change completely: the investment will be spread over a large number of subscribers, meaning that the cost of innovation might no longer be a prohibitive factor.



Conclusion

Current ADAS systems suffer from substantial shortcomings: their sensors lack accuracy, they work in silos instead of in concert, and they only provide input, leaving it to the driver to take action.

This paper focused on some domains of improvements and future trends:

- Sensor technology – cameras, radars and lidars – with its pros and cons and how they will evolve
- Sensor fusion, with focus on the cooperative approach of sensor fusion
- The role of AI in future automotive systems and the role of embedded 'edge' computing in sensors
- How these new technological developments come with a new business case: mobility as a service.



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