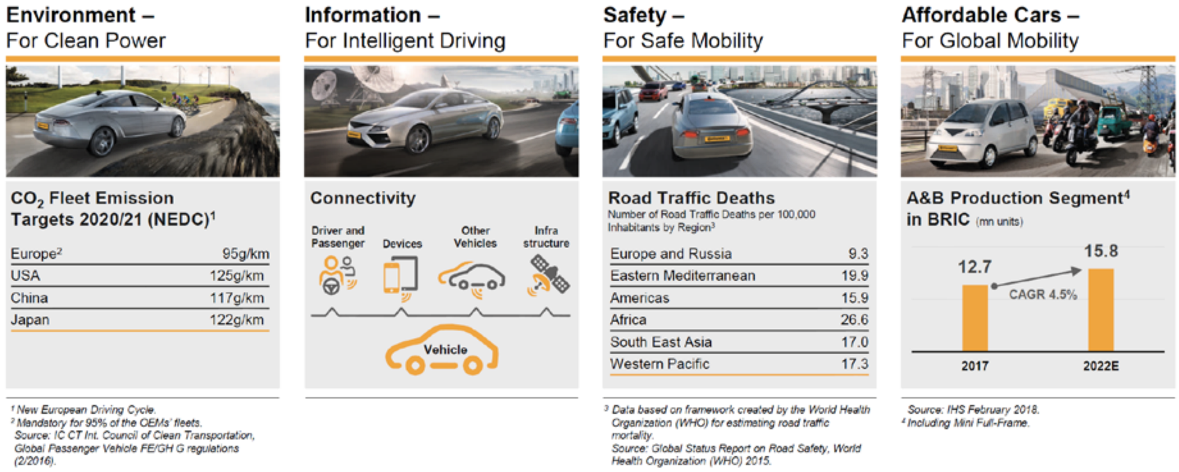
AUTOMOTIVE MARKET DRIVER

1. INTRODUCTION

The four megatrends characterizing 21st century automotive industry are: (i) *environment features* and clean power, (ii) *information processing*, especially enabling intelligent driving or self-driven cars, (iii) *safety* in car mobility, and (iv) *affordable cars*, capable to enable a global mobility.

On top of these trends, European road transport sector[1] has even more ambitious quantitative targets: 50% more efficient car fleet by 2030, CO_2 emissions reduced significantly (by 80% in cars, by 40% in trucks, with new fuels entering the market), mobility to be 50% more reliable and traffic safety improved significantly (with the target of reducing road accidents by around 60%).



CO_2 Fleet Emission Targets 2020/21 (NEDC)[1]

Europe[2]	95g/km
USA	125g/km
China	117g/km
Japan	122g/km

[1] New European Driving Cycle.
[2] Mandatory for 95% of the OEMs' fleets.
Source: IC CT Int. Council of Clean Transportation, Global Passenger Vehicle FE/GH G regulations (2/2016).

Road Traffic Deaths
Number of Road Traffic Deaths per 100,000 Inhabitants by Region[3]

Europe and Russia	9.3
Eastern Mediterranean	19.9
Americas	15.9
Africa	26.6
South East Asia	17.0
Western Pacific	17.3

[3] Data based on framework created by the World Health Organization (WHO) for estimating road traffic mortality.
Source: Global Status Report on Road Safety, World Health Organization (WHO) 2015.

Source: IHS February 2018.
[4] Including Mini Full-Frame.

Figure 1: *Four megatrends of the automotive industry, as highlighted by Continental[2] based on various sources cited in the figure.*

In this context some of the more general growth drivers for this market are: (i) increasing vehicle production, (ii) increasing electronic content per vehicle, serving a large variety of functions, and (iii) growing demand for advanced vehicle safety and comfort systems. Another driver of future car business is the so-called *mobility-as-a-service* with providers offering car sharing, intelligent driving, electrical vehicles, etc. A paradigm shift to *mobility-as-a-service*, along with new entrants, will force traditional car manufacturers to compete on multiple fronts and/or forge new partnerships with mobility providers (Uber), technology giants (Apple, Google), and specialty OEMs (Tesla).

The future of the global automotive semiconductor market looks very bright with growing opportunities for passenger cars, commercial, and electric vehicles. The global automotive semiconductor market is expected to reach $67.5 billion by 2023 with a CAGR of 13.1% from 2018 to 2023[3]. The average electronics content continues to increase per car from $312 in 2013 to $460 in 2022, which results to a healthy 6.7% CAGR from 2017 to 2024. Among the various categories of semiconductor device categories, microcontroller ICs will grow the fastest over the next five years driven by automated driving and by an increased number of sensors, followed by optical semiconductors, memory ICs, and analog ICs. Particularly, it is considered that at short to mid-term, the adoption of sensors owing to the development and adoption of ADAS technologies will boost revenues in the global semiconductors for automotive market.

Emerging trends, which could have a direct impact on the dynamics of the automotive semiconductor industry, include the development of new electronic chips for radar sensors, the larger deployment of

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[1] European Roadmap Safe Road Transport, ERTRAC, June 2011 (www.ertrac.org).
[2] 2017 Fact Book, Continental – The Future in Motion. Investor Presentation.
[3] https://www.lucintel.com/

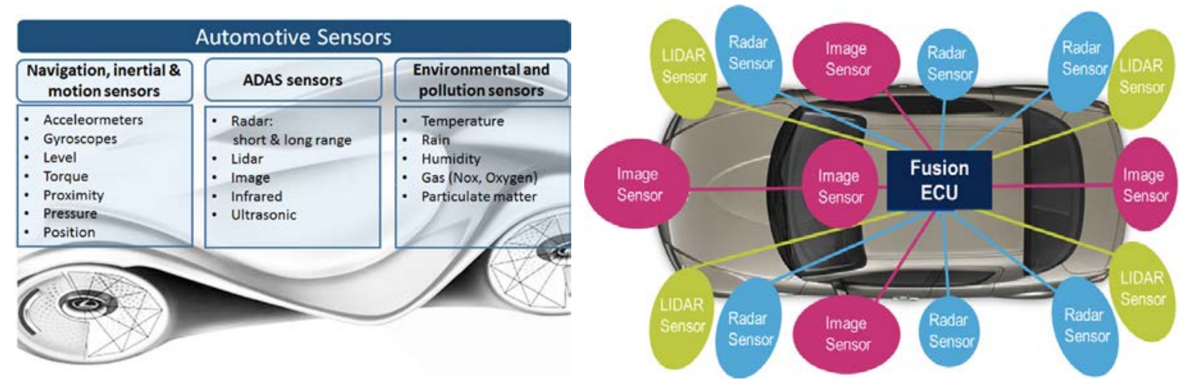
high-efficiency power semiconductors, and new categories of smart sensors dealing with the driver- and passenger-car interactions for more safety, comfort and services on-board. Simultaneously, the car is considered more and more to operate as an Edge Artificial Intelligence (AI) Device, with the electronic system operating independently of the cloud and even covering tasks of (health)care for the passengers.

This chapter has the goal to address automotive as a driver for future electronic technologies and is aligned in great part with NEREID's European automotive roadmap for smart sensory systems, which considers the car electronic technology as a part of Edge Internet of Things (IoT), with some specific advanced demands in terms of reliability and robustness:

(I) Sensors for car system performance, navigation, inertial and motion sensors;
(II) Advanced Driver Assistance System (ADAS) sensory systems: radars (for short and long range), Lidar, image, infrared and ultrasonic sensors;
(III) Smart sensors for environmental monitoring, and
(IV) Smart sensors for monitoring driver's condition and interaction with the car: health, alertness and fatigue, advanced safety and comfort systems.

1.1. CURRENT STATE OF TECHNOLOGY AND RESEARCH

Automotive smart sensors are widely used in four key applications: chassis, powertrains, body electronics and safety and security. Powertrain is the most popular application as sensors play an imperative role in improving fuel efficiency and reducing emission. Major automotive smart sensor categories are illustrated in Fig. 2, and include[4]: (I) navigation, inertial and motion sensors, (ii) ADAS sensors, and, (iii) environmental and pollution sensors.



Automotive Sensors

Navigation, inertial & motion sensors	ADAS sensors	Environmental and pollution sensors
Acceleormeters Gyroscopes Level Torque Proximity Pressure Position	Radar: short & long range Lidar Image Infrared Ultrasonic	Temperature Rain Humidity Gas (Nox, Oxygen) Particulate matter

(a) (b)

Figure 2: *(a) Automotive sensors categorization, (b) placement and fusion of various categories of ADAS sensors.*

In general, the design and fabrication of automotive sensors is very challenging. The harsh automotive environment puts stringent reliability requirements[5], as they are exposed to dirt, vibration, large temperature operating range (from -40°C to 200°C) and large supply voltage variations. Simultaneously, automotive sensors are under continuous cost and volume pressure, requiring smarter solutions that occupy less physical space. Today, the majority of automotive sensors are expected to be smart and have a digital output. Therefore, they require analog-to-digital converters, which are followed by some digital signal processing. Overall, the requirements for robustness, low-cost, accuracy and digital output makes the design of automotive smart sensors extremely challenging.

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[4] J. Ahopelto et al., Nanoelectronics Roadmap for Europe: From Nanodevices and Innovative Materials to System Integration, Solid State Electronics, 2019.

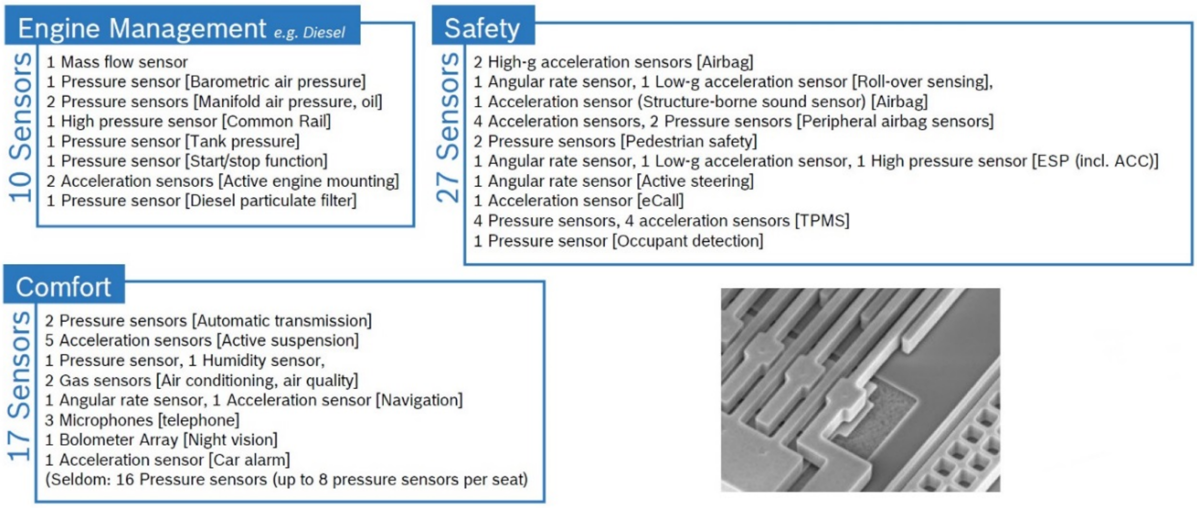
[5] Robert van Veldhoven et al., Sensors for automotive applications: Challenges and solutions, 5th IEEE International Workshop on Advances in Sensors and Interfaces IWASI, 2013.

An example of successful state-of-the-art sensor technology for automotive is Micro-Electro-Mechanical-Systems (MEMS), deployed today in a many applications. According to Bosch, the automotive MEMS sensors should fulfill a very demanding set of requirements:

- High functional requirements:
    - ➢ high accuracy, self-test, advanced safety concepts
- High reliability / quality: 15 years, < 1 ppm
    - ➢ extreme environmental conditions (-40 to +120°C)
- Additional 15 years of aftermarket supply
- Product life cycle up to 10 years and product development of 3 years

Today there are more than 50 types of state of the art MEMS sensors for engine management, safety and comfort functions in automotive applications, as per Fig. 3, which demonstrate the maturity of MEMS technology and its particular suitability for the extreme requirements made by the automotive industry. More breakthroughs are expected in terms of wafer level CMOS-MEMS integration and aggregation of multiple sensors in a single system/product.

MEMS devices primarily drive the automotive sensor market. Accelerometer and gyroscope markets are projected to reach $5 billion by 2022[6]. Parking sensor systems based on proximity and displacement sensors hold at present the maximum revenue share. Motion sensors are used in fully autonomous vehicles, in air bags and voice-controlled equipment and are expected to witness future growth opportunities. On the other hand, accelerometer and gyroscope have become an integral part of all consumer electronic devices, although the MEMS market in mobile/portable applications grows more slowly[6].



Engine Management *e.g. Diesel*

10 Sensors

1 Mass flow sensor
1 Pressure sensor [Barometric air pressure]
2 Pressure sensors [Manifold air pressure, oil]
1 High pressure sensor [Common Rail]
1 Pressure sensor [Tank pressure]
1 Pressure sensor [Start/stop function]
2 Acceleration sensors [Active engine mounting]
1 Pressure sensor [Diesel particulate filter]

Safety

27 Sensors

2 High-g acceleration sensors [Airbag]
1 Angular rate sensor, 1 Low-g acceleration sensor [Roll-over sensing],
1 Acceleration sensor (Structure-borne sound sensor) [Airbag]
4 Acceleration sensors, 2 Pressure sensors [Peripheral airbag sensors]
2 Pressure sensors [Pedestrian safety]
1 Angular rate sensor, 1 Low-g acceleration sensor, 1 High pressure sensor [ESP (incl. ACC)]
1 Angular rate sensor [Active steering]
1 Acceleration sensor [eCall]
4 Pressure sensors, 4 acceleration sensors [TPMS]
1 Pressure sensor [Occupant detection]

Comfort

17 Sensors

2 Pressure sensors [Automatic transmission]
5 Acceleration sensors [Active suspension]
1 Pressure sensor, 1 Humidity sensor,
2 Gas sensors [Air conditioning, air quality]
1 Angular rate sensor, 1 Acceleration sensor [Navigation]
3 Microphones [telephone]
1 Bolometer Array [Night vision]
1 Acceleration sensor [Car alarm]
(Seldom: 16 Pressure sensors (up to 8 pressure sensors per seat)

Figure 3: *MEMS sensor solutions in automotive (50 types of industrial MEMS sensors), after Bosch[7].*

The projections made by the automotive industry suggest that advanced cars will have in medium term more than 100 sensors each, by a multitude of technologies. New challenges for automotive sensors are related to application-specific data fusion at low power, from various types of sensors in the categories of Fig. 2 (a). Enabling manufacturing technologies include 3D heterogeneous integration and advanced (miniaturized) packaging for few mm^3 sensors operation in harsh environments.

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[6] Accelerometer and Gyroscope Market and Industry Vertical (Consumer Electronics, Automotive, Aerospace & Defense, Industrial, and Healthcare) - Global Opportunity Analysis and Industry Forecast, 2014 – 2022, February 2017. www.alliedmarketresearch.com.

[7] Udo Martin Gomez, Bosch MEMS sensors: enabler for IoT. https://www.vde-wuerttemberg.de/resource/blob/1626698/6a4a186d3efd4977a078c79af13ffc4d/vortragsfolien---pdf-data.pdf

1.2 DRIVERS AND SUPPORTING ELECTRONIC TECHNOLOGIES

One of the most important technology drivers is the **autonomous driving**. It is therefore useful to first summarize the different classifications and definitions of the levels of driving, from driver only to full automation, as presented in Table 1. These classifications are the current adopted standards by the international engineering and automotive industry associations in USA and Europe.

Table 1: Classification (standards) of levels of autonomous driving

Level	**Definition, functions expected**
Level 0	Driver only: the human driver controls everything independently, steering, throttle, brakes, etc.
Level 1	Assisted driving: assistance systems help during vehicle operation (Cruise Control, ACC).
Level 2	Partial automation: the operator must monitor the system at all times. At least one system, such as cruise control and lane centering, is fully automated.
Level 3:	Conditional automation: the operator monitors the system and can intervene when necessary. Safety-critical functions, under certain circumstances, are shifted to the vehicle.
Level 4:	High automation: there is no monitoring by the driver required. Vehicles are designed to operate safety-critical functions and monitor road conditions for an entire trip. However, the functions do not cover all every driving scenario and are limited to the operational design of the vehicle.
Level 5:	Full automation: operator-free driving.

The question for future technology roadmapping is which sensors are required for autonomous driving from Levels 1 to 5? For instance, the categories of ADAS sensors of Fig. 2 are directly answering this question, with present focus on three main groups of sensor systems: camera-, radar-, and LIDAR-based systems. Today the state of the art in the field is roughly at Level 3.

Driver assistance systems that enable autonomous driving from Level 3 onwards will need innovations and developments at least three types of sensor systems: camera, radar, and LiDAR systems. The vision is that several of each type of sensor will operate at various locations on the vehicle and data fusion and local artificial intelligence will enable the decision process and the car driving. Although many semiconductor technologies and development of the camera and radar sensors are already available today, it is estimated that the development of the LiDAR system will act as one driver and pose the bigger and most dynamic challenges from electronic design, technology and commercial perspectives[8].

2. TRENDS, CHALLENGES AND TECHNOLOGY REQUIREMENTS

Mckinsey predicts[9] that automotive revenue will significantly increase and diversify toward *on-demand mobility* services and *data-driven* services. This could create up to 30 % more in additional revenue potential in 2030, compared with about $5.2 trillion from traditional car sales. Another progressive scenario foresees fully autonomous cars accounting for up to 15% of passenger vehicles sold worldwide in 2030. Meanwhile, ADAS will play a crucial role in preparing regulators, consumers, and corporations for the medium-term reality of cars taking over control from drivers.

In this roadmap, we identified two major trends in automotive that that are triggering combined device and systems challenges and will certainly involve specific technology requirements, as detailed in the following trends.

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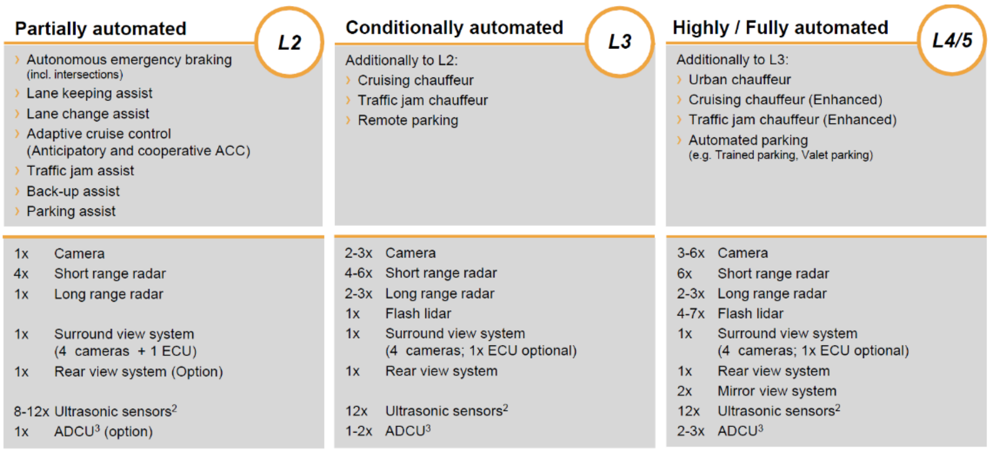
[8] G. Rudolph, U. Voelzke, Three Sensor Types Drive Autonomous Vehicles, 2017. https://www.sensorsmag.com/components/three-sensor-types-drive-autonomous-vehicles

[9] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry

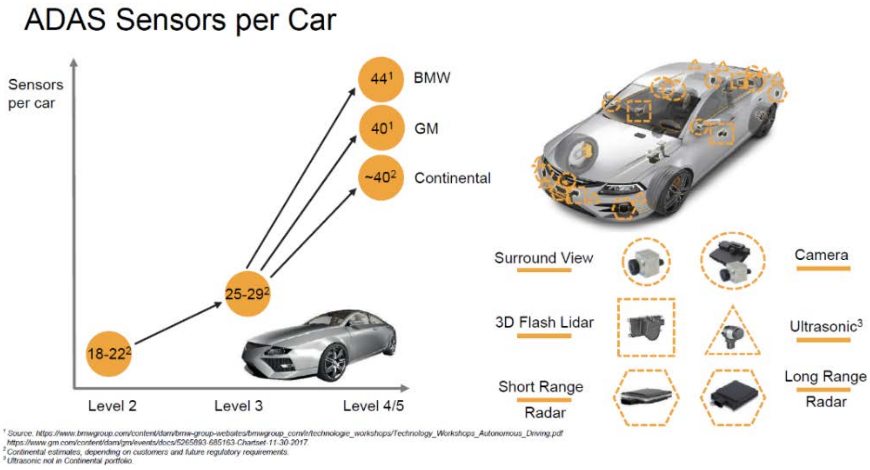
<u>Future Trend 1:</u> From automated to fully autonomous driving

The first clear global trend is related to the gradual evolution in increasing the automation driving level. Regarding technological readiness, both big tech players and start-ups will have an important role in the development of future autonomous vehicles. However, regulation and consumer acceptance barriers should be addressed first and/or in parallel with the developments and, once these barriers lowered, autonomous vehicles will certainly offer high value for consumers, enabling work while commuting or the convenience of using social media while traveling. When increasing the level of autonomy, from partially automated (level L2) to fully automated (level L5) driving, the number of ADAS electronic sensor systems increases, reaching in all manufacturers visions more than 40 ADAS sensors per car (Fig. 4), with a complex software and increased local computing power (equivalent to up to 10 high performance computers).



Partially automated L2	Conditionally automated L3	Highly / Fully automated L4/5
› Autonomous emergency braking (incl. intersections) › Lane keeping assist › Lane change assist › Adaptive cruise control (Anticipatory and cooperative ACC) › Traffic jam assist › Back-up assist › Parking assist	Additionally to L2: › Cruising chauffeur › Traffic jam chauffeur › Remote parking	Additionally to L3: › Urban chauffeur › Cruising chauffeur (Enhanced) › Traffic jam chauffeur (Enhanced) › Automated parking (e.g. Trained parking, Valet parking)
1x Camera 4x Short range radar 1x Long range radar 1x Surround view system (4 cameras + 1 ECU) 1x Rear view system (Option) 8-12x Ultrasonic sensors[2] 1x ADCU[3] (option)	2-3x Camera 4-6x Short range radar 2-3x Long range radar 1x Flash lidar 1x Surround view system (4 cameras; 1x ECU optional) 1x Rear view system 12x Ultrasonic sensors[2] 1-2x ADCU[3]	3-6x Camera 6x Short range radar 2-3x Long range radar 4-7x Flash lidar 1x Surround view system (4 cameras; 1x ECU optional) 1x Rear view system 2x Mirror view system 12x Ultrasonic sensors[2] 2-3x ADCU[3]

(a)



[1] Source: https://www.bmwgroup.com/content/dam/bmw-group-websites/bmwgroup_com/ir/technologie_workshops/Technology_Workshops_Autonomous_Driving.pdf https://www.gm.com/content/dam/gm/events/docs/5265893-685163-Chartset-11-30-2017.

[2] Continental estimates, depending on customers and future regulatory requirements.

[3] Ultrasonic not in Continental portfolio.

(b)

Figure 4: *(a) Automated ADAS features and corresponding systems and sensors for partially automated, conditionally automated and fully automated cars. (b) Number of ADAS sensors per car, including surround view, LIDARs and Radars, after Continental.*

The qualitative and quantitative technology requirements for the field of ADAS at different time horizons are roadmapped in details in Table 2, where the meaning of the symbols/acronyms used is: *** = critical, high priority or probable to come first, **= less critical, middle priority or less probable to come first, *= not critical, lower priority or low probability, R&D: research and development, DP: Demonstration and Prototype, RS: Regulations and Standards.

Time Horizon	2023	2026	2029	2033
Figures of merit (FoMs) or evolution				
ADAS domain control	*Feet-off*	*Hands-off*	*Eyes-off*	*Mind-off*
(3D) Image Sensors				
Sensitivity			**	***
Price	5$ to 10$	5$ to 10$	5$ to 10$	5$ to 10$
Number of sensors/car	5	6	8	10
Autofocus (AF)			No AF in car	
Optical Image Stabilization (OIS)	No OIS in car		Market introduction	
Dual camera technology	Standard function		Replaced by single camera with Lidar	
Time of flight (ToF)	**			***
Structure light (SL)	Market intro. (in-cabin)		Standard (in-cabin)	
3D Sensing cameras/4D	*		**	
Saturation signal	*		**	
Dark signal	*		**	
Resolution (pixels)	**		***	
Pixel size/number	~3.5um 2Mp to 8Mp		~2 to 2.5um 4Mp to 16Mp	
Read noise	**		**	
Detection range (m)	1-100 m	1-150 m	1-200 m	1-250 m
Field of view	60 °	90 °	120 °	180 °
Chip/image size	3.5 um/ 2 to 8 Mp	3 um/ 2 to 10Mp	2.5 um/ 3 to 12 Mp	2 um/ 4 to 16Mp
LiDAR				
Resolution	**			***
Price	< 250 $	< 200 $	< 150 $	< 100 $
Number of sensors/car	1	1	2	2-4
Power consumption				
Detection range/range accuracy	1-100 m / < 2 cm	1-150 m / < 1 cm	1-200m/< 0.5cm	1-250m/<0.1 cm
Scanning angle/angular accuracy	270 ° /5-10 °	300 ° /4-8 °	330 ° /3-7 °	360° / 2-5°
Scanning time	20 Hz	50 Hz	75 Hz	100 Hz
Thermal Infrared Sensors				
Camera resolution	**			***
Price	< 500$	< 400$	< 300$	< 250$
Number of sensors/car	1	1	2	3
Power consumption				
Pixel pitch/number			100 um/ 82 x 62	
Detection range (NIR/LWIR)	150/ 400 m	160 / 425 m	180/475 m	200/ 500 m
NETD (f/1; 300k; 50 Hz)				
Frame rate	***		***	***
Size/weight	**		***	***
Common features				
Failsafe			Mandatory	Mandatory
Robustness: operating T (-40°C, 105°C)			Mandatory	Mandatory
Reliability/lifetime	10 years	12 years	14 years	>15 years

Future Trend 2: Holistic Connectivity—the car as Edge Artificial Intelligence Internet of Thing System

The trends and related implementation challenges in future intelligent mobility are about:

- *Informing well*: comfort, convenience, ergonomics, intuitive;
- *Connecting at any time, everywhere*: holistic wirelessly connectivity with added value mobility services, and
- *Low cost and ease-of-use*: system integration of all functions in superior systems.

Many analysts and car manufacturers foresee the holistic connectivity, in which the car is practically an Edge AI IoT object as one of the most important future trends in automotive. In fact, a well-designed AI autonomous car should be able to mix the Edge (localized) processing and the Cloud processing, (see Fig. 5.). While sensory data is processed in real-time and driving actions are taken, other data is being sent up to the cloud. The cloud processes such data, looking for complex long-term patterns, and eventually sends down to the autonomous car other types of information for less-sensitive parts of the decision process. In the future, the Edge AI part of such self-driving cars will be running on up to 10 high-performance processors; will include data from more than 200 sensors, and more than 150 actuators will be involved in the process. Such vision will involve sensor data collection at the edge, data fusion at the edge, virtual dynamic world/environmental models at the edge, and action planning and car-control commands determined at the edge supporting the execution of safe autonomous driving. Therefore, the future of autonomous driving is related to increasing the roles of many traditional and new semiconductor electronic technologies and their integration with AI functions.

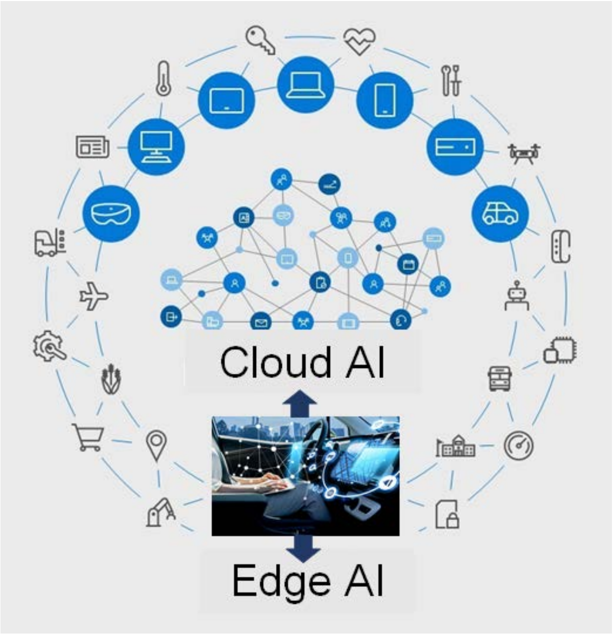


Figure 5: *Autonomous car driving as a process that involves mixing Edge AI and Cloud AI based computing and data analytics, with emphasis on local Edge AI as crucial part for the most sensitive parts of data generation and processing of the decisional parts.*

3. CONCLUSIONS

Miniaturized smart MEMS sensor technologies—MEMS smart sensors will play a very important role in the automotive value chain. Increase in automation for vehicles, low-power consumption, and small size are anticipated to provide numerous opportunities for MEMS in the future. In general, automotive applications will offer growth, profitability and new opportunities for MEMS sensors in a vision that foresees more than 200 individual sensors per fully automated car.

Technology and packaging—*will be even more closely related* by automotive requirements from-transistor-to-housing, which will include multi-domain co-design (chip, package, system) and high reliability. In addition, the necessary building blocks for monitoring autonomous cars will deal not only with sensors but also with software, Electronic Control Unit (ECU), data management and connectivity.

Semiconductor power technologies—power devices will remain one of the most important components of car electronics systems. Intelligent power devices based on silicon or on post-silicon technology (GaN, SiC) are expected to continue to offer solutions for engine control devices and vehicle safety control devices.

ADAS systems—appear to form in all manufacturers' visions as a key enabling technology for the progression of autonomous driving to levels 4/5, with very clear specifications and challenges for electronic technologies, high local computation power, and appropriate software.

Holistic Connectivity and Artificial Intelligence at the Edge—the future car will be increasingly operated as an AI Edge device, where the holistic connectivity and local intelligence/processing will play increasingly important roles. Specific AI semiconductor chips, data fusion from various sensors, and machine learning appear to be simultaneously needed. Moreover, new smart sensors and human-machine interfaces for better interactions with the car passengers will be needed for new services.

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