Autonomous vehicles: classification, technology and evolution

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Abstract. In the context in which most industries focus on digitalization and automation of production processes and on developing new products, the car manufacturing industry is advancing significantly. The automotive industry together with the IT field, are at an advanced stage in terms of the structure of autonomous vehicles, developing new technologies. The objective of this paper is to present the current state of technology regarding autonomous vehicles. Aspects regarding the devices and technologies used in the construction of these vehicles are approached, but there is also information regarding the way of classifying them according to the driver's assistance level. In addition, some information about the evolution of automated vehicle development is presented.

1. Introduction

Nowadays, when the world is in constant motion, the number of own means of transport (especially cars) or public transport is growing very fast, both due to the needs and due to the current trend. "According to statistics, there are 1.1 billion vehicles, but it is expected to increase to 2 billion in the next 10-15 years" [3]. With the increase in the number of land transport, one thing that has been observed for several years, is the overcrowding of cities. Overcrowding is characterized by the lack of parking spaces and by the traffic jams present throughout the day in the most interesting areas of a metropolis or even small towns. All this leads to the loss of significant amount of time during the day, spent behind the wheel of the vehicle or in means of transport (busses, trolleybuses, etc.), which has direct effects on the state of fatigue and implicitly of the driver's attention. In addition, traffic jams have an adverse effect on the environment, because significant amounts of harmful substances are generated during operation, even when waiting at a traffic light. All these factors mentioned above, often lead to the generation of accidents, which can be material or in the worst case can result in injury or even death of some people. As an alternative for the future, regarding the elimination of the disadvantages of conventional traffic, the autonomous (or automated) vehicle brings a series of facilities in order to facilitate urban and interurban mobility. These facilities range from driver assistance systems to complex system (hardware and software) capable of activities such as: perception, decision and reaction, with the role of streamlining road traffic through better of the driving process a vehicle.

Vehicles equipped with various driving assistance systems are no longer a novelty, they have been on market for several years. These systems have an important contribution to reducing the number of road accidents. According to recent data, approximately 1,2 million people die worldwide due to road accidents, [3].

The autonomous vehicle can be defined as an ordinary vehicle that can move from one place to another without the intervention or assistance of a driver, in other words the vehicle is able to analyze the environment and make favorable decision, to travel alone, due to equipment from endowment.

2. Evolution

Around the 1920s, in the USA, due to the large number of accidents caused by the carelessness of drivers, the development of driverless vehicles was discussed. Thus, in August 1921, the first vehicle without driver on board was presented, which was radio-controlled from an army vehicle located 30m behind it. It can be said that this is the pioneer of cars without a driver. The development of this prototype being closely linked to the technology owned by the army, [3].

Of course, after this presentation, other vehicles appeared either based on the same technology or on something more innovative:

- in 1925, the electronic engineer Francis P. Houdina, equipped an ordinary vehicle with the equipment necessary to perform driving maneuvers, being controlled remotely by radio waves, [1], [2].
- in 1939 during the exhibition "Futurama", an innovative concept propelled by magnetic field generated by the electric circuit incorporated in the running track was presented. It was made by industrial designer Norman Bel Geddes with the support of General Motors, [2].
- in 1958 – the first "automatically guided automobile" completed a one-mile test at the GM Technical Centre (Michigan).It was a Chevrolet that had two electronic sensors mounted in the front that followed a cable stretched along the track, thus, controlling the position of the steering wheel and implicitly the steering wheels, [1].
- in the 1980s, research on autonomous vehicles took off in many countries, both academically and industrially, [1].
- in 1994 in the PROMETHEUS-Project, Ernst Dickman's team developed with the help of Mercedes Benz W140 – a robotic vehicle, which was able to travel on congested highways around Paris at speeds of up to 130 Km/h, [1].

Thus, manufacturers companies such as: Mercedes-Benz, General Motors, Continental Automotive System, Autoliv, Bosch, Nissan, Toyota, Audi, Hyundai Motor Company, Volvo, Tesla Motors, Peugeot, Navya, Google, BMW, Local Motors, Easy Mile, etc., have developed and are still developing new prototypes of autonomous vehicles. Due to this technological boom, the legislative framework on the testing and circulation of autonomous/automated/robotic vehicles in many countries needs to be rethought. In this sense, in 2013 the UK government allowed their testing on public roads, after that, in 2014, the French Government adopted the same legislative measures, followed by other European countries and not only(in 2015, 5 US states allow AV testing on public roads: Nevada, Florida, California, Virginia, Michigan), [4].

3. Classification

According to the J3016 standard published by SAE International, regarding the degree of automation of the driving function, there are 6 levels, from SAE Level 0 (without automation) to SAE Level 5(fully autonomous vehicle). It can be said that this ranking was made on the one hand based on the volume of activities in which the driver is involved, and on the other hand based on the performance and equipment of the vehicle. In addition, this standard (SAE Standard J3016, 2016) corresponds to the levels defined by the Federal Highway Research Institute of Germany (BASt - Bundesanstalt für Strassenwesen), but also to some extent with those formulated by the National Administration for Traffic and Safety (NHTSA), [4].

SAE Level 0 (No Automation): this is where most current vehicles fall. In this case, as it is known, the driver is responsible for all actions,(acceleration/braking, maintaining direction, changing direction, using lights and signals, avoidance of obstacles, etc.), but in some situations, the vehicle may be equipped with warning systems (object warning in the blind spot of the mirror, collision warning).

SAE Level 1 (Driver assistance): systems implemented on the vehicle, at this level, can take control of the acceleration/brake (adaptive cruise control or emergency braking), or the direction of travel, using the information taken with the help of sensors in the environment in which they move (can keep the vehicle on the lane – Lane keeping assist system-LKAS). The driver must be able to take control if the situation so requires.

SAE Level 2 (Partial automation/assistance): the vehicle can control the steering, acceleration and braking, but the driver must be able to intervene when needed, constantly monitoring the surrounding conditions: traffic, weather and road conditions.

Therefore, for the first three levels, the driver is primarily responsible for monitoring the environment (traffic, weather, road condition), he must be prepared at all times to take control of vehicle, when the auxiliary equipment warns him. Starting with level 3, the autonomous driving systems are clearly superior to the assistance equipment present at the previous levels, because they have the capacity to monitor the driving environment.

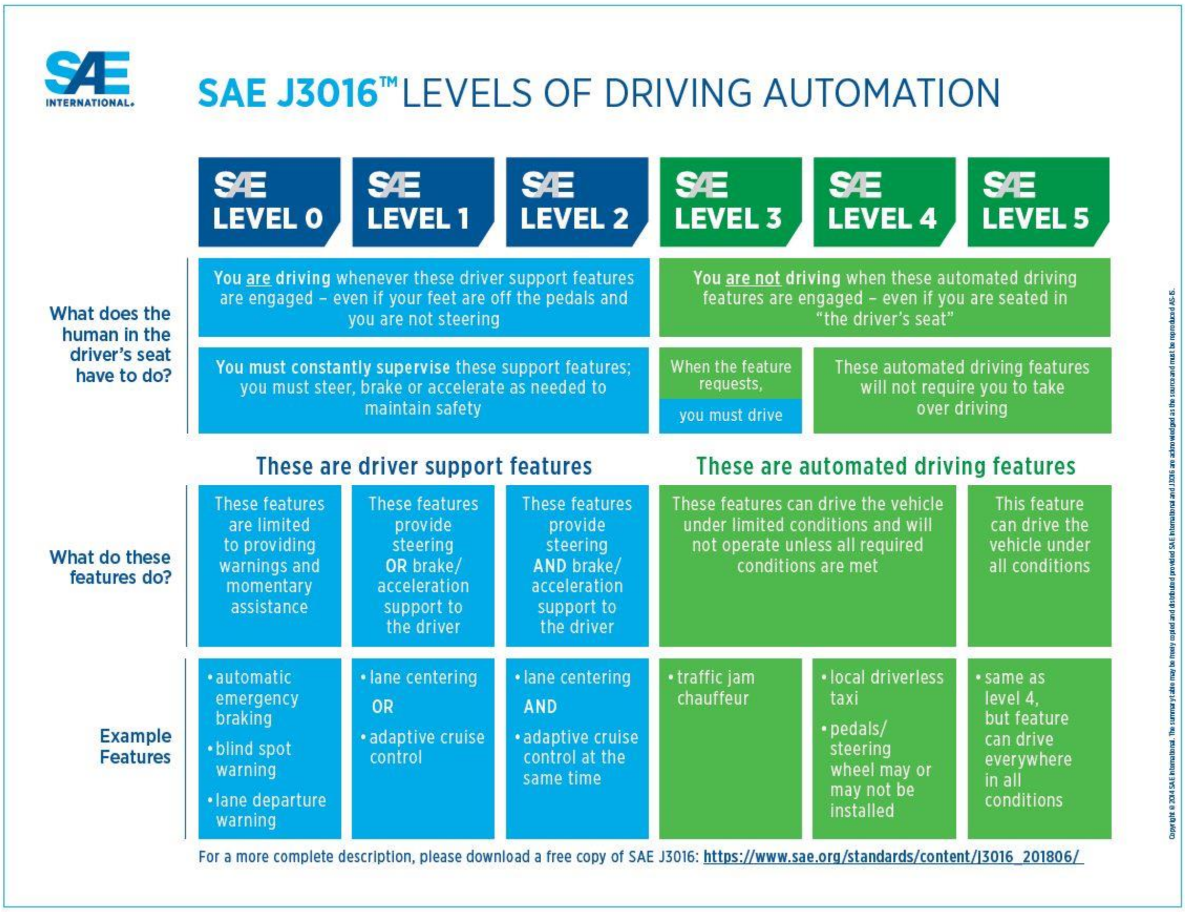

Figure 1. Levels of driving automation according SAE J3016 [12]

SAE Level 3 (Conditional Automation): in this case, the vehicle is able to monitor the surroundings, and control the direction, acceleration and braking in case of highway travel. But, even at this level, the driver must be prepared to intervene if the vehicle asks for this.

SAE Level 4 (High Automation): the activities regarding the controls of the vehicle during the movement can be taken over by an automatic driving system, in some well-defined situations. In some cases, vehicles equipped with such a system no longer have pedals and steering wheel installed.

SAE Level 5 (Full Automation): in this case vehicle is able to manage all the activities necessary for safe driving in any conditions. The only duties of the driver are to start the vehicle and enter the destination.

4. Technology used

In order to be able to travel, autonomous vehicles must be equipped with a variety of sensors and devices that can replace the skills and vigilance of the human factor. The essential devices that are part of an autonomous vehicle, and that help it to move safely are presented in this section. However, it does not mean that all autonomous vehicles have the same type of sensors or technology, these aspects being characteristic of every manufacturer or developer.

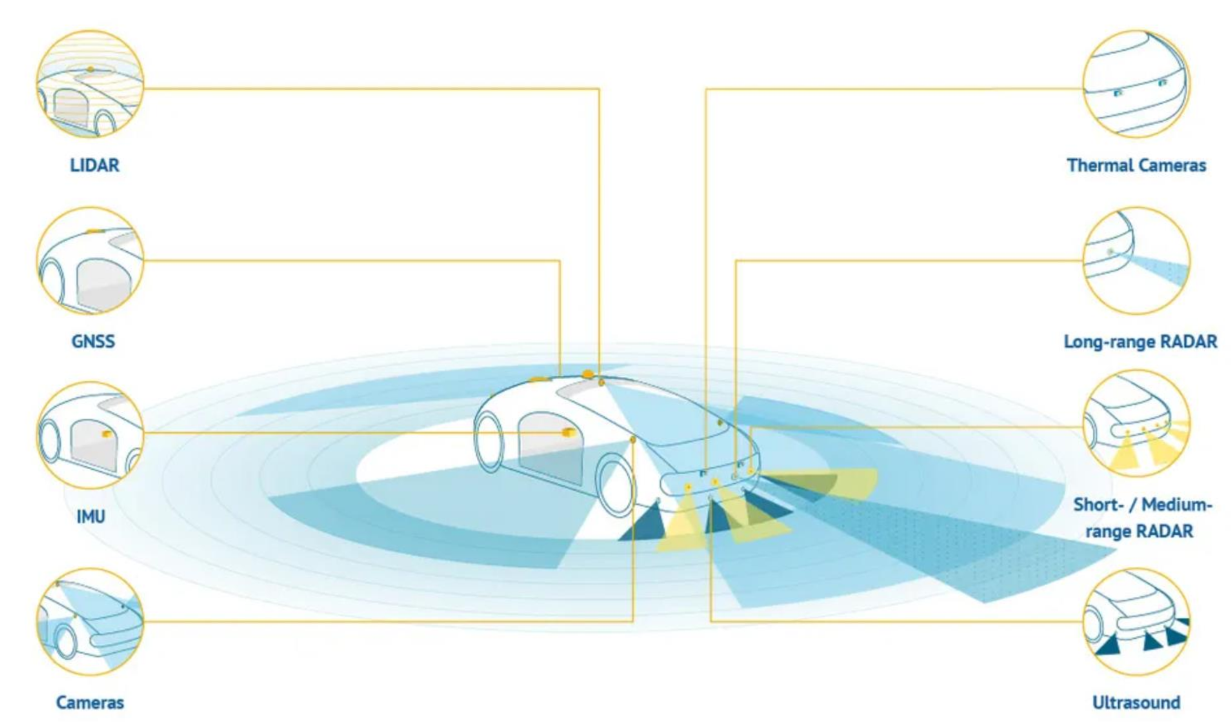

Figure 2. The sensor and device system of an autonomous vehicle [5]

LIDAR (Light detection and ranging) - is a device for measuring distance based on laser beam technology, transmitting light waves (beams) to a target (obstacle), then analyses the reflected light. It can detect static or dynamic objects (vehicles, pedestrian, cyclists, buildings, etc.) in the vicinity of the vehicle. It is capable to create a virtual map (2D or 3D) with these obstacles. It is usually mounted on the roof of the vehicle so that it can have a range of 360 degrees, [2], [4], [6], [9].

RADAR (Radar Detection and Ranging). Radar sensors that equip autonomous vehicles can be grouped in two broad categories: long range radar (LRR) or mid-range radar (MRR). These sensors are mounted on the front, rear and sometimes on the side corners of the vehicles. Radar systems operate on the basis of electromagnetic waves and are used to detect various obstacles or oncoming vehicles. They can also be used to determine the speeds of oncoming vehicles, or for the correct operation of some equipment: adaptive cruise control (ACC), impact warning, for self-parking, etc., [2], [4]. Most often autonomous vehicles have both LRR and MRR radar systems. These systems can have a range of up to about 200m with a dispersion of up to 40° (or even 75°- in this case the range decreases considerably), [2], [4], [7].

GNSS (Global Navigation Satellite System) include all satellite navigation systems, whether we are talking about regional or global systems [8]. GPS (Global Positioning System) the most widely used, is a navigation system that can provide information about time and current position almost anywhere on earth, as long as it is within range of four or more satellites. The system (GPS) helps to keep the vehicle on the desired route with a fairly high accuracy (approximately 30 cm), this being possible also due to the other systems in the endowment of the AV with which it collaborates, [4], [8].

Ultrasonic sensors: these sensors detect objects in the immediate vicinity of the vehicle, being mounted on almost all sides of the vehicle. They are used in parking assistance application, already having a wide spread on the market [4], [10].

Inertial measurement unit (IMU): an inertial measurement unit is a device that can measure the linear and angular motion of the vehicle, as well as the gravitational forces acting on it, using accelerometers and gyroscopes. For high position accuracy, the output data from the IMU are combined with the data obtained from GPS system [2], [4].

Thermal cameras: with their ability to detect heat, they provide a wider range of action than headlights, so they can detect in a timely manner the presence of various obstacles (pedestrians, animals, other vehicles, etc.), on the road or near it. They have the ability to detect even in more difficult conditions of movement: at night, through smoke, on the strong brightness of the sun, etc.

Video Cameras: the video cameras that come with autonomous vehicles are high-resolution stereo cameras, positioned at the front next to the rear-view mirror. Their role is to constantly monitor the road, and to transmit the information (images) for their processing in order to recognize the traffic signs, pedestrian, crossings, traffic lights, cyclists, etc. Some cameras also have the ability to estimate the distance to detect objects. Often autonomous vehicles have video cameras in the back, or mounted on their roof, to be able to see a range of 360°, [1], [2], [3], [4].

ADAS (Advanced driver assistance system) - is one of the most widespread and developed applications in the field of autonomous vehicles, being implemented even in vehicles of the middle and lower class of the market. The advanced ADAS functions used in autonomous driving involve a series of interconnected systems and sensors, thus making it possible to move the autonomous vehicle safely [10]. In other words, ADAS is a piece of equipment that includes both the software solution and hardware part. It is able to carry out the driving process safely without the intervention of the driver, [2].

5. How it works

If we were wondering how we could use an autonomous vehicle to make a trip, compared to a classic vehicle, this is relatively simple: the driver/user/passenger must enter the desired destination, and the vehicle chooses the route or it can be chosen by the driver/ the occupant. This activity is similar to setting a destination on a regular navigation system/device. After setting the destination and the route, the vehicle takes over, [4].

Just as people must have certain abilities to be able to drive a vehicle, so must it be in the case of autonomous vehicles. But in their case, the senses and abilities are taken over by a system of software and hardware devices. The main component of this system is artificial Intelligence through algorithms. Through these algorithms, information is processed and compared, and finally decisions are made regarding the driving commands (acceleration, breaking, steering, etc.) of the vehicle in order to avoid any possible incident.

The system that coordinates an autonomous vehicle can easily be likened to a child’s brain and senses, because it is based on approximately the same learning processes (stimulus-perception-processing-classification/comparison-decision making-action). Both, the system and the child need to be initiated in any activity. And with the accumulation of new knowledge, they will be able to better face new challenges in life (in the case of child) or in traffic (in case of the vehicle).

In order to be able to cope in real traffic conditions, the system that ensures the coordination of the vehicle must have a series of data that will represent the database with which it will be able to compare the different situations during the travel. In addition to these data, during the trip the vehicle also records data in order to increase the database, for a better management of the following situations.

Through artificial intelligence, this information is processed so that the vehicle (the algorithms) learns to manage the following situations similar to the previous ones, which were recorded.

Data storage (video/images) and processing is not sufficient for safe driving, so communication with road infrastructure, other vehicles in traffic and even the server are great solutions to improve the safety of manoeuvres.

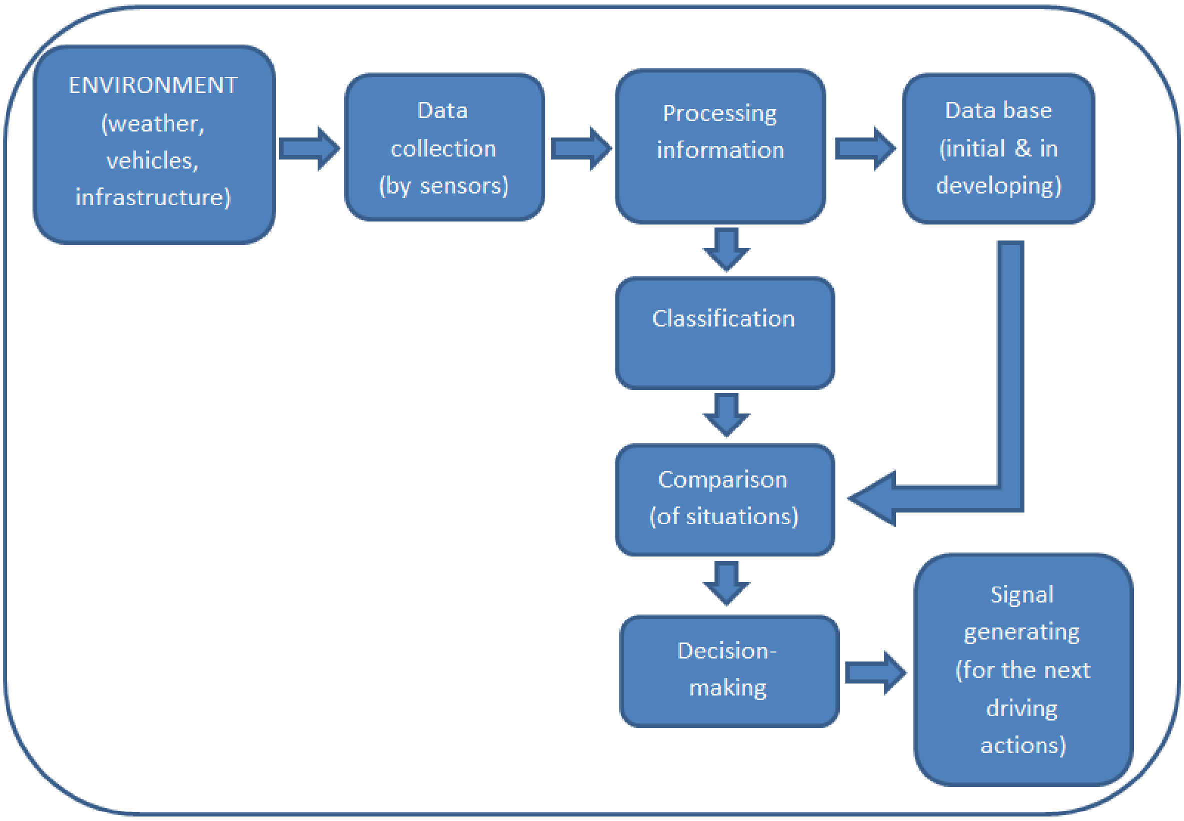

Figure 3. The process behind the every driving action

In other words, artificial intelligence simulates/mimics the complex process specific to human being: perception, processing and decision making, thus realizing the control of the main commands of the vehicle (acceleration, braking, steering, avoiding obstacles, etc.).

Of course, in addition to all the advantages of this technology, there are a number of weaknesses at moment:

- the difficulty of moving in areas under construction that have not been implemented on the digital map;
- the difficulty of moving in off road areas or in chaotic traffic;
- Cyber security, because there is a risk of hacking.

6. The usefulness of autonomous driving technology - possible ways of use

Self-driving technology offers a wide variety of use cases, but only four of them are described below:

Autonomous Valet Parking: refers to the situation in which the vehicle takes control only to move to the first parking lot where there is a free space, or to a parking lot chosen by the driver. Of course, this function can also be used in reverse, for example, the car in the parking lot can be called at the meeting point where it left. Due to the system's ability to manage parking manoeuvres, hard to reach spaces for beginner drivers can be used. Another advantage would be that the size of parking spaces can be reduced, which will provide more space for other purpose in overcrowded cities. Of course, all these actions (travel to the parking lot or vice versa) must be carried out in strict compliance with the legislation on motor vehicles on public roads, [11], [1].

Interstate pilot: refers to the situation in which the degree of automation of the vehicle allows taking over driving functions (acceleration, braking, steering), through an autopilot, but only in the presence of the driver. This function is intended in particular for travel on the motorway or in stop-and-go traffic jams, thus facilitating the reduction of driver stress in the situations mentioned above. With the help of this function the number of accidents can be reduced, at the same time improving the traffic flow. Activation of the function (transfer of commands) must be performed in a safe manner, [1], [11].

Full automation using driver for extended availability: can be considered a higher version of the "interstate pilot" function, mentioned above. By transferring the driving functions to the automatic system, the driver becomes a passenger, being able to release the steering wheel and pedals, but his/her absence is not allowed. By means of this function the vehicle can move in almost any situation, as long as the movement area is not restricted from a legal point of view, regarding the movement of vehicles equipped with autonomous driving systems, [1], [11].

Vehicle on demand: through this concept and technology, the availability of vehicle in (almost) any location, at the request of an applicant, is possible. This solution is suitable for both passenger and freight transport. By replacing the human operator with an autonomous (automated) driver, the time spent in traffic would be considerably reduced, because the system does not require breaks for rest, being available 24 hours a day. This concept is closest to what an autonomous vehicle (SAE Level 5) means in the future, [1], [11].

7. Conclusion

It is noted that the development of driver assistance systems as well as attempts to make various prototypes of automated/autonomous vehicles has as a starting point the minimization of the number of road accidents (driver and passenger safety, goods safety, and other road users).

In the last 15 years, the technology has developed at a fairly fast pace. The autonomous vehicle and its development bringing together companies from different fields: companies developing navigation system, camera devices, software and hardware solutions, up to the major automotive concerns. But an extremely important factor in the development of this industry is the legislative framework. This is the reason why most often the developers of autonomous vehicles have to meet with the governments of countries of the world, in order to regulate the use of these vehicles in the public space.

The Internet of things (IoT), the giant network of connected devices and users, which collect and share information about the environment where they are, is in continuous development. The evolution of this technology but also of the road telematics (long-range information transfer) made possible the developing of vehicles with a certain level of driving autonomy and increased the safety of using this type of vehicles. Through continuous developing of Internet of Things technology and its integration into automotive filed, the way of interacting between user and vehicle or/and between vehicle and another devices (especially road infrastructure) will be change completely.

In order to increase safety, it will be necessary to intensify the communication protocols between vehicles (V2V) but also the communication with the infrastructure (V2I). Thus, the current (conventional) infrastructure will have to be improved so that it can meet the requirements of autonomous vehicles. And as a considerable improvement in the exchange of information, communication with everything (V2X) – any other device- will further facilitate the movement of autonomous vehicles because they will have enough information to meet the challenges. But all this is possible only with the help of artificial intelligence that requires continuous improvement, so that in the coming years to reach fully autonomous vehicles (SAE-LEVEL 5).

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