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Quo Vadis – Autonomous driving

State of the art and future directions

[Markus Kucera, Andrei Földi]

***Abstract*— Autonomous driving is considered one of the most disruptive technology change of the past decades. However, many challenges have to be overcome in order to fulfil the dream of a completely autonomous driving car. The paper clarifies what autonomous driving is from the engineering point of view, what the challenges are and presents approaches on how society, industry and research are trying to solve them.**

***Keywords*—autonomous driving, driverless car, autonomous driving systems**

I. Why autonomous driving? Is it safe? Is it legal?

There are quite a few unanswered questions about autonomous driving. For many questions the public doesn't yet agree on the "right" answer and interested parties push the adoption of a certain answer.

The very often used term of "Autonomous Vehicle" is not used by the industry. The SAE Standard J3016 [22] uses Automated Driving Systems or Driving Automation Systems to describe the technologies behind the different levels of automation in the modern vehicles.

Studies [19] list a few of the advantages that the autonomous driving technology will bring, such as a higher mobility for all people, even for those who are not allowed or able to drive, less accidents and the associated reduction in economic losses, bigger driving comfort and optimal gas consumption. Of course there are also disadvantages like possible hacker attacks on the always connected cars, the fact that small failures in standard systems could impact and cause a lot of the accidents with the implementing vehicles. Higher mobility for classes of people that are not participating now at the traffic, could also mean more cars on the streets on the long run.

Numbers from the German Federal Statistical Office correlated with the numbers from the State of California, Department of Motor Vehicles from the Autonomous Vehicle Disengagement Reports 2017, support the thesis that the number of accidents will decrease with the introduction of the autonomous driving systems. Same conclusion reached a study by the consulting group McKinsey [6]. According to this study, the introduction of the autonomous driving would save milliards of Euros in repairing costs after accidents, would reduce dramatically the number of causalities in car accidents and it would also save driving time by optimizing traffic [4], [10].

Markus Kucera, Andrei Földi
University of Applied Sciences Regensburg
Germany

According to statistical data, around 94 percent of the car incidents are caused by driver fault. [7], [8]. Cumulated numbers indicate approximate 1,2 Million casualties per year in the world. Only the economic harm is evaluated at 277 billion dollars in damages and repairs only in USA. [20]. However, the percent of the fatal incidents in Europe and USA compared to the rest of the world must be taken into consideration when establishing how big the impact will be on the total number of casualties in the world, as soon as autonomous driving systems will be present on the streets.

Autonomous vehicles being tested in the last years had a clean record until recently. Until 2017 only small accidents were recorded for the test cars and the vast majority were caused by the other traffic participants and not by the test vehicles [12], [28].

The 74 countries that signed and ratified the Vienna "Convention on Road Traffic", an international treaty from 1968 meant to facilitate international traffic, must emit special permits for allowing autonomous vehicles to be tested on public roads. The treaty in its original form forbids vehicles that are not under human driver control at all times [2], [3].

II. Legal status in:

A. *Europe*

The "convention on Road Traffic" from Vienna, 1968 was regarded as an obstacle for the mass introduction and adoption of the autonomous cars. One paragraph states that: "Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all maneuvers required of him." Some European governments proposed amending article 8 of the Convention to allow automated driving technologies and on September 23rd, 2014, a change to the previous mentioned convention has been agreed to by all the 73 signing parties . The change become effective 18 months later on April 23rd, 2016.

The exact change to the original convention text mentions: "Vehicle systems which influence the way vehicles are driven and are not in conformity with the aforementioned conditions of construction, fitting and utilization, shall be deemed to be in conformity with paragraph 5 of this Article and with paragraph 1 of Article 13, when such systems can be overridden or switched off by the driver."

According to experts, [5],[21], the new change to the convention permits "the system to perform, in certain use cases, all the required maneuvers to control the car".

The same experts make it even clearer by explaining that the change would allow for certain situations like driving on

the highway, to have the car drive by itself without any permanent monitoring from the driver. But a complete autonomous vehicle, (like a taxi), in the sense of the Google developed car, which has no brake or gas pedal and where no steering wheel is available, is still not allowed by the current convention since its driving systems cannot "be overridden or switched off by the driver".

B. *The United States of America*

Even if the regulation seems to me moving faster in the United States, there are concerns of cities and states that the congress regulation is moving too fast and it may limit the ability to regulate vehicle safety at the local level. However, the general opinion is that a nationwide set of standards will help and speed the pace at which the development of self-driving technology is advancing. Until 2017, 33 states have introduced regulation concerning autonomous driving systems technology. [14]

The fast innovation pace makes it hard to set up regulation that isn't obsolete in a decent amount of time. Some states and cities decided to not regulate self-driving testing at all, hoping that the car makers will adapt their systems as concerns arise.

Current regulation allows tests starting with 25000 self-driving cars in 2018 and it increases gradually up to 275000 cars by 20121. Some states or cities have passed regulation that allow testing but under very strict conditions. This implies for example testing only on predefined routes and with a police escort. [13]

C. *The rest of the world*

As mentioned in the previous subchapter, the old "Convention on Road Traffic" makes testing autonomous vehicles on the public streets illegal without special government permits. US, Germany, Netherlands and UK were among the first countries to issue self-driving test permits [17].

China is trying to close the gap with Europe and the USA. Beijing became in December 2017 the first city in the country to allow open road test for the autonomous cars. The regulation requires car testers to first complete a set of test on a closed zone and then allows testing with at most 5 cars at any time on the open roads. There are plans to adapt the current infrastructure so that it becomes more easily recognizable by the self-driving technology [16].

The Chinese National Development and Reform Commission made the development of smart cars a national priority and presented a three-year plan on how to move in this direction. More Chinese cities are relaxing the regulation that make the testing of the self-driving technology possible [15].

South Korea built the largest model city (K-City) with the designed purpose of testing the autonomous driving systems.

Recently passed legislation in Singapore doesn't require anymore a vehicle to have a human driver. New Zeeland has no legal requirement for a human driver either.

A KPMG report, situates surprisingly Netherlands on the top position in a country ranking for "Autonomous Vehicles Readiness". This report mentions that: "the Netherlands provides an Autonomous Vehicles readiness model for other countries to follow, with excellent road infrastructure, a highly supportive government and enthusiastic adoption of electric vehicles." [18]

III. How does an autonomous driving system work?

There are 3 hardware components that can be found in most of the autonomous test cars:

- LIDAR – an acronym for LIght Detection And Ranging or Light Radar. The current implementations use a roof mounted LIDAR sensor that measures the distance to obstacles by illuminating them with pulsed laser light and measuring the reflected pulses with a sensor.
- RADAR - an acronym for RAdio Detection And Ranging or RAdio Direction And Ranging, it is the techology developed in the second World War, that uses radio waves for the moving object detection.
- Camera(s) – the majority of the current autonomous driving systems use stereo cameras.

An autonomous driving system is based on software that processes and analyzes the hardware sensors data in order to safely navigate the vehicle to its destination.

Radar sensors are mounted in the front and rear bumper. Some car makers use them as a redundant system or validation system for the LIDAR System. They are used to evaluate the status of the traffic and reacting to fast changes in the traffic situation or the sudden appearance of obstacles.

Camera or stereo cameras are also used for building a surroundings map for navigation. Some car makers even renounce completely to the expensive LIDAR sensor and use only a combination of stereo cameras used as the "eyes" of the system and different (long and short) range radar sensors mounted on the side of the car, supplementary those mounted in the front and rear bumper. [23]

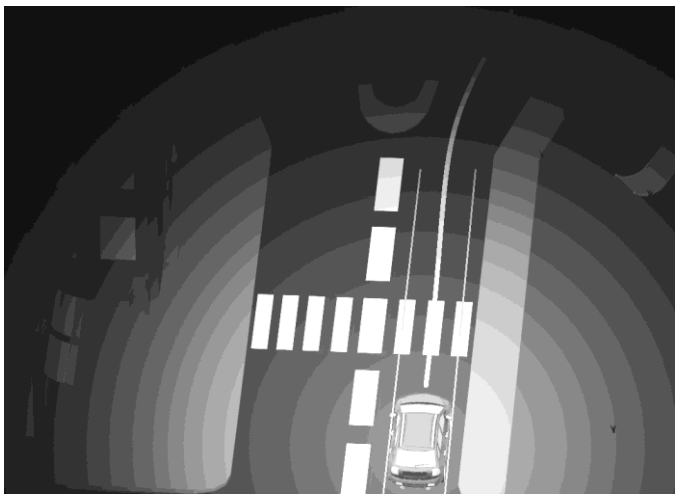

Figure 1. SLAM in action - Mapping, Localization. A map of the surroundings is built on the fly. The ADS has to position itself on this map

With the help of the previously mentioned sensors the ADS - advanced driving system will create a precise map of its surroundings and also position itself inside this map. This is the so called SLAM problem – Simultaneous Localization and Mapping. There are more SLAM algorithms, but they are similar in how they work [24].

The vehicle ADS - Advanced Driving System can only see a small portion of its surroundings. The system has maps available for the region where it is navigating but GPS positioning is not precise enough to enable for example lane keeping.

This is where the SLAM Methods come into play. Using these methods, a map of the surrounding is incrementally build and used for navigation.

IV. What is an autonomous vehicle (driving system)?

From the engineering point of view, as defined by SAE (The Society of Automotive Engineers) [1],[8], there are 5 intermediate steps to full automated vehicles. Each of the steps moves more of the driver's responsibilities from the driver's hands to the cars autonomous driving systems.

Most of the newer cars already passed the level 0 in which the human driver does all the needed actions to control the car. They can all be ordered under level 1 of automation, where the car has advanced driver assistance systems (ADAS) which assist the human driver in either steering or braking and accelerating. But they will not assist in both steering and accelerating or braking simultaneously. Cars that have lane assist systems or adaptive cruise control systems can be categorized at this level, which is also called Driver Assistance Level.

TABLE I. SAE AUTOMATION LEVELS

Level	Name	Definition
Environment monitoring by human driver		
0	No Automation	The human driver monitors the environment and controls the vehicle
1	Driver Assistance	ADS controls at times either steering or braking / accelerating, human driver performs all remaining tasks
2	Partial Automation	ADS controls at times both steering and braking / accelerating. Human driver does the rest.
Environment monitoring by the ADS		
3	Conditional Automation	ADS controls vehicle but expects human driver to respond appropriately to a request to take over
4	High Automation	ADS controls vehicle even if human driver doesn't respond appropriately to a request to take over
5	Full Automation	ADS controls the vehicle in all the situations

Some of the commercial cars nowadays (2018) that have an autonomous drive mode [4], [27] can be categorized under the level 2 of automation –SAE Partly Automated Driving level. These vehicles feature semi-autonomous driving assistance systems, (Steering and Lane Control Assistants with Traffic Jam Assistant)[11], that enhance the driving experience and take the strain from the driver, but still have the human driver fully in control of the maneuvering. The driver must pay attention to the traffic conditions at all times.

TABLE II. SAE AUTOMATION LEVELS - CONTROL

Level	Steering & Acceleration	Monitoring	Fallback	Capability / Driving Modes
0	Human	Human	Human	Not available
1	Human and ADS	Human	Human	Some Driving Modes
2	ADS	Human	Human	Some Driving Modes
3	ADS	ADS	Human	Some Driving Modes
4	ADS	ADS	ADS	Some Driving Modes
5	ADS	ADS	ADS	All

The Conditional Automation level 3 – the fourth level in the SAE categorization, require the vehicle to control all monitoring of the environment and under certain defined conditions, like driving on a highway, it can take complete control of the steering and acceleration or braking. This level of automation allows the human driver to turn their attention away from the road under those defined conditions. There is still a need for the driver to take over control in unexpected situations such as missing lane demarcation or construction sites. Audi planed originally to be at this level with the A7 model going in production for consumers in 2017 and later moved this deadline to 2018, BMW plans to have its Co-Pilot system in production in 2021. Ford decided to skip direct to level 4 [25].

Level 4, described by SAE as Highly Automated Driving, still allows a human driver to request control. This means the car still has to have a cockpit to enable driving. The system will inform the driver that the driving conditions are safe for the system to take over and only then it will switch to this mode. The vehicle should be able to handle the majority of the driving situations independently. It must be able to brake, accelerate, steer, monitor the vehicle and road and act accordingly to the traffic situation, i.e. determining when to change lanes or turn and also make use of car signals in order to follow the planed route. Unexpected driving situations that would pose a problem for level 3 systems, like construction sites should be handled alone by the vehicle, without asking for any user intervention. At this level the driver should still be capable of taking over control if needed but he may also take a nap. In case the driver intervention is required, failing to intervene will have the car transition to a safe condition.

The Full Automation Level, SAE level 5 means autonomy for the vehicle and no human attention is required. The vehicle is not even supposed to still have a cockpit, since it is capable of handling all the driving tasks and unique situations that may appear during traffic.

V. Current Status

Cars in production today offer Level 1 - driver assistance as defined by the SAE J3016 standard, since the 1st of November 2014 all cars registered in EU must have Electronic Stability Control systems [26] and these can be classified as a SAE level 1 system. In the US the National Highway Traffic Safety Administration requires all new passenger vehicles sold in the US to have ESC as of the 2012.

The Auto-Pilot in Tesla vehicles is a SAE level 2 system, according to the press releases the hardware available in the vehicles currently in production (HW2) supports SAE level 5 automation. It includes a NVidia Drive PX 2[32] GPU for CUDA based GPGPU computation [9]. The Tesla CEO corrected in 2015 [27] his prediction that autonomous technology will be ready in five years to only two years. The current incidents where Tesla vehicles were involved, including those with loss of human life may have postponed that development [12].

Continental sees the success of autonomous driving systems as a synergy of more components. Sensors, car to car communication, human-computer interfaces, reliability are key factors in implementing and promoting the autonomous driving technology. Promoting the technology includes working on the public acceptance of the autonomous driving systems [29].

Regarding the responsibility in case of accidents some car maker themselves declared that they will take responsibility for the accidents caused by their cars driving autonomously. In the press release, the Volvo CEO, went so far as to say that there will be no loss of human lives driving in a Volvo car [30].

Car insurance companies see no problem in insuring autonomous driving vehicles. Even with perfectly working autonomous vehicles, it won't be so that there will be no accidents anymore, even if the number of accidents will be drastically reduced vehicles will still need a liability insurance. However, the reduced number of accidents will may be reflected by a sensible reduction in the cost of the insurance rate [31]. And bottom line, any type of autonomous vehicle will be insured, as mentioned by the chairman of Allianz AG insurance company:" Our company will insure even cars without a steering wheel" [31].

VI. Outlook

Major players in the car business like Audi Volkswagen Group, Daimler-Benz and Ford and tier 1 suppliers as Continental and Bosch plan to make their self-driving technology production ready until 2020 [19], BWM is planning with production of vehicles with autonomous driving technology in 2021. [1] It is not very clear communicated which level each automaker will implement in their autonomous driving systems.

As mentioned in the previous chapter, Ford decided to skip the implementation of the SAE level 3 in its vehicles after it observed how the test drivers were behaving behind the steering wheel of the test vehicles. According to the observations the drivers got comfortable with the systems and stopped paying attention to the traffic [19] The SAE Level 3 which still requires the human driver to take over in certain unique situation may pose safety risks when drivers trust the automated driving systems too much. The few seconds required from the driver to assess the current situation and act accordingly may be not enough to avoid potential risks [7].

Different automakers are driving two different strategies [19]: the so called evolutionary strategy and the other called the revolutionary strategy. The evolutionary adds incrementally autonomous technology to their systems, the revolutionary want to skip some of the SAE defined levels and jump directly to full automation. The two approaches are sometimes also referred to as "something everywhere" for the evolutionary strategy, meaning that the vehicles will include a certain degree of automation and will be available in all markets, everywhere. The other camp referred to as "everything, somewhere" means that the vehicles will be capable of doing everything without driver's assistance, but these will only operate in certain regions and not everywhere.

VII. Conclusions

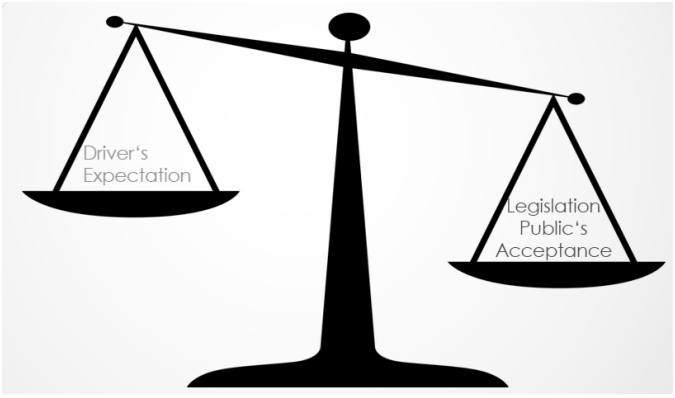

Figure 2. What do we expect from the car of the future?

Even if the current press releases sound optimistic and announce approximately the year 2021 being the year of the big leap to the first commercial products to include automated driving systems, it is now difficult to predict when these kind of vehicles will populate the streets. Not only that there are still technical challenges, but society and driver acceptance must be also taken into consideration.

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