——ONLINE FIRST(NOT Peer-Reviewed)——

Title: “A new approach for the Classification of Advanced Vehicles in Transportation Systems”

Received: 2018-07-31

Accepted: 2019-03-22

Process: 1、First trial(Field and check) ✓

2、Peer review ☐

3、Editing and three trials ☐

4、Published online ☐

EnPress Publisher, LLC. United States

“A new approach for the Classification of Advanced Vehicles in Transportation Systems”

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Abstract

Automated vehicles represent one of the most active research topic in different engineering fields in the recent years; in particular, transportation systems theory, mathematical modeling, informatics and electronics are all involved in the development of more efficient, accurate and error resilient systems regarding this topic. For modeling purpose, it is useful to introduce a vehicle classification, but the current 6 SAE levels are too detailed, without sharp borders in some case, to be useful for practical applications; thus a 2-class meta-classification has been proposed but it seems too coarse. This paper starts from an analysis of the 6 SAE levels and of sensors developed and used in modern vehicles to establish a relationship between them; this study is useful to devise a new effective 3-class meta-classification useful to transport systems analysis involving automated vehicles.

Keywords: advanced vehicles, sensors, transportation systems

1. Introduction

Evolution has always been a fundamental component of life and technology developments have always represented a fundamental step in human civilization evolution. In fact, it is possible to say that technology speeds up everyday life thanks to the continuous introduction of innovative techniques, new devices and new perspectives. This results in turn in huge modifications in human activities perception, due to the time involved, their safety and in general their degree of difficulty.

Among the various cases of the daily life, one of the most discussed and interesting issue of the last years is related to automated or self-driving vehicles. The introduction of such vehicles resulted in the fact that nowadays car company cannot think of just projecting the mechanical parts or the basic electronic used in the vehicle, but are also involved in the project of sensors, integration issues and in the development of the related software.

In this way the integration of electronic components has become a necessary part in the vehicle development, in order to obtain an increase in safety and in easiness of the driving experience (e.g. Anti-Breaking Systems, Hydraulic Break Assist, Electronic Stability Control, etc.), as well as a reduction of impacts such as air pollution, noise, fuel consumption. This resulted in a major cooperation between companies coming from different backgrounds and in the creation of partnerships and joint ventures among them.

These effects result in a renewed impulse in the research related to the vehicles, due to the growing mingling among the various sectors of the industry. The common goal is to develop new models or update the old ones to simulate real life situations and predict the future developments of the automotive and, in general, of transportation research field. Considering the field of transportation systems engineering, it is possible to state that right now the main focus is to achieve a deeper understanding of the hardware and software involvement in this new kind of vehicles. This, in turn, allows to obtain better models developments and more reliable simulations.

These issues are often accentuated by the impossibility of retrieving commercial standards, due to the fact that, in some cases, it is not yet available or the vehicles are still prototypes.

New technologies for automated vehicles look very appealing, but, it may easily be anticipated that the time needed to turn the existing stock of traditional vehicles into the new ones will last several years during which mixed traffic is expected, requiring ad hoc tools for analysis and design [1].

A vehicle classification is surely helpful to support specification and calibration of models for transportation systems analysis, but the well known current 6 SAE Levels (briefly discussed in section 2) are too detailed, without sharp borders in some cases, to be useful for practical applications. Thus a 2-class meta-classification has been proposed but it seems too coarse for effective specification and calibration of models. Several considerations related to sensors functionality and their application ranges (section 3) support the choice of a careful redefinition of the 2-class meta-classification of SAE levels. This paper starts from an analysis of the 6 SAE Levels and of sensors developed and used in modern vehicles to establish a relationship between them; this study is useful to devise a new 3-class meta-classification effective to transport systems analysis involving automated vehicles (section 4), more effective than the current one based on 2 classes only.

The aim of this paper is to provide:

- an analysis on sensors used in the automotive field;
- a clear correspondence between used sensors and SAE classification;
- a 3-level meta-classification useful to transport systems analysis.

2. SAE Levels

The schemes that is internationally used as standard for the classification of "Automated Vehicles" is the "SAE Levels" [2], written by "SAE INTERNATIONAL" (U.S.-based, globally active professional association and standards developing organization for engineering professionals in various industries) (Figure 1).

As shown in Figure1, a six levels taxonomy proposed; these six levels are collected in a meta-classification based on two macro categories (Human Driver e Automated Driving System) that identify the technology inside the vehicle and the type of driver.

To understand the differences between each SAE level, guidelines written by AdaptIVe (a project co-founded by European Commission) [3] have been taken into account. In the following a brief explanation for each SAE level is reported:

- Level 0: no electronic device and human driver;
- Level 1: some electronic devices but the driver is still human;
- Level 2: more electronic devices for security, the driver is helped in some maneuvers, but it still has the main control of the vehicle;
- Level 3: in a smart road, the vehicle is supervised by human driver that takes control of the vehicle in case of emergency;
- Level 4: in a smart road, the vehicle is still supervised by the human driver, but the driver can make other actions;
- Level 5: completed automated vehicle.

A description of the sensors involved in automotive applications is discussed in the following chapter, in order to provide the reader a context for the proposed approach.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 1 - SAE LEVELS [2]

3. Sensors Critical Analysis

During the last years, electronic systems assumed a growing importance in the development of assisted and automated systems. In particular, the research has been focused around two main topics:

- the development of new algorithms and the improvement of the already existing ones, at the end of obtaining more compact, less consuming and, above all, faster implementations, in order to fit the needs of the automotive industry;
- the development of "ad hoc" sensors capable of operating in the various environments and having performances suitable to detect, intervene and advice the driver in time, making it possible for the human or autonomous driver to take the best decision due to the particular conditions.

This work starts from the sensors evolution to give an insight of the different techniques and sensors families used in nowadays autonomous vehicles, in order to gain insight on the different issues related to their development and provide ideas useful to better integrate them into the traffic models, obtaining more fitting models and better results.

First of all, it is possible to define four types of sensors and related systems used in nowadays smart vehicles:

- Image sensors and processors;
- Radar sensors and systems;
- Lidar sensors and systems;
- Ultrasonic sensors and systems.

Moreover, the data coming in from the different sensors have to be considered as a whole, in order to have a redundant and robust system and to discriminate in the case of contrasting detections from different sensors. This exchange of information between the different systems is done using an internal network, such as a CAN bus, to avoid the instantiation of several sensors of the same type. Ideally, the aim of the data from and to these control units is to describe the status of the car and formulate the actions to be taken at any time. It is interesting to note, that with the new smart vehicles also systems to process and take into account the data coming from other vehicles have to be considered, causing a huge increase in the amount of data to be processed and, thus, an increase in the research for fast computing, stream processing systems and diagnostic protocols [4].

A careful examination of the various techniques used has to be developed, together with evaluation of the differences between the different types of sensors and how and when to use them, in order to achieve both a better understanding of their behavior and develop new models.

3.1. Image sensors and processors

The use of image sensors in automotive field goes back to vision guided auto-parking systems which has been around for the past twenty years [5]. Nevertheless, some of the main techniques are still used nowadays, the main topic has shifted from parking problems to active detection during driving. Several studies have been conducted on these applications, e.g. dedicated to pedestrian crossing and signal recognition. In particular in this type of problems the image sensor has to acquire the images from the environment at resolutions and acquisition rates suitable for the detection problem. Together with the sensor also the image processing methods have to be considered. In particular, to enhance the performances of the sensors in terms of processed frame rate per second (fps) hardware accelerators closely coupled to the image sensor are used. The accelerators are mainly dedicated to filtering operations on the incoming images from the sensors, aiming to send to the processing units only the significant data to be taken into account in the detection. Several systems have been developed, like the ones dedicated to edge detection and recognition, segmentation and object recognition. However, the trend is shifting to the use of Artificial Neural Networks capable of calibrating the various detection parameters according to the incoming stimulus and their previous history. Neural Networks hardware accelerators have been developed in the last years to make the systems capable of operating in real-time. While the training of the Neural Networks to determine the optimal parameters is usually done offline, some parameters could also be varied on-the-fly to achieve a resilience of the system to false detections or to improve the driving performances.

The challenge is nowadays to develop faster Neural Networks systems operating together with the image sensors, in order to process higher amount of data while operating with higher resolution frames; on the other hand, the development of new dedicated algorithms could also allow a complexity reduction of the problem which, in turn, could cause lower latencies in the system and better detection performances, both from a correctness and a speed standpoint.

3.2. Radar Sensors

Radar systems are used in automotive to help solve problems like auto-parking, pre-crash sensing and adaptive cruise control, since one of the main characteristics of a radar system is the capability of inferring the velocity of the detected objects in its range. Radar systems used in automotive applications usually operate at 77 GHz frequency. The measurement time could be reduced to 10 ms allowing controlling the scene 100 times per second [6].

Radar systems are used together with other systems and results particularly efficient for detections at distances up to approximately 200 m, with a range resolution of 1 m[6]. These peculiarities make the radar system particularly appealing for mid range applications in condition of non-optimal visibility, which could cause major problems to systems based on image sensors. However, radar systems have got poor object detection issues in medium ranges (30 m to 60 m) for angles larger than $\pm\pi/6$; for that reason, they need to be supported by other detection systems, based on different technologies [7]. Moreover, it has to be highlighted that a typical radar system shows difficulties in taking into account targets having different azimuth values and, thus, more sophisticated data processing systems are needed, like tracking ones. These systems could show problems in the case of wrong modeling assumptions for the targets, causing detection problems, like target loss.

3.3. Lidar Sensors

Lidar systems are capable of good performances in presence of adverse environmental conditions, such as fog, heavy rain or snow, but also in the case of scenes having low illumination levels.

However, also lidar systems show some drawbacks, due to the fact that in some cases the dynamic range of the lidar system could be exceeded. When it happens two extremely severe types of error occur: the loss of targets and the generation of ghost targets, which worsen the detection performances unacceptably in some cases[7].

3.4. Ultrasonic Sensors

Ultrasonic systems are mainly used for parking assist systems, where they are capable of insuring low costs and good performances. Several threshold systems are designed to achieve the correct detection of corners and edges, while other systems take care of the steering angle and wheel speed; all is coordinated by a network, like the CAN bus previously mentioned [8]. Moreover, this kind of systems demonstrated to work well in cooperation with laser parking systems or to substitute them [9].

Finally, it has to be highlighted that great importance has to be put on decision algorithms, which could be usually implemented in software and which could represent the bottleneck in some systems. In what follows we concentrate on the effect related to the sensors, assuming that the performances of the software are the same for all the considered systems in order to do not undermine the comparison results.

4. Evidences and motivations for a new meta-classification

This section reports several considerations about the relationships between kinds of sensors available on a vehicle and SAE Levels in order to define a 3-class meta-classification useful to effectively support specification and calibration of models for transportation systems analysis.

Table 1 shows the relationship between SAE Levels and types of sensors, supporting the 2-class meta-classification in Figure 1: Human driving vs. Automated driving. It could be noticed indeed that there is a huge difference between the type of sensors installed in vehicles of each level. Note that the ultrasonic sensors are used only for parking maneuvers and not for drive assistance, thus they will not be further considered within the following.

	Human Driving			Automated Driving		
	SAE 0	SAE 1	SAE 2	SAE 3	SAE 4	SAE 5
Image sensors and processors	N	N	Y	Y	Y	Y
Radar sensors and systems	N	Y	Y	Y	Y	Y
Lidar sensors and systems	N	N	N	Y	Y	Y
Ultrasonic sensors and systems	N	Y	Y	Y	Y	Y

Table 1 Relationship between SAE Levels and types of sensors

From these considerations, it is possible to see why many authors choose to use two macro classes, to group SAE Levels[10]:

- Human Driver: as shown in Figure 1, the vehicle certified within SAE Level 0 to Level 2 are in this macro class. Even if they show some technological differences between each levels, in this type of vehicles the driving function is still human related. Hence, the currently available models for transport systems analysis[11] can almost straightforwardly be applied to these vehicles;
- Automated Driving System: the other levels are defined this class; the types of vehicles in this class are still at a prototypal stage, but it can easily be anticipated that new models need to be studied and developed.

This meta-classification is probably over-simplified: at a closer look, vehicles in the "Automated Driving System" class cannot be conceived as homogeneous, as shown below.

First, looking at the relationship between Automated Driving SAE Levels (3 to 5) and ranges of sensors, as shown in Table 2, it can easily find out that application ranges of sensors for SAE levels 3 and SAE Level 4 and quite different from those for SAE level 5.

	SAE 3	SAE 4	SAE 5
Radar sensors and systems	200 [m]	200 [m]	200 [m]
Image sensors and processors	250 [m]	250 [m]	200 [m]
Lidar sensors and systems	150 [m]	150 [m]	100 [m]

Table 2 Relationship between Automated Driving SAE Levels (3 to 5) and ranges of sensors

In addition, SAE Level 3 and SAE Level 4 vehicles still need a human driver, especially in emergency conditions for safety, possibly with different reaction times and different from SAE Levels 0 to SAE Levels 2; these vehicles can be considered a technological evolution of traditional vehicles aiming at reducing effort of human drivers and will likely be mostly privately owned. On the other hand, SAE Level 5 vehicles do not need a human driver at all, not even a steering wheel (as show in some prototype vehicle); these vehicles should be considered an evolution of taxi, other vehicles available on demand and public transport system and will likely be mostly not privately owned.

Therefore different "user definitions"[11] that must be considered in the two cases. Moreover, the new models needed to be studied and developed should be differentiated, at least with respect to parameters.

For all these reasons, a new approach to vehicle meta-classification should be formulated. Assuming that:

- the sensors related software and involved algorithms are the same for each vehicle and level;
- the sensors have their functional range as described in Table 2;
- the sensors functional range as line of vision for the user;
- the SAE Level Certification remains as fundamental definition for the type of vehicles.

The new meta-classification is the following including three classes:

- Human Driver: the same definition as the previous 2-class meta-classification;
- Advanced Driving System: this class includes the SAE Level 3 and SAE Level 4 vehicles; these vehicles can be modeled as the same type of vehicle for the "user definition", since a human driver is needed to control the vehicle and the considered sensors have the same application range;
- Automated Driver: this class includes the SAE Level 5 vehicles only.

This meta-classification allows the analysis of the following future scenarios:

- short-term scenarios with both Human Driver and Advanced Driving System vehicle classes only,
- medium-term scenarios as above with low percentage of Automated Driver class vehicles,
- long-term scenarios with Advanced Driving Systems and Automated Driver classes only and no Human Driver class.

5. Future Developments

The proposed 3-class meta-classification support several possible outcomes, such as:

- specification of new models of Traffic Flow Theory to deal with congestion in mixed traffic;
- new path choice models for travel demand assignment aiming at Transportation System Analysis [12] [13];
- parameter calibration from real, or at least, laboratory studies (survey, driving simulator, etc.).

Acknowledgement

Both the authors want to fulfill their gratitude to prof. Giulio Erberto Cantarella for the support in developing and publishing this paper; Orlando Giannattasio wishes also to thanks prof. Angela Di Febbraro, his Ph.D tutor, and prof. Nicola Sacco for their helpful comments.

References

1. Cantarella G E, Di Febbraro A, Transportation systems with autonomous vehicles: Modeling issues and research perspectives. In the 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems, MT-ITS 2017, Proceedings 8005580, pp. 1-6.

2. SAE document J3016, (2014), Taxonomy and Definitions for Terms Related to On-Road Automated Motor Vehicles.
3. Bartels A, Eberle U, Knapp A, System Classification and Glossary. H2020 AdaptIVe Project Deliverable D2.1, 2015.
4. Schweppe H, Zimmermann A, Grill D, Flexible On-Board Stream Processing for Automotive Sensor Data, IEEE Transactions on Industrial Informatics, 2010, 6(1): 81-92.
5. Xu J, Chen G,Xie M, Vision-Guided Automatic Parking for Smart Car, IEEE Intelligent Vehicles Symposium 2000Dearborn (MI), USA October, 2000: 725-730.
6. Rohling H, Meinecke MM, Waveform Design Principles for Automotive Radar Systems, Radar, 2001 CIE International Conference on, Proceedings, 2001, 4: 1-4.
7. Rasshofer RH, Gresser K, Automotive Radar and Lidar Systems for Next Generation Driver Assistance Functions, Advances in Radio Science, 2005, 3: 205–209.
8. Park WJ, Kim BS, Seo DE, Kim DS, Lee KH, Parking Space Detection Using Ultrasonic Sensor in Parking Assistance System, 2008 IEEE Intelligent Vehicles Symposium Eindhoven University of Technology, 2008: 1039-1044.
9. Jeong SH, Choi CG, Oh, JN, Yoon PJ, Kim BS, Kim M, Lee KH, Low Cost Design of Parallel Parking Assist System Based on an Ultrasonic Sensor, International Journal of Automotive Technology, 2010, 11(3):409−416.
10. Di Febbraro A, Sacco N, Open Problems in Transportation Engineering with Connected and Autonomous Vehicles, Transportation Research Procedia, 2016, 14: 2255-2264.
11. Cascetta E, Transportation System Analysis: Models and Applications, New York: Springer, 2009.
12. Cantarella G E, Di Febbraro A, Transportation Systems with Autonomous Vehicles: models and algorithms for equilibrium assignment. In Transportation Research Procedia 27 (2017) 349–356.
13. Cantarella G E, Di Febbraro A, Di Gangi M, Giannattasio O, Solving Stochastic Assignment to Transportation Networks with TVs and AVs. Proceedings of the European Transportation Conference 2018. Submitted to.