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Analysis of necessary sensors in city e-buses for observing the environment for each level of autonomy

Bartosz Patkowski[1], Dariusz Adamczyk[1,3], Franciszek Sidorski[1,3], Michał Sierszyński[1,2], Michał Pikuła[1,2], Łukasz Chełchowski[1,2], Dariusz Michalak[1]

[1]*Solaris Bus & Coach S.A., Research Development Department, Obornicka 46, Bolechowo-Osiedle 62-005 Owińska, Poland, bartosz.patkowski@solarisbus.com, dariusz.adamczyk@solarisbus.com, franciszek.sidorski@solarisbus.com, michal.sierszynski@solarisbus.com, michal.pikula@solarisbus.com, lukasz.chelchowski@solarisbus.com, dariusz.michalak@solarisbus.com*

[2]*AGH University of Science and Technology, Adama Mickiewicza 30, 30-059 Kraków, Poland,*

[3]*Poznan University of Technology, Piotrowo 3A, 60- 965 Poznań, Poland*

Abstract

Increasingly restrictive policy of local governments and city authorities causes demand on rapid development of environment-friendly public transportation vehicles. PTOs (Public Transport Operators) in Europe have a significant influence on industry, which causes new challenges for automotive, peculiarly for bus manufactures. The first step in order to meet the requirements was to develop buses, which have marginal environmental impact in the place of operation. Behavior of the driver, as the most unpredictable factor, is causing various energy consumption and harmful emission [1]. This aspect can be reduced using driver-assistance systems. Adapting ADAS (Advanced Driver-Assistance Systems) and self-driving technologies into vehicles will lead not only to ecological aspects, but also to road safety and improvement of traffic flow. In recent years the number of experienced drivers have noticeably decreased [2]. Nowadays, the vast majority of bus drivers and PTOs indicate the need to develop and implement systems supporting maneuvering.

Every ADAS and autonomous system should be founded on well-adjusted components. This paper will describe the methods of evaluating the matching devices for each level of autonomy. Furthermore, market analysis and comparison of distinctive ADAS and autonomous equipment will be presented [3]. Owing to the scientific research gained from cooperation of AGH Science and Technology University, Poznań University of Technology and Solaris Bus & Coach experience is leading to development of ADAS. Analysis of necessary sensors in city e-buses, including case study, will be presented in the paper.

1 Introduction

1.1 Work environment of a driver-assistance system

One of the key aspects of autonomous vehicle development is defining the operating areas in which drivers supporting systems will take over the most challenging manoeuvres. The most important factor for all of the vehicle manufacturers is the safety of the people utilizing and having contact their products. Therefore the first tests of the autonomous prototypes take place in areas restricted for public use to ensure that no harm will be done to the vehicle crew and the bystanders. The entry levels of driving automation (0 to 2 level according to the SAE J3016) require the presence of the driver and indicate that operator is responsible for the whole scope of the vehicle operation. On these level ADAS serves only as the assistance for the driver. As the result, thanks to the continuous supervision of the operator, in many countries there is a possibility to conduct autonomous vehicle tests on the public roads.

The several assumed conditions need to be fulfilled in order to provide the proper performance of the system. One of the major requirements is to assure that all of the road surface markings and the traffic signs are clearly visible and presented in the standardized manner. It shall be taken into account during the design process of the vehicle that early stage sensors can be sensitive to the atmospheric conditions. Along with achieving higher automation levels the vehicle is becoming progressively less human dependent. Additionally, the legislation related to the autonomous vehicles impact was analysed in the further chapters.

As a rule of thumb the first evaluation trial of the vehicles with driver support devices fitted is conducted on the restricted areas (preferably on the specially distinctively designed test track). The course should be prepared to implement adjustments necessary to emulate diverse working conditions. After successfully performed initial inspection, the further analysis should be made on the designated part of the public routes. Thanks to the autonomous vehicle friendly law elected in California, the first tests of the driverless heavy goods vehicles traveling on the predefined routes were executed. Still, due to the lack of dynamic road conditions adaptation, we cannot define this vehicle as the fully autonomous, however the High Automation level is achieved. The highest SAE level (Full Automation) is accomplished when the vehicle is able to adapt to all road circumstances. In case of occurrence of the unexpected or previously not appeared situation the vehicle have to be capable of making the proper decision in the real time.

1.2 Different levels of driving automation

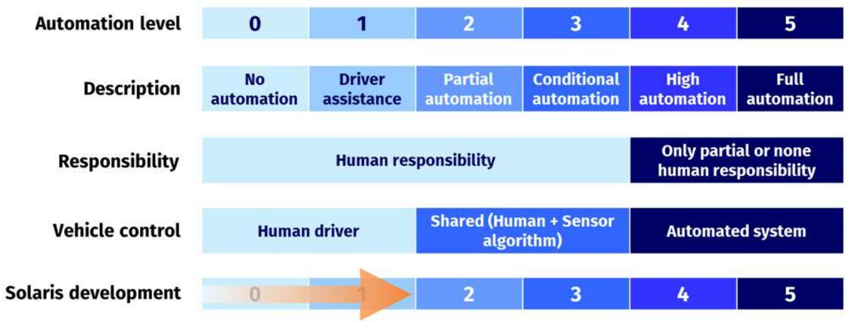

Figure 1: Levels of driving automation including Solaris development[5]

The level of the driving automation is described as the stage of development of the drivers supporting units in the vehicle. Currently the most accepted explanation of the particular levels is presented by the SAE J3016 document. The norm distinguish 6 levels of driving automation, which are classified according to the predefined criteria. The system functionalities and responsibility distribution between operator and the algorithm are detailed. Each vehicle equipped with drivers supporting system needs to have a data logging devices on-board. Thus the black box data acquisition system should be installed in the vehicle. On the basis of the received data the division of the action performed by the system and the driver in case of the road accident is feasible. The SAE document determines 4 crucial criteria and upon them it is possible to indicate the level of system automation.

The first parameter is the sustained lateral and longitudinal vehicle motion control. This functionality allows to maintain vehicle in the preordained state. Illustrative example of the feature fulfilling the requirements mentioned is cruise control, which allows the vehicle to keep the constant speed without analysis the external environment. The unit works only thanks to the pretrained operating scheme.

Second classification factor is an OEDR (Object and Event Detection and Response). It describes the reaction behaviour of the system for the objects recognition and feedback on the unexpected situation occurrence. The clear example of an OEDR activity is a case when pedestrian jaywalks and the system recognizes the threat and undertakes the action to prevent the serious accident. The system feedback approach is crucial to evaluate the autonomy level

Two remaining benchmarks used to define SAE stage are DDT (Dynamic Drive Task) fallback and ODD (Operational Domain Design) fallback. The DDT indicates how the systems reacts to the dynamic driving conditions such as road surface change or variable weather type. The DDT implementation into the drivers support system is obligatory to meet the least the Conditional Driving Automation level requirements. ODD (Operational Domain Design) according to the glossary means a description of the operating domains in which an automated driving system is designed to function, including geographic, roadway, environmental and speed limitations. Based on our experience, meeting the ODD requirements is the most challenging part of designing the system. Furthermore this criterion is the most demanding in terms of computing power and requires large quantity of sensors.

Level of the driving autonomy inflicts the separation of responsibilities. SAE norm distinguish three types of control responsibility: human responsibility, partial system responsibility and full system responsibility. Until reaching the second level of SAE driving automation the system is utilized only as the passive supporting device – via visual, haptic or sound alerts. In the next step, after the more complex devices and algorithms were applied, it is possible to proceed to the next levels when some of the steering tasks are taken over by the system. Adaptive cruise control system can be described as the example of the partial automation feature – some of the assignments are managed by the vehicle. High and full automation levels are achieved after the system is able to replace the human in all of the manoeuvres. Detection of the specific environment points, self-localization and conducting complex steering operations without the human intervention are some functionalities of the fifth and sixth level of the SAE driving automation.

1.3 Autonomous vehicle law regulations

Currently prototypes of vehicles equipped with driver assistance systems and autonomous vehicles become more and more accessible and common. Manufacturers of public transport vehicles outdo each other in equipping their vehicles with technological innovations, however not all components are certified and approved for use in public road traffic. Before creating series autonomous system it is obligatory to verify its safety through a series of tests and legal regulations.

The definition of an autonomous vehicle varies depending on the country or organization. The taxonomy created by SAE (described in the chapter above) is the currently being used as the most respectful document describing different levels of driving automation stages. When the Conditional, High or Full level of the vehicle automation is reached, the algorithm could manage the steering tasks independent of a driver. In case of the vehicle accident it is difficult to indicate who is responsible for the situation - the vehicle manufacturer or the driver. Among other things, such dilemmas have caused that some countries are not legislating even for testing autonomous vehicles on public roads.

In 2018, the auditing and consulting company KPMG International conducted a study on the readiness of individual countries of the world for introducing self-driving vehicles to the market. One of the key factors defining the result, and thus the position of the country in the ranking, was the state of the country's legislation on the vehicles with ADAS and autonomous systems. High places in this ranking are occupied by such countries as the Netherlands, United States and Germany.

Regarding to the creation of legislation regulating the law on the use of electric vehicles, it was possible to create many projects that enabled testing and gathering experience from the operation of vehicles in real conditions. Autonomous vehicle industry is developing rapidly. There are many projects related with autonomous vehicles, such as WEpod - operating in Wageningen in the Netherlands without a driver on a university campus, or Waymo - an autonomous passenger vehicle on the roads of California.

2 Technical analysis of driver-assistance system components

2.1 Required data obtained to driver-assistance algorithm

Achieving Driver Assistant level require information about environment identification and status of predefined conditions. Data processed by an autonomous systems could be divided into two categories: information about vehicle status - current working devices in the vehicle and information about working area. Vehicles equipped with ADAS have additional sensors monitoring close environment. The supplementary devices are needed to increase redundancy of the system. During creating architecture of the vehicle with autonomous system, there is a need to take into account preparation of the additional space for devices, which are collecting data. Data acquisition from the near area around the vehicle comes from different independent sensors. Currently in automotive industry there is no standard which defined cohesive architecture of the system. The most often used devices are ultrasonic sensors, radars, vision systems and laser scanners. Algorithm implemented in ADAS relies on the data obtained from the sensors that observe the surroundings.

One of the groups including autonomous systems are object detectors. Their main functionality is to measure distance between vehicle and objects located in the near area. Data acquired regarding an environment lets a system knows about possible dangers, therefore it could react in a proper way. The essential aspect for a driver is an information about objects located in the blind spots. Sensors being part of an autonomous system monitor blind spots for the driver and warn the operator about aberrant situation. In specific weather conditions like fog, radars have broader field of view then the human eye. Data collected from the radars allows the driver to continue the course despite the difficult weather condition.

Communication between devices is a part of autonomous system and therefore communication protocol should be uniform. In automotive industry the most common solution is CAN, thus it is expected that it will be used as the standard communication protocol. The most significant parameter of the sensors is their reliability. Proper evaluation of the operation during continuous work is required. Status information from each device is based on the data format DM1 (Diagnostic Message 1).

Radars are not able to provide all the information about the working area, thus the cameras are broadly utilized in the autonomous vehicles. On the basis of obtained information from the vision systems, the autonomous system is able to identify earlier defined objects and classify them.

2.2 Selection and sensors fusion of components

Creating an autonomous system requires a wide analysis of the environment in which the vehicle will operate and the devices in which the vehicle will be equipped. Autonomous system requires an individual configuration. As mentioned before fundamental sensors in the autonomous architecture are radars and laser scanners. The main advantages of these devices are wide-angle field of view, high frequency of data refreshing and multiple beams. Based on the data provided by sensors the system is able to create a map of working area.

Vision systems are mandatory devices at higher levels of autonomy. Based on the information from cameras the system is able to get more detailed information from the workplace. Utilizing the image data, the system is available of performing the identification and interpretation of the infrastructure existing in the close surrounding including the road signs classification feature.

Figure 2: Example of vision system research on Solaris electric vehicle [6]

The key aspect of the autonomous system is the integration of collected information. This data integration is called Sensor Fusion. Overlapping measurement allows verification of information from one area from several independent sources. An important task of the whole system is to determine the redundancy of individual sensors to ensure safe operation of the vehicle.

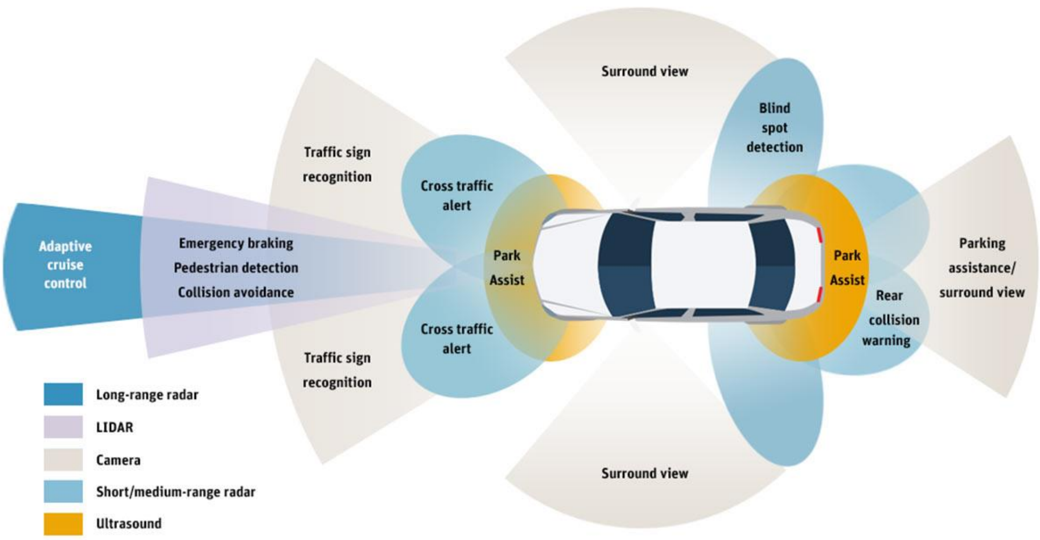

Figure 3. Sensors architecture of autonomous vehicles [8]

Figure 3 shows example of Sensor Fusion use. Each sensor is defined with its own trust factor estimated on the real condition tests. Duplication of measurements of the one, common area increases the credibility of the information obtained.

Table 1- Redundancy of the autonomous vehicle sensors

System state	Individual probability
3 sensors working	$P = 0{,}93^3 = 0{,}804$
2 sensors working, 1 sensor failed	$P = 3 \cdot 0{,}93^2 \cdot 0{,}07 = 0{,}181$
1 sensors working, 2 sensor failed	$P = 3 \cdot 0{,}07^2 \cdot 0{,}93 = 0{,}013$
3 sensor failed	$P = 0{,}07^3 = \mathbf{0{,}0003}$

The constraints of these systems are computing units that are not able to process all the sensors information or size and power consumption of ECU is not designed for the automotive purposes. The structure of the autonomous system consists of two independent computers. The first one is used to collect and define the reliability of data. The second unit is able to process specific algorithms, such as identification, grouping, determining the danger or sending control signals to the executive systems.

2.3 Case study of Solaris e-bus equipped with ADAS

It should be observed that Solaris Bus & Coach S.A. has a comprehensive experience and constantly develops ADAS technologies and systems operating in the bus fleets. Driver assistance systems during the process of electric bus connecting to the pantograph charging station was one of the first ADAS technologies used in everyday public transport operation in Hamburg, as well as in Barcelona. Vehicles delivered to these cities were equipped with RFID (ang. Radio Frequency Identification) sensors supporting positioning of the vehicle at the charging stations. The principle of the operation of the sensors described above is shown in the Figure **4.**

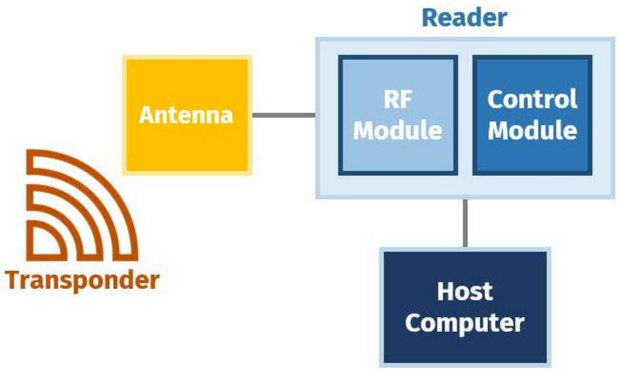

Figure 4: The principle of operation of RFID system [7]

The basic RFID system consists of antenna, transceiver and transponder. This units can be divided into active and passive devices. Active units have their own power source, while passive ones receive energy from the reader. It is worth noting from the Figure 4 that appearing in the read zone transponder transfers data to the reader, which decodes the data. In next step the data is transferred to interfaces like host computer or logic computer as well [7]. Solaris Bus and Coach S.A. uses RFID technology to support bus drivers. The pantograph positioning system (PPS) is a driver assistance system used when the vehicle is positioned in a direction that allows correct connection of the pantograph (contact head) to the docking dome (contact dome). The principle of the operation of PPS system is shown on the Figure 5.

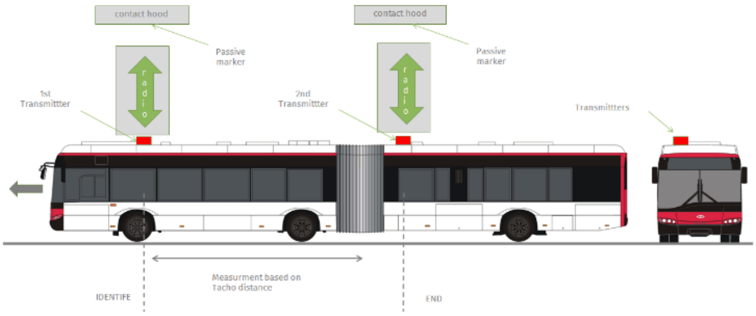

Figure 5: The principle of operation of Solaris Bus & Coach PPS system [6]

Electric bus during arrival to the pantograph charging station receives signals from RFID transponders. Signals returned to the bus driver allow positioning the vehicle accurately under the contact dome. The RFID technology used in PPS system allows saving the time required for the bus positioning and simplifies the process for less experienced drivers. A similar installation has been applied to electric buses delivered to Hamburg. In this case the PPS system is assisting the driver during positioning the vehicle under the inverted pantograph charging station. It allows correct connection of pantograph to the electric charging rails installed on the roof of the vehicle. The driver who is performing the maneuver receives graphic information on the driver's desk showing approximate distance to the point of connection to the charging station what is shown in the Figure 6.

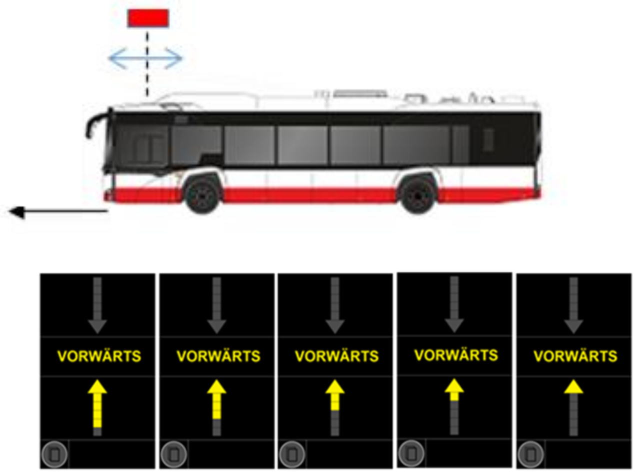

Figure 6: Solaris Bus & Coach PPS system used in Hamburg [6]

When the driver reaches the charging point, he receives STOP information on the dashboard. Operator is additionally supported by the sound signals. It is worth noting that the use of RFID systems is associated with certain problems like accuracy of the process in unfavourable weather conditions. Limitation of technology leads Solaris to search for additional systems, which increase the accuracy and reliability of ADAS. Differential GPS, 3D cameras, radar technologies will allow in the future to obtain higher levels of autonomy in the operation of the bus in public transport [3].

3 The future development of electric bus autonomous equipment

ADAS is currently based on several technologies, which support the driver during various maneuvers. In the future, this type of systems will be based on the sensor fusion concept described in previous chapters. The main advantages of the solutions based on the sensor fusion are reliability and the ability to operate with very high precision. In addition, there is an increasing support by legal regulations carried out by the governments of European Union countries. Germany is one of the European countries introducing an advanced fusion sensor in public transportation vehicles. It is planned from 2021 to introduce mandatory equipment for buses with a driver support systems based on data obtained from devices such as radar, LiDAR and vision systems. The current state of art data transfer systems focus from zero to second level of driving automation. Commonly used Human Machine Interfaces are vision, sound or haptic systems. Human factor is the largest unknown in the process of the vehicle control, therefore in the future it is planned to replace the driver with executive systems. Estimated increase in the share of sales of autonomous vehicles is presented in the Figure 7.

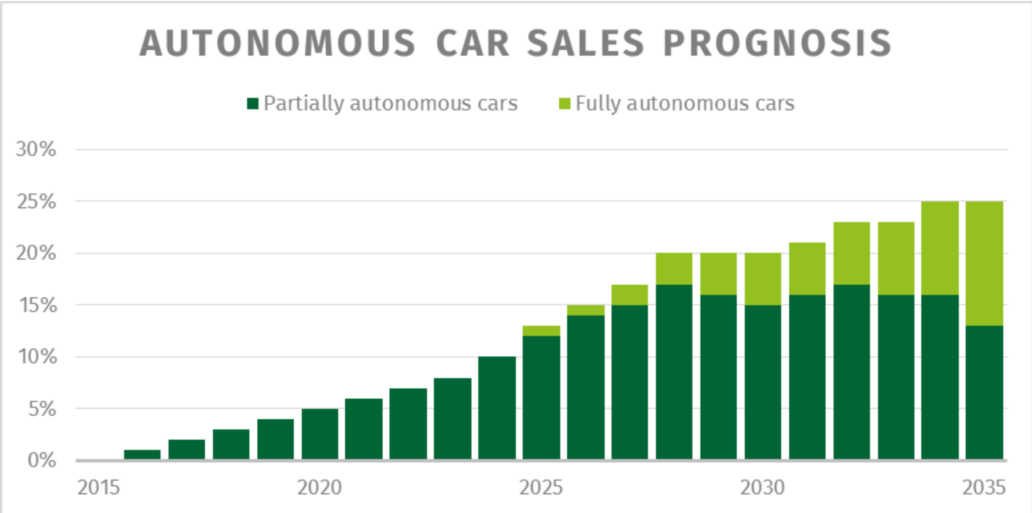

Figure 7 – Estimation of the autonomous vehicle sales

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Authors

Bartosz Patkowski – received the M.Eng. degree in Automatic Control and Robotics Engineering from Poznan University of Technology in 2017.

In Solaris Bus & Coach since 2017. He works as a Junior Design Engineer in Advanced Technology Team.

Dariusz Adamczyk – graduated from Poznan University of Technology at Faculty of Mechanical Engineering and Management.

In Solaris Bus & Coach since 2015. Currently works as a Junior Design Engineer in Advanced Technologies Team.

Franciszek Sidorski – PhD candidate in Institute of Electrical Power Engineering of Poznan University of Technology at the field of Modern Electrical and Information Engineering. In Solaris Bus & Coach works in Homologation and Testing Department since 2017. Responsible for testing electrical buses and charging stations.

Michał Sierszyński – graduated from Poznan University of Technology at Faculty of Electrical Engineering, Automatic Control and Robotics and from Poznan University of Economics and Business - Project Management studies.

In Solaris since 2004. Since 2012 as Advanced Technology Manager in Research and Development Department.

Michał Pikuła - graduated from Poznan University of Technology in the Electrical Engineering Faculty. He holds a M.Eng. in Electric and Computer Systems in Industry and Vehicles since 2001.

In Solaris since 2001. Since 2014 Director of Bus Development in Research and Development Department.

Łukasz Chełchowski – graduated from Poznan University of Technology at Faculty of Electrical Engineering. In Solaris since 2005. Currently works as the Electrical Systems Manager. Responsible for developing new electrical solutions.

PhD Eng. Dariusz Michalak – after graduating from the Faculty of Machines and Transportation at Poznan University of Technology, from 1993 until 1998 Michalak worked as researcher and teacher in the Institute of Machines and Motor Vehicles. He obtained his PhD at the Poznan University of Technology.

Joined Solaris in 1998. On August 2012 appointed to the Solaris Management Board.