The role of smart sensors implemented in vehicles for traffic automation of the future

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Abstract

The development of advanced technologies such as information-communication technology, sensor technology and computer technology lead to the transfer of information held by sensors to the microcontroller at any moment, so that software, as the primary medium for decision-making, can direct the vehicle to desired destination, thus improving the participation of all traffic members. Applications of smart sensors and mechatronic systems are represented in almost all devices and are at the forefront of technologies such as: traffic, railway and air transport systems. Nowadays, cars are very complex sophisticated electronic control systems and most innovations in the automotive industry have been achieved through electronics and the implementation of smart sensors. The development and research of advanced technologies has led to a significant progress. The best example is the automotive industry, where almost every high-end car has over 100 ordinary and smart sensors, 100-150 electric motors, network systems with thousands of signals, and over 70 microprocessors and microcontrollers. The aim is to achieve an increase in safety for all traffic users. The paper presents the trend of development and implementation of smart sensors in vehicles, as well as their development and research in the coming period.

Keywords*: car, advanced technologies, sensor, smart sensors, microprocessor, microcontroller.*

1 Introduction

Based on statistical data collected by the World Health Organization (WHO) [1], it is known that every year around 1.3 million people die in traffic worldwide, and that 20-50 million people suffer injuries caused by participation in traffic, either as cyclists, pedestrians, motorcyclists, drivers or passengers in vehicles. The largest number of victims were young people aged 5-29 (more men than women), so for example 73 % of all deaths are young men under the age of 25. Likewise, 93 % of deaths come from low and middle income countries. Many factors have an influence on the increase in traffic accidents, such as driving at high speed and driving under the influence of alcohol and psychoactive substances. In addition to these factors, there are many other factors that have a negative impact on safety on roads such as: not using helmets when riding bicycles and motorcycles, not using seat belts and safety systems for children, the use of mobile phones, thus leading to impaired driving, unsafe vehicles, unsafe road infrastructure, etc. In order to reduce the number of people killed in traffic accidents and the number of injured traffic users, progress in modern technologies is very important, especially progress in the sensor technology in the automotive industry, i.e. mechatronic systems equipped with smart sensors, the so-called micro-machine and micro electro mechanical systems (MEMS). Their implementation began in 1981

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with the introduction of a pressure sensor for controlling engine operation in vehicles. Their advantage is that they are miniature and use the latest basic technologies of Industry 4.0, so that drivers have all the necessary information to make a decision while driving at all times. In other words, the driver has the ability to make a decision even at the moment when he starts to make mistakes. Their implementation in vehicles is increasing and improving every day, as well as other road infrastructures that serve for the development of traffic. The implementation of micromechanical and micro electro mechanical systems (MEMS) and their connection with information communication technology in vehicles can be called intelligent transport system. It is designed to reduce travel time, improve performance, efficiency and safety in traffic.

2 Trend of development of "smart sensors"

A sensor (in Latin–sensus: sensation; sensation, sense) can be defined as a devicethat is part of a measuring system that measures a physical quantity (e.g. pressure, number of revolutions, displacement, temperature, speed, etc.) and gives an output signal that depends on the value of the measured quantity, turns it into a signal suitable for further processing, and most often into an electrical signal that serves as an input for system control.

Many companies in the world have developed different constructions of sensors for measuring different physical quantities. In the middle of the twentieth century, Samuel Bagno applied his patent for sensors used as burglar alarms. At the beginning of 1940s, Samuel Bagno began to research ultrasonic alarms. His research focused on a network of ultrasonic waves that were sent from the modem around the room and bounced off static objects back to the modem, so in the event of movement there would be interference waves and the modem would detect them and trigger the alarm.

The development and research in new technologies has progressed so much that sensors are used in all segments of our lives. The historical development of sensor technology is shown in Figure 1.

Fig. 1. Historical development of sensor technology

As Figure 1 shows, the development and implementation of smart sensors is an ongoing process, starting with mechanical sensors, electrical sensors, and electronic sensors. The standard defines smart sensors as sensors with little memory and a standardized physical connection that enable communication with the processor and data network [2,3,4]. The block diagram of the smart network sensor is shown in Figure 2.

Fig. 2. Block diagram of a smart network sensor and schematic representation of a smart sensor

The block diagram of the smart network sensor shown in Figure 2 gives an insight into how the monitoring of the parameters is achieved, i.e., what other devices are necessary for monitoring the parameters. Based on Figure 2, which gives a schematic representation of a smart sensor, we see

that smart sensors with built-in IO-Link (the first standardized IO technology in the world (IEC 61131-9) for communication with sensors and actuators) work the same as standard I/O sensors that are used until the moment they are connected to the IO-Link Master. When the sensors are connected to the IO-Link Master, we are able to access all the advanced data and configuration capabilities that IO-Link can offer.

Many companies in the world have developed a whole range of smart sensors for temperature, pressure, speed, proximity sensors, photoelectric sensors, laser sensors, etc.

Fig. 3. Presentation of different constructive versions of smart sensors

The leader in implementation is the company ''Rockwell Automation'' from the USA. Due to limitations, we will show only a small part of the design solutions of smart sensors in Figure 3 [5,6].

The implementation of smart sensors is constantly increasing, and their application can be found in all segments of our environment. The reason for this is simplified application through the standardization of process data and the latest achievements of IO-Link devices with regard to the interface and integration with many different engineering tools. Their implementation can be found in houses, production processes and logistics of production processes, road infrastructure, vehicles, and other segments of our environment. In other words, it is impossible to imagine a product without a built-in sensor that gives us some information. The paper will pay more attention to the sensors used in the automotive industry.

3 Implementation of smart sensors in the automotive industry

In the automotive industry, until recently, sensors were implemented as direct devices that were used to measure coolant temperatures, fuel levels, oil pressure, etc. The development of electronics and information technology accelerated the development and research in sensor technology so that development and progressive implementation of sensors took place. We can mention that, for example, in 1995, the number of implemented sensors in vehicles increased to ten, while the increase in 2010 was more than 30, as stated in [7]. Today, almost every high-end car has over 30 mechatronic systems (electrical/electronic systems) and over 100 smart sensors built into it. Many companies that produce sensors are investing in the development of new types of smart sensors, because they want to remain competitive on the global market. Every year around 100 million vehicles are produced in the world, and knowing the number of sensors implemented in one vehicle, one can see that the demand for sensors is enormous. Modern cars cannot be imagined without sensors. Figure 4 shows a set of different constructions of sensors hat are implemented in vehicles.

Fig. 4. Different constructive versions of smart sensors for implementation in vehicles [8,9,10]

Sensors in vehicles have the role of measuring and sending certain parameters in the vehicle to the central computer, after which data are processed and the vehicle is in operation state. This process happens in milliseconds and the reaction is very fast. Most often implemented sensors in vehicles are those for state, temperature, movement, position, proximity, distance, direction of movement, position, speed and acceleration (angular, linear), elapsed time and frequency, noise and vibration, liquid level, pressure (absolute, differential, atmospheric), flow, speed, force and moment, mechanical stress, orientation, fluid viscosity, electric voltage and current strength, humidity and rain, light intensity, gas concentration, etc. Of all the listed sensors, two are dominant, namely the intake manifold pressure sensor and the airbag accelerometer [11].

There are only two sensors in the world that are applied more than these, namely the read/write print head sensor and the disposable blood pressure sensor. Sensors implemented in vehicles must meet very strict requirements, such as temperature range from 40-125 º (in the engine), vibrations that increase up to 10 years, accuracy, robustness, electromagnetic interference, compatibility, manufacturability, replaceability, including the low price [11].

Perhaps the best example of the conditions in which certain sensors work is a very important sensor that is found in practically all new cars intended for the European market. These are sensors of ABS devices that are located near the axle on all four wheels and are exposed to extreme heat or cold depending on the season. They have to withstand shocks and support the wheels and, at the same time, remain completely insensitive to moisture and chemical agents such as gasoline, oil, acid from the battery, coolants, etc.
Only then can we understand the harsh conditions of sensor exploitation. In order to have an insight in the increase in the implementation of sensors and advanced technologies in vehicles, Figure 5 displays the increase in the implementation of sensors in vehicles every 20 years.

Fig. 5. Evolution of the implementation of advanced technologies in the automotive industry every 20 years for the period from 1950 to 2010 (signal/data, cables, connectors)

Based on Figure 5, we can conclude that the use of advanced technologies in 1950 was almost negligible and the number of signals/data and connectors was very small [12,13]. The development of advanced technologies contributed to the increase in the implementation of sensors in the automotive industry, which can be seen in Figure 5. In 2010, the implementation was so advanced that everything was wired and connected. The reason for this progress is the fact that consumers have an increasing need for improved safety while driving cars. Driving safety is ensured by the implementation of advanced technologies, one of which is sensor technology. In order to get an insight into the standard sensors that are implemented in almost every vehicle nowadays, we have provided an illustration in Figure 6.

Fig. 6. Implementation of basic smart sensors for obtaining status information

Figure 6 shows the following sensors: engine temperature sensor, rpm sensor, air temperature sensor, load sensor, throttle position sensor, rain sensor, steering wheel position sensor, fuel level sensor, wheel speed sensor, mirror sensor, pedal position sensor throttle, vehicle speed sensor and headlight position sensor. The listed sensors provide the driver with information for safe participation of the vehicle in traffic.
Ever since the appearance of the first car, there has been development and research in this area, so

that there has been continuous progress in the field of safety and comfort when driving a car. We will list the levels of car automation [15,17] :

- *Level 0:*there is no automation, and the driver controls the vehicle,
- *Level 1:* maintaining the distance between cars is automated, and the driver still controls the vehicle,
- *Level 2:* partial automation, e.g., keeping a lane and keeping a distance between cars; the driver can take over driving the car at any time,
- *Level 3:* when the car is aware of the environment in which it is located and of all traffic participants; it has the possibility to independently pass the car in front of it,
- *Level 4:* when the system controls the car independently, reacts to traffic participants as well as to sudden traffic events; the car informs the driver when he has to take control of the vehicle, and is provided with enough time to take control; this automation is in test stage with maximum speed up to 50 km/h.
- *Level 5:* complete automation when the system controls the car independently and the car can independently go from point A to point B without the presence of a driver and park itself in any environment and conditions.

The development and research of advanced technologies, primarily sensor technology, and its implementation in the automotive industry brings us to level 5, i.e., the autonomous car. The sensor systems that make this possible are shown in Figure 7 [15].

Fig. 7. Smart sensor systems implemented in the autonomous car

As we can be seen in Figure 7, many smart sensors and mechatronic systems have been implemented in the autonomous car, with which it can independently participate in traffic with or without the influence of the driver. The main element of its successful functioning, as a car that is not driven by a human, is for the vehicle to be aware of its surroundings and other traffic users, which is enabled by the aforementioned numerous smart sensors, radars, GPS and communication with smart infrastructure. Modern cars already have partial automation, and the predominance of fully automated cars is expected by 2030.

4 Research and development in sensor technology

Continuous research and development of advanced technologies that are implemented in the automotive industry have led to the upgrade of the classic traffic system, which achieves a significant improvement in traffic performance, more efficient transport of passengers and goods, improvement in traffic safety, comfort and protection of passengers, reduction of environmental pollution, etc. The upgrade of the classic traffic system is nothing but intelligent traffic system, which is defined as a holistic, management and information communication (cybernetic) upgrade [16,17].

Intelligent traffic systems enable information transparency, controllability and improved response of the traffic system. In other words, it supports the ability to act adaptively in changing conditions and situations, where it is necessary to collect enough data and process them in real time. The collection of data is provided by palm sensors that are implemented both in cars and devices for traffic regulation and other traffic participants. In order to ensure the intelligent transport of people and goods in the future, research, development and improvement of smart sensors need to be continuously conducted, as shown in Figure 8.

Fig. 8. Development of a smart sensor-radar, the future of intelligent traffic

Figure 8 indicates that there are four steps of development of the smart sensor-radar of the future, which started in 2019, and enabled us to measure the height in traffic. Progress in research and implementation of a smart sensor-radar continued in 2021 with a high resolution in which sensors could record and recognize nearby objects [12,13]. In 2021, the improvement of the smart sensor-radar is reflected by reduced interference and increased safety. The improvement is ongoing so that the smart sensor-radar records, classifies and marks traffic participants. The development and implementation of smart sensors in vehicles is constantly increasing, as shown in Figure 9.

Fig. 9. Trend of sensor-camera implementation in vehicles for the period 2012-2024

Based on Figure 9, we can conclude that the implementation of sensor-cameras on vehicles has been increasing on annual basis. In 2012, 2 cameras were implemented in vehicles, while in 2014 this number has increased to 5 sensor-cameras. In 2020, vehicles with 9 implemented sensors-cameras appeared. Sensor-cameras provide information about what is happening in front of the vehicle, behind the vehicle, night vision, driver monitoring, circular view, etc. so that the driver can make decisions in time. The development of sensor technology has led to the point where one smart sensor can be used for more information, i.e., there has been a fusion of smart sensors (Figure 10). For example, in 2020, there has been a fusion of smart ultrasonic sensors used for monitoring the blind spot and parking assistance, or the radar sensors which are used for monitoring the blind spot, parking assistance and maintaining a preset speed and distance from the vehicle in front, as shown in Figure 10. The development in new technologies and sensor technology is expected to increase the fusion of data provided by smart sensors by 2030 [12,13].

Fig. 10. Trend of smart sensor data fusion in 2020, as well as predictions of data fusion provided by smart sensors until 2030

The data fusion provided by smart sensors is used for automated driving. Each smart sensor used in the vehicle enables greater functionality. New research and development will continue to increase the functionality of each smart sensor for use in the automotive industry as well as other industries. It is expected that a trend in innovations in advanced technologies will increase in the coming years, including sensor technology, as shown in Figure 11 [14,17].

Based on Figure 11, we can see that new innovations are expected from some advanced technologies in 2 years, some technologies in 2-5 years, whereas certain technologies will take 5-10 years and more than 10 years for the development.

Fig. 11. Expectations of innovation in advanced technologies

Figure 11 lists advanced technologies with certain specified years. It is expected that development and research in sensor technology will lead to biodegradable sensors, and such

research and development requires more than 10 years. It is estimated that the development will lead to a reduction in sensor dimensions and an increase in performance [19,20].

5 Conclusion

It is well-known that traffic is continuously increasing, and therefore many problems appear. One of the most important problems that need to be addressed and solved is the issue of traffic accidents. Research and development of advanced technologies used in the automotive industry are directed towards traffic safety, i.e., increasing safety for all traffic participants. Development and research of advanced technologies, including sensor technology, has led to the development of smart sensors that are implemented in cars to facilitate traffic. They also assist the driver to make a timely decision on what to do in order to increase traffic safety and reduce the number of accidents and fatalities of traffic participants. The implementation of sensors in vehicles is continuously increasing on annual basis, so that almost every high-end car has over 100 implemented sensors and over 30 mechatronic systems (electrical/electronic systems) that serve to ensure the safe participation of all traffic users. In the coming years, the trend of innovation in sensor technology will increase, so we can expect a greater fusion in one smart sensor that will be multifunctional. Smart sensors represent the basis for an autonomous vehicle and intelligent traffic systems that will facilitate the movement of goods, people and information in the future. Future research in sensor technology leads to biodegradable smart sensors, which is the goal of reducing pollution in the world.

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