Utilization of modern sensors in autonomous vehicles

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***Abstract*— The aim of this work is the development and innovation of localization methods in interior and exterior spaces. In this work, sensors used to locate the position in autonomous vehicle systems are mentioned. Furthermore, this work deals with the fusion of data acquired from different types of sensors as well as their processing.**

***Keywords*— Autonomous vehicles, ADAS, Localization of position, Space mapping, Measurement of diestance**

I. Introduction

Thanks to the development of electronic technologies integrated into the automotive industry, there has been a revolution in the technology of road vehicles in the last 20 years. Nowadays modern vehicles, about 100 microcomputers that provide the driver with comfort, assistance, and security are implemented. Electronics systems control almost all of the functions in the vehicle and due to this fact, there are efforts to harmonize vehicle-to-vehicle communication (V2V) and vehicle-to-infrastructure (V2I) information exchange. Advanced Driver Assistance Systems (ADAS) address more complex and complicated tasks for the driver. For example, Adaptive Cruise Control (ACC) or lane keeping assistance (LKA) make driving easier. In the near future, public road vehicles will be able to ride without a driver. This paper deals with the architecture and functionality of today's highly autonomous vehicle control systems.

II. Introduction to Autonomous Vehicles

A. Reduction of accidents

The reduction in the number of accidents and the severity of accidents is, according to EU objectives, the most important one, not only a European goal but a global one, that affects the whole of society. Every year, nearly 50 million people are injured in the world and 1.2 million people die in traffic accidents. More than half of them are people between 15-44 years of age. Predictions indicate, that without major improvements in road safety, road accidents will be the second leading cause of death by 2030. New solutions for transportation have to face the limited infrastructure and even further growing demand for transport. Therefore, highly automated road vehicles (integrated into the intelligent environment) will have a key role to play in improving road safety. The EU road safety strategy defined in 2001 has achieved significant results, but there is still room for improvement.

B. Decision making of autonomous vehicles

Autonomous vehicles bring, in addition to innovation, the risks which humanity will face in the future, such as the ethics of accidents. The achieved development of autonomous vehicles promises to reduce road accidents. An important aspect of autonomous control will be the choice of the system in a special situation when the vehicle will have to choose between pedestrian life or harm crew. Car manufacturers have to deal intensively with the decision of autonomous vehicles.

C. Saving energy and reducing emissions

Another global challenge is to increase efficiency and environmental friendliness. Europe is accelerating its progress towards a low carbon society, with a view to achieving an 80% reduction of emissions below 1990 levels by the the year 2050. To achieve this, emissions should be reduced by 40% by 2030 and by 60% in 2040. Every industry must contribute to this goal and transport plays a crucial role. Autonomous vehicles increase driving efficiency with Active Green Driving (AGD), Automatic Queue Assistance AQUA. Active Green Driving and Automatic Queue Assistance are implemented in eHorizon [1].

Active green driving is focused on fuel economy and emissions reduction. The vehicle records the route profile (altitude, the power of the engine, breaking action ...) on the eHorizon. eHorizon records the driving profile and provides it to other vehicles. eHorizon consists of three elements:

- Static eHorizon provides topographic digital maps for predictive vehicle management
- Dynamic eHorizon (permanent connection with clouds) use clouds to receive information from sensors of autonomous vehicles and this information is provided to other vehicles
- Road Database keeps the digital maps up to date thanks to the sensors that are located on the autonomous vehicles.

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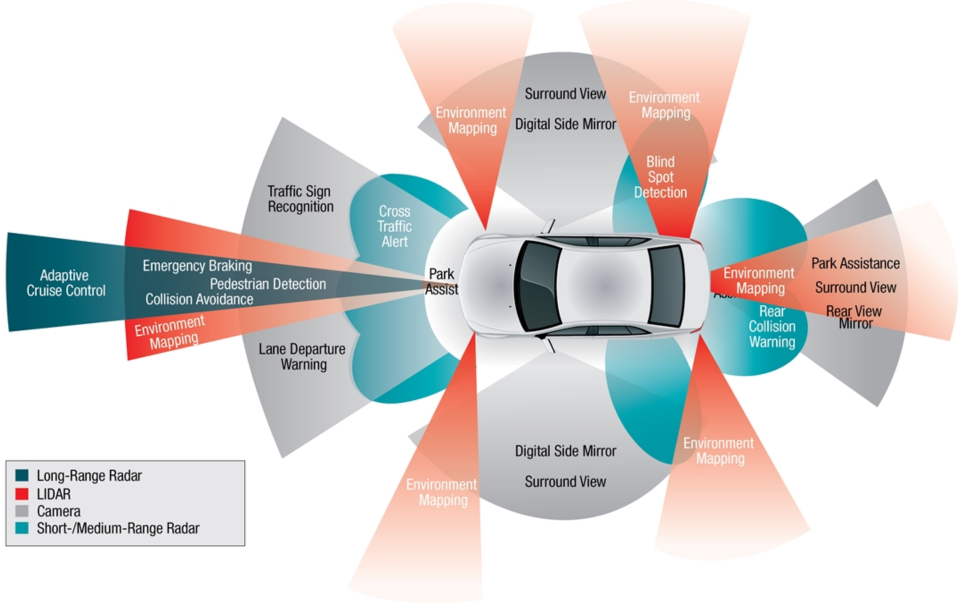

Fig. 1. Sensors layout on the autonomous vehicle *[4]*

III. THE CONCEPT OF AUTONOMOUS VEHICLES

The autonomous vehicle is controlled by the control system based on sensor information. Sensor information defines the Autonomous Vehicle Management Framework.

A. Sensors layout on the autonomous vehicle

The basic system for the control of the autonomous vehicle is based on so-called environmental sensors, which provide information about the surrounding area. The system consists of a remote radar located in the front of the vehicle in its bumper, the long-range radar which serves as a detector for objects in front of the vehicle at higher speeds. Medium-distance objects around the vehicle are mapped by the Lidar Laser Scanners (in most cases multi-layer laser scanners), which is another part of this system. Optical cameras are used to identify traffic signs and driving lanes. To map the near area in front of the vehicle, medium and short-range radars and ultrasonic sensors are used. The arrangement of the sensors in the autonomous vehicle is in Fig. 1.

B. Sensors properties

The role of environmental sensors is to provide comprehensive information about surrounding objects around the vehicle. On the vehicle, various types of sensors are implemented, which provide information from near, medium and distant ranges. Different location of environmental sensors is due to the variation of weather effects, the detection angle and the maximum distance of the observed object. Additionally, the system has to deal with the varying intensity of the illumination or reflection of the surfaces of the detected systems. A sharp change in light intensity may occur during changing the direction of a vehicle or during drive through the tunnel exit.

The Tab. 1 shows the comparison of the basic properties of the sensors used for autonomous vehicles. From the table is clear, that no sensor is suitable for all applications, therefore, the combination of various sensor types based on different physical principles is used. The yellow color indicates the sensors that can be used for a specific case.

The configuration of the sensors varies depending on the car manufacturer. The Tesla S model has eight spatial cameras that cover a 360 ° area with a maximum front camera range of 250 meters. Space vision also supports eight ultrasonic sensors to detect both hard and soft objects. A radar with advanced data processing is provided on the front of the vehicle to provide additional space data in front of the vehicle. This radar is capable of measuring distance even through heavy rain, fog, and dust.

TABLE I. COMPARE OF SENSOR PROPERTIES

	Camera	Radar	Lidar
Detection of objects		+	+
Pedestrian detection	+		
Weather	-	+	
Light conditions	-	+	+
Dirt of the sensors	-	+	-
Speed detection		+	-
Measurement of distance		+	+
Measurement range		+	

The basic difference between radar and lidar is the physical nature on which they work. The radar works with a sound wave and a lidar with an optical beam.

Radar sensors can also detect distances of transparent objects such as windshields of cars or shop showcase. Detecting transparent objects using lidar is not possible because light passes through transparent materials. A comprehensive solution to weather problems and other impacts can be solved by linking data from all sensors. Data fusion from all sensors provides a complex environment map for the control system of an autonomous vehicle.

IV. SENSORS FOR AUTONOMOUS VEHICLES

For the localization of position, a combination of various sensors to achieve the most comprehensive image of the surrounding environment is used.

A. *Cameras for autonomous vehicles*

The autonomous vehicle cameras are usually located behind the windshield, but it can be also located in other parts of the vehicle. In autonomous vehicles complementary metal oxide semiconductor (CMOS) and charge coupled devices (CCD) cameras are used. In CMOS sensors, photons are converted to voltage separately at each pixel. Several transistors located near each pixel serve to measure and amplify the signal from each pixel. The advantage of this arrangement is that the data collection process takes place in the whole chip. The result of this technique is at CMOS chip rate. This difference in chip reading techniques causes significant changes in sensor architecture. The CMOS sensor (Fig.2) converts the charge of each pixel into an electrical signal directly on the chip, which causes less sensitivity. In CCD, only the total number of photons per pixel is measured. For color capture, a color filter or a three-chip camera is required. CCD chip is more sensitive than CMOS.

Car cameras can be classified in several ways, the most important aspect of classification is the location of the camera. In most autonomous applications, they are implemented as a front or rear cameras. The exception is the Tesla car manufacturer, where the cameras are used for lateral shooting of the surrounding area. Another classification is based on color, i.e. black and white, monochrome + one color of RGB and RGB color. These cameras can be further divided into mono and stereo space perception. The color of the sensed environment affects the reliability and precision of some camera functions, although most of the key features can be secured using a

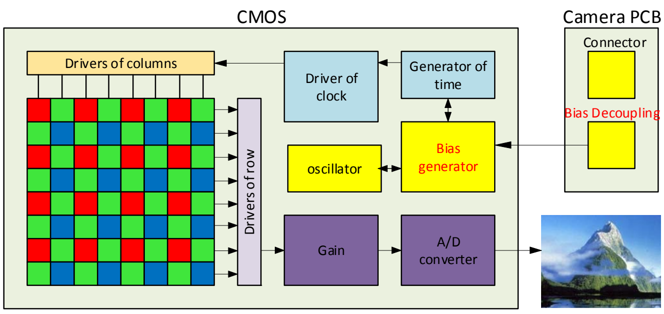

Fig. 2. CMOS Camera

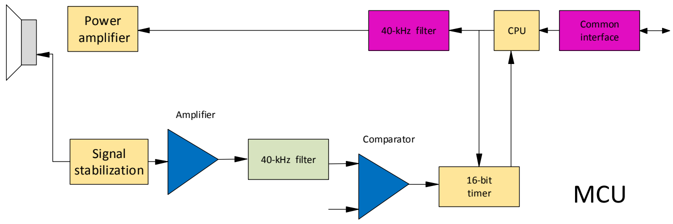

Fig. 3. Block diagram of ultrasonic sensor

a black-and-white camera that captures only the brightness level of each pixel. By adding at least one color, the significant improvement in performance can be achieved, for example by using red-sensitive pixels, the identification of traffic signs can be more reliable. Stereo cameras also have a significant impact on 3D vision, which is important for measuring object distance.

B. *Ultrasonic sensors*

Ultrasonic sensors are mainly used as a short distance parking assistant. They are mostly located in the vehicle's bumpers. Ultrasonic sensors use sound waves above 20 kHz above the human hearing threshold. They are used to determine the distance between the ultrasonic sensor and the object on which the sensor is oriented. The ultrasonic sensor is active as the beacon sends an audible signal to measure the distance. This signal is reflected from the obstacle and spreads toward the sensor. The sensor measures the time between transmitted and reflected wave, using this time the sensor calculates the distance of the object from the sensor. The minimum length of the transmitted signal indicates its minimum measured distance. The distance calculation is as follows and results from the sound propagation velocity in the environment.

$$d = \frac{c \cdot t}{2}. \tag{1}$$

Where c is the speed of light and t is the time that is measured between the transmitted and the reflected signal. The actual sound velocity in the ideal gas is calculated as follows [5]:

$$c = \sqrt{k \cdot R \cdot T}, \tag{2}$$

where k is the adiabatic constant, R is the gas constant and T is the thermodynamic temperature in Kelvin.

In the automotive industry, ultrasonic sensors are mainly used as parking assistants. The range of such sensors is from 25 to 400 centimeters. The Fig.3 shows the architecture of ultrasound systems in automobiles.

The principle of the ultrasonic sensor is based on generating a sound wave. During the transmission of this sound wave, the threshold for the receiver is set, due to the elimination of interference between generated sound wave and receiver. With elapsing time from the start of the transmission, this threshold decreases as the amplitude of the reflected wave diminishes due to the distance achieved and the reflection capability of the material [3].

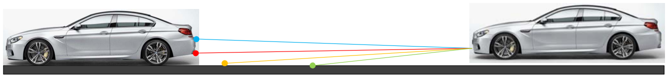

Fig. 4. Four-layer laser scanner

C. Laser scanner

Similarly to ultrasonic distance measurement, the laser scanner works as a distance measurement. The laser scanner is located in the front bumper of the vehicle or on the roof of the vehicle. The main purpose of this measurement system is to track other vehicles, static objects such as barrier or various obstacles along and pedestrian tracking. The car laser scanner is designed either as a 2D system with a rotating mirror for mapping the distance from a vehicle or in most cases as a 3D system that has a multi-directional mirror system and therefore provides 3D space information. Due to the laser technology used, this process can be performed many times per second, 5-50 times per second in most cases, allowing to create a real-time 3D view of the surroundings [1].

To measure the distance of the laser scanner two methods are used - the first method is to measure the time between the beam generation and receiving of the reflected beam. The second method used for evaluating the distance of the laser scanner is to measure the phase shift between the received and the reflected beam. The advantage of laser scanners is their measuring range, measuring accuracy and measuring speed. On the other side, laser scanners cannot measure the distance of transparent objects such as glasses. Fig.4 shows the scanning of a four-layer 2D laser scanner. Fig.5 shows the scanning of a laser scanner connected to the image [4][5][6][7].

D. Radars

Radars used in cars are responsible for detecting objects around the vehicle and also serve to detect dangerous situations. Object detection and detection of hazardous situations to alert or warn the driver can be used. If the car is at a higher level of autonomous control, it can interfere with the braking system or vehicle control. Radar systems are capable of detecting obstacles around the vehicle and also their relative speed. Radar sensors work on the principle of evaluating the difference between the transmitted and received reflected signals [8][9].

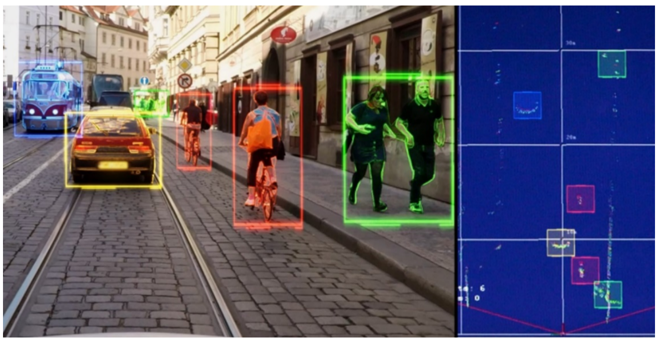

Fig. 5. Data fusion from laser scanner and camera [10]

The main benefits of radar sensors include:

- Object detection
- Distance of detected objects
- Relative speed of objects

The distance measured by sensor radar is calculated by the elapsed time between the transmitted signal and the received reflected signal. With the measured elapsed time and speed of sound wave spread, it is possible to calculate the distance to the detected object. The measurement of the relative speed of detected objects to the vehicle is based on the Doppler effect. Based on the phase shift and the frequency of the reflected wave, the speed of the detected object can be calculated, as well as its direction. Radar systems in autonomous cars work in two bands 24GHz and 77GHz [1].

V. Data fusion

The data fusion (Fig.6) is responsible for comparing all relevant information from the sensors, enhancing the reliability of individual sensor information and increasing the precision of the sensor information. The data fusion provides all the necessary information for the next management layer to successfully complete its task.

Each sensor measures different aspects of objets, for example, laser sensors measure position and speed, while the camera simply estimates the location of the object. Therefore, all sensor data must be evaluated and filtered as first in order to achieve a common (homogeneous) object representation. Then, effective data fusion is coming in. There are several algorithms for sensor data connection, such as Cross-Covariance Fusion, Information Fusion, Maximum A-Posterior Fusion and Covariance Fusion. The standardized output state for each detected object contains the position, speed, object size, object classification, and the level of reliability of the data [1].

Texas Instruments provides a data capture system "TDA2x" that focuses on data capture from cameras and radar screens.

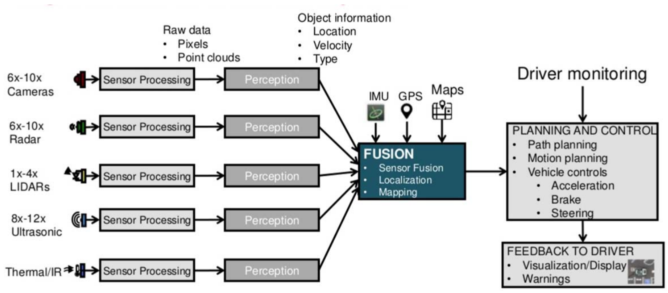

Fig. 6. Data fusion [11]

VI. CONCLUSION

The aim of this work was to analyze the state of the technique in the field of sensors of autonomous vehicles. The first of all, one of the concepts of the configuration of sensors on vehicles was mentioned. The location of the sensors depends on the sensing direction and the field of view. On autonomous vehicles, the sensoric system consists of a combination of sensors, a laser scanner, a radar, a camera and an ultrasonic sensor. The total number of sensors varies, depending on each manufacturer of the autonomous system.

In the next part of the thesis, the advantages and disadvantages of the sensors in various weather influences was mentioned. Therefore, it is necessary to use more types of sensors in order to improve the autonomous system. Subsequently, the principle of the operation of individual sensors was described, from which it can be concluded that no sensor provides sufficient information about the surroundings. The advantage of a combination of sensors is that the disadvantage of one sensor can be improved by the advantage of the second sensor. Barometer, a magnetometer thermometer, and a rain sensor can be used as additional sensors.

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