SIMULATION TECHNIQUES OF THE ADAS PERCEPTION SENSORS: REVIEW

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Abstract: Sensors play a vital role in the perception system for autonomous driving. The development of these systems requires prototyping, testing, and validation of the concept at a low cost and in a safe condition. Simulation is the perfect tool for this role. In this paper, we analyze some possibilities to simulate the most relevant sensor of the perception system.
Keywords: camera, radar, LiDAR, ultrasonic, GNSS.

1. Introduction

Automated vehicles (AD) and Advance Driver-Assistance systems (ADAS) are important branches of the automotive industry. In the last 10 years, this direction conquered more and more space in the automotive world, because some entry-level cars are equipped with ADAS systems [1]. The aim of the AD and ADAS is to assist an existing driver, to increase safety and comfort through its applications [2]. This idea is proved by the fact that in the last years it was observed a decrease in fatal traffic accidents. Moreover, this aspect is seen even if the number of vehicles used daily is increasing [3].

Over the years, the automated functions of the vehicle knew a deep transformation. If the cruise control [4] was developed in late 1960 and it was only for the comfort of the driver, the adaptive cruise control is meant to improve safety [5].

In the last years, the new sensor technology developed has powered the safety system based on autonomous decisions. A good perception of the environment helps the system to take the best assisting decision to increase the safety of traffic. Therefore, functionalities as an automated emergency brake (AEB)[6], line keeper, cornering monitoring, and collision avoidance[7] are part of many vehicles. Besides these, passive safety increased based on the sensors and ADAS capabilities. In this category, we can put pre-tensioned seatbelts, airbags, prepared impact zone in the car, driver monitoring, etc. In addition to this, some features related to comfort and safety are developed: sign recognition, steering wheel assisted, automated parking, etc.

To reach the fully automated vehicle the newest sensors technologies, algorithms, and computation capabilities need to be used, verified, and validated. It is also relevant that the public trust to be reached. Thus, there is a need to develop reliable testing systems for very complex decision, planning or control algorithms. The new perceptive instruments need to be validated throughout many tests in various scenarios. This aspect involves very expensive technology and a lot of effort to create scenarios for a dynamic environment. A proven method used for laboratory tests is to simulate the environment and perception system and then observe and validate the control system.

The perception of the environment is realized with high-performance sensors. Depending on the autonomous level, different sensors or fusion of multiple sensors are used. The most relevant sensors in this category are described in Tab. 1.

Tab. 1. Sensors description

Sensor	Scope	Inputs	Parameters	Reference
Camera	Its aim is to capture images of the surround of the car for: - Identify the distance to the objects around - Identify the road signs - Tracking the line - Used in the vehicle to vehicle communication or vehicle to infrastructure	Reflected light	Dynamic range, temperature range, speed, light intensity;	[8], [9]

Radar	Measurements of range and velocity. Independent of weather conditions.	Microwave rays that build up a Radar beam	Power of beam; vertical and horizontal angle, Cross-section of the target radar;	[10], [11]
LiDAR	It can measure distances by simply calculating the round-trip time of a laser pulse traveled to the target and back; it creates high definition maps	Laser beam	Detection range, field-of-view, Scan Pattern, Cross Talk Immunity, Multiple returns, precision and accuracy.	[12], [13]
Ultrasonic	Measure the distance to the object ahead based on ultrasonic wave;	Ultrasonic ray	Material and surface, air properties, dimension of the objects	[14], [15]
GPS/GNSS/IMU	Determine the position of the vehicle in the space; also, it offers information on velocity and timing	Radio Signals	Attenuation of the signals, wrong antenna orientation, interference with other signals/systems	[16], [17]

In Fig.1 its functional schema describes each sensor. If the camera sensor is based on processing the recorded pixels, the other sensors are based on transmitting ray, and receiving an echo.

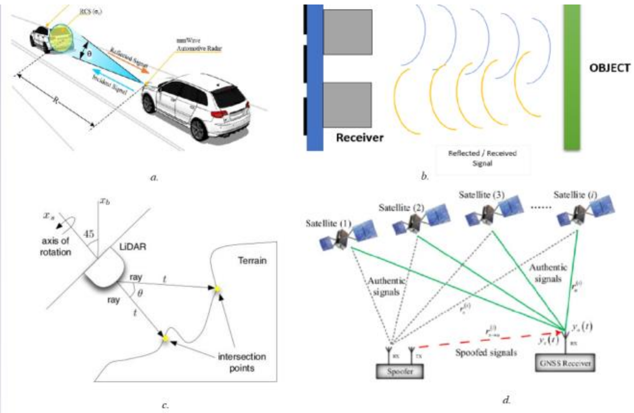

Fig. 1. a) Radar functional schema[18]; b) Ultrasonic sensor function principle[19]; c)LiDAR sensor schema[20]; d) GNSS operation principle [21]

In this paper, we are trying to summarize the existing simulation methods of the sensors used in perception systems and identify the challenges and future directions in research.

The paper is structured on 5 chapters, following these topics: chapter 1 – Introduction in the topic, chapter 2 – Methods, chapter 3 – Results, chapter 4 – Discussion, chapter 5 - Conclusion.

2. Methods

To realize this study and identify the simulation techniques of the perceptive system components, we performed research in the autonomous driving area of perception, starting with the sensors name and continued with specific terms like physical sensor simulation, automotive visual module simulation, camera module testing, camera sensor simulation, radar sensor model, radar sensor simulation, DARTS radar, ultrasonic sensor simulation, ultrasonic sensor model, LiDAR sensor simulation, LiDAR sensor functional test, LiDAR model, GPS module, GPS model and simulation, on specialized platforms like IEEE EXPLORE, Google Scholar with results on different scientific database or directly on the platforms of dSpace, kPit, Vector, and another testing producer. All the information gathered in this process were analyzed, interpreted, and in some situation, a deeper search was performed.

3. Results

3.1. Searches

Considering the first searching terms, the results were not very close to the topic, but they bring a good overview of the sensors or how they are integrated into the perceptive system. The search for specific terms enumerated in chapter 2 has generated the results in tab. 2.

Tab2. Search results

Keywords	Results		Compatible with the topic
	Google Academic	IEEE Explorer	
automotive visual module simulation	9750/50 analyzed	12/12 analyzed	1 / 0

camera module testing	19600/50 analyzed	229/50 analyzed	3/1
camera sensor simulation	24900/50 analyzed	3340/50 analyzed	8/2
radar sensor model	24300/50 analyzed	1533/50 analyzed	26/15
radar sensor simulation	20200/50 analyzed	4676/50 analyzed	23/8
DARTS radar	564/50 analyzed	11/11 analyzed	3/2
ultrasonic sensor simulation	16800/50 analyzed	195/50 analyzed	8/5
ultrasonic sensor model	25000/50 analyzed	381/50 analyzed	5/5
LiDAR sensor simulation	16800/50 analyzed	418/50 analyzed	12/10
LiDAR sensor functional test	17300/50 analyzed	7/7 analyzed	3/2
LiDAR model	26500/50 analyzed	989/50 analyzed	12/7
GPS module	18300/50 analyzed	366/50 analyzed	2/1
GPS modelling and simulation	16900/50 analyzed	281/50 analyzed	10/10

3.2. Results

Early testing is a desired aspect of the development cycle. In majority situation, a virtual simulation is the only possibility to achieve this aspect.

The results for each sensor are presented in the following paragraphs.

3.2.1. Camera

For the camera sensor, three technologies are presented:

a) the camera uses video stream 3D images generated [22]. In this case, the working principle is the following: The images are generated within game engines for specific scenarios. It is suitable for creating special scenarios where the complexity of the environment is not relevant.

The output of the simulation: a synthetic generated video. It could be used for MiL/SiL simulation environment.

b) HiL-Monitor [23]. Working principle: a monitor is placed in front of a real camera. On the screen are played real or generated videos for specific scenarios. Simulation Output: an environment that supports images/videos background for camera input. Simulation technique used for HiL system.

c) Recorded video injected directly into ECU with video interface Box [24]. Working principle: video data is provided at the input of the processing unit from outside source. Real images or processed with specific scenarios are used.

Output: videos that contain all the information needed for images processing. It might be used for MiL, SiL, HiL systems.

3.2.2. Radar

a) Automated Signature Generation for Automotive Radar Verification (ASGARD1) [25]. Working principle: the method originates from the observance principle of the target: the distance causes a delay that is counted as described in [10]. In this situation, the delay is transformed into the frequency of the received signal shifted by a beat frequency. The shifted signal represents the target detected in the front of the sensor. It could be done in analytical mode or using a pre-existing data record.

Capabilities of the simulation: Simulation of multiple vehicles, pedestrians, trees, road and traffic situations, weather conditions. Used in HiL system.

b) Radar sensor signature and stimulation input generation (RASIG) [26], [27]. Working principle: the radar signature generation provides the time delay, azimuth, Doppler, and power density and it is depended of the position, orientation, and material properties of the surface that is simulated to be in contact with the ray.

Output: simulation of sensor information: Doppler frequency, distance, azimuth angle, reflected power. Used in HiL systems.

c) DARTS technology from dSpace [28]. Working principle:It is a hardware solution for controlling the echo. The feedback can be delayed, or its frequency changed, or the reflected power attenuated and then the distance or velocity or object size are simulated. The azimuth angle could be determined by changing the position of the transmitter/receiver.

Information from the sensor simulation: reflected power, frequency, velocity, size of object, azimuth angle.

Used in HiL systems.

3.2.3. Ultrasonic sensor

a) Mathematical model [29], [30]. Working principle: the method consists of measuring a real detection area of the sensor and then computing a multi-ray model.

Output: simulate a beam of rays to a specific point. Used in MiL, SiL simulations.

b) Ultrasonic Sensor Test System from dSpace [31]. Working principle: a real sensor is stimulated and the echo signal is manipulated to obtain the scenario.

The output of simulation is the distance to a point in the virtual space. Used in HiL systems.

3.2.4. LiDAR

a) Augmented LiDAR simulator [32]. Working principle: the method is based on the scan and simulation principle. A real scan is performed and then the results could be manipulated to add points of interest.

It allows simulation of LiDAR sensor properties: range, horizontal and vertical field of view, angular and vertical resolution. Used for SiL, HiL.

b) LiDAR based on intensity simulation [33], [34]. Working principle: LiDAR intensity simulation model is based on a generative adversarial network trained with real data. A valid hash projection is developed to transform 3D LiDAR point cloud to a 2D image.

Transform 3D point cloud to spherical projection image. The simulation is used in SiL systems.

c) Depth Buffering [35]. Working principle: LiDAR sensor can be simulated via graphics cards. The Z-buffer (depth buffer) can store information about the depth map of an image. With this information, it could rebuild the beams and their intersections in the image, from the camera sensor perspective.

The image information is transformed into LiDAR information. It is used in SiL, HiL simulations.

3.2.5. GNSS/GPS

a) Mathematical GPS models [36], [37]. Working principle: the GPS mathematical models are used for development and validation. There are multiple methods for modeling and simulation of the GPS sensor. They are based on mathematical equations that realize a connection between the movement of the simulated car and the position on the map.

Output: maps and evolution of coordinates depending on the vehicle movement. It is used in MiL, SiL simulations.

b) GPS Simulator from dSpace [38]. Working principle: the industry solution for simulating the GPS sensor is to create maps with high resolution. dSPACE and Spectracom, a provider of GNSS signal management solutions, have created a solution using a dSPACE hardware-in-the-loop simulation system and a Spectracom Global Satellite Generator and Global Navigation Satellite Simulation.

Outputs of the simulation: maps and coordinates as signals. Used in HiL simulation systems.

4. Discussion

Simulation in the area of sensors used in complex systems is the simplest method to experiment and test a prototype or even a concept. In addition, it is often used in laboratory testing for verification and validation. In the last years, the evolution of machine learning and computation power raised the opportunity to have better simulation environment capable to run accurate sensor models.

The camera sensor is now available for use in the laboratory, either by using recorded video images and therefore with high complexity and accuracy, either by synthetically generated images. The second solution is easier to use for scenario creation, but its complexity is lower.

Radar sensor models are available and, in some cases, validated by the industry. The complexity of the function based on this sensor needs a high accuracy from the model.

LiDAR sensor is a modern and expensive technology. The simulation of this sensor is difficult due to the large number of parameters that influence sensor functionality. The technology behind the model creation of the LiDAR sensor is based on these three methods: ray-tracing methods [39], depth buffering [40], and environment modeling [41].

The ultrasonic sensor is already widely used in some industries. Therefore, the technology is well known and the models for this one are validated.

GPS/GNSS/IMU sensor has been studied for years and models created for years. In this case, models and simulation technology are already in use and well tested.

5. Conclusion and future work

5.1. Challenges and future work

There are multiple challenges for the modeling and simulation of the perception system. Based on the purpose of testing, the complexity of the function analyzed or the number and diversity of simulated sensors, the gap between the real measured data and generated data, or between two different sensors used for the same purpose should be decreased.

Another challenge is to create a correlation between all the sensors in a virtual environment. In the case of fusion data, the sensor models have to generate data that match virtual reality.

In future work, we will try to create models that simulate multiple sensors that work dependent on the environment and process feedback. In this context, we will try to simulate an adaptive cruise control that is based on two sensors camera and ultrasonic sensors. We realized a paper in this direction [42], and it would be a challenge to simulate the ultrasonic sensor that works based on the camera input. In addition, we will test some models and compare them for accuracy and performance.

5.2 Conclusion

This work is a review of the main technologies and techniques used for the simulation of the sensors in different scenarios. We analyzed them from different points of view. First, we looked at the presence of this topic in the research area and in the industry area. Then, we analyzed the possibilities to use them in testing environments.

A generic conclusion is that the domain has a major need to continue the research and to bring new methods based on machine learning and mathematical processing to validate the perception system and to develop stable algorithms for the control and planning system in the automated vehicle.

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Personal Notes

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