Conceptual Sensors Testing Framework for Autonomous Vehicles

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Abstract—This paper highlights a conceptual sensors testing framework for autonomous vehicles. This framework is part of the efforts by the Advanced Mobility Institute (AMI) at Florida Polytechnic University to establish a state-of-the-art sensors testing facility for autonomous vehicles. The conceptual sensors testing framework will address the different types of sensors and communication schemes related to autonomous vehicles and provide a versatile approach to perform testing scenarios in a way similar to what happens in the physical world.

Keywords—autonomous vehicles, framework, sensors, testing, chamber, anechoic

I. INTRODUCTION

By 2020, it is projected that approximately 10 million autonomous vehicles (AV) will hit the roads [1]. Multiple tech companies, AV startup companies, and even big automotive manufacturers are currently developing and implementing various sensor technologies and systems to enable autonomous transportation and mobility. With the growing interest in this field, it is essential to be able to standardize these technologies and develop testing facilities capable of characterizing their performance under various conditions before being deployed onto public roadways and infrastructures.

Thus, as part of the efforts led by the Advanced Mobility Institute (AMI) at Florida Polytechnic University (FPU), this paper will portray a general AV sensors testing framework with a conceptualized design for a state-of-the-art sensors testing and objects recognition facility for AVs.

The primary goal in mind for the AV testing framework is to have the capability to implement realistic sensors testing scenarios that can capture what happens in the real world.

Using publicly available information, we started with surveying current proving grounds, AV testing facilities, automotive testing, and sensor testing methodologies [2]. This helped us to have a better understanding of the capabilities and limitations of these testing facilities in order to conceptualize solutions that can be implemented in future proving grounds or test facilities. Figure 1 depicts a top-level block diagram for the overall testing framework we are developing, where the main focus of this paper will be on the sensors testing part.

We will start with a brief overview of the AVs sensors ecosystem in Section II, followed by a description of AV sensors testing roadmap and the conceptual chamber design in Sections III and IV, respectively. Finally, summary and conclusions will be presented in Section V.

II. AUTONOMOUS VEHICLES SENSORS

There are four main groups of sensor systems that operate on AVs to provide the needed information for object identification and data fusion, namely: Optical-based systems, Radio-based systems, Infrared-based systems, and Ultrasonic-based systems. In addition, the vehicle to everything (V2X) communication module exists to handle the AV to AV or AV to infrastructure exchange of information. This section briefly describes some of the important properties of these AV sensors systems.

A. Ultrasonic Sensors

Autonomous vehicles use these sensors to detect obstacles in their immediate vicinity. Ultrasonic sensors play an important role in automated parking. A typical range for this type of sensors on AVs is up to 2 meters [3, 4].

B. Optical-based Sensors

Optical-based sensors or cameras can detect colors and therefore are able to interpret traffic signs, lane markings, etc. They can generate images of the AV’s surrounding imitating human eyesight [3, 4]. However, the quality of their output is
limited by weather conditions such as fog, rain, snow, and sunlight. In addition, they are susceptible to changing lighting conditions.

C. Radio-based Sensors

Radio-based sensors or RADAR sensors are deployed all around the AV. They can be used for short range and long range (SRR and LRR, respectively) detection depending on their operating frequency. LRRs operates at 77 GHz frequency while SRRs operate at ~ 24 GHz frequency [3, 4]. Both LRRs and SRRs are known for their robustness in varying environmental / weather conditions, but they are limited in terms of resolution and can suffer from electromagnetic interference from other active sources operating at similar frequencies.

D. Infrared-based Sensors

Infrared-based sensors used in AVs are LiDARs [3, 4]. They scan the surrounding environment with a nonvisible low-intensity laser beam that can measure ranges and create 3-dimensional images of the surrounding environment. When combined with data from cameras, LiDAR sensors allow AVs to identify obstacles accurately. However, similar to other types of sensors, LiDAR measurements suffer some weather limitations, e.g., fog, rain, and snow.

E. Vehicle to Everything (V2X) Communication

Reliable and secure V2X communication over the network allows vehicles to interact with other vehicles, infrastructure, and pedestrians [5, 6]. V2X paves the way for connected cars and will enable applications such as hazard warnings, traffic condition warning, intersection collision warning, etc. Long-term evolution (LTE) combined with multi-access edge computing (MEC) provides a reliable and cost-effective V2X communication that is on the way to the faster 5th generation (5G) communications standard.

III. SENSORS TESTING ROADMAP

As previously mentioned, several testing facilities including those designated by the U.S Department of Transportation (DOT) were surveyed. DOT has designated 10 proving ground pilot sites to encourage testing and information sharing around AV technologies. These proving grounds will foster innovation that will help in expediting the evolution of the AV industry. The following subsections identify some common capabilities and shortcomings (gap analysis) for these sites and how the proposed sensors testing framework and conceptual design can mitigate those gaps.

A. Capabilities and Limitations of Current Testing Facilities

Most of the surveyed proving grounds have physical test tracks for on- and off-road testing capabilities. Some proving grounds, like the SANDAG and affiliates [7], focused on mobility hubs, cybersecurity, smart cities, and smart transportation, while other proving grounds, such as SunTrax [8], positioned themselves to accommodate tolling technologies and environmental testing.

Although the 10 DOT proving grounds have physical test tracks to test AVs on roadways, not all of them are capable of performing tests under different testing scenarios that may include environmental conditions, particular roadway hazards, or electromagnetic compatibility (EMC) and interference (EMI) from potential external sources. In addition, most of the surveyed testing facilities lack the capability to actuate simulated testing scenarios, in an environment that can mimic the real world, which can involve individual sensors or all of them at once.

B. Strategy and Test Procedures

Gap analysis from the surveyed proving grounds was helpful to set up a framework for the proposed testing facility. According to that, the test procedures will adopt a strategy with multi-level testing as follows:

- Individual sensors testing: The purpose of this level is to create the baseline for sensors under testing when operating under normal conditions in a controlled environment. This means that these tests will be performed in the testing chamber and will test important parameters that will characterize the sensor performance (e.g., range, resolution, etc.).

- Specified testing: This level will address the effect of certain operating conditions on the performance of the sensors, namely: environmental and thermal variability to check sensors performance at extreme temperatures and environmental conditions, radio frequency interference (RFI) to check how signals from other active sources interfere with the sensor measurements, sensor stability to check the sensors’ performance over long periods of operation, and finally internal calibration to check whether or not the sensor needs to go through any calibration loop every time it starts.

- All sensors testing: In this level, the performance of all sensors will be tested when all the systems are working simultaneously to investigate any possible cross effect. Also, operating conditions (environmental, lighting, thermal, etc.) will change with different testing scenarios. This will be helpful for object identification models that may depend on multi-sensor data fusion, so the model can assign more weight to one sensor measurement under certain conditions rather than treating them all equally.

Any testing procedure to be developed under the aforementioned testing levels must focus on important sensor parameters that have a direct impact on the object identification model. Range, resolution, ability to detect speed and distance away from AV are probably among the most important parameters to be checked for accuracy. Further, thermal, environmental, and lighting conditions in addition to RFI must be controlled, and sensors output must be evaluated while varying these conditions.

Therefore, having a well-designed testing chamber that can accommodate these tests is of utmost importance to the successful implementation of these testing procedures and strategies. The following section will go over some of the details about the conceptual chamber design.
IV. CONCEPTUAL CHAMBER DESIGN

Generally, traditional anechoic chambers are designed for a specific purpose or task. For example, they can be designed to perform antenna characterization at a specific frequency or to do over the air testing of wireless radio frequency (RF) devices. However, given the various types of sensors equipped on AVs, traditional chambers simply wouldn’t provide adequate testing capabilities. Thus, this section provides an overview of a conceptual design that can support the test and characterization of multiple scenarios across multiple sensors used by AVs.

A. Design Considerations

To design an innovative testing chamber for AVs, it must account for the following:

- Capability to check sensors specifications as provided by the manufacturer (i.e., sensors baseline).
- Capability to measure sensors specifications as we change the operating conditions (e.g., environmental & thermal conditions).
- Capability to actuate a simulated testing scenario in a realistic environment.
- Capability to evaluate the effect of other sensors, i.e., interference and compatibility, on the device under testing.

B. Chamber Design and Examples

The conceptual testing chamber is envisioned to support testing of all AV sensors including RADAR, LiDAR, V2X, and Cameras. The platform is capable of dealing with individual sensors using mounts with 6 degrees-of-freedom (DOF) for positioning in addition to holistic testing of sensors based on actual sensors location on the AV body. Figure 2 shows a top view of the chamber with more details to follow. The chamber anechoic walls are dual sided with the ability to pivot. One side for V2X testing and the other side for mm-Wave RADAR testing.

For RADAR testing, mounting towers are utilized. They can revolve around the vehicle platform using the embedded rail system in the chamber as seen in Fig. 3. These sensor/antenna mounting towers will allow for multiple static mounting points and full 360 degrees of rotation around the vehicle under test for Radar. Radar target simulators (RTS) are used to emulate various object responses to radar signals.

For Camera testing, we propose a transparent panoramic projection screen that will surround the 6 DOF vehicle platform as seen in Fig. 4. This will allow for the projection of realistic scenes around the vehicle under test which can be used for the testing of the AV object recognition capabilities in combination with other AV sensors. Further research is needed into the specific type of material that would be used for this screen mainly due to the possible attenuation and reflection that the other AV sensors would have including the SRR and ultrasonic sensors on the vehicle.

Figure 5 depicts the proposed mountable photodetector panel designed to aid in the test and characterization of various LiDAR sensors. This panel can be set up in various configurations around the vehicle utilizing the embedded rail system within the test chamber floor. It employs a matrix of light emitting diodes (LEDs) to simulate returns of a LiDAR system.

Dual rail mounted arches located in the test chamber presented in Fig. 6 will support the testing of various V2X modules with motorized TX/RX Modules. These arches are capable of rotating up to 180 degrees allowing for a combined 360 degrees of simultaneous RF signal injection of multiple types and a multiple points surrounding the vehicle under test. This capability will support multiple interference points for adjacent, co-channel, and other interference types.
For EMI/EMC testing, the interior of the chamber will include additional RF sources to simulate various potential EM environments as shown in Fig 6. The proposed arrangement enables EMI testing across an increasingly complex EM environment and how it impacts sensors outputs.

V. SUMMARY

The AV sensors testing framework is developed to serve as a roadmap for a state-of-the-art AV testing facility. The testing of AV sensors remains an open research problem and will evolve with technology implemented. However, the proposed testing framework focused on providing the capability to test and characterize AV sensors performance individually and all at once under different operating conditions. It also provides the design flexibility to implement different testing scenarios to mimic what happens in the real world.

As future work, single and multi-sensor test procedures will be established. This will require deriving the chamber physical requirements for controlled tests and prepare a list of test equipment to be used for measurements, data acquisition, and analysis. Finally, models to simulate different environmental effects on the different sensors parameters of interest have to be identified.

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