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Range Sensor Overview and Blind-Zone Reduction of Autonomous Vehicle Shuttles

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Abstract. In recent years, with the advancement in sensor technologies, computing technologies and artificial intelligence, the long-sought autonomous vehicles (AVs) have become a reality. Many AVs today are already driving on the roads. Still, we have not reached full autonomy. Sensors which allow AVs to perceive the surroundings are keys to the success of AVs to reach full autonomy. However, this requires an understanding of sensor configurations, performance and sensor placements. In this paper, we present our experience on sensors obtained from AV shuttle iseAuto. An AV shuttle iseAuto designed and developed in Tallinn University of Technology is used as an experimental platform for sensor configuration and set-up.

1. Introduction

Recently, there has been growing interest in autonomous vehicles (AVs), which are regarded as a potential trend of transportation in the future. A reliable AV perceives the environment consistently by different sensors, then transfers the sensory data to a computer for post-processing. Sensors in AVs produce information with different characteristics, Global Navigation Satellite System (GNSS) provides the approximated location of vehicles with a general reference; Inertial Measurement Unit (IMU) measures angular rates, linear velocities and orientation of the vehicles base body; range sensors include cameras, LiDARs, radars and sonars detect the objects that are around vehicles in different scales and properties. Sensor fusion algorithms combine sensory data to create more coherent and certain results than using the data individually. Path planning module uses real-time perception of the surrounding environment to update paths of the vehicle in short and long ranges. Fully AVs are supposed to be able to control the self-motions, as well as auxiliary functions in practical situations, for example, the closing and opening of the door. The motion control module, at last, controls the movement of the vehicle to follow the paths and execute the motion commands that are computed by path and motion planners. Security measurements like emergency braking and obstacle avoidance are invoked to the control system directly to improve the safety and reduce the accidents. Fig.1 summarizes the general workflow of AV modules.

Range sensors provide 3D geometry information of vehicles surrounding environment and reflect the properties (speed and acceleration) of objects that are expensive to compute from vision-based perception systems. Examples of range sensors for AVs include radar, LiDAR, sonar and infrared sensors. In particular, radar sensors make a crucial contribution to Advanced Driver Assistance System (ADAS) in the aspects of emergency braking/brake assist, collision



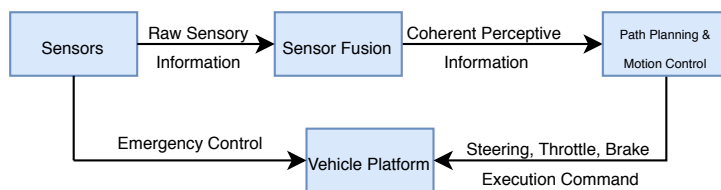


Figure 1. Modules workflow of autonomous vehicles

warning/avoidance, park assist, distance control and so on. LiDAR sensors are a relatively new technology in the AVs field and have attracted much attention in recent years. LiDARs are widely used to measure the distance and describe the environment in three dimensions. However, because of the natural characteristics of laser-based systems, LiDARs are limited by the low level of target reflectivity, resolution and refresh rate. Contrarily, the energy source of sonar sensors is acoustic/ultrasonic waves in a specific frequency, which is less affected by the reflectivity level of targets. Compared with LiDARs, sonar sensors have the advantage of low-cost and are widely used in underwater applications. Typical infrared (IR) sensors are a relatively well-developed technology, which has the advantages of cost, size and reliability. Active IR sensors share the similar principle of sonar but rely on infrared waves (wavelength usually bigger than 780nm that above the visible red light). Passive IR sensors only have receivers to detect infrared radiation and are irreplaceable in the scenarios of human/human-motion detection. This paper analyzes range sensor configurations and blind zones reductions for particular AV shuttle iseAuto.

2. Primary Perceptive Range Sensor Set-ups

In recent years, autonomous vehicles commonly use laser-based range sensors as the primary approach to perceive the environment and measure distances. One of the most popular laser-based sensors is LiDAR, a light-based detection and ranging remote sensing tool that has contributed significantly to AV technology due to the high accuracy and precision.

Currently, decreasing cost and power consumption of LiDARs promote their usage in applications that are sensitive to the vehicle's size and weight, such as Unmanned Aerial Vehicles for mapping and navigation purposes. Other related research and experimental platforms are:

- On the roof of Stanley, the vehicle that won the 2005 DARPA Grand Challenge, there are five lasers measuring cross-sections of the approaching front terrain in different distances out to 25 meters [1];
- VIAC vehicles were equipped with four laser scanners (two lateral laser scanners, one off-road laser scanner and one central laser scanner) which have different characteristics [2];
- More recently, Gao *et al.* [3] set four laser sensors (two single-line lasers, one four-line laser and one 64-line laser) in their Mengshi autonomous vehicle;
- Other experimental vehicles that have laser-sensors installed [4] [5] [6];

AV shuttles are the most common low-speed vehicles using LiDARs, and not only for ranging but also for localization and object classification. AV shuttles that were deployed on the real traffic pilot cases around the world are in limited numbers. Most known brands are Navya and Easymile, followed by iseAuto and GACHA. All these vehicles are relying mostly on LiDARs as the main localization and ranging sensor. Fig.2 presents the main sensor locations on these vehicles.

In this paper we are focusing on the TalTech iseAuto that was designed and developed in the Autonomous Vehicles lab in TalTech, Estonia [7] [8]. The initial design and sensor configuration



Figure 2. Real traffic AV shuttles: Navya Evo, Easymile EZ10, TalTech iseAuto and GACHA

development of iseAuto was supported by mechatronic modeling methodology [9] [10], which emphasizes the importance of early design stage. The output of the initial conceptual design stage proposed to use two Velodyne VLP-16 Puck LiDARs on the front top corners, as shown in Fig.3(a). To detect as many blind zones that are in front of the shuttle as possible, the sensor plane inclined toward the front and side (in practical, 8.3° toward the front and 6.9° toward the side), as shown in Fig.3(b) and 3(c).

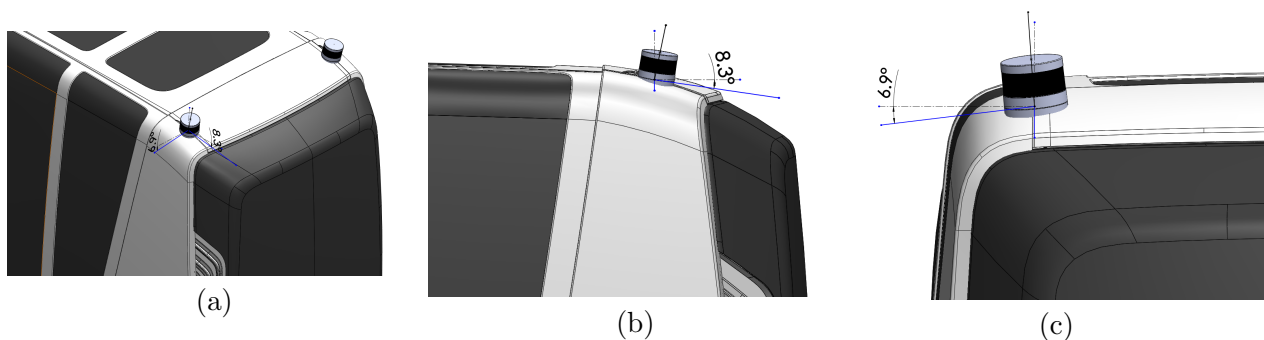


Figure 3. (a) Initial design of LiDARs location, (b) Front-tilted angle, (c) Side-tilted angle

However, in practical situations, our initial Velodyne VLP-16 sensor location (Fig.3(a)) has no vision of the shuttle's backside because laser beams shooting toward the back were heavily blocked by the shuttle itself. The points cloud of initial location configuration were showed in Fig.4(c). Additionally, the vision of left and right sides is too limited to cover the blind zones of the automatic door, which directly affects the safety of the shuttle. Therefore, our latest configuration of two VLP-16 sensors is locating them in the middle of the front and back sides with some inclines, as shown in Fig.4(a). Moreover, an adjustable mount base allows us to change the front-tilted-angle of the VLP-16 sensor, and a bigger angle helps to detect more blind zones in the front/back of the shuttle but reduce the maximum detection range correspondingly. The points cloud based on the latest configuration were presented in Fig.4(b). Compared with the previous configuration (Fig.4(c)), the coverage of the left and right sides is reduced, but the full view of the backside is available. On the other hand, current configuration helps to reduce the occasional interference patterns and shadowed azimuth ranges that may appear in data when using multiple Velodyne sensors close to one another (especially on top of the vehicle).

3. Blind Zones Reduction

Blind zones detection is an essential task for AVs because it has straight affections to safety. LiDAR-based sensors generally are installed on top of the vehicles to have wider horizontal Field of View (FoV) and further detection range. However, a top-placement configuration of LiDARs results in bigger blind zones around the vehicles, which raise problems in many post-practical

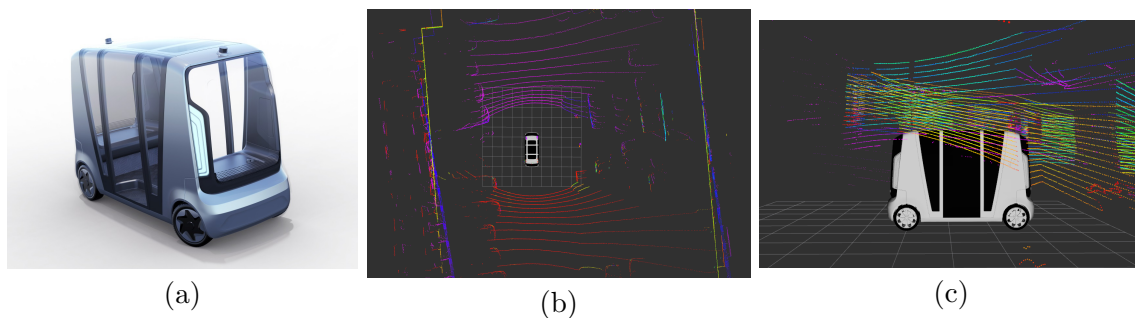


Figure 4. (a) Latest design of LiDARs location, (b) Points cloud of latest design, (c) Points cloud of initial design

processes such as motion planning in multi-interaction environments and lane change alert in ADAS.

The common solution to reduce the blind zones is installing specific sensors in corresponding positions. Variety types of sensors can be used to detect the objects in blind zones.

- Jamaluddin *et al.* [11] installed an ultrasonic sensor above the rear tire to measure the distance of approaching vehicles. The selection of the ultrasonic sensor maximally prioritizes the cost of the total sensor setup but compromises the performance and accuracy in some real-life scenarios [12].
- Using LiDARs to cover the blind zones is a popular topic in recent because they create detailed 3D points cloud. Researchers can carry out complex post-processes that are based on points cloud data to pursue the best performance. The work in [13] formulated the blind zone problems by occupancy grid and proposed a generic algorithm to optimize the configuration of LiDAR placements. Meadows *et al.* [14] introduced a system that has three LiDARs and used neural work to evaluate the effectiveness of various LiDAR poses.
- Other sensor choices include cameras and radars. Image-based information is usually processed alongside other sensory data. Rangesh *et al.* [15] described a multi-object tracking approach which is capable of working with varying camera FoVs and LiDARs. Dey *et al.* [16] put the camera and radar together and proposed a framework that can optimize the location and orientation for a heterogeneous set of sensors on a given target vehicle.

Installing sensors in corresponding areas provides direct sensory information of the objects in blind zones. However, in the scenarios that the objects' detailed detections are not vital, mathematical processes can be used to calculate the states of the objects when they are in blind zones. Zhou *et al.* [17] proposed to use Kalman Filter to estimate the movement of the approaching vehicles in blind zones for traffic intersection motion planning. Correspondingly, substitute sensors with mathematical algorithms help to reduce power consumption and hardware maintenance work.

In our case, because of the structure of the iseAuto shuttle, the front-top and back-top Velodyne LiDARs cannot detect the blind zones on two sides. Accurate and detailed detection of the objects in the right blind zone, especially the area that is close to the shuttle, is vital for us because the control of the automatic door should be strictly based on it. Our solution is installing two RS-Bpearl LiDARs on the left and right sides of the shuttle.

RS-Bpearl is a short-range LiDAR specifically designed for the detection of the blind zones. Compared with VLP-16 Puck, RS-Bpearl has a shorter range of detection but a much wider 90° vertical FoV and 32 channels. For iseAuto shuttle, the unique FoV design of RS-Bpearl helps to cover more areas on two sides, and the dense points cloud data provides more details of the objects in blind zones. Fig.5 presents the points cloud data that was produced by an

RS-Bpearl LiDAR that was installed on the right side of the shuttle. The scenario in Fig.5(a) is the outdoor environment that has buildings and parking cars. Fig.5(b) shows the ability of the right RS-Bpearl LiDAR to detect the object details (human and ladder) that are close to the automatic door.

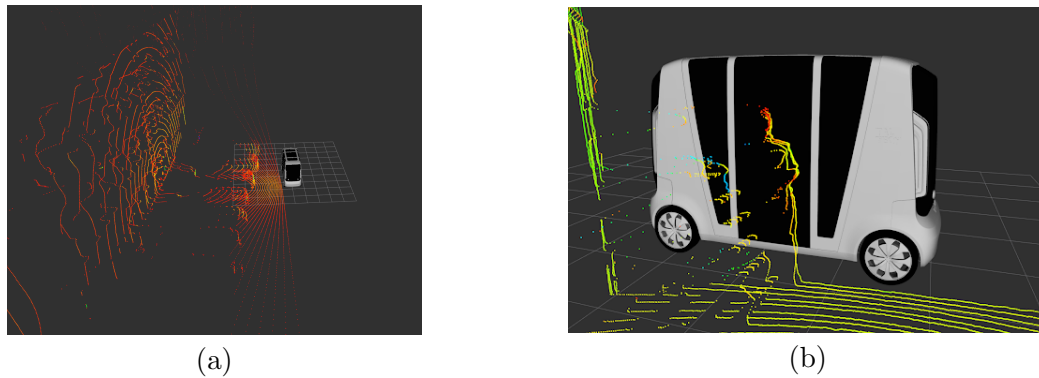


Figure 5. (a) Points cloud in outdoor environment, (b) Details around automatic door area

Another key blind zone for iseAuto shuttle is the close front area, which is not able to be detected by either front-top VLP-16 or side RS-Bpearl LiDARs, as shown in Fig.6(a). The perception of small objects (kids, pets, etc.) in this area is important for the shuttle's safety system. Available sensor choices to detect this blind zone such as IR and ultrasonic sensors have the economic advantages but compromise in the accuracy. In terms of cost and performance, solid-state LiDARs are believed to be more suitable for large-scale deployment, because solid-state LiDARs are relatively cheaper and do not have inside complex mechanical mirror systems.

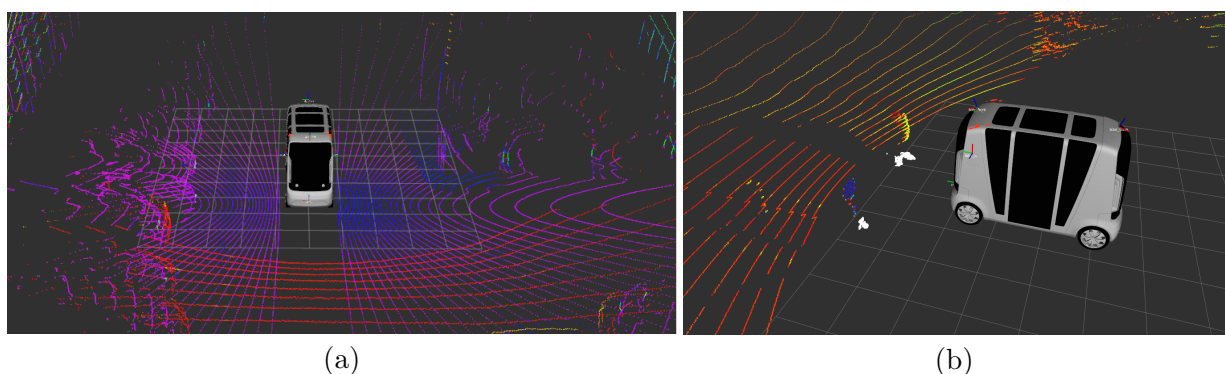


Figure 6. (a) Front blind zone, (b) Points cloud from bottom-front and top-front LiDARs

We deployed a Benewake CE30-C LiDAR on the front-bottom of the shuttle to detect the blind zones. Benewake CE30-C is a typical solid-state LiDAR that is based on the Time of Flight (ToF) ranging principle. The measurement is performed based on the received emitted modulated near-infrared light, which is reflected by the objects. Fig.6(b) shows the merged points cloud data from front-top Velodyne and front-bottom Benewake LiDARs. Benewake solid-state LiDAR can detect the down part of traffic signs and human legs (white points) that cannot be seen by the front-top Velodyne LiDAR.

4. Summary and Future Work

This paper provided an overview of the most common range sensors that are used for AVs and more specifically for AV shuttle, iseAuto. We evaluated the configuration and location of all

range sensors that were deployed on iseAuto shuttle for primary perception and blind zones detection. As a result of the analysis, we managed to get a full view of the shuttle surroundings and cover most of the vital blind zones by five LiDARs that have different characteristics.

The future work will focus on the sensor fusion and integration of the long and short range radars into the range-sensor set of the iseAuto as well as implementing AI-based situation awareness defined in the research [18]. The second target is to create a digital twin, which is compliant to our other research results [19] of the vehicle in order to simulate all critical traffic situations and increase the total safety of the deployed system.

Acknowledgments

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