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Validating multi-sensor object tracking in Heavy-Duty Trucks with extended trailer dynamics for road traffic situations.

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Abstract

Multi-sensing technologies in vehicles have the potential to improve road and pedestrian safety. Freight trucks with extended trailer face challenges in urban maneuvering due to limited visibility. In this paper, we evaluate and validate extended trailer dynamics for Heavy-Duty Trucks in road traffic situations with multi-sensor object tracking emphasizing trailer dynamics, back-end parameters, and characteristics that influence decision-making strategies. A custom in-vehicle compute unit, in combination with the onboard truck's computer, facilitated this research.

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1. Introduction

Freighting vehicles for logistical purposes in urban environments and regions is a multifaceted and intricate matter considering extended trailer dynamics. The impact of these freighting vehicles as they navigate through these urban environments exemplifies the characteristics of factors influenced by road traffic conditions. These intricate and diverse elements include dynamic environmental factors [1], driver perception, and transportation accidents [2]. Particularly evident is how heavy-duty trucks navigate urban environments in right turns. It emphasizes the importance of decision-making in such traffic scenarios involving heavy-duty freight trucks towing an extended trailer in a combined length of 25 meters and weight of 76 tons and beyond in some cases. An instance of such circumstance is in Figure 1, which illustrates the complexities and number of pedestrian challenges with the possibilities that can lead to accidents. In

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figure 1a, an HDT approaching a right-turn has clear visibility on the towed trailer dynamics on the right side indicated in the side mirror as to the visibility of the dummy (Test subject). Contrasting to figure 1b during a right-turn, the visibility and scope of visual feedback using the dummy are limiting and constrained in this case. Consistently, the dummy is no longer visible through the right side mirror with some portion of the towed trailer. In a controlled environment such as depicted in both figures of Figure 1, this complication might not be much of a concern compared to an urban environment with pedestrian activities, foot traffic, other vehicles, and road infrastructural limitations.



Fig. 1: Simulation of a Right-Turn scenario under a controlled environment with side mirrors visibility

Presently, a proliferation of driving assistive hardware sensors [7] and software associative [8] has substantially improved pedestrian and road safety. Classification of roadside pedestrian safety impacted by the perceptions of automobile sensors employing radars, Li-DAR, and cameras. These utilized assistive hardware and software sensing ascribes to modules via Machine Learning [6]. A subset of passenger-range vehicles derives advantages from these assistive functionalities. They do so when traversing traffic environments with some amount of confidence concerning pedestrian identification, stationary and moving object detection, and situational awareness. The precise back-end data delivery and efficient execution of such operations by these driving assistive hardware sensors alleviate the onus of accountability for split-second decision-making in traffic situations beyond the drivers' and commuters' control on responsiveness, dynamism, and consistency. Such capabilities are illustrative in today's connected, intelligent, and autonomous vehicles.

1.1. Scope of this research

This research assesses the back-end procedures and scenarios leading to decision-making attributes, particularly for heavy-duty trucks (HDTs) and freighting trucks (FTs) towing long or extended trailers in a right-turn. The scope of this experiment also encompasses the use of driving assistance hardware sensors such as radar, Li-DAR, and cameras, in combination with specialized software implementations. These technologies facilitate the computation of various parameters, such as the perimeter safety zone of heavy-duty trucks (HDTs), especially trailer turn positions and dynamics, trajectory, and arc. These integrated technologies are through a specialized computing unit installed in a Renault T520 vehicle for the examination process. The research analyzes and evaluates all the above via scenarios impacting pedestrian activities as in Figure 1.

1.2. Research Motivation, and Contributions

Research in this specific field of study and area of interest continues to grow with the undeniable rise of autonomous vehicles. Additionally, research into the perception of freighting truck right-turn reveals drivers frequently overlook cyclists in right-hand turns [3], despite their comprehensive orientation. There is an impact on the speed selection and gaze behaviors during right-turns by urban infrastructure and interaction type [4], driver's visual perception, and peripheral vision [9] constraint. These challenges show that the prominence of decision-making in traffic circumstances

is pronounced particularly for heavy-duty trucks (HDTs) and freight trucks towing long and extended trailers in such traffic situations.

Therefore, research in this field is broad yet requires effort in the HDTs and FTs range with driving assistance hardware and software sensors. Hence, this research aims to make the following contributions:

1. Illustrate real-time traffic dynamics for heavy-duty and freight trucks with the help of driving assistive hardware sensors.
2. Analyze the benefits and restrictions of multi-sensor fusion and tracking capabilities.
3. Validate utilization of custom compute modules, algorithms, and hardware configurations of multi-sensor fusion and tracking on HDT trailer positioning and dynamics: validation is performed in both real traffic situation and in a control environment.

The subsequent sections of this paper are structured starting with the experiment of high-level system architecture in Section 2, preceding the introduction in Section 1. The details on the experiment and related data are in the experimental setup in Section 3. Preceding is the implementation and testing in Section 4. Experiment validation and results follow in Section 5 and concluded in Section 6 as the conclusion and future work.

2. High-Level System Architecture

A visual representation of the customized compute module implementation management is in Figure 2a while the actual compute module is in Figure 2b. The system architecture depicts the hierarchy of code-based implementation, utilizing color-coded marks. In the figure, each block within every section symbolizes a sub-block that visually represents a distinct process or application. The system architecture employs a base Ubuntu Operating System (OS) shown in three segments, with the core system mirroring the experiment software platform and development environment. The network block is on the left, whereas the visualization is on the right as the third component. The network section is responsible for managing the connectivity of sensors, encompassing both the CAN network and Ethernet interfaces.

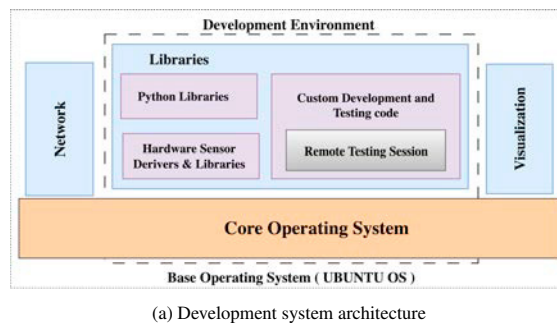


Fig. 2: high-level Overview of experiment system architecture with physical wiring and multi-sensors

The library block demonstrates a reciprocal interaction, where each sub-block interacts with each other and other components. Specifically, it utilizes the visualization block as output to present diverse internal and external processes associated with sensor readings obtained from hardware and software and other visual representations. This block also includes the libraries employed and integrated during the experiment. Two utilized unique libraries were the proprietary and experiment-implemented libraries. The proprietary libraries consist of hardware sensor drivers and associated development kits. The experiment-implemented libraries consist of custom Python libraries, modified third-party libraries, and the experiment code-base implementation and configuration, all part of the Custom development and testing code. It also includes libraries for specific testing sessions, such as remote testing during on-road testing sessions.

3. Experiments Setup

In this section, the experiment is illustrated in stages indicated as subsections. Each subsection represents a milestone within the experiments but does not necessarily follow in that order. They cover related details and their requirements, including further descriptions of the processes and procedures employed.

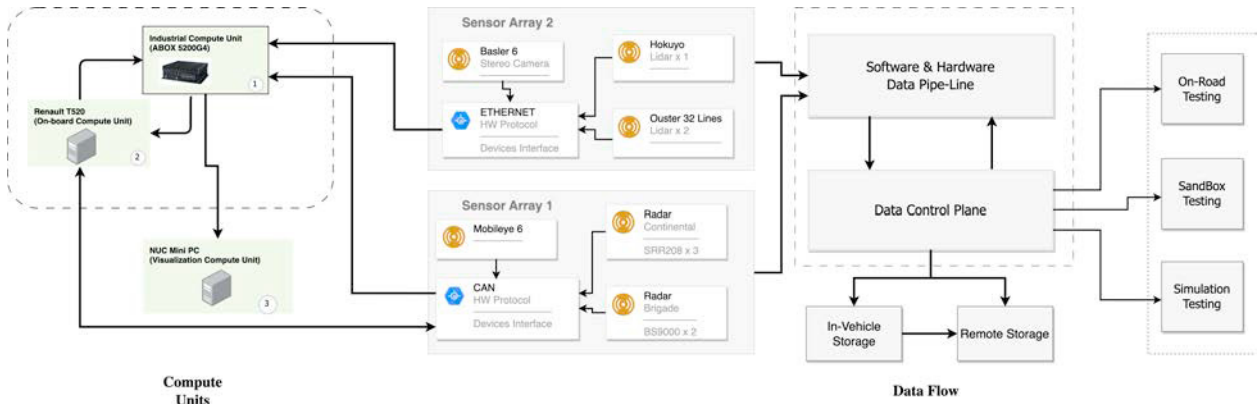


Fig. 3: Hardware specifications for High-Level Experiment System Architecture: Corresponding schema of configuration

3.1. Experiments Datasets

The data analyzed in this experiment are from the multi-sensor arrays illustrated in Figure 3. The data accumulation and processing procedure follows the proposed data flow in 3, which has a software and hardware data pipeline (SHDP) and a data control plane (DCP). The corresponding accumulation and procedure are in the software and hardware data pipeline (SHDP) and the data control plane (DCP). Custom data processing algorithms for specific queues intercept, transform and analyze results are in the software and hardware data pipeline and control plane. In the SHDP and DCP, data are then utilized by corresponding data consumers to facilitate seamless analysis, elaborated further in subsequent sections. All data being as a result of the experiments, the sample choice mechanism does not directly affect the presented results.

3.2. Evaluation metrics

In this work, the conducted research assessment and validation is via the analysis of results obtained from the three testing scenarios from section 3.1 in Figure 3: the on-road testing, sandbox testing, and simulation.

These test instances influenced the results showcased later in subsequent sections based on a controlled environment testing with and without an active pedestrian in each case. It covered the two pedestrian instances: approaching a right turn and during a right turn. The sole purpose of this testing session as evaluation metrics is to accurately evaluate back-end processes and object tracking algorithms in a controlled environment to simulate the urban right-turns where the driver has limitations on the right side due to a constraint field of view, side mirror range, and dead zone compensating. Sensor deployments are used in this experiment to investigate various decision-making back-end computational strategies utilizing a corresponding custom compute module and configuration shown in Figure 2. The algorithms, hardware, and software configurations used are all evaluated as a collective impact on in-traffic decision-making.

3.3. Experiment Details

The setup comprises two implementation phases utilizing the Renault T520 heavy-duty truck. These phases involve configuring a customized onboard hardware compute processing unit in Figure 2b and implementing software

components schema in Figure 3 on which data architecture in Figure 2a reside in compute module 1. The computing hardware integrated into the system is the DealComp ABOX-5200G4 compute unit. The ABOX-5200G4 has an Intel 6 Cores i7-8700T processor, boasting a 32Gb DDR4-2133 memory configuration. It features a Modem 4G with a SIM7600E-H module with an NVIDIA GeForce GTX graphics processing unit with CUDA Core support. Moreover, it provides the functionality of Dual Hot Swappable SATA Storage RAID 0, 1, 5, along with a 9-48V DC Input and an operating temperature range spanning from -40 to 60°C. In addition, the device is equipped with ten Gigabit Ethernet (GbE) Local Area Network (LAN) ports, allowing for the possibility of eight Power over Ethernet (PoE) ports. It also offers compatibility with a CAN adapter, PEAK Dual CAN, IPEH-003049, WLE200NX WLAN adapter, and uBlox ZED-F9-P GPS. A further comprehensive inventory of components and sensors is also visible in Tables 1a and Table 1b. The Tables provide a detailed overview of the power requirements and other relevant technical parameters.

3.4. Calibration Details

The calibration of all hardware sensors before the installation of the Renault T520 is beyond the scope of this paper. However, sensor calibrations after installation example for the stereo camera used the checker-board calibration available in the OpenCV documentation with additional details related to this experiment in [5].

Table 1: High-Level System Architecture for experiment

Type	Name	popular in	Explanation
Accessory	combination antenna	2	Antennas for satellite cell network and Wifi
Computing platform	Mobile PC	1	Main computing unit for data fusion and decision making
Computing platform	Mini PC	1	HMI control unit
Communication	Network switch	1	12 port network switch
Communication	Integrated Network switch	1	Integrated Network switch
Communication	Peak	2	Can to USB converter
Communication	Integrated Peak	1	Can to USB converter
Power distribution	DC/DC Converter	1	24 to 12 Vdc - 10A
Power distribution	DC/DC UPS power	1	24 to 12 Vdc - 6A
Power distribution	DC/AC Inverter	1	24 Vdc to 220 Vac inverter

(a) Configuration requirements

Type	Name	popular in	Explanation
Sensor	LiDAR Ouster 32 lines	2	Perception sensor based on light detection and ranging
Sensor	LiDAR Hokuyo long range	1	Perception sensor based on light detection and ranging
Sensor	SRR Radar	5	Smart perception sensor based on short range radar
Sensor	360 degree camera subsystem	4-to-1	Perception sensor for blind spot detection
Sensor	Basler HD camera	1	Perception sensor for image detection
Sensor	Smart Camera	1	Smart perception sensor publishing detected object list
Sensor	Integrated GPS module	1	GNSS global positioning and timing sensor on the truck
Sensor	Murata IMU	1	Unit for positioning correction

(b) Hardware sensor counts

4. Implementation and Testing

The implementation consists of three compute units depicted in Figure 3, each represented by numerical identifiers. The first computing module (ABOX 5200G4-CU) is the central component responsible for hosting the Ubuntu operating system and managing the allocation of all tasks. The second and third components are the in-vehicle cabin Renault T520 truck on-board computer (RCU-T520) and a Next Unit of Computing Mini PC (NUC-PC) as visualization controller. All compute units (CU) described are inside the short-dash lines in the center of sensory arrays 1 and 2, except CU-3. The two primary hardware input interface protocols are the Controller Area Network (CAN) and Ethernet. These protocols facilitate the connection of sensors and devices by utilizing their preferred high-speed interfaces. The initial sensor array block facilitates the integration of a continental, brigade, and Mobileye 6 connection using the CAN-Bus protocol. The second sensor array block equips a Baasler 6 stereo camera, Hokuyo sensor, and Ouster 32-line LiDAR connected through the Ethernet hardware protocol interface.

In the back-end, these CUs utilize custom algorithms, data queue pipeline, and DCP data consumers, visible in Figure 4. The real-time data stream in the DCP sub-control plane *data_source* flows into a *raw_data_queue*, directed into the *worker_pools* handling the data. Two decision-events blocks, D1 and D2, evaluate and manage tasks related to the control plane. The processed data queue plane (PSQP) then requests the specific data stream as data consumers subscribe to a pool of data streams with the queue via Python Classes indicated as Q1 and Q2. Depending on the subscriptions, the queue requests are scalable in both DCP and PSQP. For example, Q1 and Q2 are queue requests via subscriptions from tracking consumers and fusion consumers feeding into the decision-event block D3 linked with algorithms on both sides to the output results. The output results can be visible via the NUC-PC utilized by the visualization block previously discussed in Section 2.

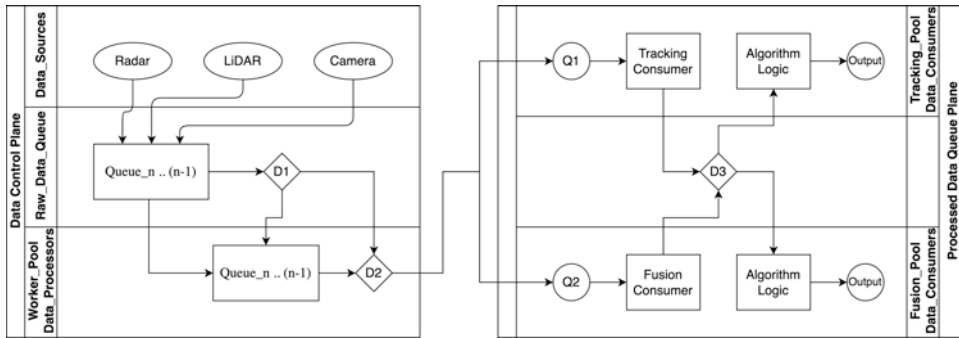


Fig. 4: Hardware and Software data pipeline and Data Control plane implementation

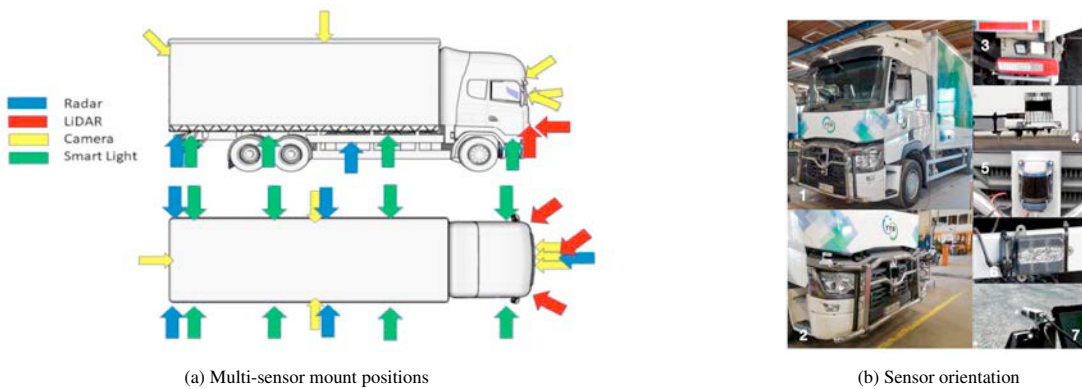


Fig. 5: Controlled environment Testing scenarios with pedestrian dynamics.

5. Validation and Results

The output of Figure 2b and its associating multi-sensors in Figure 5b and Figure 5a data-aggregation in the three scenarios extensively provided a variety of instances for decision-making, including the scenario illustrated in Figure 6. The driver of the HDT approaching the junctions in the figure is in clear view of the trailer position dynamics. However, on the right side, a safe distance with the help of the radars in conjunction with the LiDAR on the same side compensates for a reduced field of view. For example, in the 6a part, the decision-making scenarios illustrate the LiDAR visualization output, which encompasses the various objects and obstacles within the surrounding confines of the extended trailer. In this particular situation, the testing results demonstrate in-traffic decision-making capabilities utilizing the Ouster LiDAR on the right side as it tracks the movement of the black SUV throughout its approach towards a right turn. The movement of the vehicle approaching on the left side is also in the view of the tracking. In 6b, the right-side LiDAR tracks the external trailer positioning, dynamics, and arc in turns as it performs a right-turn while keeping the SUV from 6a in view.

In the high-way road testing, the results shown in Figure 7b focus on road awareness events relying on the front LiDAR and the stereo camera for object detection, tracking, and safety distance calculations from the radars at the back-end on the perimeter of the truck including the trailer. Sensors including the tail radar in Figure 5b-3, side radar 5b-6, front stereo camera 5b-7, front LiDAR 5b-5, and front-left-right LiDAR 5b-4 are zonally sensor-fused to maintain on-road awareness throughout the testing duration. The utilized 360 aerial camera provides an aerial perspective of the vehicle and, if applicable, its accompanying trailer.

Figure 8 illustrates sample data obtained during the synchronization phase, as depicted in Figure 7a. In addition to the stereo camera employed for object tracking, the other front-facing sensors detected object range. For example, several measurements obtained from the front Hokuyo Li-DAR and Continental radar are in 8b and 8c. Both figures served as comparative synchronization in Figure 8a plot using samples designated A and B. Hence, the numerical

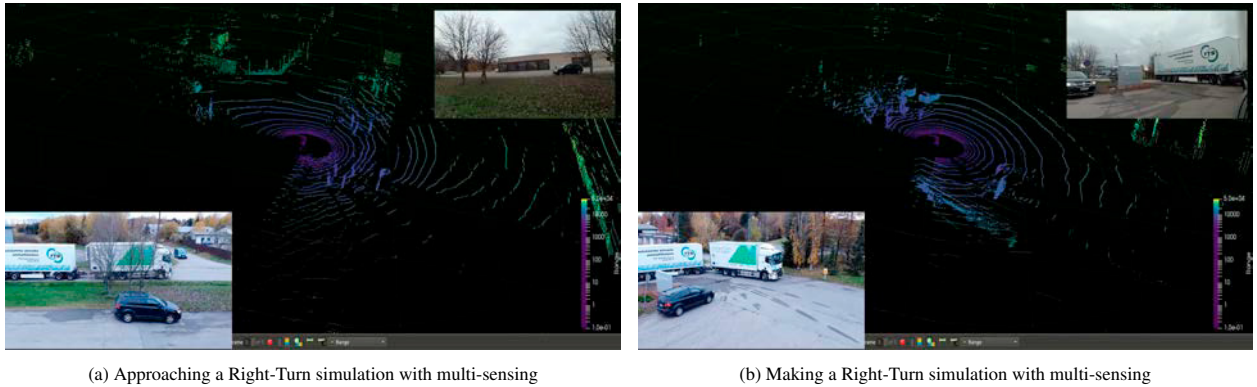


Fig. 6: Simulation of HDT with extended trailer Right-turn characteristic with LiDAR,Radar, and Camera

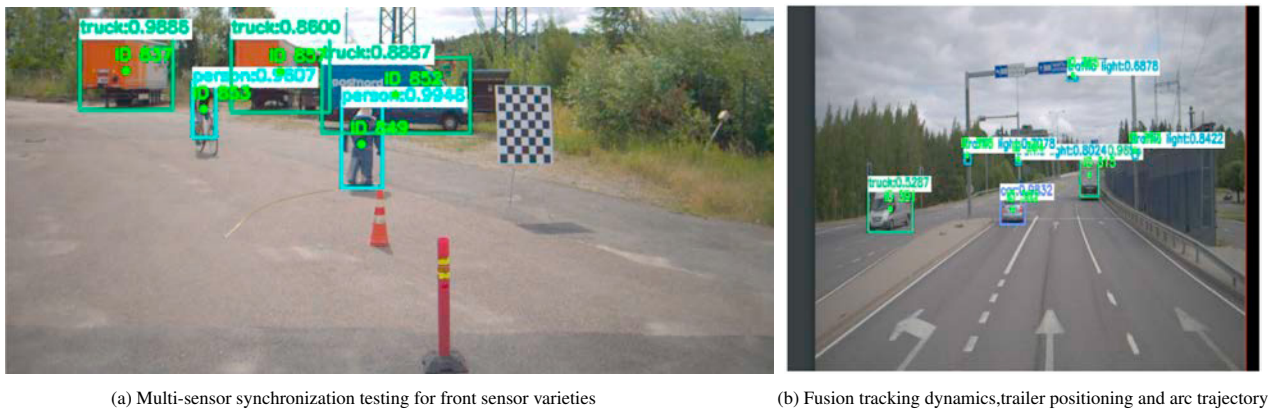


Fig. 7: On-Road high-way testing with multi-sensing capabilities

points in Figure 8a denote specific tolerances between the designation points. The coordinate system in the Figures is in truck coordinates, with the orientations determined by the positions of the sensors. The comparative plot in 8a has three segments, the first of which is the 0° crossing of both sensors for observed y and x range values. Since the truck coordinates represent the orientation, the y-range values are the focal point of this measurement. Due to its front position, it indicates that the y-range values can only be positive, whereas the x-range values have the potential to be negative or positive. The x-range values indicate the location of the detection. For example, negative values mean the object is to the left of a particular sensor measurement, whereas positive values indicate it is on the right.

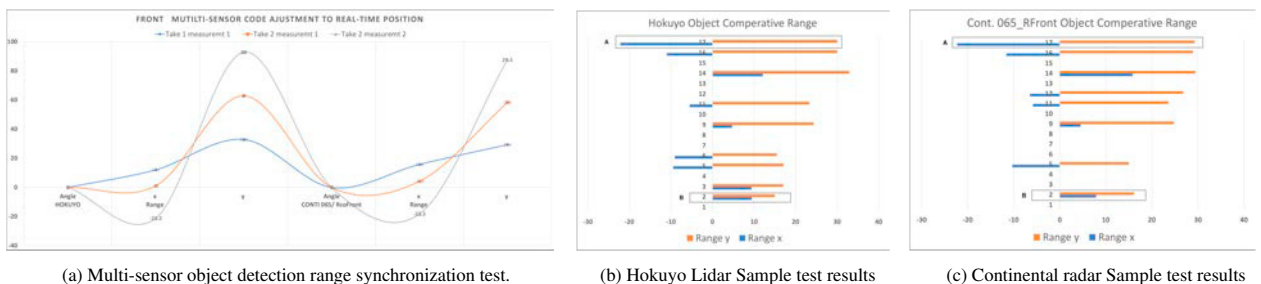


Fig. 8: Front multi-sensor synchronization test evaluation and sample test results from each sensor

6. Conclusions and Future scope

Technological advancement in the automotive sector has seen the use of multi-sensing technology in vehicles to improve road and pedestrian safety. In this paper, we investigated, evaluated, and validated multi-sensor object tracking and trailer dynamics in heavy-duty trucks. Radars, cameras, and Li-DARs were used for a right-turn scenario in a heavy-duty truck with an extended trailer of 25-meter length and 76-ton in weight. In addition, a custom in-vehicle compute unit in combination with the native truck's onboard computer was used for the back-end computations, resulting in all presented results. This research outcome has proven that decision-making in traffic dynamics can be improved using hardware and software multi-sensing in a right-turn. The results make this research a significant contribution applicable beyond HDTs to passenger vehicles towing any external trailer in urban or highway driving.

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References

- [1] Bagheri Ramiani, M., Shirazian, G., 2020. Ranking and Determining the Factors Affecting the Road Freight Accidents Model. *Civil Engineering Journal* 6, 928–944. URL: <https://www.civilejournal.org/index.php/cej/article/view/2025>, doi:10.28991/cej-2020-03091518.
- [2] Et al., Xiao Li, 2021. Statistics of Dangerous Cargo Accidents during Highway Transportation. *CONVERTER* 2021, 53–63. URL: <http://converter-magazine.info/index.php/converter/article/view/265>, doi:10.17762/converter.265.
- [3] Jashami, H., Hurwitz, D.S., Monsere, C.M., Kothuri, S.M., 2019. Evaluation of driver comprehension and visual attention of the flashing yellow arrow display for permissive right turns. *Transportation Research Record* 2673, 397 – 407. URL: <https://api.semanticscholar.org/CorpusID:149671831>.
- [4] Kircher, K., Ahlström, C., 2020. Truck drivers'interaction with cyclists in right-turn situations. *Accident Analysis & Prevention* 142, 105515. URL: <https://doi.org/10.1016/j.aap.2020.105515><https://linkinghub.elsevier.com/retrieve/pii/S0001457519317439>, doi:10.1016/j.aap.2020.105515.
- [5] Novickis, R., Levinskis, A., Fescenko, V., Kadikis, R., Ozols, K., Ryabokon, A., Schorn, R., Koszescha, J., Solmaz, S., Stettinger, G., Adu-Kyere, A., Halla-aho, L., Nigussie, E., Isoaho, J., 2021. Development and Experimental Validation of High Performance Embedded Intelligence and Fail-Operational Urban Surround Perception Solutions of the PRYSTINE Project. *Applied Sciences* 12, 168. URL: <https://www.mdpi.com/2076-3417/12/1/168>, doi:10.3390/app12010168.
- [6] Scheiner, N., Kraus, F., Appenrodt, N., Dickmann, J., Sick, B., 2021. Object detection for automotive radar point clouds – a comparison. *AI Perspectives* 3, 6. URL: <https://aiperspectives.springeropen.com/articles/10.1186/s42467-021-00012-z>, doi:10.1186/s42467-021-00012-z.
- [7] Taraba, M., Adamec, J., Danko, M., Drgona, P., 2018. Utilization of modern sensors in autonomous vehicles, in: 2018 ELEKTRO, IEEE. pp. 1–5. URL: <https://ieeexplore.ieee.org/document/8398279/>, doi:10.1109/ELEKTRO.2018.8398279.
- [8] Yeong, D.J., Velasco-hernandez, G., Barry, J., Walsh, J., 2021. Sensor and sensor fusion technology in autonomous vehicles: A review. *Sensors* 21, 1–37. URL: <https://www.mdpi.com/1424-8220/21/6/2140>, doi:10.3390/s21062140.
- [9] Yu, B., Chen, Y., Wang, R., Dong, Y., 2016. Safety reliability evaluation when vehicles turn right from urban major roads onto minor ones based on driver's visual perception. *Accident Analysis & Prevention* 95, 487–494. URL: <https://linkinghub.elsevier.com/retrieve/pii/S0001457515300476>, doi:10.1016/j.aap.2015.08.014.