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Autonomous Vehicle Simulation: Integration of CARLA and Autoware for testing and development

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Abstract:

This paper explores the integration of CARLA, an open-source simulator, with Autoware, open-source software for autonomous vehicle (AV) systems, to create a comprehensive virtual testing environment. This integration enables safe and cost-effective testing of AV reactions to dynamic, real-world scenarios with unpredictable factors and changing environments. We simulate a variety of scenarios, from city traffic to severe weather, using CARLA 0.9.15 and Autoware 2204.01, which are linked via an ROS-based bridge, and use AV sensors like as LIDAR, cameras, and radar to mirror real-world configurations. Performance metrics are collected and analysed to determine system strengths and limitations. The findings show that CARLA and Autoware integration provides a strong platform for end-to-end AV simulations, which is critical for developing safe, compliant, and efficient autonomous transportation systems.

Keywords: Autonomous, Compliance, Safety, CARLA, Autoware

1. Introduction:

Autonomous vehicles also known as driverless vehicles are vehicles capable of operating and functioning without any type of human intervention or control. This revolutionary mode of transport is being developed and tested to be made available on a large scale. The most important task for the Autonomous Vehicles (AVs) is ensure safety in its dynamic environment. These vehicles need to be tested and trained to adapt and act according to its dynamic surroundings. There is high risk in performing such tests in the physical world without causing actual harm or damage to life or expensive components. Here arises the requirement for virtual simulation to accomplish the required outcomes without actually causing any loss. The primary objective of this paper is to demonstrate the use of virtual simulation to check results and outcomes in situations and form a collection of the AV's reaction in the changing environment. This virtualization is made possible with tools like CARLA and Autoware which are available freely. Analysis of the virtual world and physical world is done to check the results and compare with expected outcomes in a given scenario [1-4].

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2. Motivation:

There are various image based datasets are present for machine learning applications[5-10]. The primary focus is to guarantee safety and efficiency while employing AVs for personal or commercial use. Maintaining the level of safety and efficiency is a milestone for the AVs. Cities and roads include multiple unpredictable actors like pedestrians, animals and other vehicles which coexist together. The AV needs to be trained and tested to the unpredictable movements of these actors and must react in the required method. It is easier, safer and more cost effective to test and train virtually.

In this research paper, we look at the importance and use of the Carla-Autoware integration in virtual simulation for the development of the AV. Preparing a virtual environment along with the specific vehicle and calibrated sensors put to test in random scenarios can help in checking the output of the system and compare the same with the expected output/reaction. The aim is to record strengths, limitations and shortcomings to ensure the same is not the case in the physical world.

The AV system also need to be policy compliant and are needed to meet the requirements and policies of the government to be allowed for use. The goal is to develop safer, reliable, compliant and efficient autonomous transportation services for all.

3. Objectives:

In this paper, we focus on the work of the Carla and Autoware integration for the purpose of recording the reactions of the AVs in random environment and compare the same with the physical world. The main objective is a safe, efficient, compliant, and cost-effective autonomous transportation solution for everyday use.

1. Integrate the Carla and Autoware for the autonomous vehicle simulation to test reactions of the systems in dynamic environments and changing scenarios and situations. The results are recorded for comparison with the physical world.
   Car Learning to Act (CARLA) – open-source simulator designed for autonomous vehicle research. It provides an environment with dynamic traffic, pedestrians and weather conditions.
   Autoware – open-source software which provides modules for perception, planning and control.
2. Analysis of the recorded results aids in the development for the physical world and helps in identifying the limitations and faults in the system for future reference and rectification. Performance metrics like perception, accuracy, decision-making, efficiency, collision avoidance and traffic rule adherence are evaluated to understand the functioning and the limitations.
3. Compare scenarios and tests from virtual world to physical world and record the differences and limitations. Analysis of these differences can help in finding the ideal system for AVs. This process involves validating the simulation against the physical world to measure efficiency and accuracy.

Integrating CARLA and Autoware allows to conduct end to end simulations of the autonomous

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systems and within a realistic virtual environment which is safer and cost-effective as compared to the experiments carried out in the physical world. This integration enables us to carry out random scenarios without the concerns of loss or damage while recording reactions of the systems.

4. Methodology:

4.1 Integration Process

4.1.1 Integrating CARLA and Autoware

In this research paper, the latest release of CARLA (0.9.15) along with its additional maps files is being used as the default for the simulator version. At the same time, for better compatibility with the Autoware software, it was recommended to use Autoware (2204.01). A Carla-Autoware bridge is developed for this purpose which helps in the integration based on the Robot Operating System (ROS). This bridge is the perfect connection between these open-source software as it is responsible for the simultaneous use of features from both software.

4.1.2 Software & Hardware Requirements

Software Requirements:

Carla-Autoware bridge is compatible with both Linux and Windows OS, although preferably better on Linux. Ubuntu 20.04 LTS is the version in use. Some pre-requisites needed for the functioning include NVIDIA Container Toolkit, ROS2 Humble (better compatibility with current version of the CARLA-Autoware bridge), and the CUDA toolkit. Python 3.7, Pip, Git, and Docker are the Linux tools required for downloading and installing all these softwares.

Hardware Requirements:

GPU: At least 6GB, 8GB recommended, NVIDIA GeForce 470 GTX or AMD Radeon 6870 HD or higher

RAM: Minimum 8GB

Processor: Quad-core Intel or AMD processor, 2.5GHz or faster

Disk Space: Around 200GB required for the software and its builds

4.2 Scenario Simulation & Development

Scenarios are random situations with varying conditions. These conditions include random pedestrian, vehicle and animal movements which need to be detected and correct actions must be taken. There are other conditions based on the weather in which the vehicle is operating which needs to be taken into consideration. These scenarios also need to include varying environments of driving like city traffic driving, highway merging and crossings and tolls. This scenario testing in simulation also assists in testing these scenarios in the physical world. CETRAN has certain scenario categories on which autonomous vehicles are assessed. This assessment permits AVs on the public roads. The criteria CETRAN proposes needs to be maintained in the simulations and the physical world. Ideally the system should react the same in the virtual and physical world to ensure a passing assessment. The collection of scenarios needs to cover a variety of what an AV can encounter in the real world. This collection of scenarios is required to be reviewed regularly for missing scenarios or other conditions. Each

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scenario outcome needs to be recorded and checked with the expected outcome, the same outcome is expected in the physical and virtual world for the assessment to be successful.

4.3 Simulation Configuration

The virtual simulation using CARLA-Autoware simulator needs to be correctly configured with the system which is implemented in the physical world to ensure the recorded results are on the same basis of comparison. The configuration includes the scenarios developed along with other dynamic conditions. It also includes configuring the sensors in the simulation to mimic the physical world. The sensors used have to be setup in the same method in both the worlds and need to be reading and producing the same results to obtain the expected outcome. The LIDAR sensors, cameras and radar also need to be installed and functioning for the correct reactions required for the assessment. This configuration is the answer to the safety, efficiency and compliancy of the AVs. There is also the requirement to choose the optimum vehicle model and the control algorithm to ensure that there are no issues while carrying out the scenarios. For the simulations, the weather conditions, traffic density and the time of the day are factors which need to be recorded and considered, as each outcome will differ. This might be a problem while recreating the scenario in the physical world.

LIDAR – Light Detection and Ranging is a remote sensing technology for detecting and sensing the environment around the AV. It used in providing high resolution 3D images of the surroundings which helps the AV in perception, detection and navigation. These sensors are the least affected by the weather conditions and hence provide the long range and robustness.

Cameras – Most commonly used camera setup in AVs is the 360-degree surround camera. They provide a wide field of view of all the surroundings which includes blind spots which the other sensors may not be able to cover. It also allows for better detection and tracking which improves safety for passengers and pedestrians. It also assists the AV in navigating tight spaces and avoiding collisions which also helps in parking assist.

Radar – Radio Detection and Ranging is sensor technology which works on the emission of radio waves in surroundings of the AV and measuring the time it takes to return. Similar to LIDAR it helps in long range and low visibility areas and is not affected by the weather conditions. These sensors are used for object detection, cruise control and blind spot detection.

These are the most commonly used sensors on AVs which assist the functioning. They require to be configured to obtain the correct output and react accordingly. Configuration of these sensors means the safe, efficient implementation of AVs.

5.Expected Outcomes:

5.1 Successful Integration

CARLA and Autoware integration are the perfect environment required for a smooth simulation setup for testing of autonomous vehicle systems. CARLA is responsible for the simulated world along with the traffic, pedestrians and weather conditions. Autoware is responsible for the sensors, control algorithms and the systems for perception and detection. If

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integrated successfully, the perfect virtual simulation is possible to test the different scenarios developed. These simulations aid in the development and fixes that are required on the systems in the physical world.

5.2 Simulated Scenarios

Virtually simulated scenarios are developed following the criteria and categories set by CETRAN. If the assessment of the systems is successful in the virtual and physical world then that scenario is successfully recorded for later reference. The varying conditions and movements in a simulation mimic the dynamic environment and help in configuring the systems. Ideally the virtual simulations are run first to get an overview of the system behavior and limitations. This is executed to ensure there is no unnecessary damage caused when the same scenario is carried out in the physical world.

5.3 Analysis of Performance

The performance metrics for each scenario are pre-defined and need to be recorded after execution of the virtual simulation. These metrics normally aid in the comparison of the virtual and the physical world. Readings in the same metrics are recorded in the physical scenario execution. Analyzing the metrics, assists in the understanding of the working, limitations and shortcomings of the system being tested. In short, metrics provide grounds for comparison in recorded results.

5.4 Understanding the Analysis

The analysis of the recorded results after comparison, aid in understanding the strengths, weaknesses, limitations and shortcomings of the proposed system. This includes the hardware and software used in the AV. Depending on the different variables in the dynamic environment, certain criteria and expectations must be satisfied before a successful assessment can be authorized. The limitations and weaknesses need to be addressed and a working alternative solution needs to be presented to display an upgraded system. The analysis also helps in understanding the response of the AV and its decision taking skills and perception of its surroundings. All this together helps in recognizing the areas of improvement and the development still required for smooth operation of AVs.

6. Observations

6.1 Simulation Environment

Integration of CARLA and Autoware provides an environment that covers both the aspects of realistic scenarios and the system of sensors and their readings. This allows end-to-end simulations in a virtual environment without the worry of damage or loss.

6.2 Sensor and Perception

Integration provides the option to configure and setup the hardware of the system the same way it is in the physical world. LIDAR, radar, and cameras are the equipment used for perception,

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detection and collision avoidance.

6.3 Scenario Testing

Integration allows the creation of different scenarios with changing conditions to simulate a dynamic environment. It also includes the animal, pedestrian and traffic movement and behavior to the same. Changing weather conditions can also be simulated to test the system accordingly. This also looks at performance of the control algorithms.

6.4 Verification

The same scenarios can be tested and implemented in the real world to test the performance and compare the results to the virtual simulations. This verifies the results recorded and can help in noting the strengths and weaknesses of the system.

6.5 Reproducibility

CARLA and Autoware are open-source software available freely for all. It becomes easy to refer and setup systems based on the integration of both. However, the compatibility of the software and its peripherals with the workstation needs to be precise. Any version mismatch can cause errors in integration. Integration is compatible with Windows and Linux but prefers Linux. Hence it is easier to setup and use on Linux workstations.

7. Conclusion

Integration of CARLA and Autoware for testing and development of autonomous vehicles and their systems is the most efficient and cost-effective method while keeping in mind the safety and compliance. This integration of open-source softwares helps in the virtual simulations in dynamic environment which simulates the physical world. Parameters and configurations can aid the creation of the required CETRAN scenarios and record their reaction and movement. Assessment based on the results of these scenarios allows the further research into introduction of autonomous vehicles into the daily life. Step-by-step the progress towards AVs is noticeable. The future for Autonomous vehicles is promising with the focused development of systems and vehicles for personal and commercial use.

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