2. Literature Review

This chapter discusses the various other related works. The first part explores some state of art autonomous vehicle simulators and identifies its key features, advantages and limitations. The subsequent part summarizes about the preceding approaches for defining a metric for the comparison of Autonomous vehicle simulators. The last part of this chapter discusses about the different types of Generative Adversarial networks (GANs), a Generative AI algorithm which is applied in this thesis and highlights the key advantages in those approaches.

2.1 State of art simulators

There are numerous simulators available in the market, however this section discusses about some of the relevant and popular simulators

2.1.1 CARLA

CARLA (Car learning to act) is an open-source software developed by the Computer Vision Centre (CVC) and the Barcelona Supercomputing Centre (BSC) in collaboration with the Toyota Research Institute for research and development of autonomous driving. It provides realistic and diverse environments with various urban scenarios, climates and sensors. It is developed using unreal engine 4 for rendering high quality visual effects and OpenDRIVE standard 1.4 to define roads and urban settings. The figure 1 depicts a scene from the simulators in various weather. The key feature of this simulator is that it is built as a server client architecture. The server handles the physics and computation of simulators whereas the user can control the simulator using C++ and python APIs making it scalable. Another upside of this simulator is that it facilitates the flawless process of developing, training and validating machine learning algorithms. Various algorithms like modular pipeline, Imitation learning, Reinforcement learning [2] can be trained and validated in this simulator making it one the best choices for researchers. Moreover, it provides variety of sensor data such as cameras, Lidars, various meta data and ground truth which makes it more beneficial and handy. This simulator also provides access to various digital assets (actors) in the environment carefully designed to maintain high level of realism. However, currently it supports only 2 pre-defined urban maps with 2.9 kms and 1.4 kms of driving failing to provide diversity and generalization.

2.1.2 LGVSL

LG Silicon Valley lab (LGSVL) is developed by LG electronics as an open-source simulation engine. It uses Unity gaming engine to render photo realistic environments and also takes advantage of technologies such as High-definition render pipeline (HDRP). The simulator is developed into two parts, Simulation engine and user autonomous driving (AD) stack. The simulation engine is open source and it receives input from the AD stack and simulates the environment, sensors and vehicle. The AD stack consist of three parts Perception, planning and control which can be configured by user. The AD stack and simulation engine are connected through communication bridge interface such as Cyber RT. The simulator comes with various default set of sensors such as camera Lidar, Radar… However, the one of the key feature of this simulator is that the user can built and configure their own sensor. In addition to default sensors, Model of real world sensors can be imported as a plug in. For Example, Velodyne VLP-16 LiDAR generate point clouds in the same format as real sensors. The sensor data and its position can be exported and defined using JSON formatted text which make it easy to use The unique feature of this simulator is it’s ability to use real world maps to build the environment. Maps in formats like Lanelet2, OpenDRIVE and Apollo 2 HD map can be and used as the virtual environment. This makes it more suitable for researchers in OEMs

2.1.3 SUMMIT

A Simulator for Urban Driving in Massive Mixed Traffic (SUMMIT) a open source simulator developed as an extension of CARLA simulator inheriting its physics and visual realism. It uses Python based APIs to communicate with CARLA Most of the other simulators simulates a rule-based traffic where all the actors acts according to a rule with minimal degree of randomness. However, the real world traffic is comparatively aggressive and chaotic. The distinguishable feature of SUMMIT is that is simulates the aggressive and chaotic behaviour of the traffic in real world. This attracts users who are interested in training and testing the algorithms which drives vehicles in un regulated traffic. In this simulator, a crowd behaviour algorithm “Context - GAMMA”, a velocity – space optimization algorithm is used to simulate the traffic behaviour geometrically and topologically. Moreover, it uses the real world map from OpenStreetMap to extract features such as roads, sidewalks, roundabouts, which can be further used in the simulator to replicate real world maps. The figure3 shows the Real map and its counterpart with un regulated traffic behaviour in SUMMIT of Magic- Roundabout, England. This feature of using real world map and taking advantage of Visual realism from CARLA and simulating chaotic traffic behaviour makes it even powerful.

2.2 Comparative study on simulators

This section will analyse some other work involving in comparative study of Autonomous vehicle simulators and summarizes the analysis

In the work of Guan Yang, et.al., (2021) in the “Survey on autonomous vehicle simulation platform”, the team had conducted an extensive research on various autonomous vehicle simulation platform. They had broke down the objective of the simulator into 5 parts i.e., Static environment simulation, Dynamic environment and behaviour simulation, Traffic flow simulation, Sensor simulation and vehicle dynamics simulation. Moreover, for they have defined a taxonomy for existing simulator, They categorized the simulation platform into Point cloud based and 3D engine. Point based simulators are the one which simulates the sensory data and reconstructs the environment based on sensor data. Some example of this simulators are CarCraft from Waymo and Apollo from Baidu. Figure 4 shows the map from Apollo a point based simulation platform, whereas 3d engine based platform uses gaming 3 d engines such as Unity, Unreal to render a environments in accordance with laws of real physics. Figure 5 shows a map of PanoSim, a 3d engine based simulator. A Table with comparision simulators and its available feature is framed and the same is shown in figure 6. Thoug this table compares helps to compare the simulators the no of features is not enough for a concrete decision and there is no single metric which define the useability of that simulator to the user. It provides a categorization of simulators but a comparative method among simulator is not clearly defined

In the work of Md Salman Ahmed et.al (2016), an extensive research on connected vehicle simulator was discussed. The domain of connected vehicles includes Vehicle to vehicle communication, vehicle to server communication… and requires a simulator to train as it will be expensive to train in real world. In this paper several simulators which simulates the Vehicle communication system and compared based its memory consumption, computing environment (Sequential or Parallel) and no. of vehicles it can handle and the results are summarized. However these results corresponds to a specific domain of Connected and this method cannot hold for any other type of AV simulators.

**CLEAN TEXT**

2. Literature Review

This chapter explores different works related to the topic. The initial section examines the existing state-of-the-art autonomous vehicle simulators. The second part provides a summary of previous methodologies used to define a comparative metric for evaluating autonomous vehicle simulators. The last part of this chapter discusses about the different types of Generative Adversarial networks (GANs), a type of Generative AI algorithm utilized in this thesis. It identifies the key advantages associated with these approaches.

2.1 State-of-the-Art Simulators

Numerous simulators are available in the market, but this section highlights some relevant and popular simulators and highlighting their advantages, limitations and applications.

2.1.1 CARLA

CARLA, (Car Learning to Act) is an open-source software developed collaboratively by the Computer Vision Centre (CVC) and the Barcelona Supercomputing Centre (BSC) in partnership with the Toyota Research Institute. It is primarily designed for autonomous driving research and development, which provides diverse and realistic environments, various climates and wide range of sensors. CARLA operates on a server-client architecture, built on Unreal Engine 4 and utilizing the OpenDRIVE standard 1.4 to define roads and urban settings. This unique structure allows the server to manage simulator physics and computation while enabling user to communicate the server through C++ and Python APIs, providing scalability.

A notable feature of CARLA is its seamless support for developing, training, and validating machine learning algorithms. Researchers can employ various algorithms like modular pipelines, imitation learning, and reinforcement learning within this simulator [2], making it a preferred choice for researchers. Leveraging Unreal Engine 4, CARLA offers high-quality, realistic rendering of environments. Figure 1 showcases scenes from the simulator in different weather conditions. Additionally, it provides an array of sensor data such as cameras, LiDAR’s, various metadata, and ground truth, enhancing its useability. Moreover, CARLA offers access to diverse digital assets (actors) within the environment, meticulously designed to maintain a high level of realism. However, it currently offers support for only two pre-defined urban maps covering 2.9 km and 1.4 km, which limits its diversity and generalization capabilities.

Figure1: Scenes from the CARLA simulator in different weather conditions.

2.1.2 LGVSL

LG Silicon Valley Lab (LGSVL) is an open-source simulation engine developed by LG Electronics. It utilizes the Unity gaming engine to render photorealistic environments and taking advantage of technologies like the High-Definition Render Pipeline (HDRP) from Unity.

This simulator is developed in two parts: the Simulation Engine and the User Autonomous Driving (AD) Stack. The Simulation Engine, an open-source platform, receiving its inputs from AD stack and simulate the environment, sensors, and vehicle dynamics. The AD Stack comprises three key elements: Perception, Planning, and Control, offering various user-configurable functionalities. The AD Stack and the Simulation Engine is connected through communication bridge interface, such as Cyber RT, ensuring seamless integration. While the simulator comes with a default sensors including cameras, LiDAR, and Radar, its unique feature lies in its adaptability. Users can build and configure their own sensors, even importing models of real-world sensors as plugins. For instance, the plugin for Velodyne VLP-16 LiDAR replicates point cloud generation similar to its actual counterpart [3]. These sensors' data and its positions are defined through JSON-formatted text, simplifying their utilization. Figure 2 showcases the array of default sensors accessible within this simulator.

Figure 2: Different types of sensors. Left (top to bottom): Fish-eye camera,LiDAR, Radar; Right (top to bottom): Segmentation, Depth, 3D Bounding

Box.

A distinguishing aspect of this simulator is its capability to incorporate real-world maps to construct virtual environments. Map formats like Lanelet2, OpenDRIVE, and Apollo 2 HD map can be imported and used as the virtual environment. This features of LGSVL appeals to engineers of automakers and making it a highly suitable tool for their research.

2.1.3 SUMMIT

SUMMIT (The Simulator for Urban Driving in Massive Mixed Traffic) is an open-source simulator developed as an extension of the CARLA simulator, inheriting its physics and visual realism. Unlike many other simulators that predominantly simulate rule-based traffic with minimal randomness, SUMMIT stands out for its ability to replicate the aggressive and chaotic nature of real-world traffic. This distinctive feature attracts users interested in training and testing algorithms for vehicles navigating unregulated traffic scenarios. SUMMIT employs the 'Context-GAMMA', a velocity-space optimization crowd behaviour algorithm [4] to geometrically and topologically simulate traffic behaviour. Additionally, it utilizes real-world maps from OpenStreetMap, extracting features such as roads, sidewalks, and roundabouts. These features are then incorporated into the simulator, enabling the replication of real-world maps. An illustrative example can be seen in Figure 3, which showcases the comparison between a real map and its counterpart with unregulated traffic behaviour in SUMMIT at the Magic Roundabout in England.

Figure3: Scenes in the real world and corresponding scenes in SUMMIT

SUMMIT's utilization of real-world maps, combined with CARLA's visual realism and the simulation of chaotic traffic behaviour, significantly enhances its capabilities.

2.2 Comparative Study on Simulators

This section examines notable studies that compare autonomous vehicle simulators and summarizes their results.

In Guan Yang et al.'s work (2021), "Survey on Autonomous Vehicle Simulation Platforms," [5] the team extensively researched different autonomous vehicle simulation platforms. They broke down the simulator's objectives into five parts: Static environment simulation, Dynamic environment and behaviour simulation, Traffic flow simulation, Sensor simulation, and Vehicle dynamics simulation. They also established a taxonomy for existing simulators, categorizing them into Point Cloud-based and 3D Engine-based platforms. Point-based simulators, such as CarCraft from Waymo and Apollo from Baidu, reconstruct the environment based on sensor data. Figure 4 displays the map from Apollo, a point-based simulation platform. On other hand, 3D engine-based platforms, like PanoSim, utilize gaming engines like Unity and Unreal to render environments following laws of physics (Figure 5).

Figure 4: Scene from Apollo Simulator

Figure 5: Scene from Apollo simulator

Figure 5: Scene from PanoSIM simulator

They further created a table comparing simulators and their available features [5] (Figure 6) .

Figure6 : A Comparison table of various simulator

Although this table aids in comparing simulators, it doesn’t compare sufficient features for making a concrete decision, and lacks a single metric defining the level of usability of the simulator for a user. While the categorization of simulators is provided, a clear comparative method among simulators is not clearly defined.

In Md Salman Ahmed et al.'s work (2016), an extensive study on connected vehicle simulators was presented [6]. The focus was on the domain of connected vehicles, including vehicle-to-vehicle and vehicle-to-server communication. The paper assessed several simulators based on their memory consumption, computing environment (Sequential or Parallel), and the number of vehicles they could handle. However, these results are specific to the connected vehicle domain and may not be applicable to other types of autonomous vehicle simulators.

List of figures

Figure 1: Scenes from the CARLA simulator in different weather conditions.

Figure 2: Different types of sensors. Left (top to bottom): Fish-eye camera,LiDAR, Radar; Right (top to bottom): Segmentation, Depth, 3D Bounding Box

Figure3: Scenes in the real world and corresponding scenes in SUMMIT

Figure 4: Scene from Apollo Simulator

Figure 5: Scene from PanoSIM simulator

Figure 6: A Comparison table of various simulator

List of tables

References

[2]: Dosovitskiy, A., Ros, G., Codevilla, F., Lopez, A. &amp; Koltun, V.. (2017). CARLA: An Open Urban Driving Simulator. <i>Proceedings of the 1st Annual Conference on Robot Learning</i>, in <i>Proceedings of Machine Learning Research</i> 78:1-16 Available from <https://proceedings.mlr.press/v78/dosovitskiy17a.html>.

[3]: G. Rong et al., "LGSVL Simulator: A High Fidelity Simulator for Autonomous Driving," 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), Rhodes, Greece, 2020, pp. 1-6, doi: 10.1109/ITSC45102.2020.9294422.

[4]: Cai, Panpan, et al. "Summit: A simulator for urban driving in massive mixed traffic." 2020 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2020.

[5]: G. Yang et al., "Survey on Autonomous Vehicle Simulation Platforms," 2021 8th International Conference on Dependable Systems and Their Applications (DSA), Yinchuan, China, 2021, pp. 692-699, doi: 10.1109/DSA52907.2021.00100.

[6]: M. S. Ahmed, M. A. Hoque and P. Pfeiffer, "Comparative study of connected vehicle simulators," SoutheastCon 2016, Norfolk, VA, USA, 2016, pp. 1-7, doi: 10.1109/SECON.2016.7506701.