A 3D Simulation Environment for Assessing Interactions with Autonomous Vehicles

Giorgos Karamitsos
Phd Student
gkaramit@auth.gr
Xenofon Karamanos
Phd Student
karamanos@auth.gr
Dimitrios Vlachos
Professor
vlachos1@auth.gr
Department of Mechanichal Engineering, School of Engineering, Division of Industrial Management, Aristotle University of Thessaloniki, Thessaloniki, Greece

Dimitrios Bechtsis
Assistant Professor
dimbec@ihu.gr
Pantelis Mentesidis
Postgraduate Student
mentes.pantel@gmail.com
Department of Industrial Engineering and Management, School of Engineering, International Hellenic University, Thessaloniki, Greece

Abstract

Self-driving passenger cars are already on public roads to support the vision of a sustainable city. The research community and academia should further support the human-machine symbiosis of autonomous vehicles, manually driven vehicles, and even pedestrians.
At the time being, most vehicles operate at level 2 of the Society of Engineers (SAE) autonomy scale as they only have partial automation. However, they are expected to escalate due to cost reduction of essential hardware components (sensors and actuators) and software advancements in Deep Neural Networks (DNN). The main challenge is thoroughly testing self-driving behaviors and human-machine symbiosis scenarios for improving safety conditions and engaging citizens in this concept.
Video game simulators could provide a basis for testing and showcasing the innovative features of autonomous driving. Unreal Engine and Unity are two prominent examples of software tools for creating photorealistic graphical environments. In addition, the scientific community and academia elaborate on open-source simulators due to their interoperability features for data exchange and their inherent connections with robotic frameworks.
The proposed research work presents an integration framework for the CARLA simulator. The framework uses an integrated Graphical User Interface (GUI) to facilitate the deployment of a fully functional simulation that enables users to include an environment for the passenger cars and several Non-Playable Characters (NPCs) that will participate in the simulation. The purpose of this study is to exploit the interactions of manually driven and autonomous vehicles in a 3D simulation environment and provide evidence that further supports human-machine symbiosis on public roads.

Keywords
3D Simulation, Autonomous Vehicles, Robot Operating System (ROS), Deep Neural Networks (DNN).

1. Introduction

Autonomous driving enables vehicles to identify their surrounding environment while moving from one point to their final destination without any intervention from a human driver. For many years efforts from academia and car, industries are focused on autonomous driving in order to radically change the way we are moving and this will hopefully provide a tremendous bust to the commercial vehicle sector (Kim et al. 2021). In order to promote the development of autonomous driving the Defense Advanced Research Projects Agency (DARPA) held a series of competitions called the DARPA Grand Challenge from 2004 until 2007. Although these competitions presented much simpler challenges than those typically encountered on public roads, they are considered milestones for the development of autonomous driving. Since the DARPA challenges ongoing research on self-driving cars has escalated in both academia and industry around the world. Notable examples of universities conducting research on self-driving cars are Stanford University, Carnegie Mellon University, MIT. On the other hand, there are also examples in the business sector namely Google, Uber, Baidu, Lyft, Aptiv, Tesla, Nvidia, Aurora, Zenuity, Daimler and Bosch (Badue et al. 2021).

To provide an approximate scale regarding the levels of autonomous driving the Society of Engineers defined six levels of autonomy depending on driver intervention. At Level 0 the driver fully operates the vehicle. At Level 1 the system aids the driver in acceleration/deceleration, steering and lane-keeping. At Level 2 the system aids the driver with highway driving and offers parking assistance. At Level 3 the vehicle under certain conditions can slow down during traffic congestion and perform lane changes. At Level 4 the system drives autonomously on predefined public roads and without any intervention from the driver. Finally, Level 5 enables fully autonomous driving without the driver regardless of any situation on the road. Nowadays, commercial self-driving vehicles operate mostly at Level 2 and 3 of the Society of Automotive Engineers (SAE) classification, restricted to road environments where driving is possible (NHTSA).

Furthermore, emerging technologies in the field of Artificial Intelligence (AI), especially in the areas of image classification and recognition, have contributed remarkable developments in the efforts to overcome adversities of autonomous driving and improve safety for drivers and weak road users on public roads with greater accessibility and less environmental impact (Sonata et al. 2021). However, in order to overcome traffic conditions, impulsive behavior of road users (i.e., cars, pedestrians, cyclists), and extreme weather conditions (i.e., heavy rain, snowfall) multi-year accumulated driving experience is required to create robust driving behavior. Nevertheless, the collection of quality data is considered a challenge mainly down to the sheer amount of information (image, point cloud) necessary for training Deep Neural Network (DNN) models (Campisi et al. 2021).

To that end, video game simulators could provide a staple for testing and showcasing the innovative features of autonomous driving. Unreal Engine and Unity are two prominent examples of software tools for creating a photorealistic 3D simulation. In the automotive industry simulation software is used not only to imitate real-life conditions on public roads but also to mitigate the risk of jeopardizing state ownership and physical integrity. Thus, an important asset of driving simulators is the creation of specific scenarios unfolding in a virtual environment, i.e., a pedestrian crossing in front of a vehicle, or when a driver stops before a red traffic light. The scenarios can be varying by changes in traffic patterns, weather, and events inside the environment (Kaur et al. 2021).

This research aims to explore the driving characteristics of autonomous vehicles along with their interaction with the surrounding environment (traffic lights, road signals) and manual-driven vehicles in a 3D simulation environment. An integrated Graphical User Interface (GUI) for the CARLA simulator is proposed and a fully functional simulation that enables the inclusion of passenger cars and Non-Playable Characters (NPCs) to participate in the simulation is deployed. Moreover, a Deep Neural Network (DNN) architecture is integrated for object detection inside the 3D simulation environment through the vehicle's camera to recognize objects from the environment. The overarching aim of this study is to present a 3D simulation environment for supporting human-machine symbiosis on public roads through manually driven and autonomous vehicles' interactions.

2. Literature Review

Simulation frameworks are used for reproducing a real-world environment when (i) physical space is unavailable, (ii) the application can become detrimental to state ownership, or (iii) the potential risk for accidents is high. To that end, simulation usage for autonomous driving applications is preferred prior to testing on public roads. Rong et al. (2020) proposed LGSVL, a simulator based on the Unity game engine that provides a photo-realistic virtual environment that depicts the real world and enables the use of Deep Neural Networks (DNN) for the development and testing of self-

driving vehicles. The simulation engine is comprised of the environment, sensors, and vehicles while other aspects such as weather, sensor data and vehicle control are integrated as subsets to the simulation environment. LGSVL also utilizes Software In Loop (SIL) and Hardware In Loop (HIL) testing for asserting sensor data and providing a thorough analysis of car hardware components in a digital twin environment for evaluating self-driving behavior.
The upgrowth of Deep Neural Networks (DNN) has contributed to the progression of autonomous driving as a feasible solution for tackling traffic congestion and reducing the rate of traffic accidents. However, DDNs require sensor data (i.e., image, point cloud) to create meaningful correlations and identify objects in a real-world setting. Dosovitskiy et al. (2017) proposed Carla, an open-source simulator for autonomous driving that provides digital assets and a vast number of environments, scenarios, vehicle models and sensors for evaluating autonomous driving behavior. Furthermore, three approaches of autonomous driving (modular pipeline, imitation learning, and reinforcement learning) in four driving scenarios with different weather patterns were evaluated, clearly indicating the success of the simulation as a training ground for DNN applications but also highlighting the need for more robust algorithms and model architectures for improved autonomous performance.

Moreover, Santara et al. (2021) presented MADRaS, a car-racing simulator based on TORCS simulator that supports multi-agent training and a client-server architecture where the server is acting as the simulation environment and the client as the agent. The authors trained reinforcement learning agents to accomplish challenging tasks such as navigation through static and moving obstacles. MADRaS provides simulation scenarios of high variance and complexity that are valuable for autonomous driving research.

The combination of sensor data under a unified software tool is crucial for an autonomous driving application. Reke et al. (2020) proposed software architecture for Autonomous Driving by using the latest version of the Robot Operating System, ROS2. The updated ROS2 meta-operating system combines real-time behavior along with standardized message types by enabling data fusion of sensor data and the creation of an occupancy grid map. The performance of the software tool was tested on a real car in various driving scenarios to evaluate real-time performance. Results highlighted that real-time performance was effective but the integration of a kernel capable of arranging real-time coding demands is necessary.

AbdelHamed et al. (2020) utilized Gazebo simulator for testing autonomous driving algorithms in realistic scenarios. The authors developed an environment and a vehicle based on ROS and implemented autonomous vehicle algorithms for testing different use case scenarios. The application is further used for enhancing object detection and classification algorithms with the use of cameras and LiDAR sensors.

Hofbauer et al. (2020) created Telecarla, an open-source tool for teleoperated driving applications based on the CARLA simulator and the ROS framework. The application utilizes a client-server architecture for teleoperated driving in a 3D simulation environment, providing a low delay streaming pipeline, a communication interface for exchanging control commands and status information between the CARLA server and client. This framework is an extension to the existing CARLA simulator and can be utilized with other simulators supporting a ROS bridge interface.

Simulation and real-world applications can operate simultaneously to optimize the driving experience. Kang et al. (2020) suggested the concept of a remote driver taking control over an autonomous vehicle when facing an unpredicted situation or failure e.g., bad weather, malfunction, or contradictory sensor input. However, a major disadvantage is associated with network communication due to real-time latency occurring between the vehicle and remote driver. During the evaluation process, the feasibility of real-time video streaming over wireless networks (LTE, Wi-Fi) was assessed in terms of frame latency, frame size and loss rate of different resolutions marking the frame size as the major cause of latency during intermediary communication.

Furthermore, Zofka et al. (2020) proposed a simulation architecture for testing autonomous driving behavior in a simulation framework. The purpose of this application is the integration of real traffic scenarios by using a ROS-based server-client architecture where the models are integrated within a client-multi-server network.
Elmquist et al. (2017) the authors developed an application for simulating autonomous vehicle interaction with Chrono, an Open-Source multi-physics simulation engine for creating sensors in edge weather cases and providing accurate data based on physical noise models and effects from the environment. Furthermore, they utilized CAVE simulator, a framework for testing connected autonomous vehicles in a virtual environment.

Hoffmann et al. (2021) present a software teleoperation control tool for driving applications with the objective of making it applicable for a multitude of UGVs and supporting teleoperated driving research. The ROS framework is used to facilitate the maintainability and modularity of the system. The testing of the software tool was performed on an AUDI Q7, a 1:10-scale RC car and on the LGSVL simulator, allowing the driver to take control over the vehicle in emergency situations.

Table 1. Critical taxonomy of the existing research.

Authors	**Frameworks**
Rong et al. 2020	LGSVL
Dosovitskiy et al. 2017	CARLA
Santara et al. 2021	MADRaS, TORCS
Reke et al. 2020	ROS2
AbdelHamed et al. 2020	Gazebo, ROS
Hofbauer et al. 2020	Telecarla, CARLA, ROS
Kang et al. 2020	LTE, Wi-Fi
Zofka et al. 2020	ROS
Elmquist et al. 2017	Chrono, CAVE
Hoffmann et al. 2021	LGSVL, ROS

3. Methodology
3.1 Open source simulation tools
To explore the concept of autonomous driving we use CARLA and ROS to simulate the interaction of vehicles inside a dynamic environment.

CARLA is an open-source simulator for autonomous driving research-based on Unreal Engine 4 (UE4). The simulator ecosystem constitutes interoperable plugins providing realistic real-world physics, high image quality and composing scenes using 3D models. CARLA enables the dynamic incorporation of NPCs such as pedestrians, cyclists and vehicles, reenacting movement patterns reminiscent of their real-world counterparts. CARLA provides a wide range of sensors such as cameras and LiDAR for perception tasks like object detection and obstacle avoidance. The sensor pipeline is supported through ROS-bridge, a ROS package that allows interchangeable data exchange and interoperability with external systems such as control and perception modules for controlling the vehicles. CARLA utilizes a client-server architecture based on Python programming language, where the server constitutes the simulation environment, and each vehicle is a client communicating and interacting with the surrounding environment. CARLA is available for Windows and Ubuntu operating systems, however, for the purpose of this study, Ubuntu was selected due to its innate compatibility with ROS.

ROS is a meta-operating system that provides tools and protocols for controlling and handling robot subsystem communication. ROS operates based on a graph architecture of interoperable nodes that communicate with one another via channels called topics and form clusters capable of executing specific programmed tasks. The framework is integrated along with Gazebo and Rviz simulators and provides tools for interacting with simulation and real-world scenarios.

3.2 Custom Graphical User Interface (GUI)
In order to provide a user-friendly experience, a GUI was created for CARLA by using ROS and the Python programming language. The GUI presents two options that initializes the server and client components (Figure 1). The server interface prompts the user to select a specific layout and the approximate number of NPCs (Figure 2) that will operate in a network environment. The client interface has an option for vehicle selection, a textbox to name the specified client and a checkbox that controls the manual or autonomous operation of the vehicle. The carlaviz and rviz simulators enable the visualization of sensor data streaming from the vehicle. Finally, the home button returns the user to the initial menu and the exit button terminates the simulation.
In order to explore the capabilities of CARLA a use case scenario was executed that included two clients. The clients control a manually operated and an autonomous vehicle that are navigating simultaneously inside the same layout and start from a specific rendezvous point. By utilizing the custom GUI a specific environment (server) and two vehicles

(clients) were introduced from 2 different computers in a network environment. The process successfully validated the capabilities of CARLA for supporting multi-vehicle simulation.

Figure 1. CARLA Graphical User Interface

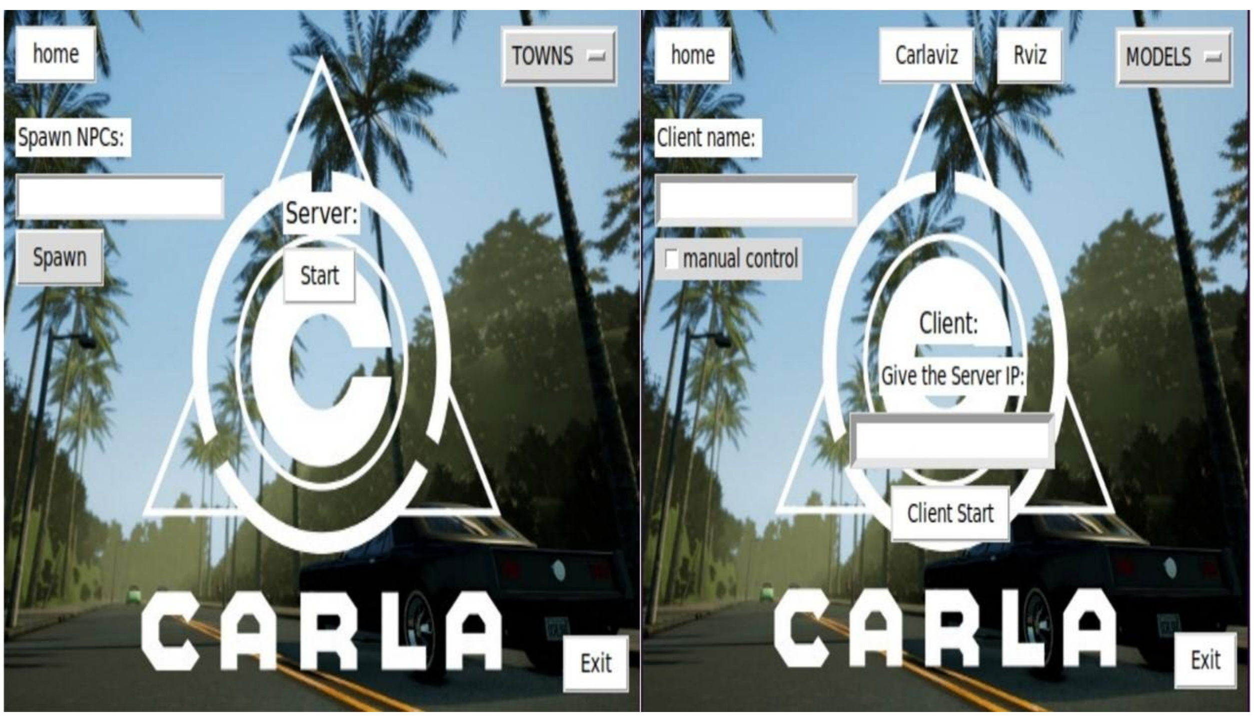

Figure 2. CARLA Graphical User Interface (a) server interface, (b) client interface

3.4 Deep Learning Model

Additionally, to further explore the capabilities of CARLA we applied Detectron 2 library along with Faster RCNN deep learning model for performing object detection through the ROS image data stream derived from the vehicle. Detectron 2 is a deep learning framework created by Facebook AI Research that provides state-of-the-art detection and segmentation algorithms (Wu et al. 2019). Faster R-CNN is a deep learning model capable of performing object detection in real-time with high speed and accuracy. The Faster R-CNN deep learning model was pretrained on Microsoft Common Objects in Context (MS COCO) (Lin et al.) a large-scale image dataset containing 328,000 images and 80 classes of different objects. The vehicle was able to navigate in the environment and perform real-time detection of objects, recognizing pedestrians, cyclists, traffic signs, and other vehicles (Figure 3).

Figure 3. Using Faster R-CNN model for object detection inside CARLA environment

4. Conclusion

In this study, the authors proposed a software tool for creating a network simulation environment that includes multiple autonomous vehicles. A GUI is introduced for the CARLA simulator that customizes the simulation environment (indicatively selecting a specific town layout, the introduction of manually controlled or autonomous vehicles) and initializes a connection with ROS for controlling the autonomous vehicles. Furthermore, Detectron 2 framework is utilized along with Faster RCNN DNN model to perform object detection inside the simulation. Experiments with the simulation provide evidence that a multi-client simulation environment can support the introduction of autonomous vehicles to the wider public while hiding the complexity of the details for the setting up of the command-line interfaces. Future work could also provide functions for configuring the autonomous vehicle's behavior (indicatively slow or fast driving or the pedestrian behavior (indicatively passing only from the light of crossing).

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Biography

Giorgos Karamitsos is a PhD candidate at the Industrial Engineering and Management Department, International Hellenic University, Thessaloniki Greece. He is a Junior Researcher (since 2019) at the Laboratory of Statistics and

Qualitative Analysis Methods of the Industrial Management Division of the Mechanical Engineering Department of the Aristotle University of Thessaloniki (A.U.Th)., Greece. His research interests include industrial systems, autonomous systems, and neural network methodologies.

Xenofon Karamanos is PhD Candidate at the Division of Industrial Management of Mechanical Engineering, Aristotle University of Thessaloniki (A.U.Th.), Greece. He is a Junior Researcher (since 2019) at the Laboratory of Statistics and Qualitative Analysis Methods of the Industrial Management Division of the Mechanical Engineering Department of the A.U.Th., Greece. He is interested in various scientific topics, such as Information Technology, Robotics, Autonomous Navigation and Deep Learning.

Pantelis Mentesidis is a postgraduate student at the Industrial Engineering and Management Department, International Hellenic University, Thessaloniki Greece.

Dimitrios Bechtsis is an Assistant Professor at the Industrial Engineering and Management Department, International Hellenic University, Thessaloniki Greece, in the area of computer science for supply chain management. His research interests include information systems, autonomous systems, industrial systems, digital supply chain design and simulation techniques, while he is focusing on the incorporation of autonomous systems into the digital supply chain ecosystem. He has conducted research activities in the fields of autonomous systems and supply chain management, and he has participated innumerous research projects.

Dimitrios Vlachos is the Director of the Laboratory of Statistics and Quantitative Analysis Methods, Logistics and Supply Chain Management (LASCM) of the Department of Mechanical Engineering of the Aristotle University of Thessaloniki (AUTh), Greece. He conducts research and consulting in the fields of supply chain management, logistics, applied operational research, combined transport systems management, business restructuring and strategy development. He has performed research activities in the field of supply chain management. He has participated as a consultant or expert in numerous projects funded by public and private organizations.