1. Introduction

1.1. Autonomous Vehicle

Transportation had played an important role in the mankind since early age. The invention of rotary wheel had been a groundbreaking innovation in the human history. It facilitates the long-distance commutation ultimately, paves ways to trading and sharing knowledge. However, the field of transportation had been evolved rapidly in the last century in particular after the invention of steam engines which is initially used for goods transportation, but soon it had a direct impact on civilians in the form of road cars. After 1930s proper road infrastructures are developed to cope up with the rapid improvements in vehicle performance. The fourth industrial revolution had taken the science field by strom, where the machines are controlled by intelligent systems reducing manual errors and increased performance. The automotive field is not an outlier to this fact, various driver assistance system such as ADAS not only reduces the human effort in driving but also ensures the safety of the occupants and the vehicle. Engineers and scientist around the world are working keenly to develop the performance of the intelligent system. The big target for this community is to achieve complete autonomous driving, where no human is needed to guide the car to reach its destination. The concept of Autonomous driving has it’s origin in 1926, where a radio controlled car is developed by Houdini Radio control of new York city. The components of the car operate using the commands received from another car following it, thus achieving a first driverless car. In 1960 at Transport and road research laboratory in the United Kingdom, Magnetic cables are laid beneath the road which serves as a path detection tool for the car running on the road. The car uses the magnetic cables for its navigation and drove without human aid and delivered better performance even at high speeds. However, the first self sufficient autonomous was achieved by Mercedes in 1995 where a retro fitted Mercedes S class equipped with efficient cameras and exclusive processors aiding parallel computing was developed in the aim of autonomous vehicle. The car had clocked the maximum speed of 175 kmph and drove 1500 kms from Munich, Germany to Copenhagen, Denmark. This car had performed various overtakes and drove in traffic. This had been a significant milestone in field of autonomous driving. In late 2010s various carmakers like Toyoto, volvo had developed their own prototypes of Avs. In addition, Tech companies like Google, Waymo and universities had initiated research in autonomous vehicle. The parallel development in Artificial Intelligence and hardware such as Processors and sensors had catalysed the research on self driving. Notably, development in camera and GPUs enabled fast and efficient processing. On other hand intelligent algorithms like neural networks laid foundation for AV’s. In 2014, Tesla had launched it functional semi autonomous driving car with various assistance features like Lane detection, autonomous breaking and parking and speed limit recogonization using computer vision. This had been a significant leap in the community. In the same year Society of automotive engineers (SAE) had drafted the 6 level taxonomoy for Autonomous driving. Several countries like United states of America, united kingdom Japan had decided to draft a law for autonomus driving.

Currently various leading carmakers like Mercedes Benz, BMW, Volvo had also launched their own commercial full/semi autonomus vehicle for public and improving their levels of automation as classified by SAE. For example, in 2022 Mercedes Benz had reached SAE level 3 automation with its S class and EQS models, which features advanced driving tech like automated lane keeping system. However, Tesla Motors had been the leader in this domain with better performance.

The six level of automation in Autonomous vehicle classified by SAE as J3016, Taxonomy and Definitions for Terms Related to On-Road Motor vehicle Automated Driving Systems ranges from fully manual driving to fully automated.

Level0 : No Driving automation :

This Levels adopts no driving assistance system and the entire process of driving is controlled manually

Level 1: Assisted

Vehicles with a single automated system under driver’s monitor are categorized as Level 1

Level2 : Partially automated

Multiple automated systems like automated steering, braking works simultaneously under drivers attentation, where the driver should be ready to take the control at any time

Level3: conditional driving automation

This level encapsules a system with intelligent algorithm that can take decisions such as overtaking navigation. However, the human attentation is required

Level4: Highly automated

At this level, the vehicle can could take optimistic decision in case of a failure, which further reduces the human interaction, but still attentation is needed, which could mostly be used in a confined area/region

Level5: Full driving automation

At this level the vehicle can perform all driving task than an experienced driver does without the human interaction.

Applications

1.2 Simulators

Simulators is a system which replicate the dynamics and other features of a real world systems. There are variety of simulators available which can be software, hardware or combination of both. These system can replicate various functions of a system. These systems can interact with humans, receive inputs/ controls from the user and give the feedback for the input after executing. For example, Driving simulators which furnishes the drivers setup with screens which visualizes the outside environment. These simulators used for driver’s training and testing. These systems can be classified according to the problem, some of them

Based on Time step:

Discrete event simulation: In this simulation every timestep is discrete and each timestep can be mapped to a specific duration. The state will be transited to a new state for every time step. Driving simulators are usually discrete event simulators where the state of observation changes for every time steps. These time steps are can be defined based on the precision required

Continuous simulation:

In this simulation the timestep is continuous, which mean that there is no discrete time steps rather time periods. These simulations or backed by differential equations. These kind of simulators can be used in micro biology to growth/ decay of microbe for example.

Based on stohacticity

Stohastic simulation;

These simulates certain level of randomness in the parameters within the sensible range. This simulations are used to study the systems with noises. For example usage of a social media cite in a day

Deterministic simulation:

These systems are driven by deterministic algorithms which had no room for randomness. These types of simulators are often used in engineering. The results of this simulation can be replicated and un changed for given set of parameters.

Parameters are the variable which the users can tune to obtain optimistic results. Usually, Simulations are done to find the optimal parameters. This concept of simulations have various application since it can replicate the change over millions of years or changes in a nano seconds. Some times distributed simulations are used to parallelize the events. These simulations are used in analysis of results, safety engineering, designing… This methos prevents lot of time in testing and can considerably improve the results of testing. For example testing a autonomous car for 10000 kms in the real world consume lot of time and resource. In comparision in simulator this can be done in significantly lesser time. However, there will be often a gap between the real world and simulations which could account for errors in the analysis.

The field of Machine learning and robotics make use of simulation a lot, especially in reinforcement learning , a virtual user (agent) takes various action in various conditions in a simulator and learns from the feedback of simulators. Simulation plays a crucial role in Artificial Intelligence

1.3 Problem Statement

1.3.1 Lack of comparison metrics

In the field of autonomous vehicle research and development, simulators play a significant roles like training an algorithm, testing its performance in various setups, comparing different methods…. There are numerous simulators of various types are available in the market which can be used directly or indirectly used for research. On the other hand the research in self driving vehicles itself a broad topic which differs from each other. For example, Indoor robots, Industrial AV’s, On road vehicles, semi-autonomous vehicles… are all different application but comes under the topic of Autonomous vehicle. Each requires a unique simulators of their to work with. Since each simulators has its own features advantages and limitations, it’s difficult to compare and select them. For example, despite a simulator could perform, very well in all aspects, if it could not simulate a sensor that a user wants, then the simulator is not useful for that particular user and viceversa, This Thesis aimed to define a concrete system of metric for comparison. The proposed metric will be generic and adaptive to user, which means the user could able to vary the importance of what they are looking for and it can be used to all types of Autonomous vehicle simulators. By this system a user can able to assign personalized rating to simulators, and can chose the best of his choice.

1.3.2 Simulators Based on Generative AI

Generative AI had gained momentum in recent years, which performance has been improving rapidly. The domain primarily uses deep networks which will be trained in any data provided and learns its distribution. The trained model can be used to generate new meaningful samples of data which is not in the training corpus but similar to it.

One of the objectives of an autonomous vehicle simulators is to render new scenarios and environment. This can make it a better suited platform for testing algorithms as the algorithm which drives the vehicle can be tested on various different environments. One the other hand, training on new environments could also improve the model’s performance. At the same time, the new scenarios should be meaningful and plausible and should replicate the real-world features,

Sensors are the instrument which is used to understand the real world. There are various sensors used in autonomous vehicles like cameras, Lidar, Radars … to perceive the environment. The second part of the thesis aimed to design and develop a simulator which is driven by Generative AI model, which is trained on the real-world sensory data. The model is expected to generate new meaning full sensory data. The simulator is designed to a discrete time step simulator and the generated data should be relative to the timesteps before. Consequenty, The newly generated sensory data can replicate the new environments.

**CLEAN**

**TEXT**

1. Introduction

1.1. Autonomous Vehicles

Transportation has played an important role in the human history, evolving from the invention of the rotary wheel to the modern road cars. The invention of fuel engines in the last century marked a significant revolution, impacting faster goods transportation and extending to civilian life with the introduction of road cars. This period also witnessed the development of proper road infrastructures to accommodate the advancements in vehicle performance.

The fourth industrial revolution mark a start of new era where intelligent systems-controlled machines are developed which reduces the manual errors and enhancing performance. The automotive industry is also undergone this transformation with various intelligent driver assistance systems like Advanced Driver Assistance Systems (ADAS) which not only reducing human effort in driving but also ensuring safety. Engineers and scientists globally are working to enhance the capabilities of intelligent systems, aiming for complete autonomous driving, eliminating the need for human guidance.

The concept of autonomous driving dates back to 1926, with the development of a radio-controlled car in New York City. In 1960s, the Transport and Road Research Laboratory in the United Kingdom laid magnetic cables beneath the road, serving as a path detection tool for self-driving cars and tested its performance. Later, in 1995 Mercedes Benz achieved a significant milestone with the development of first self-sufficient autonomous vehicle, a retrofitted Mercedes S class equipped with efficient cameras and exclusive processors for parallel computing. This vehicle reached a maximum speed of 175 kmph, covering 1500 kms from Munich, Germany, to Copenhagen, Denmark, performing various manoeuvres in traffic without human assistance. In the late 2000s, carmakers like Toyota and Volvo, along with tech companies such as Google and Waymo, developed their prototypes of Autonomous Vehicles (AVs).

The parallel advancements in the field of Artificial Intelligence and efficient hardware accelerated research in self-driving technology. Notably, improvements in cameras and GPUs facilitated fast and efficient processing, while intelligent algorithms like neural networks laid the foundation for Autonomous Vehicles (AVs). In 2014, Tesla Motors launched Model S, a semi-autonomous driving car. This vehicle featured a various assistance feature, including lane detection, autonomous braking and parking, and speed limit recognition using computer vision. Tesla's entry into functional semi-autonomous driving represented a notable advancement in the field. During the same year, the Society of Automotive Engineers (SAE) had drafted a 6-level taxonomy for autonomous driving. This framework provided a standardized and structured classification system for assessing the level of autonomy in vehicles. Recognizing the growing impact of autonomous driving, several countries, including the United States of America, the United Kingdom, and Japan, made decisions to formulate laws addressing autonomous driving in the next few years. Various leading car manufacturers, including Mercedes Benz, BMW, and Volvo, have introduced their commercial fully or semi-autonomous production vehicles. They are continually enhancing their automation levels, as classified by the Society of Automotive Engineers (SAE). For instance, in 2022, Mercedes Benz achieved SAE Level 3 automation with its S-Class and EQS models, equipped with advanced driving technologies like an automated lane-keeping system. However, Tesla Motors has been a leader in this field, showcasing superior performance.

The SAE J3016 classifies autonomous vehicles into six levels, ranging from fully manual driving to fully automated systems.

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| Level 0 | No driving automation | This level involves no driving assistance system, and the entire driving process is manually controlled. |
| Level 1 | Driver assistance | Vehicles at this level feature a single automated system under the driver's supervision. |
| Level 2 | Partial driving automation | Multiple automated systems, such as automated steering and braking, work simultaneously under the driver's attention. The driver must be ready to take control at any moment. |
| Level 3 | Conditional driving automation | This level involves a system with an intelligent algorithm capable of making decisions like overtaking navigation. However, human attention is still required. |
| Level 4 | High driving automation | At this level, the vehicle can make optimistic decisions in the event of a failure, reducing the need for human interaction. This level is often suitable for confined areas or regions |
| Level 5 | Full driving automation | Here, the vehicle can perform all driving tasks without human interaction, comparable to an experienced human driver. |

Driverless vehicles find applications not only in passenger cars but also across various areas like shuttling people on campuses, moving goods in warehouses, and in military operations. Especially in industries, these automated machines could transport goods across the premises which save time and minimize human error. However, ensuring their safety of operation is crucial especially when it comes to road cars. Governments worldwide are creating regulations for autonomous mobility. Moreover, vehicle manufacturers are enhancing hardware and software while conducting extensive testing to ensure safety and prevent failures.

1.2. Simulators

Simulators imitate real-world systems, replicating their dynamics and features. They come in different types: software, hardware, or a mix of both. These systems replicate various functions, interacting with users, taking inputs, and providing feedback to the users. For example, driving simulators create visual environments and hardware setup for driver training and testing, Which takes control commands from users and update their states. Simulators can be classified based on various features Some of the examples are

Based on Time

Discrete Event Simulation: Each step happens at distinct intervals, which are mapped to specific durations. Driving simulators fall into this category, where observation states change at each step. The time duration of a single time step is defined by required precision.

Continuous Simulation: In this type of simulation, time moves continuously without distinct steps, backed by differential equations. These are useful for modelling continuous events like microbe growth in biology.

Based on Stochasticity:

Stochastic Simulation: This type of simulation introduces a controlled amount of randomness within sensible limits in the parameters. It's helpful for studying systems with random noise, like analysing daily usage patterns on a social media site.

Deterministic Simulation: These systems operate using deterministic algorithms without any randomness. They're commonly applied in engineering. The outcomes of these simulations remain consistent and reproducible for a specific set of parameters.

Users can tweak these parameters to test and tune the results of the system. Usually, simulations help to find the optimal parameters and it have diverse applications, for events spanning millions of years to nanoseconds. Simulations play a vital role in result analysis, safety engineering, and design processes. They save significant time during testing and can enhance the testing outcomes. For instance, testing the driving of an autonomous car for 10,000 km in the real world demands a lot of time and resources, whereas using a simulator significantly reduces this timeframe. However, there's often a discrepancy between the real world and simulations, which might lead to errors in analysis. In fields like machine learning and robotics, it contributes a crucial role. One of the three paradigm of Machine learning is reinforcement learning where a virtual agent within a simulator takes diverse actions under various conditions and learns from the feedback provided. In robotics, algorithm which drives the robots are trained using simulation for tasks like localization, pick and place, faulty detection…

1.3 Problem Statement

1.3.1 Lack of system of comparison

In the growing domain of autonomous vehicle research and development, simulator plays a significant role such as algorithm training, performance evaluation across diverse environments and comparison of method. There are numerous simulators, varying in types and functionalities, available in the market for direct or indirect use in research works. In addition, the domain of self-driving vehicle research is broad, includes distinct applications such as indoor robots, industrial autonomous vehicles (AVs), on-road vehicles, and semi-autonomous vehicles. Each application requires a unique simulator tailored to its specific requirements.

The challenge arises due to the diversity among these simulators, each comes with its own set of advantages, features, and limitations. Consequently, comparing and selecting the most suitable simulator becomes a complex task. For instance, a simulator might perform well in numerous aspects, yet fail to simulate a crucial sensor required by a user, making it unsuitable for that specific application. Conversely, another simulator might lack certain features but could be better suited for the user.

The aim of this thesis is to establish a concrete set of metrics for comparison purposes. The proposed metric will be generic and adaptable to individual user preferences. Users will have the flexibility to adjust the importance of criteria based on their specific requirements and they are universally applicable across all types of autonomous vehicle simulators. Through this systematic approach, users could able to assign personalized ratings to simulators, facilitating informed decision-making in selecting the most suitable simulator according to their preferences and needs.

1.3.2 Simulators Based on Generative AI

Generative AI had gained momentum in recent years, continuously enhancing its performance. This field primarily uses deep neural networks trained on provided data, learning its distribution. These trained models can generate novel, meaningful data samples not present in the training set but similar to it.

In the domain of autonomous vehicle simulators, rendering new scenarios and environments is a one of its objectives. This feature enhances its suitability for algorithm testing across diverse environments, potentially improving the model’s performance. It’s also important that these new scenarios closely resemble real-world features while being meaningful and plausible.

Sensors in Autonomous cars play a important role in understanding the real world where the vehicle navigates. These vehicles utilize an array of sensors such as cameras, LiDAR, and radar to perceive their surroundings. The second part of this thesis aims to design and develop a simulator driven by a Generative AI model trained on real-world sensory data. The expected outcome is the generation of new, meaningful sensory data can effectively reproduce diverse and realistic environments. The simulator will operate on discrete time steps, ensuring that the generated data remains relative to preceding time steps.