3. Framework for Comparative study

The level of suitability of an autonomous vehicle simulator to a specific user various diversly depending on various factor. Some of the factor constitute to this issue are the application, availability of sensors, integration of real-world components such as vehicle, maps…, computation resource… In this proposed method, 69 such parameters are identified and those parameters are used to devise a single score for a simulator which can be used to compare.

3.1 Comparison Parameters

The considered parameters are further classified into 6 broad classifications. They are Sensors, Actors, Environment, Vehicle, Framework and Algorithm. Each parameter is measured by a score between 0 to 1. In case of binary classification type for example availability of a feature, this corresponding parameter gets score 0 if it’s not available and 1 if it’s available

3.1.1 Sensors

Sensors are the tool used to perceive the environment in the vehicle is driving on. It plays a crucial role in driverless vehicle as it provides input to the algorithm and the action is taken based on that. Various types of sensors are used in vehicles and in autonomous vehicles it’s very common to use multiple sensors at a time. It’s also important to model and integrate those sensors within the simulator which the real vehicle uses. This part examines various aspects of the sensors that can be used in autonomous vehicle simulator

3.1.1.1 Ready to use sensors

Most of the simulators provides some default sensors which are ready to use. A simulator will be assigned a score of 1 if it provides the below mentioned sensors else it will be assigned 0.

1. RGB camera

RGB Camera is a device which maps the 3d environment in its field of view as a 3-channel 2D image (Red Green Blue). Figure 11 illustrates the example data of a RGB camera mounted on a car. These images can be used to understand the surroundings such as traffic lights, sign boards, pedestrian crossing…

1. Depth Camera

Depth camera also captures a single channel image in which depth information is embedded. Each pixel in this image measures the distance between the mounting point of the camera and object in the 3d environment to which the pixel referring to. Figure 12 illustrates the example data of a Depth Camera mounted on a car. This data is often used to measure the distance between the vehicle and other fellow vehicles.

1. 3D Lidar

Unlike the other 2 other cameras 3D lidar maps the environment in 3D point cloud. Position of each voxel refers to a point on the object in the surrounding. This sensor projects laser beam and calculate the position based on time of flight. Figure 13 illustrates the isometric view of a point cloud measured by 3D lidar. However, the energy laser beam can be interrupted by various factors like fog, texture of the object… These sensors are sometimes attached to a rotary motor to read 360 degrees around the device.

1. Radar

This sensor similar to 3D lidar, which maps the environment to 3d point cloud. However this sensor uses EM (electro-magnetic) waves as an alternative to Laser beam. This wave has various advantages such as traveling long distances, less distortion to external factors. Both 3D lidar and Radar are used to read the surroundings

1. IMU sensor

Inertial Measurement unit (IMU) sensor is that measure the specific forces like acceleration, angular velocity. It reports the information about orientation and change in its position. This unit is composed of sensing elements such as accelerometer and gyroscope. These sensors help determine the vehicle's acceleration, changes in direction, and rotation

1. Semantic information

Semantic Information is a not an actual sensor that is directly used in autonomous vehicles. It is an ability of a simulator to provide sematic information of every object within the environment. The semantic information could have class or name of the object such as trees, dogs, child, women… with the coordinates of the bounding box which encapsulates the object. Figure 14 illustrates the environment with bounding boxes and class label of the objects within it. This information could be useful in some training algorithms such a reinforcement learning to provide rewards and penalties.

1. Force Impact sensor

It is a sensor which can be used to measure the force experienced by the vehicle during an impact with another object. This measure directly corelates to the damage occurred to the vehicle and the object. This measure could also be used to provide weighted rewards and penalties

1. Lane detection or infringement sensor

Like Semantic information, this is also not an actual sensor but provides information about the driving lanes. This feature is an ability of a simulator to provide the information about the boundaries of the lane and level of infringement (percentage of body of the ego vehicle infringing the lane). This method is used in various level 2 autonomous vehicle which uses ADAS.

1. Fuel/ Battery sensor

This sensor monitors the information about the fuel or power consumed by the vehicle. The self-driving vehicle should be efficient and researchers around the world are constantly working to improve the fuel efficiency. In such cases, it’s important for a simulator to provide such information.

1. Vehicle speed sensor

This sensor is a common sensor which can be found on almost all the vehicle. This measures the velocity of the vehicle. This measure is crucial especially when driving in areas with speed limits such as city roads, warehouses…

1. GPS

Global positioning system (GPS) is a geo location sensor which can be used to locate and navigate. Its also most common sensor found in the commercial vehicles for path planning. This sensor crucial both on road and in house driving.

In terms of simulator, the simulator should able to provide information about the coordinates of the vehicle and its destination with respect to its global boundaries. It is also important that it should follow a same scale throughout the simulator.

1. Visibility sensor

The driving visibility can be impacted by various environmental cause such as fog, smog, pollution etc… Visibility is a measure which defines the maximum distance at which an object can be clearly seen. This measure plays an important role in driving. It’s also important for a simulator to provide this information especially when the simulation environment mimics the foggy surroundings. This measure is usually measured in meters.

1. Any other vehicle sensor related to vehicle dynamics

A typical car can have numerous sensors which can measure various properties of the car such as tyre pressure, parking aid, engine rpm… However not all these vehicle sensors are usually used in autonomous vehicle research. An ideal simulator should provide an infrastructure to model any of these vehicle sensors whenever required by the user. This parameter quantifies the ability of a simulator to provide facility to define a sensor and provide its data related to the ego vehicles.

1. Any other Environment sensor related to perception

This parameter corresponds to ability of a defining a sensor by a user that can measure properties of an environment. These user defined sensors could provide data related to the surroundings of the car such as no of people / vehicle in the car’s field of perception, audio sensor to recognize priority vehicles such as fire truck.

1. Any Macroscopic global sensor

This is also a user defined sensor which provides information about the simulation world. This sensor could be modelled to provide information not only about the local area near to the vehicle but also some global information such as traffic in a certain part of the map, possible weather condition in future, which can be used for path planning.

3.1.1.2 Multiple synchronous sensor

In most of the cases, multiple sensors are used in autonomous vehicle simultaneously. The data from multiple sensors provide more reliable information about the environment rather than one from the single sensor and it can be used as backup in case any of the sensor fails. An AV simulator should handle multiple sensor model and provide its data. It is important that the sensors are synchronized both in data and time, which means the data simulated by multiple sensors at a time should refer to a same timestep and relative to each other. This parameter corresponds to the ability of a simulator to simulate synchronized data.

3.1.1.3 User defined position and orientation of sensor.

The placement of a sensor in a vehicle plays a crucial role in the useability of that sensor. The mounting point and the orientation of a sensor are designed by engineers. In most of the cases the it varies especially when using multiple sensors where sensor blind spot should be avoided. This parameter is a check for an ability of a simulator in which the user can define the location and orientation of the sensor with respect to vehicle.

3.1.1.4 Precision of the sensor readings

The precision of a sensor can be defined as the smallest change in measurement which the sensor can sense. This is be applied for any type of sensor and its measurement. The precision by the user varies depending upon the application. A versatile simulator should accommodate different levels of precision and it should be configurable by the user. This parameter confirms the ability of a simulator in which precision of the simulators can be configured

3.1.1.4 Real time sensor Models

Many Vehicles manufactures and develop their sensors in house with unique features. Digital models of these devices could be used as sensors within the simulator which make it useful for the user to retain those features in the simulator. Moreover, there are many popular and frequently sensor available in the market which can be used in vehicle. This parameter checks the ability of a simulator to import real time sensors’ digital models and use it within the simulator.

3.1.1.5 User defined sensors and observers

In the growing field of autonomous driving, lot of new sensors are being developed and the performance of existing sensors are updated to better understand the environment. Moreover, Within the simulator a user can be interested in and need to monitor any data of his interest for their application. A simulator should facilitate a user to define an observer which monitors the data or model a sensor. This parameter ensures this property of user defined sensors and observers.

3.1.2 Actors

Actors are the different objects that makeup the environment within the simulator. These actors can be broadly classified into stationary and non- stationary actors. Stationary actors are the objects which position stays the same, some examples of stationary actors are Buildings, trees, traffic signs, roads, parked vehicles… on the other hand non stationary objects changes it position during the course of simulation and some examples are People, animals, fellow cars. The actor are the constructors of the environment. This part explains various parameter of actors in a simulator that can be used to compare the simulators. Most of the parameter in this section will be scored 1 if a simulator possesses that feature and 0 if not.

3.1.2.1 Geometry

a) Pre defined of scenarios

There are various types of environments in which a vehicle can drive such as rural, urban, industrial… Each type of environment possesses unique features and actors. For example, it less probable to see a child in an industrial environment whereas very likely to see a cargo truck. A simulator could have presets of environments with reasonable actors and this ability of possessing pre-defined set of actors is checked by this parameter

b) Pre defined models for actors

This parameter checks the ability of the simulator to provide access to some pre-defined digital assets (actors) under various categories. For example, a simulator should able to provide 3d models of Buildings, vehicles, person, traffic signs which are meticulously designed and ready to deploy and use.

c) User defined Actors

Apart from the pre-defined libraries of 3d models of actors, a simulator should facilitate a user to import 3d models of actors within the simulator. Moreover, the imported models should follow a common scale which the simulator follows. This can be useful in some unusual cases such as Golf field where a user should able to import 3d models of golf cart and players

d) No of actors and spawning location

The nature of an environment also depends on no of actors within the environment. This measure should be changeable by the user such that the nature of environment can be configurable. For example, a traffic in a particular road can be defined by no of vehicles and people commuting in that road. Moreover, the location of the actors should also be configurable for example location of Traffic light pole. This parameter measures the ability of a simulator to facilitate user to define the number and location of actors.

e) Recreate real time models

This parameter ensures the usage of models of real time actors within the simulator. The simulator should posses real time 3d models of actors such as cars, buildings… and their physical properties like geometry, texture, should be maintained. This helps the users who intended to work with real time vehicles.

f) Path/ destination of actors

The moving trajectory of non-stationary actors should be configurable and the actors should respawn in a new location when the actor moves out of the environment boundaries. This ability of defining paths and destination of non-stationary object is checked by this parameter.

g) Context aware spawning

The spawning/ respawning of actors should be reasonable and context aware. It’s more sensible to spawn more ambulance near hospital than any other location. This type of intelligent spawning is marked by this parameter.

3.1.2.2 Behaviour

The Behaviour refers to the rules for actions taken by the actors and their feedback to actions taken by other actors and change in environment.

1. Pre-defined Rules

Some of the actor’s behaviour can be predefined and regulated. The Simulator coud define certain set of rules for the actors’ behaviour. For example, Traffic rules of certain countries can be pre-defined and ready to use

1. User defined rules

A simulator should facilitate the user to define certain behaviour pattern for the actors within the simulator in addition to pre-defined rules. This can provide more freedom for customization for the user. This parameter evaluates this feature of user defined rule within a simulator.

1. Distinguishable behavioural pattern

For a simulator, to reproduce real environment, it should distinguish the behavioural pattern within the actors. For example, the behavioural pattern of an adult and a kid and a dog walking a pavement differs a lot. This parameter is given score 1 if a simulator can simulate this phenomenon

1. Sensitivity

Sensitivity refers to feedback or counter action taken to the action taken by fellow actor. The fellow actor could be either the ego vehicle or any other actor within the environment. An example for this feature could be an adult refrain to cross the road in response to the horn honked by a car. A score of 0.5 is given if the actors within the simulator respond only to ego vehicle and 1 is given if the actor responds to all other fellow actors and 0 if not responds

1. Level of aggressiveness in driving

This feature appeals particularly to the vehicle within the simulator. The driving pattern varies widely among the people. A simulator should facilitate a user to define the level of aggressiveness using some metrics like violations per km driven. This parameter of defining behavioural pattern in driving can help the user to train and test in different driving condition

1. Reproducibility

Certain random behaviour of the actors can give unique response from the ego vehicle and user should able to reproduce the same action from the actor to further study the case. In this case a simulator should able to reproduce a set of random action performed by actors again this method is called seeding and the parameter refers to the seeding feature of the simulator.

**CLEAN TEXT**

3. Framework for Comparative Study

The suitability of an autonomous vehicle simulator for a particular user varies significantly based on several factors. These factors include various aspects such as the intended application, sensor support availability, integration of real-world components like vehicles and maps, computational resources... Within this proposed method 69 such parameters are identified and these parameters collectively contribute to formulating a single score for each simulator. This score serves as a means for comparison between different simulators.

3.1 Comparison Parameters

The identified parameters are categorized into six broad classifications: Sensors, Actors, Environment, Vehicle, Framework, and Algorithm. Each parameter is evaluated using a scoring system ranging from 0 to 1 where 0 being worse and 1 is best. In cases of binary classification, where a feature's availability is assessed, the corresponding parameter receives a score of 0 if the feature is unavailable and 1 if it is available.

3.1.1 Sensors

Sensors serve as the tool to perceive the vehicle's surrounding environment. They play a crucial role in driverless vehicles by providing inputs to the algorithm, which determines subsequent actions of the vehicle. In autonomous vehicles, multiple sensor types are commonly utilized simultaneously. It is also important to accurately model and integrate these sensors within the simulator to mimic those employed in real vehicles. This section examines the various aspects of sensors that can be used within an autonomous vehicle simulator.