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 road, possible weather condition in future, which can be used for path planning.

**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.