AuE-8360

Scaled Autonomous Vehicles

Simulation Tools for Scaled Vehicle Courses

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List of Simulation Tools for Scaled Vehicle Courses

- TurtleSim
- Official F1TENTH Simulator (Rviz)
- Driving Scenario Designer
- Gazebo Simulator
- F1TENTH Simulator (Gazebo)
- CoppeliaSim (formerly V-REP)
- F1TENTH Simulator (LGSVL)
- Isaac Sim
- AutoDRIVE Simulator

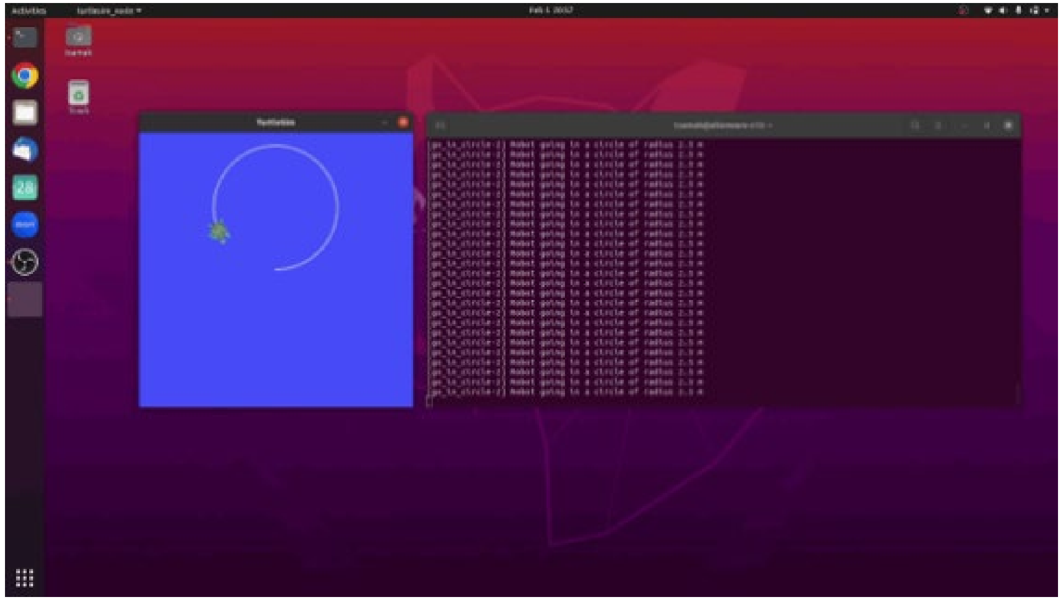
Recommended for Courses/Training

- DRIVE Sim
- CARLA Simulator
- LGSVL Simulator
- AirSim
- AWSim
- RaiSim
- OpenAI Gym
- Ansys Autonomy
- CarMaker
- CarSim
- TORCS
- Deepdrive
- rFpro
- dSPACE AURELION
- PreScan
- Webots
- Cognata
- Metamoto
- VIRES VTD
- GTA V
- Project Chrono

Recommended for Research

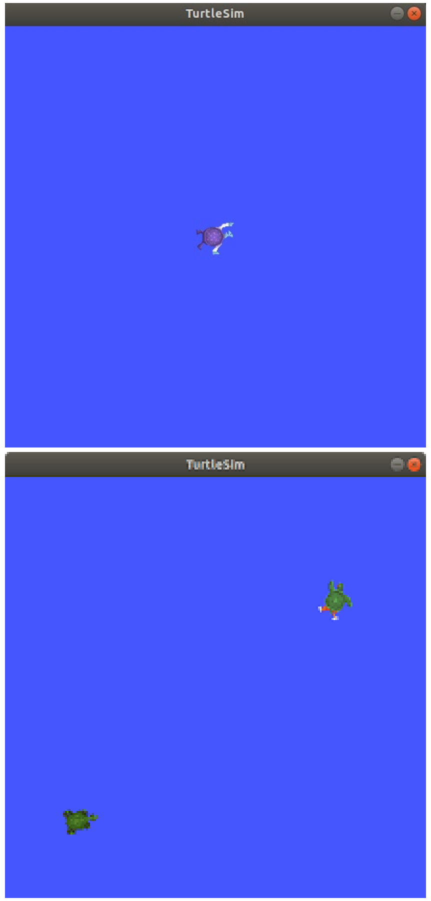
TurtleSim

- Advantages
  - Open source
  - Simple & intuitive
  - Multi-robot support
- Disadvantages
  - 2D kinematic simulation
  - Environments not supported
  - Only differential-drive architecture
  - No cross-platform support



Source: Tinker Twins GitHub

Source: ROS Core Stacks

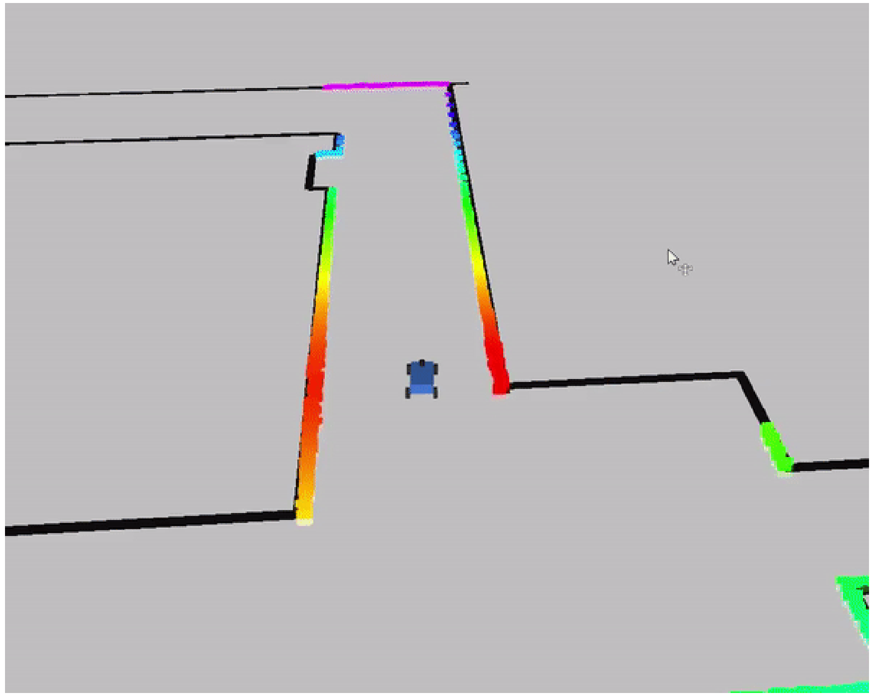


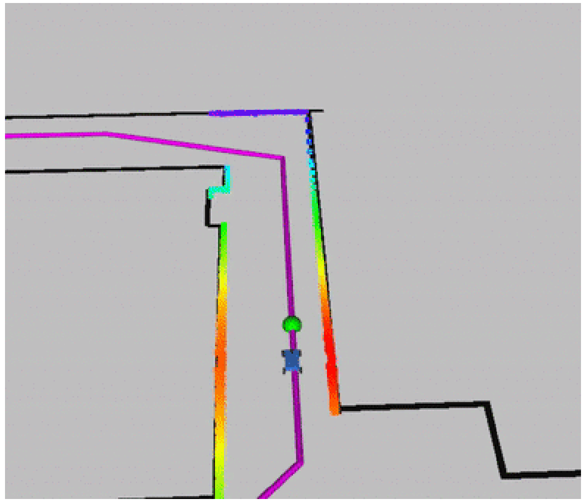
Source: ROS Wiki

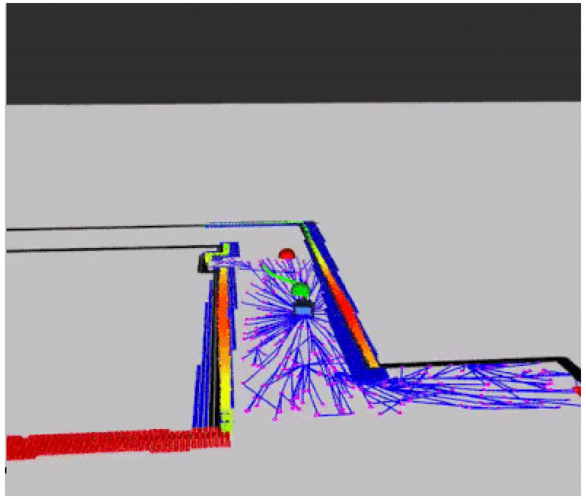
Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
2D	Custom (kinematic simulation)	OpenGL	No	Pose	ROS, ROS 2	Open Robotics	Free	Yes	Exploration and understanding

Official F1TENTH Simulator (RViz)

- Advantages
  - Open source
  - Simple & intuitive
  - Uses same stack as real vehicle
- Disadvantages
  - 2D simplistic simulation
  - No vertical/roll/pitch dynamics
  - 2D environment representation
  - No cross-platform support
  - Inaccuracies (e.g., 360° LIDAR simulation - real is 270°)





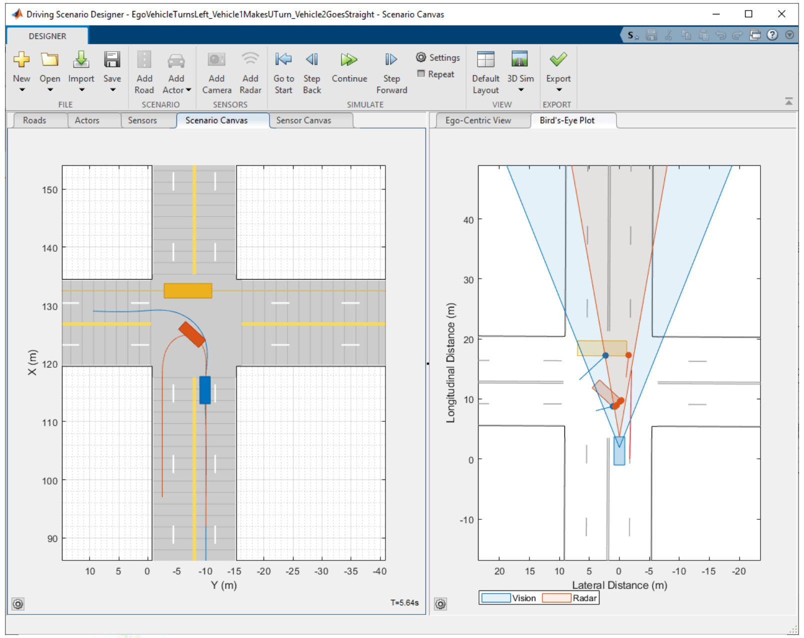


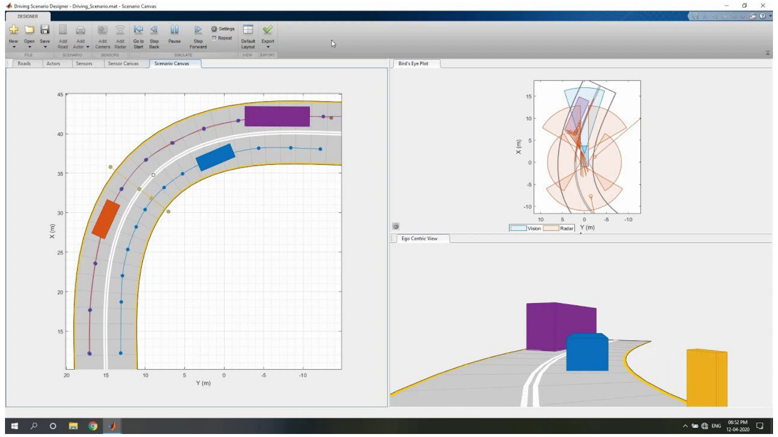
Source: F1TENTH

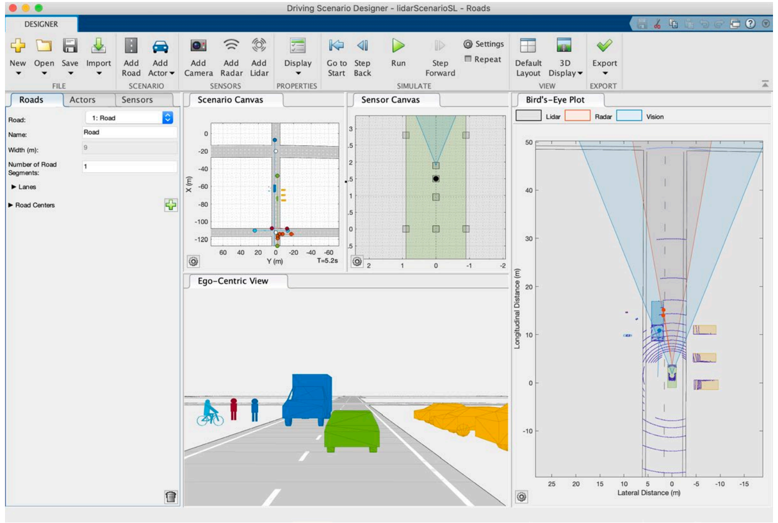
Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
2D	Custom (single track dynamics)	RViz	Single-track dynamics	2D LIDAR	ROS, ROS 2, Autoware	UPenn	Free	Yes	Exploration, understanding, course, competition

MathWorks Driving Scenario Designer

- Advantages
  - Simple & intuitive
  - Multi-agent support
  - Comprehensive sensor suite
- Disadvantages
  - Commercial product
  - 2D/3D simplistic visualization
  - Simplistic trajectory replay







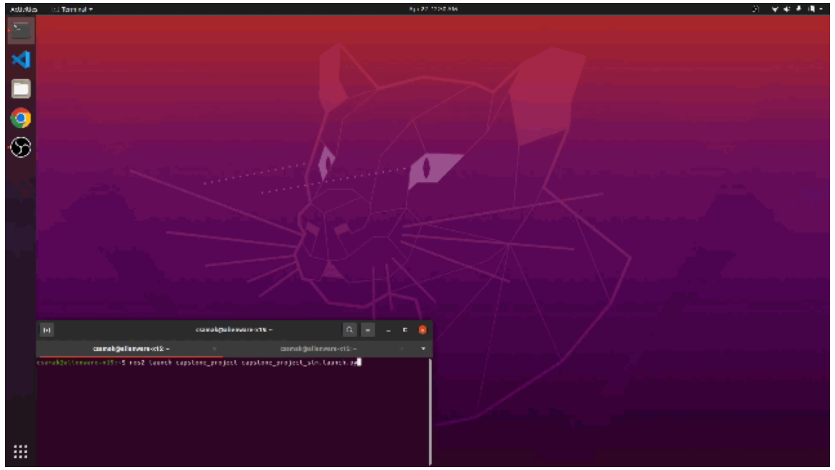
MathWorks®

Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
2D/3D	N/A	MATLAB App	No	Camera, RADAR, LIDAR, INS, Ultrasonic	MATLAB, Simulink	MathWorks	Paid License	No	Exploration and understanding

Source: MathWorks

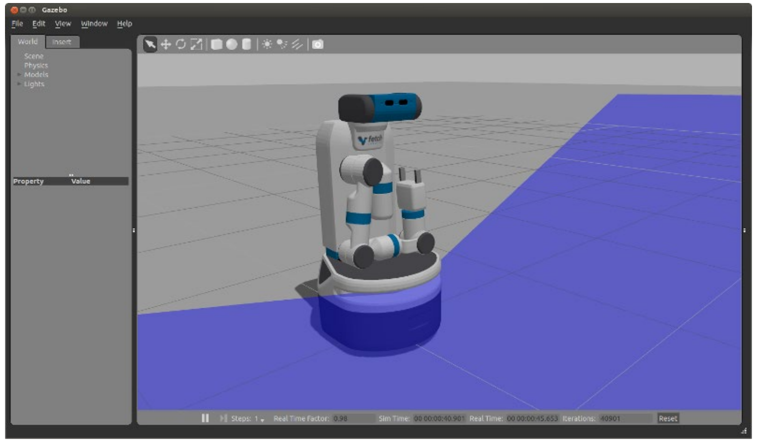
Gazebo Simulator

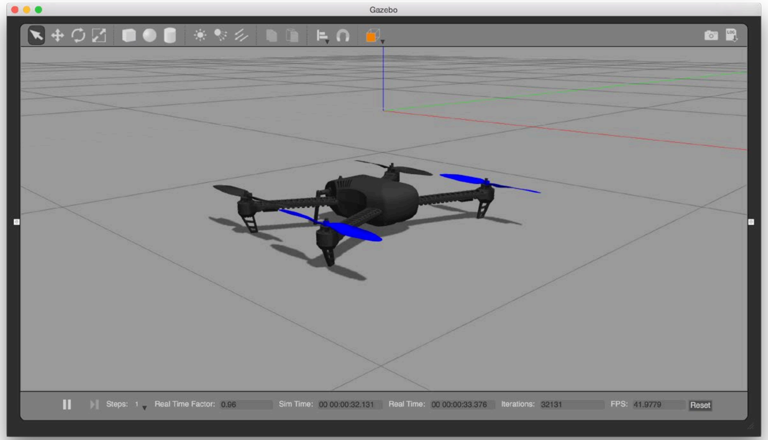
- Advantages
  - Open source
  - Multi-agent support
  - Comprehensive sensor suite
  - General robotics simulation
- Disadvantages
  - Low fidelity dynamics
  - Simplistic visualization
  - No cross-platform support



Source: Tinker Twins GitHub

GAZEBO



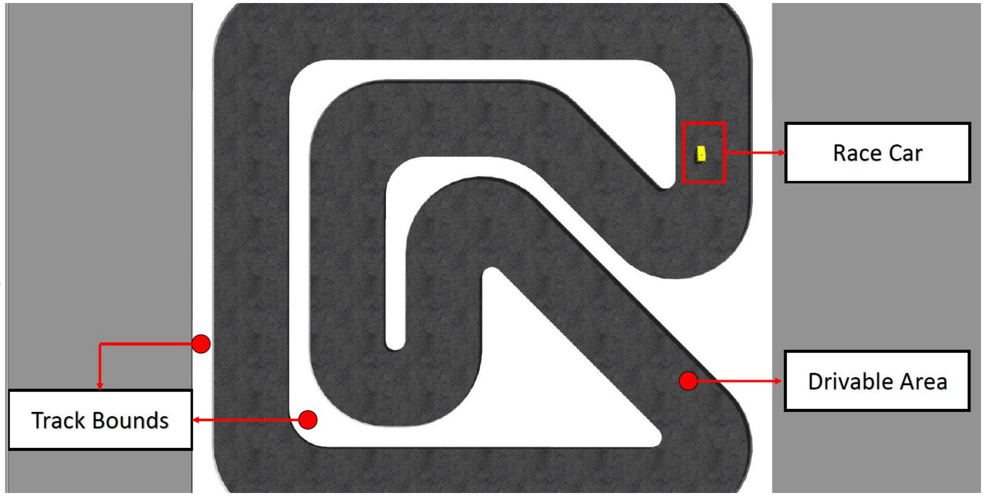


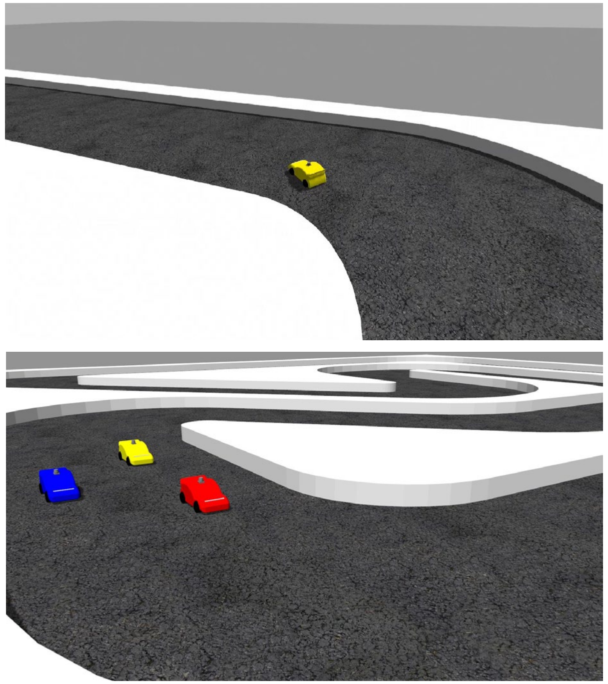
Source: GazeboSim

Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
3D	ODE	Custom	Yes	Pose, Joint States, Camera, LIDAR, IMU, GPS	ROS, ROS 2	Open Robotics	Free	Yes	Exploration and prototyping

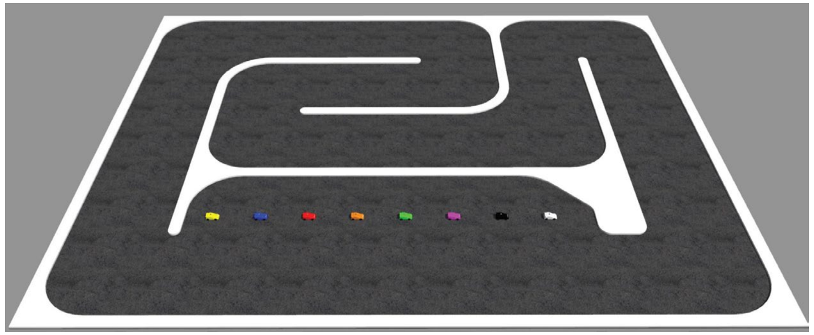
F1TENTH Simulator (Gazebo)

- Advantages
  - Open source
  - Multi-agent support
  - Uses same stack as real vehicle
  - 3D simulation environment
- Disadvantages
  - Low fidelity dynamics
  - Simplistic visualization
  - No cross-platform support





f1tenth.dev

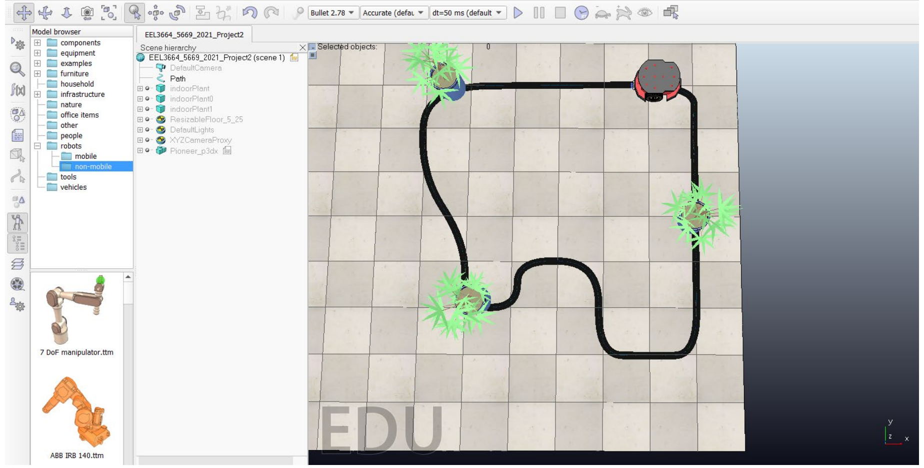


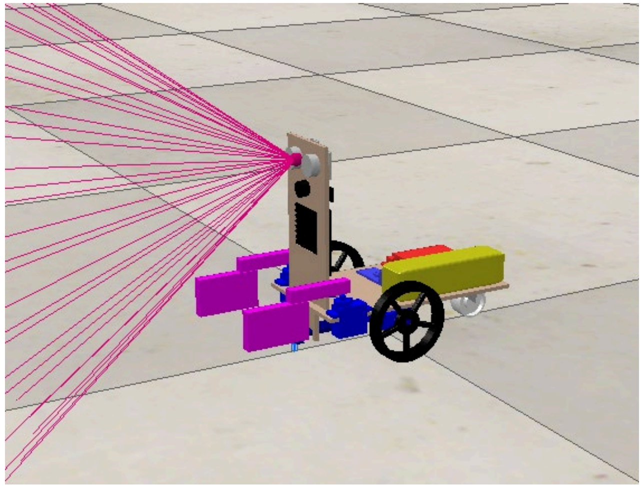
Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
3D	ODE	Gazebo's Custom	Yes	2D LIDAR, Pose TF	ROS	UVA	Free	Yes	Exploration, prototyping, course

Source: f1tenth.dev

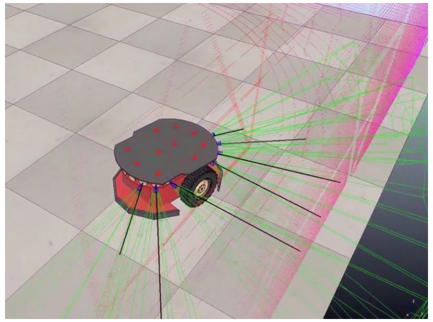
CoppeliaSim (formerly V-REP)

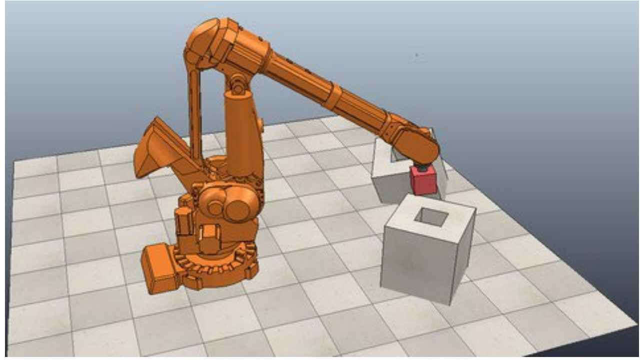
- Advantages
  - 3D simulation environment
  - Multiple physics engines
  - Cross-platform support
  - Extended API support
  - General robot simulator
- Disadvantages
  - Moderate compute requirements
  - Medium fidelity graphics





CoppeliaSim



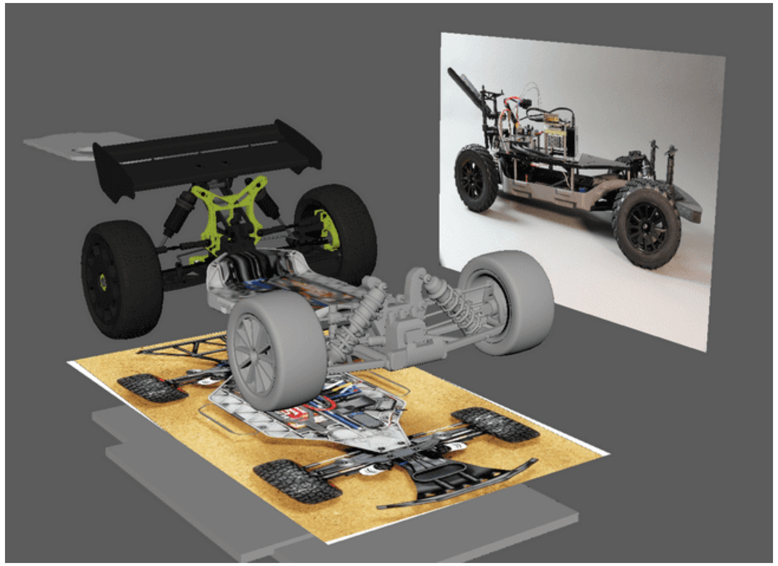


Source: Coppelia Robotics

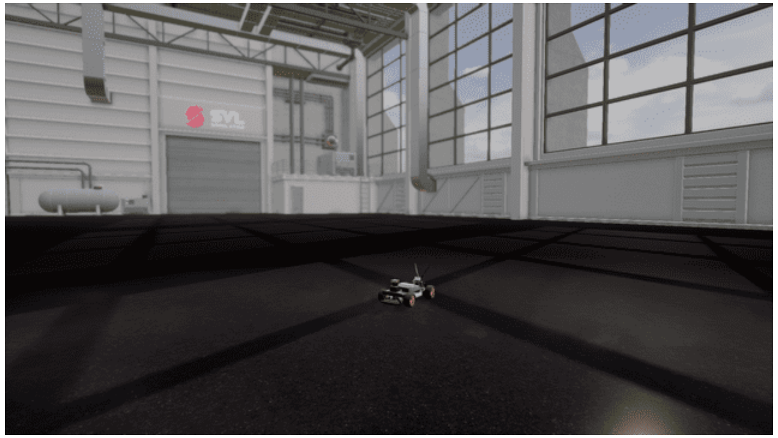
Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
3D	PhysX, Bullet, Vortex	Custom	Multi-body physics modules can be adapted for vehicle dynamics	2D/3D LIDAR, Camera, GNSS, IMU, Encoders, State Variables	ROS, ROS 2, Python, C++ MATLAB	Coppelia Robotics	Free (Edu)	No	Exploration and education

F1TENTH Simulator (LGSVL)

- Advantages
  - 3D simulation environment
  - Photorealistic graphics
  - Cross-platform support
- Disadvantages
  - Inaccurate parameters
  - Heavy compute requirements
  - Discontinued



LGSVL SIMULATOR

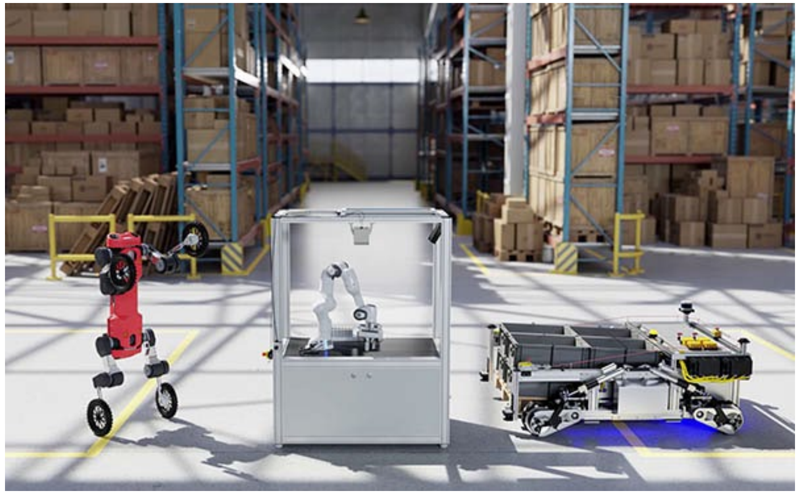


Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
3D	PhysX	Unity HDRP	Wheel torque model	2D LIDAR, Camera	ROS	LG	Free/ Paid	Yes	Exploration and research

Source: SVLSimulator

Isaac Sim

- Advantages
  - 3D simulation environment
  - Photorealistic graphics
  - Realistic physics
  - Cross-platform support
  - Indoor robot simulator
- Disadvantages
  - Extreme compute requirements
  - Only NVIDIA RTX supported



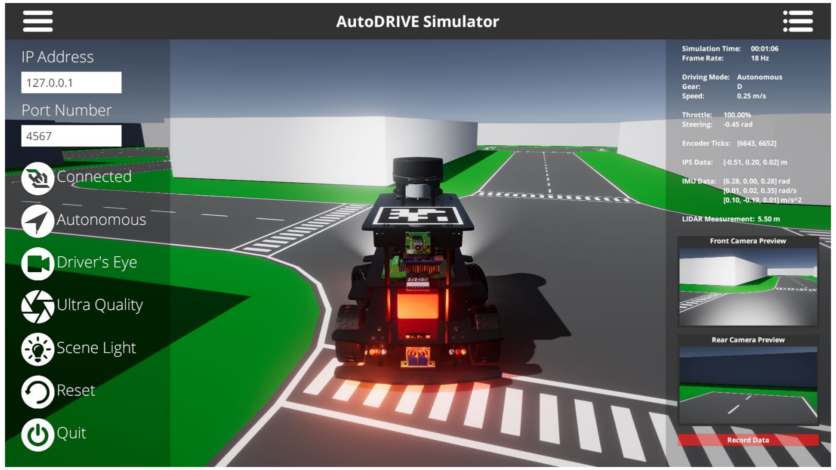
NVIDIA ISAAC

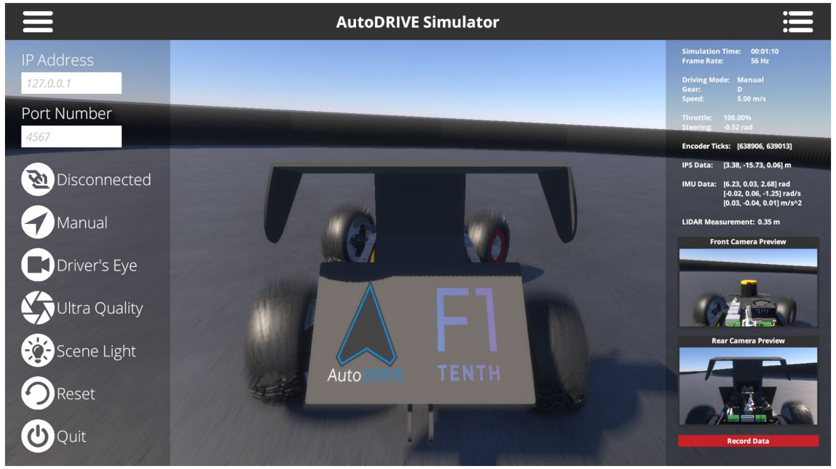
Source: Isaac Sim

Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
3D	PhysX	Omniverse	Multi-body physics modules can be adapted for vehicle dynamics	2D/3D LIDAR, Camera, GNSS, IMU, Encoders, State Variables	Python, ROS 2*	NVIDIA	Free	No	Exploration, education and research

AutoDRIVE Simulator

- Advantages
  - 3D simulation environment
  - Photorealistic graphics
  - Realistic physics
  - Cross-platform support
  - Extended API support
  - On/off road AVs across scales
- Disadvantages
  - Moderate compute requirements





AutoDRIVE

Source: [AutoDRIVE Ecosystem]

Simulation Quality	Physics Engine	Graphics Rendering	Vehicle Dynamics Support	Sensor Support	API Support	Developer	Cost	Open Source	Applications
3D	PhysX	Unity HDRP	Full car model for lateral, longitudinal, vertical and RPY dynamics with tire-terrain interaction	2D/3D LIDAR, Camera, GNSS, IPS, IMU, Encoders Steering Feedback, Throttle Feedback, State Variables	ROS, ROS 2, Python, C++, MATLAB, Simulink, Webapp	CU-ICAR, NTU, SRMIST	Free	Yes	Exploration, education and research

Comparative Analysis

Simulator	Year	Open Source	Realistic Perception	Customized Scenario	Back-end	Map Source		API Support		
						Real World	Human Design	Python	C++	ROS
TORCE [178]	2000	✓	✓	×	None	×	✓	×	✓	×
Webots [179]	2004	✓	✓	✓	ODE	✓	✓	✓	✓	✓
CarRacing [180]	2016	✓	×	×	None	×	✓	✓	×	×
CARLA [142]	2017	✓	✓	✓	UE4	×	✓	✓	✓	✓
SimMobilityST [181]	2017	✓	×	✓	None	×	✓	✓	×	×
GTA-V [156]	2017	×	✓	✓	RAGE	×	×	×	×	×
highway-env [182]	2018	✓	×	✓	None	×	✓	✓	×	×
Deepdrive [183]	2018	✓	✓	✓	UE4	×	✓	✓	✓	×
esmini [184]	2018	✓	✓	✓	Unity	×	✓	✓	✓	×
AutonoViSim [185]	2018	×	✓	✓	PhysX	×	✓	×	×	×
AirSim [186]	2018	✓	✓	✓	UE4	×	✓	✓	✓	✓
SUMO [187]	2018	✓	×	✓	None	✓	✓	✓	✓	×
Apollo [188]	2018	✓	×	✓	Unity	×	✓	✓	✓	×
Sim4CV [189]	2018	✓	✓	✓	UE4	×	✓	✓	✓	×
SUMMIT [72]	2020	✓	✓	×	UE4	✓	✓	✓	×	✓
MultiCarRacing [190]	2020	✓	×	×	None	×	✓	✓	×	×
SMARTS [80]	2020	✓	×	✓	None	×	✓	✓	×	×
LGSVL [191]	2020	✓	✓	✓	Unity	✓	✓	✓	×	✓
CausalCity [77]	2021	✓	✓	✓	UE4	×	✓	✓	×	×
MetaDrive [74]	2021	✓	✓	✓	Panda3D	✓	✓	✓	×	×
L2R [192]	2021	✓	✓	✓	UE4	✓	✓	✓	×	×
AutoDRIVE [193]	2021	✓	✓	✓	Unity	×	✓	✓	✓	✓

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