AuE-8360
Scaled Autonomous Vehicles

Capstone Project Proposal

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Comparative Analysis of Hardware Platforms

Platform/Ecosystem				Cost *	Sensing Modalities							Computational Resources		Actuation Mechanism		Dedicated Simulator	V2X Support			API Support				
	Scale	Open Hardware	Open Software		Throttle	Steering	Wheel Encoders	GPS/IPS	IMU	LIDAR	Camera	High-Level	Low-Level	Ackermann Steered	Differential-Drive/ Skid-Steered		Multi-Agent Support	V2V	V2I	C++	Python	ROS	MATLAB/Simulink	Webapp
AutoDRIVE	1:14	✓	✓	$450	✓	✓	✓	✓	✓	✓	✓	Jetson Nano	Arduino Nano	✓	★	✓	✓	✓	✓	✓	✓	✓	★	✓
MIT Racecar	1:10	★	✓	$2600	✗	✗	✗	✗	✓	✓	✓	Jetson TX2	VESC	✓	✗	Gazebo	★	★	✗	✗	✗	✓	✗	✗
AutoRally	1:5	★	✓	$23,300	✗	✗	✓	✓	✓	✓	✓	Custom	Teensy LC/Arduino Micro	✓	✗	Gazebo	★	★	✗	✗	✗	✓	✗	✗
F1TENTH	1:10	★	✓	$3260	✗	✗	✗	✗	✗	✓	✗	Jetson TX2	VESC 6MkV	✓	✗	RViz/Gazebo	✓	✓	✗	✗	✗	✓	✗	✗
DSV	1:10	★	✓	$1000	✗	✗	✓	✗	✓	✓	✓	ODROID-XU4	Arduino (Mega + Uno)	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
MuSHR	1:10	★	✓	$930	✗	✗	✗	✗	✗	✗	✓	Jetson Nano	Turnigy SK8-ESC	✓	✗	RViz	✓	✓	✗	✗	✗	✓	✗	✗
HyphaROS RaceCar	1:10	★	✓	$600	✗	✗	✗	✗	✓	✓	✗	ODROID-XU4	RC ESC TBLE-02S	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
Donkey Car	1:16	★	✓	$370	✗	✗	✗	✗	✗	✗	✓	Raspberry Pi	ESC	✓	✗	Gym	✗	✗	✗	✗	✓	✗	✗	✗
BARC	1:10	★	✓	$1030	✗	✗	✓	✗	✓	✗	✓	ODROID-XU4	Arduino Nano	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
OCRA	1:43	★	✓	$960	✗	✗	✗	✗	✓	✗	✗	None	ARM Cortex M4 μC	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗
QCar	1:10	✗	✗	$20,000	✗	✗	✓	✗	✓	✓	✓	Jetson TX2	Proprietary	✓	✗	Simulink	✓	✓	✗	★	★	★	✓	✗
AWS DeepRacer	1:18	✗	✗	$400	✗	✗	✗	✗	✓	★	✓	Proprietary	Proprietary	✓	✗	Gym	✗	✗	✗	✗	✗	✗	✗	✓
Duckietown	N/A	✓	✓	$450	✗	✗	★	✗	★	✗	✓	Raspberry Pi/Jetson Nano	None	✗	✓	Gym	✓	✗	★	✗	✗	✓	✗	✗
TurtleBot3	N/A	✓	✓	$590	✗	✗	✓	✗	✓	✓	★	Raspberry Pi	OpenCR	✗	✓	Gazebo	★	★	✗	✗	✗	✓	✗	✗
Pheeno	N/A	✓	✓	$350	✗	✗	✓	✗	✓	✗	✓	Raspberry Pi	Arduino Pro Mini	✗	✓	✗	✓	✓	✗	✗	✓	★	✗	✗

✓ indicates complete fulfillment; ★ indicates conditional, unsupported or partial fulfillment; and ✗ indicates non-fulfillment. * All cost values are ceiled to the nearest $10.

T. Samak, C. Samak, S. Kandhasamy, V. Krovi, and M. Xie, "AutoDRIVE: A Comprehensive, Flexible and Integrated Digital Twin Ecosystem for Autonomous Driving Research & Education," Robotics, vol. 12, no. 3, p. 77, May 2023, doi: https://doi.org/10.3390/robotics12030077

Comparative Analysis of Simulation Platforms

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	×	✓	✓	✓	✓

Opportunity!

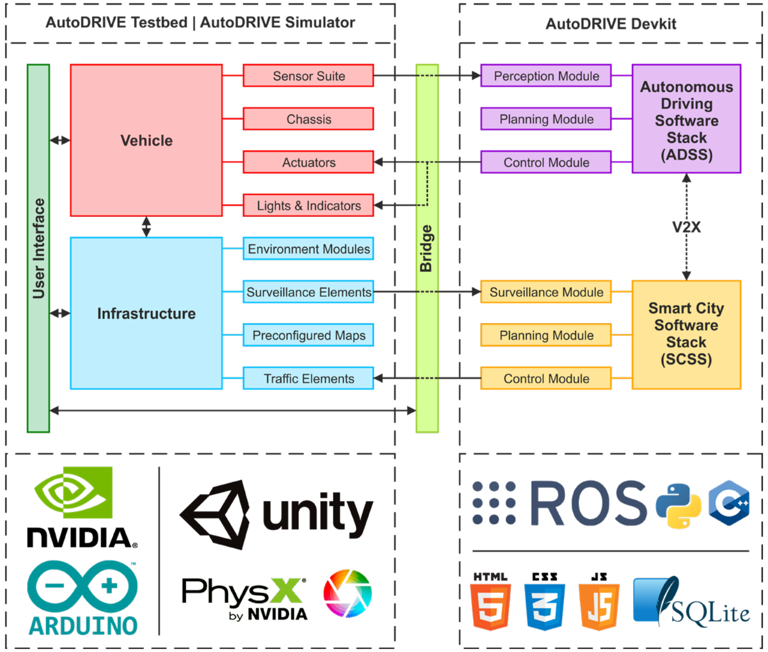
W. Ding, C. Xu, M. Arief, H. Lin, B. Li and D. Zhao, "A Survey on Safety-Critical Driving Scenario Generation—A Methodological Perspective," in IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 7, pp. 6971-6988, July 2023, doi: 10.1109/TITS.2023.3259322

AutoDRIVE Ecosystem

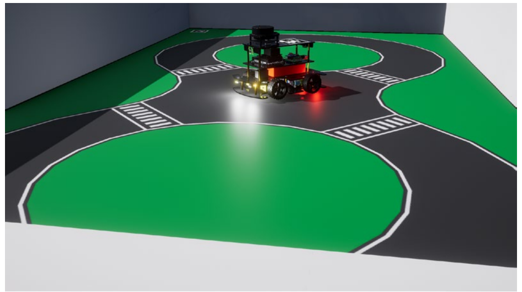
- Ackermann-steer, skid-steer, independent 4WD4WS
- 1/14 scale open chassis
- Scaled infrastructure
- Small form factor

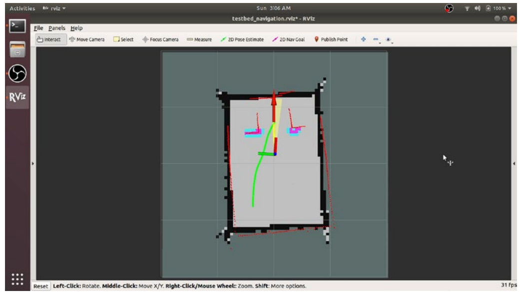
- Flexible APIs
- High-fidelity simulation
- Mechatronic testbed
- AD + SC applications
- Affordable cost

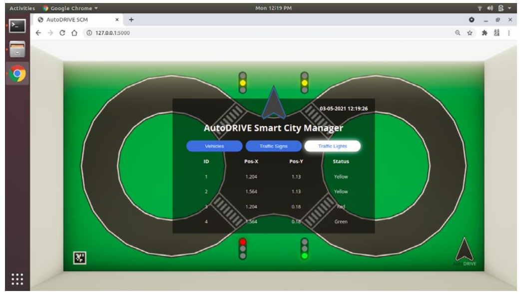
- Website
- GitHub
- YouTube



Version	Mobile Base	Battery	Computer(s)	Sensor(s)	Actuator(s)	Developer	Release	Cost
Nigel	Open-Source	5200 mAh	Jetson Nano or Jetson Orin Nano	RPLIDAR A-1, Pi-Cameras, Intel RealSense D435i, 9-Axis IMU, 6-Axis IPS, Encoders, Microphone, Steering Feedback, Throttle Feedback	DC Motors, Steering Servo(s)	CU-ICAR + NTU + SRMIST	2021	$450





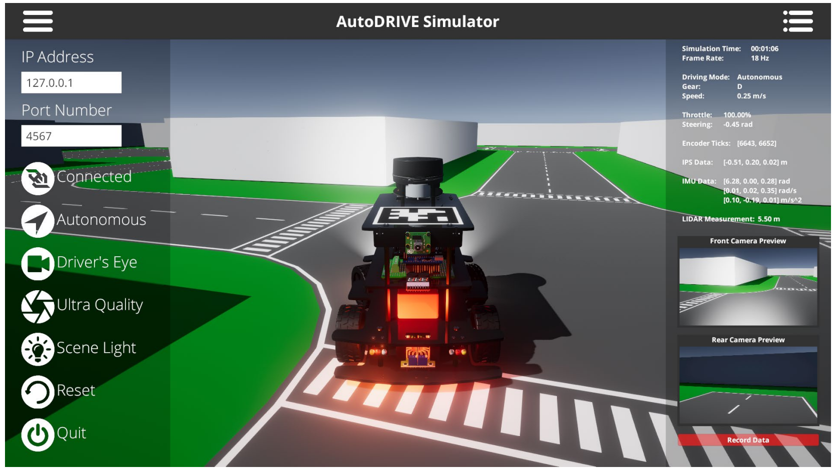


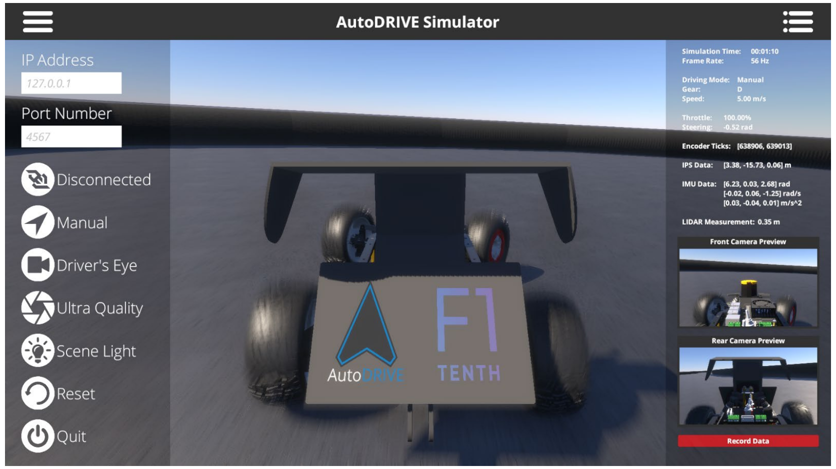
AutoDRIVE

Source: https://autodrive-ecosystem.github.io

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
  - Small development team



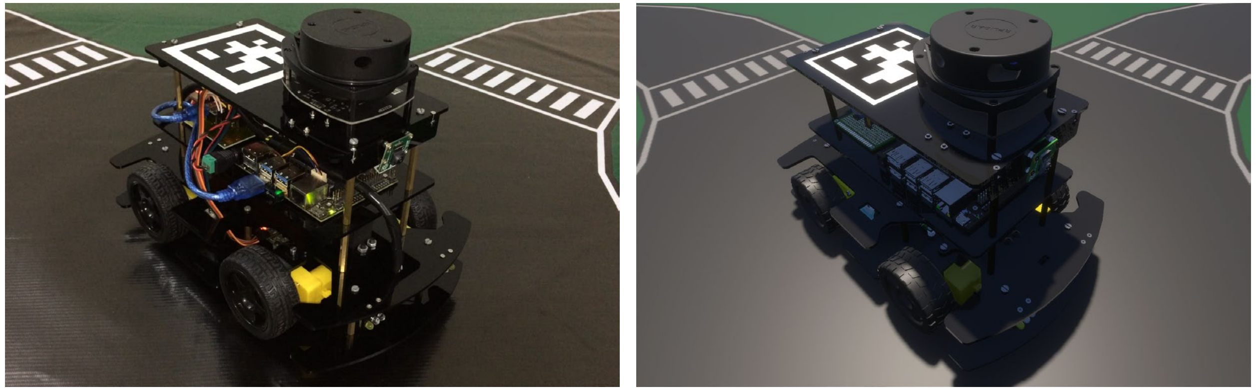


AutoDRIVE

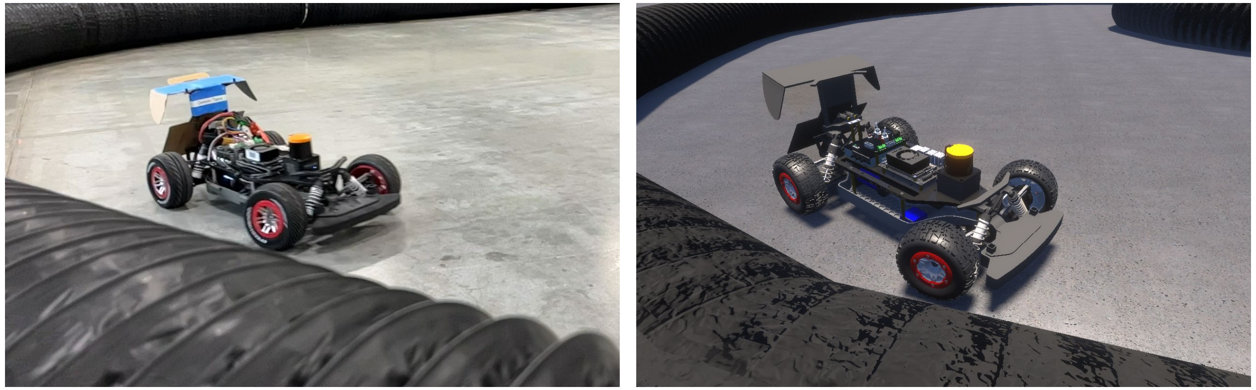
Source: AutoDRIVE Ecosystem

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

Digital Twin Capabilities of AutoDRIVE Ecosystem



Nigel (Native Scaled Vehicle)



F1TENTH (Scaled Vehicle)

OpenCAV (On-Road Full Scale Vehicle)

RZR (Off-Road Full Scale Vehicle)

Source: AutoDRIVE Ecosystem

Digital Twin Capabilities of AutoDRIVE Ecosystem

Source: [AutoDRIVE Ecosystem]

Digital Twin Capabilities of AutoDRIVE Ecosystem

Source: AutoDRIVE Ecosystem

Digital Twin Capabilities of AutoDRIVE Ecosystem

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Digital Twin Capabilities of AutoDRIVE Ecosystem

Source: AutoDRIVE Ecosystem

Planned Project Objectives

- ODD focus: on-road autonomous navigation
- Platforms:
  - Small-scale: Nigel/F1TENTH
  - Full-scale: OpenCAV
  - Simulation: AutoDRIVE Simulator
  - Software-stack: Autoware
- True digital twin framework:
  - Immersive teleoperation demo
- Autoware demo:
  - Autonomous navigation (waypoint following)
- Documentation

Planned Project Objectives

AuE-8360 Capstone Project (Fall 2023)								
Task	10/18	10/25	11/01	11/08	11/15	11/22	11/29	12/06
Announcements								
Project Proposal								
Phase 1								
Phase 2								
Phase 3								
Project Presentation								
Project Report								

References

1. T. Samak, C. Samak, S. Kandhasamy, V. Krovi, and M. Xie, "AutoDRIVE: A Comprehensive, Flexible and Integrated Digital Twin Ecosystem for Autonomous Driving Research & Education," Robotics, vol. 12, no. 3, p. 77, May 2023, doi: 10.3390/robotics12030077
2. W. Ding, C. Xu, M. Arief, H. Lin, B. Li and D. Zhao, "A Survey on Safety-Critical Driving Scenario Generation—A Methodological Perspective," in IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 7, pp. 6971-6988, July 2023, doi: 10.1109/TITS.2023.3259322
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5. Autoware Foundation, "Autoware Project: The world's leading open-source software project for autonomous driving." [Online]. Available: https://autoware.org