

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	X	X	X	X	✓	✓	✓	Jetson TX2	VESC	✓	X	Gazebo	★	★	X	X	X	✓	X	X
AutoRally	1:5	★	✓	\$23,300	X	X	✓	✓	✓	✓	✓	Custom	Teensy LC/Arduino Micro	✓	X	Gazebo	★	★	X	X	X	✓	X	X
F1TENTH	1:10	★	✓	\$3280	X	X	X	X	X	✓	X	Jetson TX2	VESC 6MKV	✓	X	RViz/Gazebo	✓	✓	X	X	X	✓	X	X
DSV	1:10	★	✓	\$1000	X	X	✓	X	✓	✓	✓	ODROID-XU4	Arduino (Mega + Uno)	✓	X	X	X	X	X	X	X	✓	X	X
MuSHR	1:10	★	✓	\$930	X	X	X	X	X	X	✓	Jetson Nano	Turnigy SK3-ESC	✓	X	RViz	✓	✓	X	X	X	✓	X	X
HyphaROS RaceCar	1:10	★	✓	\$600	X	X	X	X	✓	✓	X	ODROID-XU4	RC ESC TBLE-02S	✓	X	X	X	X	X	X	X	✓	X	X
Donkey Car	1:16	★	✓	\$370	X	X	X	X	X	X	✓	Raspberry Pi	ESC	✓	X	Gym	X	X	X	X	✓	X	X	X
BARC	1:10	★	✓	\$1030	X	X	✓	X	✓	X	✓	ODROID-XU4	Arduino Nano	✓	X	X	X	X	X	X	X	✓	X	X
OCRA	1:43	★	✓	\$990	X	X	X	X	✓	X	X	None	ARM Cortex M4 µC	✓	X	X	✓	X	X	✓	X	✓	X	X
QCar	1:10	X	X	\$20,000	X	X	✓	X	✓	✓	✓	Jetson TX2	Proprietary	✓	X	Simulink	✓	✓	X	★	★	★	✓	X
AWS DeepRacer	1:18	X	X	\$400	X	X	X	X	✓	★	✓	Proprietary	Proprietary	✓	X	Gym	X	X	X	X	X	X	X	✓
Duckietown	N/A	✓	✓	\$450	X	X	★	X	★	X	✓	Raspberry Pi/Jetson Nano	None	X	✓	Gym	✓	X	★	X	X	✓	X	X
TurtleBot3	N/A	✓	✓	\$590	X	X	✓	X	✓	✓	★	Raspberry Pi	OpenCR	X	✓	Gazebo	★	★	X	X	X	✓	X	X
Pheeno	N/A	✓	✓	\$350	X	X	✓	X	✓	X	✓	Raspberry Pi	Arduino Pro Mini	X	✓	X	✓	✓	X	X	✓	★	X	X

✓ indicates complete fulfillment; * indicates conditional, unsupported or partial fulfillment; and X 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	×	✓	✓	✓	✓

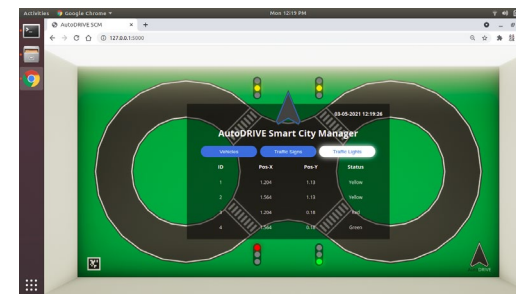
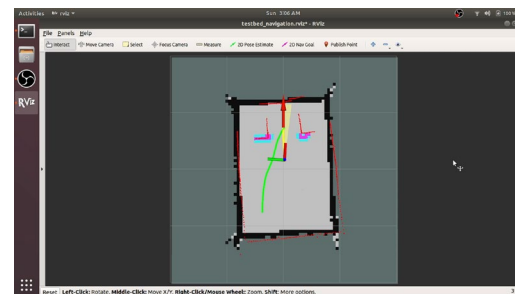
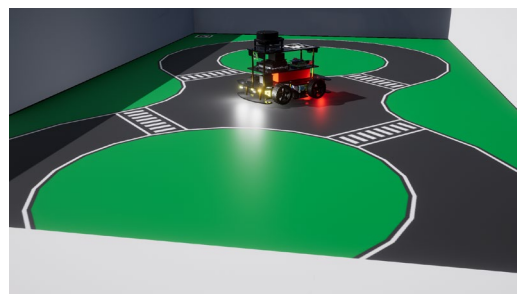
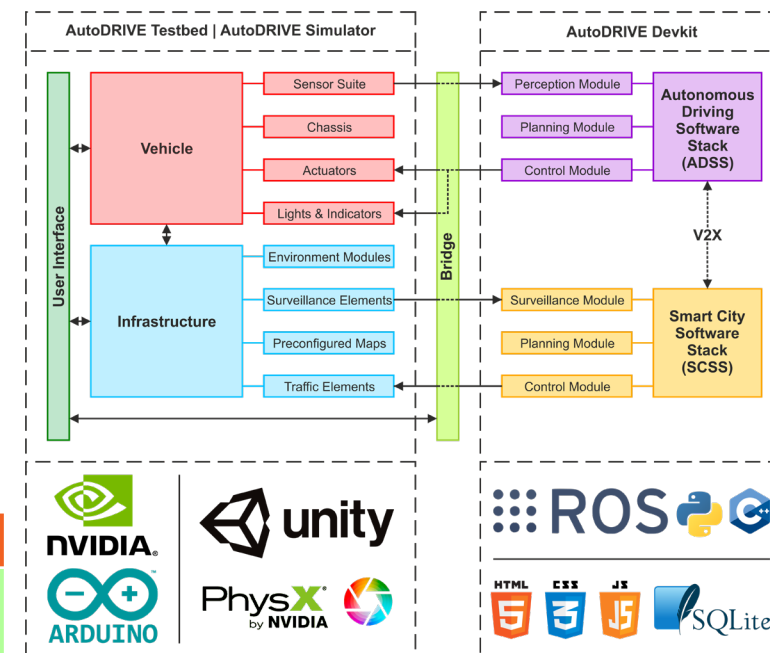
Opportunity!

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](https://doi.org/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



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

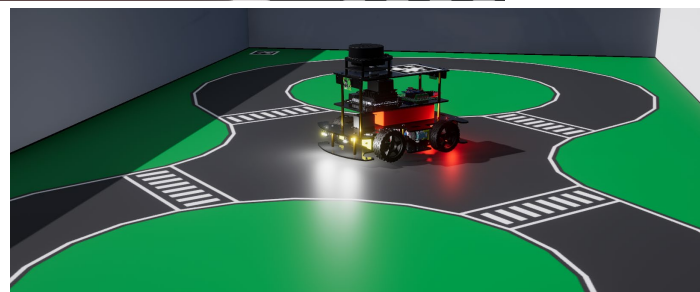
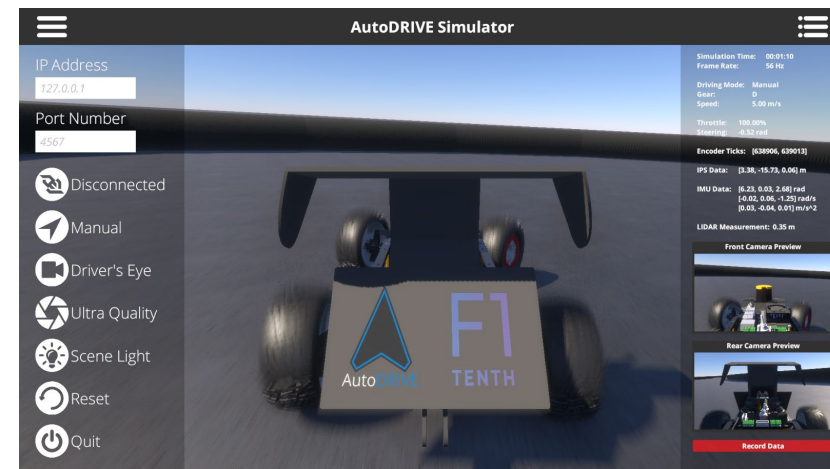
AutoDRIVE Simulator

Advantages

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

Disadvantages

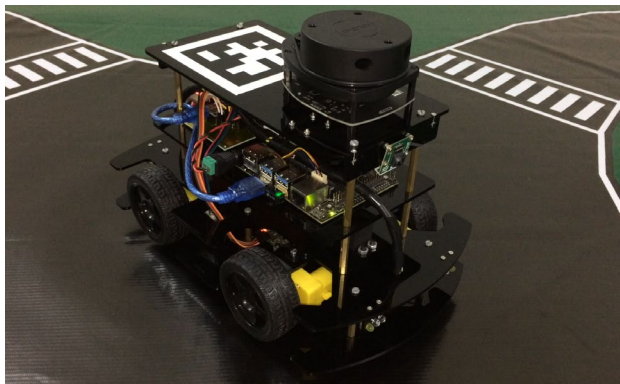
- Moderate compute requirements
- Small development team



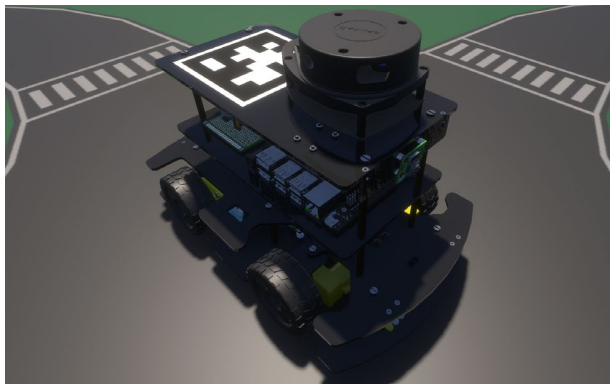
Source: [AutoDRIVE Ecosystem](#)

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](#)

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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



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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)



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](https://doi.org/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](https://doi.org/10.1109/TITS.2023.3259322)
3. M. Quigley, K. Conley, B. Gerkey, J. Faust, T. Foote, J. Leibs, R. Wheeler, and A. Ng, “ROS: an open-source Robot Operating System,” in *ICRA 2009 Workshop on Open Source Software*, vol. 3, Jan 2009. [Online]. Available: <http://robotics.stanford.edu/~ang/papers/icraoss09-ROS.pdf>
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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>