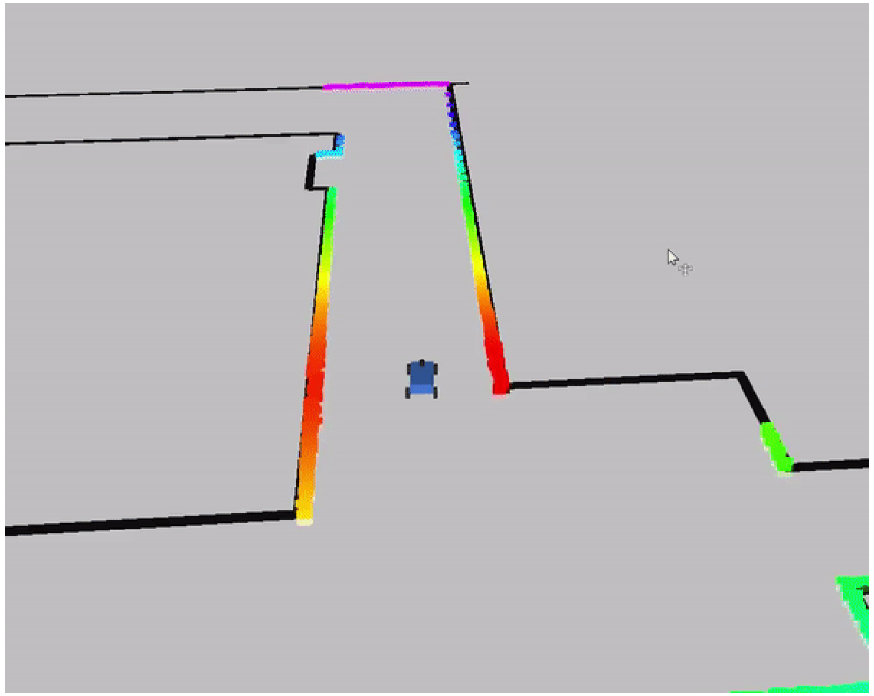
AuE-8360
Scaled Autonomous Vehicles

Simulation Setup for Scaled Autonomous Vehicles

Chinmay Samak
PhD Candidate, CU-ICAR
csamak@clemson.edu

Tanmay Samak
PhD Candidate, CU-ICAR
tsamak@clemson.edu

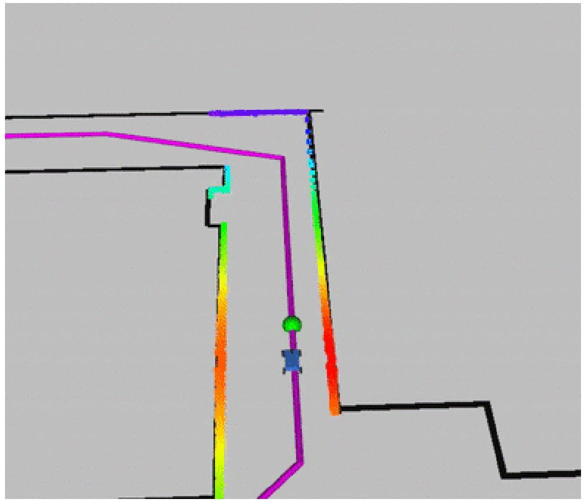
Official F1TENTH Simulator - Introduction

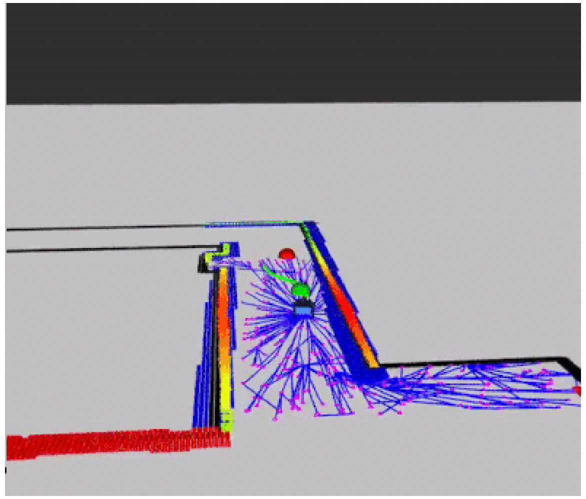


- Advantages
  - Open source
  - Simple & intuitive
  - Uses same stack as real vehicle
- Disadvantages
  - 2D simplistic simulation (RViz)
  - No vertical/roll/pitch dynamics
  - 2D environment representation
  - No cross-platform support
  - Inaccuracies (e.g., 360° LIDAR simulation - real is 270°)

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

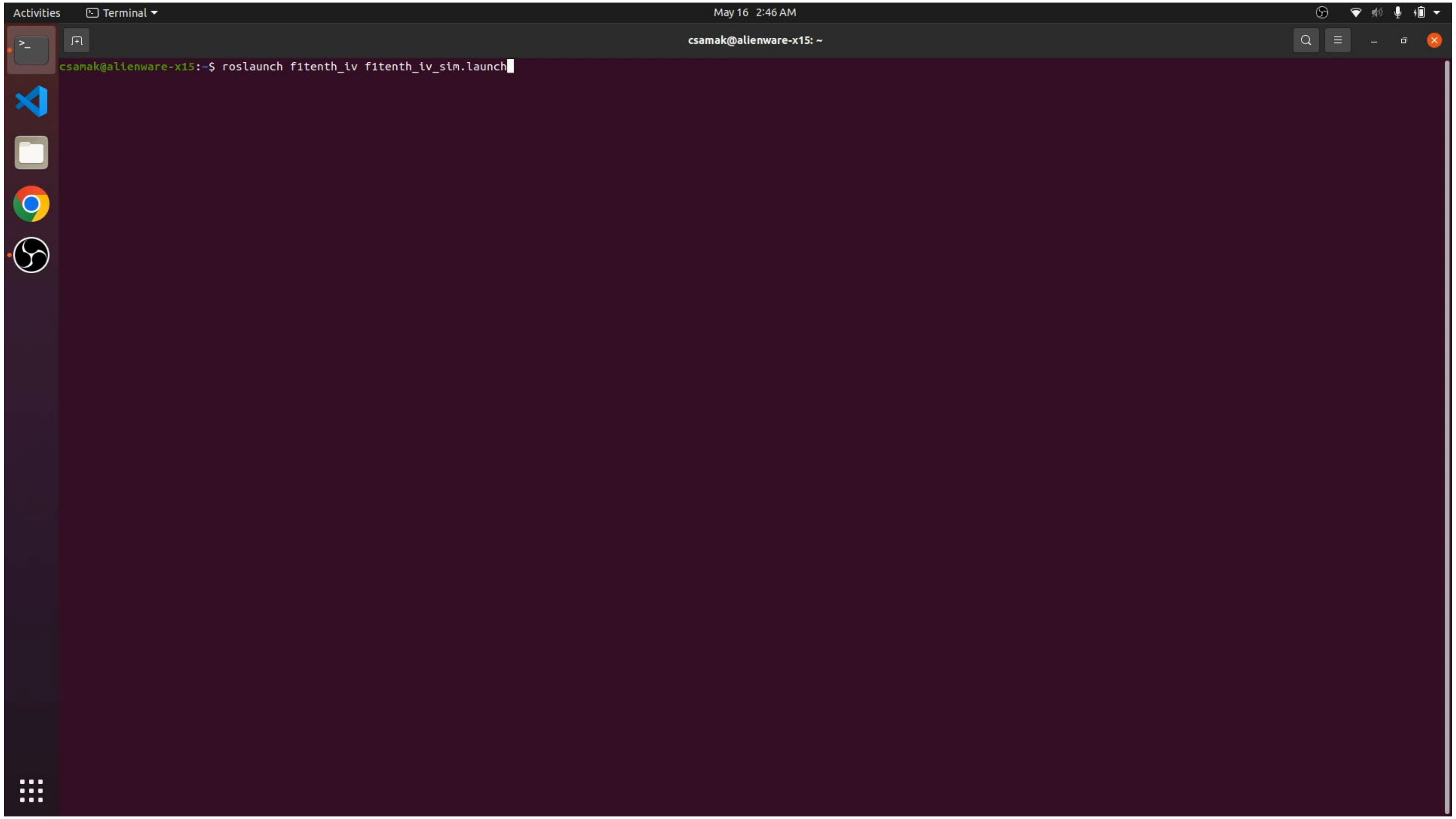
F1 TENTH





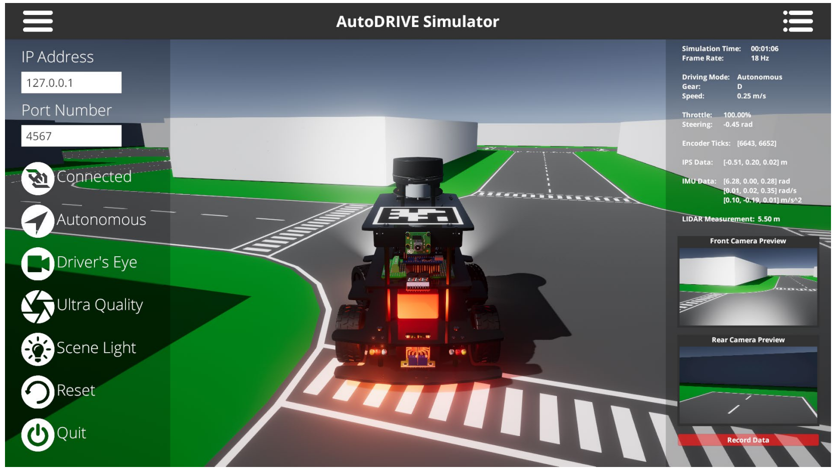
Source: F1TENTH

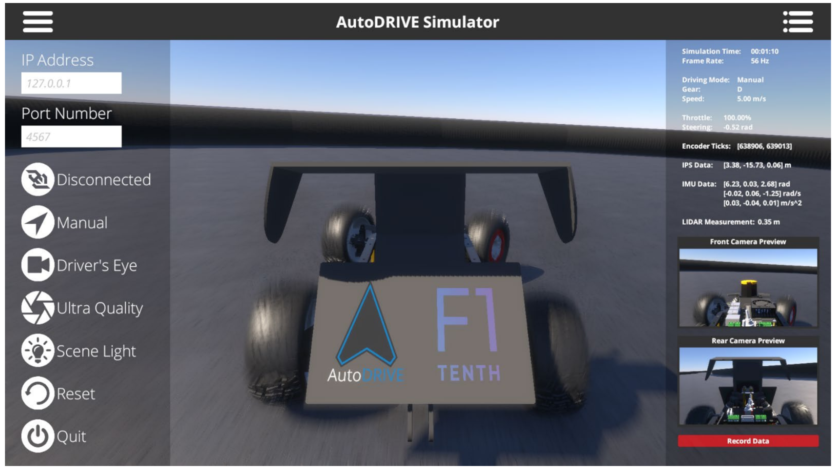
Official F1TENTH Simulator - Setup & Exploration



AutoDRIVE Simulator - Introduction

- 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



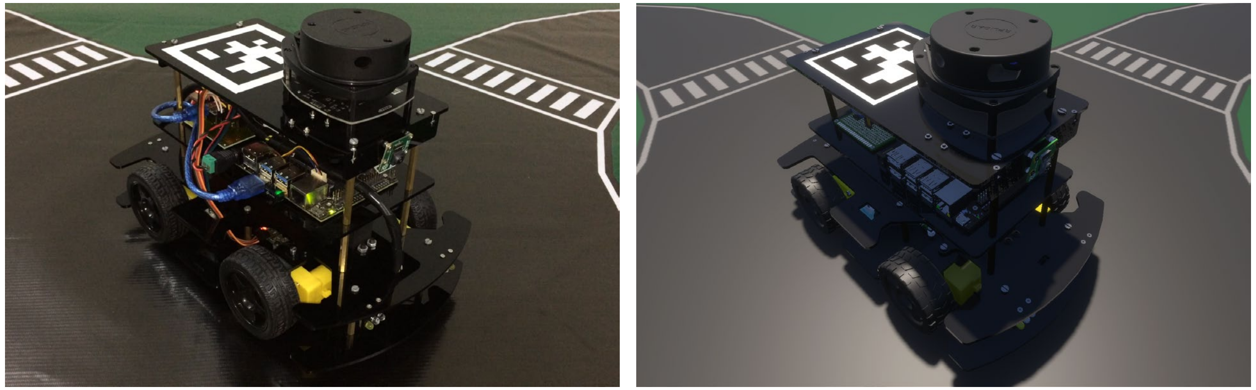


AutoDRIVE

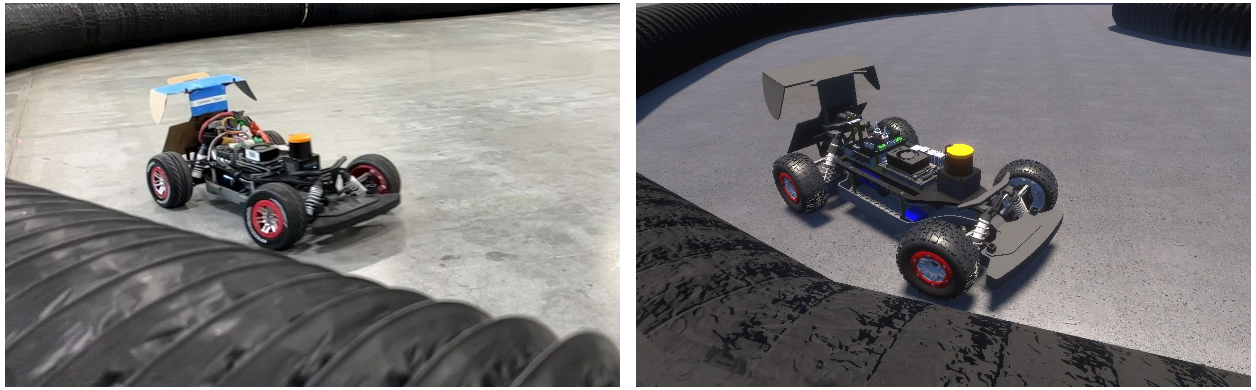
Source: AutoDRIVE Ecosystem

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

AutoDRIVE Simulator - Digital Twin Capabilities



Nigel (Native Scaled Vehicle)



F1TENTH (Scaled Vehicle)

OpenCAV (On-Road Full Scale Vehicle)

RZR (Off-Road Full Scale Vehicle)

Source: AutoDRIVE Ecosystem

AutoDRIVE Simulator - F1TENTH Simulation

- Vehicle dynamics
  - Rigid-body dynamics
  - Suspension dynamics
  - Tire dynamics
  - Actuator dynamics

$$M = \sum {}^iM \qquad X_{COM} = \frac{\sum {}^iM * {}^iX}{\sum {}^iM}$$

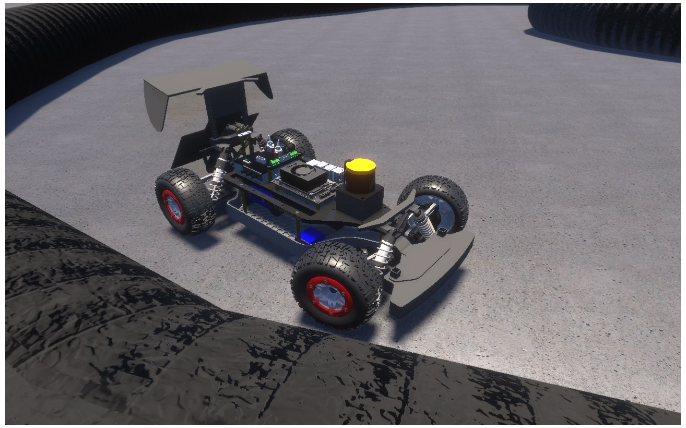
$${}^iM * {}^i\ddot{Z} + {}^iB * ({}^i\dot{Z} - {}^i\dot{z}) + {}^iK * ({}^iZ - {}^iz)$$

$${}^im * {}^i\ddot{z} + {}^iB * ({}^i\dot{z} - {}^i\dot{Z}) + {}^iK * ({}^iz - {}^iZ)$$

$$\begin{cases} {}^iF_{t_x} = F({}^iS_x) \\ {}^iF_{t_y} = F({}^iS_y) \end{cases} \qquad {}^iS_x = \frac{{}^ir * {}^i\omega - v_x}{v_x} \qquad {}^iS_y = \tan(\alpha) = \frac{v_y}{|v_x|}$$

$$F(S) = \begin{cases} f_0(S); & S_0 \leq S < S_e \\ f_1(S); & S_e \leq S < S_a \end{cases}$$

$$f_k(S) = a_k * S^3 + b_k * S^2 + c_k * S + d_k$$



$${}^i\tau_{drive} = {}^iI_w * {}^i\dot{\omega}_w \qquad \tau_{steer} = I_{steer} * \dot{\omega}_{steer}$$

$${}^iI_w = \frac{1}{2} * {}^im_w * {}^ir_w{}^2$$

$${}^i\tau_{idle} = {}^i\tau_{brake}$$

$$\begin{cases} \delta_l = \tan^{-1}\left(\frac{2*l*\tan(\delta)}{2*l+w*\tan(\delta)}\right) \\ \delta_r = \tan^{-1}\left(\frac{2*l*\tan(\delta)}{2*l-w*\tan(\delta)}\right) \end{cases}$$

AutoDRIVE Simulator - F1TENTH Simulation

- Sensor physics
  - LIDAR
  - Throttle & steering sensors*
  - Incremental encoders*
  - Indoor positioning system*
  - Inertial measurement unit*
  - Cameras*

$$\tau_f^t = \tau_u^{t-1} \qquad \delta_f^t = \delta_u^{t-1}$$

$$^w\mathbf{T}_v = \left[\begin{array}{c|c} \mathbf{R}_{3\times 3} & \mathbf{t}_{3\times 1} \\ \hline \mathbf{0}_{1\times 3} & 1 \end{array}\right] \in SE(3)$$

$$\{x, y, z\} \qquad \{a_x, a_y, a_z\} \qquad \{\omega_x, \omega_y, \omega_z\}$$

$$\{\phi_x, \theta_y, \psi_z\} \qquad \{q_0, q_1, q_2, q_3\}$$

$$\texttt{raycast}\{^w\mathbf{T}_l, \ \vec{\mathbf{R}}, \ r_{max}\}$$

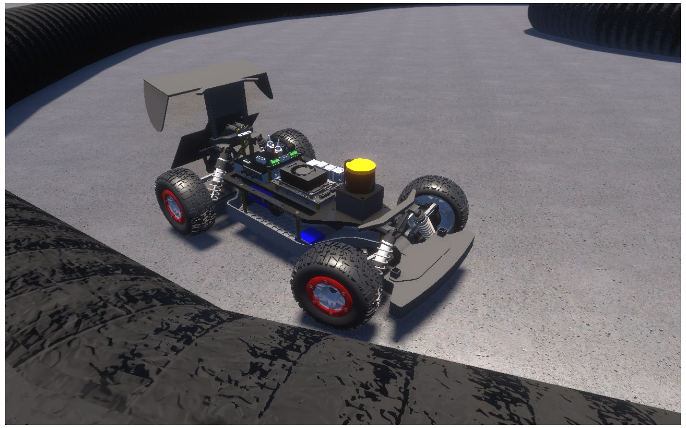
$$\theta \in [\theta_{min} : \theta_{res} : \theta_{max}]$$

$$^w\mathbf{T}_l = {^w\mathbf{T}_v} * {^v\mathbf{T}_l} \in SE(3)$$

$$\vec{\mathbf{R}} = [r_{max} * sin(\theta) \ \ r_{min} * cos(\theta) \ \ 0]^T$$

$$\texttt{ranges[i]} = \begin{cases} \texttt{hit.dist} & \text{if } \texttt{ray[i].hit} \text{ and } \texttt{hit.dist} \geq r_{min} \\ \infty & \text{otherwise} \end{cases}$$

$$\texttt{hit.dist} = \sqrt{(x_{hit} - x_{ray})^2 + (y_{hit} - y_{ray})^2 + (z_{hit} - z_{ray})^2}$$



$$\mathbf{V} = \begin{bmatrix} r_{00} & r_{01} & r_{02} & t_0 \\ r_{10} & r_{11} & r_{12} & t_1 \\ r_{20} & r_{21} & r_{22} & t_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \mathbf{P} = \begin{bmatrix} \frac{2*N}{R-L} & 0 & \frac{R+L}{R-L} & 0 \\ 0 & \frac{2*N}{T-B} & \frac{T+B}{T-B} & 0 \\ 0 & 0 & -\frac{F+N}{F-N} & -\frac{2*F*N}{F-N} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

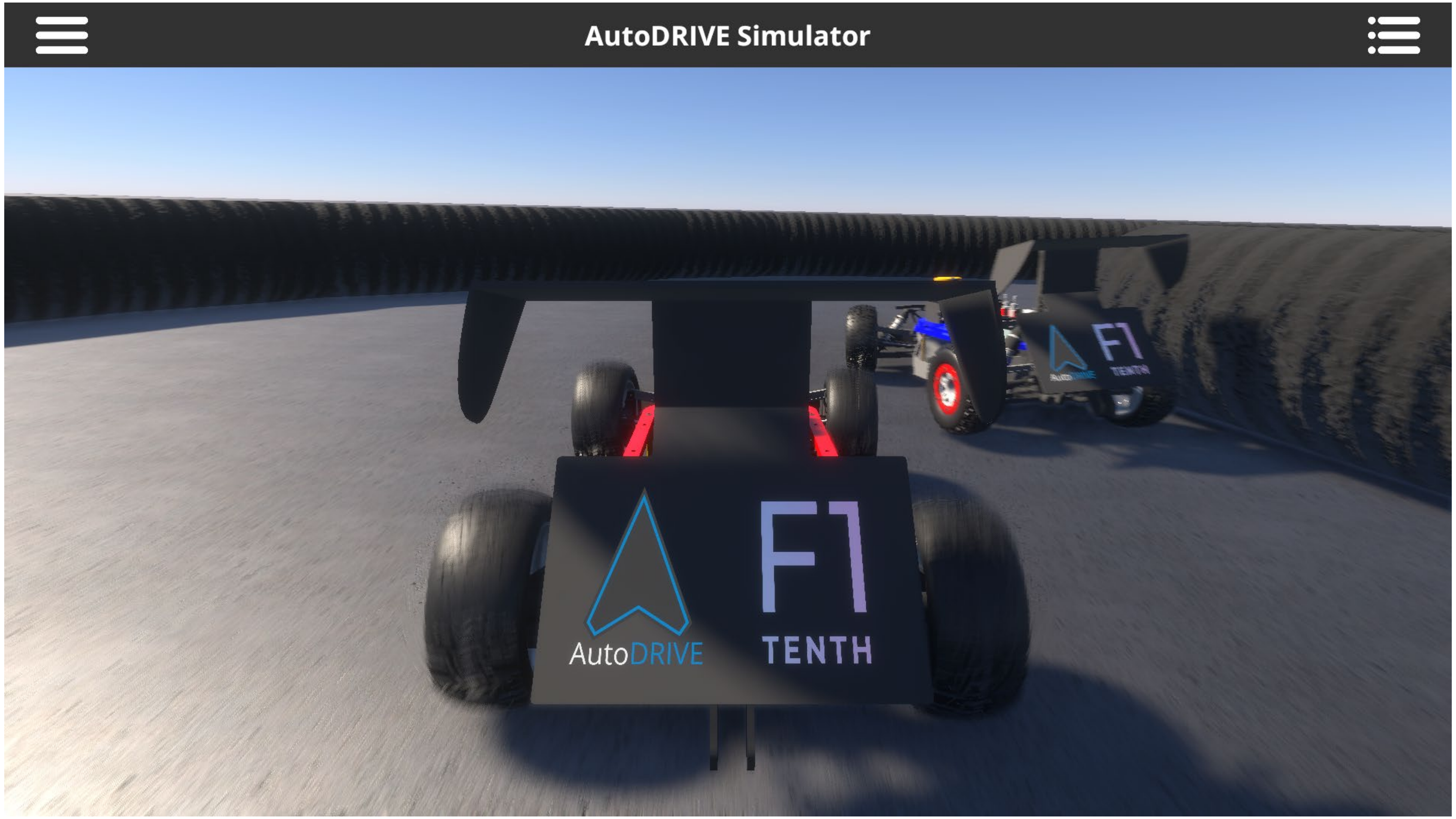
$$f = \frac{2*N}{R-L}, \ a = \frac{s_y}{s_x}, \text{ and } \frac{f}{a} = \frac{2*N}{T-B}$$

$$\mathbf{W} = [x_w \ \ y_w \ \ z_w \ \ w_w]^T$$

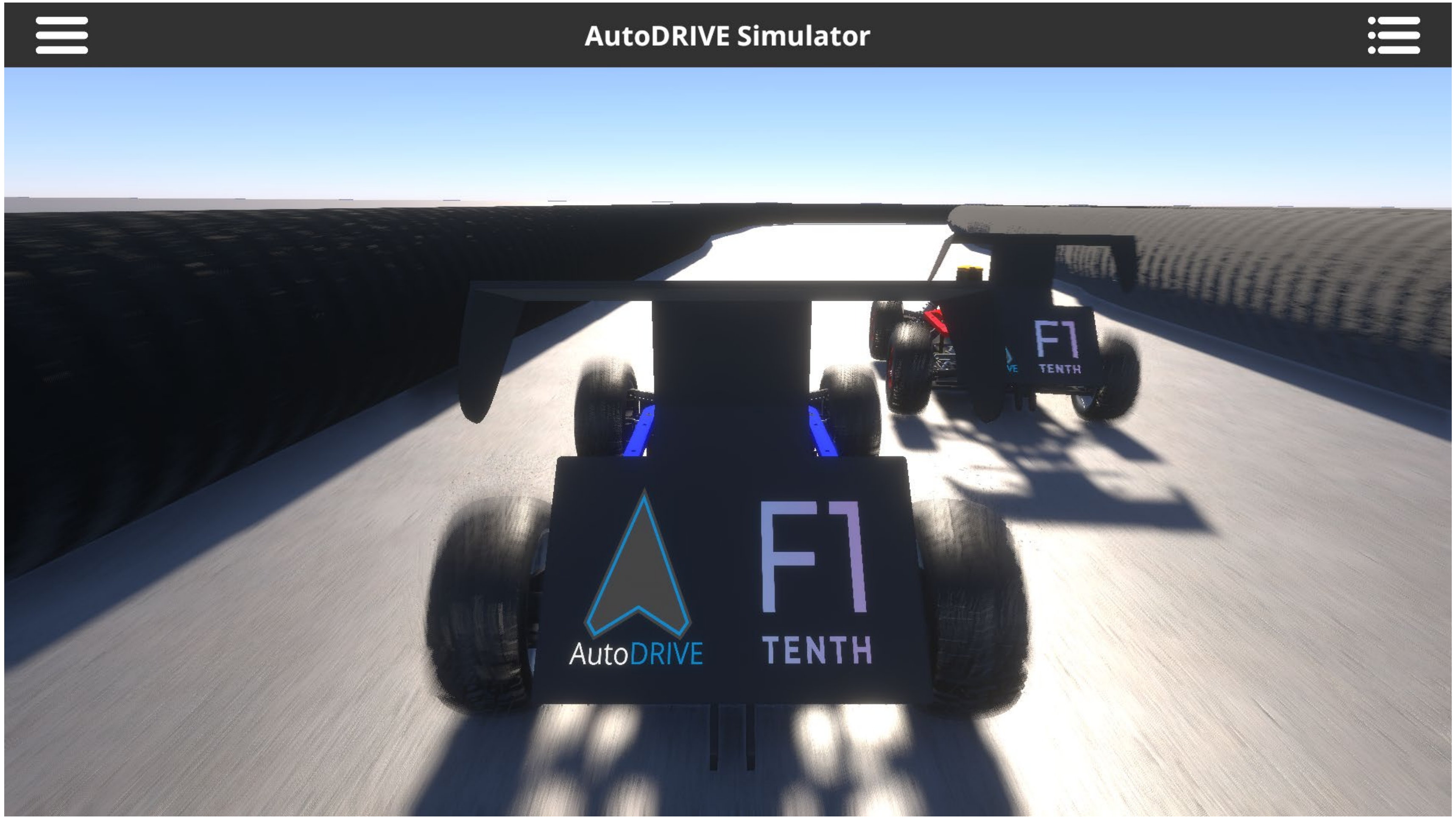
$$\mathbf{C} = [x_c \ \ y_c \ \ z_c \ \ w_c]^T$$

$$\mathbf{C} = \mathbf{P} * \mathbf{V} * \mathbf{W}$$

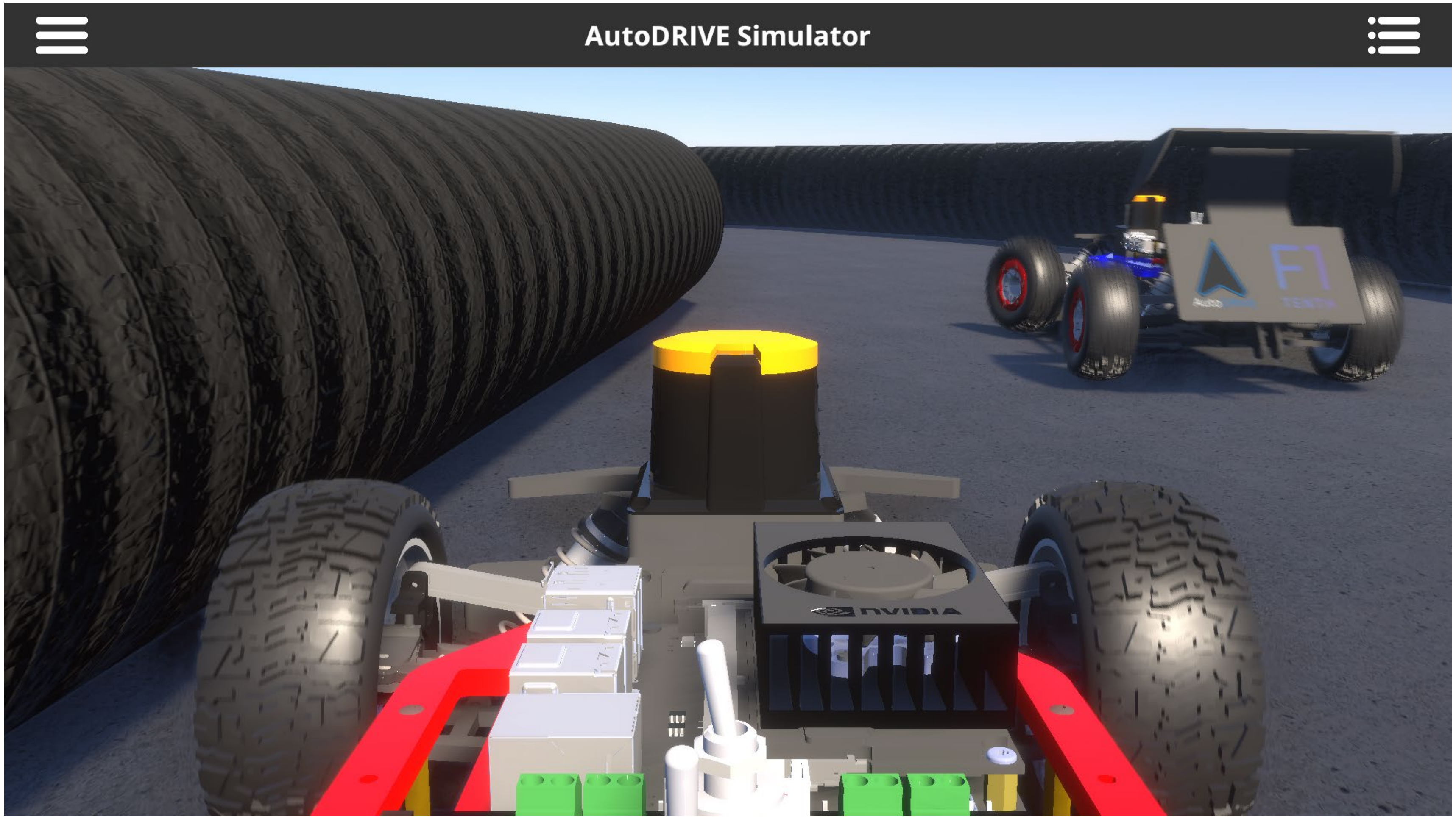
AutoDRIVE Simulator - F1TENTH Simulation



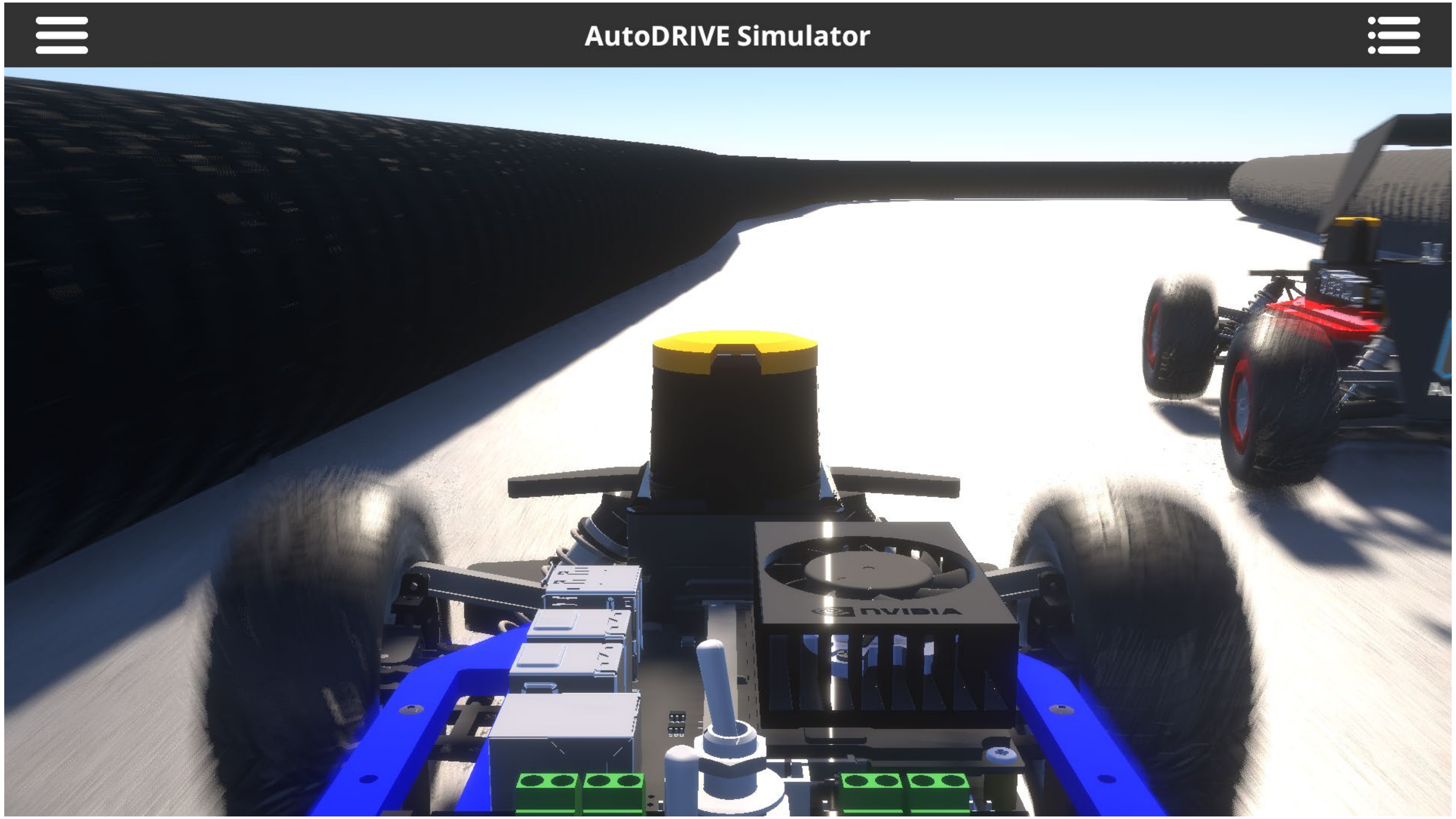
AutoDRIVE Simulator - F1TENTH Simulation



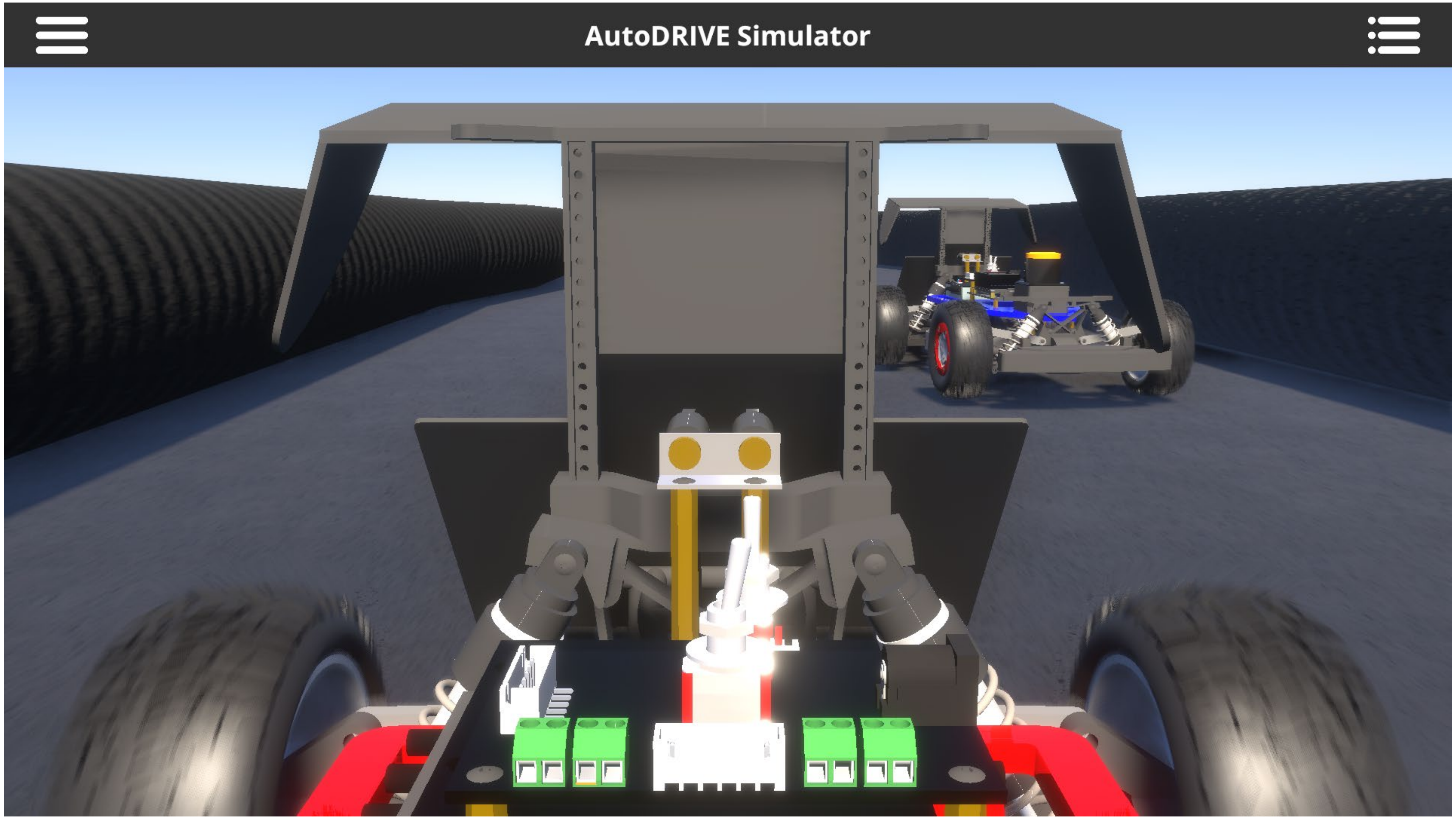
AutoDRIVE Simulator - F1TENTH Simulation



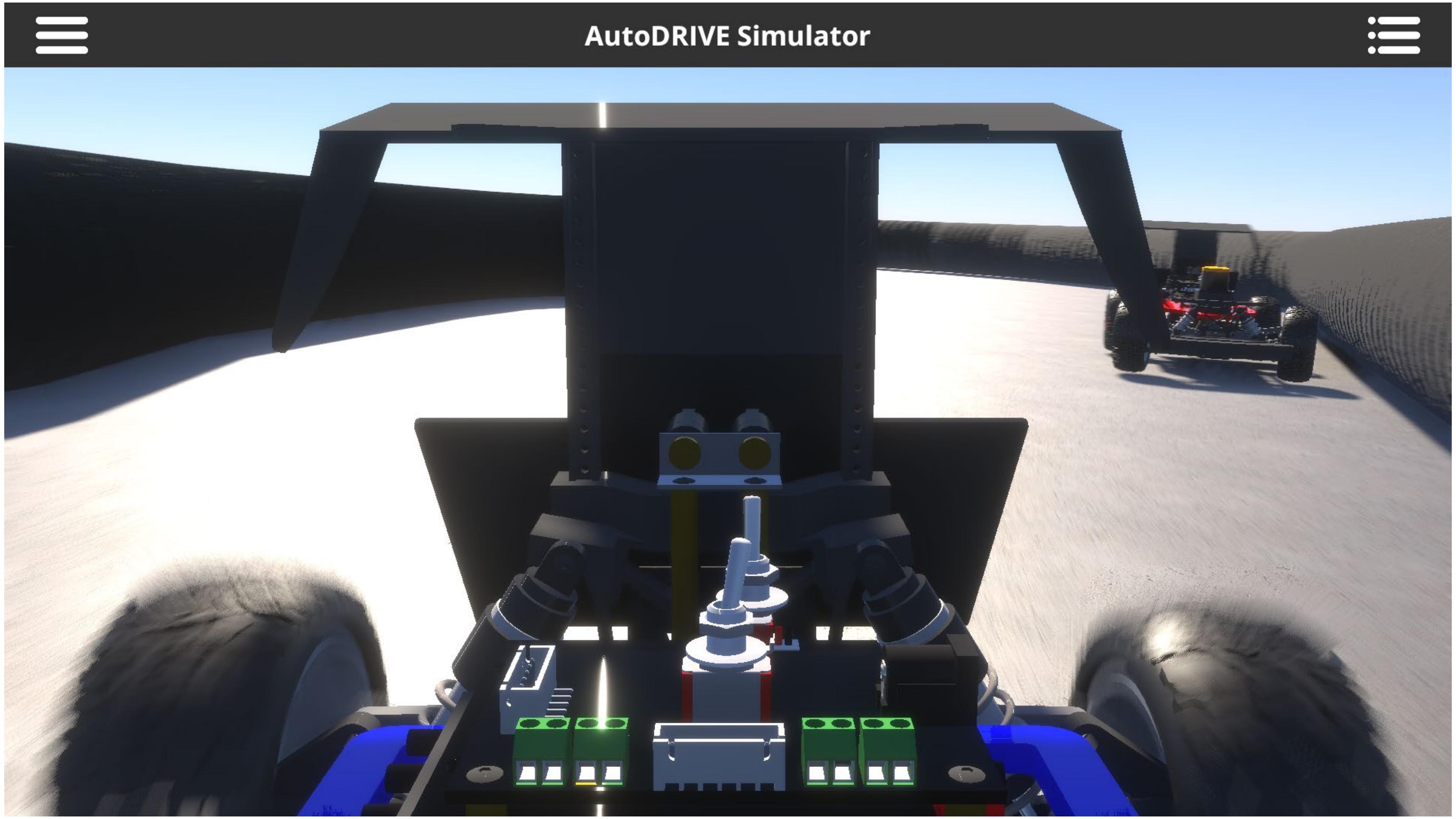
AutoDRIVE Simulator - F1TENTH Simulation



AutoDRIVE Simulator - F1TENTH Simulation

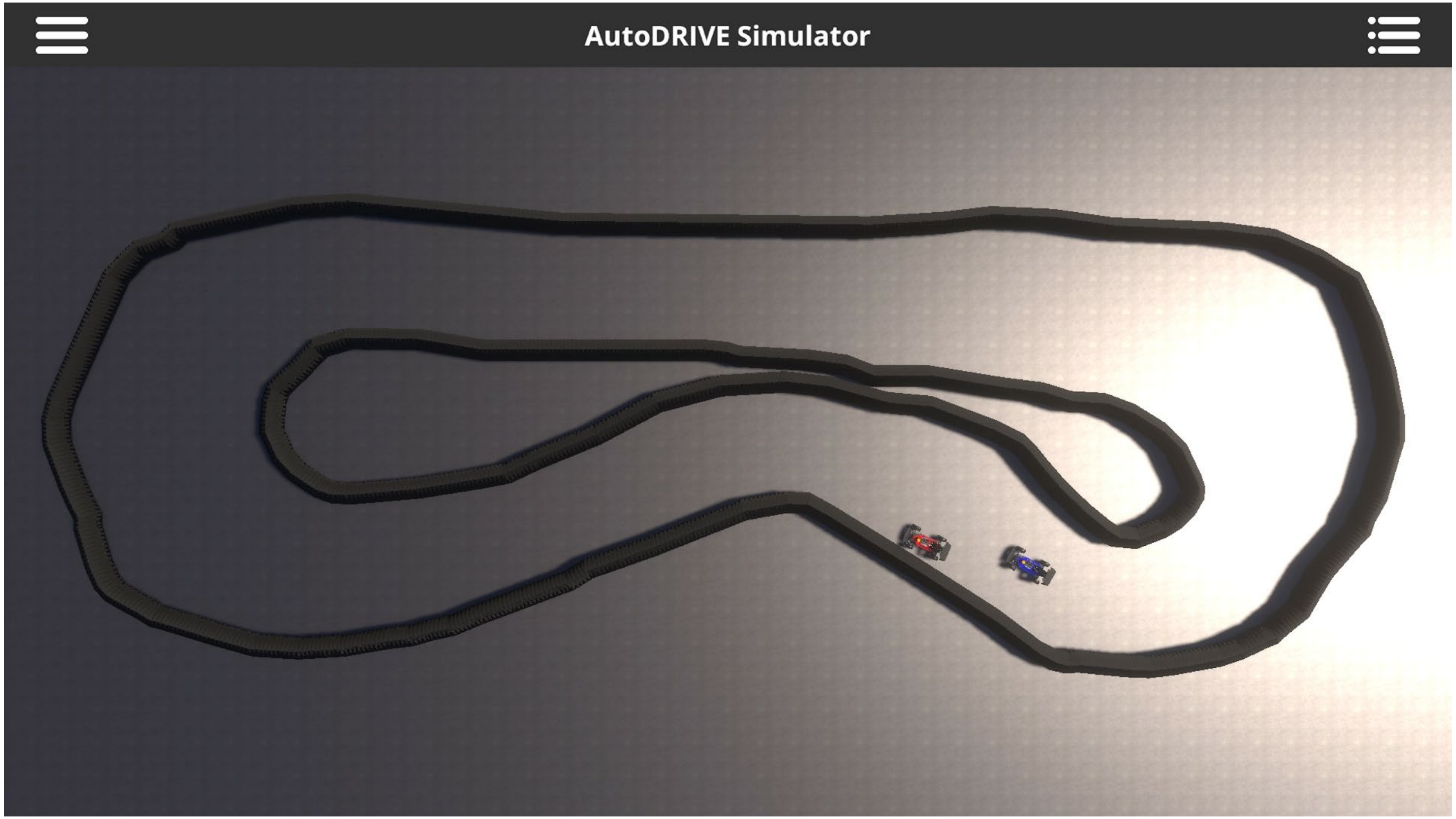


AutoDRIVE Simulator - F1TENTH Simulation



AutoDRIVE Simulator - F1TENTH Simulation

AutoDRIVE Simulator - F1TENTH Simulation



AutoDRIVE Simulator - F1TENTH Simulation

Live Demo!

References

1. 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
2. S. Macenski, T. Foote, B. Gerkey, C. Lalancette, and W. Woodall, “Robot operating system 2: Design, architecture, and uses in the wild,” Science Robotics, vol. 7, no. 66, p. eabm6074, 2022. [Online]. Available: https://www.science.org/doi/abs/10.1126/scirobotics.abm6074
3. M. O'Kelly, H. Zheng, D. Karthik and R. Mangharam, “F1TENTH: An Open-source Evaluation Environment for Continuous Control and Reinforcement Learning,” Proceedings of Machine Learning Research, H.J. Escalante R. Hadsell (eds.), Proceedings of the NeurIPS 2019 Competition and Demonstration Track, PMLR, vol. 123, pp. 77-89, December 2020. [Online]. Available: https://proceedings.mlr.press/v123/o-kelly20a.html
4. 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