A Chrono-Based Framework for Large-Scale Traffic Simulation with Human in the Loop

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EXTENDED ABSTRACT

1 Introduction

Human-in-the-loop (HIL) simulation provides a safe and inexpensive testing environment for many vehicle operation scenarios that involve human intervention. To be effective, HIL simulation requires high-fidelity vehicle dynamics and a realistic virtual driving environment. HIL is important in studying human-automation interplay in the context of autonomous vehicle operation, human-machine interaction for human factors testing, traffic simulation involving one or more human drivers, driving simulation for clinical applications, etc. For HIL simulation, to accurately capture a human's reaction to a vehicle and its environment, three aspects of the simulation need to be considered and properly implemented: (i) a realistic vehicle dynamics response, such as the vehicle's pitch, roll, and yaw; (ii) the rendering of a realistic virtual driving environment; and (iii) real-time simulation performance. We report on a simulation framework built upon Chrono [1] that addresses the requirements of HIL simulation above by leveraging high-fidelity vehicle simulation, high-performance computing, high-accuracy rendering, and sensor simulation. The open-source simulation module is called Chrono::HIL and leverages the Vehicle, Sensor, and Synchrono modules in Chrono.

2 Chrono::HIL Highlights

Vehicle dynamics simulation at multiple fidelity levels. Depending on the focus of the simulation and the available hardware capabilities, multiple vehicle dynamic models can be chosen from. The highest fidelity model is directly defined in Chrono::Vehicle, which provides a template-based vehicle definition. The Chrono::Vehicle module provides simulation support for all mechanical components of the vehicle, including but not limited to chassis, tire models, suspensions, drive trains, engines, etc. [2]. The Chrono::Synchrono module allows vehicles to be simulated in parallel by different CPU processes via MPI or DDS [3]. Chrono::HIL also provides 21-DOF reduced-order vehicle models (ROMs) to allow faster simulation speed with simplified vehicle dynamics, as well as kinematic vehicle representation, in which vehicles are simply represented as objects with externally-defined motion.

Sensing and Rendering. Chrono::Sensor uses NVIDIA's Optix ray-tracing API to provide both sensor simulation and graphics rendering [4]. Users of Chrono::HIL can directly launch the rendering window from Chrono::HIL with easy camera definition as Chrono::Sensor is well embedded to work with any simulation created within Chrono. Alternatively, one can use Unity [5] as a rendering engine.

Soft Real-Time Enforcing. Chrono::HIL ensures that the simulation time is periodically and with high frequency synced to the real time. In other words, the Real Time Factor (RTF), defined as the ratio of simulation to simulated time, has to be precisely 1. We employ a soft real-time synchronization method in which we might sometimes allow simulation steps to run slower than real-time. As shown in Figure 1, if a simulation step runs slower than real time, it is expected that a later simulation step runs faster than real time to average out at an RTF=1. In cases when the simulation step runs faster than real time, an active synchronization delay is employed to delay the simulation via a "sleep" function call.

Hardware Coupling. Chrono::HIL provides flexible controller coupling capabilities to support a range of driving simulator platforms, from a simple one-screen desktop setup to a full-cabin driving simulator. Chrono::HIL achieves this by providing two types of controller input reading methods - direct and hardware streaming. Specifically, it can be programmed to read inputs directly from a joystick connected to the same machine running Chrono::HIL. If the driving simulator is being driven by an external third-party software, Chrono::HIL is able to accept inputs from a UDP network data stream. This latter scenario is illustrated in Figure 2, which shows the coupling of Chrono::HIL with a full-cabin driving simulator in the Traffic Operations and Safety Laboratory at UW-Madison. Therein, the simulation is conducted by Chrono::HIL – the driver's inputs were sent through as a UDP packet and captured by proprietary third-party software.

3 Demonstration of technology

The open-source nature of the software allows customization and freedom to define a spectrum of driving scenarios by controlling the environment, ego car dynamics, lead vehicle behaviors, etc. Chrono::HIL has been recently used in human-factor research. Two data collection scenarios have been conducted – a human factor distraction experiment, which showcases the capabilities of simulation to reproduce dangerous edge cases [6] and a classic ring experiment [7] involving one human driver in the loop, which showcases the ability to simulate real life traffic behaviors and provide useful data for researchers in traffic dynamics.

4 Conclusion and Future Work

Video gaming usually focuses on the excitement of the experience and pays limited attention to the fidelity of the simulation itself. At the other end of the spectrum, commercial driving simulation solutions are often expensive, closed source, and lack the ability

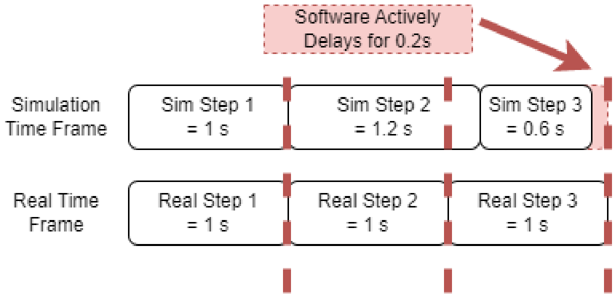

Figure 1: Chrono::HIL global soft real-time enforcement.

Figure 2: Chrono::HIL coupled with full-cabin simulator.

Figure 3: Chrono::HIL used for studying human-automation interplay.

Figure 4: A ring experiment to explore traffic pattern using Chrono::HIL. The simulation involves 23 vehicles, including 1 human-driven vehicle and 22 autonomous vehicles.

to easily customize/adapt simulation scenarios and data collection. The Chrono::HIL framework aims to democratize the use of simulation as a tool for traffic and human factors research. Owing to its open-source nature, the proposed Chrono::HIL framework leverages high-fidelity vehicle dynamics simulation and high-performance parallel computing to allow broad customization of the experimental environment. Looking ahead, we plan to provide a more user-friendly software interface to allow researchers to control scenario parameters and deploy simulation quickly. A second development thrust is tied to improving Chrono::HIL's execution speed, which gets compromised on slow hardware or when used for complex scenarios.

References

[1] A. Tasora, R. Serban, H. Mazhar, A. Pazouki, D. Melanz, J. Fleischmann, M. Taylor, H. Sugiyama, and D. Negrut, "Chrono: An open source multi-physics dynamics engine," in *High Performance Computing in Science and Engineering – Lecture Notes in Computer Science*, T. Kozubek, Ed. Springer International Publishing, 2016, pp. 19–49.

[2] R. Serban, M. Taylor, D. Negrut, and A. Tasora, "Chrono::Vehicle template-based ground vehicle modeling and simulation," *Intl. J. Veh. Performance*, vol. 5, no. 1, pp. 18–39, 2019.

[3] J. Taves, A. Elmquist, A. Young, R. Serban, and D. Negrut, "Synchrono: A scalable, physics-based simulation platform for testing groups of autonomous vehicles and/or robots," in *Proceedings of 2020 International Conference on Intelligent Robots and Systems (IROS) – Las Vegas, USA*, 2020.

[4] A. Elmquist and D. Negrut, "Modeling cameras for autonomous vehicle and robot simulation: An overview," *IEEE Sensors Journal*, vol. 21, pp. 25 547–25 560, 2021.

[5] Unity3D, "Real-Time 3D Tools," https://unity3d.com/, 2016, accessed: 2022-12-28.

[6] J. Zhou, "SynChrono Iowa highway autonomous vehicle testing with human in the loop," Simulation-Based Engineering Laboratory, University of Wisconsin-Madison, https://uwmadison.box.com/s/39107d2577slfg2c54j6xeu5z5va0zes, 2022.

[7] R. E. Stern, S. Cui, M. L. Delle Monache, R. Bhadani, M. Bunting, M. Churchill, N. Hamilton, R. Haulcy, H. Pohlmann, F. Wu, B. Piccoli, B. Seibold, J. Sprinkle, and D. B. Work, "Dissipation of stop-and-go waves via control of autonomous vehicles: Field experiments," *Transportation Research Part C: Emerging Technologies*, vol. 89, pp. 205–221, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0968090X18301517