SynChrono: A Scalable, Physics-Based Simulation Framework for Off-Road Autonomous Vehicles

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***Abstract*—In this contribution we outline the MPI-based, scalable, physics-based simulation framework SynChrono, and its use in autonomous vehicle studies in off-road conditions. SynChrono builds on the simulation capabilities of Chrono, but shows better scaling behavior, making it a useful environment for multi-vehicle mobility studies. When combined with GymChrono, a platform based on OpenAI Gym for reinforcement learning, SynChrono serves as a useful tool for integrated vehicle studies in both on- and off-road environments.**

***Index Terms*—multi-body dynamics, simulation, simulation-to-reality, sensing, reinforcement learning, vehicle dynamics**

I. Chrono

Two modules of the Chrono simulation engine [1], Chrono::Vehicle [2] and Chrono::Sensor, provided the motivation for developing SynChrono.

Chrono::Vehicle provides for the physics-based simulation of wheeled and tracked ground vehicles, through a templated approach that separates components such as the wheels, suspension, steering and driveline. A HMMWV modeled in Chrono::Vehicle is shown in Fig. 1 navigating an obstacle on granular terrain. Chrono::Vehicle provides support for several types of terrain and one deformable soil model in particular, the Soil Contact Model (SCM) [3], has been exercised in SynChrono. This semi-empirical model for deformable terrain is a useful tool for studying the dynamics of vehicles in off-road environments as useful parameters exist that capture the behavior of a wide range of soils.

Chrono::Sensor is motivated by the goal of reducing the simulation-to-reality transfer gap and to this end provides models of camera, lidar, GPS and IMU sensors that can be used in simulation as proxies for their real-world counterparts. A Chrono::Vehicle Sedan is shown navigating a city environment in Fig. 2. Data from a simulated lidar can be used to inform the decision-making algorithm of the vehicle, for example for it to come to a stop when it senses a vehicle ahead of it in its lane.

II. SynChrono

SynChrono does not expand Chrono's physics support, rather, it leverages the existing physics simulation capabilities of Chrono and distributes the computation across multiple processes. This makes the simulation more scalable as more agents get added to the simulation, which is illustrated in Fig. 3.

In many areas, such as vehicle dynamics, there is no interest in contact or collisions between agents, only in the internal dynamics of each agent and in their collective behavior as a whole. In these scenarios, a simulation can be parallelized across separate processes, so that each process handles the

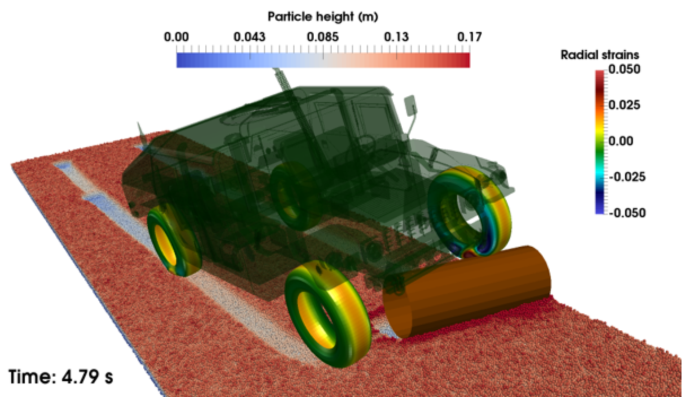

Fig. 1. A HMMWV simulated in Chrono::Vehicle with flexible tires navigates an obstacle on granular terrain.

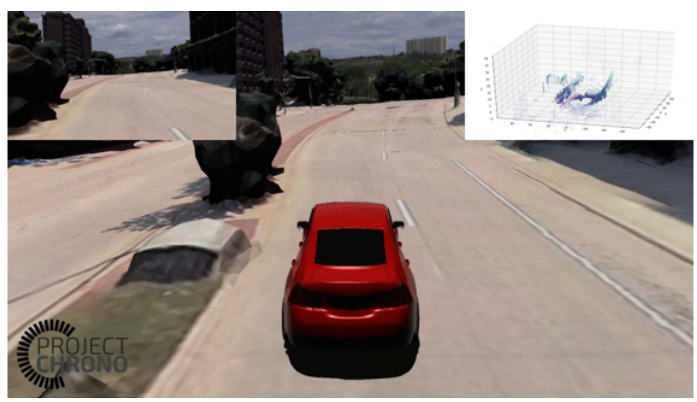

Fig. 2. A sedan drives through a simulated world. The views from a forward-facing (main image) and rear-facing (top-left) camera are rendered with Chrono::Sensor along with the view from a lidar (top-right)

dynamics for a single agent, and the overall state of the agents are synchronized less frequently, for the purpose of sensing. In the course of simulating the dynamics for their single ego-agent, each process will reach a synchronization point after a pre-defined number of time-steps. At this point they compile their resulting state data which for wheeled vehicles is the position and orientation of their center of mass along with the position and orientation of all wheels. They then communicate their state data to all agents in the simulation. Each process uses the state data to update a visualization asset in their simulation so that the ego-agent on their rank is able to sense the position of other agents.

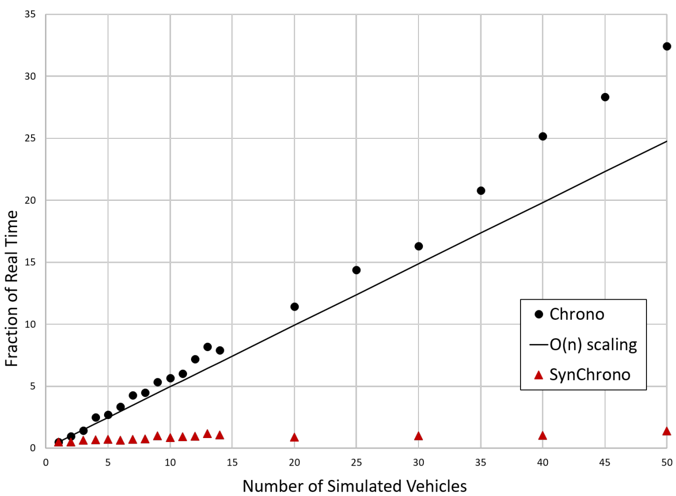

Fig. 3. Comparison between the scaling behavior of SYNCHRONO and CHRONO. Fraction of real time is defined as the time taken in the real-world per unit of simulation time, numbers greater than 1 indicate that the simulation ran slower than real-time. CHRONO shows near linear scaling behavior as more vehicles are added to its monolithic simulation, SYNCHRONO scales at a close to constant rate as more vehicles are added.

III. Mobility Studies

To exercise SYNCHRONO and demonstrate the novel work that it enables, we investigated the scenario of several vehicles navigating a series of obstacles on deformable terrain. The goal for the four vehicles was to follow each other in a convoy and navigate a series of obstacles placed along their path as they move across a region of deformable terrain. The vehicle leading the convoy knew about the path to be followed and used a simple path-following algorithm to remain on it. The three follower vehicles had no knowledge of the path, and used a reinforcement-learned policy to determine how best to drive across the terrain. In learning their policy to navigate the terrain, the follower vehicles relied on a camera, location acquired through GPS sensing and compass heading. The learning was done in GymCHRONO, a CHRONO-based extension to OpenAI Gym. The vehicles were rewarded for staying within a certain distance and heading of the vehicle ahead of them, whether the lead vehicle or another follower vehicle.

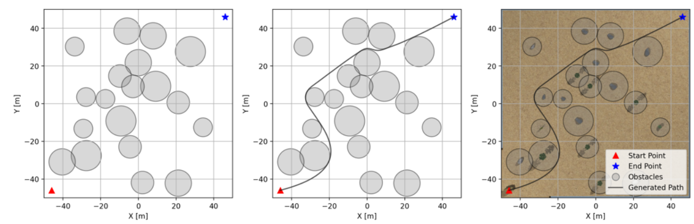

Fig. 4. The environments used for learning consisted of square terrain, with a series of obstacles placed randomly (left image) in the field. For each set of obstacles a simple path-finding algorithm was used to determine the best path through the field of obstacles (middle image). The circles shown were used to force an interesting path, in the final environment that the vehicles learned in, collision shapes were placed inside each circle, but the collision shapes did not reach fully to the edges of all circles to allow the vehicles space to pass through (right image).

Fig. 5. With the final policy learned, a convoy of four vehicles navigates a field of obstacles. The fourth vehicle is displayed without a chassis asset to showcase suspension motion as it moves over ruts. The deformable soil used in this case is given a snow texture as it is a relatively soft soil.

IV. Future Work

Development on all of the technologies outlined above is ongoing and will continue to be released through Project Chrono [4]. Development on CHRONO::Sensor focuses on improving the realism of sensors. Further efforts in SYNCHRONO will focus on improving the speed of simulation by decreasing the MPI overhead, and in allowing multiple agents per simulation rank which can improve resource sharing in resource-intensive scenarios.

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