Autonomous Driving Simulator for Self-Driving Vehicle Development

(Technical Paper)

An Investigation in the Process of Fostering Public Trust in Autonomous Vehicles

(STS Paper)

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John Grant

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signature John M. Grant Date 11 Mar 2022
John Grant

Signature Date 03 May 2022
STS Advisor, Richard D. Jacques, Ph.D. Department of Engineering & Society

Introduction

There is no doubt that the integration of autonomy in modern technologies is a rampant trend among almost every sector of the world's industries today. Autonomous systems have been implemented in manufacturing to ease the burden of menial and potentially dangerous tasks, in the commercial world to disrupt human-to-human interactions in light of a global pandemic, and most relevantly to this topic, in the automotive industry to free our ever-busy hands and minds while commuting in cars. Surely autonomy is prevalent in a plethora of other fields, but it is in these sectors, and a few others unmentioned, where ethical dilemmas sprout from underneath every effort at its implementation into technology. As human oversight is disconnected from the functions of these technologies, there arises concern in how they will behave in situations which commonly require the complicated nature of human intuition and decision-making. In general, the dilemma our society faces as autonomy spreads throughout the world is how it will be safely integrated into organizations and human daily life. There are many ways to navigate the process of fostering public trust in autonomous systems, but the particular one of interest in this context is simulated studies. Specifically, virtually simulating autonomous automobiles and how they interact with their environment. Simulation software such as this can allow self-driving vehicle manufacturers to gain insight on how the algorithms their autonomous systems utilize hold up in potential real-world scenarios. I am in a mechanical engineering capstone group where we are seeking to develop an autonomous driving simulator. While we are very much still in the preliminary stages of the project, gathering relevant research and information on existing technologies has been a guiding factor in the process. We also have gathered feedback from potential customers to establish our primary goals and target specifications. With our research and customer input in mind, we aim to develop an autonomous driving simulator as a valuable resource for self-driving vehicle production and familiarization.

Autonomous Driving Simulator for Self-Driving Vehicle Development

Before delving into the specific breakdown of autonomous simulators, it is important to establish an understanding of basic driving simulators. There are several components which make up the technology of a driving simulator. The two main pieces are the simulation software and the physical controls/chassis. These two elements are interfaced with one another through electronic/mechatronic systems, which constitute sensors, actuators, etc. The software, mechatronic systems, and physical user-controlled components all coalesce to create an immersive, simulated driving experience.

In the software sector, there are several programs which work together to generate the computations and visual and haptic feedback of the simulator experience. Certain software is required to compute the physics which characterize the behavior of the virtual environment, while other software is used to generate the graphics, although it is common for some programs to integrate both of these functions. Additionally, there are programs required to relay the digital data to the actuators and sensors in the physical driving simulator. For a software developer working on a simulator like this, much of their job is concerned with efficiently interfacing all the separate programs in order to reduce latency and computational energy. Therefore, there is a critical balance to be achieved between the complexity and efficiency of simulator software. My capstone group has identified this as a key factor in the development of our own simulator. Based on the feedback of our potential customers, one of the primary goals of our software team is to minimize latency between user input and the graphical response. This will involve utilizing our core software, Robot Operating System (ROS), to interface our more specialized programs. Among these are Gazebo, the virtual environment generator; and OpenDS, our physics simulation program. ROS essentially receives the outputs of these two programs and merges them to render the complete virtual environment. Additionally, it will output all the necessary data to the user display and physical actuators. Our target specification regarding latency between user input and graphical/haptic feedback is 10-15 milliseconds. Therefore, our goal is to create the most realistic virtual environment while maintaining this specified constraint on latency. There are a few methods by which we could achieve this. One involves removing OpenDS from our system architecture and utilizing Gazebo for both the physics and virtual environment generation. In this way, we would reduce some of the latency contributed from the cross-platform communication between the two separate programs. However, this would require more system memory to be allocated to Gazebo and could potentially increase its computational time. Our group intends to weigh the pros and cons of this approach.

The chassis of a driving simulator is made up of all the user controls and structural components. The physical sector's main purpose is to foster user immersion in the simulator experience (Meywerk, 2016). Components include controls such as the driving wheel, pedals, gear shift stick, etc. It is common for simulators to implement the actual hardware used in real cars to maximize immersion. The chassis would also have things such as the seat, dashboard, and visual display. All the user controls are interfaced with the simulation software using sensors, encoders, potentiometers, and more to translate the mechanical motion of each component into digital data to be processed in the virtual realm. Haptic and visual feedback are provided to the user by means of actuators, vibrational emitters, and electronic displays. As the car virtually encounters features such as bumps, hills, and turns, these elements would manipulate the driver's cabin to induce an appropriate sense of motion. Our team's goal for this section of our project is to prioritize user immersion. Specifically, we aim to acquire realistic hardware and controls used in actual cars, implement an enclosed cabin and surrounding display system, and integrate both automatic and manual transmission options for operating the simulated vehicle.

An autonomous driving simulator includes all of the aforementioned components, though the main differences exist in its software. Programs capable of simulating and integrating autonomous algorithms are required to achieve simulation of self-driving cars. Some of these include NVIDIA DriveSim, CARLA, SUMMIT, and more. As autonomous vehicle production has increased, there's been a substantially increasing trend in the development of software such as these to simulate their functionality. For our particular project, we aim to use RTMaps, a lower-level autonomous sensor simulation program. The previously mentioned software all include physics computations and environment generation, while RTMaps is solely for simulating self-driving vehicle sensors and testing autonomous algorithms. This will allow us more freedom to modify our software architecture in order to achieve our target specifications.

From a technical perspective, one of the main goals a self-driving car simulator seeks to accomplish is an accurate rendering of real-world scenarios. This is the core of the whole purpose of the software: to virtually insert an autonomous vehicle and its algorithms into a potential real-world scenario. The software manages this by generating realistic environments for the virtual vehicle to navigate and simulating the characteristics of the autonomous algorithms to a certain degree of precision. Different simulators achieve this in various ways. The CARLA driving simulator seeks to assess the performance of three different approaches in autonomous driving: a classic modular pipeline, an end-to-end model trained via imitation learning, and an end-to-end model trained via reinforcement learning (Dosovitskiy et al., 2017). In this case, users of this software must adapt their algorithms to one of those three methods of autonomous development. On the other hand, a software such as Nvidia DriveSim supports a larger-scale, more complex simulation of the self-driving car sensors (Mirocha, 2018). For our own simulator, we are intending to use a conglomerate of individual programs to allow for the most possible freedom in customizing the simulation environment. This is beneficial to developers of autonomous vehicles as they will not have to modify their algorithms to agree with the pre-structured format present in CARLA and Nvidia DriveSim.

An Investigation in the Process of Fostering Public Trust in Autonomous Vehicles

The implementation of autonomy into society has inevitably brought with it many ethical dilemmas. As human hands are removed from the wheels of cars, how can we as a society trust that a machine will make the right decision in a complex scenario? A study conducted by The Brookings Institution found that only 21% of participants were willing to ride in a self-driving car (West, 2019). There undoubtedly needs to be extensive testing of these systems in realistic scenarios to gauge their performance, though there are further dilemmas in doing so. It is very challenging to insert an autonomous car in a testable, realistic driving scenario without risking the safety of those involved. The way to get the best and most accurate understanding of a self-driving car's performance would be to put it in a real-life environment with actual humans and cars, though this puts at stake the safety of others in the event that the vehicle doesn't perform well. Waymo, an autonomous vehicle manufacturer, had 18 self-driving vehicle accidents in only 2 years of their development process (Wiggers, 2017). Many of these involved pedestrians, cyclists, or other drivers. It is also imperative that these tests can be highly repeatable, especially in the early stages of development. High repeatability means high cost of money, resources, and manpower. Clearly there is a need to assess the functionality of self-driving cars accurately and repetitively without risking the safety of others and expending excessive resources. Simulation technology is the best way to accomplish this. The safety of no pedestrian nor car operator is put at risk in simulation software. Repeatability in a simulated environment incurs virtually no additional expenses than what it cost to develop and initialize the program. In this way, manufacturers of autonomous vehicles can test their products without bearing the burden of financial and safety hazards, furthering the development of these machines so that one day they can safely navigate our roadways without inducing fear and distrust in the public.

While data from simulation trials can help legitimize the safety of self-driving cars from a technical standpoint, government involvement in autonomous development would also bring about more trust from the public. A 2018 report from the RAND corporation suggested that local DMVs play a larger role in requiring autonomous vehicle manufacturers to more transparently demonstrate their progress in the development process. The report also called for efforts towards data-sharing between different self-driving vehicle corporations and government (Fraade-Blanar, 2018). While this might hamper competitiveness between these companies, having access to larger pools of test trial data would allow for each manufacturer to address points of safety concern in their products with more awareness and understanding. Overall, the field of autonomous vehicle development is still very young, and while it is a great field of financial opportunity, it is imperative that the safety of these products is prioritized in order to procure public trust.

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