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Driving In the Virtual World

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ABSTRACT

This paper describes a highly configurable driving simulator developed at Iowa State University. The simulator includes real-time vehicle dynamics, motion and force feedback capabilities, and a virtual traffic environment complete with intelligent autonomous agents and a roadway/scenario editor. Explicit component interface definitions support a modular, building-block approach to system's design, operation, and maintenance. As a consequence, future enhancements of individual components can occur without requiring system-wide modifications.

KEYWORD

Driving Simulator, Virtual Reality, Traffic Simulation, Behavior Models

1. INTRODUCTION

The driving simulator, which originally grew out of the aviation community, first began to appear in primitive forms during the 1970's *(10)*. Its initial popularity is attributed to factors of safety, cost and efficiency. Additionally, simulators also provided a tightly controlled environment that allows repeatable results. The lack of realism, however, has limited widespread acceptance of driving simulators within the general research community. The recent resurgence of interest in diving simulators coincides with significant advances in enabling technologies (*e.g.*, computing, graphics, projection and actuation) that are promising quantum improvements in fidelity.

Typically, driving simulators consist of some (or all) of the following components: real-time vehicle dynamics simulation; motion and force feedback; high resolution video and audio; intelligent agents; realistic scenarios; a correlated database; and data distribution facilities. These components are strongly interconnected and must operate in seamless synchronicity. However, they are distinct subsystems with unique performance specifications and implementation requirements.

The systems challenge is to provide seamless integration while preserving a clean separation among distinct functional subgroups. This delineation promotes a modular design and software interchangeability. In turn, this will allow incremental improvements to the simulator without requiring modifications of other components.

The results described herein came out of an effort at Iowa State University (ISU) to develop a "low cost", actuated-base simulator. It consists of a set of completely self-contained components and can be operated in a variety of configurations. Specifically, the paper is organized as follows: a short overview of the system architecture is provided in section 2; section 3 describes the vehicle dynamics; section 4 describes the motion and force feedback subsystems; section 5 details the traffic simulation and virtual environment; networking is described in section 6. Conclusions follow.

2. SYSTEM CONFIGURATION

The basic simulator architecture is shown in Figure 1 below. The solid blocks represent major subsystems that have explicit interface definitions (*e.g.*, API), while the arrows represent dependencies. The major implication of this figure is that the function of each block is completely isolated from the implementation. *E.g.*, each block represents a particular function (necessary); it matters not how the function is implemented (sufficient). Thus, an implementation may be changed/modified/replaced with minimal disruption to the system.

The dependencies imply that the removal of a block (function) will affect only the behavior of objects downstream. For instance, the removal of the washout filter block will disable only the motion feedback; video feedback will not be affected.

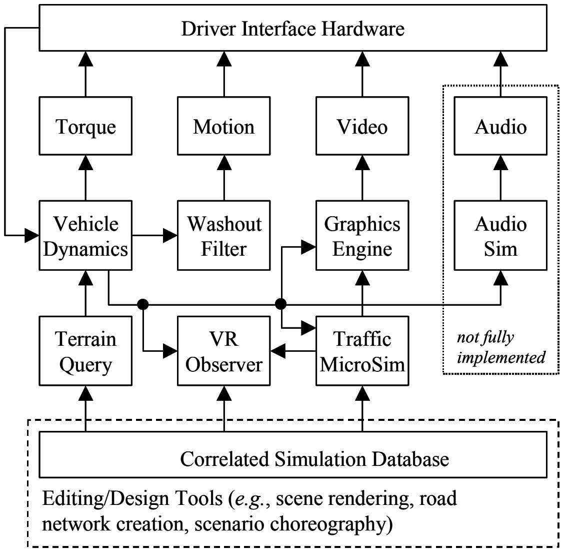

Figure 1. Driving Simulator System architecture.

The processing load is distributed among several computers. A Pentium II PC (400 MHz) running the QNX real-time operating system is charged with handling the time- and safety-critical decision-making tasks. A bank of analog servo control cards is used to control the motion base actuators. The audio, video and other non-time critical tasks are managed by an ultra high performance Silicon Graphics (SGI) supercomputer. This approach fully exploits the unique performance capabilities of the different computing systems.

The i86-based PC is a relatively cheap commercial off-the shelf (COTS) platform that is easily upgradeable and widely supported. The QNX operating system is a true real-time OS for PC's. It supports multi-threaded operations and provides priority-driven preemptive scheduling and fast context switching. Users can set task priorities. Other advantages include a very small microkernel, stability, and (albeit limited) 3rd-party support.

This makes the QNX PC ideal for housing the vehicle and actuator dynamics, washout filter, and watchdogs and fault detection schemes.

The SGI platform was chosen as the graphics engine due to its unique ability to seamlessly blend and synchronize multiple parallel scenes. The video is composed of 8 scenes simultaneously projected onto a 4-sided environment. Each wall contains 2 images to provide the user with a stereoscopic (3-D) view of the world.

3. REAL TIME VEHICLE DYNAMICS

Real time vehicle simulation is a key element in driver simulators. A common result of poor dynamics representation is the feeling of driving on ice. Elements of the vehicle dynamics models include tires, powertrain, suspension, and engine descriptions (Figure 2). Our efforts in this regard have focused on achieving the optimal level of modeling fidelity/complexity, within stringent computational limitations imposed by the time determinism requirement.

The resulting vehicle model consists of 25 degrees of freedom (DOF): 2 engine, 4 sprung mass, 3 front unsprung mass, 3 rear unsprung mass, 4 wheel rotational inertia, 1 wheel inertia about steer axis, and 8 for tire slip. The transmission is modeled as nonlinear algebraic relationship between the torque and speed differential across the torque converter.

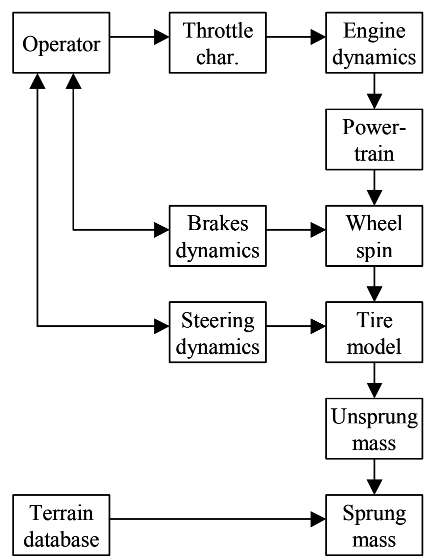

Figure 2. Vehicle dynamics subsystem.

The introduction of the 8 tire slip DOF's follows Bernard and Clover's extended tire model formulation *(6)*. Their approach solves the so-called "stopping-on-a-hill" problem, which is critical in vehicle simulation applications. The cost comes as additional first-order dynamics for the lateral and longitudinal slips at each tire.

The dynamics of the ISU simulator are updated at 200 Hz, which is the commonly accepted value for passenger vehicle models *(1)*. However, the simulator is capable of integrating the dynamics at 500 Hz. As suggested by *(10)*, the Adams integration method was selected for increased accuracy and simplified calculations.

4. MOTION AND FORCE FEEDBACK

Driver behavior research using fixed-base driving simulators have revealed limitations due to the driver's reliance on motion and haptics cues *(1)*. The limitations typically manifest themselves in motion sickness or unrealistic driver behavior.

The ISU simulator can manufacture low frequency, small acceleration cues with a compact electromechanical 6 DOF system from Sarnicola Simulation Systems. The vehicle dynamics are "washed out" using the classical algorithms of Grant and Reid *(17)*.

Force feedback is provided by DC servo motors attached to the steering and brakes. The steering realigning torque is computed as a function of vehicle velocity, steering angle and terrain properties. The formulation follows Howe et al. *(15)*.

5. VIRTUAL TRAFFIC ENVIRONMENT

Arguably, visual cues are the most important element of a successful driving simulator because it impacts driver response at all levels, *i.e.*, strategic, tactical and control. While the importance of realistic and high-resolution scenes is clear, the need for realism in the surrounding traffic has often been neglected in past efforts.

In contrast, the work at ISU focuses specifically on traffic behavior at vehicle-level granularity. Each simulated agent is capable of charting its path and making tactical decisions (*i.e.*, following distance, lane change) based upon the behavior of the human subject and other simulated agents.

The simulated agents and human subject interact in a 3-D virtual environment that also includes a terrain database, traffic management system and scripted scenarios. These are described in greater detail in the following.

Terrain Database

The terrain database is divided into the road network and the off-road section. By default, the simulation assumes that every simulated vehicle remains on-road. Therefore, terrain queries for each simulated vehicle can be restricted to the road network. This saves considerable time and effort due to the sheer number of simulated vehicles. The human driver, by contrast, is allowed to leave the road and will need to query both the on-road and off-road sections.

A provided road network editor can create the road network and necessary correlation data. It specifies the network as a collection of links and junctions *(20)*. The designer can specify engineering parameters, such as grade, curvature, and bank angles. Figures 3 and 4 provide examples of two views of the database created by the editor.

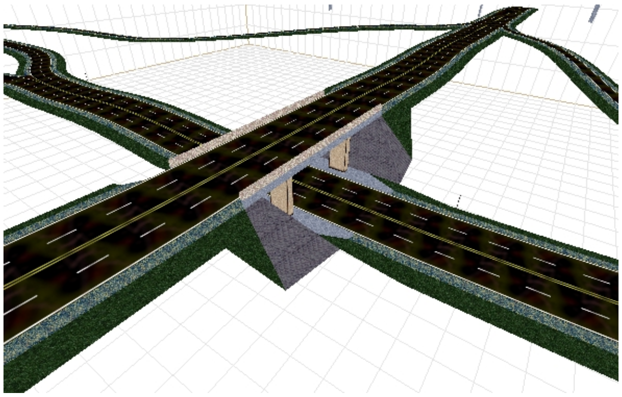

Figure 3. The road database in simulation mode.

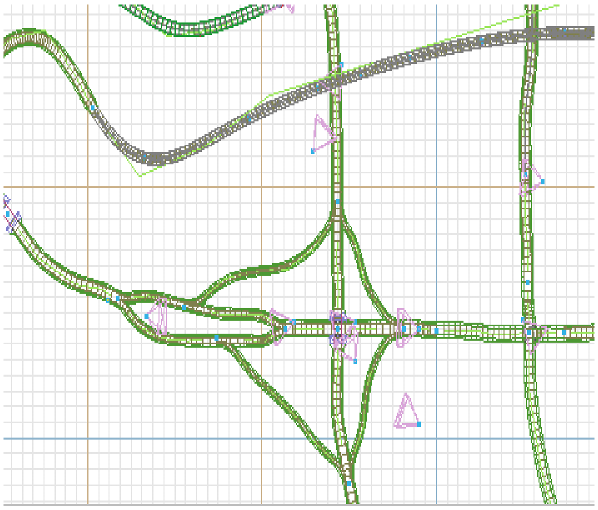

Figure 4. The road database in editor mode.

Traffic Management System

Traffic management system includes traffic lights and traffic signs. Traffic signs are invariant, while traffic lights need to be updated at each time step. To add to the complexity, different light systems are required at different road junctions, *e.g.*, 4-lane boulevards are different than 2-lane rural intersections.

With regard to the ISU simulator, the traffic light system at each node is selected from a control table of predefined classes at the time of network creation. The classes defines distinct types with dynamic properties that can vary with traffic density and time-of-day. The current implementation is simplistic, but can be easily upgradeable to a more sophisticated system in future developments.

Intelligent Agents and Scenarios

Virtual traffic environments are difficult to model for a variety of reasons, including computation complexity, need for artificially intelligent agents and correlated databases, and lack of real-world modeling data. These issues are specifically addressed in the ISU effort.

As previously stated, the road database is decomposed of links and junctions. Another necessary description of road database is the lane. Each simulating car would follow these lanes in the database and decide its path based on lane's connection. From the road database, each simulating car knows its current lane and information about this lane, like lane speed limit. The information about branch in and branch out in the lane is also needed. For overtaking, lanes near the lane are also available in the database. Lanes are the logical database for simulation and constitute the road network in the simulation. This connection network reduces the cost of all processes of navigation through the database (location, motion, and search) *(16)*.

Database not only includes static database, like road database, but it also includes dynamic database. Each car's information is a kind of dynamic database in the simulation. Every vehicle in the simulation must get its surrounding environment information including information of other vehicles near it. Obviously, it is not efficient to check every vehicle's position to find if it is nearby. In this study, each vehicle is assigned an allocation based on its relative position in its current lane. When the vehicle searches other vehicle around it, it only searches along its current lane and the lane at the side if necessary. This approach increases the efficiency of searching tremendously. Though the more environment information can be got, the better it seems for the whole simulation, the cost of calibration would be one of factors that is needed to consider. In a virtual traffic environment, hundreds of cars are running inside. Each of them has to finish updating its status in a frame (30 frames/sec). Even with the powerful processors, it may be not possible to handle such complicated simulation. To reduce unnecessary information from environment will improve the performance of the simulation.

Driver behavior study is to construct driver's model to simulate driver's behavior. The typical model distinguishes between four driving situations, in which drivers behave in a significantly different way *(12)*. In this research, four basic driver behavior models as follows are used in the simulation: uninfluenced driving; lane changing; breaking to avoid an obstacle or accident; following. One problem in studying driver behavior models is the lack of real world data. Fortunately, some experiments have been set up to get the driver behavior using radar to track vehicle distance and velocity. The real world data has been collected by a radar-tracking device and been used to construct driver behavior models. The stratergy control level of driver behavior has been studied, and the fuzzy and dynamic path-planner has been implemented into traffic simulation.

Since the virtual environment varies with time, the control for cars cannot be static. The simplest artificial intelligence for a car agent is to decide what it should do with a set of condition-action rules. This is called a reflex agent *(18)*. In this research, the reflex agent with internal state has been implemented into the simulation. A goal-based agent model and utility-based agent model are highly desired for intelligent agents and scenarios.

3D Graphics

A high resolution graphics will make the virtual environment more realistic. Graphics database is different with the simulation database although graphics database is based on the simulation database. Graphics database is unlimited and has a lot of additional objects not including in simulation database. Figure 5 shows a graphics database for the simulation. The simulation database only includes road database and traffic light and signs information.

But in graphics database, a lot of buildings and mountains have been added.

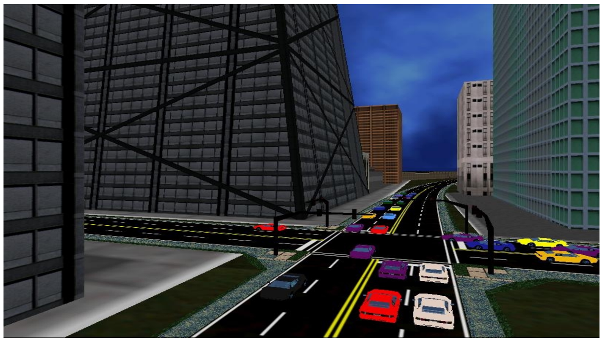

Figure 5. Graphics database example.

In the simulation, the graphics is rendered by Performer in SGI. The database for the simulation has been converted to performer format and edited. Multigen is used to created impressive graphics effects based on the database has been preprocessed.

6. NETWORKING

Virtual reality system has more extensive applications with the network supporting. Two groups can collaborate and communicate through the network while watching the same virtual objects. It makes possible to solve problems on line and saves a lot of money on travelling. The network in driver simulators also has an important role. The multiple observers can sit outside the driver simulator, even in remote sides, and observe the behavior and the whole traffic simulation.

In the application of network communication, a set of simulation status data has to be sent to other sites though all the sites have the same database. Considering the limitation of network rate, the data can not be so large. Therefore, at each site only the local data, i.e. what the observer or driver only can see, will be passed and a data compression technology has been used to reduce the data size. In real application, the C6, the observer's site, will update the whole simulation and pass the simulation data to the C2, the driver's site at each frame.

7. CONCLUSIONS AND FURTHER WORK

The driving simulator development at Iowa State University combines force/motion feedback with rich graphics in a realistic, dynamic traffic environment. The modular design approach is taken with an eye towards scalability and upgradeability with minimal disruption of the existing system.

Possible development directions include: integrating commercially available vehicle models for a greater variety of vehicles; distributing the traffic simulation over multiple PC's to increase simulation population size; and importing existing digital maps into the road network editor.

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