Virtual Driving and Eco-Simulation

VR City Modeling, Drive Simulation, and Ecological Habits

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Abstract

This paper introduces a VR city model developed for research in driving simulation, driver behavior, and vehicle emissions. The project is a part of an interdisciplinary multi-year academic research grant at Arizona State University. First, the outline of the research is explained. The methods of VR city modeling are then introduced. The modeling process of creating road and intersection networks and traffic flow is explained. The system integration with a PC, modeling and VR software, and a Drive Simulator is illustrated. A research study of driver behavior and vehicle emissions is detailed. Next, a case study linking research in ecological driving with a simulator and Japan's National Agency for Automotive Safety & Victims' Aid is examined. Lastly, computational tools to extract driving behavior data and future endeavors are discussed.

1. INTRODUCTION

Virtual Reality (VR) as it pertains to this study is a simulation of a specific environment, real world or fantasy. It enables an interactive experience with computer generated 3D models in a particular situation or scene. Virtual 3D cities have been recently available to the roughly 1.5 billion internet users across the world free of charge (www.internetworldstats.com). Two of these programs include Google Earth and Microsoft Virtual Earth [Google 2009], [Microsoft 2009]. Both programs allow users to navigate the globe and immerse themselves in 3D terrain and virtual city environments. On a professional and academic level, these VR programs are vital to the fields of architecture, urban planning, and geography. 3D visualization is an integral part of the workflow and decision making process in these disciplines.

A drive simulator is a hardware tool that can be used for entertainment, training, education, or research purposes. It consists of a vehicle interior, with seat, steering wheel, brake and accelerator pedals. A screen mounted atop the dashboard shows an out-the-windshield view of the drivable VR scene. It is an immersive environment with realistic driving conditions and controls as well as vehicle sounds. Drive simulators can monitor driver behaviors and train drivers to operate different kinds of vehicles in a safe VR environment. For instance, Arizona Department of Transportation uses a simulator to train drivers of large snow plow trucks. Since it only snows two months a year and the job is hazardous, simulator training helps drivers to be better prepared for the winter season [Kihl et al. 2006]. Using additional hardware and software, it is also possible to track a user's head and eye position for studies on fatigue, inattention, and lane changing habits [Ji and Yang 2002].

This paper presents the relatively new concept of conducting research using a driving simulator in conjunction with a realistic VR model and road network of an actual city (Phoenix, Arizona). The city and road network were created using multiple 3D modeling packages, as well as an off-the-shelf driving simulation package. The resulting VR city environment contains traffic simulation capabilities that emulate reality as closely as possible. Computational tools were developed that allow for the extraction of driving behavior data from the simulation for analysis and application on several other research endeavors.

2. BACKGROUND

A VR city model of Phoenix, Arizona was created as part of the Digital Phoenix project. This grant project was collaboration between architecture, urban planning, design, and high speed computing at Arizona State University. The project's goal was to visualize the past, present and future of the core downtown area while creating a tool to better understand growth patterns, policy changes and urban

dynamics of the city of Phoenix and surrounding Maricopa County. A 3D model of the metropolitan area was a large part of this project. Urban planning and high speed computing used a software tool, UrbanSim, to run macro simulations of social, economic, and environmental scenarios. This data was integrated and visualized to better understand the impacts of policy choices of the growing urban area. The broader research objective of the project as a whole is to develop computational tools and digital contents to visualize and simulate several urban issues at a 3D immersive theater.

A VR city model of a one mile square of downtown Phoenix was created using a variety of off-the-shelf software packages. It included approximately 500 buildings quickly modeled and textured using photogrammetry. Approximately 70 roads, 200 intersections, and a section of the 1-10 (a major US Interstate that runs through the heart of downtown Phoenix) are also included in the model (*see Figure 1*). In addition to the existing buildings, many large-scale construction projects scheduled for completion by 2011 were created by hand using renders from several architecture and development firms.

Figure 1. Photo of I-10 traffic flow (top) and realistic VR simulation of I-10 traffic flow (bottom)

The VR Phoenix model was visualized in a traffic simulation and civil engineering software package called

UC-win/Road [Forum8 2009]. Popular in Asia, this software had never been used to simulate such an extensive area. A built-in function of the software is automatic traffic generation on a created road network. Each traffic element (cars, motorcycles, buses, and trucks) behaves as an intelligent agent, stopping at red signals and changing speed and lanes corresponding to the surrounding vehicles. These vehicles have the ability to be controlled by an exterior input device. A gaming pad, a gaming steering wheel, or a full-size driving simulator, for example, can be used to control any vehicle in the model for an in-car perspective.

The research donation of a driving simulator by Forum8 allowed the Digital Phoenix Development Team to explore real world traffic scenarios while driving through the city at various times of day. It also enabled software customization to extract driving behaviors from the simulator and the ability to calculate CO_2 emissions, gas consumption, and other statistics from each drive through the model.

3. METHODS
3.1. Creating the VR City Model

Three pieces of modeling/VR software were used in the creation of the virtual city environment: Nverse Photo, 3D Studio Max, and UC-win/Road. In order to save time in both modeling and texturing of buildings, photogrammetry was the chosen method. First, a pilot and photographer were hired to fly over the city of Phoenix at 6000 feet. The photographer was directed to take one photograph straight down, and four angled shots from north, south, east, and west.

The negatives from these pictures were scanned in at 2400dpi, resulting in each .tiff image being larger than a gigabyte. A Precision Lightworks product, Nverse Photo, was used for the rapid 3D modeling of the urban environment [PrecisionLightWorks 2009]. This is a plug-in for 3DS Max that utilizes photogrammetry for quick modeling and texturing. The five aerial images are imported into the software, and linked together by tagging the same reference points in multiple shots. Buildings are quickly and efficiently modeled through an extrusion and automatic texture wrapping process shown in Figure 2. This allows for an extensive urban area to be modeled in a fraction of the time it would take to do this manually. A two mile by one mile area of downtown Phoenix was modeled, including over 500 buildings in a two week period by two individuals. 3DS Max was used to hand model and texture future buildings.

Figure 2. Ground Plane and Building Geometry Modeled Using Nverse Photo

UC-win/Road is a VR environment that allows users to navigate in a 3D space. The software was developed as a traffic simulation and visualization tool for civil engineering. The first step in creating the virtual city environment is to import the ground texture maps. To achieve this, an orthorectified satellite image is tiled and mapped onto the ground plane of the VR space. Adobe Photoshop was used to tile this image. The second step is to import the hundreds of buildings created and textured by Nverse photo. They were exported out of 3dsMax in quadrants of 24 buildings. The final step is to place the quadrants on the correct location of the ground map. UC-win/Road has built in functions to move, scale, and rotate imported objects in 3D space, which makes it easy to line up the quadrants properly (shown in Figure 3).

Figure 3. Buildings Imported into VR Environment (UC-Win/road)

3.2. Road Network Creation and Traffic Controls

UC-win/Road has an intuitive function to create road networks and automatically generate intersections. Once a road network is created, the software will generate 3D modeled traffic on the roads. The traffic will respond to traffic signals, road hazards, and other cars as it progresses through the VR environment.

In a 2D overhead view, the satellite ground map is used as a reference. Vector lines are traced over the satellite image in the approximate location of the roads. Each road can be edited to change the number of lanes, road texture, size of the sidewalk, cutting, banking, and road height. Where these lines cross, default intersections are automatically generated.

Once created, the intersection has many editable features. Lines can be added to the texture to represent stop lines and crosswalks. The intersection can identify when a 3D model of a traffic light has been placed in its vicinity, and will control the light accordingly. The timing of the lights and the signal phases can all be manually set. Drive paths of vehicles through the intersections as well as stopping points are also fully controllable.

Once back in the 3D view, the software will generate fully functional roads with textures. The software comes built in with a vehicle library including many varieties of cars, busses, trucks, motorcycles. The amount of vehicles per hour can be set for the start and end of each road in the model. At the click of a button, traffic is simulated and will drive throughout the road network in the model. This feature, coupled with the importing of 3D building data, creates a lifelike virtual urban environment. By ctrl+alt clicking any vehicle on any road, the user is given an in-car perspective of the 3D scene (see Figure 4). If a driving simulator or gaming wheel is attached to the PC, the user can actually drive the vehicle around the model.

Figure 4. In-Car Perspective While Driving Through the City

3.3. System Integration

Because of the vast amount of texture data associated with the VR city model, a high-performance PC is required to run it smoothly. The PC currently running the model and simulator has dual Xeon processors, 4 GB ram, an Nvidia Quadro fx4500 video card (512 MB dedicated memory), and operates on the Windows XP platform.

The drive simulator connects to the PC with two USB cables for data transfer. The 45" LCD display connects to

the computer with a 30ft VGA cable. The drive simulator has built in 5.1 surround sound speakers, with a subwoofer located under the seat to feel vibration. An external Creative soundcard also connects to the PC via USB 2.0, and to the simulator with three 3.5mm jack speaker cables. The simulator components and the speaker amplifier plug into a standard outlet with two universal PC power cables.

Once both the computer and the drive simulator are powered up, UC-win/Road is opened. This connects the two devices, and the simulator turns the wheel automatically to calibrate it. The user sits in the driver's seat. Buttons on the dashboard let a user scroll through options for driving. A predesigned scenario can be run with constraints to a given area and vehicle, or the user can freely drive on any road with any vehicle. Once the selection is made, a first person view of the roadway appears on the LCD screen. The user must start the vehicle with the key by turning the ignition. The user then depresses the brake pedal and puts the vehicle in 'drive' using the gear shift.

Once in drive, the vehicle performs true to life. The simulator is built with the seat, pedals, and steering column directly out of a Hyundai so it looks, feels, and responds like a real car (see Figure 5). The software still has complete modeling and editing functionality using mouse and keyboard even while connected to the simulator.

Figure 5. Drive Simulator in Use

3.4. Implementation of Eco-Drive

UC-win/Road offers several functions to extract driving data. One such function is the Eco-Drive plug-in. Although this plug in is still under development, it provides an accurate result based on a driver's habits while using the simulator. This plug-in is based on a carbon dioxide emission model of an average gasoline powered sedan. The software calculates fuel consumption and carbon footprint using a formula based on the results of a driving log. According to the research by Oguchi, the CO_2 emission amount can be estimated using the following formula:

$$E = K_c \left(0.3T + 0.028D + 0.056 \sum_K \delta_k (v_k^2 - v_{k-1}^2)\right)$$

E is the CO_2 amount (kg-c), T is the traveling time, D is the travel distance (meters), K is the number of speed measure points, δk is the speed incremental value (1 or 0), and vk is the speed (m/sec) at the point k (Oguchi 2002). Figure 6 shows the CO_2 calculation panel (the Eco-Drive plug in results).
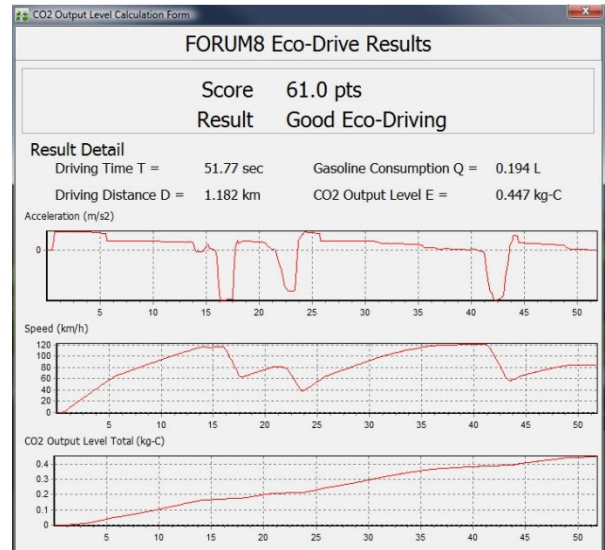

Figure 6. Eco-Drive Results Screenshot

As seen in Figure 6, the Eco-Drive Results chart is shown on the screen after a driver completes a designated scenario. This chart shows a main score (from 1 to 100), and also a result based on this score. The chart also shows readouts of the driving time, distance traveled, gasoline consumption, and CO_2 output level. Three graphs are also shown (acceleration/time, speed/time, and CO_2 output/time).

The main readout, the Eco-drive score, is calculated using the following formula:

Score = MIN [(Distance(km)/Fuel (L)) : 10] *10

Fuel consumption is determined by the distance that can be driven on one liter of gasoline. Metric measurements are used as this software is developed out of Tokyo, Japan. Eco points will be high if the extent of the consumption of gas is low. The scale of the eco score awards drivers with a low fuel consumption. 10 km/L will equal the highest rating of 100 eco points. This score is calculated by dividing the distance by fuel consumed, and multiplying by 10. The result shown is based on the score, and can be Poor Eco

Driving (1-49pts), Good Eco Driving (50 to 79pts), or Excellent Eco Driving (80-100pts).

Similar research has been done using VR models and drive simulators to measure fuel efficiency. One study used a prototype fuel efficiency support tool, which advised participants on how to change their behavior to decrease fuel consumption as they drove in the simulator (van der Voort, Dougherty, and van Maarseveen, 2000). Simax, a company based in Spain, produces a hardware/software solution to test ecological driving. This product enables a user to drive through a generic simulated urban environment, testing for fuel consumption, co2 emissions, car performance, and driver behavior (Simax, 2009).

The digital Phoenix eco-drive study is unique in that the 3d VD urban environment is very similar to the real driving conditions in downtown Phoenix. A section of a major interstate, as well as a square mile of inner city roads are provided to drive through. The NASVA Driving Behavior Assessment also used a 3D scene based on a real world environment in Tokyo, Japan. The goal was to make the VR environment as realistic as possible. This was important in making the simulations more accurate to an area the users had driven in the past.

4. CASE STUDIES
4.1. Digital Phoenix Eco-Drive Testing

The Eco-Drive plug-in was developed in spring of 2009, and the Digital Phoenix urban model was used as a beta test. This model was chosen because of the highly detailed road network and realistic downtown driving environment. It was important to replicate a situation where a driver would be forced to switch between the gas and brake pedals extensively in a relatively short distance. Realistic city driving would also require many other cars on the roadway to incur frequent starts, stops, and distractions.

A scenario was developed to drive down a mile segment of Jefferson St. through the core of downtown Phoenix. This scenario starts the driver in a mid-sized sedan. The driver has to navigate down the road, with traffic volume set at 5000 cars per hour, and follow all traffic signals. The traffic amount is meant to simulate mid-afternoon weekend flow. There are twelve traffic lights that must be navigated through before the scenario ends and the Eco-Drive results window is automatically shown on screen.

In this initial beta testing, three drivers ran through the scenario a total of twenty times each. The purpose of this study was to see if the Eco-Drive results were valid and repeatable. The first driver was instructed to drive the designated course normally, making sure to avoid other traffic and stop at all the signals. The second driver was given the same instructions about traffic and signals, but told to get to the end of the course as quickly as possible. He had to stay under 50 mph while doing so. The third driver

was specifically told to be extremely cautious with gas and brake pressure in order to reduce carbon emissions.

As seen in Table 1, the results of the Eco-Drive plug-in reflected the driving behavior of each tester. The first driver, only instructed to obey traffic laws, had a mean score of 66.4. Most of his results were in the range of "good eco-driver" (50-79 eco points). The second driver was told to get to the end as fast as he could while still obeying signals and staying under 50 mph. Because of these restrictions, his use of the gas and brake pedals was hard and jerky. His scores reflected this aggressive style of driving. All 20 of his scores fell into the "poor eco driver" category (0-49 eco-points). Driver 3 was instructed to drive gently as this would impact his overall CO2 emissions. All but three of his scores were in the "excellent eco-driver" range (80-100 eco-points). His scores reflected the informative nature of the concept of eco-driving. He was made aware of carbon footprint impact by better gas and braking habits, and the results of the plug-in indicated improved scores over the other two drivers.

	Driver 1	Driver 2	Driver 3
Min	44.1	18.0	72.1
Mean	66.4	31.8	85.8
Max	78.7	41.2	99.9

Table 1. Eco-Score Results of Beta Test

Beta testing of the Eco-Drive plug-in for UC-win/Road was important in the development of this tool. A drive simulator paired with a realistic downtown VR model provided a platform and an environment to further research on informing drivers of bad ecological habits.

4.2. NASVA Driver Behavior Assessment

The same technology and methods used to create the Digital Phoenix model and Eco-Drive (outlined in section 3) were utilized for Japan's National Agency for Automotive Safety and Victim's Aid (NASVA) in creating the NASVA NET system, a VR driver behavior assessment course taken online (NASVA, 2009). This study was done independently of the Digital Phoenix Eco-drive case study, but used the same software platform. Prior to adopting a VR platform for assessing driver safety, NASVA required participants to visit a local office for a traditional pen and paper exam. The nature of assessing driver behavior with this method was inherently flawed, as NASVA associates were unable to determine if a poor exam score actually translated to unsafe driving practices.

Using UC-win/Road, an interactive driver behavior course was developed that grades participants on defensive, hasty, considerate, and eco-driving behaviors. Every action the driver performs throughout the simulation is recorded

and analyzed so that appropriate strategies can be suggested for safer driving. The VR assessment provides valuable information that the previous pen and paper exam could not illustrate. The simulation can also be taken either online or at a NASVA office with a driving simulator, gaming controller, or gaming steering wheel (Figure 7).

Figure 7. A Gaming Wheel Can Be Used With the VR System.

The NASVA simulation uses a customized version of UC-win/Road to calculate a participant's safety score. The driver is taken through a series of courses that explore different driving environments: expressways, shopping areas, tollgates, pedestrian crossings, and other potentially hazardous environments (see Figure 8). Following the course, participants receive an aptitude diagnostic sheet based on the data collected from the simulations. If the test is taken at a NASVA branch, guidance is given to the driver individually or in a group.

Figure 8. Drivers navigate through common road environments in NASVA NET simulations

After integrating VR simulations into their driving assessment program, NASVA has experienced several positive outcomes. 1) Time and travel costs can be saved because the test is available 24 hours a day online. 2)

Driving characteristics can be analyzed more concretely than with the previous testing method. 3) The integration of Eco-Drive promotes fuel economy in addition to driver safety. 4) Lastly, the new technology and streamlined assessment process has had positive effects on customer service and public relations for NASVA.

For future development of the NASVA NET system, NASVA hopes to integrate more advanced 3D imagery to heighten the realism of simulated driving in hazardous conditions. Further development of UC-win/Road and Eco-Drive will also allow more detailed information to be collected from drivers using the system. Finally, hardware integration with eye-tracking technology will allow greater analysis of driver distraction and attentiveness.

5. CONCLUSION AND FUTURE WORK

This paper introduced a VR city model developed for driving simulation. The VR model covered a one mile by two mile area of downtown Phoenix with all buildings, all intersections with controllable traffic signals, and all streets with the exact lane conditions. The process of making buildings, street networks, and traffic data was described. By using the VR city model and plug-in tool, commute times in different traffic conditions and Eco-Drive results were analyzed.

A future project is to develop a more flexible system to extract specific driving data in VR environments using the drive simulator. For example, 1) the evaluation system of good driving, safe driving, or eco-friendly driving; 2) a cognitive system to analyze driver vision by integrating with eye tracking systems; and 3) interactive traffic control systems to change the traffic amount interactively without restarting.

VR simulations and computer models have been created to visualize design output for only the last decade. Some projects use these kinds of models to show the results of scientific analysis such as energy effect, aerodynamics, and carbon footprint information. However, the human cognitive aspect has not yet been analyzed well using this framework. A future goal is to innovate by implementing the VR framework outlined in this paper to bridge the gap between the cognitive sciences and the design field.

Based on successes with NASVA and the Eco-Drive system, an "Eco Driver Awareness Program" is currently being developed to educate drivers on their current habits and their impact on CO_2 emissions and fuel consumption. Although the relationship between cautious driving and fuel conservation have been well documented, the goal of this program is to provide drivers with a more tangible score that they can work to reduce in their daily habits.

Digital Phoenix project at Herberger Center for Design Research at the College of Design, Arizona State University.

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