DEVELOPMENT OF REALISTIC MICROSCOPIC TERRAIN SURFACES AND FEATURES FOR DRIVING SIMULATION ENVIRONMENTS

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Abstract

The successful immersion of drivers within a simulation scenario is dependant upon a number of factors. One significant factor is the visual scene (database) constructed to represent the simulation environment. Vehicle motion and behavior cues, surface materials and simulated environmental conditions are enhanced through the use of correlated terrain and features constructed using development techniques that focus upon the driver and roadway at sub-meter resolutions. Successful implementation of these microscopic elements requires a large degree of realistic visual representation and correspondingly high degree of correlation. This paper presents methods and tools in use at the National Advanced Driving Simulator for rapid database development that permit the creation of realistic, detailed and interactive simulation environments by non-experts using familiar drag and drop interfaces. Addressing qualitative issues within self-contained tile databases makes it possible to generate a large variety of environments in a timely and cost-effective manner. This paper presents some of the technical requirements that arise when building tiles, including high resolution road surface matching, complex terrain surfaces, feature concentration and connectivity. Examples are presented from ongoing development of geo-specific and generic research environments.
Section 1  Introduction

This paper introduces the National Advanced Driving Simulator (NADS) visual subsystem and some key support technologies and describes databasing goals, methods and techniques developed to support the NADS and its research goal of conducting safety-related transportation research by providing realistic immersive environments. Section two introduces the NADS visual subsystem hardware configuration. Section three describes the operational parameters of the database construction system and construction methods of generating geo-specific and general-purpose virtual environments, illustrated with examples from various project development efforts. Section four is a summary. Section five contains acknowledgements and references.

The NADS is designed to help researchers understand the complex driver-vehicle-environment relationships. A suite of user-friendly tools allows researchers to develop experiments quickly and easily, exercising a high degree of control over every aspect of their simulators virtual environment. An essential component to the control over the virtual environment and a tool for rapid database development is the Tile Mosaic Tool (TMT). The TMT provides a graphical user interface to the tile library and generates data that produces the static portion of the synthetic environment. Tiles are discrete databases consisting of visual and correlated virtual databases. At present, the tile library contains over 63 different tiles, which depict urban, residential, commercial, highway and industrial environments. The tile library is expandable so long as construction constraints are followed to ensure compatibility with existing tiles. Tiles connect to each other using road and terrain profile definitions, ensuring surface continuity across different tile types. Roads are constructed according to the American Association of State Highway and Transportation Officials (AASHTO) standards and traffic control devices are constructed to conform to the Manual on Uniform Traffic Control Devices. A pool of database models provides the capability of populating the terrain database with scenario elements controllable during simulation. The Scenario Object Library is a graphical interface to this pool of dynamic models.

Section 2  The NADS facility

 Constructed to accommodate entire vehicles, the NADS cab enclosure is a 24’ projection dome. Mounted on a turntable, the dome is operational within a 66 x 66 foot motion envelope, illustrated in Figure 1.
Computer imagery is generated from an Evans & Sutherland Harmony™ image generator. The Harmony consists of an accelerated graphics engine (AG) and real-time (RT) rendering system. A typical Harmony configuration contains a Windows NT®, RT and AG engines (AGE). One RT and AG comprise a channel processor (CP) \(^7\). The NADS IG is a multiple CP system and contains 7 channel processors subchannelled for multiple video outputs. Six of these seven CPs drive two video outputs. The master CP drives three video outputs, and the remaining CPs synchronize to it. The Harmony system operates at an update rate of 60 Hz with a transport delay less than 50 ms \(^8\). The Harmony is capable of simulating a variety of visibility and illumination conditions, including precipitation, haze, continuous fog, patchy fog, smoke, glare, snow, and water covered surfaces \(^9\). The Harmony calculates non-linear image mapping to map the computed imagery onto the dome surface.

The NADS visual system consists of 15 Barco 2100 LCD projectors. There are five projectors for the rear channels; each has a field of view (FOV) that is 40° vertical by 31.8° horizontal with a 1.8° horizontal overlap for edge blending. The rear channels have a resolution of 640x480. There are seven forward channels, also with a FOV of 40° vertical by 31.8° horizontal with a 1.8° horizontal overlap for edge blending; these forward channels have a resolution of 1024x768. The center forward channel contains three high-resolution insets with the central area of interest directly forward of the driver. These inset channels each have a FOV that is 7.2° vertical by 9.6° horizontal with a 0.6° overlap for edge blending, with a resolution of 640x480, resulting in resolution within the AOI better than 1.1 arc minutes per optical line pair \(^10\). The high-resolution inset channels are positioned so that their top edge is 5.2° up from the drivers eye point center line which is located at 55 inches above the dome floor \(^11\). The projection surface has a contrast ratio not less than 25:1 within the AOI and a luminance of at least five (5) foot Lamberts (fL) \(^12\).

In addition to the primary NADS simulator there is a stationary simulator development module (SDM) simulator located on-site at NADS. This simulator utilizes a single channel processor Harmony with three video outputs. The SDM also uses three Barco 2100 LCD projectors to render a 40° vertical by 134.76° horizontal FOV \(^13\). The SDM channels have a resolution of 640x480.
Section 3  Database construction constraints

It is within this environment the simulator subject interacts with intelligent autonomous traffic while performing driving tasks. The 360° horizontal FOV requires development of visuals that provide sufficient complexity to support driving tasks while balancing system resources to avoid overload situations. This requirement presents configuration challenges for the database engineer, because there are very few limits imposed upon the way tiles are connected to create the environment. There is an additional requirement to provide sufficient extraneous elements, or clutter within the scene consistent with a real-world environment to reduce the impression of a sterile, computer-generated world. Terrain surface modulation, feature concentration and photo-derived texture provide visually compelling scenery, resulting in more sensory information available to the driver, enhancing their control of the simulated vehicle. Detail elements provide the driver with additional motion and speed cues as well as providing visual fill to prevent gaps in the environment.

Tile Development

Source Data

Data sources for tile development can be acquired from existing data and converted into real-time models through standard 3-D modeling software and commercially available 3-D file format translators. Tiles can be created through modifications to existing tiles, generated from specifications, or created from scratch. Constructing terrain surfaces from scratch is possible utilizing a variety of software. These programs generally use a grayscale image to create a height field, and various filter operations are then performed over the resulting surface. These techniques can produce reasonable terrain, but the resulting mesh typically contains far more geometry than can realistically be supported without generous use of LOD (see Figure 2).
Although tiles are constructed as self-contained and complete databases it is within their context as reusable, repeatable and associative library elements they provide the researcher with capabilities to generate complex databases. Tile compatibility is ensured through developmental constraints, including unitized dimensions, the definition of a common local origin and orientation, and considerations for tile edge blending.

Terrain

Generalized surface resolution devours precious simulation resources both in terms of general processing and specialized scenario requirements (reducing the amount of resources available for traffic for example). The ideal construction method focuses on the roadway as the primary construction factor. Topologies that describe surface variations consistent with the real world are better suited for use within the NADS simulation environment than those which do not.

We define these topologies as roadway focused terrain (RFT). Using RFT the terrain resolution can be focused where it counts, along the roadways or in regions that are visible from the road. Tile terrain consists of a modulating surface which either conforms to the road surface or provides additional relief in the form of hills and valleys. Terrain elevation data can be acquired through any standard format or created using standard construction techniques. The resulting surface is then reduced to the fewest possible number of polygons.

Terrain representation can also provide important motion cues through the surface texture. Typical methods of surface decoration utilize a bitmap pattern to imply generic surfaces. This method uses a small amount of texture memory while sacrificing scenic detail. It is possible to modify generic texture by introducing a high frequency noise pattern as a detail texture. This produces the appearance of greater terrain detail near the eyepoint, illustrated in Figure 3.

Figure 3. Generic pattern combined with detail image
However, terrain surface characteristics change at polygon edges of different surface types, making them hard edged and difficult to conceal. The use of a complex surface texture presents a surface that enhances elevation modulation at the cost of increased use of texture memory, as illustrated in Figure 4. This technique is most effective when the texture resolution approaches pixel resolution, providing greater perceived detail.

![Figure 4. Surface decoration comparison](image1)

**Features**

Terrain is decorated with cultural features such as buildings, individual trees, tree groves or forests. The placement of these cultural features plays a dual role by constricting the viewers FOV while describing the synthetic environment. Careful feature positioning can enhance the environment by providing higher scene density at little cost because it becomes possible to implement level of detail (LOD) using ranges shorter than might otherwise be necessary to prevent elements from popping into view, as illustrated in Figure 5. Repeating and layered features can be planted onto a terrain surface but they present more convincingly when additional cues are integrated, such as shading and topology changes that accommodate the feature.

![Figure 5. Roadway focused implementation of LOD](image2)
Features are constructed typically but within a uniform size constraint that provides a framework to ensure consistent feature sizing. Buildings are scaled such that their doorways are 6.5 feet tall and between 3 and 4 feet wide. Feature texture is created from photo-derived sources, commercial sources or digitized imagery to provide realistic surfaces. Consolidating feature texture within a single map facilitates texture memory management.

**Texture**

Without adequate reference material the database engineer must rely upon preconceived ideas. While this may suffice for very basic elements, good reference material is important to develop realistic environments (see Figure 6). This is especially important when developing texture, as generic patterns are typically unable to adequately represent surface details, particularly at sub-meter resolution.

![Figure 6. Feature generation without and with adequate reference material](image)

Site visit information is desirable for capturing high fidelity imagery; but it may also create new problems in correlating visual information, especially when constructing geo-specific databases. Database development for portions of the Aberdeen Proving Grounds involved the use of aerial photographs, site maps, video and more than 400 high-resolution images captured on-site. Developing appropriate correlation without survey data was a time-intensive process involving many reviews of video and cross-referencing stills, but resulted in reasonably realistic databases for the Munson, Perryman and H-field proving grounds, illustrated in Figure 7.
Roads

Road surfaces are primary tile elements. Roads are created at very high resolution using AASHTO standards in conjunction with tile constraints. NADS has the capability to generate roads of differing width, superelevation, surface characteristics and related features and signs. Road surfaces have been implemented as flat surfaces and feature typical elements such as shoulders and elevated curbs. Generic road surface characteristics include asphalt, concrete and tar/gravel implemented as both continuous and slabbled surfaces\textsuperscript{17}.

Correlated data

Virtual environment data is encoded within the visual database, which ensures a high degree of correlation. This data is extracted using off-line tools that generate the virtual environment\textsuperscript{18}.

Section 4 Summary

Road focused terrain, one of the key development concepts behind database development, pushes the realism envelope of typical database visuals. The RFT concept provides increased feature density within a concentrated region of interest. This has the effect of focusing feature population regions to areas nearest roads. Concentrating the features in such a way means potentially huge areas of the visual scene may be culled out entirely with little or no perceived loss of detail in world complexity, at the same time avoiding a 'corridor' or 'channel' look. With interest focused on a concentrated area it becomes instrumental to use the highest quality textures possible. Photo-derived textures coupled with the increased number of features near the driver offer a more 'natural' visual synthetic environment than can be achieved through generic image patterns.

Consistent construction methods have generated a library of database elements, reducing development time and lowering construction costs. These methods combined with the tools and baseline experimental databases available at NADS provide enormous flexibility in rapid database generation and scenario development.
Section 5  Acknowledgements and References

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