An Image Generator PC-cluster for a High Flexible Multi-simulator Configuration

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Abstract

In the last several years, PC-based real-time image generator (IG) technology has rapidly advanced on what was once the domain of high-cost specialized computer platforms. As processor speeds increased this market once dominated by million and multimillion dollar hardware-based solutions gave way to solutions revolving around commodity graphics chips enclosed in the PC-chassis. With these changes a new (and sometimes old) set of opportunities and challenges have presented themselves to system integrators and visual software specialists.

In 2003, the DaimlerChrysler (DCX) Driving Simulator Lab in Berlin began the process of upgrading most of its major subsystems. Included in the upgrade was the replacement of the IG. The IG upgrade included the requirement to simultaneously drive one of several simulators in a way that allowed for rapid reconfiguration depending on the daily operational needs of the laboratory. The implemented solution is now in place and consists of 18 PC-based IG channels which may be reconfigured to run multiple simulators or via “channel ganging” a single multi-channel driving simulator.

In addition to the requirement for rapid reconfiguration, a second requirement stipulated that the system was to rely on industry standards and COTS equipment in order to lower system maintenance costs. The basic software package and the visual database format conform to this requirement. The visual software that is specific to driving simulation, however, was developed by gForce Technologies. The software provides an identical interface to all DCX simulators regardless of the number of IG channels each system has been configured to utilize. A programmable Ethernet switch is used to partition the network of graphics PCs into a number of virtual sub-LANs, thereby isolating the real-time communications of the various IG subsystems. The Berlin installation currently has 8 projectors and 13 monitors to which arbitrary IG channels may be connected. The graphical output of all PCs is routed through a programmable video switch to the target display devices.

This paper describes the performance, configuration details and capabilities of this IG system architecture; it also describes some of the features that have been lost over the years as the industry has moved from expensive specialized solutions to COTS-style PC-based approaches.

The DaimlerChrysler Driving Simulator

The DaimlerChrysler Driving Simulator, located in Berlin, Germany, has been in use since 1982. Over the years several hundred experiments have been performed. The two major fields of research include vehicle development studies and experiments in the area of the human machine interface (HMI). More recently, with the continued expansion of in-vehicle entertainment and information systems driver distraction studies have become increasingly common.

History

During the time of operation two major system upgrades have taken place. The initial simulator had the following general characteristics:

- Six DOF hydraulic motion system. All computations were performed on two Gould computers with 4 MB of main memory.
- The image generation was performed by a six channel Evans&Sutherland CT5 Image Generator. This system provided 3500 polygons across the six channels with a resolution of 512x512 per channel. It did support flat shading and two - sometimes six - moving objects. It did not support textures.
- Specially designed CRT projectors were used to display a 180° by 30° field of view at 50 Hz.
- In order to include 300 MB of disk drive capacity, units the size of washing machines were required.

The first upgrade took place in 1993. The most dramatic feature enhancement was to place the 6 DOF motion base on top of a 6 meter rail system. Moved by a large hydraulic actuator, this enhancement added ± 2.3 meters of lateral motion. The spectrum and quality of vehicle development experiments was dramatically improved by this additional motion (e.g. both the realism of the overall driving experience as well as enabling new experiments related to handling.)

In addition to the improved lateral motion, the simulation computer was exchanged by a DEC-VAX with the VMS operating system. The Image Generator was upgraded to a 6 channel ESIG3000 system with 5 front channels displaying a 180° by 35° field of view and a rear channel with a 48° by 20° field of view (this was sufficient to cover most of the viewing area accommodated by passenger cars). The Image Generator included a proprietary interface and ran at a consistent 60 Hz update rate. The image was displayed with a new specially designed 6 channel CRT system with a resolution of 1024x1024.

Status after major upgrade 2004

In 2004 the second major upgrade was performed. The 20+ year old motion actuators have been replaced by identically sized hydrostatic actuators. The analog control system used for the motion was exchanged by a digital control system. This improvement has provided much smoother motion and better overall performance. The simulation computer (host system) has been replaced by a multi-processor Concurrent iHawk Intel based computer using their real-time RedHawk Linux operating system.

A new image generation system was also included in the upgrade. An Evans&Sutherland RenderBeast consisting of 18 simFUSION6500 machines has been installed. The visual application software has been created in close cooperation with our sister team at the Chrysler unit in Auburn Hills operated by gForce Technologies of Ann Arbor, Michigan. The visual databases have been created by gForce Technologies and by VIRES GmbH, a German based company. The Image Generator will be described in detail in the following sections.

After a careful comparison among the available projection technologies, a CRT system was selected again. This system creates a 230° by 45° degrees front field of view and a 58° by 28° rear field of view (passenger car). The right wing mirror has been replaced by a small LCD display. The projection uses commercial Barco 909 projectors with a special designed mounting on top of the simulator roof, creating a cross fire projection. The screen is a high gain screen, provided by Tech-Com International, Inc. During the planning phase the primarily intended digital projectors had been replaced by the analogous CRTs. The well known drawbacks of the CRT projectors, e.g. low brightness, high maintenance, and heavy weight have been accepted to get rid of the motion blur of digital projectors. Especially for driving dynamic experiments this smearing effect seemed to be unacceptable.

Outside view of the DaimlerChrysler Driving Simulator

Derivative Simulators

Within the DaimlerChrysler cooperation, especially in the areas of research and development, the need for simulators is growing. Several simulators now exist in the organization and all, with the exception of the Berlin simulator, are fixed base. A number of these systems have very specific purposes such as sound quality while others provide for general driving research applications.

None of these smaller simulators have the complexity of the simulator in Berlin. At the outset of the upgrade process it was a design assumption that we would employ as much COTS hardware and software as possible within the constraints of our functional requirements. The architecture has allowed these derivative systems to be fielded using identical hardware or to select less expensive components. The majority of these systems use single channel low cost Image Generators and less powerful simulation computers.

Expensive components such as the complex interface to the simulated cabin and the steering system are used in Berlin only. This is all consistent with the derivative simulators being used for specific tasks and limited experiments.

At the Driving Simulator in Berlin a new, more efficient concept of experiment preparation has been designed. The set-up time for a new experiment needed to be minimized in order to lower the overall operational costs for this relatively expensive system. To accommodate this need, at least two more simulators had to be implemented to aid in the preparation of experiments. Moreover, these simulators had to use identical software, but less expensive hardware. They are described later.

In summary, the aforementioned criteria define the requirements for the simulator upgrade:

- COTS hardware and software wherever possible.
- Allow the use of different quality levels of hardware.
- Software that runs on several platforms.

The Image Generator PC-cluster

The design goals of the updated visual system included the implementation of a system that was flexible; upgradeable through replacement; relatively inexpensive; and to the degree possible, based on commercially available off the shelf technology. Leading up to 2004, a number of PC-based Image Generators had appeared in the market and, therefore, during the evaluation phase these solutions were given special attention along with the more traditional solutions.

Based on our experience, the requirements for the replacement system included the following:

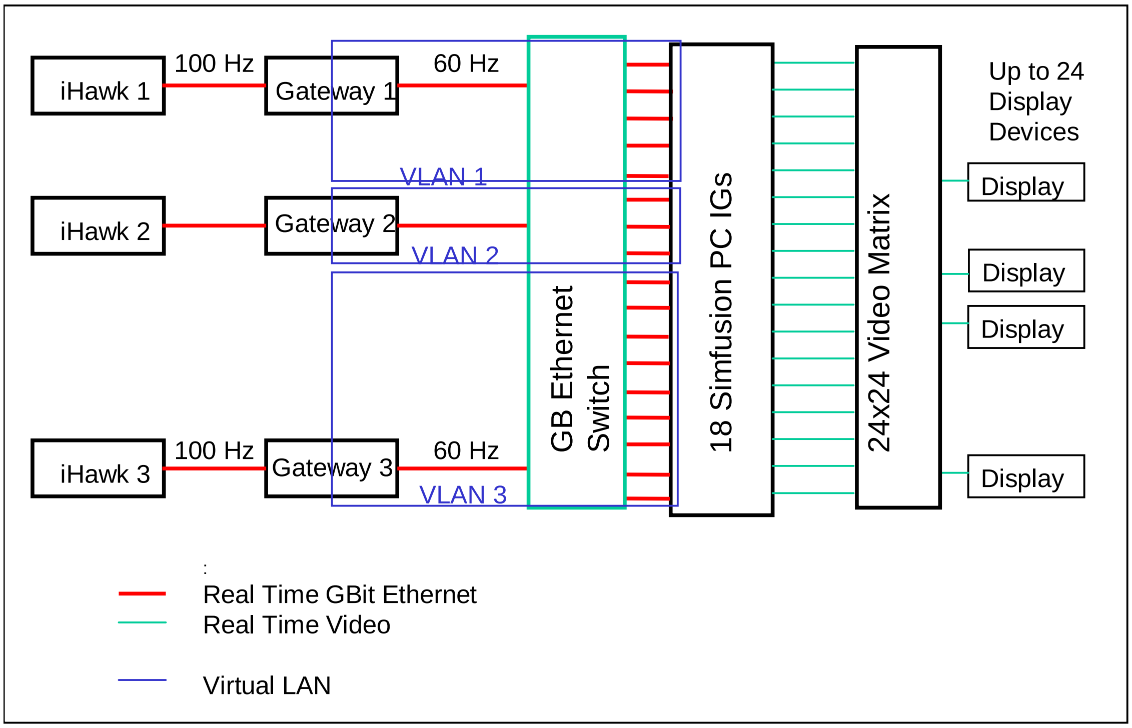
- Reconfigurable – The ability to assign visual "pipes" among the simulators located in the complex; Assign one "pipe" to multiple channels; Assign one "pipe" to one channel; Assign more than one "pipe" to one channel.
- Ease of Use – Single point of control; Drag & drop interface.
- Low Mean Time Between Repair – Minimized down times and repair without specialized skills.
- 60 Hz operation.
- Anti-aliasing (better than 4 subsamples on a rotated grid).
- Anisotropic filtering.
- Multi-texture.

- OpenGL or DirectX compliant.
- Multi-channel synchronization ("Gen-lock").

We were also interested in minimizing our software development costs and evaluated third-party interfaces to low level OpenGL/DirectX code.

Layout

The overall layout of the system has the following conceptual form:



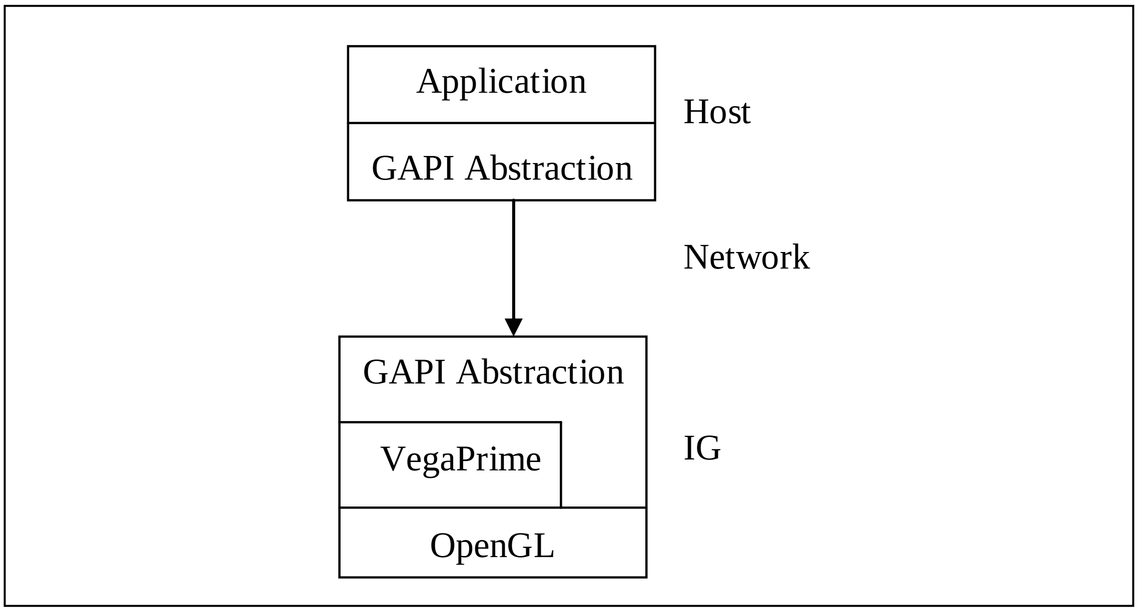
PC cluster layout

The selected IG hardware consists of 18 Simfusion 6500q from Evans & Sutherland. The host is capable of configuring the IG's such that their video output may be assigned in a variety of configurations via two GB Ethernet switches (one managed and one unmanaged.) Communication from the host to the IG's is provided by a QNX-based low-latency computer system called the "gateway." This intermediator allows for complete synchronization and transport delay corrected interpolation with the multiple IG channels.

An abstracted software layer (GAPI) was created between the host and the visual subsystem to allow the underlying visual software to be set in a replaceable modular package. This was done to minimize future upgrade costs. It consists of libraries running on the host computer and of libraries running at the visual system, including the gateway computer. The host side of the software creates the network communication that is interpreted by the application layer running on the IGs.

GAPI automatically initializes and configures the IG system and allows users to easily manipulate driving simulator experiments by including tailored API with functionality such as:

- Adding vehicles, bicycles, and pedestrians.
- Selecting the vehicle color.
- Selecting vehicle accessories such as luggage racks with or without luggage and bicycle racks with or without bicycles.
- Setting system wide or per-channel statistics.



Software layers

Experiences

The Berlin simulator is now in use for more than one year. The whole simulator environment is controlled via a graphical user interface (GUI). As there are several different software modules, each of them using many parameters, the GUI is very complex. Nevertheless the operation of the simulator got simpler with the GUI compared to the command line interface that had been in use before.

The clustering of the PC's creates some problems that don't exist on "old style" monolithic systems. The control software that comes with the machines helps a lot, but there are still some items to solve. The need for a gateway computer for the extrapolation and for the communication introduces additional latency. The transport delay from driver action to visible reaction on the screen is currently approx. 90msec. The Windows XP operating system has been adapted to support the 60Hz update rate, but the constant 60Hz update rate that had been achieved with the old Image Generator can't be guaranteed.

The complexity requires qualified operators. The ability to coherently configure the video matrix switch, the application software, the cluster control software, and the involved network switches needs some training and opens a wide field for wrong setups. Therefore the most used configurations have been fixed in different setup files. The operation is now controlled by a small GUI that controls the different setups.

The use of the commercial VegaPrime software creates as many problems as it solves. Some of the basic functionality does not work. Software plug-ins are pretty easy to install but don't always work correctly. The conflict between software synchronization that is needed by the plug-ins and the hardware synchronization that is needed to get 60Hz update rate is not yet solved.

The image quality of the new PC cluster graphical subsystems is now state of the art. The scene density is very high and the quality of the single objects is photorealistic. Tests with lower anti-aliasing settings proved that the chosen way to use special hardware is appropriate. Standard graphic boards do not yet create the quality that is needed for the huge field of view. The setup that is used most of the time uses 2 PCs for each projected image. The resolution of the image is 1600*1200 pixels. Each PC uses 4 ATI R360 chips, i.e. 8 ATI chips are used for every channel.

Highway scenario

The image that is presented to the driver has an outstanding quality. The CRT projectors create a very uniform image, even at the overlap areas. Due to the high gain screen the contrast is excellent and the brightness is acceptable.

Derivative simulators

There are currently five simulators operational in Berlin and three simulators at other DaimlerChrysler locations in Germany.

At the lowest end there are two scenario simulators installed in Berlin. These are equipped with a PC game steering wheel and use a standard office PC as Image Generator. They are used for the preparation of new experiments and for the test of new traffic environment scenarios.

A preparation simulator, located in the workshop of the simulator, allows the test of new cabins or new cabin hardware. Software in the loop components can tested here as well. This simulator is operated with a single channel Image Generator.

A development simulator is used to prepare experiments. The setup and tuning of new traffic environment scenarios, sometimes together with new vehicle components, uses most of the preparation time. The unpredictable behavior of "real" drivers – contrary to the simulator operators – creates a need for extensive testing. The development simulator is connected to one of the simulator cabins and uses a three channel visual system.

The fifth simulator is the "real" simulator with its 6 DOF motion system.

City scenario

One of the three "out of Berlin" simulators is a fixed base HMI research simulator. It uses a slightly modified real car cabin and a single channel visual system. It is used for driver distraction experiments and for ergonomic studies.

Another simulator is used in the field of vehicle sound development. It supports the online change of several vehicle sound components, allowing the subjective rating of different sound behaviors.

The third simulator uses a 180° field of view, operated by three graphic PCs. It is used for vehicle design studies in a very early vehicle development state. Several parts of new vehicles, i.e. a complete roof with a windshield, can be attached to a basic setup consisting of a seat, a steering wheel, and pedals.

These three simulators are maintained from Berlin and are operated locally. They share a low cost steering system. The easy exchange of software components like visual databases, vehicle dynamics, and complete experiment setups works very well.

Two more simulators exist in Auburn Hills. One is used for noise, vibration, harshness (NVH) studies, the other one is used for HMI research. These simulators are maintained and operated by gForce Technologies. They use the same visual software as the above described simulators. The unification of the whole simulation software is under development.

Conclusion

A new Image Generator system has been installed at the DaimlerChrysler Driving Simulator. The software concept makes it possible to operate simulators with hardware ranking from standard COTS PCs up to special graphic PC clusters, generating different levels of quality. The image quality achieved with the cluster is photorealistic. The high flexibility creates a complex setup, for further developments a simpler design would be preferable. Several simulators are operational. They all share identical software, including visual models, traffic scenarios and experiment setups.