Designing and Developing an Image Generator for the Operational Based Vision Assessment Simulator

John L. Archdeacon[1] and Nelson Iwai[2]
NASA Ames Research Center, Moffett Field, CA, 94035-1000 USA

Barbara T. Sweet[3]
NASA Ames Research Center, Moffett Field, CA, 94035-1000 USA

Many factors affect the suitability of an out-the-window simulator visual system. Contrast, brightness, resolution, field-of-view, update rate, scene content and a number of other criteria are common factors often used to define requirements for simulator visual systems. For the past several years, NASA has worked with the United States Air Force (USAF) on the Operational Based Vision Assessment Program (OBVA). The purpose of this program has been to provide the USAF School of Aerospace Medicine (USAFSAM) with a scientific testing laboratory to study human vision and testing standards in an operationally relevant environment (i.e., a research simulator). Requirements for the visual system include high luminance, a large field-of-view, a large color gamut capable of reproducing aviation red, green, and blue, a limited development budget, and a flexible design to support future technology insertion and upgrades. One of the more challenging requirements in designing the reconfigurable image generator was the resolution requirement – approximately 0.5 arc-minutes per pixel, roughly equivalent to 20/10 visual acuity. In addition to static resolution, dynamic resolution (i.e., the perceived resolution of moving imagery) was also investigated to determine how best to minimize motion artifacts in the visual system. In this paper, we will describe how the simulator specifications were developed in order to meet the vision research objectives of USAFSAM, the various design considerations, and the resulting architecture. In particular, we will discuss the image generator architecture and describe the latest performance results along with the unique challenges of developing a visual system that provides eye limited resolution.

I. Introduction

The work described here is part of the United States Air Force sponsored Operational Based Vision Assessment (OBVA) program which has been tasked with developing a high fidelity flight simulation laboratory to determine the relationship between human vision and performance in simulated but operationally relevant tasks. This paper describes the general design objectives and implementation characteristics of the image generator (IG) subsystem being developed by NASA at the Ames Research Center (ARC) for USAFSAM at Wright Patterson AFB (WPAFB). Although this paper is focused largely on the underlying system architecture for the visual system, it also briefly describes some of the issues addressed by the USAF and NASA team while designing the research simulator.

II. Background

A. Operational Vision

During the design phase for the OBVA simulator, Air Force aviators, members of U.S. Special Forces, flight surgeons, and ophthalmologists provided illuminating background for why the United States Air Force needs to study human vision in an operationally relevant environment with this simple but effective disclosure:

> ***"The ability to see is paramount in flight; none of the senses is more important. Whether it is an enemy target, friendly aircraft, aircraft environment, instruments, heads up, heads down, or electronic displays, without excellent vision the aviator is behind the curve in every task."***

---

[1] Principal Engineer and Image Generator Architect, Dell Services Federal Government, john.archdeacon@nasa.gov
[2] Senior Software Engineer, Dell Services Federal Government, nelson.iwai@nasa.gov
[3] Associate Director (Acting), New Ventures & Communications Directorate, NASA Ames Research Center, barbara.t.sweet@nasa.gov

During the validation phase and prior to the go-ahead to build the OBVA simulator, medical doctors from the Air Force School of Aerospace Medicine provided background material (Figure 1) describing current Air Force clinical measures used to measure vision (acuity, color, and contrast). The current technical maturity column below was used by the physicians and flight surgeons to discuss possible technology that could be used to improve human vision testing methods; the third column (Current Operational Relevant Scenarios) presented sample operationally relevant scenarios that could be tested in a laboratory environment using the OBVA research simulator that was yet to be built.

ASPECT OF VISION	Current Air Force Clinical Measures	Current Technical Maturity	Current Operational Relevant Scenarios
ACUITY	Snellen	Projector 20/20 to 20/10	Aircraft ID
COLOR	PIP Plate	Robust Color Gamut	Internal/external lighting and objects
CONTRAST	Contrast Charts or Electronic	Responsive Projector	Target Location & Tracking

Figure 1 – Aspect of Vision

B. Acuity

Today, the United States Air Force relies on the Snellen chart (Figure 2) to measure visual acuity. At 20 feet, the letters on the 20/20 line should subtend 5 minutes of arc (such that the limbs of the letters subtend 1 minute of arc), which means that the chart should be sized such that these letters are 8.87mm tall and the topmost "E" should be 88.7 mm tall. The Snellen acuity test is based upon one's ability to see vivid black on white Snellen letters; the test does not however reveal what the quality of the 20/20 vision is for an individual.

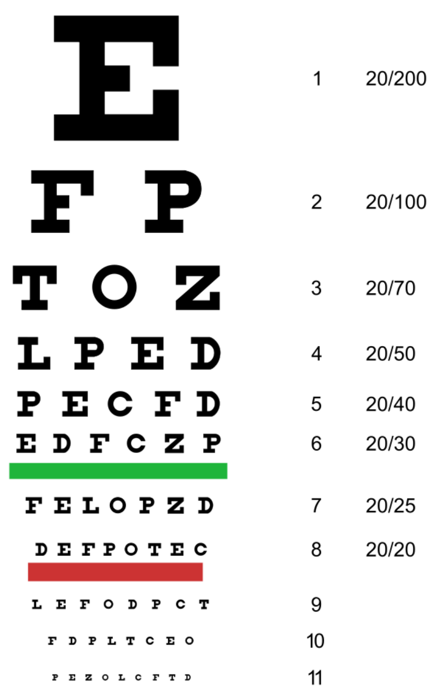

Figure 2 – The Snellen Chart for Testing Visual Acuity

The average visual acuity of the incoming pilot candidate for the USAF is a remarkable 20/13; this acuity is considerably better than the average 20/20 individual can see (Figure 3).

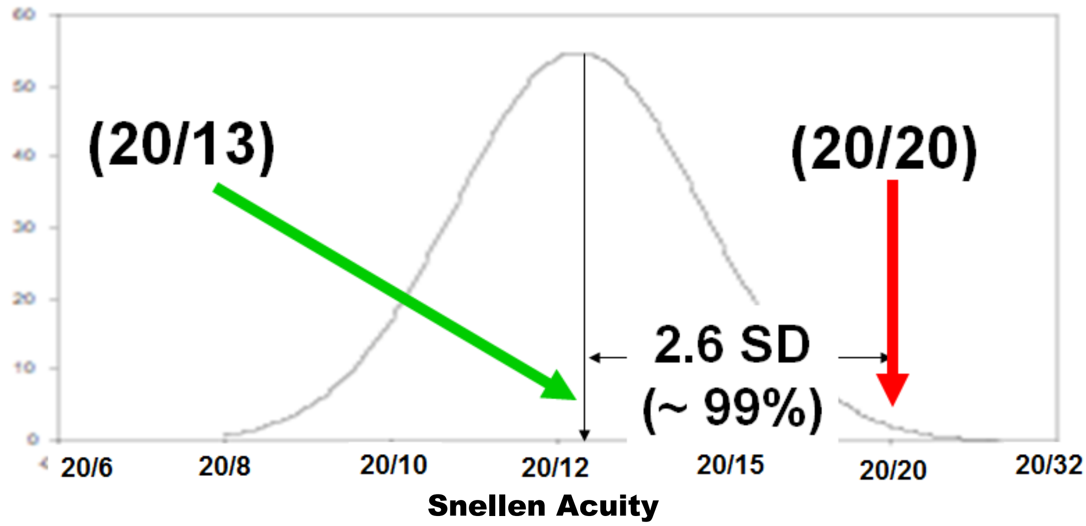

Figure 3 – Distribution of Snellen High Contrast Acuities among USAF Pilot Candidates

Between the various U.S. Armed Forces, different acuity standards exist for each service for pilots. For example, the USAF requires that Class I pilots have 20/70 uncorrected visual acuity; the United States Army requires 20/50, and the United States Navy requires 20/40 uncorrected visual acuity.

Thus, one of the most significant requirements of the visual system for an OBVA simulator is that it should generate observer-limited imagery in real-time that corresponds to the average acuity for pilot candidates (at least 20/13, preferably 20/10). That is, visually-dependent performance measured during simulated operational tasks must be limited by the observer's visual system (their eyes) and not the generated imagery or the display hardware. In the spatial domain, this requires a pixel pitch of about 0.5 arc-minutes [Ref. 1] and imagery that matches the display sampling rate. The temporal sampling requirements are less well defined. Although, the human visual system is not sensitive to stationary temporal modulation that exceeds approximately 60-Hz, simulation of moving objects requires higher frame rates in order to avoid visible motion artifacts due to sampling [Ref. 2] or hold [Ref. 3] properties.

C. Color

Color vision is the ability of the individual to perceive, as well as discriminate, wavelengths of light of different hues, saturation and tones. Today, the USAF relies on the standard PseudoIsochromatic Plate Ishihara Compatible (PIP) Plates to diagnose red–green color deficiencies, if any for a pilot candidate. A figure (usually one or more Arabic digits) is embedded in a picture as a number of spots in a slightly different color, and can be seen with normal color vision, but not with a particular color defect. The full set of tests has a variety of figure/background color combinations, and enable diagnosis of which particular visual defect is present. In order to fly for the USAF, an individual must properly identify the figure in at least 12 out of 14 tests using the PIP plates. The U.S. Navy and U.S. Army allow use of PIP plates or Farnsworth Lantern (FALANT) equipment to measure color; an individual being tested with PIP plates must score at least 13 out of 14 to fly an aircraft. An individual flying for the U.S. Navy or Army can fail the PIP tests, but pass the FALANT test and be cleared to fly.

In the design of the OBVA simulator, it was highly desirable the selected visual system (most notably the projectors) had to be able to generate aviation red and aviation green. These are specific shades of red and green outside of the normal sRGB color gamut; these colors are used in aviation such as on the wingtips of aircraft (green and red navigation lights) and at airports. Aviation Red is orange-red to deep red; the CIE numbers are in the range of 650 to 680 nanometers (nm). Aviation Green is 495 to 534 nm.

D. Contrast

Contrast sensitivity is the ability to discern between luminosities of different levels in a static image. Currently, the USAF only tests high contrast vision; it does not have a low contrast vision standard. Operationally, it was suggested by USAF pilots and flight surgeons during the OBVA investigation phase that low contrast vision may be more critical than high contrast vision abilities since the aviator's operational environment is often low contrast, low light, with significant glare light sources often present. Further, after refractive surgery, it is known that low contrast acuity recovers slower than high contrast acuity. Additionally, optical/media conditions (keratoconus, corneal degenerations, trauma, dry eyes), retinal diseases (central serous) and ocular or neurological disease (early glaucoma, diabetes, retinopathy) and other factors often degrade low contrast vision prior to high contrast vision.

As such, the OBVA visual system has to be capable of generating real-world and operationally relevant low-contrast visual environments that will later help USAFSAM physicians and vision scientists better understand the performance of air crews and individuals under simulated low-contrast conditions.

III. Design Goals and Objectives

A. COTS Technology

In order to minimize technical risk and to meet the limited R&D budget, it was decided early on during program design review meetings between NASA and the USAF that commercial-off-the-shelf (COTS) technology would be employed to the maximum extent possible.

B. Cross Platform Software

In order to reduce dependency on any one software vendor or vendor specific software architecture, it was decided during the design reviews that the various software development groups (mainly the image generator development team as a small team of two developers, and the host computer development team as another person and a half) would employ cross platform software solutions where possible and practical. A general design goal was that software developed for the program say on Microsoft Windows would be able to be moved without too much difficulty to a Linux based environment, and vice-versa.

C. 20/10 Visual Acuity

A major technical goal and objective for OBVA was to provide eye limited resolution. Since the average acuity of the incoming USAF pilot candidate is 20/13, the goal was to provide a visual system as part of the research simulator that was capable of generating eye limited out-the-window visual displays to the test subjects.

Within the past several years, ultra-high resolution projectors and monitors (sometimes referred to as "quad-HD" or "4K" displays) have become commercially available (e.g., Sony, Barco, and JVC). These display devices typically have four dual-link DVI or four HDMI 1.4 inputs and provide 4x or higher pixel resolution than a standard HD display (1920x1080). These new high-end COTS display devices provide anywhere between 8.29 million pixels (QFHD with 3840x2160) and 9.83 million (4096x2400) pixels per display depending on the manufacturer and model. Since the display surface for OBVA was a 4-meter dome, the use of these 4K projectors became much more practical since it reduced the number of projectors by four when compared to using single-HD resolution projectors.

D. 120 Hz

Modern day quad-HD projectors employ liquid crystals on silicon (LCoS) technology. LCoS projectors generally provide very good luminance due to hold times that are approximately equal to the frame interval (~16.67 milliseconds for a 60-Hz frame rate). However, when an observer tracks a moving object, the retinal image corresponding to the on-screen image (which is stationary during the inter-frame hold time) is blurred due to eye movements [Ref. 4]. The magnitude of the "tracking blur" is proportional to the product of hold time and object velocity, and can be reduced using shutters or electronics at the expense of reduced luminance. A better solution however is to increase the frame rate while maintaining a hold-time that is equal to the frame interval; this will reduce both sampling artifacts and tracking blur while maintaining luminance.

As of this writing, industry has not yet produced a quad-HD projector that supports a refresh rate of 120-Hz or more, so the OBVA program knew during the design phase it would likely have to settle upon 60-Hz refresh rates until industry can provide at least 120-Hz or even faster refresh rates. Projectors that support 120-Hz refresh rates are now commercially available from companies such as Christie Digital. In fact, during the development phase, NASA briefly tested a 1920x1080@120-Hz projector from Christie Digital at ARC. This projector significantly reduced motion artifacts but did not meet luminance requirements (see below).

The benefits of higher frame rate generated a design goal of 120-Hz refresh rate capability for the OBVA image generator [Ref. 4]. This means the rendering chores each frame must be completed within 8.3333 milliseconds instead of 16.667 milliseconds for a 60-Hz based system. This also implies the OBVA image generator would have to be at least twice as fast as the common image generator normally provided by the simulation industry.

E. High Brightness Projectors

For the OBVA projector, the goal was 6,000 lumens per projector or more. Many lower cost LCoS projectors including the pre-production 120-Hz projector from Christie Digital mentioned earlier have limited luminance, often 2,400 or fewer lumens. Higher cost projectors that employ expensive Xenon bulbs such as the Sony 4K SXRD or Barco Sim10 generally have much higher brightness.

F. Ability to Display Aviation Red and Green

For OBVA, another program objective for the projectors was their ability to display aviation red and aviation green; not all projectors investigated met this requirement. Generally, projectors tested that employed Xenon bulb technology were generally able to meet this display requirement.

G. Minimum System Latency

The program objective was to provide no more than 4-frames of latency from a stimulus within the cockpit (e.g., moving the stick or pushing a button) to the last pixel out on the projectors. The IG system itself needed to be responsible for no more than 3-frames of latency (ideally, only two) when the system was setup for synchronous operations between the host computer subsystem and the image generator. At a 60-Hz update rate, three frames would be nearly 50-milliseconds. With a 120-Hz update rate, the IG contribution to system latency would be ½ (no more than 25-milliseconds with three frames, and less than 17-milliseconds with two frames).

H. Zero Latency Distortion Correction

Historically, dome distortion correction has been accomplished in simulators using separate hardware subsystems where the image generator pixels are mathematically adjusted to account for the inherent distortion of a spherical display surface. These external subsystems generally add at least one frame of latency and usually more which is undesirable. The goal for OBVA geometry distortion correction is "zero" frame latency if possible, that is, no additional frames being introduced by the visual system as a result of blending and geometry correction for the dome.

I. Tightly Coupled Synchronization

Frame synchronization is the process of synchronizing display pixel scanning to a synchronization source. When several systems are connected, a sync signal is fed from a master system to the other systems in the network, and the displays are then synchronized with each other.

An objective for OBVA is to use commercially available software and hardware for synchronizing all of the dome projectors each using synchronized video from the various image generator "channels". Further, it is desirable the host computer coordinate its frame with this IG frame synchronization timing in order to help minimize system latency if possible. In addition, growth is desired in the chosen synchronization solution to be able to properly synchronize multiple 3D stereo displays (each with separate left and right eye scenes) in the future.

J. Technology Insertion

Historically, dramatically faster new GPUs from companies such as NVIDIA and AMD have been coming into the market every 12 to 24 months at the same general price point as the older technology but with substantially better computational and visual performance than even predicted by Moore at Intel in 1965 [Ref. 5]. Therefore, rather than relying on spare parts with today's (soon to be obsolete) technology sitting on the shelf, the general life-cycle plan for the OBVA IG is instead to refresh with "equally capable or better" compatible hardware in the future when required. Thus, the IG will be purposely designed to facilitate technology insertion and had to be capable of driving new display technology with faster refresh rates as that market segment continues to evolve.

IV. The OBVA Simulator

The OBVA simulator at Wright Patterson AFB (WPAFB) is depicted below in Figure 4. A dedicated computer room is used to house 5 standard 42-inch tall, 19-inch server racks (see Figure 5) containing all of the computers and 3D graphics hardware, host computer, and other rack-mount electronics to drive up to 15 projectors in the initial design configuration, although only 9 projectors will be supported in the initial deployment in mid-2012. The dome display surface, cockpit, and projectors will be installed in a high-bay room previously occupied by an Air Force centrifuge which has recently been removed and the room renovated for the OBVA simulator.

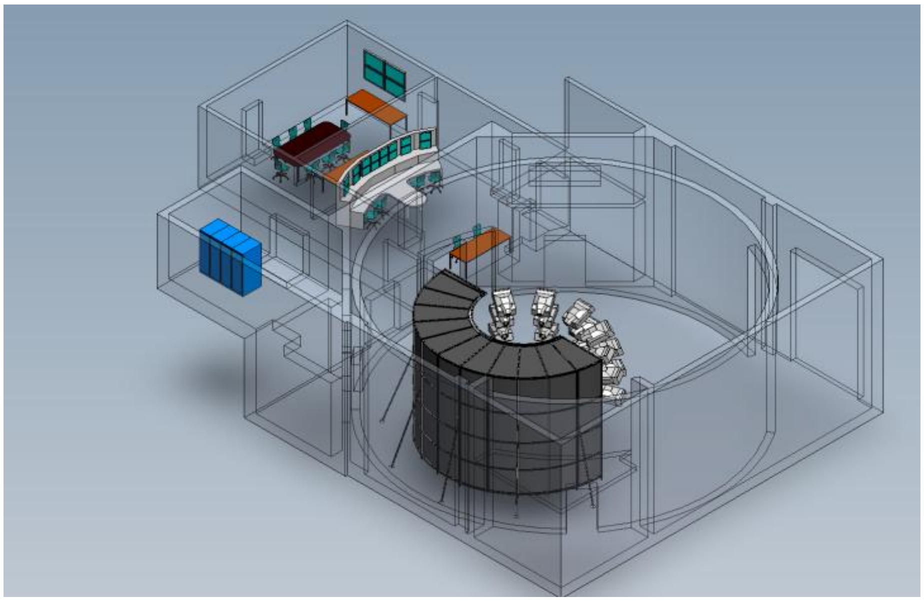

Figure 4 - The OBVA Simulator

With the possible exception of the high sampling requirements mentioned earlier, the OBVA simulator design goals are similar to those of many flight simulators. Because of the need to tile multiple projectors on a spherical screen with high accuracy, we sought tools to automate and simplify the setup for required warping and blending operations. Further, quantifying and minimizing system latency for the various subsystems and devising methods to measure total system latency within the simulator became important objectives to properly characterize the system. Finally, in order to minimize cost and leverage commercially available solutions we attempted, whenever possible, to use commercial-off-the shelf (COTS) hardware and software components.

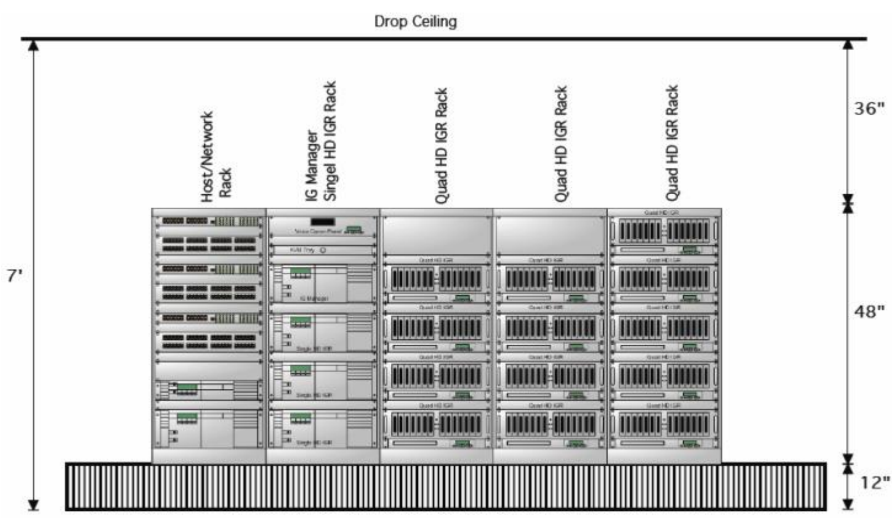

Figure 5 -Planned OBVA Computer Room Hardware

A. Fixed Base Cockpit

The fixed base cockpit for the human observer involved in vision research is placed in front of the projector subassembly as depicted below in Figure 6; the goal is to provide 20/10 visual acuity to the observer positioned at the design eyepoint location within the research cockpit (Figure 7) when positioned in front of the spherical display.

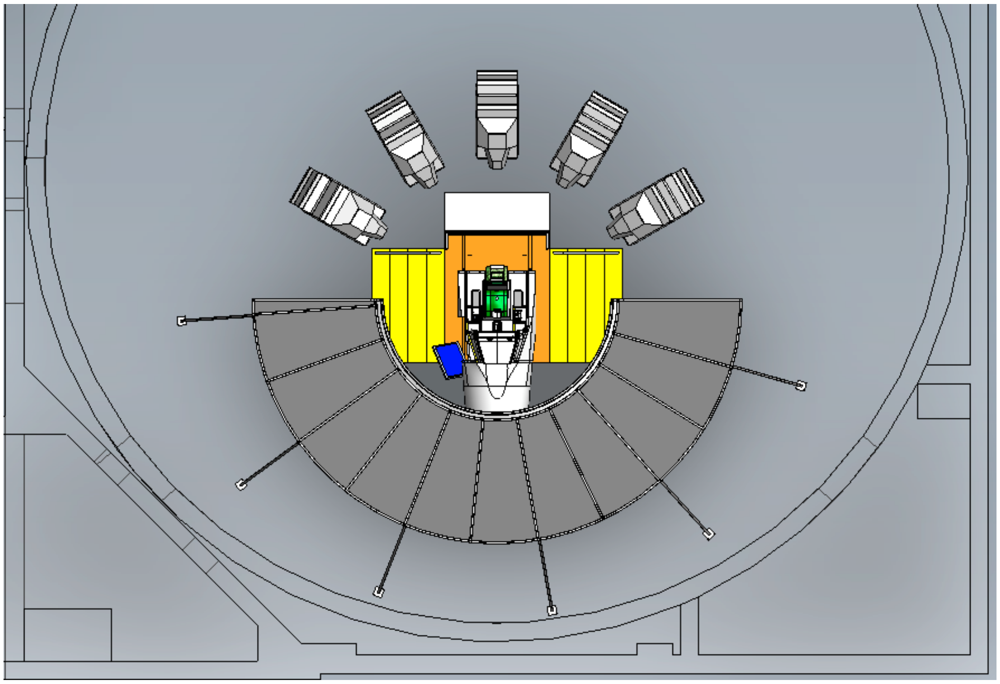

Figure 6 – Overhead View of OBVA Cockpit and Dome/Displays

The research cockpit can be configured as either a generic helicopter configuration with appropriate flight controls, or as generic fixed wing fighter as shown in Figure 7. A single 24-inch touch screen display is used to display in-cockpit symbology and experiment specific controls and displays.

Figure 7 – OBVA Research Cockpit Configured for Fixed Wing Fighter Application

B. Host Computer

The OBVA host computer is a Concurrent iHawk PC running the real-time RedHawk OS; one of the host's network interfaces is used to transmit IG commands using a data packet protocol. The OBVA host computer interfaces to the reconfigurable cockpit built by NASA (see Figure 7 above). The single-man cockpit includes a 24-inch touch screen and reconfigurable inceptors, either an F-16 stick and throttle subassembly for fixed wing operation, or helicopter cyclic and collective controls for rotary wing configurations.

Unlike most host computers, the OBVA host computer not only includes the typical real-time aerodynamics and six degree of freedom equations of motion math models (e.g., F-16) for manned flight, but the OBVA host also includes a real-time software interface to MATLAB for experiment design. Thus, vision scientists can design, develop, and operate research experiments using MATLAB to first setup the experiments, which then automatically interface to the real-time OS using application software developed by NASA for the USAF. This makes it possible for the vision research scientist to develop experiments, drive the image generator, and collect data without having to write complex C or C++ code.

C. The Visual System

The visual system is made up of three distinctive parts, i) the display surface, ii) the display electronics, and iii) the image generator. For OBVA, front projection display technology was chosen during the design phase where the display surface would be a large spherical 4-meter dome. As mentioned earlier, the image generator had to be COTS but capable of some very high frame rates from the beginning (120-frames per second).

The master IG computer, referred to as the IG Manager or IGM for short, allows the user to manipulate the slave IG computers using a straightforward graphical user interface. IGM takes care of chores for launching or terminating remote IGR applications, booting, shutting down, or even restarting the network IGR Slave computers. The IGM is also responsible for managing the synchronization of user-specified folders on all IGRs so they remain identical to the content on the IGM.

Each slave in this architecture is referred to as an IG Renderer, or IGR for short. The IGM is aware of the IGR computers in its local IG domain and automatically starts up and terminates applications when required by the IG user. A simple double click on a desktop icon, for example, can startup all remote applications across the IG network.

The IGM also listens to all incoming data packets from the host computer that is purposely allowed to transmit on the internal IG network. The IGM GUI automatically reflects changes (if any) made by the external host computer to the IG on its appropriate pages (tabs).

1. Spherical Dome Screen

The OBVA research simulator employs a 4-meter dome display surface built by Immersive Display Solutions. The finished product at Wright Patterson AFB in the high-bay rotunda is shown below.

Figure 8 – Four Meter Dome Subassembly at WPAFB

2. Projectors

During the design and development phase, four Sony 4K SXRD projectors were used for testing at the NASA Ames Research Center since the USAF had not yet selected a final projector. Each of these SXRD 4K projectors have a native resolution of 4096x2160@60 Hz.

When the simulator was setup at WPAFB in mid-2012, the IG was configured to drive 9-Barco Sim10 projectors (4096x2400 pixels each) arranged for projection on the 4-meter spherical dome display surface. Growth has been designed in to support up to 15 quad-HD projectors with an approximate 160 degree horizontal field-of-view, with a future upper capacity planned for 25 projectors.

With nine initial projectors, the human observer in the OBVA cockpit will be seeing 88.47 million pixels, believed to be the highest pixel resolution / density ever provided in a real-time simulator with planned eye limiting 20/10 visual acuity.

Figure 9 – Rear View of Projector Array Subassembly during Installation at WPAFB

3. Reconfigurable Image Generator

When large pixel count projectors were first introduced in the 2007 era from companies such as Sony and JVC [Ref. 6], each of the four DVI (or HDMI) inputs to these new high pixel count displays were often driven by four separate GPUs and CPUs. These displays were dubbed "4K" (a possibly misleading term) since each display supports over 4,000 horizontal pixels and over 2,000 pixels vertically.

With the advent of Quadro Plex® 1000 hardware from NVIDIA in that same 2007 timeframe, it became possible to drive large pixel count displays using a single computer and a single graphics subsystem containing multiple GPUs. In this case, the entire user desktop for a standard PC could then be set to an unprecedented resolution of say 4096x2160 pixels when using a new Sony SXRD 4K projector. This meant that the application developer such as OBVA could conceptually create a single, full screen OpenGL (or DirectX) program rather than managing four separate programs each rendering to a fraction of the display (e.g., four programs each rendering to one of the four 2048x1080 DVI inputs at the projector).

The next generation NVIDIA Quadro Plex hardware in 2008 took this concept to a new level where two "4K" projectors (e.g., 4096x2160 each) could be driven from a single PC. With an NVIDIA dual-HIC interface board installed in the hosting PC, two Quadro Plex units could then be configured together to form a single 4096x4320 desktop when the projectors were vertically stacked one on top of the other, or 8196x2160 pixels when arranged horizontally, side-by-side.

In 2011, NVIDIA started shipping the Quadro Plex 7000 (QP7000) hardware with its latest GPU technology. In each QP7000, there are 2 internal high-end Quadro GPU cards that are normally configured to generate one very large desktop or full screen 3D application. Using the standard NVIDIA rack-mount option, there are actually two QP7000s mounted side-by-side taking 3U of rack space for the OBVA IG as shown below.

Figure 10 – Two Rack Mount Quadro Plex 7000s

When using two Barco Sim10 projectors, this means each PC desktop or full screen 3D application on the hosting PC controls 4096x4800 pixels when the two projectors are vertically stacked or 8192x2400 pixels when the projectors are horizontally arranged.

IG Manager

The master IG computer, referred to as the IG Manager or IGM for short, allows the user to manipulate the slave IG renderer computers using a straightforward graphical user interface. IGM takes care of chores for the initial visual environment setup prior to entering runtime where updates can be provided by the host computer. IGM is also responsible for launching or terminating remote IGR applications as required, booting, shutting down, or even restarting all network based IGR Slave computers. The IGM is also responsible for managing the synchronization of user-specified folders on all IGRs so data on the IGRs remains identical to that found on IGM.

The IG software is implemented across multiple PCs in a master-slave relationship. Unlike most past IG implementations, the external host computer for OBVA is purposely permitted to transmit data at runtime on the internal, private IG local area network, directly to the IG renderers, via a UDP multicast mechanism to minimize system latency as shown below. Data packet commands from the host computer override initial settings in IGM and are also automatically displayed there in corresponding GUI sections of IGM. For example, if the host changes the time of day, this change is automatically reflected by IGM in its environment page so the user remains informed.

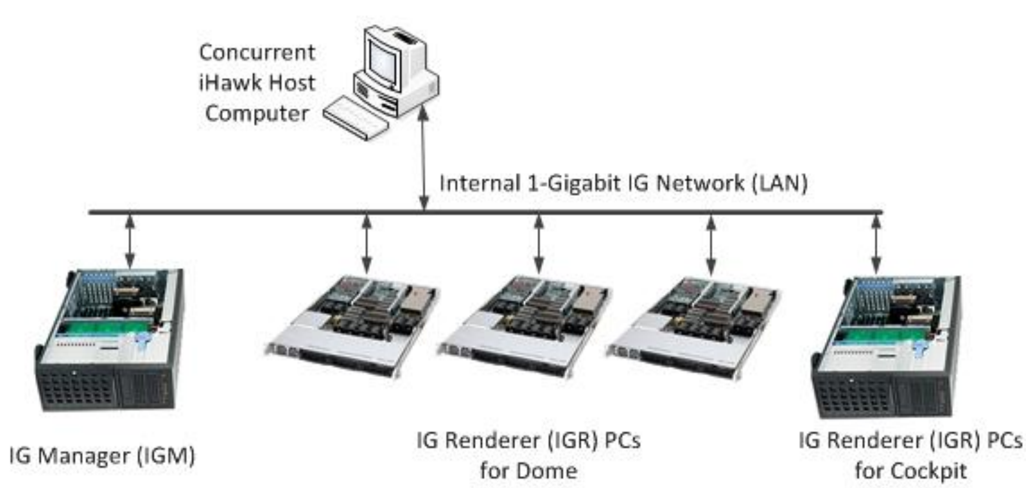

Figure 11 – Top Level IG Architecture

The IG Manager is physically a 4U rack-mount, server class PC that runs the Windows Server 2008 R2 64-bit operating system. The IGM computer has three network interfaces: one for the internal private IG network, another for access to the internet when available, and a third for the internal development network. The server OS was chosen for IGM only (rather than Windows 7 64-bit) so the IGRs could in the future be more easily setup for remote boot operations from IGM over the internal IG network if desired.

The IGM GUI software was implemented using the open source wxFormBuilder software; this GUI tool produces C++ code for the wxWidgets software layer used in IGM. Consistent with our cross platform development philosophy, wxWidgets software is also open source software and is available for download on the web.

The IGM includes a small solid-state drive for the boot/ system volume and a separate RAID-5 4-TB hard drive subassembly for OBVA IG specific data and programs.

IG Renderers

The IG Renderer (IGR) PCs are slaves to the IGM. Unlike traditional PCs, they are intended to be wholly controlled by the IGM although in practice for the current version, OS updates to the IGRs are done locally on each computer at this time. There are two types of renderer computers each assigned a software role by IGM:

1. 1U rack-mount computers with NVIDIA QP7000 graphics, each in a 19" rack half-width, 3U form factor (see Figure 10 above), for driving one or two dome projectors or other 4K displays

2. 4U rack-mount computers with dual NVIDIA Quadro 6000 GPUs for driving cockpit displays or out-the-window repeater displays with single-HD resolution (e.g., 1920x1080) such as in the conference room and operator control room

Each dome IGR is responsible for driving one or two 4K projectors (4-DVI connectors per projector). Each IGR PC for dome rendering duties is mechanized in a 1U form factor, and each is made up of server class components. Each IGR PC includes one NVIDIA PCI-Express x16 Generation 2 host interface card (dual-HIC). The IGR PCs are built by Colfax International; Colfax is a certified supplier of NVIDIA for the demanding dual-HIC hardware. The dual-HIC hardware drives two QP7000 rack-mount graphics subsystems; the rack-mount dual QP7000s are configured with NVIDIA's driver control panel software to setup a single, very large desktop as described earlier.

Each 1U IGR currently runs the Windows 7 64-bit Ultimate OS, and like the IGM, each contains a solid state drive for the boot/ system volume and a separate RAID-5 4-TB hard drive subassembly for OBVA IG specific data and programs.

Zero Latency Distortion Correction for Spherical Displays

The IGRs assigned out-the-window rendering chores on dome display surfaces use the cross platform Scalable Display Technologies EasyBlend software to perform distortion correction at runtime. During system installation, the Display Manager software is used once to produce a warp mesh file per IGR which includes blend zone integration. The warp mesh file is produced using test patterns captured by the Display Manager software using a Canon Rebel T2i digital SLR camera. The highly automated calibration software also computes the blending zones in each case where light from adjacent 4K projectors overlap. During runtime, the Easyblend software performs distortion correction and blending operations per IGR at the end of each rendering frame software with very low overhead (typically less than 0.25-milliseconds); thus zero additional frames of latency was achieved.

Pixel placement mismatch in the overlap zone after the Scalable setup process was not visually evident. Lines across projectors appeared to land squarely on top of lines and pixels from neighbouring projectors. Previous perceptual test conducted by the USAF using EasyBlend software and Sony SRXD projectors established that discrimination of the orientation of a triangle outside the blend zones required a 2.52-arcminute (arcmin) triangle base size (5 pixels at 0.5-arcmin pitch). Although the triangle base size required to make the same discrimination within two-projector and four-projector blend zones was larger (2.76 and 2.73 arcmin, respectively) the small loss of resolution was deemed acceptable. This test has not yet been performed using the Sim10 projectors.

The distortion correction alignment process for the nine Barco Sim10 projectors at WPAFB was done with on-site assistance from Scalable Display Technologies, initial setup took about 4 hours to complete. Once physical setup was complete, the actual calibration (or a re-calibration) including blend zones is expected to only take a few minutes. Automated color balancing of the nine projected images at WPAFB has not been done at this time. Ideally, this issue will be addressed in the future with automation if available, since manual adjustments can be tedious and time consuming.

Out-the-Window Atmosphere Effects

For IGRs assigned the role of generating simulated out-the-window scenes, the IG uses the Silverlining SDK software from Sundog Software [Ref. 8]. Simulating reality such as beautiful 3D clouds that we see every day in the real-world is not easy to do, especially when we need to update the scene 120 times per second. There is often a careful balancing act between performance and appearance. Even with state-of-the-art QP 7000 GPUs, it is relatively easy to tax the "fill rate" of the graphics hardware, especially when flying through a series of cumulus type 3D clouds that automatically affect the observer's visibility with a high degree of realism. The Silverlining SDK implements 3D cloud layers and is also responsible for rendering the background skydome (sun, moon, stars) with an active ephemeris model as driven by time-of-day and time-of-year commands sent to the IG from the host computer.

Swaplock and Framelock

The NVIDIA Gsync2 hardware was chosen for video synchronization because this hardware had all of the salient design characteristics to facilitate synchronization across all dome channels:

- Framelock,
- Swaplock,
- Support for stereo synchronization

With framelock synchronization, the vertical retrace for each projector can be synchronized using an external "house sync" signal generated with an Agilent Waveform generator and supplied over a standard 75-ohm BNC video cable. This house synchronization signal is also supplied to the host computer. This allows all IG dome computers and the host computer to operate on the same system "heartbeat" pulse. This will also help minimize system latency and eliminate variable latency when running synchronously.

With the swaplock capability present in the standard Gsync2 hardware, each of the dome IG renderer swap buffer calls can also be fully synchronized so all computers are rendering the same frame of data at the same time.

The QP7000 graphics hardware already includes Gsync2 hardware. All dome channels are then easily connected to the synchronization chain using short CAT5e network cables which then pass along the framelock and swaplock Gsync2 signals. The OBVA IG developers then used industry standard OpenGL driver extensions, notably `WGL_NV_swap_group`, to implement framelock and swaplock logic on the dome channels. As this is being written, synchronization efforts are still underway; our progress will be reported in greater detail when the paper is presented at the conference.

The OBVA IG does not currently have a requirement for the stereo Gsync2 synchronization signal, but this capability is felt to be a potentially useful feature for future vision research or simulator use at NASA or the USAF.

Cockpit Displays

The OBVA IG uses the popular human interface simulation tool, GL Studio [Ref. 9] from DiSTI to implement simulated cockpit displays for the OBVA IG. The GL Studio developer tool produces OpenGL compatible C++ source code from its developer GUI. An IGR that has been assigned the head-down display role by IGM will then be responsible for receiving data packets from the host computer and updating the cockpit displays as required by the particular experiment or simulation task.

4. Database Generation System

What good would an image generator with eye limiting resolution be if the synthetic world details were not at least partially eye limiting? Even with the world's most powerful GPUs, it remains impossible to visually simulate every detail found in "reality" at a 120-Hz update rate. The best we can still do in this environment is to approximate the details of the real-world by preserving only the most important features required for the mission (in our case, vision research where eye limiting detail must be available at least in designated select areas).

The DBGS designed for OBVA is built on top of two popular and commercially available software products:

1. Google Earth Pro, and
2. Presagis Creator Pro

The OBVA DBGS COTS solution allows U.S. Government end users to generate visual databases for non-commercial use by automatically capturing imagery and terrain elevation data from Google Earth Pro (or other compatible servers) and then automatically converting these to the OpenFlight format using the Presagis Creator Pro editor.

Cultural 3D models (e.g., hangars, control towers, and other important man-made structures) can also be included in the visual database from select buildings extracted from Google Earth Warehouse or hand modeled in Creator.

At this time, a visual database environment for the current IGR application software design must fit into the available 6GB of GPU memory present in the QP7000 graphics hardware. This is not a sufficient approach for databases that exceed GPU memory. Real-time database paging remains a goal for future work.

V. Results

Below are some screen captures that depict the first target database for OBVA, Sheppard AFB where each pixel in the airport area is about 1-foot resolution. This 300 by 300 mile database area was selected because it was one of the USAF pilot training facilities.

All of the runway surface markings and other airport details in the screenshots below were generated from the Google Earth Pro source imagery and not hand modeled as would typically have been done for past image generators. High resolution imagery for this database is currently only present around the immediate airfield area; lower resolution images are used elsewhere.

The airfield area in Figures 12 and 13 is modeled with over 100 4096x2048 pixel texture maps and over 300 2048x1024 texture maps elsewhere, all stored in the DXT1 format. The OBVA IG team is currently investigating possible use of larger texture map files (i.e., 8192x8192 pixels); the hardware supports up to 16384x16384 pixels per texture map.

Figure 12 – Sheppard AFB Approach on Reconfigurable IG

Figure 13 – F-35s below the 3D Clouds on Approach

System latency tests were conducted on a variety of different displays and projectors. All of the measurements in Figure 14 below were conducted using a digital signal generator providing a uniform system "heart-beat" to the host computer and image generator. A photometer was used to measure changes in light on the actual display surface, and data captured to a PC in real-time using Matlab. A Matlab program was used to verify the total system latency from a host induced change in the visual scene to a change in the visual scene using the photometer.

Display / Projector	Refresh / Update Rate	Native Resolution	Total System Latency
Sony SXRD S110 Cinema Projector	60	4096x2160 (4-2048x1080)	56-milliseconds
Christie Mirage WU-L (pre-production) Projector	120	1920x1200	28-milliseconds
Asus VGS36H LCD Panel	120	1920x1080	20-milliseconds
Sony Trinitron E210 CRT*	60	1600x1200	28-milliseconds

Figure 14 – System Latency Measurements

System latency tests for the Barco Sim10 projectors at Wright-Patterson AFB were not yet available as this paper was being finalized before these tests could be completed on-site.

VI. Conclusions

The utilization and selection of the right COTS tools and components (hardware and software) for the OBVA Image Generator have proven successful thus far. Two software developers designed, developed and integrated the OBVA IG in approximately 1 year; one visual database development engineer helped design the processes to construct high resolution visual databases using COTS technologies in ways that have never been attempted before.

As this paper is being written, the NASA OBVA team has installed the simulator at Wright-Patterson AFB, Ohio but final system setup has not yet been completed. As of this writing, all nine-projectors have been installed and preliminarily tested using the OBVA reconfigurable IG.

Further results and experiences to date will be highlighted and discussed at the AIAA Conference.

References

[1] J.P. Gaska, M. Winterbottom, W. Sweet and J. Rader 2010, "Pixel Size Requirements for Eye-Limited Flight Simulation", *Proceedings of the IMAGE 2010 Conference*, The IMAGE Society, pp. 123-130.

[2] A.B. Watson, A. J. Ahumada, Jr., and J. E. Farrell, 1986, "Window of Visibility: a psychophysical theory of fidelity in time-sampled visual motion displays", *JOSA A*, Vol. 3, Issue 3, 300-307.

[3] M.D. Winterbottom, G.A. Geri, W.D. Morgan and B.J. Peirce, 2004, "An integrated procedure for measuring the spatial and temporal resolution of visual displays", Proceedings of the interservice / industry training, simulation and education conference. ASA430109, Paper Number 1855.

[4] B. Sweet, K. Kato, 2012, “120 Hz – the New 60 for Flight Simulation?”, Proceedings from Image 2012 Conference, The Image Society

[5] K. Akeley, Microsoft Research, “GPU Gems 3”, Foreword from book, August 12, 2007, ISBN-10: 0321515269 | ISBN-13: 978-0321515261

[6] Siggraph 2007, UC San Diego, California
http://ucsdnews.ucsd.edu/newsrel/general/07-07SIGGRAPHSuperHighDefinitionVideoDR-.asp

[7] http://www.nvidia.com/object/scenix.html
NVIDIA Scene Management software engine

[8] http://sundog-soft.com/sds/features/real-time-3d-clouds/, Sundog Silverlining SDK

[9] http://www.disti.com/Products/glstudio/
GL Studio human interface design software from DiSTI Corporation